

# ELECTRONICS SESSIONS

MONDAY, AUGUST 18, 2008

## MONDAY MORNING ORAL SESSIONS

10:30am - 12:30pm

### 1EA - Transition Edge Sensors I – Physics 10:30am - 12:30pm

10:30am

#### 1EA01 - Exploring the physics of the phase transition

*M.A.Lindeman, D.E.Brandl, D.McCammon, University of Wisconsin, Madison WI; R.Cantor, J.A.Hall, Star Cryoelectronics, Santa Fe, NM; S.R.Bandler, A.D.Brown, J.A.Chervenak, F.M.Finkbeiner, N.Iyomoto, K.A.Kilbourne, F.S.Porter, J.Sadler, S.J.Smith, NASA Goddard Space Flight Center, Greenbelt, MD; H.F.C.Hoevers, Netherlands Institute for Space Research, Utrecht, The Netherlands*

We measured complex impedance, noise, and I-V curves of a variety of transition edge sensors provided by Star Cryoelectronics, SRON, and NASA / GSFC. These rich multidimensional data sets contain thousands of measurements of TES resistance, impedance, current, temperature,  $\alpha$ ,  $I_c$ ,  $\beta$ ,  $I_c$ , heat capacity, thermal couplings, and noise. We explore the relationships between these variables by cutting and plotting the data in various ways. We compare these measurements to models of the phase transition such as a two fluid superconductor model to provide insight into the physics of the phase transition. The profiles of different types of TESs such as high resistance vs. low resistance TESs are compared. These data provide comprehensive illustrations of the physics of the phase transitions to aid in the design and understanding of these devices.

10:45am

#### 1EA02 - Studies of the Superconducting Transition and Lateral Proximity Effects in Mo/Au-bilayer Thin Films

*J.E.Sadleir, NASA GSFC and UIUC Physics Dept; S.J.Smith, H.Rotzinger, R.P.Brekosky, F.M.Finkbeiner, S.R.Bandler, N.Iyomoto, J.A.Chervenak, A.D.Brown, C.A.Kilbourne, F.S.Porter, R.L.Kelley, NASA GSFC*

At NASA Goddard, microcalorimeter arrays using superconducting transition edge sensor thermometers (TESs) are under development for high energy resolution X-ray astrophysics applications. We report on studies of the superconducting transition in our Mo/Au-bilayer TES films including low current measurements of the superconducting bilayer's resistance transition versus temperature on pixels with different normal metal absorber attachment designs. We show that additional metal structures atop the bilayer and the superconducting leads impact the measured TES transition shape and transition temperature. We interpret our results to mean that the superconducting properties of the bilayer are impacted by metal structures laterally at least 10 microns away.

11:00am

#### 1EA03 - Simulation of Transient Response and TES Noise Parameters.

*Y.Minamikawa, K.Nishimura, R.M.T.Damayanthi, M.Ohno, H.Takahashi, The University of Tokyo*

Recently, Transition Edge Sensor (TES) microcalorimeter with zebra absorber has been developed and achieved promising results. However, it is not well subscribed how they suppress the noises

and why they have good performance. Here, we report the simulation calculation of transient response of TES detector, which is based on the finite difference method of heat transfer and electric circuit. A TES is modeled as simple layers. Temperature and electric current distributions are calculated by above method, as a result, we successfully obtained various signals. We present our study of noise parameter of TESs with this simulation, how thermal fluctuation noise changes with the absorber designs. These calculations are quite successful and we could get a picture of what happens inside the TESs.

11:15am

#### 1EA04 - Intermediate state evolution on thin superconducting films: optimization for radiation detection.

*M.Ribeiro Gomes, Centro de Fisica Nuclear da Universidade de Lisboa*

Superconducting-Normal-Superconducting (S-N-S) phase transitions in laminar-like superconductors continue to be a forefront research area with crucial repercussion on the use of thin superconducting films, such as transition edge sensors (TES), as highly sensitive radiation detectors. This experimental work focuses on the evolution of the intermediate state on both processes of flux penetration and expulsion. Different type-I/II pure superconducting materials were studied for different geometrical aspect ratios. While an energy barrier of geometrical origin governs the S-N process, the N-S transition seems to be geometry independent and directly related with intrinsic superconducting properties of the material. In this work, a description of S-N transition is provided in terms of flux penetration regimes and associated characteristics fields; the N-S transition, being a continuous intermediate state evolution process, is characterized by flux expulsion fields associated with the different regimes of superconductivity nucleation. The detection performance of thin films as energy sensors depends on the sample geometry, physical and chemical quality/purity and experimental environment. Characteristics such as flux trapping and vortex fluctuations constitute key aspects for a detector optimization, and will be here discussed in terms of sensitivity, reproducibility and noise.

*This work was supported by the grants SFRH/BPD/36293/2007 and PRAXIS/10033/1998 of the Portuguese Foundation for Science and Technology.*

11:30am

#### 1EA05 - The effect of magnetic impurities on the response of superconducting photon detectors.

*A.G.Kozorezov, Lancaster University; A.A.Golubov, University of Twente; J.K.Wigmore, Lancaster University; D.Martin,*

*P.Verhoeve, R.A.Hijmering, European Space Agency, ESTEC*  
In a superconductor with magnetic impurities, Kondo scattering results in the formation of bound states inside the gap. We show that electronic transitions involving scattering into and out of the localized states may result in significant changes in the non equilibrium properties of the superconductor. We have calculated the rates of inelastic transitions between continuum and discrete states in the dilute limit, and shown that they significantly modify quasiparticle interactions. The individual processes are: transitions from the continuum to the discrete states, recombination due to the collision of a mobile with a localized quasiparticle, pair breaking by sub-gap phonons with the generation of one quasiparticle at a discrete level and a second in the continuum, and detrapping of localized quasiparticles into the continuum due to phonon absorption. Our conclusion is that interactions with magnetic impurities are of fundamental importance for all superconducting detectors. We discuss their potential effects on response of STJs, KIDs and TESs.

11:45am

**1EA06 - Static and Dynamic Behavior of a Barely Phase Separated TES**

*M.Pyle, T.Lippman, B.Cabrera, Stanford University; J.Fillipini, University of California at Berkeley; P.Brink, J.Cooley, A.Tomada, Stanford University*

In almost all standard experiments, the TESs are designed and operated in a way such that the equilibrium temperature is uniform across the entire length of the sensor. Within this regime, the TES dynamic and static characteristics have been modeled with excellent success by non-linear differential equations. As one increases the length of the TES though, the thermal conduction along the TES is eventually unable to suppress thermal fluctuations and thus it loses thermal homogeneity. In the extreme limit of incredibly sharp thermal variations, the properties can also be modeled successfully. In this paper though, we discuss theoretical calculations of the equilibrium and dynamical characteristics of a TES within the unsimplistic barely phase-separated intermediate regime in which the temperature variation occurs across large percentages of the sensor paying particular attention to the questions of multiple equilibrium states, frequency resonance, and net device sensitivity to thermal changes. We will also compare these estimates to the CDMS II devices to see if phase separation can account for some of their non-ideal behavior.

12:00pm

**1EA07 - Excess noise in Ti/Au transition-edge sensors in Corbino geometry**

*K.M.Kinnunen, M.R.Palosaari, I.J.Maasilta, University of Jyväskylä*

We have characterized several different type of Ti/Au transition-edge sensors (TES) without absorbers. The detectors have a circular symmetry and radial current flow, a geometry known as the Corbino disk. In addition to full Corbino disks, we also fabricated devices where the disk was divided into several parallel slices. Here, we report DC I-V, impedance and noise measurements on these samples, performed as a function of bias and bath temperature. We discuss how the slicing influences the results, most importantly the noise spectra. The general observation is that dividing the disk seems to lower the noise, especially below the midpoint of the transition. Dependence of excess noise on other detector parameters is also discussed.

12:15pm

**1EA08 - A study of the excess noise measurements of Ir TES in the frame of statistical models**

*D.Bagliani, University and INFN of Genoa; E.Celasco, Politecnico di Torino; M.Celasco, R.Eggenhöfner, University of Genoa; F.Gatti, L.Ferrari, R.Vaccarone, R.Valle, University and INFN of Genoa*

The noise performance of Ir TES for applications of single photon detection from visible light to soft X-ray are currently under investigation in our laboratory. The Ir films of rectangular shape are grown into 1  $\mu\text{m}$  thick SiN membrane and biased with different currents in order to span over the  $R/R_n$  range. Experimental data concerning the behaviour of the noise vs.  $R/R_n$  are discussed in terms of a percolation model of a 3D resistor network of randomly switching junctions between normal (OFF) and superconducting (ON, shorted) states with suitable probability and a dynamical parameter accounting for the rate of the ON-OFF transitions. The frequency dependence of the power spectra showing the well known excess noise is analyzed in terms of a statistical approach of correlated avalanches of elementary events, which explains quantitatively the large peak observed around 1-10 KHz.

**1EB - Circuits for Mixed Signal Applications (ADCs)**

**10:30am - 12:30pm**

10:30am

*Invited*

**1EB01 - Progress in Design of Improved High Dynamic Range Analog-to-Digital Converters**

*A.Inamdar, A.Talalaevskii, A.Sahu, D.E.Kirichenko, T.V.Filippov, D.Gupta, HYPRES*

We describe several improvements that are being pursued to improve the dynamic range of lowpass phase modulation-demodulation analog-to-digital converters (ADC). The first approach involves multi-rate ADC where the modulator sampling frequency is increased in multiples of the decimation filter clock. The decimation filter is modified to accept two deserialized data streams at half the ADC sample rate. We have tested the multi-rate ADCs at sampling frequencies up to 46.08 GHz and 29.44 GHz for chips fabricated in 4.5 and 1 kA/cm<sup>2</sup> fabrication processes respectively. The signal to quantization noise ratio for a 9.92 MHz sinusoidal input with a single channel ADC sampled at 29.44 GHz is 83.93 dB in a 10 MHz bandwidth. The spur-free dynamic range is 95 dB. In another improved architecture, called the quarter-rate ADC, the modified quantizer quadruples the input dynamic range by deserializing the input on four output channels in a cyclical fashion. The prototype version of this ADC with a two channel synchronizer, fabricated in the 4.5 kA/cm<sup>2</sup> process, has been tested up to sampling frequency of 15.2 GHz. The signal to Quantization noise ratio for a 10 MHz sinusoidal input is 80.81 dB in a 10 MHz bandwidth. The progress in design of the quarter rate ADC with eight channel synchronizer is also reported. The eight channel synchronizer is expected to give a 12 dB performance enhancement compared to the single junction quantizer ADC with a two channel synchronizer.

11:00am

*Invited*

**1EB02 - A Quantum-Accurate Two-Loop Data Converter**

*Q.P.Herr, A.A.Pesetski, D.L.Miller, J.X.Przybysz, Grumman Systems Corp.*

High performance oversampling Delta-Sigma data converters require high clock rates and accurate feedback of the digital output to the analog regime. Superconductor modulators offer the unique advantages of clock rates in the tens-of-gigahertz, comparator switching energy below attoJoules, and quantum-accurate digital-to-analog feedback. We have designed a two-loop baseband modulator whose noise transfer function was calculated using a simple, linear circuit model. The circuit was fabricated in a commercial superconductor IC process with 4.5 kA-per-square cm Josephson junctions and 1.5 micron minimum feature size. The circuit was operated at a derated sample rate of 5 GHz. Measured signal-to-noise dynamic range was 81 dB over a 10 MHz band. So sensitive an ADC accurately digitized the thermal noise on the 1.8 mOhm input resistor, 600 pV/(Hz<sup>0.5</sup>) at 4.2 K. Third-order intercept was measured to be +24 dBsat in two-tone test. The measured noise transfer function was in excellent agreement with our linear model. We discuss the ways in which minor design changes extrapolate this family of modulators to significantly higher performance.

*This work was supported in part by the Office of Naval Research and by the National Reconnaissance Office*

11:30am

**1EB03 - A Flash A/D Converter Using Complementarily-Combined SQUIDS**

*M.Maruyama, H.Suzuki, Y.Hashimoto, M.Hidaka, Superconductivity Research Laboratory, ISTEK*

We propose a new design of a superconductive flash analog-to-digital (A/D) converter circuit with improved linearity. This circuit is composed of equivalently two quasi-one-junction SQUIDS (QOSs) [1,2] that are combined with each other at the comparator part. The analog signal is inputted to both front ends of the QOSs complementarily, that is, with opposite polarity for each. Though the mechanism of the quantization in each QOS is basically same as that in the conventional ones, the mixed quantized output shows superior linearity compared to the conventional ones. Moreover, unintended offsets due to L/R delays [3] are completely canceled in this circuit, suppressing dynamic distortions in the comparator even without the feedback loop for compensation. This makes the circuit free from the limitation for the bandwidth related to the time constant in the loop. We have carried out a computer simulation for A/D converter operation of the circuit and obtained the sampling frequency of 150 GS/s @ $J_c = 40 \text{ kA/cm}^2$ . [1] H. Ko et al., J. Solid State Circuits, Vol. 23, p. 1017, 1988. [2] P. Bradley et al., IEEE Trans. Appl. Supercond., Vol. 1, p. 134, 1991. [3] S. B. Kaplan et al., IEEE Trans. Appl. Supercond., Vol. 9, p. 3020, 1999. *This work was supported by the New Energy and Industrial Technology Development Organization (NEDO) as Development of Next-Generation High-Efficiency Network Device Technology Project.*

11:45am

**1EB04 - A Linear Model of Quantization Noise in Superconductor ADCs**

*A.A.Pesetski, D.L.Miller, J.X.Przybysz, Q.P.Herr, Northrop Grumman Systems Corp.*

Superconductor delta-sigma modulators feature quantum accurate feedback that allows them to operate in the ideal, quantization-noise limit. We have developed a linear model that predicts the quantization noise of the modulator analytically, by mapping the white quantization noise at the comparator to frequency-dependant noise at the output. The key advance was determination of the transimpedance of the Josephson comparator. Both first order modulators, such as the phase modulation/demodulation design, and our own second order modulator have been analyzed. We conclude that first order modulators all have the same noise shaping performance irrespective of circuit parameter values and feedback gain. The primary constraint on circuit design is instead set by thermal noise considerations. Performance of the second order modulator depends directly on parameter values, and on a more subtle interplay between thermal noise, stability, feedback latency, and feedback gain. We conclude that second order superconductor modulators should compare favorably with current state-of-art, particularly in applications demanding high dynamic range.

*This work was supported in part by the Office of Naval Research*

12:00pm

**1EB05 - Demonstration of picosecond-delay measurements of high-speed signals by single-flux-quantum double-oscillator time-to-digital converters**

*N.Yoshikawa, K.Nakamiya, Yokohama National University*

Time is the most universal physical quantities. Almost all physical units like a position, a weight, a pressure and a temperature can be captured by time measurement. A time-to-digital converter (TDC) is a device, which measures the time delay and converts it directly to a digital binary code. The resolution of the state-of-the-art CMOS TDC is about 12 ps. We have been developing TDCs using single-flux-quantum (SFQ) circuits. The advantage of the SFQ

TDC is extremely high energy- sensitivity compared to the CMOS TDC. It enables the elimination of the pre-amplification of small signals from sensors resulting in the improvement of the accuracy of the delay measurement. Another advantage is high time resolution due to the high-speed operation of SFQ circuits. Our double- oscillator SFQ TDC has high time resolution of about 2.5 ps based on the on-chip test and a wide dynamic range with a small circuit area. In this paper, we demonstrated picosecond-delay measurements of high-speed signals which are provided from room temperature electronics. Time differences between two input signals ranging from 0 ps to 1200 ps were generated by a delay line and measured by the SFQ TDC. We evaluated the error probability and the integral non-linearity (INL) of the system.

12:15pm

**1EB06 - Jitter-Induced Noise in Superconductor ADCs**

*D.L.Miller, A.A.Pesetski, J.X.Przybysz, Q.P.Herr, Northrop Grumman Systems Corp.*

Jitter in superconductor Delta-Sigma ADCs is a source of noise that adds to the ideal, quantization noise limit. Jitter arising in either the sampling clock or in the feedback has the same effect. The effect of jitter (or equivalently, phase noise) is to mix high frequency, out-of-band quantization noise into the passband, producing a jitter-induced noise floor. We have quantified this effect for first and second order modulators by means of a convolution integral involving quantization noise and phase noise. The net effect of jitter is to add a frequency independent contribution to the inband quantization noise. Our analysis is supported by measurements using single frequency modulation of an ADC sampling clock. We conclude that jitter should not be a limiting factor in superconductor ADCs using available low-phase-noise clock sources.

*This work was supported in part by the National Reconnaissance Office and by the Office of Naval Research*

**1EC - Novel Devices and Novel Junction Applications**

**10:30am - 12:30pm**

10:30am

**1EC01 - Characterizing the Nonlinear Behavior of Signal Processing Components with Precision Multitones from a Josephson Arbitrary Waveform Synthesizer**

*R.C.Toonen, S.P.Benz, National Institute of Standards and Tech.*

We have extended the application of quantum-based electrical standards from single frequency calibrations to multitone tests that characterize the nonlinear behavior of signal processing systems. Typically, multitone waveforms are generated either by adding the single tones of multiple oscillators with resistive power combiners or by programming a desired time-domain signal with a semiconductor-based arbitrary waveform generator. The first of these techniques often produces a high spectral noise floor that masks the small-amplitude distortion products generated by the system under test (SUT) while the latter pollutes the SUT with distortion components produced within the generator itself. In highly linear systems with relatively low noise figures it is advantageous to perform multitone measurements with a Josephson arbitrary waveform synthesizer (JAWS). Such a system generates signals composed of voltage pulses whose time-integrated areas are perfectly quantized and proportional to fundamental constants; therefore, the JAWS is capable of delivering multitone waveforms with unprecedented spectral purity. To demonstrate the utility of our apparatus and techniques, we present the results of intermodulation distortion measurements from a highly linear audio amplifier. Additionally, we describe a circuit used for upconverting the test signals so that we may characterize the nonlinearities of RF and microwave components.

10:45am

**1EC02 - Superconducting Four-element Array for Clinical Trabecular Bone micro-MRI**

*J.Wosik, TcSUH and Electrical and Engineering Dept., University of Houston, Houston, Texas; K.Nesteruk, Institute of Physics PAS, Warsaw, Poland; F.Ip, L.-M.Xie, TcSUH and Electrical and Engineering Dept., University of Houston, Houston, Texas*

We report on a novel clinically practical cryogenic (Cu and HTS) array with sufficiently high SNR to perform micro-MRI of trabecular bone non-invasive studies to quantify drugs treatment-induced architectural changes in osteoporosis patients. We have designed high-Q four-element, receive only, coil array integrated with low-loss electronic circuits for tuning/matching and mutual inductance cancellation. A custom-built G-10 77 K cryostat, designed according to the shape of the tibia bone. Each element of the array is designed as a double-sided structure consisting of two rotated split-rings. HTS coils were made out of 0.5 micron thick YBCO thin films deposited on both sides of LAO substrate. Measurements of each Cu coil at 295 K and 77 K yielded unloaded Q's of 300 and 900, respectively. The HTS coil, at 77 K, had an unloaded Q in the order of 19500. Q values of electronics and the cryostat were 3000 and 8000, respectively. The size of a single element was selected to maintain a coil to body resistance ratio large enough for SNR gain of about 100% and 150% for Cu and HTS, respectively. Performance of the array confirmed expected SNR gains. The array is currently under 3 T scanner tests. Assessment of the application of HTS arrays in high field MRI will be discussed.

*This work was supported by NIH grant AR053156.*

11:00am

**1EC03 - Fabrication and properties of longitudinal and transversal current rectifier devices based on superconducting films with arrays of nanodefects.**

*D.Perez de Lara, E.M.Gonzalez, Universidad Complutense; J.V.Anguita, Instituto Microelectronica (CSIC); J.L.Vicent, Universidad Complutense*

Recently, transverse superconducting rectification effects on superconducting films with arrays of asymmetric defects have been reported (1). In this device an injected ac current yields an output dc voltage drop in the direction perpendicular to the applied current. The same device shows a rectifier effect in the longitudinal direction, that is an applied ac - bias current yields an output dc-voltage in the direction parallel to the applied current (2). The device is fabricated by electron beam lithography, sputtering and etching techniques, using these techniques and Si substrates superconducting films are grown on top of arrays of non-superconducting triangles. In this work we explore the role played by the frequency, temperature, the array shapes and the nanotriangle materials (magnetic or non-magnetic triangles). We show that to enhance the effect the array shape is a crucial parameter as well as the temperature, while the frequency and the type of nanotriangle materials play a minor role. (1) E. M. Gonzalez, N. O. Nunez, J. V. Anguita, J. L. Vicent, Appl. Phys. Lett. 91, 062505 (2007). (2) J. E. Villegas, S. Savel'ev, F. Nori, E. M. Gonzalez, J. V. Anguita, R. Garcia, J. L. Vicent, Science 302, 1188 (2003)

*Spanish Ministerio Educacion y Ciencia NAN04-09087, FIS05-07392, and CAM S-0505/ESP/0337.*

11:15am

**1EC04 - Cavity Induced Phase Locking of Fluxons in an Intrinsic Josephson Junction**

*N.F.Pedersen, Techn. Univ. Denmark; S.Madsen, Univ. of Southern Denmark; P.L.Christiansen, Techn. Univ. Denmark*

A stack of inductively coupled long Josephson junctions is modeled as a system of coupled sine-Gordon equations. One boundary of the

stack is coupled electrically to a common resonant cavity. Without the cavity and with one fluxon in each Josephson junction in the stack, the inter-junction fluxon forces are repulsive, and the lowest energy state consists of spatially separated shuttling fluxons. We look at a possible transition, induced by the cavity, to a bunched state where the inter-junction forces are compensated by forces resulting from the boundary conditions, as a consequence giving rise to in-phase coherent motion of the fluxons. Most of the presented work is realized by numerical simulations; however in several cases we have been able to find analytical solutions thus providing new insight in this complicated non-linear system. Prospects for experiments on BSCCO-type samples as well as applications to terahertz oscillators will be discussed.

11:30am

**1EC05 - Josephson Junction Networks with Inhomogeneous Architecture**

*R.Russo, C.Granata, S.Rombetto, M.Russo, Istituto di Cibernetica ; P.Silvestrini, Seconda Università di Napoli and Istituto di Cibernetica ; A.Vettoliere, AtB and Istituto di Cibernetica ; B.Ruggiero, Istituto di Cibernetica*

We investigate the properties of Josephson junction networks with inhomogeneous architectures. The networks are shaped as planar lattices on which Josephson junctions link superconducting islands arranged in the plane to generate the pertinent geometry without generating superconducting loops. Two inhomogeneous architectures were investigated having different connectivity. Linear arrays are fabricated on the same chip and used as reference arrays. The Josephson Junctions have dimensions of 4x4 and 5x5 square micron and they are fabricated using the robust Nb trilayer technology (Nb/AlOx/Nb). Whereas the temperature dependency of the Josephson currents of linear array follows the well know Ambegaokar and Baratoff behavior the Josephson current of the network branches on the same chip exhibit relevant differences. Measuring current switching distribution of the first junction on different arrays and fitting of I-V curve give more insight to the experimental observations. The observed phenomena evidence new and surprising behavior of superconducting Josephson arrays and show remarkable similarities with behavior expected for the systems of pure bosons arranged in inhomogeneous shaped lattices.

11:45am

**1EC06 - Characterization of YBCO step edge junctions as a function of grain boundary angle at low temperatures**

*E.E.Mitchell, C.P.Foley, J.C.Macfarlane, CSIRO Materials Science & Engineering*

We have fabricated a range of YBCO thin film step-edge Josephson junctions in which the superconductor-barrier-superconductor interface is at an angle other than normal to the a-b axes of the YBCO crystal. Transport properties of our standard step edge junctions on MgO at 4.2K are presented and compared with other types of grain boundary junctions. The transport properties of angled step edge junctions as a function of the angle between the grain boundary at the step edge and the a-axis of the YBCO crystal are also presented. Current-voltage curves show that IcRn products decreased with increasing grain boundary angle, and exhibit multiple Andreev reflections. Anomalies in the temperature dependence of the critical current and a peak in the differential conductance at low voltage are reminiscent of mid gap states seen in a range of bicrystal and ramp edge junctions, despite the absence of an in-plane rotation of either one of the superconducting electrodes across the junction. The influence of the d-wave symmetry of the order parameter in YBCO on the characteristics of step edge junctions compared with other types of grain boundary junctions is discussed.

12:00pm

**1EC07 - YBCO Superconducting Quantum Interference Filters with Planar Ion-Damaged Josephson Junctions**

*S.M.Wu, S.A.Cybart, I.Siddiqi, J.Clarke, R.C.Dynes, UC Berkeley Physics Department / MSD LBNL*

We have designed, simulated and tested a superconducting quantum interference filter (SQIF) containing a series array of 300 YBCO SQUIDS based on ion damaged Josephson junctions. The simulations included the geometrical inductances of the SQUID loops and the Fraunhofer diffraction pattern of the individual junctions. The simulated voltage response versus applied magnetic field was used to design the layout of the SQIF. In the device, loops for the SQUIDS were patterned in a YBCO film using photolithography and argon ion milling. The Josephson junction barriers were formed with ion bombardment through 30 nm wide slits that were patterned with electron beam lithography and reactive ion etching of a bilayer mask consisting of 25 nm germanium on 700 nm of photoresist. The ion damage lowered the transition temperature  $T_c$  of the 30 nm unmasked region to produce SS'S junctions, where  $T_c = 85$  K for superconductor S and 75 K for S'. The  $I_c R_n$  product at 73 K was 0.02 mV. Voltage versus magnetic field curves were measured for different static bias currents. They show a dip at zero field which increases with increasing bias up to a saturation value of 2 mV. The maximum transfer coefficient was 17 mV/mT. The measured voltage response of the device was smaller than the predictions of the model, most likely because of inductive coupling between loops, random variations in  $I_c$  and  $R_n$ , and the effects of thermal noise. High frequency noise properties and linearity measurements will be presented.

*This work was supported by AFOSR and by DOE through the LBNL Molecular Foundry.*

12:15pm

**1EC08 - HTS Josephson junction cantilever microscopy of microwave devices**

*M.Schilling, C.Brendel, F.Stewing, TU Braunschweig*

Josephson junctions from the high-temperature superconductor  $YBa_2Cu_3O_7$  are routinely used on a cantilever to detect with spectral resolution microwave emission from room temperature microwave devices. The Josephson junctions are operated in a temperature range between 40 K to 80 K cooled by a cryocooler. Near field imaging is accomplished with a spatial resolution of below 15  $\mu\text{m}$  with operating distance of the cooled Josephson cantilever to the surface of the device under test (DUT) of about 15  $\mu\text{m}$ . Due to the realization as an active cantilever a topographic image of the DUT as well as the microwave power distribution can be obtained. We discuss measurements of the three dimensional radiation distribution above the chip surface under investigation at frequencies between 5 and 760 GHz. By these measurements we demonstrate the quantitative characterization of passive devices like transmission lines, filters and directional couplers.

**MONDAY AFTERNOON POSTER SESSIONS**

**2:00pm - 4:00pm**

**IEPA - Transition Edge Sensors II - Physics 2:00pm - 4:00pm**

**1EPA01**

**Mo-based proximity bilayers for TES: microstructure and properties**

*L.Fàbrega, Institut de Ciència de Materials de Barcelona (CSIC); I.Fernández, Instituto de Microelectrónica de Madrid (CSIC); M.Parra, Instituto de Ciencia de Materiales de Aragón (CSIC); O.Gil, Institut de Ciència de Materials de Barcelona (CSIC); F.Briones, Instituto de Microelectrónica de Madrid (CSIC); A.Camón, Instituto de Ciencia de Materiales de Aragón (CSIC); J.Sesé, J.Costa-Kramer, Instituto de Nanociencia de Aragón (U.Zaragoza); R.González-Arrabal, J.Anguila, Instituto de Microelectrónica de Madrid (CSIC)*

We report on the fabrication and characterization of Mo-based bilayers for TES microcalorimeters suitable for X-ray detection. The Mo layers were deposited on silicon nitride membranes and layers, using the sputtering technique. A vacuum chamber with base pressure of 10<sup>-9</sup>mb was specially designed, in order to prevent the incorporation of impurities. Metal layers (Cu, Au) were deposited on Mo by e-beam or sputtering. We have studied the effect of the growth-induced stress and microstructure on the superconducting transition of the bilayers. With such aim we have performed X-ray diffraction, electron microscopy and atomic force microscopy studies, as well as in-situ measurements of stress. Resistance versus temperature was measured in a dilution refrigerator. Critical temperature and transition width are correlated to the thickness of the layers, their microstructure and the growth conditions. Optimal parameters for fabrication of transition edge sensors (TES) with these bilayers are discussed.

*Work carried out with financial support from the Spanish MEC (MAT2005-02454 and ESP-2006-13608C02 projects) and Aragon Government.*

**1EPA02**

**Quasiparticle propagation in aluminum with iridium transition-edge-sensors.**

*S.W.Leman, E.Figueroa-Feliciano, S.Hertel, K.A.McCarthy, P.Wikus, MIT*

We are investigating the use of iridium (Ir) Transition-Edge-Sensor (TES) based Quasiparticle assisted Electrothermal feedback TESs (QETs) for large-mass dark-matter-detectors. As a part of this study, we have fabricated devices consisting of two Ir TESs connected by an aluminum (Al) film. X-rays from an iron-55 source are absorbed in the Al film and create quasiparticles. These quasiparticles then diffuse through the Al film and some fraction are transmitted through the Al / Ir interface. With this setup we can measure the diffusivity of quasiparticles through the Al films and the transmission of those quasiparticles through the Al / Ir interface into the Ir TESs. In this work we present our progress to date.

### 1EPA03

#### High-speed and high-efficiency photon-number resolving transition edge sensors with resonant cavities

*D.Fukuda, G.Fujii, A.Yoshizawa, H.Tsuchida, H.Fujino, H.Ishii, T.Itatani, T.Numata, M.Ohkubo, AIST*

Photon detectors with photon number resolving capabilities have wide range of applications in the field of quantum information and communication, such as quantum logic gates, quantum key distribution, and evaluation of single photon sources.

Microcalorimeters with transition edge sensors (TESs) are one of the most attractive candidates for these purposes because of their excellent photon number resolving power for very weak light pulses. Previously, we have demonstrated a 0.4-MHz counting rate with titanium-based TESs. Titanium has a relatively high transition temperature around 360 mK, that enables the fast effective time constant of 300 ns. In order to improve the quantum efficiency, we have developed new titanium TES devices with integrated optical resonant cavities. The cavities are composed of high reflection mirrors and ion-beam sputtered dielectric layers, where almost 100 % quantum efficiency can be expected in principle. In this presentation we will report on the design of the cavities, optical properties of the dielectric layers at low temperature, and the performances of the new TES devices at telecommunication wavelength.

*This work is supported by the National Institute of Information and Communications Technology (NiCT).*

### 1EPA04

#### Optimization Method for TES Microcalorimeters with Absorbers

*T.Oshima, NAOJ/NRO; K.Sato, Tokyo University of Science*

Large absorbers and a high counting rate is required for high energy resolution transition-edge sensor (TES) microcalorimeters for astronomical use. However, these two requirements have a relation of a trade-off in terms of energy resolution. Thus, besides taking saturation and linearity into account, study of the effect of thermal diffusion in large absorbers on energy resolution is essential. Therefore, we performed 3 dimensional simulations using SPICE to calculate the effect of thermal diffusion in the absorber on energy resolution. In this presentation, we will report on the optimization method and the results.

### 1EPA05

#### Fabrication of thick metal absorber with overhanging structure for TESs

*Y.H.Lee, Y.H.Kim, Y.D.Kwon, H.Y.Lee, K.B.Lee, M.K.Lee, S.J.Lee, S.I.Park, Korea Research Institute of Standards and Science (KRISS)*

In this report we describe progress in fabricating thick metal absorbers with an overhanging structure for TES applications. First, a negative photoresist is photo-lithographed in order to figure the stem of the mushroom structure. A thin seed layer of Au is sputtered over the photoresist pattern to provide an electrical contact for electroplating. Another layer of photoresist is coated and patterned to form the cap of the structure. A thick layer of Au is then electrodeposited on the open part of the seed layer. Finally, the overhanging structure is completed after releasing the photoresist and the unwanted seed layer chemically. This absorber made on a Ti/Au bilayer is currently being tested to measure X-rays with large covering factor and high detection efficiency.

### 1EPA06

#### Exploiting thermal power gain of transition edge sensors for cryomultiplexing

*P.Helistö, J.Hassel, VTT, Sensors; A.Luukanen, VTT, Millilab; H.Seppä, VTT, Sensors*

Power gain is needed for large scale multiplexing of cryogenic high-resolution detectors, such as transition-edge sensors. Usually, the power gain is given by the readout amplifier, e.g., a superconducting quantum interference device (SQUID). Here we demonstrate that by biasing a transition detector with a suitable bias resistor, thermal power gain is obtained, the maximum of which is equal to the electro-thermal loop gain. This power gain is available for cryomultiplexing in a scheme that does not require SQUID readout. In first experiments we have measured maximum power gains of about 25. The available power gain was limited by system stability and electrical and thermal disturbances. In an optimized system, we expect to achieve power gains of 50-100, allowing multiplexing of up to 100 detectors.

*The work is supported by Academy of Finland Centre of Excellence on Low Temperature Phenomena and Devices and by ESA.*

### 1EPA07

#### Development of a new TES structure using a radiation absorber self-adjusting the operating temperature

*M.Ohno, PRESTO, Japan Science and Technology Agency; H.Takahashi, R.M.T.Damayanthi, Y.Minamikawa, K.Nishimura, The University of Tokyo; H.Sato, RIKEN ; H.Toyokawa, JASRI*

We try to improve absorption efficiency and count rate of a TES, by developing a new radiation absorber self-adjusting the operating temperature. Our device consists a large gold radiation absorber and a small iridium heat sensor which has a  $T_c$  of 110mK. Both the large radiation absorber and the small heat sensor is put on the silicon nitride membrane, and they are biased in series. In this device the large radiation absorber arises the self Joule heating to a certain extent to maintain the temperature of the heat sensor. By the photon incidence to the radiation absorber, thermalization of the heat sensor induced the large current reduction, then the current through the radiation absorber also reduces, therefore the radiation absorber is expected to be cooled rapidly by the reduction of joule heating power. Minimization of the heat sensor and the separation of the radiation absorber self-adjusting the operating temperature from TES will be more effective for achievement of high count-rate, than the non-active radiation absorber that the current dose not flow, such as mushroom-type absorber. Now we are developing this device fabrication method, avoiding the chemical damage of the iridium film in the patterning process of the gold absorber using the chemical etching technique.

*M. Ohno is grateful to the PRESTO program of the Japan Science and Technology Agency for support of this research.*

### 1EPB - Transition Edge Sensors III – Physics 2:00pm - 4:00pm

### 1EPB01

#### Voltage noise and its correlation with vortex interactions

*H.Zhang, F.Zuo, University of Miami*

We report voltage noise studies in the thin Tin films in the superconducting transition. The nonlinear current voltage dependence was studied by measuring the harmonic components of the voltage signal as a function of temperature and current. The Voltage noise is found to correlate strongly with the third harmonic component (3 Omega) of the voltage, displaying the same peak temperature and similar temperature dependence. The correlation suggests that the voltage noises might come from the fluctuation of vortices due to vortex-vortex interactions.

*NASA under Grant No.NNG05WC16G*

## 1EPB02

### Characterization of the superconducting transition of thin Ir films for TES

*L.Ferrari, S.Ambrosetti, D.Bagliani, F.Gatti, R.Vaccarone, R.Valle, University and INFN of Genoa*

We are currently producing iridium based TESs to a wide variety of applications such as single photon detection of the visible and infrared light, X-ray spectroscopy and low energy nuclear beta and electron capture spectroscopy for neutrino mass search experiment. We present a study of the TES performance related to the superconductivity properties of the Ir film as function of the substrate type, Si or SiN, the physical-chemical production processes and the operating electrical parameters.

## 1EPB03

### Characterisation of NbSi TES on a 23-pixel TES

*Y.Atik, CNRS-IAS,IEF; F.Pajot, C.Evesque, B.Leriche, CNRS-IAS; M.Piat, E.Br elle, D.Pr le, F.Voisin, CNRS-APC; L.Dumoulin, CNRS-CSNSM; B.B elier, D.Bouchier, CNRS-IEF; J.P.Torre, CNRS-IAS*

Instrumental progress allowed the development of bolometric detectors adapted to submillimeter and millimeter wavelengths. Superconducting transition-edge sensors (TESs) are currently under heavy development to be used as ultra sensitive bolometers. We are investigating here the properties of NbSi thin films. NbSi is a well-known alloy for use in resistive thermometers. We present a low temperature characterization of the NbSi films on a 23-pixel array. In order to tune the critical temperature of the NbSi thermometers down to the desired range, we have to adjust the concentration of niobium in the NbSi alloy. In this experiment, we set for a Niobium concentration of 15 percent, to be able to run tests at a convenient temperature larger than 300 miliKelvin. Tests are made using Helium4-cooled cryostats, 300 miliKelvin Helium3 mini-fridges, resistance bridge and a commercial SQUID with its readout circuit. Parameters being measured are: critical temperature, resistance, sharpness of the transition and noise measurements.

*The authors are grateful to Manou Chaigneau and Dominique Broszkiewicz. This work is carried out within a framework of a partnership: D veloppement Concert  de Matrices de Bolom tres (DCMB) funded by the Centre National d'Etudes Spatiales (CNES) and Thales Alenia Space.*

## 1EPB04

### Study of the effects of configurative parameters on the response of multilayer superconductive bolometric detectors based on a 2D analytical solution

*A.Pourhashemi, A.Kokabi, A.Moftakharzadeh, S.Khorasani, M.A.Vesghi, Sharif University of Technology; J.Schubert, Forschungszentrum Juelich GmbH; M.Fardmanesh, Sharif University of Technology*

We present a new approach for 2D analytical modelling and calculation of the response of superconductive transition edge bolometers with absorber layer(s) in a wide range of modulation frequency and for different configuration of the film patterns and substrates. The method used here is based on solving the heat transfer differential equation for two different time varying heat sources related to the absorbed radiated power with considerations of two-dimensional boundary conditions for the case of spiral patterned devices. Using this approach we have investigated the effect of substrate thickness and track width and spacing on the magnitude of bolometric response, based on which the response is

optimized versus configurative parameters. In this analysis the effect of surface absorption caused by the thin film and absorber layer as well as bulk absorption in the depth of substrate is thoroughly considered. Analytical results are presented and also compared with previous analytical works.

## 1EPB06

### Control of Membrane Thermal Transport Supporting Superconducting Detector Development

*V.Yefremenko, A.Datesman, G.Wang, J.Pearson, V.Novosad, MSD, Argonne National Lab; R.Divan, CNM, Argonne National Lab; C.L.Chang, T.Downes, L.Bleem, A.Crites, S.S.Meyer, J.E.Carlstrom, KICP, University of Chicago*

We are investigating the use of partially perforated membranes for thermal management in bolometric detectors using superconducting Transition Edge Sensors (TESs). The thermal transport determines the dynamic and static operation of bolometric detectors. The control of the thermal conductance is therefore critical in the design and fabrication of detectors using TESs. These devices are typically built on silicon nitride membranes, both for purposes of thermal design, and for physical support. In this material at very low temperatures, the ballistic regime of phonon transport is expected to dominate. Sharp features in the membrane surface, such as trenches, may significantly impede the modes of phonon transport. The test configuration used in our experiments consists of one Mo/Au TES and two thin film heaters, lithographically defined on silicon nitride membranes 1 micron thick, either 3 or 10 mm square in size. Trench designs, utilizing variable geometries and depths, are incorporated between one heater and the TES, in order to determine the transport properties of the thermal control structures. The results of this investigation are compared to the ballistic phonon model.

## 1EPB07

### Investigation of Ti/Pd bilayer for single photon detection

*E.Taralli, C. Portesi, R. Rocci, M.Rajteri, E.Monticone, INRiM - Torino Italy*

In this work we report about characterization of TESs based on Ti/Au/Ti trilayer deposited on SiN/Si/SiN substrates. The Au layer is adopted to lower the transition temperature of Ti films ( about 350 mK) thanks to the proximity effect. TESs with transition temperatures from 87 mK to 103 mK have been used as single photon detectors in UV-visible range. The expression of TESs energy resolution, obtained from the Johnson noise and thermal fluctuation contributions, is not dependent from the photon energy [1]; nevertheless recently [2] has been showed that phonon down-conversion noise (originated from the loss of high energy phonons into the substrate during the initial photon energy down-conversion stage) contribute to the energy resolution with a term proportional to the square root of the incoming photon energy. Moreover a further broadening of the energy resolution has to be considered in case of multi-photon detection. The experimental energy resolution obtained with our detectors will be compared with the theoretical prediction and in particular ,comparing the energy resolution of a multi photon event with a single photon one with an equivalent energy, we will investigate the connection between the energy resolution of our detectors and the absorbed energy, considering different heuristic probability distributions of number of detected photons. [1] B. Cabrera et. al., Appl. Phys. Lett. 73, 735-737, 1998 [2] A. G. Kozorezov et. al., Appl. Phys. Lett. 89, 223510-3, 2006

### 1EPC01

#### *Invited*

#### **Polyphase Sliding Goertzel Demodulator for Continuous Phase Frequency Modulated Signals**

*P.S.Shevchenko, D.E.Kirichenko, R.Miller, D.Gupta, Hypres, Inc.*

We describe the design of a new demodulator for continuous phase frequency modulated signals such as Link-16 messages. A link-16 message consists of short RF pulses containing 32 “chips” each one having duration of 200ns. One of the main difficulties in demodulation of such signals is the very short “chip” period as compared to the frequency difference between the carrier and its’ modulation. For example in Link-16, the difference in frequency between the carrier and its’ modulated signal is only 1.25 MHz. This makes traditional demodulation approaches i.e. mixing the incoming signal with the carrier frequency and then low-pass filtering ineffective. We present a new method of demodulating such signals by digitizing the incoming signal in a superconducting delta-sigma modulator driving a 1 to 128 deserializer, then digitally filtering with a polyphase implementation of a sliding Goertzel filter. We have designed and fabricated a bandpass analog-to-digital converter (ADC) chip with an on chip deserializer, an additional room-temperature deserializer, and an FPGA polyphase implementation of sliding Goertzel filter. The results are presented for our experimental evaluation of Link-16 message demodulation.

### 1EPC02

#### *Invited*

#### **Cryogenic Semiconductor Amplifier for RSFQ-Circuits With High Data Rates at 4.2 K**

*S.Wuensch, University of Karlsruhe; T.Ortlepp, University of Technology Ilmenau; E.Crocoll, University of Karlsruhe; F.H.Uhlmann, University of Technology Ilmenau; M.Siegel, University of Karlsruhe*

For interfacing RSFQ circuits with commercial room temperature electronics and amplifying SFQ pulses with high data rates there is a highly interest in amplifiers with extremely high bandwidth, low noise and low power consumption. Various hybrid amplifiers based on commercial p-HEMT transistors in an embedded microwave design were designed and characterized. Towards the p-HEMT transistor characterization at cryogenic temperature the biasing settings according to an optimum between voltage gain and low power consumption were determined. Thus a total power consumption of 2 mW and a voltage gain of 12 dB per single stage were achieved. For a preamplifier and an amplifier concept a multiple number of these stages were implemented in a microstrip and a coplanar transmission line design with a special matched interconnect taper towards the RSFQ components. Measurements of the amplifiers, the combination of an amplifier with a RSFQ circuit at 4.2 K showed their good performances without any disturbance of the RSFQ circuit. Due to the losses between the stages a total gain of 25 dB with a four stage amplifier was achieved; pulse rates went up to 3 Gb/s. The total power consumption was in the range of 8 mW. Further increase of data rates will be achieved by improving the matching between RSFQ output stage and amplifier.

### 1EPC03

#### **Serially biased components for digital-RF receiver**

*T.V.Filippov, A.Sahu, S.Sarwana, D.Gupta, HYPRES*

Serial biasing approach is summoned up to reduce the total bias current required by RSFQ-based digital-RF receiver developed at HYPRES, Inc. It also may have a major impact on reducing the size, weight and power consumption of the complete cryocooled receiver system. The approach is based on partitioning a homogeneous design into several isolated islands biased in series and transmitting SFQ pulses between islands, over moats through inductively-coupled driver-receiver-pairs (DRPs). Experimental data on testing of 100 DRPs connected in series are reported and bit-error-rate estimations are given. Our goal is to serially bias two sets of homogeneous circuit blocks in the digital-RF receiver design: (1) digital decimation filter (DDF) bit slices, (2) output drivers. The correct operation of test chips containing four bit-slices of a second-order DDF, partitioned into 2 and 4 islands, are demonstrated. Results of 8 output drivers, serially biased on 2, 4, and 8 islands, are reported. Design issues of scaling to a digital-RF receiver, containing 18-20 DDF bit slices and 16 output drivers are discussed.

### 1EPC04

#### **Components for superconductor digital-RF predistorter**

*A.Sahu, T.V.Filippov, D.Gupta, HYPRES*

HYPRES is developing superconductor digital-RF predistorter for direct linearization of radio frequency power amplifiers. The predistorter utilizes proportional (P), squared integral (I) and differential (D) corrections. We report progress in the proportional component implementation. We designed, fabricated and tested 4-to-16 decoder, 16-to-4 memory matrix and test pattern generator integrated on a 10 mm × 10 mm chip. We also designed a pipelined differentiator, the critical element of the differential component, and its combination with decoder. The correct operation of a resettable counter to implement the integral predistorter function is reported. The design issues of the complete superconductor PID predistorter are discussed in brief.

*This work was supported by the Office of Naval Research.*

### 1EPC05

#### **Microwave Packaging for Voltage Standard Applications**

*M.M.Elsbury, University of Colorado at Boulder; C.J.Burroughs, P.D.Dresselhaus, National Institute of Standards and Technology; Z.B.Popovic, University of Colorado at Boulder; S.P.Benz, National Institute of Standards and Technology*

Improvements to the packaging of Josephson Voltage Standard (JVS) circuits have increased operating margins, reliability, and longevity of these systems. By using the “flip-chip-on-flex” technique, reliable chip and cryoprobe mounting have been demonstrated. The microwave structures on these packages have been improved so that more power can be delivered to the JVS chip over a wider frequency range. Detailed finite-element simulations were performed to optimize the chip-to-flex and SMA-to-flex launches as well as the on-flex transmission lines. It was found that coplanar transmission line designs performed better than microstrip transmission line designs due to the large discontinuities associated with through-substrate vias for microstrip ground connections. The improved coplanar-waveguide structures yielded substantially larger operating margins. These same microwave simulation and design tools have also been used to enhance on-chip microwave structures. Power splitters, bias-tees, and transmission lines have all been successfully designed, fabricated, and tested. These structures have vastly improved the performance of NIST voltage standard circuits.

## 1EPC06

### Enhancement of the output current capacity of rapid single flux quantum voltage multipliers

*F.Hirayama, M.Maezawa, S.Gorwadkar, AIST*

A Rapid Single Flux Quantum digital-to-analog converter (RSFQ DAC) which synthesizes arbitrary waveforms with metrological accuracy is under development for ac voltage standard applications. Since the RSFQ DAC operates at low temperature and is connected to a room-temperature load with a relatively long cable, it is desirable that the RSFQ DAC has high output current capacity to drive the cable capacitance. The output current capacity is determined by current amplitude of constant-voltage steps appeared in current-voltage characteristics of a voltage multiplier which is a main component of the RSFQ DAC. We employed magnetically-coupled type voltage multipliers consisting of input Josephson transmission lines and a stack of output SQUIDs. In the previous work, voltage multipliers with 2-junction output SQUIDs were utilized and the output current capacity was limited to ~0.1 mA. To increase the output current capacity, we designed new voltage multipliers in which the output SQUID consisted of N (N=4, 6, 8,...) Josephson junctions connected in parallel. Simulations showed that the output current capacity was approximately proportional to N and thus to the critical current of the output SQUID. N-junction SQUID voltage multipliers were fabricated by a 1.6 kA/cm<sup>2</sup> Nb junction technology. Test results confirmed the expected enhancement of the output current capacity. The output current capacity exceeding 0.5 mA was achieved for a 10-junction SQUID voltage multiplier, which was five times larger than that of the original circuit with 2-junction SQUIDs.

## 1EPC07

### Elaboration of NbN ADC Circuits on Large Area Wafers for HyperSCAN

*J.-C.Villegier, INAC CEA-Grenoble; D.Renaud, LETI CEA-Grenoble; C.Bornier, ID3-Semiconductors; P.Febvre, Univ. de Savoie; P.Loumeau, ENST-Paris*

The HyperSCAN project labeled by ANR French agency and by Minalogic pole is organized to design, fabricate and test large bandwidth band-pass Sigma-Delta Analog-to-Digital Converter circuits with performances targeted for applications at microwave carrier frequencies and 9K operating temperature. Self-shunted NbN-TaN-NbN SNS Josephson junctions and multilayer developed in the project are shown suitable for RSFQ medium scale integration circuits operating at very high clock frequency, up to 200 GHz. This is because the nitride technology process including two wiring levels and Mo resistors has been proved feasible by applying the high accuracy, low spread lithography and CMP planarization, managed at the CMOS CEA-Leti platform on 200mm Si wafers. Based on VHDL design of the architecture, modeling and implementation tools, the ADC NbN circuits are expected to operate with good margins inside a compact cryocooler. The cryo-package has been managed to strongly reduce the overall power dissipation in operating NbN RSFQ functions in regard to Nb ones at 4K, thanks to the design of low thermal dissipation electrical wiring limands and cold interface circuits linking the 9K stage to room temperature electronics.

We will present the accuracy obtained in lithography on submicron planar JJ and other results demonstrating the capability of NbN for addressing analog & digital sub-THz circuits and discuss on the possibility of processing 9K-NbN-ADCs chips at low cost in any semiconductor IC production facility.

*Granted by ANR06-TCOM-026 & through Minalogic*

## 1EPC08

### Fabrication Technique of Single Flux Quantum ALU by using Nb Trilayer

*J.H.Kang, University of Incheon*

Nb trilayer process has been serving as the most stable fabrication process of the Josephson junction integrated circuits for more than two decades. Fast development of semiconductor fabrication technology has been possible with the recent advancement of the fabrication equipments. In this work, we took an advantage of those advanced fabrication equipments in developing a superconducting Arithmetic Logic Unit (ALU) by using Nb trilayers. We used DC magnetron sputtering technique for metal depositions and RF sputtering technique for SiO<sub>2</sub> depositions. Various dry etching techniques were used to define the Josephson junction areas and film patterning processes. Our Nb films were stress free and showed the T<sub>c</sub>'s of about 9 K. To enhance the step coverage of Nb films we used reverse bias powered DC magnetron sputtering technique. The fabricated 1-bit, 2-bit, and 4-bit ALU circuits were tested at a few kilo-hertz clock frequency as well as a few tens giga-hertz clock frequency, respectively. Our 1-bit ALU operated correctly at up to 40 GHz clock frequency, and the 4-bit ALU operated at 5 GHz clock frequency.

## 1EPD - Cryocooler and Packaging 2:00pm - 4:00pm

### 1EPD01

#### Cryocooler interface for RSFQ DSP

*H.Engseth, R.Rafique, B.Sarabi, A.Herr, Chalmers University of Technology*

We present the characterization and measurement results of a unique high bandwidth cryo cooler package and a room temperature interface for a superconducting Digital Signal Processor (DSP). The system is developed in close cooperation with Hypres Inc. USA. It is integrated on a two stage commercial cryocooler, the Sumitomo RDK101D, which has a 100 mW specified power lift at a 4 K stage and an additional 5 W at a 60 K stage. It supports exchangeable test units for 10 mm x 10 mm or 20 mm x 20 mm Multi Chip Module (MCM) carriers. The electrical interface consist of 40 high speed I/Os with bandwidth of 2 Gbps, 64 DC bias channels for a total bias current of 2.5 A, and 4 high frequency clock lines and 4 auxiliary control lines for 20 GHz, and is equipped with 4 room temperature LNA's (DC-2.5 GHz) optimized for direct amplification of SFQ/DC converter signal (~200 μV). Cooling power is very modest, but by careful heatload optimization, 4 K operational temperature is achievable. The availability of such a system is critical for demonstration of the hybrid DSP prototype and for future commercialization.

*R. Webber, V. Dotsenko, and R. Miller at Hypres Inc.*

### 1EPD03

#### Ultra-Low Heat Leak YBCO Superconducting Leads for Cryoelectronic Applications

*R.J.Webber, J.Delmas, Hypres, Inc.; B.Moeckly, Superconductor Technologies, Inc.*

We report on High Temperature Superconductor (HTS) DC current leads developed for the specific purpose of delivering small currents  $\sim 100$  mA to cryocooled electronic devices operating at 4 K, with the minimum of heat-leak. Multi-stage cryocoolers can provide a suitable platform for niobium-based superconducting electronics operating at 4K; the necessary multiple parallel biasing of the circuitry can result in total currents of several amps, which can produce substantial thermal loading of the cryocooler when conventional resistive leads are used. Our approach has been to adapt the comparatively mature technology of high-current second-generation (2G) YBCO coated conductor tape to low-current needs by splitting the tape into electrically isolated narrow lines by ion-milling. Performance issues discussed are: obtained critical currents, thermal conductance of the composite conductors, line-to-line electrical isolation, resistance of the joints and operational stability in a vacuum. Operation as a current lead between the first and second stage of a Gifford-McMahon cryocooler is reported. *Supported in part by the Office of Naval Research contract # N00014-05-C-0205*

### 1EPD04

#### Integration of a 4-stage 4K pulse-tube cryocooler laboratory prototype with a superconducting IC

*R.J.Webber, V.V.Dotsenko, J.Delmas, T.V.Filippov, D.E.Kirichenko, S.Sarwana, D.Gupta, A.M.Kadin, E.K.Track, Hypres, Inc.*

Market applications of digital and mixed-signal superconducting electronics require the use of a closed-cycle cooling system, a cryocooler. The ideal 4K cryocooler, with full reliability, power and cost efficiency, and manufacturability, is not yet commercially available. Recently, a custom-designed laboratory prototype of a 4K 4-stage Stirling-type pulse-tube cryocooler was produced by Lockheed-Martin and delivered to HYPRES. We have adapted the system with a cryopackage which we used to mount and successfully test a superconducting IC with a variety of Nb circuits (based on a  $J_c = 4.5$  kA/cm<sup>2</sup> process) including an RSFQ binary counter. For 600 W total compressor power and a package with broadband input-output lines, extended stable operation of the counter at  $T=4.5$  K was demonstrated with a clock frequency up to 46 GHz clock speed, with 25 mW of excess cooling capacity on the coldest stage. The thermodynamic and mechanical performance is promising for the development of an improved compact cryocooler for superconducting electronic applications such as wireless communications.

*This work was supported in part by the US Army and by ONR.*

### 1EPD05

#### Cryogen-free Cryostat for Low Temperature hundred Pixel Array Detectors

*N.Zen, S.Shiki, M.Ohkubo, National Institute of Advanced Industrial Science and Technology (AIST)*

The enhancement of the detection efficiency of Low Temperature Detectors (LTDs) is quite important for material analysis with x-ray and gamma-ray spectroscopy and molecule analysis with mass spectroscopy. One solution to realize efficient analyzing tools is to produce large-scale array detectors. In this case the wiring configuration in cryostats gets much more complex. For the purpose of detecting fluorescent x-ray or macromolecules efficiently, we are developing spectrometer systems with 100 pixel array Superconducting Tunnel Junction detectors (STJs), infrared-blocking filters, and cryogen-free cryostats. Considering thermal inflow and signal attenuation through signal wires at each stage of a cryostat, the optimal combination of

wiring cables and infrared-blocking filters were determined. Furthermore, from the point of view of cryostat handling, an easy exchange of detectors and simple maintenance are necessary for practical use of the spectrometers. In this presentation, the configuration of a cryogen-free cryostat and its cooling performance is presented. *This work was supported by the JST-SENTAN Project (Japan Science and Technology Agency).*

### 1EPD06

#### Development of MgB<sub>2</sub> SQUID system cooled by pulse-tube cooler for MCG

*D.Oyama, Iwate University, Japan Society for the Promotion of Science Research Fellow ; Y.Harada, Japan Science and Tech. Agency Innovation Satellite Iwate; Y.Fujine, K.Kobayashi, Iwate Univ.; Y.Uchikawa, Tokyo Denki Univ.; M.Yoshizawa, Iwate Univ.*

We developed an MgB<sub>2</sub> SQUID system cooled by a pulse-tube cooler to detect a magnetocardiogram (MCG). This system requires no cryogen and MgB<sub>2</sub> SQUIDs are generally easier to produce than high-T<sub>c</sub> SQUIDs. A commercially available pulse-tube cooler was used. The cold head of the cryocooler is connected to the compressor via a valve unit. Because the valve unit generates magnetic noises, the cold head and the refrigerator part are installed in a magnetically shielded room (MSR), and the valve unit is set outside of it. Our MgB<sub>2</sub> SQUID was made from a high quality as-grown film of which T<sub>c</sub> is 37 K. The MgB<sub>2</sub> SQUID and a magnetometer pickup coil are installed on a cold stage. The refrigerator can reach about 5 K without any loading. Temperature is controlled by a heater while operation. DC coupling between the SQUID and a preamplifier is used and a flux-locked loop (FLL) circuit works in direct readout mode. The lowest temperature was 5.6 K and experiments were carried out at 28.6 K. The bias current of the SQUID was 370  $\mu$ A, the maximum voltage modulation was 10.2  $\mu$ V. Sensitivity B/ $\Phi$  was 19.3 nT/ $\Phi$ 0. A white magnetic noise level of 9.5 pT/(Hz<sup>1/2</sup>) was measured inside a single layer MSR. MCG signal was successfully detected, and then clear QRS complex was obtained by applying a software signal processing. This system is efficient for biomagnetic measurements without liquid cryogen.

### 1EPE - SQUID NMR / MRI 2:00pm - 4:00pm

### 1EPE01

#### Invited

#### MAGNETORELAXOMETRY IMAGING

*S.Sarangi, I.C.Tan, A.Brazdeikis, Texas Center for Superconductivity at the University of Houston, Houston, TX 77204*

The valuable information contained in the spatial distribution of magnetic nanoparticle (MNP) in tissue obtained by medical imaging techniques such as magnetic resonance imaging (MRI) is recorded indirectly. A sensitive method for detecting the MNP directly is to measure their magnetic fields using so-called magnetic relaxometry technique. Magnetorelaxometry is based on the fact that MNP relaxes after being aligned by a magnetic field pulse depending on its size and on whether it is bound or not. After polarizing field is switched off, the remnant magnetization decays (relaxes) as the alignment reverts back to chaos, either by Brownian motion or, if the particles are immobilized and cannot rotate freely, by the Neel mechanism. Magnetorelaxometry technique has unique potential to be used for high-spatial resolution imaging in particular for monitoring of the molecular interaction in vivo by using MNP as signal generators coupled to biomolecules (e.g. antibody) that provide specific binding to the molecular structures of interest. The object is placed in the selection field generated by three pairs of coil orthogonal to each other. An image of the magnetic tracer in the object is directly obtained by mapping the magnetization decays by a low-temperature SQUID system. Preliminary data shows a resolution of approximately 4 mm in an unshielded environment.

## 1EPE02

### **SQUID-Based Relaxometric Diagnostics of Magnetic Nanoparticles**

*I.A.Volkov, O.V.Snigirev, S.N.Polyakov, Physics Department of Lomonosov Moscow State University, Moscow, Russia; A.V.Volkov, Chemical Department of Lomonosov Moscow State University, Moscow, Russia; G.Y.Yurkov, Institute of General and Inorganic Chemistry of RAS, Moscow, Russia; S.Tanaka, Toyohashi University of Technology, Toyohashi, Japan*

The method of SQUID-based relaxometric diagnostics has been applied to the dilute ensembles of near-spherical Fe<sub>3</sub>O<sub>4</sub> and Co nanoparticles in order to reveal the behaviour of the anisotropy constant upon varying the mean size of nanoparticles in the ensemble (from 5 to 13 nm) and the type of polymer matrix in which they are dispersed. The crystal structure of nanoparticles and the local coordination environment have been analyzed by using XRD and EXAFS methods, respectively. The relaxation curves measured in the time range from 50 microseconds to several tens of seconds after application of a pulse (10 s) of dc magnetizing field (~ 10 G) have been approximated by theoretical dependences calculated within the framework of activation Néel–Arrhenius law with account for the size distribution function retrieved from the transmission electron microscopy data. The noticeable effects of the mean size of nanoparticles and the polymer matrix on the anisotropy constant have been found. The observed behaviour of the anisotropy constant is discussed in terms of the variations in the electronic structure of near-surface ferromagnetic atoms caused by their interactions with the surrounding matrix.

## 1EPE03

### **Ultra low-field NMR of UF<sub>6</sub> for <sup>235</sup>U detection and characterization**

*P.E.Magnelind, A.N.Matlachov, P.L.Volegov, M.A.Espy, Los Alamos National Laboratory*

We have developed an ultra low-field (ULF) nuclear magnetic resonance (NMR) measurement system for unambiguous detection and characterization of <sup>235</sup>U in the form of UF<sub>6</sub>. The ULF approach provides low-frequency signatures of both <sup>19</sup>F and <sup>235</sup>U and enables the low-frequency NMR signals to penetrate metal enclosures. The system is built around a low-T<sub>c</sub> second-order gradiometric SQUID. The prepolarization coil produces fields up to 50 mT and the measurement field coil can produce fields up to 200 microT. The UF<sub>6</sub> gas is stored in an PTFE vessel equipped with a non-magnetic heater to control the phase of the material. The temperature must, however, be kept below 100 C. The detection is based on the J-coupling between the <sup>235</sup>U (spin 7/2) and the <sup>19</sup>F (spin 1/2) which produces an octuplet compared to the singlet state for <sup>238</sup>U.

## 1EPE04

### **Magnetic fluids as contrast agents in nuclear magnetic resonance imaging using high-T<sub>c</sub> superconducting quantum interference devices**

*H.C.Yang, National Taiwan University; S.H.Liao, H.E.Hornig, National Taiwan Normal University; S.Y.Yang, Global Applied Biomedical Corporation*

we characterized the NMR spectra of the water-based magnetic fluids with different magnetic susceptibility in micro-tesla magnetic field. A broadening of proton nuclear magnetic resonance spectra and growing relaxation rates were observed with an increasing susceptibility of magnetic fluids. The magnetic susceptibility causes the de-phasing of the proton nuclear spin and reduces the NMR intensity. We demonstrated that the magnetic nano-particles can be used as a contrast agent, which results a shorter relaxation time caused by the in-homogeneity of the local field.

## 1EPE05

### *Invited*

### **NMR with superconducting-GMR mixed sensors**

*H.Dyvorne, C.Fermon, M.Pannetier-Lecoer, J.F.Jacquinot, H.Polovy, A.L.Walliang, G.Legoff, G.Cannies, G.Arrias, CEA-Saclay*

When coupled to a Giant Magnetoresistive (GMR) sensor, a superconducting loop containing a constriction can be a very sensitive magnetometer [1]. It has thermal noise levels of few fT/sqrt(Hz), comparable to LT- SQUID noise, with a flat frequency response. These mixed sensors are good candidates for detection of weak biomagnetic signals, like a cardiac or neuronal signature. Furthermore, being sensitive to the flux, mixed sensors can be used for Nuclear Quadrupolar Resonance [2], Nuclear Magnetic Resonance (NMR) detection and Magnetic Resonance Imaging (MRI) especially at low and ultra low fields. They are very robust and accept strong RF pulses with a very short recovery time compared to tuned RF coils, which allow measurements of broad signals. We will present results of NMR detection of <sup>1</sup>H and <sup>19</sup>F at low fields (below 10mT) and perspectives for Low Field-MRI. Combination of LF-MRI and Magneto-Encephalography on the same experimental setup is particularly promising for functional imaging of the brain. References [1] M. Pannetier et al., Science 304, 1648-1650 (2004). [2] Pannetier-Lecoer M, Fermon C, Biziere N, et al., IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY 17 (2): 598-601 Part 1 JUN 2007  
*This work is supported by the European program 7 ISTNMP-2 Biosensors for Diagnosis and Healthcare (Biomagsens NMP4-CT-2005-07210).*

## 1EPE06

### *Invited*

### **Applications of ultra-low field magnetic resonance for imaging and materials studies**

*M.Espy, SQUID Team, Los Alamos National Laboratory*

Nuclear magnetic resonance (NMR) and imaging (MRI) are ubiquitous tools in the sciences and medicine. NMR provides powerful techniques to probe both local and macromolecular chemical structure and dynamics. MRI is the tool of choice for tomographic imaging of soft tissue anatomy and monitoring function based on dynamic physiological processes. Recently it has become both possible and practical to perform MR at magnetic fields from μT to mT, the so-called ultra-low field (ULF) regime. SQUID sensor technology allows for ultra-sensitive detection while pulsed pre-polarizing fields greatly enhance signal. The instrumentation allows for unprecedented flexibility in signal acquisition sequences. Here we present an overview of several applications of ULF MR which exploit the unique abilities of the method. These include (1) imaging of the human brain at 46 μT in combination with magnetoencephalography, (2) application of ULF techniques to direct tomographic imaging of neural currents, (3) classification of materials via relaxation properties measured at ULF relevant to numerous non-invasive inspection applications, (4) determination of uranium enrichment fraction via relaxation and/or the J-coupling mechanism to address nuclear safeguards. We briefly describe the motivation, advantages that ULF MR with SQUID-based detection brings, and the experimental and theoretical methods for applying ULF MR to these problems.

## 1EPE07

### Invited

#### **In Vivo Imaging Applications of SQUID-based Microtesla MRI**

*S. Busch, M. Hatridge, T. Wong, M. Moessle, A. Pines, J. Clarke, UCB/LBNL; J. Simko, UCSF*

High field magnetic resonance imaging (MRI) uses differences in the longitudinal relaxation time (T1) to distinguish tissue types. Our earlier results demonstrate that T1 contrast at low fields can be much greater than at high field. We prepolarize protons in a magnetic field of 40 – 150 mT, then encode and acquire images of phantoms and tissue samples with T1 contrast established at 0.132 mT using a SQUID coupled to an untuned superconducting gradiometer. To obtain T1-values, both in and ex vivo, we acquire a series of images with a variable delay time between prepolarization and imaging, from which we calculate T1 maps by fitting an exponential decay to the six amplitudes of each voxel. We present T1 maps of prostate tissue ex vivo (T1 values for healthy and cancerous tissue are 76 and 47 ms) and of the arm in vivo (T1 values for muscle, fat and bone marrow are 54, 93, and 82 ms). These maps allow us to adjust imaging parameters to optimize the T1 tissue contrast of in vivo images and thus maximize the visibility of tissues of interest (for example, tumors). To demonstrate our in vivo imaging capabilities, we have imaged the arm with a resolution of 2mm x 2mm x 10mm in 5 minutes, using a polarizing field of 40 mT. A new electromagnet currently being tested will increase the prepolarization field to 150 mT, and should result in a resolution of 2mm x 2mm x 3mm. Given the demonstrated strength of low field T1 contrast in ex vivo prostate tissue and our in vivo imaging capability, we believe we can achieve T1 weighted contrast images of the prostate of clinical significance. *Work supported by USDOE.*

## 1EPE08

#### **The Effect of Low-frequency Disturbances on Low-field NMR**

*L.Q. Qiu, H.J. Krause, Y. Zhang, A.I. Braginski, Forschungszentrum Juelich, Germany*

Compared with high-field conventional NMR, the SQUID-based low-field (FL) NMR system has a more open sample environment. Consequently, the effect of low-frequency disturbance signals, such as those of moving vehicles, of the power line and its harmonics, etc, should not be overlooked. We investigated the influence of low-frequency disturbance signals on SQUID-detected LF-NMR measurements. The Larmor frequency (fL) varied from 2 Hz to 40 kHz; the frequency of disturbance signal (fD) was close to or even higher than fL. We applied two kinds of time-dependent (sinusoidal) signals: homogenous field and linear gradient field. In practice, any disturbance signal of a distant source can be divided into these two kinds of signals. The results are: 1. In the case of homogeneous disturbance signal, the homogeneity of measurement field is not affected, but the field amplitude changes slightly. Thus we observed Larmor- frequency-modulated free induction decay (FID) signals. 2. The gradient disturbance field influences the homogeneity of the measurement field, so the amplitude of FID signal is modulated. 3. In both cases, the spectra contain peaks from beating between fL and fD, except when fD > fL. 4. As fD increases, its influence decreases; it can be neglected when fD reaches around 20 Hz. Therefore, the power line and its higher harmonic noise do not influence the LF-NMR signal.

## 1EPE09

### Invited

#### **High-performance Low-field NMR Utilizing a High-Temperature SQUID Detector**

*L.Q. Qiu, Y. Zhang, H.J. Krause, A.I. Braginski, Forschungszentrum Juelich, Germany; S. Tanaka, Toyohashi University of Technology, Japan*

We performed high signal-to-noise (SNR) low-field (LF) nuclear magnetic resonance (NMR) measurements of liquid samples using

a HTS SQUID as signal detector. We measured within a magnetically shielded room; the Larmor frequency (fL) varied between 2 Hz and 40 kHz. The innate limitation of LF-NMR is its low SNR. To reduce this limitation, we applied before each measurement a prepolarization field (Bp ~ 10 mT) perpendicular to the measurement field. The initial amplitude of free induction decay (FID) signal decreases with increasing fL, but a proper AC-pulse parallel to Bp can recollect the signal, presumably by initializing the phase of spins. The AC-pulse (B1) is applied immediately after switching off Bp. At fL above 10 kHz, the pulse can improve the SNR of measurement by more than one order of magnitude. We investigated the effect of B1 on signal intensity as a function of the tip angle  $\Theta = \gamma \times B1 \times t$ . We noted that the measured FID signal is periodic in  $\Theta$ . Furthermore, the output signal is critically dependent upon the initial phase of B1. We reported earlier on a resonant LC input circuit suitable for a high-temperature SQUID [1]. Here, we applied this technique to LF-NMR measurements, and found it can improve the SNR by an additional factor of 4. [1]. L. Q. Qiu, et al, Rev. Sci. Instrum. 78, 054701 (2007).

### 1EPEF - Novel Junction Applications - 12:00pm - 4:00pm

## 1EPEF01

#### **Extraction of the spectral information of terahertz signals using superconducting Josephson junction**

*W.W. Xu, S.L. Ye, J. Chen, K.L. Kang, P.H. Wu, Department of Electronics and Engineering, Nanjing University*

Spectrum analyses of terahertz signals are carried out using superconducting Josephson junction mounted on a close-cycled refrigerator working at liquid nitrogen temperatures. Digital signal processing (DSP) chips are made use of to develop a data acquisition and processing system so that it can be compact, fast, and intelligent. With the completion of the relevant hardware and softwares, the measurements are now automated. The whole system and the measurement results are described and discussed in detail in the paper.

*Supported by the National Basic Research Programme of China under No 2006CB61006 and 2007CB310404, and National High-tech R&D Programme of China under Grant No 2006AA03Z214*

## 1EPEF02

#### **Characteristic behaviors of a coupled intrinsic Josephson junction (IJJ) in a Bi-2212 whisker**

*S.-J. Kim, Cheju National University*

We investigated two long intrinsic Josephson junctions (IJJs) consisting of an oscillator and a detector on a Bi2Sr2CaCu2O8+d (Bi-2212) whisker. The oscillator utilizes the effect of flux flow motion in long IJJs, and the detector receives an electromagnetic wave generated by the oscillator. The functions can be exchanged by changing the direction of the bias current or the external magnetic field (He) because those coupled junctions are of the same dimension. In-plane areas with the same junction geometry, 15  $\mu\text{m} \times 1.7 \mu\text{m}$  and with a completely separated interval of 0.1  $\mu\text{m}$  were fabricated by using a 3-D focused-ion-beam (FIB) etching method. Those oscillator and detector junctions exhibited uniform multi-branch structures and clearly upturned curves under He. The flux-flow velocities (Vff) reached  $8.7 \times 10^5 \text{ m/s}$  at 6.2 T and 10 K. We describe the characteristic behaviors between coupled, long IJJs for high-frequency device applications.

*A part of this work was supported by the Korea Science and Engineering Foundation (KOSEF) and Korea Research Foundation (KRF).*

### 1EPF03

#### **Simulation of the effect of temperature on flux-flow behavior in stacked intrinsic Josephson junctions**

*A.Irie, G.Oya, Utsunomiya University*

Intrinsic Josephson junctions operated in the flux-flow mode have attracted considerable attention because of their electronics applications such as high-frequency oscillators as well as fundamental studies on vortex and nonlinear dynamics. We have numerically studied the effect of thermal noise on the flux-flow behavior in a stack of intrinsic Josephson junctions by using the inductive coupling model taking into account thermal fluctuations. In the case of fluctuation free, the current-voltage characteristics show a series of clear Fiske and flux-flow steps depending on an external magnetic field. With increasing temperature the Fiske steps which are not corresponding to the lowest-velocity cavity mode disappear. This suggests that the out-of-phase cavity mode becomes more stable than other modes due to the fluctuations. We also show that the in-phase flux-flow mode remains even at higher temperature due to large Lorentz force although the amplitudes of flux-flow steps significantly decrease. Within this approach recent experimental observations in intrinsic Josephson junctions in the flux-flow state can be explained.

### 1EPF04

#### **RF-current dependence of switching current distributions in intrinsic Josephson junctions**

*S.Saleem, J.C.Fenton, University College London; M.Korsah, C.R.M.Grovenor, University of Oxford; P.A.Warburton, University College London*

Intrinsic Josephson junction (IJJ) arrays are tuneable oscillators with narrow linewidth in the THz range [1]. The emitted power depends upon the number of junctions which are in the voltage state – i.e. it depends upon which branch in the multi-branched current-voltage characteristics the array is biased on. We have therefore experimentally studied the dynamical behaviour of TlBaCuO IJJ arrays as a function of the number of junctions which are in the voltage state. This we have done by measuring switching current distributions as a function of both temperature and irradiated r.f. current. We have compared the switching current distributions when switching from the zeroth (supercurrent) branch with those when switching from the  $n$ th branch. In the former case the switching distributions are much narrower than the theoretical thermal distribution, whereas in the latter case they can be fit well by a thermal distribution with an effective temperature which is higher than the bath temperature. When the r.f. current is increased there is a suppression of the mean switching current on the zeroth branch but no effect on the switching current of the subsequent branches. We show that these results can be understood in terms of the dissipative environment in which the junctions are embedded, and, furthermore, that switching of a single intrinsic Josephson junction significantly changes this dissipation. [1] Ozyuzer et al. Science 318 1291 (2007)

### 1EPF05

#### **Spontaneous vortex formation in quenched long Josephson junctions**

*A.V.Gordeeva, Technical University of Denmark; A.L.Pankratov, Institute for Physics of Microstructures of RAS; R.Monaco, Istituto di Cibernetica del C.N.R.; J.Mygind, Technical Univ. of Denmark*

It was suggested by Zurek and Kibble that the universal presence of causality provides bounds of the size of correlated domains after a continuous transition due to the finite speed at which the order parameter can become correlated. Hence, appearance of the defects is a direct consequence of causality. The density of defects is of great interest. The theory predicts a power dependence between the average defect separation and the quench time with the scaling exponent  $\sigma=0.25$ . In the recent experiments [1] an undeniable scaling of defect density with quench rate has been shown. However, these experiments demonstrate that for annular Josephson tunnel junctions the scaling exponent is  $\sigma=0.5$ . In this work numerical study of Josephson phase dynamics in the course of second order phase transition is presented. The named in [1] reasons responsible for the scaling exponent are tested. [1] R. Monaco, M. Aaroe, J. Mygind, R.J. Rivers and V.P. Koshelets, Phys. Rev. B 74, 144513 (2006).

### 1EPF06

#### **Dynamical Behavior of Josephson Vortices in Bi-2212**

*K.Hirata, S.Ooi, NIMS; M.Gaifullin, Loughborough University; T.Mochiku, NIMS*

Dynamical behavior of Josephson vortices (JVs) in Bi-2212 can be applied for controlling the motion of JVs with symmetrical pinning centers and time-asymmetric input signal. JVs flow very fast with a velocity up to tenth of the light velocity in Bi-2212. This means that, if the motion of JVs can be controlled, high-speed signal processing will be achieved.

We have shown the periodic oscillations in JV flow-resistance against magnetic field in Bi-2212 (PRL89(2002)247002), which persist in wide range of temperature and magnetic field. Introducing pancake vortices (PVs) into JV system in Bi-2212, the JV flow-resistance abruptly distinguishes, because the JVs interact with the PVs strongly and the PVs are pinned in intrinsically existed pinning centers in Bi-2212. However, when we apply the input current (signal) with two frequencies, a finite dc voltage can be obtained even without the flow-resistance. This leads to a rectification effect in the JVs' motion by the PVs. The nonlinearity in  $I$ - $V$  characteristics induces the rectification effect with time-asymmetric input signals of two harmonics. This may open a new application of HTSCs.

## MONDAY LATE AFTERNOON ORAL SESSIONS

4:00am - 6:00pm

### 1EX - Transition Edge Sensors IV – Physics 4:00pm - 5:45pm

4:00pm

#### **1EX01 - Development of position-sensitive transition-edge sensor X-ray detectors**

*S.J.Smith, S.R.Bandler, A.-D.Brown, J.A.Chervenak, M.E.Eckart, F.M.Finkbeiner, N.Iyomoto, R.L.Kelley, F.S.Porter, J.E.Sadleir, NASA GSFC; E.Figueroa-Feliciano, MIT*

We report on the development of position-sensitive transition-edge sensors (PoST's) for future x-ray astronomy missions such as NASA's Constellation-X. PoST's consist of multiple absorbers each with a different thermal coupling to one or more transition-edge sensor (TES). This differential thermal coupling between absorbers and TES's results in different characteristic pulse shapes and allows position discrimination between the different pixels. The development of PoST's is motivated by a desire to achieve maximum focal-plane area with the least number of readout channels and as such, PoST's are ideally suited to provide a focal-plane extension to the Constellation-X microcalorimeter array. We report the first experimental results of our latest one and two channel PoST's, which utilize fast thermalising electroplated Au/Bi absorbers coupled to low noise Mo/Au TES's – a technology already successfully implemented in our arrays of single pixel TES's. We demonstrate 6 eV energy resolution coupled with spatial sensitivity in the keV energy range. We also report on the development of signal processing algorithms to optimize energy and position sensitivity of our detectors.

4:15pm

#### **1EX02 - Latest results on transition edge TiAu based micro-calorimeters for space applications**

*B.P.F.Dirks, L.Gottardi, H.F.C.Hoeyers, P.A.J.de Korte, J.van der Kuur, A.M.Popescu, Y.Takei, SRON*

We present the latest results of the performance of our transition edge sensors (TESs) for space applications (e.g. XEUS). Following a significant improvement of the automated acquisition system and data analysis, systematic measurements on numerous samples have been performed. Sensors based on TiAu superconductive layers with Cu/Bi absorbers having different coupling schemes to the TES are discussed and have been characterized in terms of noise, complex impedance and energy resolution. The performance of micro-calorimeters with Bi absorbers of different thickness and lateral geometry has been studied, as well as the thermal cross-talk between pixels in small 5-by-5 arrays. Results are compared with FEMlab simulations. In addition the thermal conductance of the bars from TES to heat bath is measured.

4:30pm

#### **1EX03 - Optimization of Structure of Large Format TES Arrays**

*H.Yoshitake, JAXA/ISAS; Y.Ezoe, Tokyo Metro. Univ.; T.Yoshino, K.Mukai, JAXA/ISAS; K.Ishikawa, Tokyo Metro. Univ.; K.Mitsuda, N.Yamasaki, Y.Ishisaki, JAXA/ISAS; H.Akamatsu, Tokyo Metro. Univ.; R.Maeda, T.Takano, AIST*

We fabricated 16x16 large format arrays of 180 um square Ti/Au superconducting transition-edge sensor (TES) whose transition temperature is about 110 mK. All pixels are wired with Al, and stand on SiN membrane worked as a weak thermal link.

This membrane structure is achieved by a combined process of deep reactive ion etching (DRIE) and KOH wet one. Sampled pixels without absorbers were tested by X-ray irradiation, and the energy resolution derived from the pulse analysis was 11 eV (FWHM) at 5.9 keV hence the baseline noise is about 3.7 eV. From the noise profile analysis in frequency space, we found that about 80% of total noise were explained by neither readout nor Johnson nor phonon noise, and considered that the main cause of this large excess noise is insufficient or non-uniform thermalization in TES because the rise and decay shapes varied with pulse by pulse. We have started to design gold absorbers for this array and interface effect between the TES and the absorber are also studied. We can achieve to form a dense Au film by introduction of an electron beam evaporation technique. Detailed fabrication process and results will be shown in the presentation. The dependence of energy resolution on TES and absorber geometry, and its optimization will be also discussed.

4:45pm

#### **1EX04 - Characterisation of Ultra-Low-Noise Microstrip-Coupled Transition Edge Sensors**

*K.Rostem, D.Glowacka, D.J.Goldie, S.Withington, D.Audley, V.Tsaneva, Cambridge University*

Transition Edge Sensors (TES) are rapidly becoming the detector of choice in areas such as astronomy and quantum cryptography. In astronomy, the main technological push is to reduce the NEP to  $10^{-19}$  WHz<sup>-1/2</sup> in order to take advantage of the exceptionally low thermal backgrounds of cooled-aperture space telescopes. Measuring the performance of ultra-low-noise TESs is not straightforward, but essential in order to understand and ultimately predict the properties of this device. We describe a technique for measuring the small-signal and noise properties of ultra-low-noise microstrip coupled TESs using a suspended on-chip black body load. The microstrip load is fabricated using the same technology as the TES itself, with the load and TES connected by a superconducting microstrip line. The temperature of the load is determined by Johnson-noise thermometry using SQUID readout. This 'lab on a chip' approach has many advantages: it eliminates problems associated with light leakage; it removes the need for an optical coupling scheme whose efficiency must be known; and it allows the noise and its statistics to be explored in a variety of different ways. In the paper, we describe the basic scheme, and report the first results. We explain how calibration is achieved, and describe thermal conductivity measurements of long and narrow SixNy bridges. The thermal conductivity measurements are exceedingly precise, and show how the dimensionality of the phonon gas changes.

5:00pm

#### **1EX05 - The measurement of the electrical and thermal characteristics of Ir-Au TES with Re absorber**

*D.Bagliani, L.Ferrari, F.Gatti, F.Strata, I.N.F.N. and Department of Physics; R.Vaccarone, I.N.F.N.*

By using a DC SQUID of large bandwidth we measure the response of a TES made by a superconducting Ir-Au bilayer on silicon. We report on the dependence of the resistance near the transition on the current and the temperature. The thermal and electrical behaviour of the TES polarized by AC voltage at a frequency between 1.0 and 6.0 MHz is analyzed. We amplify and demodulate the AC signal due to a single beta decay in the source/absorber made by 187 Rhenium.

**5:15pm**

**1EX06 - Properties of Iridium transition edge sensors**

*D.F.Bogorin, M.Galeazzi, University of Miami*

We have fabricated and measured thermal and electrical properties of Iridium transition edge sensors (TES). We present the performances of our devices, particularly focusing on the noise characterization and response to X-rays. The signal of the transition edge sensors is being read out using both SQUID magnetometers and transformers. We will present a comparison between the performance of the two readout schemes.

**5:30pm**

**1EX07 - Noise and impedance characterization of Ti/Au transition-edge sensors with dot-coupled absorbers**

*K.M.Kinnunen, A.K.Nuottajarvi, I.J.Maasilta, University of Jyväskylä; M.L.Ridder, J.van der Kuur, H.F.C.Hoovers, SRON Netherlands Institute for Space Research*

We have characterized several different kinds of Ti/Au X-ray transition-edge sensors (TES) with coupling between the absorber and the TES film in the shape of dots. In addition to DC I-V data, we have measured both noise spectra and the electrical impedance of the detectors as a function of bias. Modeling of impedance data indicates that the simplest thermal circuit is not enough to explain the behaviour, and more than one heat capacity is required to obtain agreement. We also describe how this thermal circuit reflects in the noise data as thermal fluctuation noise, and discuss the dependence of excess white noise on the detector parameters

**1EY - Pi Shift Devices and NanoSQUIDs – 14:00pm - 6:00pm**

**4:00pm**

*Invited*

**1EY01 - Spin measurement of magnetic molecules using a nanoSQUID**

*S.K.H.Lam, CSIRO Materials Science and Engineering; W.Yang, CSIRO Materials Science and Engineering, Australian Key Centre for Microscopy and Mircoanalysis (AKCMM), Electron Microscopy Unit, University of Sydney; H.T.R.Wiogo, School of Chemical Engineering, University of New South Wales; P.F.Vohralik, D.L.Tilbrook, C.P.Foley, CSIRO Materials Science and Engineering*

To explore the opportunities of magnetic materials at nanoscale dimensions, experimental techniques are being developed to understand the magnetic properties of individual nanoscale spin systems. Superconducting Quantum Interference Devices (SQUIDs) are very sensitive high-bandwidth magnetometers suitable for measuring magnetic signals from micron and nanometer sized particles. The requirements when using SQUIDs for such applications include: very high spin sensitivity, wide operating frequency range and the placement of the small spin system on the most sensitive area of the detector. We have previously demonstrated a spin sensitivity of 250  $\mu\text{B}/\text{Hz}^{1/2}$  at 4.2 K using a Nb thin film SQUID with hole size of  $\sim 200$  nm. Here, we report a novel procedure combining monolayer self-assembly with electron-beam lithography for attaching ferritin nanoparticles to a submicron thin-film SQUID. This allows the magnetic nanoparticles to be located optimally as far as magnetic coupling to the nanoSQUID is concerned.

Experiments are in progress to study the magnetic properties of individual ferritin-based magnetic nanoparticles. We are also investigating ways to control the density of particle attachment to allow the attachment of a single ferritin. This may have applications in the development of memory devices or for quantum computing.

**4:30pm**

*Invited*

**1EY02 - A Nano-Scale Scanning SQUID Susceptometer**

*N.C.Koshnick, J.A.Bert, C.W.Hicks, K.A.Moler, Stanford University; J.Large, H.Edwards, Texas Instruments; M.E.Huber, University of Colorado Denver*

We present a scanning DC SQUID susceptometer that combines Focused Ion Beam (FIB) defined 0.6-2  $\mu\text{m}$  diameter pickup loops with a 12 layer optical lithography process. The multiple layers allow for 1) external feedback through integrated modulation loops, which linearize the signal and allow optimal sensitivity at all applied fields, 2) local field coils which aid the background subtraction process and allow for a low magnetic field environment near the junction, modulation, and amplification stages and 3) flux noise optimization through well characterized junctions and low inductance linear coax interconnects. The tip region is lithographically patterned with terraces so that the pickup loop can come within  $\sim 100$  nm of the surface. The pickup loop size, scanning distance, and 4 Kelvin flux noise, enable spin sensitivities of  $\sim 80$  spins per root hertz. We will report on on-going scanning measurements.

**5:00pm**

**1EY03 - SFS pi-junction Applications for Quantum and Digital Logic Circuits**

*V.V.Ryazanov\*, a)\*Institute of Solid State Physics, Chernogolovka, Russia; V.A.Oboznov\*, A.Y.Rusanov\*, a)\*; A.K.Feofanov\*\*, b)\*\*Physikalisches Institut III, University at Erlangen-Nurnberg, Germany; J.Lisenfeld, S.Poletto, b)\*\*; V.V.Bol'ginov, A.N.Rossolenko, a)\*; A.V.Ustinov, b)\*\**

The talk is related to the one of the first successful realization of the quantum and digital circuits consisting of superconducting loops interrupted by pi-junction. We use pi-junctions based on superconductor-ferromagnet-superconductor Josephson sandwiches (Nb-Cu/Ni-Nb) with high critical current density up to  $10^4$  A/cm<sup>2</sup> that are suitable for applications as a passive superconducting phase inverter. The pi-junction presence does results in the superconducting phase inversion. Moreover we found no difference between the decoherence times of otherwise identical phase qubits with and without pi-junctions. We have observed also interesting behavior of the SFS pi-junctions at temperature of the pi-transition where only the second  $\sin(2\phi)$  Fourier component of the current-phase relation survives. Half-integer Shapiro steps and half-flux-quantum period of Fraunhofer patterns observed at the transition temperature were reliable evidences of the  $2\phi$ -component supercurrent flow.

*This work was supported by the RFBR Foundation, Programs of Russian Academy of Sciences and INTAS project Nr 05-100008-7923*

5:15pm

**1EY04 - Josephson junctions with stepped ferromagnetic barrier**

*M.Weides, Research Centre Juelich, Germany; J.Pfeiffer, M. Kemmler, D.Koelle, R.Kleiner, E.Goldobin, Univ. Tuebingen, Germany*

In superconducting/ferromagnet (S/F) systems the Cooper pair wave function displays damped oscillations as function of interface distance  $d_F$ , leading to non-monotonic  $I_c(d_F)$  dependence and  $\pi$  coupled Josephson junctions (JJs) in SFS/SIFS-type stacks (I: tunnel barrier). SIFS JJs based on Nb\AlO\NiCu\Nb multilayers were fabricated. Depending on the F-layer thickness the junctions were in the 0 or  $\pi$  coupled ground state. The AlO tunnel barrier yields low damping of Josephson oscillations. Using a ferromagnetic layer with a stepped thickness we obtain 0- $\pi$  JJs with equal lengths and critical currents of 0 and  $\pi$  parts. The ground state has a spontaneous vortex of supercurrent pinned at the 0- $\pi$  phase boundary, corresponding to some fraction of the magnetic flux quantum  $\Phi_0$ . The ground state is double degenerate (clockwise or counterclockwise circulating supercurrent) and can be considered as two states (up and down) of a macroscopic spin. The SIFS 0- $\pi$  JJ is the first underdamped tunnel 0- $\pi$  junction based on low-Tc superconductors. It can be measured using standard setups due to the rather high characteristic voltage  $V_c$ . The possibility to fabricate 0,  $\pi$  and 0- $\pi$  JJs within the same process, having the same  $I_c$  and  $V_c$ , opens perspectives for application of SIFS technology for  $\pi$  qubits and the investigation of fractional magnetic flux quanta. APL 89 (2006), JAP 101 (2007), PRL 97 (2006)

5:30pm

**1EY05 - Implementation of a hybrid technology including SIS and SFS Josephson Junction**

*O.Mielke, Ilmenau University of Technology; M.Weides, Research Centre Juelich; T.Ortlepp, Ilmenau University of Technology; J. Kunert, H.-G.Meyer, Institute of Photonic Technology Jena; F.H. Uhlmann, Ilmenau University of Technology*

Integrating phase-shifting elements into the Rapid Single Flux Quantum (RSFQ) electronics offers several advantages, as an increased degree of freedom of the circuit design. Thus, the construction of a naturally bistable data storage becomes possible, which is essential for every logic cell. Furthermore, the phase-shifts can be utilized as a kind of noiseless current source to improve the stability of RSFQ circuits against noise introduced malfunction. By implementing phase-shifting elements into an advanced fabrication process the capability of industrial applications can be distinctly improved. To realize such an element there are several different techniques with specific restrictions each. The most promising solution is a lumped element like a  $\pi$ -junction which allows a straightforward circuit design. We present a hybrid technology, combining the mature SIS-technology of FLUXONICS Foundry with novel SFS-junctions fabricated at the Research Centre Juelich, on one single chip. A SQUID-device composed of two Josephson junctions and a  $\pi$ -junction acting as a phase-shifting element was produced and tested. We report on first experimental evaluations and discuss possible impact to the realization of digital superconducting circuits.

5:45pm

**1EY06 - Structures and devices using  $d$ -wave induced fractional flux quanta**

*A.Andreski, C.J.M.Verwijns, J.A.Boschker, A.G.P.Troeman, J.R.Kirtley, H.Hilgenkamp, University of Twente*

We study devices in which the cuprate superconductor YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7- $\delta$</sub>  (YBCO) and the conventional superconductor Nb are connected via ramp-type Josephson junctions. The devices are designed such that the  $d$ -wave pairing symmetry of the YBCO induces extra  $\pi$ -phase shifts. As a result, spontaneously generated circulating currents appear, corresponding to half-integer

magnetic flux quanta. These half-integer flux quanta are observed in ring-like structures and in long Josephson corner junctions. The natural bistability of such structures makes them interesting candidates for superconducting digital electronics. Following up on our initial experiments<sup>{1}</sup>, in this presentation we will show our most recent results on the controlled manipulation and read-out of half-integer flux quanta. <sup>{1}</sup> Science \textbf{312}, 1495 (2006)

**1EZ - Electronic System Integration and I/O 4:00pm - 6:00pm**

4:00pm

*Invited*

**1EZ01 - Progress in the Development of Cryocooled Wideband Digital Channelizing RF Receivers**

*I.V.Vernik, D.E.Kirichenko, V.V.Dotsenko, R.J.Webber, R.Miller, P.Shevchenko, D.Gupta, O.M.Mukhanov, HYPRES, Inc.*

HYPRES is developing a class of digital receivers featuring direct digitization at radio frequency. The complete system, consisting of a cryopackaged superconductor All-Digital Receiver (ADR) chip followed by room-temperature interface electronics and a field programmable gate array (FPGA) based post-processing module, has been developed. Depending on targeted application the ADR chip comprises either a low-pass delta with phase modulation–demodulation architecture or X-band band-pass sigma-delta modulators together with digital in-phase and quadrature mixer and a pair of digital decimation filters. The chips are fabricated using a 4.5-kA/cm<sup>2</sup> HYPRES process and is cryopackaged using a commercial-off-the-shelf cryocooler. Recently, with significant improvements in chip cryopackage, room-temperature electronics and FPGA programming we were able to achieve stable operation of low-pass ADR at 28.16 GHz and X-band ADR at 30.72 GHz clock frequencies. Experimental results are presented and discussed.

*This work was supported in part by the US Navy under contract no. N00014-07-C-0663.*

4:30pm

**1EZ02 - Measurement of superconductive voltage drivers up to 25 Gb/s/ch**

*Y.Hashimoto, H.Suzuki, S.Nagasawa, M.Maruyama, K.Fujiwara, M.Hidaka, ISTEK*

This paper presents demonstrations of a superconductive voltage driver (SVD), which generates about 2-mV NRZ output with an SFQ pulse input, up to 25 Gb/s/ch. The data rate, 25 Gb/s/ch, is double of that of our previous demonstration with an SVD that generated RZ output. Generally, high-frequency components of output waveforms of SVDs are attenuated due to electrical loss of output cables, which makes signal-to-noise ratio and hence the bit-error-rate (BER) worse as the data rate increases. Since the fundamental frequency of NRZ signals is a half of that of RZ signals (duty ratio is assumed to be 50%), the digital data rate can be doubled by changing the output format from RZ to NRZ. Our RZ SVD was a DC-biased, serially connected 16 SQUIDs magnetically coupled to RS flip-flops (RSFFs), in which the SQUIDs generated voltage during the RSFFs stored data. Therefore, NRZ SVD can be realized by using a data and its complement as the set and reset signals for the RSFFs. We designed the NRZ SVD by connecting a simple logic circuit, which generates the input data and its complement, to the RZ SVD. The NRZ SVD was fabricated with our 10kA/cm<sup>2</sup> Nb process and measured at 4K with our cryocooler system. The 25 Gb/s/ch operation was stable. We also measured BER of the NRZ SVD and confirmed error-free operation (BER<10<sup>-13</sup>) at 20 Gb/s/ch for 2<sup>7</sup>-1 PRBS input.

*This work was supported by the NEDO as Development of Next-Generation High-Efficiency Network Device Technology Project.*



**4:45pm**

**1EZ03 - Development and Experiments of a high speed RSFQ output driver for direct connection to semiconductor amplifiers**

*T.Ortlepp, Ilmenau University of Technology; S.Wuensch, University of Karlsruhe; M.Schubert, Institute of Photonic Technology Jena; P.Febvre, University of Chambéry; J.Kunert, H.-G.Meyer, Institute of Photonic Technology Jena; M.Siegel, F.H.Uhlmann, University of Karlsruhe*

Superconducting analog to digital converters, network switches and microprocessor prototypes are the first demonstrated digital system based on RSFQ technology. The high-speed data exchange to semiconductor back-ends is currently a serious bottle-neck for all these systems. Therefore we identify the data interface from superconductive electronics to semiconductor electronics as one of the main design challenges for this high-speed technology. The data rate needs to be sophisticated enough to support typical clock frequencies of 20 GHz and more. Our contribution describes the combination of a digital voltage doubler circuit with a dedicated SFQ/dc converter enhanced to a robust output driver. All junctions are overdamped and the entire circuit is dc-powered. The chip is fabricated using the 1kA/cm<sup>2</sup> Nb-process available at IPHT Jena and provides an output voltage of about 400  $\mu$ V. We demonstrate experiments on the bit error rate and the high-speed operation of this new RSFQ output driver connected to a cryogenic semiconductor amplifier.

*The circuit design and fabrication were supported by FLUXONICS Foundry.*

**5:00pm**

**1EZ04 - Multi-Chip Analog-to-Digital Converter**

*S.B.Kaplan, T.V.Filippov, V.V.Dotsenko, HYPRES, Inc.*

HYPRES is developing wide-band digital receivers based on oversampling superconducting analog-to-digital converters, for direct digitization at radio carrier frequencies. The competitive advantage of these receivers is related to their very high linearity, signal/noise ratios and exploitable bandwidth. A wide-band multi-purpose channelized receiver may require several front-end digitizers attached to a smaller number of digital filters. A multi-chip implementation of such a receiver is one way to guarantee high total circuit yield while enabling modular flexibility. We have designed, fabricated, assembled and tested a module consisting of a 2.5-mm x 2.5-mm circuit die-attached to a 10-mm x 10-mm carrier to test the practicality of such an arrangement. The small circuit contains a delta modulator, while the carrier it is attached to contains both a delta modulator and a digital filter. DC switches on the carrier enable the operator to choose which modulator's bit stream is processed by the filter. Experimental results are presented and discussed.

**5:15pm**

**1EZ05 - Error-Free 20 Gb/s Output Data Link**

*Q.P.Herr, D.L.Miller, J.X.Przybysz, Northrop Grumman Systems Corp.*

Data output has been an issue for superconductor digital electronics precisely because the speed is so high and the signal level is so low. We report a design that improves on one of the standard approaches, i.e. a dc-powered series array of SQUIDs, and that effectively solves the output problem. Bandwidth of the stack is improved relative to previous designs using standard microwave engineering technique. A 20 Gb/s output data link was established using a 1:2 demux into two channels with 10 Gb/s serial data rate, NRZ. The output was connected via the cryo-probe package to an off-the-shelf LNA at room temperature.

The circuit was fabricated in 4.5 kA/cm<sup>2</sup> Nb technology. In 20 kA technology, 60 Gb/s serial data rate is expected with corresponding improvements to the bandwidth of the package and room temperature amplifier. Bit errors were not observed within the limits of our measurement, about 1e-10. First-principles analysis of the eye diagram indicates a bit error rate as low as 1e-40.

*This work was supported in part by the Office of Naval Research and by the National Reconnaissance Office*

**5:30pm**

**1EZ06 - Superconducting Switching Amplifiers for High Speed Digital Data Links**

*A.Inamdar, HYPRES; S.Rylov, I.B.M; S.Sarwana, D.Gupta, HYPRES*

In a superconductor digital-RF transmitter, the power amplifier chain can be implemented in hybrid temperature, hybrid technology environment, where the superconductor switching amplifier forms the first stage of the amplification chain. We have designed several flavors of SQUID based switching amplifiers, each targeted for different power output and bandwidth. One of the amplifiers is a differential amplifier featuring dynamic equalization. The amplifier employs pre-emphasis technique to minimize the intersymbol interference and thereby compensates for the bandwidth limitations of the channel. The amplifier has a differential output voltage of 16 mV at low speed (200 Mbps) which rolls off to 2 mV at 16 Gbps data rate, without consecutive transitions on input data. Another amplifier, called the Differential H-Tree Amplifier, has SQUIDs arranged in an "H-tree" structure, to equalize the propagation delay of the control signal for each SQUID. Simultaneous switching of SQUIDs reduces the output rise and fall times, thereby enabling higher-speed operation. The amplifier has a differential output voltage of 8 mV at low speed (200 Mbps) and rolls off to 2 mV at 12 Gbps data rate. A third type of amplifier is a differential transimpedance amplifier that consists of a pair of synchronously driven SFQ-to-DC converters that produce complementary positive and negative voltage waveforms respectively. This very high speed amplifier has a differential voltage of 0.8 mV at low speed, and both speed and voltage can be scaled as the square root of the process critical current density.

**5:45pm**

**1EZ07 - Integrated optical input module for single-flux-quantum circuit**

*S.Shinada, H.Terai, N.Wada, Z.Wang, T.Miyazaki, National Institute of Information and Communications Technology*

Single-flux-quantum circuit (SFQ) is an attractive technology to compensate a lack of functionality in optical devices. Especially, the lack of a fast memory in optical devices makes a system design of the photonic router for future optical packet network difficult. The SFQ circuit can provide logic and/or memory operation without serial-to-parallel conversion of the optical high bit rate data. To employ the SFQ circuit as a component of the photonic router, we have developed an optical input module to the SFQ circuit. The optical input module is consisting of a metal-semiconductor-metal photo-diode (MSM-PD) and superconducting micro-strip line integrated on the same chip. The SFQ circuit fabricated on the separated chip is connected to the module by the flip-chip bonding technique. As a preliminary test, we fabricated the optical input module made of Si substrate and executed a functional test of the optical input. A simple SFQ circuit consisting of DC/SFQ converter, Josephson transmission line and SFQ/DC converter was chosen in this test and connected to the MSM-PD. We confirmed a SFQ pulse generation by the optical input with the pulse duration of

**TUESDAY, AUGUST 19, 2008**

**TUESDAY MORNING POSTER SESSIONS**

**10:00am - 12:00pm**

**2EPA - Digital - II 10:00am - 12:00pm**

**2EPA01**

**Influence of bias current distribution on the operation of RSFQ circuits**

*X.Zhou, University of Science and Technology of China; M.J. Feldman, University of Rochester*

A great challenge in operating and testing RSFQ circuits is to find the proper bias currents which can be very different than their nominal values. To understand the origin of this difficulty and find possible solutions, we study the distribution of bias currents in the network of Josephson junctions and geometrical inductances and between connected RSFQ cells. Using a simple circuit model and considering fabrication errors, we discover that due to leakage of bias currents to adjacent cells the actual bias conditions of the Josephson junctions in an RSFQ circuit can be very different than in the design. We show that this can lead to malfunction of the circuit and may limit its parameter margin and scalability severely. We suggest methods to reduce or eliminate this adverse effect and restore the proper operation of the RSFQ circuit.

**2EPA03**

**The Effects of DC Power Layers in a 10-Nb-Layer Device for SFQ LSIs**

*H.Akaike, K.Shigehara, A.Fujimaki, Nagoya University, CREST-JST; T.Satoh, K.Hinode, S.Nagasawa, M.Hidaka, SRL/ISTEC, CREST-JST*

The device structure for SFQ LSIs is required to have a high tolerance for the magnetic fields induced by the dc-bias currents and the accompanying return currents flowing in a ground plane. To meet the requirement, a 10-Nb-layer device has been developed by our CREST team. The development was based on study on the influence of the magnetic fields and study on the device fabrication. In this work, we describe the former study. The 10-Nb-layer device consists of DC power (DCP) layers, an active layer containing a Josephson junction layer, and passive transmission line (PTL) layers with stripline structures. The order of stacking them becomes important for determining the device structure. We investigated the effects of the number of ground layers, between the DCP layer and the active layer using SQUIDs. An increase in the number of ground layers reduced the magnetic flux coupled to the SQUIDs, which indicated that the PTL layers should be inserted between the DCP layer and the active layer. Another investigation was the effects of the negative DC power (n-DCP) layer for extracting return currents from the ground plane. We evaluated the effects using large-scale Josephson transmission line (LS-JTL). There was no clear difference in the operating margins of the LS-JTL between the extraction using the ground plane and the extraction using the n-DCP layer. As a result, the 10-Nb-layer device contains only a DCP layer.

**2EPA04**

**Wafer bumping process and interchip connections for ultra-high data transfer rates in multi-chip modules with superconductor integrated circuits**

*S.K.Tolpygo, D.A.Tolpygo, R.T.Hunt, HYPRES, Inc.; S.Narayana, V.K.Semenov, Stony Brook University*

Josephson-junction cells and superconductor microstrip lines are able to process and transfer digital data with rates up to several hundred

gigahertz as has been demonstrated in single-chip experiments. However, the existing chip-level bumping technique in InSn solder and resulting inter-chip connections do not allow for expanding these rates to multi-chip circuits. We developed a whole wafer bumping technology using lithographically-defined bumps deposited either by e-beam evaporation or electroplating, and suggested a novel design for high-frequency interconnects which allows to easily exceed 100 GHz data transfer rates in the framework of 4.5 kA/cm<sup>2</sup> HYPRES fabrication technology. In the presentation we will discuss experimental results and effective parameters of the new multi-chip module technology.

*This work is supported by ONR*

**2EPA05**

**Research of effective moats for Nb multi-layer device structure**

*K.Fujiwara, ISTEC-SRL, JSPS Fellow, JST-CREST; S.Nagasawa, ISTEC-SRL, JST-CREST; Y.Hashimoto, ISTEC-SRL; M.Hidaka, ISTEC-SRL, JST-CREST*

We have developed Nb multi-layer devices for realization of high-performance (high-speed and high density) SFQ circuits. Its structure is composed of three functional layers, the top layer is used for making up active gates which include Josephson junction and 3 wiring layers, the middle one constructs passive transmission lines (PTL), and the lower part is devoted to dc power supply. The number of total Nb layers is ten. We also are developing a cell library for the multi-layer devices. The effective moat for the Nb multi-layer cell was investigated. We assumed its cell size is 30  $\mu\text{m}$  squares and each cell has 4 bias current supply ports at every corner. The ports have pillar structure from the dc supply layer to the active layer. Because the pillar is surrounded by insulator, it is a natural moat. In our test structure, a two-junction SQUID is put in a cell and 500 cells were serially connected. We designed various test circuits with various moat structures. The number of SQUIDs which critical current value is less than 10% of their normal value by flux trapping was counted. This test is under earth magnetism for accelerated tests. It can be concluded that the ports plus rectangular shaped moats in the active layer ground plane which surround the SQUIDs is a suitable moat for the cell.

*This multi-layer structure was based on a result of NEDO*

*"Superconductor Network device" Project. This work is partially supported by JSPS Research Fellowships.*

**2EPA06**

**Experimental study of the effect of flux trapping on the operation of RSFQ circuits**

*B.Ebert, T.Ortlepp, Ilmenau University of Technology; P.Febvre, University of Savoie; F.H.Uhlmann, Ilmenau Univ. of Technology*

The digital Rapid Single Flux Quantum (RSFQ) electronics family is a high speed technology capable to perform signal processing at several tens of GHz. The information is represented by the presence or absence of a magnetic flux quantum. This circumstance makes a RSFQ circuit very susceptible to any environmental magnetic field. Magnetic shielding is one option to reduce the sensitivity but not always appropriated e.g. in magnetic sensor applications. Since external magnetic flux quanta are typically captured during the cool down process, we performed several hundred thermal cycles in order to get deeper insights of this process. Our measurements were carried out on single Josephson junctions and on simple RSFQ circuits. For single junctions we obtained a distribution of the critical current with several bunches e.g. at one third of the nominal critical current. These bunches can only be explained by attractive positions for capturing flux quanta in the vicinity of the JJ. Since moats in the ground plane are attractive for flux pinning a complex digital circuit with different ground plane configurations was implemented to determine the most robust layout. We present one particular digital circuit in six different ground plane configurations and the experimental comparison of their probability of malfunction caused by trapped flux.

*Circuit design and fabrication are performed at FLUXONICS Foundry.*

## 2EPA07

### **Mechanically cryocooled RSFQ circuit tests**

*C.J.Fourie, Stellenbosch University, Dept. E&E Engineering;  
T.Ortlepp, Ilmenau Technical University, Institute of Information  
Technology, RSFQ design group*

For superconductive digital electronic systems to find widespread industrial application, cryogen-free cooling is necessary. Such mechanically cooled systems are inherently noisy, and careful system design is required to provide operating margins comparable to those of liquid helium-cooled systems. We present test results for RSFQ circuits cryocooled in a pulse tube refrigerator with custom-built shielding and input/output electronics. Simple circuits with well-known operating margins, manufactured with the IPHT Jena 1kA/cm<sup>2</sup> Nb process, are used. Measured results for bias current margins and bit-error rates at various temperatures are compared to those obtained for the same circuits in liquid helium, and conclusions discussed.

*This work has been supported by the European Community via project "S-PULSE".*

## 2EPA08

### **Invited**

### **Possible application of a flash-type SFQ A/D converter to optical communication systems and their measuring instruments**

*H.Suzuki, M.Maruyama, Y.Hashimoto, SRL/ISTEC; K.Fujiwara, SRL/ISTEC, JSPS; M.Hidaka, SRL/ISTEC*

We propose a possible application of a high-speed flash type SFQ analogue-to-digital converter to optical communication systems and their measuring instruments. One of the problems in optical networks are chromatic dispersion over standard single mode fiber, and has to be recovered by optical dispersion compensation. Recently, there has been great interest in 100Gbit/s Ethernet technologies as the next generation optical networks in which chromatic dispersion becomes more severe. Among several types of architecture which have been investigated, digital coherent technology is a promising technology. The correction of the dispersion is performed electrically after digital conversion without any optical compensation, which would ease the system construction. Digital storage oscilloscopes using high speed ADCs are crucial for investigating the architecture and for constructing the 100GbE system. Then, a flash type SFQ ADC is attractive for its high-speed sampling clock capability, especially as the instrument for the digital coherent receiver. The maximum operating frequency of the comparator in the ADCs was studied by simulation for various critical current densities ( $J_c$ ). The simulation suggested that using  $J_c$  of 20 – 40kA/cm<sup>2</sup> enables the comparator to operate at more than 100 GHz clock frequency.

*This work was supported by the New Energy and Industrial Technology Development Organization (NEDO) as Development of Next-Generation High-Efficiency Network Device Project.*

## 2EPB - Electronic Device Fabrication I – LTS

10:00am - 12:00pm

## 2EPB01

### **Hybrid Josephson critical current density process for multi-rate superconductor integrated circuits.**

*D.Yohannes, R.Hunt, J.Vivalda, D.Donnolly, A.Kirichenko, A.Inamdar, S.K.Tolpygo, HYPRES Inc.*

Many applications of superconductor integrated circuits may require a small part of the circuit to work at the highest possible clock frequency, e.g. an ADC in the receiver front-end, while more complex parts of the circuits may work at a lower frequency, e.g. a digital filter. Since the maximum clock frequency is proportional to the square root of the Josephson critical current density  $J_c$ , such circuits can be realized as hybrid circuits containing trilayers with different  $J_c$ s. A fabrication technology will be presented enabling a single chip to accommodate circuits optimized for different critical current densities. Details of the Hybrid process will be discussed as well as the typical circuit implementations and test results.

## 2EPB02

### **Effect of electrical stress on Josephson tunneling characteristics of Nb/Al/AlO<sub>x</sub>/Nb junctions**

*D.Amparo, S.K.Tolpygo, Dept. of Physics and Astronomy, Stony Brook University*

Fabrication-induced variations in the critical currents of Josephson junctions significantly affect the performance and yield of complex superconducting integrated circuits. Electrical stress that may develop during plasma processing steps in the fabrication process is suggested as a possible cause of these variations. The effect of dc electrical stress on the Josephson tunneling characteristics of single Nb/Al/AlO<sub>x</sub>/Nb junctions was investigated. The electrical stress was applied at room temperature using a constant-current source. I-V characteristics at room temperature and at 4.2 K were measured before and after each stress application. The general effect of applied stress was an increase in critical current and a decrease in sub-gap resistance and normal resistance. A subharmonic gap structure was also observed in the return branch of the I-V characteristic. These results will be compared with I-V characteristics of junctions showing fabrication-induced variations from design values. The mechanisms of tunnel barrier degradation under electric stress will also be discussed.

## 2EPB03

### **Fabrication of Submicrometer High Current Density Nb/Al-AlN<sub>x</sub>/Nb Junctions and Integrated Circuits**

*G.L.Kerber, A.W.Kleinsasser, Jet Propulsion Laboratory*

We have developed a submicron Nb/Al-AlN<sub>x</sub>/Nb junction and integrated circuit fabrication process using deep-UV lithography and inductively coupled plasma etch tools. The baseline process consists of 10 masking steps including ground plane, PdAu resistor, Nb/Al-AlN<sub>x</sub>/Nb trilayer, and two Nb wiring layers. The AlN<sub>x</sub> tunnel barriers are grown with plasma nitridation. These junctions exhibit low subgap leakage, even at current densities exceeding 100 kA/cm<sup>2</sup>. Critical current spreads of 50-kA/cm<sup>2</sup>, 0.6 μm diameter, 100 junction arrays are under 3%. For very high current density applications, these junctions are a good candidate to replace Nb/Al-AlO<sub>x</sub>/Nb junctions particularly in future generations of very high speed, rapid single flux quantum logic circuits. In this paper, we discuss our baseline fabrication process and device characterization including junction capacitance extraction from direct measurements of the Josephson plasma resonance frequency.

## 2EPB04

### Multi-layer Nb Integrated Circuit Structure Incorporating the Top Active Layer

*T.Satoh, K.Hinode, S.Nagasawa, Y.Kitagawa, M.Hidaka, SRL / CREST-JST; N.Yoshikawa, Yokohama National Univ. / CREST-JST; H.Akaike, A.Fujimaki, K.Takagi, N.Takagi, Nagoya Univ. / CREST-JST*

We have been developing an advanced process for fabricating a next generation multi-layer Nb integrated circuit structure incorporating the top active layer. In this structure, the PTL layer is placed between the top active layer and a dc-bias current layer at the bottom. This structure offers a flexible design of active circuit and PTL wiring, and also offers an effective shielding of the active circuits from a magnetic field generated by a large dc-bias current. Both the dc-bias current layer and the PTL layer are planarized, however the top active layer is fabricated without planarization. In order to realize this new structure, we need a better planarization process for junctions those are formed over underlying Nb patterns. A combined process of an additional SiO<sub>2</sub> deposition and an additional mechanical polishing after the standard caldera planarization enables a superior planarization for junction formation. We confirmed excellent characteristics of junctions formed over underlying pattern edges, when they fabricated on the surface planarized by using this new process.

*This work was supported by JST, and based on the results of Superconductors Network Device Project supported by NEDO.*

## 2EPB05

### A Novel Power Line to Reduce the Magnetic Field of Supply Currents in Josephson Digital Circuits

*Y.Yamanashi, Yokohama National University; T.Van Duzer, University of California; N.Yoshikawa, Yokohama National University*

One of the important issues facing the operation of Josephson digital circuits is that the dc supply currents are large and produce magnetic fields that have adverse effects. Various schemes have been devised to reduce the effects of the fields. A very good, but not perfect, solution is to have a thick ground plane covering the power lines. We have devised a patterning scheme that produces the equivalent of the twisted pair commonly used in wired electronic circuits. The equivalent array of circulating currents can be represented as an array of magnetic dipoles, the magnetic fields of which fall off as the third power of transverse distance from the twisted pair. It is proposed to use this scheme in an advanced technology with sufficient Nb layers to cover the twisted pair with a ground plane. Thus far, we have used the present NEC/SRL niobium process in a first demonstration without the covering ground plane. There was a very considerable reduction of magnetic field compared with a microstrip supply line. This paper will show the fabrication scheme, the analysis, and the preliminary successful experimental results.

## 2EPB06

### SIS Mixer Fabrication for ALMA Band10

*M.Kroug, A.Endo, T.Tamura, T.Noguchi, T.Kojima, Y.Uzawa, NAOJ; M.Takeda, Z.Wang, NICT; W.Shan, PMO*

ALMA Band10 is a planned heterodyne receiver covering the frequency range 790-950 GHz. Currently being in an early stage of development, where optimum choice of materials and circuit designs have to be tested, the fabrication of SIS mixer devices aims at reliability and simplicity in order to achieve a high throughput. Devices are hybrid structures combining 'standard' Nb/Al-AIOx/Nb junctions with a NbTiN/SiO<sub>2</sub>/Al embedding circuit, the substrate material is either crystalline quartz or MgO. The junction definition process has been greatly simplified by introducing an inductively-coupled-plasma (ICP) etcher to the fabrication. Process parameters in a low pressure CF<sub>4</sub>/O<sub>2</sub> atmosphere are chosen such

that a substantial contribution to the etching is due to sputtering (as opposed to purely reactive). Under these conditions the entire tri-layer can be removed in a single step. Accurate end-point detection is possible by means of an optical spectrometer that monitors the process. Ground-plane and junction side walls are doubly passivated. First by anodization, forming 30 nm of Nb(TiN)Ox, followed by the deposition of 300 nm of SiO<sub>2</sub>. Typical junction diameters are 0.9-1.0 micrometer and for current densities up to 8 kA/cm<sup>2</sup> quality factors  $q > 15$  are obtained. Sharp resonance steps appear at positions as high as 2.4 mV indicating low losses in the tuning circuit beyond 1 THz. For RF characterization, devices are mounted in a waveguide type receiver. A DSB noise temperature (corrected for optical losses) of 240 K has been measured at 950 GHz.

## 2EPB07

### Improved Technique for Junction Capacitance Measurements Based on the Josephson Plasma Frequency

*A.W.Kleinsasser, G.L.Kerber, A.H.Silver, JPL; M.W.Johnson, D-Wave Systems Inc.*

Josephson junction capacitance, which is not routinely measured and reported, is an important circuit parameter for accurate junction modeling and circuit simulation. It is possible to accurately measure the Josephson plasma frequency of a relatively large junction from the current-voltage characteristics of a simple structure consisting of two externally-shunted, series-connected tunnel junctions. However, the measured junction must be much larger than the junction used to generate the ac signal. Thus, this technique cannot be used to measure the minimum-size junctions, which are typically of greatest interest in a circuit process, particularly at high current density. We present both experimental and theoretical demonstrations of an improved technique, which circumvents this limitation by using a SQUID to generate the required ac signal.

## 2EPB08

### Assessment of overdamped SNS niobium-based Josephson junctions for digital applications

*V.Lacquanti, INRIM Torino; N.De Leo, M.Fretto, S.Maggi, A.Sosso, INRIM; D.Bouis, University of Savoie; P.Febvre, University of Savoie*

SNS Nb/Al-AIOx/Nb Josephson junctions have been recently developed with Al layer thicknesses 30-100 nm, for which non-hysteretic I-V characteristics have been obtained by oxidation ranging from 150 to 200 Pa.s. The Stewart-McCumber parameter of the junctions can be lower or higher than unity, depending on the above-mentioned conditions. Typical J<sub>c</sub> values of several tens of kA/cm<sup>2</sup> and RnI<sub>c</sub> values up to 0.5-0.7 mV at 4.2 K have been obtained, suitable for digital applications. Two interesting features of this technology are: i) the absence of external shunt resistance that can allow higher integration and; ii) the reproducibility of technological parameters that is connected to a least dependence of the Josephson critical current on the barrier thickness. In this work, we will present a detailed analysis of speed and jitter that can be expected from basic digital circuits based on such a technology. This analysis is based on the accurate experimental extraction of typical quantities, like the Stewart-McCumber parameter or specific capacitance. In particular, the influence of the temperature of operation on the performance of elementary cells will be assessed. A comparison with similar cells based on externally-shunted Josephson junctions will be presented in order to evaluate the ranges of parameters for which this technology exhibits some clear advantages. In particular we will show the technological constraints that need to be met in order to build circuits that can compete with existing technologies.

## **2EPC01**

### **Sub-micron HTS biepitaxial junctions**

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The recent quantum performances of high critical temperature superconductor (HTS) Josephson junctions have encouraged proposals for quantum circuitry. Biepitaxial grain boundary have played a relevant role. Further advances are expected applying nanotechnology to reduce the junctions' dimensions, with benefits in terms of reproducibility and control over their microstructure. This will also lead to further understanding of the rich physics behind these devices, from a complete identification of transport mechanisms to insights on dissipation and decoherence in HTS. Nevertheless, significant technological hurdles have to be overcome in order to manipulate sensitive HTS materials in the sub-micron range, especially for multilayered structures such as the biepitaxial junctions. We report on the first successful attempts to reproducibly fabricate biepitaxial HTS sub-micrometric junctions, down to 0.6 $\mu$ m in width, using electron beam lithography and a carbon mask. The junctions properties point to high quality devices, where a deeper control of the barrier microstructure is achieved and d-wave induced effects are revealed. These results are very promising for further advances of nanotechnology applied to HTS and quiet quantum circuitry.

## **2EPC02**

### **Preparation of narrowed nanobridges down to 30 nm with reduced degradation**

*K.Kajino, T.Kimura, Y.Horii, M.Watanabe, M.Inoue, A.Fujimaki, Nagoya University*

We have successfully prepared YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7-x</sub> (YBCO) nanobridges down to 30 nm in width with extremely high critical current densities. Since nanobridges are made of a monolayer and behave like Josephson junctions, they have a potential to be applied to nanoSQUIDS or optical input/output interfaces of single-flux-quantum circuits. The key technique to form nanobridges with high reproducibility is to establish deep sub-micron or sub-sub-micron fabrication technique of YBCO films. However, degradation of the films is caused from all the surfaces because of ion bombardment in the dry etching process, and thus YBCO nanobridges reported so far have low reproducibility in a sub-sub-micron range. To overcome this, we employ regeneration of the degraded parts rather than suppression of the deterioration. In concrete terms, we re-deposit ultra thin YBCO films after nanobridge formation. The typical thickness of the film is 2-3 nm, which is nonsuperconductive when the film is deposited on a MgO substrate. We have examined width dependence of critical current density at 4 K.

The nominal critical current density increases with reducing the widths and shows approximately 600MA/cm<sup>2</sup> for a 30-nm-wide nanobridge, which is close to the depairing current density. We currently examine the temperature/magnetic field dependence of critical current density and try to reduce the width on nanobridges.

## **2EPC03**

### **YBCO nanostructures**

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We report on the fabrication and electric characterization of YBCO nanostructures. The process is capable to obtain features with a line-width down to 80nm on (001) oriented YBCO thin films. Superconductivity properties of patterned devices are very close to those of the unprocessed films down to line-width of 150nm. We present a study for the setup of a fabrication procedure of HTS nanowires with orientation different from (001) and/or containing an artificial grain boundary.

## **2EPC04**

### **Improving the IcRn product and the reproducibility of HTS Josephson nano-Junctions**

*M.Sirena, T.Wolf, J.Lesueur, LPEM, CNRS-ESPCI-UPMC; G.Faini, LPN, CNRS; J.Briatico, R.Bernard, UMP, Thales-CNRS; N.Bergeal, LPEM, CNRS-ESPCI-UPMC*

High T<sub>c</sub> Superconducting (HTS) Josephson nano-Junctions[1] made by ion irradiation look promising for technological applications, such as cryogenic electronics. Their main assets are the possibility of accurately tune their characteristics, the high critical current densities (a few 10<sup>4</sup> A/cm<sup>2</sup>), and the easy integration into complex devices. The present work deals with the improvement of both the reproducibility and the IcRn product of those junctions. We have shown numerically that the main source of dispersion is the variation of the slit's width (20 nm) used to define the junction, and confirmed it experimentally by changing the irradiation energy[2], and therefore the defect profile which controlled the behavior of the system. We then used low temperature (80°C) annealing to decrease further the spread in characteristics, and made a model showing that the vacancy-interstitial annihilation in the main mechanism involved in this process[3]. Those combined technics allowed to increase by a factor of 2 the IcRn product, and decrease its spread down to 10% or so. [1] N. Bergeal et al, Applied Physics Letters 87, 102502 (2005) [2] M. Sirena et al, Applied Physics Letters 91, 262508 (2007) [3] M. Sirena et al, Applied Physics Letters 91, 142506 (2007)

*Acknowledgements to MPPU-CNRS for support through a post-doctoral grant*

### 2EPD01

#### **Eddy-current-based SQUID-NDE System for Copper Tubes with Laser Displacement Sensor**

*S.Kanai, Y.Hatsukade, Toyohashi University of Technology; K.Mori, Sumitomo Light Metal Industries, Ltd.; S.Tanaka, Toyohashi University of Technology*

Copper tubes have been used as heat-exchanger. Tiny flaws of a few tens micro m in depth on the tube surface have caused breakage when the tubes are post-processed. Nowadays, it's difficult by eddy current testing on production line to detect flaws less than 50 micro m in depth. Thus, we've developed more sensitive NDE system using HTS-SQUID gradiometer. In this system, a tube is moved through excitation coil to measure magnetic response from excited tube. Flaws on the tube surface disturb the response. However, the response can be also disturbed by displacement of tube surface, deviation of tube thickness and vibration of moving tube. Therefore, we studied the major source of the disturbed response by employing a laser displacement sensor to measure outer diameter of tube, for the NDE system. We prepared two flawless straight copper tubes of  $9.8 \text{ mm}^{\text{D}} \times 0.4 \text{ mm}^{\text{t}}$ . Displacement of outer diameter and magnetic response of each tube was measured by the system, while moving tubes. Displacement of outer diameter of each tube was small and within several micro m. However, anomalous magnetic signal of 2.5 micro  $\phi_0$  was measured from one tube, while smaller anomalous signal of 0.8 micro  $\phi_0$  was measured from the other. Then, deviation of each tube thickness was measured. The former had deviation of 20 micro m in thickness, while the latter had that of 5 micro m. These results suggest anomaly in the magnetic response should be mainly due to deviation of tube thickness.

### 2EPD02

#### **Optimization of NDE characterization parameters for a designed RF-SQUID gradiometer based system using an analytical method.**

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We investigate the dependence of the NDE signal to different parameters of the RF-SQUID based system for samples with desired flaw depth and shape. According to experimental results and the associated analytical analysis using FEM simulation, we derive the optimized parameters for maximum spatial resolution and sensitivity. Our NDE systems is designed based on a High-TC YBCO gradiometer RF-SQUID magnetic sensor with a base-line of 1.5mm and flux noise level down to  $5\mu\Phi\sqrt{\text{Hz}}$  at 500Hz. The considered parameters in our study include the distance between sample and sensor, the flaw depth and the excitation parameters which depend on current frequency and amplitude as well as coil configuration. Introducing a new model for anomalies in eddy current due to flaws and applying superposition effect allowed by the linearity characteristics of the problem, we could obtain the real characteristics of the artificial defects in our samples by use of FEM simulation.

### 2EPD03

#### **Robot-based NDE System using 3-D-Mobile HTS-SQUID**

*Y.Hatsukade, K.Yotsugi, Toyohashi University of Technology; H.Wakana, Y.Tarutani, K.Tanabe, Superconductivity Research Laboratory, ISTEK; S.Tanaka, Toyohashi University of Technology*

So far, HTS-SQUID NDE has been rarely applied to inspect large fixed structures because it's difficult to mobilize typical HTS-SQUID using bicrystal junctions in environmental field due to occurrence of flux jumping. However, HTS-SQUIDs using ramp-edge junctions with higher robustness in magnetic field were recently developed. We studied the robustness of the novel HTS-SQUID, and set it in a robot-based SQUID-NDE system to move it three-dimensionally in unshielded environment. The HTS-SQUID gradiometer using ramp-edge junctions has differential pick-up coils. Dimension of one coil is 3 mm x 3 mm. The gradiometer was mounted in a small cryostat, and cooled at 80 K. White noise level of the gradiometer was  $10 \text{ micro } \phi_0 / \text{Hz}^{1/2}$  in unshielded environment. To study the robustness, ac magnetic field at 100 Hz was applied to the gradiometer. We applied the field of certain amplitude for 20 s, and then turned it off to measure SQUID's noise. The procedure was repeated increasing the amplitude. Until the peak-peak amplitude reached to 2.9 mT, the noise profile and optimum bias current did not changed. Compared to HTS-SQUID gradiometers using bicrystal junctions, the maximum applicable field to the novel gradiometer can be  $10^4$  to  $10^5$  times larger. The gradiometer in the cryostat was installed on a robot-arm, and was moved in unshielded environment without flux jumping.

### 2EPD04

#### **Non-contact Thickness Gauge for Conductive Materials using HTS SQUID's System**

*T.Kiwa, H.Tahara, H.Yamada, K.Tsukada, Okayama Univ.*

With rapid increase of demands on achieving a good balance between safety and cost efficiency, the thickness testing of conductive materials has become an important procedure to maintain various types of artificial structures. For example, the testing of pipe walls used in such as electric power plants and ships are critical issue and the pipes are generally covered by heat insulators. Therefore, it could be difficult to adapt the contact measurements for practical use. On the other hand, an eddy current non-destructive evaluation is one of good candidates for non-contact measurements of conductive materials, because it measures the magnetic field produced by the eddy current in the test samples at free space. In this study, a non-contact thickness gauge using a HTS SQUID was developed and thickness measurements of conductive plates were demonstrated. Since the skin depth of the eddy current depends on the frequencies of applied magnetic field, the thickness of the materials could be obtained by measuring frequency dependence of the magnetic field by the eddy current. Our system consists of the induction coil and SQUID, which were coaxially aligned. The cancelation coil was adopted at near the SQUID, when the large magnitude of magnetic field was applied. The aluminum plates with the size of 50 mm times 100 mm were used as the samples. The thickness of plates was varied from 1 mm to 8 mm. We also compared the pulsed magnetic field measurements with the sine wave field with frequency-sweeping.

## 2EPD05

### **Non-destructive testing of YBCO coated-conductor by multi-channel HTS SQUID gradiometers**

*T.Hato, S.Adachi, H.Wakana, K.Hata, Y.Tarutani, T.Machi, K.Tanabe, SRL-ISTEC*

We developed a non-destructive testing system utilizing multi-channel HTS SQUIDs in order to examine YBCO coated-conductors scribed into multi-filamentary lines. While a reel-to-reel testing system utilizing a Hall sensor array is available for measuring Ic distribution in coated conductors before scribing, the strong point of our system is that we can detect macroscopic defects in each filamentary superconducting line at a high speed up to 30 m/h. The 5-channel HTS SQUID gradiometer array was composed of ramp-edge junctions with LaErBaCuO and SmBaCuO electrode layers, and fabricated by using an HTS multi-layer fabrication technique. The parallel gradiometers with 1 mm× 1 mm pickup loops and a baseline of 1 mm detected the vertical element of magnetic field gradient induced around defects by an eddy current. In our system, a coated conductor was fed from a reel to reel, and cooled below its Tc by pre-stages and a main-stage connected to GM coolers. The gradiometer array was cooled by thermal conduction from a liquid nitrogen bath and placed above the coated conductor on the main stage with a lift-off of about 1.5 mm. By employing a 3 kHz induction current generating the maximum field of 50 uT, macroscopic defects in 5-mm-wide coated conductors with and without scribing into five lines were successfully detected.

*This work was supported by NEDO.*

## 2EPD06

### **SQUIDs and GMR sensors for non-destructive evaluation of advanced composite materials**

*C.Bonavolonta`, CNR-INFN ; G.P.Pepe, G.Peluso, M.Valentino, University of Naples*

The aerospace and aeronautical industries pay much attention to improve the flight safety of the airlines. In the aircraft design it's important to couple the low structural weight with a high damage tolerance. For this reasons new advanced composite materials called Fiber Metal Laminates (FML) that combine the best features of organic matrix composites and metals are used. In this work we present non-destructive evaluation measurements on GLARE specimens by using eddy current techniques employing HTS SQUID (Superconductive QUantum Interference Device) and Giant Magneto-Resistive (GMR) sensors. Our aim is to produce a comparison between performances from two techniques, and more generally the capability of these advanced magnetic sensors to detect the presence of damages in composite materials, and inside them. Experimental results for the detection of defects in aeronautical structures with very high magnetic sensitivity in the case of SQUID and with very high spatial resolution in the case of GMR will be presented and discussed.

## 2EPD07

### **Signal Processing Techniques for Improved Performance of a SQUID-Based Metal-Detector.**

*K.R.Blair, F.Weiss, D.A.Clark, G.J.J.B.Degroot, M.Bick, CSIRO Materials Science and Engineering, Lindfield, Australia; D.Sen, School of Electrical Engineering & Telecommunications, University of New South Wales, Sydney, Australia*

A SQUID-based prototype sensor system for the detection of stainless steel contaminants in food has been previously reported [1]. In this work, we describe the use of adaptive filters, matched filter correlation and component estimation algorithms for automatic contaminant detection for this prototype detection system. Assessment of measured data of environmental sources of interference typically encountered in this sensing application area is considered in the development of these algorithms.

The specification of the probability of false positives - using statistical analysis and modelling - allows the resulting contaminant detection limit to be determined. These improvements will enable commercial operation of SQUID based stainless steel detection systems in standard factory environments with acceptable correct and false positive detection rates.

*[1] Bick M, Sullivan P, Tilbrook D L, Du J, Gnanarajan S, Leslie K E, and Foley C P 2005, Superconductor Science Technology, 18, pp346-351.*

## 2EPE – NanoSQUIDs 10:00am - 12:00pm

### 2EPE01

#### **Focussed Ion Beam NanoSQUIDs as Novel NEMS Resonator Readout**

*L.Hao, J.C.Gallop, D.Cox, National Physical Laboratory, UK; E.Romans, London Centre for Nanotechnology, University College London, UK; J.Macfarlane, Physics Dept., University of Strathclyde, UK; J.Chen, School of Engineering & Design, Brunel University, UK*

Nano-electromechanical systems (NEMS) represent an important new class of devices with wide-ranging applications. As electromechanical devices become smaller, approaching the nanoscale, the oscillation displacement amplitude scales down in proportion to size. Thus ultra-sensitive transducer techniques and low dissipation excitation schemes are needed to operate NEMS sensors. Developing suitable excitation and readout methods is crucial and may have spin-offs into a number of other nanotechnology applications. We propose here a novel form of NEMS displacement readout provided by our on-going development of nanoSQUIDs [1]. A focussed ion beam SQUID structure is fabricated on the same chip as the NEMS resonator. The vibration of the resonator modulates the inductance of the nanoSQUID loop allowing sub-picometre amplitude sensitivity to be achieved, according to our model results. We present detailed calculations of the performance of these readout methods and also preliminary device fabrication details. Key words: NEMS, NanoSQUIDs, Mechanical resonators

*[1] Hao L, Macfarlane J C, Lam S K H, Foley C P, Josephs-Franks P and Gallop J C 2005 IEEE Trans. Appl. Superconductivity 15 514-7. Hao L, Macfarlane J C, Gallop J C, Romans E, Cox D, Hutson D and J. Chen 2007 IEEE Trans. Appl. Supercond. 17 742. Hao L, Macfarlane J C, Gallop J C, Cox D, Beyer J, Drung D and Schurig T 2008 Appl. Phys. Lett. 92 192507.*

### 2EPE02

#### **Miniature Thin-Film SQUID Susceptometer with Improved Field Coil and Persistence Switch**

*S.T.P.Boyd, University of New Mexico; R.Cantor, J.A.Hall, STAR Cryoelectronics*

We are developing a miniature SQUID susceptometer for applications in metallic magnetic microcalorimetry and thermometry. We have previously reported 4 K and 50 mK measurements characterizing the behavior and performance of the first generation of this device with flux-locked-loop readout. In this report we present a description and measurements characterizing the performance of the second generation of the device, which incorporates layout changes designed to improve persistence switch function, increase critical current of the field coils to 50mA, and alter field coil geometry to achieve 0.05 T at the pickup coils without a flux-concentration washer. Measurements made in liquid helium have demonstrated success for these design changes. We also report on ongoing measurements from 4 K-50 mK in vacuum with both flux-locked-loop and SQUID-array-amplifier readout.

## 2EPE03

### **SQUID sensors based on niobium Dayem nano-bridges for ultra high spatial resolution investigations**

*C.Granata, A.Vetoliere, E.Esposito, L.Petti, R.Russo, B.Ruggiero, M.Russo, Istituto di Cibernetica-CNR, Italy*

Recently there is a growing interest in development of SQUID devices for micro and nanoscale applications. Here, dc-SQUID sensors based on niobium Dayem nano-bridges for ultra high spatial resolution investigations will be presented. The sensors have a hole dimension ranging from 20 to 0.2 micrometers and two Josephson nano-bridges of  $80 \times 100 \text{ nm}^2$ . They consists of a Nb(30 nm)/Al(30nm) bilayer patterned by electron beam lithography (EBL) and shaped by lift-off and reactive ion etch (RIE) processes. The Al film acts as both a resistive shunt and a self-aligned mask for the RIE process. The presence of the Nb coils integrated on-chip and tightly coupled to the SQUID, allows to easily excite the sensor in order to get the voltage-flux characteristics and to flux bias the SQUID at its optimal point. Current-voltage, current-magnetic flux and voltage-magnetic flux characteristics at different temperatures will be showed. Current modulation depth corresponding to more than 30% of the critical current and a maximum voltage-flux transfer coefficient as high as  $1 \text{ mV}/\Phi_0$  have been achieved. The noise measurements are performed using a direct coupled low noise readout electronics noise. The sensors exhibit a magnetic flux noise level as low as  $2.5 \text{ microPhi}_0/\sqrt{\text{Hz}}$  in the white region.

## **2EPF - Transition Edge Sensors V – Readout 10:00am - 12:00pm**

### 2EPF01

#### **Multiplexed readout of AC polarized TESs by a SQUID array and a SQUID amplifier.**

*D.Bagliani, I.N.F.N. and Department of Physics; J.Beyer, D.Drung, P.T.B.; L.Ferrari, F.Gatti, I.N.F.N. and Department of Physics; R.Vaccarone, I.N.F.N.; R.Valle, I.N.F.N. and Department of Physics*

In the framework of the MARE experiment, aimed at the precise measurement of the neutrino mass, a small array of TESs made by Ir-Au bilayers has been polarized by voltage sources at frequencies distributed between 0.5 MHz and 6 MHz. The TESs has a very sharp transition near 80 mK. The array and the SQUIDs are cooled by a dilution refrigerator. The currents flowing in each TES, distinguished by different frequencies, are summed in the input coil of a SQUID array or a SQUID amplifier. Different SQUID systems will be compared.

### 2EPF02

#### **A cryogen free ADR test platform for extensive TES characterization**

*M.A.Lindeman, D.E.Brandl, K.A.Barger, S.G.Crowder, D.McCammon, University of Wisconsin, Madison*

We developed a facility for characterization of transition edge sensor (TES) calorimeters and bolometers, which are contributed by various research groups. TESs are readout with SQUIDs from Star Cryoelectronics installed in a Janis Cryogen free adiabatic demagnetization refrigerator (ADR).

We have demonstrated low noise, high bandwidth readout of TESs, and long hold times from the ADR. Along with the hardware, we have developed measurement techniques and computer software to provide comprehensive measurements of these devices.

### 2EPF03

#### **Towards frequency domain multiplexed readout of TES-based direct detector arrays**

*J.van der Kuur, Y.Takei, L.Gottardi, M.P.Bruijn, H.F.C.Hoevers, SRON Netherlands Institute for Space Research; M.Kiviranta, VTT, Tietotie 3, 02150 Espoo, Finland; P.A.J.de Korte, SRON Netherlands Institute for Space Research*

Frequency domain multiplexing (FDM) is considered to be potentially one of the best options for high count rate microcalorimeter readout for XEUS, as well as for low-NEP bolometer readout for SPICA. We report on the development status of this readout system at SRON. We will discuss detector performance under AC bias, and show the results of a 2 pixel multiplexing demonstrator, which uses a classical SQUID feedback system. Furthermore we will show recent results obtained on the development of baseband feedback, which is one of the promising ways to fully exploit the available 10 MHz bandwidth in a SQUID readout system. Based on the current knowledge of the system, we will show why we think that multiplexing of 45 - 90 pixels is possible.

### 2EPF04

#### **Control and Readout for the Super Cryogenic Dark Matter Search.**

*J.C.Hall, D.A.Bauer, F.DeJongh, S.Hansen, T.Kiper, Fermi National Accelerator Laboratory*

The Super Cryogenic Dark Matter Search (SCDMS) is a search for weakly interacting massive particles, a proposed class of dark matter. The experiment uses germanium detectors kept at 30 mK. Particle interaction energies are measured with arrays of transition edge sensors instrumented with SQUID amplifiers. This is combined with a traditional ionization measurement to discriminate particles causing nuclear recoils from the far more abundant electron recoils. This technology has enabled the CDMS-II experiment to gather an exposure of more than 3 kilogram years with an expected background of less than 1 event. SCDMS will continue and enhance this experimental program, increasing the total mass of germanium from 4 to 25 kilograms and improving background rejection capability. This is achieved by adding to both the size and number of detectors. The control and readout electronics has been redesigned to reduce cost, cables and connectors, and power consumption as well as increase performance. We discuss both improvements over previous electronics and planned future development.

*The authors would like to acknowledge Martin Huber at the University of Colorado Denver for advice and testing. The Sadoulet group at the University of California Berkeley was also instrumental in design and testing. This work is supported by the Fermi National Accelerator Laboratory.*

## 2EPF05

### Superconducting L-C filter circuits for Frequency Division Multiplexed readout of TES detectors

*M.P.Bruijn, L.Gottardi, H.F.C.Hoevers, P.A.J.de Korte, J.van der Kuur, SRON*

L-C filter circuits form an essential component of FDM readout of Transition Edge Sensor based detectors. They serve the functions of blocking wide band noise from adjacent pixels into their frequency band and separation of bias frequencies in case of a topology with a comb of AC bias frequencies per column of pixels. One of the key requirements is a high quality factor Q (narrow band resonance), implying a full superconducting circuit, a low loss dielectrics for the capacitors and low magnetic loss environment for the inductors. Typically the Q should be in the range of 1000 to 10000 times the bias frequency  $f$  [MHz] below 4.2 K. We describe in details the fabrication process and the characterization of high-Q and high critical current superconducting L-C circuits for two types of astronomical applications: An array of TES X-ray microcalorimeters (for missions like ESA's XEUS) and arrays of Far Infrared TES bolometers (for missions like JAXA's SPICA). The requirements for these different applications are discussed. We have demonstrated circuits with a Q of 4000, although with limited critical current. An improved process resulted in critical currents  $\gg$  10 mA, but Q was limited to 700 due to capacitor electrode roughness. We expect to show circuits with both high-Q and high Ic at the conference.

## 2EPF06

### Time-division SQUID multiplexers for TES Readout

*G.C.Hilton, W.B.Dorise, L.R.Vale, Y.X.Xu, J.A.Beall, W.D.Duncan, L.Ferreira, K.D.Irwin, J.A.B.Mates, C.D.Reintsema, J.N.Ullom, NIST*

Time-division SQUID multiplexers are currently deployed as readout circuits for TES microcalorimeter arrays on several astronomical instruments. We have developed these multiplexers in two basic configurations: 1x32 linear chips such as those used in the Millimeter Bolometer Array Camera (MBAC) on the Atacama Cosmology Telescope (ACT) and in the Multiplexed SQUID TES Array at Ninety GHz (MUSTANG) on the Green Bank Telescope, and 32x40 wafer-scale multiplexers such as those used in the Submillimeter Common Use Bolometer Array (SCUBA2) at the James Clerk Maxwell Telescope on Mauna Kea. In this talk we will present recent results obtained for both our 1x32 and 32x40 multiplexers, as well as discuss recently implemented improvements in our multiplexer performance.

## TUESDAY AFTERNOON POSTER SESSIONS

2:00pm - 4:00pm

### 2EPG - Nanowire Detectors - 12:00pm - 4:00pm

## 2EPG01

*Invited*

### Readout Multiplexing for Large-area Arrays of Superconducting Nanowire Single-Photon Detectors

*A.J.Kerman, MIT Lincoln Laboratory; E.A.Dauler, J.K.W.Yang, K.K.Berggren, MIT Research Laboratory of Electronics*  
Superconducting nanowire single-photon detectors (SNSPDs) have the potential to be an enabling technology in many areas, particularly those requiring high-speed counting of near-infrared photons. Their persistent disadvantage, however (aside from the need for cryogenic cooling) is the difficulty of making large active areas while maintaining speed and detection efficiency. One reason for this is the device yield which decreases as the area is increased; another is that larger devices have slower count rates, due to the increased kinetic inductance. An effective way to mitigate both of these problems is use arrays of many smaller pixels to build up large areas. Given that independent readout of many pixels is at the moment impractical for these cryogenic detectors, a method for multiplexing the outputs of many pixels together is necessary. We have demonstrated a simple, low-power analog method for this multiplexing, which is in principle scalable to many pixels, and possibly even to imaging arrays. Progress on this method will be reported. This work is sponsored by the United States Air Force under Air Force Contract #FA8721-05-C-0002. Opinions, interpretations, recommendations and conclusions are those of the authors and are not necessarily endorsed by the United States Government.

## 2EPG02

### Development of SSPD system with Gifford McMahon cryocooler

*S.Miki, M.Fujiwara, M.Sasaki, Z.Wang, NICT*

We report on the development of superconducting single photon detector system. The detector system is based on Gifford McMahon cryocooler system which work by 100 V AC power supply and has a 2nd stage capacity of 0.1 W at 4.2 K. Up to 6 SSPD packages are able to be set into a refrigerator system, and brass semi-rigid coaxial cables were introduced and connected to each packages for biasing current and reading output signals. Single mode optical fibers were also introduced into the refrigerator to achieve a accurate coupling between illumination spot from the end of fiber and nanowire meander area. The cryocooler system achieved lowest temperature of 2.9 K within 10 mK fluctuation which is sufficient to operate NbN SSPD. Our typical SSPD device is consisted of 4-nm-thick, 2000-um-long and 100-nm-wide NbN nanowire which shows the Tc of 12 K and Jc of  $8 \times 10^6$  A/cm<sup>2</sup>. We will also present the SSPD system performance such as system detection efficiency, dark count, device inductance, and so on. *The authors thank B. Baek, S. W. Nam (NIST), R. H. Hadfield (Heriot-Watt Univ.), A. J. Miller (Albion College) for helpful discussions.*

## 2EPG03

### **Efficiently coupling light to superconductive nanowire single-photon detectors**

*X.Hu, C.W.Holzwarth, D.Masciarelli, K.K.Berggren, Massachusetts Institute of Technology*

We designed superconductive nanowire single-photon detectors (SNSPDs) integrated with gold optical antennas for free space coupling and a dielectric waveguide for fiber coupling. - A superconductive niobium nitride (NbN) nanowire detector works by generating detectable voltage pulses upon absorbing photons. The amount of absorption strongly depends on the spatial overlap between the light and the nanowire. Therefore, maximizing this overlap is crucial for enhancing the overall efficiency of SNSPDs, and is very challenging due to their small active areas. To address this problem, (1) for the free-space coupling case, we designed the SNSPD to integrate gold optical antennas between adjacent nanowires so that transverse-magnetic-polarized light can be efficiently focused onto the NbN nanowire. According to our finite-element simulation, absorptance of the NbN nanowire at 1550 nm can be as high as 90%. (2) For the fiber coupling case, we designed the SNSPD to integrate the nanowire with a Si<sub>3</sub>N<sub>4</sub> waveguide and a reverse-taper coupler so that light can be adiabatically coupled to the Si<sub>3</sub>N<sub>4</sub> waveguide via the coupler, and eventually coupled to the NbN nanowire. According to our finite-element simulation and calculation of the integrated system (single-mode fiber, coupler, waveguide and NbN nanowire), the absorptance of the NbN nanowire can reach 76% at 1550 nm including the coupling efficiency of the coupler.

## 2EPG04

### **Robust packaging technique and Characterization of Fiber-Pigtailed NbN Nanowire Superconducting Single Photon Detector**

*J.L.FX.Orgiazzi, University of Waterloo / Institute for Quantum Computing (IQC); A.H.Majedi, University of Waterloo, Institute for Quantum Computing (IQC)*

Efficient packaging and fiber coupling of a NbN nanowire superconducting single photon detector is in itself a real challenge and is often a limiting factor to reach a high system quantum efficiency. Our approach makes use of a controlled expansion alloy, Invar 36 R, that has been adequately heat treated to enhance its characteristics for cryogenic operation, insuring the integrity of the optical coupling done at room temperature while providing a high low frequency electromagnetic interference filtering due to the high relative permeability of this nickel-iron alloy. The small form factor of this optical fiber pigtailed package makes it versatile and could be easily integrated with a commercial cryogen-free system or simply dipped into a standard helium transport Dewar. We report on our experimental methodology to evaluate the optical coupling quality and present the DC and optoelectronic characterization of a device packaged in this way.

## 2EPG05

### **Photon-Number Resolving Superconducting Single-Photon Detectors**

*S.Dorenbos, E.Reiger, R.Schouten, V.Zwiller, Delft University of Technology; J.Kitaygorsky, R.Sobolewski, University of Rochester*  
Photon-number-resolution (PNR) capability is one of the most critical features in successful implementation of single-photon detectors (SPDs) in advanced optical quantum cryptography and quantum computing schemes. We present here an approach that enabled us to resolve the difference between the single- and multi-photon events in photoresponse transients generated by meander-type, nanostructured NbN superconducting SPDs (SSPDs). To achieve PNR, we integrated the SSPD with a low-noise, cryogenic HEMT amplifier with a 500-Ohm input resistor. The high-input amplifier allowed us to relate the shape of the SSPD output voltage

pulse to the number of photon absorption events along the NbN nanostructure, by a careful analysis of its amplitude distribution function. In essentially single-photon events, we observed a single-Gaussian distribution, while when the intensity of laser pulses was adjusted such that multi-photon events were present, the recorded amplitude distributions were much wider than that for the single-photon regime and could be fitted several overlapping Gaussians. Independent temperature dependence studies of the SSPD output-pulse amplitude distributions shed new light on the dynamics of hotspot formation and its subsequent healing in two-dimensional superconducting nanostructures.

*This work was supported in part by the US AFOSR grant FA9550-06-1-0348.*

## 2EPG06

### **Readout electronics using single-flux-quantum circuit technology for superconducting single-photon detector array**

*H.Terai, S.Miki, Z.Wang, National Institute of Information and Communications Technology (NICT)*

Superconducting single-photon detector (SSPD) based on NbN nanowire has high counting rate, low dark count rate and small timing jitter, which are promising for quantum communication systems. In a recent quantum key distribution experiment implemented with the SSPD, a 12.1 bps secure key rate over 200 km of fiber has been demonstrated. A multi-element SSPD has recently attracted attention to provide higher counting rate, spatial and photon number resolution. However, an increasing number of output cables will make the use of a compact GM cryocooler difficult, because the output cables must be wideband to match the fast response of SSPD. To reduce the number of output cables, a signal processing in cryogenic environment will be required, but small output signal amplitude of SSPD will not allow the use of semiconductor circuits in terms of power consumption for signal amplification with wide bandwidth. We propose to employ the single-flux-quantum (SFQ) circuits for readout electronics of the SSPD array. Once output signals of SSPD are converted into SFQ pulses, signal processing with various applications can be executed with very low power consumption. We discuss the feasibility of the SFQ readout electronics for the SSPD array, focusing on the interface circuit between SSPD and SFQ circuit, effective circuit design for signal processing and required circuit scale.

## 2EPG07

### **New Read-Out Technique to Resolve Photon Events from Dark Count Events in Nanostructured NbN Superconducting Single-Photon Detectors**

*J.Kitaygorsky, R.Sobolewski, University of Rochester; S.Dorenbos, E.Reiger, R.Schouten, V.Zwiller, Delft University of Technology*

Dark counts in superconducting single-photon detectors (SSPDs) manifest themselves as spontaneous, transient voltage pulses, typically indistinguishable from photon counts. We present here a new read-out technique, based on integrating the SSPD with a low-noise cryogenic HEMT amplifier with high-input impedance. This arrangement allowed us to achieve amplitude resolution of the recorded output transients. Since the physics of photon counting by SSPDs is based on the hotspot formation mechanism, while dark counts correspond to voltage transients triggered by the vortex-antivortex motion, their respective waveforms are different and can be distinguished by comparing the output pulse amplitude distributions. Our scheme allowed us to perform detailed, temperature dependence studies of the vortex-antivortex generation mechanism in two-dimensional superconducting nanostructures, as well as shed new light on the physics of the photodetection mechanism in SSPDs. The presented read-out technique should also enable energy-resolving capability of standard devices.

*This work was supported in part by the US AFOSR grant FA9550-06-1-0348.*

## 2EPG08

### **Microwave Parametric Measurements On The Superconducting Single Photon Detector Nanowires**

*Z.Yan, A.H.Majedi, University of Waterloo*

Superconducting Nanowire Single Photon Detectors (SNSPD) have been demonstrated to be one of the successful candidates to acquire the fastest single photon optical detection with low dark count and very low-jitter time. Since the relationship between the kinetic inductance and bias current can shed light on the SNSPD photon response mechanism, we use microwave measurement techniques to explore the kinetic inductance of the SNSPD, in particular its non-linear behavior under different excitations, including the different dc bias ratios, different levels of microwave and optical power excitations. We employ microwave S-parameter measurements in order to extract the nonlinear behavior of the SNSPD kinetic inductance. Moreover, we have performed single tone and two tone measurements by applying a single or double monochromatic high frequency signal and looking at the reflected power spectrum to investigate the SNSPD nanowire parametric properties. From the single tone measurement, we observed up to forth order harmonics above the noise floor; in the two tone measurement, we were able to see the microwave signal mixing properties within superconducting nanowires of the SNSPD. Lastly, we also report the microwave characterization of the microwave interconnect components, including the power divider/combiner, amplifier, and cryogenic coaxial cables. The experimental results reported may be desirable to devise parametric amplification schemes for the single photon detection readout electronics of SNSPDs.

### **2EPH - NbN and MgB<sub>2</sub> Thin-Film Device Fabrication**

**2:00pm - 4:00pm**

## 2EPH01

### **Self-shunted NbN junctions with NbN<sub>x</sub>/AlN/NbN<sub>x</sub> multilayered barriers for 4 K operation**

*R.Kanada, Y.Nagai, H.Akaike, A.Fujimaki, Nagoya University.*

We have fabricated and evaluated NbN/(NbN<sub>x</sub>)/AlN/NbN<sub>x</sub>/NbN overdamped junctions operating at 4 K for Single-Flux-Quantum (SFQ) circuits. Comparing with Nb/AlO<sub>x</sub>/Nb junctions used in SFQ circuits, NbN junctions are expected to have higher IcRn products leading to higher operating speed of SFQ circuits. In addition, these NbN junctions have a superconductor - normal conductor - insulator - normal conductor - superconductor structure. Then, these junctions would behave as self-shunted junctions, which results in an increase in the integration level of the circuits. In this work, we selected NbN<sub>x</sub> and AlN as the normal conductor and the insulator because the junctions with nitrided layers only can have chemical stability. As the first step, we fabricated Nb/AlN/NbN<sub>x</sub>/NbN junctions to investigate the properties of the AlN/NbN<sub>x</sub> barriers and the junction behavior. These junctions showed overdamped I-V characteristics at 4.2 K. The values of Jc and IcRn product were 1.2 kA/cm<sup>2</sup>, and 0.2 mV, respectively, for 10 μm × 10 μm junctions with a 3 nm-thick AlN and 6 nm-thick NbN<sub>x</sub>. We are fabricating junctions with various film thicknesses of the NbN<sub>x</sub> and AlN layers deposited under various conditions to improve the IcRn products. We will report fabrication and I-V characteristics of the junctions.

*This work was supported by a Grant-in-Aid for Science Research in a Priority Area "Single-Flux-Quantum localized electromagnetic wave integrated circuits" from the Ministry of Education, Sports, Culture, Science, and Technology, Japan.*

## 2EPH02

### **Evaluation of self-shunted NbN/TaN/NbN Josephson junctions for digital electronics**

*P.Febvre, D.Bouis, University of Savoie; V.Michal, R.Setzu, J.-C.Villégier, CEA-INAC Grenoble*

Intrinsically shunted Josephson junctions based on NbN superconducting material can exhibit RnIc products in the 1-3 mV range at temperatures in the 4-10K range, while presenting non hysteretic current-voltage characteristics. For these reasons, they are a suitable alternative for digital electronics since they can be ultimately highly integrated, while operating at clock frequencies above 100 GHz. In this work, departing from some experimental data of Josephson junctions measured in different conditions, we will present the expected performances in terms of ultimate speed, bit-error-rate and temperature of operation that can be reached with such a technology, for a few breadboard digital circuits. Circuits using interface converters, Josephson transmission lines, shift registers and several flip-flop cells are investigated for this purpose. An analysis is done in order to compare the potentialities and drawbacks of this technology with its existing low-Tc and high-Tc counterparts. The emphasis will be put on the technological requirements that are necessary to be met in order to achieve a given performance.

*This work is funded by the HyperScan project of the French National Agency and by the micro-nano cluster of the Région Rhône-Alpes. It is also supported by the Minalogic pole of competitiveness.*

## 2EPH03

### **Fabrication and characterisation of epitaxial NbN/TaN/NbN Josephson junctions grown by pulsed laser ablation**

*M.R.Nevala, I.J.Maasilta, University of Jyväskylä; K.Senapati, R.C.Budhani, Indian Institute of Technology Kanpur*

We report the fabrication and characterization of epitaxial NbN/TaN/NbN Josephson junctions grown by pulsed laser ablation [1] on single crystal (100) MgO substrates. The high quality of the NbN films is reflected in the high transition temperatures ~ 16 K achieved. These SNS junctions with non-hysteretic I-V characteristics can be used elements of rapid-single-flux-quantum (RSFQ) logic. Several NbN/TaN/NbN trilayers were e-beam lithographically patterned into mesas of different sizes using reactive ion etching in CHF<sub>3</sub>+O<sub>2</sub>. E-beam lithography was again used for patterning a PECVD-grown SiO<sub>2</sub> layer, followed by an uncharacteristic lift-off after CVD growth. For small devices, a top Nb contact layer was e-beam evaporated to facilitate bonding. Ar-ion sputtering before Nb deposition was necessary to make a good contact with the top NbN layer. I-V measurements of the junctions were performed at several different temperatures from 4.2 K upwards. The Rn values were observed to be from ~ 25 mOhms to 180 mOhms. From the observed values of the critical current Ic we also calculated the the IcRn product, which is the appropriate figure of merit for junctions in RSFQ circuitry. Observed values were comparable to values measured before for sputtered NbN films [2]. *This work has been supported by The Technological Foundation of Finland. [1] K. Senapati, et al., Phys. Rev. B 74 (2006) 104514. [2] A. Kaul, et al., Appl. Phys. Lett. 78 (2001) 99.*

## 2EPH04

### High-quality NbN/AlN/NbN tunnel junctions with a wide range of current density

Z.Wang, M.Takeda, H.Terai, W.Qiu, Kobe Advanced ICT Research Center, NICT

We report on the fabrication and properties of high-quality NbN/AlN/NbN tunnel junctions with a wide range of  $J_c$  for various applications such as quantum devices, THz-band detectors and so on. The junctions were fabricated by reactive dc-magnetron sputtering deposition of NbN/AlN/NbN trilayers, i-line stepper lithography, lift-off and RIE technique. The junction area was varied in 0.25-250  $\mu\text{m}^2$ . In a wide range of  $J_c$  from a few of  $\text{A}/\text{cm}^2$  to several tens of  $\text{kA}/\text{cm}^2$ , the junctions showed excellent Josephson tunneling properties with a large gap voltage of 5.6 mV and a large  $I_c R_N$  product of 3.5 mV. The quality factor  $R_{\text{sg}}/R_N$  of the junctions, where the  $R_{\text{sg}}$  is the subgap resistance measured at 4 mV, is about 45 for the junction with a  $J_c$  of 3  $\text{A}/\text{cm}^2$ , and above 10 for the junction with a  $J_c$  of 25  $\text{kA}/\text{cm}^2$ , respectively. The interface properties of the junctions were investigated by cross sectional observation of the NbN/AlN/NbN interface using a transmission electron microscope (TEM). The junctions showed a very smooth and clear electrode-barrier interface. Both of base and counter NbN electrodes had a single-crystal structure without dependence on the AlN barrier thickness.

## 2EPH05

### Patterning techniques for magnesium diboride films for superconducting transition edge sensor bolometer arrays

D.E.Travers, S.Aslam, W.T.Hsieh, H.H.Jones, NASA Goddard Space Flight Ctr, Detector Systems Branch; B.Lakew, NASA Goddard Space Flight Ctr., Planetary Systems Laboratory; T.R. Stevenson, NASA Goddard Space Flight Center, Detector Systems Branch

We present a comparison of several patterning techniques for magnesium diboride films with the goal of making membrane-supported superconducting transition edge sensor bolometer arrays suited for far infrared exploration of outer planets and icy moons. We compare etch properties such as etch rate, selectivity to resist, and edge roughness for wet etching, reactive ion etching, and ion-milling processes.

## 2EPH06

### Study of tunnel junctions on MgB2 films with different orientations

K.Chen, The Penn State University; C.G.Zhuang, Peking University; Q.Li, X.X.Xi, The Penn State University

Two-band superconductor MgB<sub>2</sub> has a large sigma-band gap of about 7.4 meV and a small pi-band gap of about 2.2 meV. Due to the quasi-two-dimensional nature of the sigma-band, in order to study the large band gap, it is preferable to form a Josephson tunnel junction on MgB<sub>2</sub> film whose ab-plane is exposed to the tunneling current. We have studied MgB<sub>2</sub> films on variously oriented single crystal substrates including (001) SiC, (111) MgO, (211) MgO, and (100) MgO. Tunnel junctions with Pb or Ag as the counter electrode have been made on these films.

Less than 1% sigma-band contribution to the tunneling current was observed on the junctions made on (001) SiC and (111) MgO substrates while up to 11% sigma-band contribution was observed on the junctions made on (211) MgO and (100) MgO substrates. Tunnel junctions made on tilted MgB<sub>2</sub> films may be used for applications that benefit from the large sigma-band contributions. *We would like to thank John Rowell for helpful discussions. This work is partially supported by ONR.*

## 2EPH07

### Fabrication of over-damped Josephson junctions with MgB2/Al/AlN/MgB2 structures

H.Shimakage, Z.Wang, National Institute of Information and Communications Technology

The over-damped Josephson junction is useful for some electronics applications, such as single flux quantum (SFQ), superconducting quantum interference device (SQUID), Josephson mixer, and so on. Although the over-damped Josephson junction is fabricated by the structure for SIS junctions with external shunt resistors, it has a junction loop, and structurally has inductance. Moreover, as the space per junction is relatively large because of shunt resistors, the integration of the junctions is not well. We propose the multi-layer junctions as MgB<sub>2</sub>/Al/AlN/MgB<sub>2</sub> structures, and report on the over-damped characteristics. Superconductive layers, insulator layer, and metal layer were deposited by a sputtering method on the c-plane sapphire substrates in a same chamber. The junction fabrication process was same as that of our SIS junctions. The current-voltage characteristics of the junctions showed the non-hysteresis characteristics, and well fitted by the resistivity shunted junction (RSJ) model with  $I_c R_N$  products of 0.19 mV. The Josephson current was ideally modulated by applying an external magnetic field, which indicated that the Josephson current flowed uniformly in the junctions. The junction showed the clear Shapiro steps under an irradiation of millimeter wave. A comparison of the characteristics with single and 11-series junctions indicated that the junctions uniformity in the chip was excellent.

## 2EPH08

### Low NbN-MgO-NbN Josephson Junctions for fundamental tunneling experiments

G.P.Pepe, V.Pagliarulo, N.Marrocco, L.Parlato, G.Peluso, A.Barone, University of Naples Federico II and CNR-INFN Coherentia, Italy; A.Kawakami, Kobe Advanced ICT Research Center, National Institute of Information and Communications Technology, Japan

Decay of the zero-voltage state of a Josephson junction at low temperatures can be seriously affected by the action of an ac component of the bias current (Euclidean resonance). The possibility to observe this quantum effect is strongly related to the availability of materials showing very short electron relaxation times such as NbN. We have fabricated epitaxial NbN Josephson junctions with very low critical current densities ( $<10 \text{A}/\text{cm}^2$ ) on MgO substrates. Junctions have been characterized in terms of I-V,  $dI/dV$ -V and  $I_c$ -T behaviors down to temperatures  $<4\text{K}$ . Experimental results are discussed according to their potential use for novel quantum experiments.

**2EPJ01**

**Fabrication of Micron and Nano Plough Constriction Type Josephson Junctions using an Atomic Force Microscope**

*A.A.O.Elkaseh, U.Buettner, V.V.Srinivasu, Department of Electrical and Electronic Engineering, Stellenbosch University; W.J.Perold, Senior Member, IEEE; Department of Electrical and Electronic Engineering, Stellenbosch University*

Using an Atomic Force Microscope, we successfully ploughed micron and nano size planar constriction type junctions on YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7-x</sub> thin films. The 100 nanometer thin films are deposited on MgO substrates by an Inverted Cylindrical Magnetron (ICM) sputtering technique. The films are then patterned into 8-10 micron size strips using photolithography and dry etching. A diamond coated tip was used in this process [1]. We are able to observe well defined I-V characteristics and Shapiro-steps demonstrating the Josephson effect in these junctions. Further we compare the critical current ( $I_c$ ) vs Temperature (T) behavior of the micron- and nano-size junctions. Reference: [1] A.A.O. Elkaseh et al., Journal of Nanoscience and Nanotechnology, Vol. 7, 1-2, 2007. *The financial assistance of the International Centre for macro Molecular Chemistry and Technology in Libya.*

**2EPJ02**

**HTS arrays for fast switching in a programmable voltage standard**

*A.Sosso, V.Lacquanti, INRIM Torino; A.M.Klushin, Forschungszentrum Jülich ; M.He, Nankai Univ., Tianjin*  
Devices based on arrays of JJs with non-hysteretic current-voltage characteristics can be successfully applied in ac voltage and power quantum metrology. Non-hysteretic junctions are naturally available in a high-temperature superconductor (HTS) technology and may be interesting for these applications. To obtain small uncertainties of the generated ac voltages, short transient time while switching between the voltage steps should be achieved. We have shown that one of the main reasons of large transient time is long cables between a sample and room equipment. Here we present results for an improved version of an HTS array with 256 shunted YBCO junctions, aimed at minimizing these error contributions in metrological applications. We have developed a cryoprobe with the sample located on the top of the standard dewar, making use of short cables to reduce transients. A small distance between the Josephson array and room equipment also minimizes the uncertainties in the calibration of the power converter.

**2EPJ03**

**Periodic resistance peaks in two Bi-2212 stacks coupled with a submicron hole**

*S.-J.Kim, Cheju National University; T.Hatano, National Institute for Materials Science*

Two-stacked array of Bi<sub>2</sub>Sr<sub>2</sub>CaCu<sub>2</sub>O<sub>8+δ</sub> (Bi-2212) intrinsic Josephson junctions with a submicron hole shows typical I-V characteristics with uniform multi-branch structures. With applying external magnetic fields, the clear periodic modulation patterns of critical current and flux-flow resistances in high magnetic fields are obtained and well fitted to the calculated value. When we change the angle from ab-plane, sharp periodic resistance peaks were appeared with regular intervals. We mainly report the periodic resistance peaks from incident angle dependence of external magnetic field at current biased sample.

*A part of this work was supported by the Korea Science and Engineering Foundation (KOSEF) and Korea Research Foundation (KRF).*

**2EPJ04**

**The Behavior of Subgap Structures of Intrinsic Josephson Junctions in (Bi,Pb)<sub>2</sub>Sr<sub>2</sub>CaCu<sub>2</sub>O<sub>y</sub> under Magnetic Field and Microwave Irradiation**

*H.Kaneoya, A.Irie, G.Oya, Utsunomiya University*

We have extensively studied the behavior of pronounced subgap structures on the quasiparticle branches of the current-voltage characteristics of intrinsic Josephson junctions in (Bi<sub>1-x</sub>Pb<sub>x</sub>)<sub>2</sub>Sr<sub>2</sub>CaCu<sub>2</sub>O<sub>y</sub> (with  $x = 0.15$ ) single crystals at 4.2 K for their applications in THz range. The subgap structures have been found between 6.2 and 29.8 mV, which may be caused by the interference of optical phonons with ac Josephson current in the junctions. Their behavior has been studied under magnetic field up to 5 T and with irradiation of microwave of 2-100 GHz. Under the magnetic field, it has not been strongly affected, although the vortex flow has been induced in the junctions. On the other hand, under microwave irradiation, it has been observed that their peak amplitude decreases gradually and each peak splits into two, and then they shift far from each other, with increasing microwave power. This behavior may be expected to the application to microwave detection.

**2EPJ05**

**Non-volatile flash memory effect in Y-123 intrinsic Josephson junctions by the flow dynamics of Josephson and pancake vortices**

*T.Hatano, H.B.Wang, Y.Inamoto, M.Nagao, K.S.Yun, S.Arisawa, National Institute for Materials Science*

Layered oxide high-T<sub>c</sub> superconductors, being regarded as intrinsic Josephson junctions (IJJs), are widely studied for novel electronic applications. We propose here a superconducting flash memory utilizing the switching between a zero-voltage state and a flux-flow state (finite voltage state). The device operations can be realized by the hysteretic transition of vortex configurations under near-layer-parallel magnetic field. The flux-flow state, namely

**2EPK01**

**Invited**

**Fetal magnetocardiography using two-dimensional gradiometers in unshielded environment**

*Y.Seki, A.Kandori, Advanced Research Laboratory, Hitachi, Ltd.; Y.Kumagai, Central Research Laboratory, Hitachi, Ltd.; M.Ohnuma, Design Division, Hitachi, Ltd.; A.Ishiyama, T.Ishii, Y.Nakamura, H.Horigome, T.Chiba, National Center for Child Medical Health and Development*

We measured fetal magnetocardiograms (fMCGs) by using a pair of two-dimensional gradiometers. To achieve high signal-to-noise ratio, each gradiometer, based on a low-T<sub>c</sub> superconducting quantum-interference device (SQUID), detects the gradient of a magnetic field in two orthogonal directions. As a result, an fMCG waveform of a fetus at 25 weeks' gestation was measured under an unshielded environment in real time. Moreover, the P and T waves were also measured at 25 and 34 weeks' gestation, respectively, by averaging. These results demonstrate that the developed fMCG system using a pair of two-dimensional gradiometers can measure not only fetal heart rate but also basic MCG time parameters, such as PQ interval, QRS width, and QT interval, in an unshielded hospital environment.

## 2EPK02

### Invited

#### **A SQUID system for measurement of spinal cord evoked field of supine subjects**

*Y.Adachi, J.Kawai, M.Miyamoto, G.Uehara, H.Ogata, Kanazawa Institute of Technology; M.Tomori, S.Kawabata, T.Sato, Tokyo Medical and Dental University*

An LTS SQUID biomagnetometer system was developed for the non-invasive diagnosis method of the function of the spinal cord for orthopaedic application. The developed biomagnetometer system is characterized by a uniquely shaped cryostat. It has a vertical cylinder-shaped main body and a protrusion of 380 mm in length from its side surface. An array of vector SQUID gradiometers, whose typical noise level is 5 fT/rtHz in white region, is installed in the protrusion. Supine subjects are able to fit their cervixes stably to the sensor array by putting them on the protrusion during the measurement. The sensors directed vertically upwards detect magnetic signals from the back of the cervix. An X-ray imaging apparatus is integrated to the SQUID system for the in-situ acquisition of the anatomical information that reveals the position of cervical vertebrae relative to the location of the sensor array. For verification of the performance of the developed system, we examined the spinal cord evoked field measurement of a normal subject. We succeeded in observing the transition of the cervical magnetic field distribution induced by the electric pulse stimulation on the median nerve at the subject's wrist.

## 2EPK03

#### **Performance of digital SQUID gradiometer for MCG measurement under different shielding conditions in a variety of noisy environments**

*J.Q.Jiao, X.Wang, L.Tong, J.Gao, W.Wang, P.Ma, State Key Laboratory for Artificial Microstructure and Mesoscopic Physics, Peking University*

In this work, two HTc YBCO SQUIDs are used to form a gradiometer without electronic subtraction and digital data processing is applied to cancel the environmental noises. With healthy volunteers as measuring subjects, MCG recordings of various signal to noise ratio-SNR are obtained under different shielding conditions in environments of different noise components and characteristics. To extract the signal, data processing procedures based on adaptive filtering, wavelet transform and independent component analysis are studied and utilized to raise the SNR in each measurement respectively. The performances of these numerical methods are evaluated and compared. The result shows that using appropriate data processing method can get acceptable signal quality in comparatively more noisy environment with weakly shielding.

## 2EPK04

#### **Mobile High-Tc SQUID System for MCG Measurement**

*D.Oyama, Iwate University, Japan Society for the Promotion of Science Research Fellow ; K.Kobayashi, M.Yoshizawa, Iwate University; Y.Uchikawa, Tokyo Denki University*

We developed a mobile high-Tc SQUID system for magnetocardiogram (MCG) measurement. The points of this system are easy handling and low cost. A prototype of the mobile high-Tc SQUID system was composed of a small cryostat, a high-Tc SQUID magnetometer, a digital FLL circuit, and a computer. A vacuum bottle was used as a cryostat. It could be had by hands and its capacity of liquid nitrogen was about 0.5 L. The effective area of the SQUID is 0.5 mm<sup>2</sup>, and sensitivity is 3.8 nT/Φ<sub>0</sub>. The maximum voltage modulation is 7.0 μV. Neither the cryostat nor the SQUID magnetometer are custom-designed. Wide dynamic range was achieved by a flux-quanta counting method with a digital FLL circuit. Furthermore, careful tuning and a double-counter method were important to realize low cost circuit. It was made of a generally used one-chip microcontroller and inexpensive devices

easily obtained. Experimental demonstration was carried out inside a single layer magnetically shielded room, and a cryostat was held by a hand. MCG signal was measured for three minutes. Fluctuations of measured signal were caused by movement of cryostat. Although it was 35 nT, the system could maintain steady operation by its wide dynamic range. A white noise level of 2 pT/(Hz<sup>1/2</sup>) was measured. QRS complex and T wave of MCG are clearly observed after using a band-pass filter and averaging processing. Finally, our method is well suitable for multi-channel system, so that noise performance will be improved by statistical signal processings.

## 2EPK05

#### **A whole-head SQUID system in a superconducting magnetic shield making progress towards a real-time SQUID**

*H.O.Ohta, T.M.Matsui, NICT; K.M.Miyanaga, SHI Hiroshi Ohta and Toshiaki Matsui, National Institute of Information and Communications Technology, Noise spectra of a SQUID in the superconducting magnetic shield are almost one hundred times better than those of the same SQUID in a typical magnetically-shielded room of Permalloy below 1 Hz. We observed readiness magnetic fields from 1500 msec before to 500 msec after finger tapping. We obtained data of very good SN(signal-to-noise) ratio by averaging only 20 events during five minutes while 150 through 250 events are averaged in most papers. Five minutes for each subject or patient is short and practical enough for clinical application. Each datum of 20 events has considerable SN ratio meaning real-time datum. Each datum of 20 events contains real-time auditory response corresponding to the sound of the compressor of the cryogenic refrigerator. Sensors are made of telegraph-noise-free SNS(superconductor/normal metal/superconductor) junctions.*

*We would like to thank Professor Uchikawa and his graduate students of Tokyo Denki University and Sumitomo Heavy Industry for their cooperation about neuro-magnetic measurements.*

## 2EPK06

#### **A SQUID array magnetometer for MEG**

*M.Kiviranta, L.Grönberg, VTT; J.S.Penttilä, Aivon Oy; J.Hassel, VTT*

We have designed and fabricated a magnetometer/gradiometer utilizing a LTS SQUID series array, in order to facilitate use of a simple readout electronics in multichannel magnetoencephalography instruments. The design guidelines will be reviewed and the device performance described.

## 2EPK07

#### **A comparative MCG study with various anesthetics in rabbits using HTc rf SQUID**

*L.Tong, J.Q.Jiao, J.Gao, X.Wang, W.Wang, P.Ma, State Key Laboratory for Artificial Microstructure and Mesoscopic Physics, Peking University*

We have developed a High Tc (HTc) YBCO rf SQUID system for detecting the weak biomagnetic fields generated by electrophysiological activity of the heart. The HTc SQUID system was used to detect the magnetocardiogram (MCG) signals of rabbits anesthetized with different agents while the electrocardiograms (ECGs) were recorded simultaneously. Differences between MCG and ECG waveforms were observed when the same anesthetic was used to rabbits, and changes in MCG waveforms were also found when the rabbits were anesthetized with various agents. The amplitude of the MCG signals differed significantly as using different anesthetics and so did the time courses of the signals. The results show that MCGs can be used as a complementary method to understand how the magnetic field caused by the electrophysiological activity of the rabbit heart responds to the anesthetic as a stimulus.

## 2EPK08

### **A novel SQUID magnetocardiography system for small animals with a U-shaped cryostat**

*Y.Adachi, M.Miyamoto, J.Kawai, G.Uehara, H.Ogata, M.Kawabata, T.Shimozu, H.Kado, Kanazawa Institute of Technology; K.Komamura, National Cardiovascular Center*

Magnetocardiography (MCG) is effective for large-scale animal testing in drug evaluation because it is totally contact-free and high-throughput method. We developed a compact SQUID biomagnetometer system for MCG of small animals, such as rats and mice, aimed at pharmaceutical laboratory use. The SQUID system was characterized by a cryostat with a quasi-U-shape structure. It was composed of two 500-mm high cylinders with a distance of 590 mm. One was a main body with a capacity of 7.8-liter liquid helium (LHe). The other was a slim tower of 55 mm in diameter. Both were connected at their bottoms by a LHe delivering tube. Only the slim tower was inserted in a double-layer cylindrical magnetically shielded box (MSB) from the bottom. An LTS SQUID sensor module was embedded at the top of the slim tower. A sample lay on a non-magnetic stage in the MSR. This structure enables the sensor to approach to the thorax from underneath. Therefore, it is not necessary to turn over the sample for acquisition of the MCG pattern, and examination of non-anesthetized animals is also possible. The MCG measurement of normal rats by the developed system was demonstrated. The transition of their MCG pattern was successfully observed as a result.

### **2EPL - Novel Devices and Applications 2:00pm - 4:00pm**

## 2EPL01

### **Functional decoupling of HTS strips for electromagnetic detectors**

*R.Gerbardo, G.Ghigo, L.Gozzelino, F.Laviano, G.Lopardo, B.Minetti, E.Mezzetti, A.Rovelli, Dept. of Physics - Politecnico and INFN-To, Torino, Italy*

In this work we report on a single device approach to the mapping of elm signals and on the very basic characterization. The functional principle relies upon carving contiguous rows of heavy-ion (HI) nanostructured mesas across YBCO films strips. Such HI modulated nanostructuring is able to bring contiguous regions into planned (B,T) phase points to rule the elm response of each one. In presence of an external large excitation, i.e. an external B, the irradiated microchannel generates a voltage drop proportional to B, while the as-deposited YBCO stays in the dissipation-less state. We show the structural, MO and elm properties of a typical detector viable to exploit the functional decoupling of the irradiated zone from the surrounding as-deposited film: the pristine parts only play the role of thermal buffers and current leads. The electrical transport characterization under external B is devoted indeed to measure the portion of the phase diagram enabling the decoupling of the mesa part from the contiguous superconducting medium. Perspective future applications in the elm spectra detection are discussed.

## 2EPL02

### **CONTROL SCHEME OF QUANTUM-BASED PICONEWTON FORCE MEASUREMENT**

*S.G.Lee, Y.W.Kim, Korea University; J.H.Choi, M. Y.Kim, KRISS*  
We propose control-measurement scheme for flux-quantum-based piconewton force metrology. A micron-sized superconducting ring placed in magnetic field gradient can serve as a pico-newton force gauge [1]. Constant-force steps can be realized by controlling the flux quanta in the superconductor ring. Two different schemes are proposed to control and measure the number of flux quanta in the ring. They are the fixed current-bias mode and the fixed flux-bias mode. In the fixed current-bias mode, a transport bias-current is fixed just below the critical current of the ring and the flux quanta is counted by measuring the voltage in the ring with increasing applied flux.

At the targeted number of flux quanta, bias-current and flux are reset to zero in sequence. After force measurement, remaining flux quanta in the ring can be confirmed by counting the voltage bumps with increasing the bias current up to the fixed bias value at zero flux bias. In the fixed flux-bias mode, external bias-flux is fixed just below the resistive transition and entry of the flux quanta is counted by counting the voltage pulses with increasing bias current. At the targeted number of flux quanta, both bias-current and flux are reset to zero. After measurements, remaining flux quanta in the ring can be confirmed by counting the voltage pulses with decreasing the bias flux down to the minus of the fixed bias value at zero current bias. More details will be discussed. [1] J. H. Choi, M. S. Kim, Y. K. Park, M. S. Choi, Appl. Phys. Lett. 90, 073117 (2007).

*This work was financially supported by Korea Research Institute of Standards and Science.*

## 2EPL03

### **High critical temperature superconducting wire based flux transformers and gradiometers**

*H.Dyvorne, J.Scola, R.Guerrero, C.Fermon, M.Pannetier-Lecoecur, J.F.Jacquinot, CEA Saclay*

Flux transformers are currently used for signal detection with high sensitivity magnetometers like SQUIDS, as an alternative to direct coupling between the magnetometer and the sample. To avoid extra noise, most of them are made of superconducting material, namely low critical temperature ( $T_c$ ) wires and high  $T_c$  thin films. We made flux transformers with high  $T_c$  commercial Bi-2212 wires [1]. Because the loops were closed by tin soldering, the device has a residual resistance of a few  $\mu\Omega$ . We will present the magnetic flux transfer characteristic measurements and the calculations of the noise induced in the detection chain by this kind of flux transformer. The possibility of gradiometry will be explored as well as the tuning of the flux transformer with a capacitor [2]. Finally we will show how we use this device for NMR signal detection with mixed sensors [3]. References [1] H. Dyvorne et al., Rev Sci Instr 2008, accepted. [2] W. Myers et al., Journal of Magnetic Resonance 186 (2007) 182-192. [3] M. Pannetier et al., Science 304, 1648-1650 (2004).

*We thank Sumitomo, American Superconductors and Nexans for supplying the superconducting wires used in this work. This work is supported by the European program 7 ISTNMP-2 Bio-sensors for Diagnosis and Healthcare (Biomagsens NMP4-CT-2005-07210).*

## 2EPL04

### **Application of MgB<sub>2</sub> Wire to Liquid Hydrogen Level Sensor**

*M.Takeda, Kobe University; Y.Matsuno, I.Kodama, Iwatani Industrial Gases Corporation; C.Kazama, Kobe University; H.Kumakura, National Institute for Materials Science*

Hydrogen is expected to be the ultimate energy source, because only water is produced after chemical reaction of hydrogen and oxygen. In the near future, new generation consuming a large amount of hydrogen energy is promising. In the storage and transport of a large quantity of hydrogen, liquid hydrogen (LH<sub>2</sub>) has the advantage of high storage efficiency. Precise control of the liquid level is desired from the viewpoints of economy and safety, so that a liquid-level gauge with high resolution and good reproducibility is essential to precisely control the level of LH<sub>2</sub>. Recently, a LH<sub>2</sub>-level sensor based on MgB<sub>2</sub> wire has been studied from the viewpoint of applied superconductivity. This level sensor utilizes the difference in the electric resistance between the liquid and vapor phases of hydrogen. MgB<sub>2</sub> wires used for the level sensor were fabricated by the in situ method on the basis of the powder-in-tube method, and were reinforced by a CuNi (7:3) sheath. To conduct a feasibility study of the level sensor, we report the level-detecting characteristics of our newly fabricated MgB<sub>2</sub> sensors: heater input dependence, pressure dependence, and linearity of the detected level.

## 2EPL05

### Application of LTS-SQUIDs in Nuclear Measurement Technique

*W.Vodel, R.Neubert, A.Steppke, R.Geithner, Jena University*

Applications of LTS-SQUIDs reach from precision measurement technique in laboratory research to high energy physics. This contribution describes an LTS SQUID-based measurement tool for nuclear physics. This device makes use of the Cryogenic Current Comparator (CCC) principle and is able to measure e.g. the absolute intensity of high energy ions extracted from a particle accelerator or the so-called dark current, generated by superconductive RF accelerator cavities at high voltage gradients. The CCC mainly consists of a high performance LTS-DC SQUID system, a special toroidal pick-up coil, and a meander-shaped superconductive ring structure for magnetic shielding. The design of the CCC requires a thorough knowledge of several noise contributions to achieve a high current resolution. As the SQUID and the pick-up coil are extremely sensitive to external magnetic fields it is necessary to shield both sufficiently against any disturbing field sources other than the magnetic field to be measured, e.g. ion beams or dark currents. Theoretical investigations showed that with strong attenuation of external noise sources an improvement of the sensor performance is dependent on the ferromagnetic core material embedded in the pick-up coil. Several ferromagnetic and nanocrystalline materials were investigated and the temperature- and the frequency dependence measured. The current results, which have to be evaluated to achieve a high accuracy of the CCC in the different applications, will be presented and discussed.

### 2EPM - Novel Junction Applications – II 2:00pm - 4:00pm

## 2EPM01

### Invited

#### Design of high-linearity HTS SQUID-array sensors

*J.Talvacchio, J.M.Murduck, Q.P.Herr, Northrop Grumman Corporation*

Response linearity is a key figure of merit for SQUID arrays used as wideband, low noise, RF sensors and amplifiers. We performed successive design steps to improve linearity. Simulations of voltage response were performed at each step to determine 2nd-order and 3rd-order spur-free dynamic range (SFDR), which are both important in wideband applications. Simulations included variations in junction critical currents to match HTS fabrication capabilities. Since SFDR for 3rd-order mixer products scales as the number of junctions to the 2/3 power, the first step was to maximize array size. The next step was to employ differential pairs of counter-biased arrays to greatly reduce even-order spurs. We generalized an approach of Kornev, et al, to scale loop areas by factors of 1:3:5 to create a triangle-wave periodic response. We extended that approach to multiple parallel SQUIDs and to low bias currents where single-SQUID responses are non-sinusoidal. Finally, we employed a method of selective dc phase offsets to the various SQUID loops. For arrays with 22,000 junctions, projected SFDR was as large as  $127 \text{ dB-Hz}^{2/3}$ , even taking the 50 ohm output load into account. No change in SFDR was found between simulations with 0% and 40% 1-sigma spreads in critical current distributions. Phase shifters offer great freedom to shape response curves, although the effect on linearity, particularly when parameter variations are taken into account, is not yet clear.

*Supported by the Office of Naval Research*

## 2EPM02

### I-V Characteristics of Superconductive Heterostructure Arrays

*B.G.Ghamsari, A.H.Majedi, University of Waterloo*

There has been recently a growing interest in superconductive heterojunctions such as gate controlled and injection controlled weak-links, with a variety of new applications. Although the properties of single superconductive heterojunctions have been long understood in great details, the properties of arrays of heterojunctions are understood less and only more recently. This paper studies the I-V characteristics of the periodic and aperiodic arrays of superconductive heterostructures, such as S-N, S-Semi and S-I arrays, based on the Bogoliubov-de Gennes (BdG) method for inhomogeneous superconductive structures. Proper boundary conditions are applied to account for the proximity effects at each interface and the Transfer Matrix Method (TMM) is used to formulate the characteristic equation of the array. In the special case of infinite periodic arrays, which is an excellent approximation for finite periodic arrays with many unit cells, the Bloch-Floquet theorem is applied to obtain the closed form for the characteristic equation. The characteristic equation is then solved numerically, in order to find the coherence factors of the heterostructure array as a function of the position, which in turn are employed to obtain the I-V characteristics of the structure under external bias. Characteristics peculiar to the periodic structures such as formation of band gaps and negative resistance regions are explicitly discussed and their applications in optoelectronics and active/passive microwave-photonics are addressed.

## 2EPM03

### High linearity SQIF-like Josephson-junction structures

*V.K.Kornev, I.I.Soloviev, N.V.Klenov, Physics Department, Moscow State University, Moscow, Russia; O.A.Mukhanov, Hypres, Inc., 175 Clearbrook Road, Elmsford, NY 10523, USA*

Recently we have reported an approach to synthesis of multi SQUID structures capable of providing periodic high linearity voltage response [1]. The reported structures were developed mostly to form periodic voltage response. The paper presents possible solutions for multi SQUID structures providing SQIF-like high linearity voltage response. The structure is differential scheme of two SQIFs where one of them is magnetically shifted. In case of the specially formed SQIF response, such a subtraction is able to provide high efficiency compensation of the response deviations from linear low. The developed structure implementations based on both low- and high-temperature superconductor technologies are considered, and possible microwave applications of the structures are discussed. [1] V. K. Kornev, I. I. Soloviev, N. V. Klenov, and O. A. Mukhanov, *Superconducting Science and Technology (SUST)*, v. 20, 2007, p. S362-S366.

*This work was supported in part by CRDF GAP Grant 1493.*

## 2EPM04

### **Josephson current enhancement in a multi-terminal device based on superconductor - insulator- normal metal – insulator – superconductor structure**

*I.P.Nevirkovets, S.E.Shafranjuk, Department of Physics and Astronomy, Northwestern University, Evanston IL 60208, USA; O.Chernyashevskyy, Department of Physics and Astronomy, Northwestern University, Evanston IL 60208, USA; Institute for Metal Physics NASU, 36 Vernadsky Blvd., UA-03680 Kyiv-142, Ukraine; J.B.Kettersen, Department of Physics and Astronomy, Department of Electrical and Computer Engineering, and Materials Research Center, Northwestern University, Evanston IL 60208, USA*

Josephson current is studied in a multi-terminal SINIS (Nb/Al/AIOx/Al/AIOx/Al/Nb) device which has electrical leads connected to a thin middle N (Al) layer. It is found that a current passing through one of the subjunctions (NIS), may stimulate the Josephson current through the other subjunction (SIN) above its steady-state value. A theoretical model is proposed that explains the effect in terms of nonlinear coupling of the two junctions caused by the proximity effect in the N layer, which is controlled by a local supercurrent.

*This work was supported by the National Science Foundation under the grants EIA-0218652 and DMR-0509357; use was made of facilities operated by the NSF-supported Materials Research Center. One of the authors (S.S.) acknowledges support from AFOSR grant FA9550-06-1-0366*

## 2EPM05

### **Development of a scanning laser magneto-optical detection system**

*H.Murakami, R.Kitamura, Osaka University; I.Kawayama, M.Tonouchi, Osaka University, CREST-JST*

Developments of superconductor devices utilizing a magnetic flux quantum, such as a single flux quantum logic circuit and a superconductive quantum-bit device, have attracted much attention as candidates for the next-generation ultrafast operational device. In the present study, to detect the dynamic motion of the local magnetic flux states in a superconductor device, we have developed a scanning laser magneto-optical (MO) imaging and detection system, and carried out primitive studies to evaluate its specific characteristics. In the system, laser is used as an optical source, and linearly polarized laser beam is scanned over a sample surface by using a set of galvanometers. The Faraday rotation signal which intensity is proportional to the local magnetic field is detected by using a photomultiplier, and the temporal photocurrent signal is directly converted into the pixel data without any averaging or integration process. In the MO studies using an YBCO superconductor vortex flow transistor device, we have succeeded in the observation of the magnetic field distribution generated around the control current line with applied current larger than 100 mA and the magnetic field penetration into the device with increasing the external field up to ~50 mT. Furthermore, it was found that the fabricated system has the sensitivity better than 0.1 mT and the spatial resolution less than 500 nm. The details of the fabricated system and the experimental results are presented.

## 2EPM06

### **Novel Coupling Scheme for the Dynamics of Non-Uniform Coupled SQUID**

*P.Longhini, A.Leese de Escobar, F.Escobar, V.In, A.Bulsara, SSC San Diego*

Recently, there is a growing interest in non-uniform coupled SQUID devices in the science community. Similar to how antenna array technology has moved from uniform arrays to non-uniform, sparsely populated arrays, the traditional uniform SQUID arrays evolves to an unconventional structure making these mesoscopic quantum devices (for RF reception) a feasible concept. The focus of this work covers theoretical and numerical computations which exploits well-designed coupling schemes to modeling the dynamics of the device where the behavior of the non-periodic voltage response related to the external flux exhibits an anti-peak which is present only around the zero applied magnetic field. It is known that many nonlinear dynamical systems are highly sensitive to small external perturbations, especially when they are near the onset of a bifurcation. Exploring parameter variations, such as; inductive coupling between neighboring elements, unconventional grating and fabrication parameters may lead to a significant performance enhancement. There are theoretical indications that variations in coupling could provide very high dynamic range. Application of these devices with the ability to detect and amplify will result in a new generation of electrically small antennas.

*We acknowledge support from the Office of Naval Research (Code 30), Steve Pappert in MTO and SPAWAR internal (S&T) program.*

## 2EPM07

### **Three Distinctive Temperatures of N/S Transition Detected by the SFCO-method: their role for proper identification of the nature of superconductivity**

*S.G.Gevorgyan, Yerevan State University, ARMENIA*

A stable tunnel diode oscillator with an unusual single-layer flat coil (SFCO-method) is an excellent MHz-range sensor with which one may study fine effects in SC state, in tiny HTSC. It enables to detect 1pH changes of film's magnetic inductance (2-3A changes of SC penetration depth) with 6 orders relative resolution. Due to pick-up coil's flat design, low operation frequency, so high resolution & an ability of the method to operate in magnetic fields it has advantages over others, which become crucial at non-destructive studies in flat objects with small signals - especially at start of formation of electron pairs. Due to these, a fine 'paramagnetic' peculiarity of N/S transition is detected in YBaCuO film, which proceeds diamagnetic expel. It enabled to reveal also a nano-watt scale absorption of a power by HTSC film upon its transition, with a peak located after the onset of diamagnetic expel - close to its center. Extracted from fluctuation region these 2 subtle effects (1-st precursor, while 2-nd - posterior to Meissner expel) indicate an existence of 3 critical temperatures at N/S transition. Crucial role of these temperatures for true understanding of the real nature of SC-phenomenon is discussed.

*Study was supported by NFSAT and CRDF under Grants ISIPA 01-04 & UCEP 07/07.*

## TUESDAY LATE AFTERNOON ORAL SESSIONS

4:00pm - 6:30pm

### 2EX - Transition Edge Sensors VI – Readout 4:00pm - 5:45pm

4:00pm

#### **2EX01 - Design of TES Detectors for Frequency Domain Multiplexing**

*M.Lueker, B.A.Benson, University of California, Berkeley; C.Chang, Kavli Institute for Cosmological Physics; H.M.Cho, National Institute of Standards and Technology, Boulder CO; M.Dobbs, McGill University, Montreal, Quebec; W.L.Holzappel, A.T.Lee, J.Mehl, T.Plagge, E.Shirokoff, University of California, Berkeley; H.Spieler, Lawrence Berkeley National Laboratory; J.Vieira, Kavli Institute for Cosmological Physics*

In contemporary cosmology experiments, the noise of a single bolometer pixel is dominated by photon statistics. Thus sensitivity can only be improved by increasing the number of pixels observing at a time, and so contemporary TES receivers contain 1000s of pixels. For cryogenic reasons, it is important to limit the thermal load due to the wiring of each TES pixel. Frequency-Domain Multiplexing (fMUX) limits the wiring load by AC-biasing each detector at a unique frequency, and thus many detectors can be read out via the same pair of wires. We will describe the fMUX system, and some of the details associated with TES design for use with the fMUX system. In particular, we will discuss issues related to noise and stability of electrothermal feedback in the context of an fMUX readout, using the detectors built for the South Pole Telescope (SPT) as a case study.

*Development of the fMUX Readout System at Berkeley has been supported by NASA under Grant No. NNG05GD71G. The SPT is supported by the U.S. National Science Foundation under Grant No. OPP-0130612.*

4:15pm

#### **2EX02 - Time-division multiplexing of high-resolution TES microcalorimeters**

*W.B.Dorise, G.C.Hilton, K.D.Irwin, C.D.Reintsema, L.R.Vale, Y.Xu, NIST; C.A.Kilbourne, S.R.Bandler, J.A.King, NASA/Goddard*

Many upcoming instruments will require multiplexed readout of kilopixel-scale arrays of fast transition-edge-sensor microcalorimeters. In the SQUID time-division-multiplexer (TDM) architecture, the TESs are dc biased. Each TES is coupled to its own first-stage SQUID. Rows of first-stage SQUIDs are turned on one at a time. The signal from the active row in each column is passed to a series-array SQUID amplifier, and then to a room-temperature amplifier. A suite of digital-feedback electronics maintains each first-stage SQUID in a linear portion of its sinusoidal flux-to-voltage transfer curve. The last few years have seen the development of very-high-energy-resolution TES microcalorimeters, with best performance of  $\sim 2$  eV (FWHM) for 5.9 keV x rays, and  $\sim 25$  eV for 103 keV gamma rays. Reading out arrays of these detectors has allowed us to probe the performance limits of the TDM architecture. We present data and also extensive numerical modeling of the multiplexed readout of an array of 32 high-resolution 6 keV x-ray TESs. The detectors had critically damped time constants of around 280  $\mu$ s. Important effects to be discussed include aliased SQUID noise, crosstalk, and the dependence of optimally filtered pulse heights on the arrival time of the x-ray pulses in sparsely sampled data.

4:30pm

#### **2EX03 - Readout for Time Domain Multiplexing of 23 TES with SQUID and Integrated Circuit Operating at 4.2 K**

*D.Prele, F.Voisin, M.Piat, E.Breelle, APC; G.Sou, G.Klisnick, M.Redon, LISIF*

The readout of large TES arrays requires the development of ultra low noise amplification and multiplexing electronics operating close to the sensors, at cryogenic temperature. Time domain multiplexing with SQUID transducers creates a part of the cryogenic multiplexing with ultra low noise performances. However, this technique still requires a lot of wires that we propose to reduce drastically by using another multiplexing circuit based on an ASIC operating at 4.2 K. We have designed two ASICs based on standard BiCMOS SiGe technology that has proved to operate at cryogenic temperatures. We report the cryogenic characterisation of the first demonstrator dedicated to the readout of a 2x4 TES array. The results obtained with this first ASIC have shown the possible realisation of such an electronic operating at 4.2 K to reduce drastically the number of wires needed to readout large superconducting detector arrays. We also report on the development of the second version of this circuit to readout a 23 TES array. A new cryogenic amplifier was designed with 3 multiplexing differential inputs and expected improved low frequency noise performances than the previous version. The ASIC also includes adjustable voltage and current references sources for its polarisation. Another part of this circuit is dedicated to the multiplexing current polarisation of 8 SQUIDs.

*The authors are grateful to M. Pairat, D. Broszkiewicz and the collaborations DCMB (CNES) and BSD (P2I).*

4:45pm

#### **2EX04 - A novel single-stage SQUID multiplexer for TES array readout**

*J.Beyer, D.Drung, PTB Berlin*

We introduce a novel SQUID multiplexer (SQMUX) for time-division multiplexing of low impedance cryodetectors such as transition edge sensors and magnetic microcalorimeters. This SQMUX both reduces complexity and improves sensitivity and reliability of addressing for TES array readout. The individual channels in our SQMUX circuit are highly robust and sensitive SQUID series arrays (SSAs) with an input inductance of ca. 3 nH. Several of these SSAs form one column, of which exactly one SSA is active at a time. The addressing of the individual readout channel is performed by means of superconducting-to-normal conducting switching elements which are integrated into the SQMUX circuit. The addressing signal is applied galvanically decoupled in order to avoid complications when row-addressing multiple columns. The SQMUX is at the TES operating temperature. It is directly read out by a room temperature preamplifier. Our first realizations of this single stage SQMUX are 4:1 and 2:2 multiplexers. We achieve a current sensitivity of the active SSA channel in a N-channel-column of ca. 5 pA/rtHz at 100 mK. There is no noise contribution from the off-channels of a column. We present the application of the new SQMUX to read out X-ray TES microcalorimeters and discuss the achievable switching speeds, power dissipation and crosstalk levels.

**5:00pm**

**2EX05 - Single-flux-quantum circuit based readout system for detector arrays by using time to digital conversion**

*A.Bozbey, S.Miyajima, H.Akaike, A.Fujimaki, Dept. of Quantum Engineering, Nagoya University, Nagoya, Japan*

We propose a single-flux-quantum (SFQ) based readout circuit for the transition edge sensor (TES) arrays for X-ray radiation detection. Utilization of SFQ circuits for this purpose enables large-scale integration of TESs due to very high speed processing ability of the received signals and using an already established LSI circuit design environment. We utilize the cooling time dependence of the TES on the incident X-ray energy. Time to digital conversion is made by using an SFQ based quasi-one-junction SQUID (QOS), which works as a 1-bit comparator with an adjustable current threshold level, and an SFQ based high speed counter. The readout system is composed of two separate chips that are connected to each other with polyimide based flexible superconducting wiring. The QOS - MUX chip is directly connected to the TES array and it performs the digital conversion of the TES output. The DEMUX - counter chip, which will be placed at elevated temperatures, receives the multiplexed SFQ pulses and determines the duration of the TES output which is above the predetermined threshold level. Final goal of this work is to readout more than 10k TES pixels and in this paper, feasibility of the system and current status of the development process is demonstrated.

*Ali Bozbey is supported by TUBITAK (Scientific and Technical Research Council of Turkey)*

**5:15pm**

**2EX06 - Do we really need SQUIDs to read out Transition Edge Sensors?**

*M.Galeazzi, D.F.Bogorin, University of Miami; F.Gatti, University of Genoa and INFN Genoa; L.Parodi, INFN Genoa*

In this paper we show that it is possible to read out the signal from Transition Edge Sensors (TES) without using SQUIDs. We propose a simple, fully integrated scheme using only passive components on the cold stage of the refrigerator which gives, essentially, the same performance. Using AC biased TES in an RLC resonant circuit the amplitude of the resonant peak depends linearly on the inverse of the TES resistance. Using typical values of R, L, and C, the resonance is sufficiently strong to bring the TES noise above the noise of a room temperature amplifier used to read out the voltage from the resonant circuit, making the electronics noise negligible and the performance comparable to that of frequency multiplexed SQUIDs. Moreover, as the resonant circuit is simply made of inductors and capacitors, it can be fully integrated on the detector chip, or on a separate chip on the cold stage of the refrigerator. We report the results of both our theoretical and experimental work, showing that, in fact, we can measure TESs without any degradation in performance.

**5:30pm**

**2EX07 - Input Noise of Microwave Frequency-Division SQUID Multiplexers**

*J.A.B.Mates, NIST / Univ. of Colo. Boulder; G.C.Hilton, K.D.Irwin, L.R.Vale, NIST; K.W.Lehnert, JILA / NIST / Univ. of Colo. Boulder*

The bandwidth available at microwave frequencies can enable readout of future ultra large arrays of TES detectors. To utilize this

bandwidth we couple dissipationless rf SQUIDs to high-Q superconducting microwave resonant circuits for frequency-division multiplexing. Signal currents from existing TES detectors can modulate the SQUIDs and thereby modulate the resonators' response to microwave signals within their bands. We have demonstrated successful readout of SQUIDs coupled to sufficiently high-Q resonators to multiplex thousands of detector signals onto just a few wires. We have shown sufficiently low flux noise for TES noise to dominate at typical input couplings. We present our continuing work on modulation schemes, minimization of system noise, and multiplexability.

**2EY - Nanowire Detectors – II 4:00pm - 5:45pm**

**4:00pm**

*Invited*

**2EY01 - Performance of ultrafast superconducting single photon detector with photon number resolving capability**

*G.Goltsman, A.Divochiy, M.Tarkhov, A.Korneev, O.Minaeva, I.Golenischeva, M.Elezov, K.Smirnov, Yu.Vachtomin, N.Kaurova, V.Seleznev, B.Voronov, Moscow State Pedagogical University*  
Superconducting single-photon detectors (SSPDs) are nanodevices patterned from 4-nm-thick NbN films as meander-shaped 500-um-long and 100-nm-wide stripes. The SSPDs exhibit excellent performance parameters in the visible-light to near-infrared radiation wavelengths: quantum efficiency of the best devices approaches a saturation level of ~30% limited by the NbN film optical absorption, and dark counts rate as low as  $2 \times 10^{-4} \text{ s}^{-1}$ . The advanced NbN SSPDs which features subnanosecond response time due to low kinetic inductance and photon number resolving capability consist of several meander-shaped nanowires connected in parallel and covering 10um x 10um active area. We present result of our investigation of the photoresponse pulse duration vs number of parallel sections which is in subnanosecond range. The same SSPDs exhibited the dependence of the photoresponse amplitude on the number of simultaneously detected photons providing photon number resolving capability. These devices were implemented in a two channel receiver system.

**4:30pm**

**2EY02 - Measuring Photon Statistics with Multi-element Superconducting Nanowire Single Photon Detectors**

*E.A.Dauler, MIT; MIT LL; M.J.Stevens, B.Baek, S.W.Nam, R.P.Mirin, NIST; R.Molnar, A.J.Kerman, J.K.W.Yang, MIT LL; K.K.Berggren, MIT*

Multi-element superconducting nanowire single photon detectors (MESNSPDs) are capable of not only detecting the presence of a single photon, but resolving the number of photons in an optical pulse. This feature makes MESNSPDs useful for measuring the photon statistics of various light sources such as coherent, thermal and single-photon sources. The low timing jitter (*This work is sponsored in part by the United States Air Force under Air Force Contract #FA8721-05-C-0002. Opinions, interpretations, recommendations and conclusions are those of the authors and are not necessarily endorsed by the United States Government.*

4:45pm

**2EY03 - Superconducting nanowire photon number resolving detector at telecom wavelength**

*F.Marsili, IPEQ, EPFL; D.Bitauld, A.Fiore, COBRA Research Institute, TU/e; A.Gaggero, M.Mattioli, R.Leoni, IFN-CNR; M.Benkahoul, F.Levy, IPMC, EPFL*

We present a new photon number resolving detector (PNR), the Parallel Nanowire Detector (PND) [1], which uses spatial multiplexing on a subwavelength scale to provide a single electrical output proportional to the photon number. The basic structure of the PND is the parallel connection of several NbN superconducting nanowires (~100 nm-wide, few nm-thick). Electrical and optical models were developed in order to understand its working principle. PNDs were fabricated on 3-4 nm thick NbN films grown on sapphire (substrate temperature TS=900°C) or MgO (TS=400°C) substrates by DC reactive magnetron sputtering. The photoresponse pulse is as short as 660ps (full width at half maximum). Counting performance was observed up to 80 MHz repetition rate. Building the histograms of the photoresponse peak (the present counting capability is of six photons), no multiplication noise is observable and the one photon quantum efficiency can be estimated to be 3% (at 700 nm wavelength and 4.2 K temperature). The PND significantly outperforms existing PNR detectors in terms of simplicity, sensitivity, speed, and multiplication noise. [1] A. Divochiy et al., Nature Photon., to be published (2008).

5:00pm

**2EY04 - Large signal superconducting single photon detectors**

*M.Ejrnaes, C.N.R.-Inst. of Cybernetics; A.Casaburi, C.N.R.-Inst. of Cybernetics; Univ. of Salerno, Dept. of Physics; O.Quaranta, S.Marchetti, Univ. of Salerno, Dept. of Physics; F.Mattioli, A.Gaggero, R.Leoni, R.Cristiano, C.N.R.-Inst. of Photonics and Nanotechnologies; S.Pagano, Univ. of Salerno, Dept. of Physics; C.N.R.-Inst. of Cybernetics*

A new parallel configuration of ultra-thin NbN nano-wires for detection of single infrared photons has recently shown to output larger signal pulses [1]. In this detector the increase in signal amplitude is due to a photon that induces a cascade switch of all the parallel nano-wires. Here we report on the fabrication, characterization and optical illumination of our second generation of detectors based on parallel nano-wires. The ultra-thin NbN film have been obtained by DC magnetron sputtering at room temperature. The detectors all use 24 nano-wires covering a 5x5 square micron area in various configurations, ranging from blocks of 4 to 24 wires in parallel. In particular, for the latter detector we measured a signal pulse amplitude of 4 mV with a signal to noise ratio of 52 for detection of single infrared photons. We believe this is the best value obtained so far for superconducting single photon detectors. [1] M. Ejrnaes et al, Appl. Phys. Lett., Vol 91, 262509 (2007)

5:15pm

**2EY05 - Niobium Nanowire Single-Photon Detectors**

*A.J. Annunziata, D.F. Santavicca, J. Chudow, Yale Univ.; M.J. Rooks, IBM Watson Research Center; L. Frunzio, Yale Univ.; A. Frydman, Bar Ilan University; D.E. Prober, Yale University*

We have fabricated and tested optical single-photon detectors based on a current-biased superconducting nanowire meander made from ultra-thin, pure Nb films. Single photon counting performance is shown with good quantum efficiency from the UV into the visible range. We report the reset time, jitter, and dark count rate for single photon detection in the visible, and discuss limitations on the sensitivity for longer wavelengths.

We compare these results to reports for NbN detectors and show Nb to be a viable alternative with some specific advantages. Potential applications include VLSI circuit diagnostics, quantum communication, and single molecule spectroscopy.

*This work is supported by NSF – EPDT (GOALI) and IBM research.*

5:30pm

**2EY06 - Application of superconducting single photon detector technology to practical quantum key distribution systems**

*B.Baek, S.W.Nam, National Institute of Standards and Technology; D.Rosenberg, J.E.Nordholt, Los Alamos National Laboratory; H.Takesue, NTT Corporation; Y.Yamamoto, Stanford University and National Institute of Informatics; M.Sasaki, A.Tomita, National Institute of Information and Communications Technology*  
Quantum Key Distribution (QKD) offers a provably secure way to exchange secure cryptographic keys based on quantum information technology. Optical fiber offers a practical QKD channel of remarkable quality that significant effort is being devoted to develop optical-fiber-based QKD systems. Superconducting single photon detectors (SSPDs) have enabled the demonstration of QKD systems that are more practical than early demonstrations. We will describe the use of our SSPD system in various QKD architectures such as decoy-state BB84, DPS-QKD, entanglement-based QKD, and BB84 in underground fiber. We will also present how the unique properties of the SSPDs such as their low-jitter and sensitivity at 1550nm are critical in the implementation of various practical QKD systems.

**2EZ - Circuits for Digital Applications 4:00pm - 6:00pm**

4:00pm

*Invited*

**2EZ01 - Demonstration of an SFQ-Based Accelerator Prototype for a High-Performance Computer**

*A.Fujimaki, S.Iwasaki, K.Takagi, R.Kasagi, I.Kataeva, H.Akaike, M.Tanaka, N.Takagi, Nagoya Univ., CREST-JST; N.Yoshikawa, Yokohama Univ., CREST-JST; K.Murakami, Kyushu Univ., CREST-JST*

We have demonstrated an accelerator prototype based on a reconfigurable data path (RDP) architecture utilizing ultra high-speed, ultra low-power SFQ circuits toward a 10 TFLOPS desk-side computer. The RDP is composed of many stages of the array of floating-point units (FPUs) connected by operand routing networks (ORNs). In general, all the FPUs in the RDP have shift registers (SRs) to forward data to the next stage. The data-path is reconfigured so as to reflect a long series of instructions appearing in a loop of large-scale calculations. We can implement parallel and pipelined processing without memory access, reducing the required band width between a memory and a processor. The SFQ high-speed network switches and bit-serial/slice FPUs realize reduction in the circuit areas and in the power consumption compared to semiconductor devices. We have successfully demonstrated reconfiguration in a 2x2 RDP accelerator prototype composed of double arrays of dual bit-serial 5-function arithmetic logic units. The prototype also has dual 5-bit SRs in each array and four 4:3-ORNs. The prototype chips are prepared based on the SRL standard process and made up of 10839 junctions including circuits for high-speed testing. We currently examine a larger-scale, 26k-JJ 4x4 RDP accelerator.

4:30pm

**2EZ02 - A high-throughput single-flux-quantum floating-point serial divider using the signed-digit representation**

*M.Tanaka, K.Obata, K.Takagi, N.Takagi, A.Fujimaki, Nagoya University, CREST-JST; N.Yoshikawa, Yokohama National University, CREST-JST*

We propose a floating-point serial divider for the single-flux-quantum (SFQ) logic implementation with extremely high throughput and low latency. It is based on the non-restoring division algorithm. We employ the radix-2 signed-digit (SD2) representation with a digit set of  $\{-1, 0, 1\}$ , by which we can perform an addition/subtraction without carry/borrow propagation. As a result, a fast division is performed by digit-serial calculation from the most significant bit. The divider is implemented with a regularly aligned pipeline structure called a systolic array. A serial division takes approximately  $6N$  clocks and the next operation can be started after  $(N + 3)$  clocks, where  $N$  is the length of the significand. The throughput is almost maximized in the serial processing, and as high as those of floating-point serial adder and multiplier. The latency is only three times higher, while several tens of times in general processors. We have designed and tested a processing element (PE) of the divider. It computes a partial remainder and one bit of quotient. The PE is composed of a subtractor, an absolute value calculator, and a sign detector of a SD2 number, and occupies a  $0.76 \times 0.72 \text{ mm}^2$  area. We have confirmed the correct operations at low-speed with a bias current margin of 25%. We are designing a 25-GHz half-precision floating-point divider ( $N=11$ ) and will test it at high frequencies.

4:45pm

**2EZ03 - Design and Implementation of SFQ Half-Precision Floating-Point Multipliers**

*H.Hara, H.Park, Y.Yamanashi, K.Taketomi, N.Yoshikawa, Yokohama National University; K.Obata, M.Tanaka, N.Takagi, K.Takagi, A.Fujimaki, Nagoya University; S.Nagasawa, ISTECSRL*

We are developing a large-scale reconfigurable data path (LSRDP) using single-flux-quantum (SFQ) circuits as a fundamental technology for future high-end computing systems, which overcomes the power-consumption and memory-wall problems in CMOS microprocessors. An SFQ LSRDP system is composed of several thousands of SFQ floating-point units that are connected by reconfigurable SFQ switch networks to achieve high-performance calculations with low power consumption. In this study, we have designed and implemented SFQ floating-point multipliers (FPM), which are one of the components of the SFQ LSRDP. We have designed a systolic-array-type bit-serial half-precision FPM using  $2.5 \text{ kA/cm}^2 \text{ Nb}$  process. Resultant circuit area and the number of junctions are  $6.22 \times 3.78 \text{ mm}^2$  and 11044, respectively. The designed clock frequency is 25 GHz. We have tested the circuit and confirmed the correct operation of the 5-bit exponent part of the circuit at present. In addition, we have also tested a 4-bit systolic-array multiplier, which is a circuit component of the FPM, and confirmed its correct operation at low speed. We will present on-chip high-speed test results of the whole FPM system at the conference. This research was supported by CREST, Japan Science and Technology Agency.

5:00pm

**2EZ04 - A two-bit asynchronous switch matrix**

*A.F.Kirichenko, S.Sarwana, D.Gupta, HYPRES*

We have designed a multi-bit switch matrix for routing of digitized data streams from analog-to-digital converters (ADCs) to digital signal processors. A  $2 \times 2$  version of the two-bit switch was designed and fabricated at HYPRES's standard  $4.5 \text{ kA/cm}^2$  fabrication process. The switch was successfully tested and demonstrated at high speed.

5:15pm

**2EZ05 - Multi-purpose ADC utilizing switch matrix**

*A.F.Kirichenko, P.N.Shevchenko, A.Sahu, D.E.Kirichenko, S.Sarwana, HYPRES*

We have developed a multi-rate multi-band ADC. The ADC consists of a low-pass front-end, band-pass front-end, digital mixer, two deserializers with amplifiers, and a  $2 \times 2$  switch matrix, which provides routing of the data between ADC's components. All digital post processing, as well as data acquisition, is performed by FPGA interface. The ADC is designed on a  $1 \times 1 \text{ cm}$  chip. The chip was fabricated at HYPRES's standard  $4.5 \text{ kA/cm}^2$  process. The ADC has allowed us to measure noise produced by on-chip digital mixing and directly compare it to the noise produced by poly-phase algorithm in the FPGA.

5:30pm

**2EZ06 - Design and High-Speed Test of a Radix-2 Butterfly Unit for the Fast Fourier Transform Using SFQ Circuits**

*K.Taketomi, Y.Yamanashi, H.Park, N.Yoshikawa, Department of Electrical and Computer Engineering, Yokohama National University; A.Fujimaki, Department of Quantum Engineering, Nagoya University; Y.Hashimoto, SRL-ISTEC; H.Terai, NICT*

The fast Fourier transform (FFT) is widely used in large-scale data processing, real-time image processing, wireless communications and so on. We are developing high-speed FFT processors using single-flux-quantum (SFQ) circuits for real-time image processing in 2D and 3D X-ray CT. Since the FFT processor consists of many complex multipliers and adders, the large power consumption is very serious problem in CMOS FFT processors. The SFQ FFT processor has potential to solve the problem because of its ultra-low power consumption and high-speed operation. In this paper we have developed a radix-2 butterfly unit for the SFQ FFT processor. The FFT operation can be divided into a 2D array of butterfly operations, which are performed by complex-number multiplications, additions, and subtractions. We have designed an 8-bit bit-serial butterfly operation unit and evaluated the circuit performance assuming the  $2.5 \text{ kA/cm}^2 \text{ Nb}$  process. We have implemented the 8-bit butterfly unit using the SRL standard  $2.5 \text{ kA/cm}^2 \text{ Nb}$  process. The total junction number is 11339. On-chip high-speed test results of the circuit will be shown at the presentation.

5:45pm

**2EZ07 - An Operand Routing Network for an SFQ Reconfigurable Data-Paths Processor.**

*I.Kataeva, H.Akaike, A.Fujimaki, Nagoya University; N.Yoshikawa, Yokohama National University; N.Takagi, Nagoya University; K.Inoue, H.Honda, K.Murakami, Kyushu University*

This paper presents results of the development of an operand routing network (ORN) for an SFQ reconfigurable data-paths processor (SFQ-RDP). SFQ-RDP consists of a two-dimensional array of floating-point units (FPU), outputs of which can be connected to the inputs of one or more FPUs via operand routing networks (ORN). We consider two possible implementations of the ORN: one is based on multiplexers and the other – on crossbar switches. The performance and complexity of the ORN architectures have been compared. Despite a large number of Josephson junctions, the main advantage of the crossbar-based ORN is a pipelined structure that allows high throughput and does not limit the performance of the FPUs. We have designed a crossbar switch with a broadcasting function using CONNECT cell library. It contains 788 Josephson junctions, requires a bias current of 87 mA and occupies an area of  $1.28 \text{ mm} \times 1.0 \text{ mm}$ . The designed operating frequency is equal to 27 GHz and the circuit has been experimentally tested at the frequencies up to 28.2 GHz. We also plan to present results of the measurements of the 1:4 ORN. *The work is supported by CREST-JST.*

## **WEDNESDAY, AUGUST 20, 2008**

### **WEDNESDAY MORNING ORAL SESSIONS**

**10:00am - 12:00pm**

#### **3EA - Transition Edge Sensors VII – Applications**

**10:00am - 12:00pm**

**10:00am**

##### **3EA01 - The South Pole Telescope SZ survey detectors**

*E. Shirokoff, B.A. Benson, University of California, Berkeley; C. Chang, Kavli Institute for Cosmological Physics, University of Chicago; H.M. Cho, National Institute of Standards and Technology, Boulder, CO; M. Dobbs, McGill University, Montreal, Quebec, CA; W.L. Holzapfel, A.T. Lee, M. Lueker, J. Mehl, T. Plagge, University of California, Berkeley; H. Spieler, Lawrence Berkeley National Laboratory; J. Vierra, Kavli Institute for Cosmological Physics, University of Chicago*

We will discuss the design, fabrication, and testing of a 960-element TES array installed on the new 10 meter South Pole Telescope (SPT). This array is designed to survey for galaxy clusters using the Sunyaev-Zel'dovich (SZ) effect, which is the inverse-Compton scattering of Cosmic Microwave Background photons by plasma bound to clusters of galaxies. The SPT bolometer array consists of fully lithographed spider-web absorbers fabricated on adhesive-bonded silicon wafers with an embedded metal back plane. The absorbers are connected to aluminum-titanium bilayer TESes with a transition temperature of approximately 500 mK. Additional normal-metal features adjust the devices' thermal properties to suit our readout system and observational strategy. The focal plane is cooled using a commercial, closed cycle, pulse-tube refrigerator and a three-stage helium sorption refrigerator with a base temperature of 250 mK. *The SPT is supported by the U.S. National Science Foundation under Grant No. OPP-0130612.*

**10:15am**

##### **3EA02 - Performance Statistics from the Atacama Cosmology Telescope Kilopixel Transition Edge Sensor Arrays**

*S.T. Staggs, Princeton University; A.C.T. Collaboration, various*  
The Atacama Cosmology Telescope (ACT) project has deployed three arrays of 32x32 close-packed free-space coupled Transition Edge Sensor (TES) bolometers for observations of the fine-scale structure in the cosmic microwave background sky. The operating frequencies of the three arrays are defined by filters at 145, 215 and 280 GHz, respectively. The transition edge sensors were designed and fabricated at Goddard Space Flight Center (GSFC). We report on how variations in parameters measured for the devices before their installation into arrays impacted the operability and performance of the arrays. Directly measured parameters include transition temperatures, normal resistances, saturation powers, and noise spectra.

*With thanks to the ACT Collaboration.*

**10:30am**

##### **3EA03 - Electrical and Thermal Characterization of Membrane-Isolated, Antenna-Coupled, TES Bolometers for the Spider Experiment**

*J.A. Bonetti, P. Day, M. Kenyon, A. Turner, H.G. LeDuc, Jet Propulsion Lab / Caltech; C.L. Kuo, Stanford University; J.J. Bock, Jet Propulsion Lab / Caltech*

We have fabricated and characterized the transition-edge-sensors (TES's) to be employed on the Spider experiment, a balloon-based observatory for studying the polarization of the cosmic microwave background (CMB). Several important parameters were measured. Transition temperature measurements were performed by measuring the Johnson noise in the Ti thermistor. Current-voltage characteristic measurements were carried out at various temperatures allowing for the deduction of the thermal conductance between the TES island and substrate. Electrical noise equivalent power was measured to sub-Hertz frequencies. In addition, noise properties with and without normal metal bars (zebra stripes) were investigated. Finally, the time constant of the devices was measured within the Al and Ti transitions where electrothermal feedback speeds up the bolometer response. This time response is compared with the natural time constant measured just above the Ti transition temperature. The results are within the design specifications for Spider.

*We would like to thank the Gordon and Betty Moore Foundation for support. The research described in this publication was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.*

**10:45am**

##### **3EA04 - Response time and sensitivity of transition-edge sensing bolometers suitable for space-borne far-IR/submillimeter spectroscopy**

*M. Kenyon, P.K. Day, C.M. Bradford, J.J. Bock, H.G. LeDuc, Jet Propulsion Laboratory*

To meet the challenging detector requirements for the Background-Limited far-IR/Submillimeter Spectrograph (BLISS), a proposed NASA instrument, we built transition-edge sensing bolometers (TESs) designed so their response time ( $\tau$ ) and noise equivalent power (NEP) are less than 100 ms and  $5 \times 10^{-20}$  W/Hz, respectively. Each TES consists of a Mo/Au bilayer patterned onto a suspended, thermally isolated absorber that is connected to the substrate through four SixNy beams. By reducing the thermal mass of the absorber, making the thermal conductance G of the support beams very small, and tuning the transition temperature T<sub>c</sub> of the Mo/Au bilayer to about 60mK, our measurements show that these TESs are suitable for BLISS.

*This research was carried out at the Jet Propulsion Laboratory and Caltech under contract with the National Aeronautics and Space Administration*

11:00am

**3EA05 - Measurements and Design of a Transition-Edge Hot-Electron Microbolometer for Millimeter-wave Astrophysical Observations**

*E.M.Barrentine, P.T.Timbie, University of Wisconsin-Madison; T.R.Stevenson, NASA Goddard Space Flight Center; S.Ali, Lawrence Livermore National Laboratory; W.T.Hsieh, K.U-Yen, K.Denis, J.A.Chervenak, S.H.Moseley, E.Wollack, C.A.Allen, A.D.Brown, N.Cao, T.M.Müller, T.Travers, NASA Goddard Space Flight Center*

Future experiments to probe the Cosmic Microwave Background (CMB) polarization will need arrays of 1000s of sensitive bolometers. We are developing a Transition-edge Hot-electron Microbolometer (THM) to fill this need. This small-volume bolometer consists of a superconducting bilayer Transition-Edge Sensor (TES) and a thin-film absorber. The THM employs the decoupling between electrons and phonons at mK temperatures to provide thermal isolation. The devices are fabricated photolithographically and are read out by SQUIDs. We present the details of a thermal model for a test THM with a Mo/Au TES and Bi/Au absorber which conforms to noise, responsivity, and thermal conductance measurements. We also present the design of a new thermally optimized antenna-coupled THM for illumination by an RF source. We hope to report initial measurements of these new devices, which are designed to reach photon-noise-limited levels.

11:15am

**3EA06 - GISMO, a 2 mm TES-Based Bolometer Camera Optimized for the Study of High Redshift Galaxies**

*J.G.Staguhn, Univ. of MD & NASA/GSFC; D.J.Benford, C.A.Allen, S.H.Moseley, NASA/GSFC; E.H.Sharp, GST & NASA/GSFC; T.J.Ames, NASA/GSFC; R.G.Arendt, D.J.Fixsen, Univ. of MD & NASA/GSFC; S.F.Maher, SSAI & NASA/GSFC; T.M.Miller, Muniz & NASA/GSFC; E.J.Wollack, NASA/GSFC*

We have developed key technologies in an architecture to enable highly versatile, kilopixel, infrared through millimeter wavelength bolometer arrays. The Backshort-Under-Grid (BUG) array consists of three components: 1) a transition-edge-sensor (TES) based bolometer array with background-limited sensitivity and high filling factor, 2) a quarter-wave reflective backshort grid providing high optical efficiency, and 3) a superconducting bump-bonded large format Superconducting Quantum Interference Device (SQUID) multiplexer readout. In November of 2007 we demonstrated a monolithic 8x16 array with 2 mm-pitch detectors in the field using our 2 mm wavelength imager GISMO (Goddard IRAM Superconducting 2 Millimeter Observer) at the IRAM 30 m telescope in Spain for astronomical observations. We anticipate to obtain more astronomical observations on a second run at in Spring of 2008. We will present results demonstrating the instrument performance under real observing conditions.

*This work was supported in part by NSF Grant AST 0705185.*

11:30am

**3EA07 - Submillimeter Antenna-Coupled Hot-Electron Direct Detectors**

*B.Karasik, Jet Propulsion Laboratory*

Superconducting Hot-Electron Direct Detector (HEDD) is a promising approach for meeting sensitivity needs of future submillimeter space missions. Our recent results with submicron-size titanium HEDD have demonstrated the feasibility of the record low NEP  $< 10^{-20}$  W/Hz<sup>1/2</sup> at 50 mK and NEP  $< 10^{-17}$  W/Hz<sup>1/2</sup> at 370 mK. The on-going laboratory development is aimed at the optical NEP measurements and demonstration of the single THz photon detection. Whereas the most sensitive regimes (moderate resolution spectroscopy in space, R~1000) require a few-Kelvin background, the background limited performance of micron-size HEDDs on ground based and suborbital platforms can be achieved at ~ 300 mK. The studied HEDD devices are coupled to spiral or twin-slot planar antennas. The optical response is measured using a cryogenic black body source (1.5-20 K) and a set of bandpass and highpass filters. The output noise and its bandwidths are studied and compared with the bolometric model. We will also present a concept of the HEDD spectral imager intended for the moderate resolution spectroscopy at THz frequencies. The HEDDs will be embedded into single-mode waveguides and be integrated into a ~ 1000-pixel array of micromachined Si horn antennas for frequencies up to 2 THz. For higher frequency coverage (up to 10 THz), spiral antennas will be used. Multiplexing of fast HEDDs (1  $\mu$ s) will be done using a microwave SQUID based multiplexer.

*This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.*

11:45am

**3EA08 - Development of low-G TES-bolometers for SPICA**

*H.F.C.Hoeyers, M.P.Bruijn, B.P.F.Dirks, P.A.J.de Korte, A.M.Popescu, M.L.Ridder, J.R.Gao, P.D.Mauskopf, SRON Netherlands Institute for Space Research; D.Morozov, Department of Physics and Astronomy, Cardiff University, UK; S.Withington, Cavendish Laboratory, Cambridge, UK*

We describe the development of low thermal conductance (G) bolometers for use in instruments on future cooled FIR space telescopes, such as the European SPICA Instrument. The design goal for a FIR-Fourier transform spectrometer on SPICA is an optical NEP of  $10^{-19}$  W/rt[Hz] in combination with a time constant of 10 ms. At present, an electrical NEP of  $10^{-18}$  W/rt[Hz] and a time constant of 0.2 ms are observed at T<sub>c</sub> = 205 mK. We discuss the design, production and performance of TES-based bolometers with silicon nitride thermal isolation. The excess heat capacity observed by JPL in their low-G bolometers at 100 mK is not seen in the SRON devices which have, until now, an operating temperature of 205 mK. Further work is ongoing to evaluate the performance at 100 mK. Apart from the above empirical approach, we will also address the design of compact low-G TES bolometers from a fundamental point of view.

**3EB - Marc Feldman Quantum Computing Session**  
**10:00am - 12:00pm**

**10:00am**

**Invited**

**3EB01 - Remembering Marc Feldman**

*A.Kleinsasser, Jet Propulsion Laboratory/Caltech;*  
*A.Lichtenberger, University of Virginia*

Our colleague Marc J. Feldman was diagnosed with lung cancer last November and died on December 4, 2007. Marc was a creative scientist who bridged the gap between theory and experiment, particularly in superconducting electronics. at UC Berkeley, Chalmers University, NASA/Goddard Institute for Space Studies, the University of Virginia, and the University of Rochester, Marc made fundamental and influential contributions in many areas, including Josephson parametric amplifiers, RSFQ logic, and quantum computing. His work constituted the basic underpinnings of Josephson array voltage standards and SIS heterodyne mixers. Recently Marc turned his attention to room temperature "ballistic electronics," leading a team that envisioned room temperature transistors employing electrostatic control of electrons in a 2D electron gas. His group demonstrated transistor action in such devices just before his death. Marc balanced his professional life by being a devoted husband to his wife Susan and father to his sons Lucas and Benjamin. Those who knew Marc well will remember his characteristic jeans and clogs, a black Filipino cigarette in one hand, a long hold-time stainless steel coffee dewar in the other, and a copy of the current New Yorker in his back pocket. On very hot days he often resorted to evaporative cooling by means of a wet handkerchief on his head. Marc is still vividly remembered by colleagues for his enthusiastic observation of, and interest in, the entire world around him.

**10:30am**

**3EB02 - Design and Study of Low-loss Superconducting Resonators**

*J.M.Sage, MIT Lincoln Laboratory*

I report on progress made toward the design and measurement of high-Q superconducting coplanar waveguide resonators and discuss the potential for their application in quantum information science. The resonators are fabricated by depositing and patterning Nb films on Si/SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> substrates. They are measured in a 3He refrigerator capable of reaching temperatures as low as 300 mK; Q values in excess of 10<sup>6</sup> are observed. The resonators are measured as the temperature and incident power are varied. An anomalous dependence of the resonator loss and resonance frequency on temperature and power is observed. The results are consistent with the presence of quantum systems in the substrate.

**10:45am**

**3EB03 - Loss in superconducting microwave resonators due to vortices**

*C.Song, T.W.Heitmann, M.P.DeFeo, K.Yu, B.L.T.Plourde, Syracuse University; R.McDermott, University of Wisconsin*

Vortices trapped in superconducting traces can result in substantial reductions in the quality factor of microwave resonators. Understanding this dissipation mechanism can be important in the design of superconducting qubits. We present a design for a system of microwave resonators for studying the loss contributed by trapped flux over the frequency range from 2 - 12 GHz.

This consists of a multiplexed set of quarter-wave superconducting resonators with a wide range of lengths that are capacitively coupled to a common superconducting feed-line. By cooling the resonators in different magnetic fields, we are able to probe the loss from vortices as a function of field at the resonance frequencies contained in our design.

*\*Supported by NSF DMR-0547147*

**11:00am**

**3EB04 - A Tunable Josephson Junction Resonator as a Cavity Bus for Mediating Quantum Information**

*J.A.Strong, F.Altomare, K.Cicak, A.J.Sirois, J.D.Whittaker, NIST; K.D.Osborn, Laboratory for Physical Sciences and UMD Department of Physics; R.W.Simmonds, NIST*

Several recent experiments have coupled high quality superconducting cavities with fixed frequencies to tunable superconducting quantum bits (qubits). Such cavities have been used successfully to perform quantum non-demolition (QND) measurements of the qubit state and as a bus for exchanging quantum information between two qubits (Sillanpaa et al, Nature 449, 438 (2007), Majer et al, Nature 449, 443 (2007)). Here we present a tunable Josephson Junction Resonator (JJR) which acts as a cavity with a tunable frequency to be used in similar experiments. The ability to tune the cavity frequency allows us to mediate qubit interactions between any number of two-level systems (qubits) whose frequencies are fixed. This includes two-level system defects found inside the Josephson junction tunnel barrier. The JJR can be used to perform QND measurements on these two-level systems in order to investigate their coherent properties directly. We will describe our efforts for fabricating and measuring these tunable JJR devices.

*We thank IARPA and NIST for funding this project.*

**11:15am**

**3EB05 - Superconducting Resonators Containing Amorphous and Microcrystalline SiNx**

*K.D.Osborn, H.Paik, Laboratory for Physical Sciences and University of Maryland*

Amorphous interlayer dielectrics cause a loss of coherence in superconducting quantum circuits. These dielectrics are typically grown below 100 C in the community, and the loss tangent is described by a bath of two-level systems. The origin of the two-level systems can be related to the amorphous structure of the film, and therefore a microcrystalline film may exhibit lower loss. We have grown SiNx films with high-density plasma chemical vapor deposition (HDPCVD) on substrates at a temperature of 300 C with different stoichiometries. The films systematically show a different stress and microstructure, and we are in the process of quantitative measurements of the microcrystallinity. We have fabricated these films within the capacitors of superconducting circuit resonators. Data will be presented on the loss tangent measurements of these resonators at the low temperatures and electric fields relevant for superconducting qubits.

*This research was supported by the National Security Agency.*

11:30am

**3EB06 - Low-Loss Vacuum-Gap Capacitors for Superconducting Qubits and High-Q LC-Resonators**

*K.Cicak, M.S.Allman, D.Li, NIST, Boulder, CO; K.D.Osborn, presently at LPS, College Park, MD; A.J.Sirois, J.A.Strong, R.W.Simmonds, NIST, Boulder, CO*

On-chip signal loss is known to plague many high frequency devices which implement lossy dielectrics in capacitors and insulating layers. Using standard lithography techniques we have developed superconducting vacuum-gap capacitors with loss-tangents of  $4 \times 10^{-5}$  at 6 GHz, significantly lower than in capacitors with dielectrics such as SiO<sub>2</sub> and SiN<sub>x</sub> at mK temperatures. These capacitors improve superconducting phase qubits where spurious two-level systems in dielectrics cause decoherence and lower the visibility of qubit states. Our vacuum-gap technology can be used to fabricate on-chip wiring crossovers without insulators and vacuum suspended Josephson junctions spatially isolated away from lossy dielectrics. Furthermore, we have investigated the possibility of frequency multiplexing superconducting LC resonators that utilize our capacitors for potential applications in wide bandwidth photon detectors. Our low-loss capacitors ensure a high-Q for each individual resonator leading to a measurement system with high spectral resolution. In addition, the footprint of a vacuum-gap capacitor is at least ten times smaller than a comparable capacitor formed using planarized inter-digitated fingers. This, along with a high spectral resolution, allows for an order of magnitude improvement in the number of multiplexed resonators per unit area of the measurement system.

11:45am

**3EB07 - Quantization of Mesoscopic LC Circuit and Transmission Line Including Josephson Junctions**

*J.Amirloo, A.H.Majedi, University of Waterloo*

Recent progress in Circuit Cavity Quantum Electrodynamics (CQED) and solid state quantum information processors stimulates theoretical and experimental investigations on the quantum properties of electrical circuits. In these applications, Josephson Junctions (JJs) as the most important nonlinear electronic components are integrated into either a lumped RLC circuit or a conventional transmission line. We investigate the energy, flux and charge quantization and circuit decoherence of the conventional JJ-loaded RLC circuit and the discrete JJ transmission line. In the JJ-loaded RLC circuit we will show how the displaced squeezed number state that is inherent to RLC circuits can be engineered by the nonlinearity in JJ. The possibility of having persistent current or Coulomb blockade regimes are investigated. Our systematic approach is then applied to both discrete JJ right-handed and left-handed transmission lines to show how the quantized flux or energy is propagating or diffusing along the finite JJ transmission line. The propagation and attenuation constants for propagation and diffusion regimes are determined and the properties of such transmission lines, such as dispersion relationship and group velocity will be discussed.

**3EC - Nanowire Detectors – III 10:00am - 12:00pm**

10:00am

*Invited*

**3EC01 - Electrothermal Feedback in Superconducting Nanowire Single-Photon Detectors**

*A.J.Kerman, MIT Lincoln Laboratory; J.K.W.Yang, E.A.Dauler, K.K.Berggren, MIT Research Laboratory of Electronics*

One of the most important features of superconducting nanowire single-photon detectors (SNSPDs) is their high speed, which enables applications such as high data rate, high-sensitivity optical communications, spectroscopy of ultrafast quantum phenomena, and quantum key distribution. In the past, this fast photoresponse has been explained solely in terms of microscopic nonequilibrium behavior; however, equally important is the macroscopic interaction of the device

with the load of its readout circuit, which can be described in terms of electrothermal feedback, and which modifies this behavior. In a correctly functioning SNSPD, the feedback is relatively slow (~ns) and consequently highly unstable, and is responsible only for restoring the device to the superconducting state after it has detected a photon. However, if faster reset times are desired, the feedback must be made faster; this eventually results in stable negative feedback and the phenomenon known as “latching” where the device is locked into a state with a stable non-superconducting hotspot. In addition, speeding up the negative feedback more efficiently counteracts the device’s response to a photon, and may affect the timing jitter. This work is sponsored by the United States Air Force under Air Force Contract #FA8721-05-C-0002. Opinions, interpretations, recommendations and conclusions are those of the authors and are not necessarily endorsed by the United States Government.

10:30am

**3EC02 - SQUID-Readout for the Superconducting Nanowire Single-Photon Detector**

*A.D.Semenov, H.-W.Huebers, DLR Institute of Planetary Research, Germany; A.Kirste, T.Schurig, PTB (German National Metrology Institute); K.S.Ilin, M.Siegel, Institute for Micro- und Nanoelectronic Systems, University Karlsruhe, Germany*

Superconducting single-photon detectors from thin niobium nitride nanostrips exhibit a cut-off of the wavelength-independent quantum efficiency along with a moderate energy resolution in the near-infrared spectral range. Before the cut-off, the intrinsic quantum efficiency of the detector reaches 30% from the ultimate physical value which is the absorbance of the detector structure. The intrinsic quantum efficiency is most likely controlled by non-homogeneities of the niobium nitride films. We have developed the electro-thermal model that describes the initial growth, diminution and disappearance of the normal domain created by a photon in the superconducting nanostrip. The response parameter extracted from the model allowed us to optimize the SQUID-based readout and to achieve in the temperature range from 1 to 4 K a photon counting frequency of 30 MHz and a dark count rate less than one in two hours. The detector operates in a 3He sorption refrigerator integrated in a pulse-tube mechanical cooler.

10:45am

**3EC03 - Optical Properties of Superconducting Nanowire Single-Photon Detectors**

*V.Anant, Research Laboratory of Electronics, MIT; A.J.Kerman, MIT Lincoln Laboratory; E.A.Dauler, J.K.W.Yang, Research Laboratory of Electronics, MIT; K.M.Rosffjord, University of Maryland; K.K.Berggren, Research Laboratory of Electronics, MIT*

We report on measurements of the optical absorbance of superconducting nanowire single photon detectors. We found that 200-nm-pitch, 50%-fill-factor devices had an average absorbance of 21% for normally-incident front-illumination of 1.55-um-wavelength light polarized parallel to the nanowires, and only 10% for perpendicularly-polarized light. We also measured devices with lower fill-factors and narrower wires that were five times more sensitive to parallel-polarized photons than perpendicular-polarized photons. We developed a numerical model that predicts the absorbance of our structures. We also used our measurements, coupled with measurements of device detection efficiencies, to determine the probability of photon detection after an absorption event. We found that, remarkably, absorbed parallel-polarized photons were ~ 1.4 times more likely to result in detection events than perpendicular-polarized photons that had been absorbed. Finally, we present a hypothesis that qualitatively explains this result.

*This work was sponsored in part by the United States Air Force under Air Force Contract #FA8721-05-C-0002 and IARPA. Opinions, interpretations, recommendations and conclusions are those of the authors and are not necessarily endorsed by the United States Government.*

**11:00am**

**3EC04 - Investigation of Quantum Efficiency and Polarization Effects in NbN Superconducting Single Photon Detectors**

*L.Maingault, P.Cavalier, J.-C.Villegier, INAC CEA-Grenoble; R.Espiau, L.Frey, LETI CEA-Grenoble; M.Tarkhov, MSPU; J.-P.Poizat, P.Feautrier, Inst. Neel CNRS-Grenoble*

Superconducting Single Photon Detectors based on NbN nanowires have been optimized in regards to the quality of the NbN epitaxial layer grown on M-plane 3' Sapphire wafer, leading to  $T_c \sim 13K$  and  $J_c \sim 4MA/cm^2$  for a 5nm thick layer patterned down to 80nm stripe width using an e-beam writer. The photon coupling at 1.55 $\mu m$  wavelength has been increased significantly by using a specially designed optical structure bonded on the SSPD, waveguiding the light absorbed by the NbN nano-wire. Large Quantum Efficiency values have been demonstrated even at 4.2K for 100nm line width with very low dark counts giving excellent SNR. Clear effect of detection efficiency dependent on the light polarization has been also quantified even without the optical coupling structure. Quantum Efficiency varies by a factor 3 to 4, almost the same for a great number of tested SSPDs, stripe width varying from 100 to 300nm. The SSPD has been modelled as a detector with different QE when incident light is polarized Transverse Magnetic (TM) and when polarized Transverse Electric (TE). This model is in good agreement with experimental data, but FDTD analysis results in only a factor of 1.3 between TE and TM absorption, so we will try to propose an explanation to the observed polarization magnitude.

*EC Sinphonia NMP4-CT-2005-16433*

**11:15am**

**3EC05 - Fabrication of Superconducting Nanowire Single-Photon Detectors with High Fill-Factors**

*J.K.W.Yang, MIT; A.J.Kerman, Lincoln Laboratory MIT; E.A.Dauler, K.K.Berggren, MIT*

In the past, we have fabricated superconducting nanowire single-photon detectors (SNSPDs) with record detection efficiencies (DE) as high as 57% at 1550 nm wavelengths. The nanowires in these SNSPDs were 90 nm wide and were separated by 110 nm (i.e. a 45% fill factor) in a meander structure patterned in NbN films. While a 57 % DE is acceptable for many applications, a much higher DE will be valuable if not required in certain applications such as linear-optics quantum computing and photon number resolution. One approach to increasing the DE of SNSPDs is to increase the optical absorption of the device by increasing the fill factor of the meander structure. Also, reducing the nanowire width would lead to an increase in DE. Recently we developed a high-resolution nanofabrication method using a combination of a high-contrast resist process and electron-beam lithography to achieve sub-10-nm nanostructure dimensions. This technique could be used to fabricate SNSPDs with fill factors as high as 80 % and wire widths as narrow as 40 nm. We will describe the fabrication methods used for these extremely high fill-factor devices, and also the consequences of the very narrow intra-wire spacing on key device performance metrics such as detection efficiency, reset time, and device jitter.

*This work is partially sponsored by the United States Air Force under Air Force Contract #FA8721-05-C-0002. Opinions, interpretations, recommendations and conclusions are those of the authors and are not necessarily endorsed by the United States Government.*

**11:30am**

**3EC06 - Submicrometer photoresponse mapping of nanowire superconducting single-photon detectors**

*R.H.Hadfield, P.A.Dalgarno, J.A.O'Connor, E.Ramsay, R.J.Warburton, Heriot-Watt University, UK; E.A.Gansen, B.Baek, M.J.Stevens, R.P.Mirin, S.Nam, NIST, USA*

Single-photon detectors based on superconducting nanowires are promising candidates for infrared photon counting applications, ranging from quantum cryptography to medical imaging and remote sensing. Important challenges in device development are to better understand how light is absorbed in nanowire structures and to improve device performance and yield. We report on the photoresponse mapping of NbN nanowire superconducting single-photon detectors using a focal spot significantly smaller than the device area (10 x 10 micrometer<sup>2</sup>). Using a confocal microscope configuration and solid immersion lens, we achieve a spot size of 320 nm full width at half maximum onto the device at 470 nm wavelength. We compare the response maps of two devices: The higher detection efficiency device gives a uniform response, whereas the lower detection efficiency device is limited by a single defect or constriction. Reference: Hadfield R.H. et al, Applied Physics Letters 91 241108 (2007)

*This work was supported by the Royal Society of London and EPSRC (United Kingdom) and the NIST Quantum Information Science Initiative (USA). We thank G. Gol'tsman for providing the devices used in this study.*

**11:45am**

**3EC07 - Nanoscale superconducting single-photon detector**

*D.Bitauld, COBRA Research Institute, TU/e; F.Marsili, IPEQ, EPFL; A.Fiore, COBRA Research Institute, TU/e; A.Gaggero, F.Mattioli, R.Leoni, CNR-IFN; M.Benkahoul, F.Levy, IPMC, EPFL*

Superconducting single photon detectors (SSPD) have shown to be very attractive when near infrared single photon detection is needed. Their sensitivity, low jitter and high counting rate make them highly valuable for many applications (e.g. quantum communications, sensing). Their detection principle is intrinsically nanoscale, as it is based on the formation of a resistive hot-spot (few tens of nm in diameter) in a superconducting nanowire (typically 100 nm in width). This extremely low-dimensionality make it difficult to fabricate perfectly uniform nanowire. Indeed, the spatial variation of wire width and/or film properties, resulting in constrictions is thought to be at the origin of the low yield of high-efficiency devices. In order to better understand the cause of those defects, we performed the mapping of the quantum efficiency (QE) in a superconducting nanowire with 5 microns spatial resolution, and directly correlate the variations in QE to inhomogeneities in the wire observed with scanning electron microscopy. Additionally, we show that the strong dependence of QE on stripe width can be exploited to fabricate a detector with very high spatial resolution (about 100x100 nm<sup>2</sup> active area), by patterning a lithographic constriction. Such a device, to our knowledge the smallest single-photon detector ever fabricated, could have important applications in near-field imaging at the single-photon level.

## WEDNESDAY AFTERNOON POSTER SESSIONS

2:00pm - 4:00pm

### 3EPA - Transition Edge Sensors VIII – Applications

2:00pm - 4:00pm

#### 3EPA01

##### **Design and development of a large-format TES array for CMB polarimetry**

*K.W.Yoon, J.A.Beall, National Institute of Standards and Technology; D.T.Becker, University of Colorado, Boulder; H.-M.Cho, W.B.Dorise, W.D.Duncan, National Institute of Standards and Technology; N.W.Halverson, G.C.Hilton, University of Colorado, Boulder; K.D.Irwin, D.R.Schmidt, J.N.Ullom, National Institute of Standards and Technology*

The next generation of cosmic microwave background (CMB) polarization experiments targeting the signatures of inflation will require unprecedented sensitivities in addition to careful control of systematics. With existing detector technologies already operating close to the background photon noise limit, improvements in system sensitivities must come from ever-larger focal plane arrays of millimeter-wave detectors. We report on the progress towards such a large-format array employing a monolithic, microfabricated polarimeter architecture coupled to SQUID-multiplexed TESs.

#### 3EPA02

##### **Kilopixel Transition Edge Sensor Arrays for the Atacama Cosmology Telescope**

*J.A.Chervenak, NASA Goddard Space Flight Center*

Our team has optimized kilopixel transition edge sensor arrays for measurements at three separate wavelengths in the millimeter band (145 GHz, 215 GHz, and 280 GHz). We report on their design, fabrication, assembly, and successful installation in the Millimeter Bolometer Array Camera (MBAC) instrument of the Atacama Cosmology Telescope. The bolometers consist of a millimeter-sized silicon membrane whose temperature change is read-out by a small superconducting bilayer element located on the membrane. The silicon is doped to an impedance suitable for efficient coupling of radiation into the silicon. To create close-packed, two-dimensional arrays, the bolometer arrays employ the Pop-Up architecture, which uses 90-degree bending of the thermal isolation structures in the silicon to locate the wiring and readout behind the focal plane. The focal plane is situated in a stepped impedance transformer consisting of three dielectric layers that promotes pixel efficiency and reduces total reflection and transmission of stray light into the receiver. We describe the success of this implementation in terms of maximizing pixels counts and adhering to tolerances required for astronomical observations. The architecture of the cameras is readily extensible to the detector requirements at the different wavelengths without changing the component fabrication or assembly methods.

#### 3EPA03

##### **Absorber Type TES Polarimeter at Millimeter and Submillimeter**

*G.Wang, V.Yefremenko, A.Datesman, J.Pearson, V.Novosad, MSD, Argonne National Lab; R.Divan, CNM, Argonne National Lab; L.Bleem, C.Cheng, A.T.Crites, T.Downes, J.McMahon, S.S.Meyer, J.E.Carlstrom, KICP, University of Chicago*

Millimeter and submillimeter waves are an approved probe of the early universe through the Cosmic Microwave Background (CMB) radiation, of the star formation through the dusty high redshift galaxies and through the gas and dust in the local universe.

The frontier of CMB is to detect or to place a stringent constraint on the polarization induced by inflationary gravitational waves. In the local universe, polarization measurements are used to investigate the magnetic field believed to be critical to the process of star formation. To build large, dual-polarization, multi-band focal planes for these astronomical observations, we have been developing bolometric polarimeter using superconducting Transition Edge Sensor (TES). We report an absorber coupled TES polarimeter consisting of an absorptive metal grid and a Mo/Au bilayer TES on a silicon nitride membrane. The electromagnetic design of the polarization sensitive absorbers, the heat transport modeling of the detector, and the thermal analysis of the TES are presented. We also report the results of laboratory tests of single pixel prototype devices, and compare with theoretical expectations.

#### 3EPA04

##### **Fast scanning passive terahertz camera based on TES-bolometers**

*G.Zieger, T.May, V.Zakosarenko, S.Anders, M.Starkloff, M.Schubert, H.-G.Meyer, G.Thorwirth, Institute of Photonic Technology (IPHT), P.O. Box 100239, D-07702 Jena, Germany; E.Kreysa, Max-Planck-Institute for Radio Astronomy, Auf dem Huegel 69, D-53121 Bonn, Germany*

We present a fast-scanning passive terahertz camera. Based on a Helium-3 sorption cooler it uses transition edge sensor bolometers operated at 0.45 K. Images of objects at a distance of 5 meters are obtained by detecting their natural emission at 0.34 THz. The penetration properties of electromagnetic radiation at such frequencies allow to detect hidden objects under clothing. The achieved resolution is about 1 cm. The optical system is a Cassegrain-type telescope composed of an aspheric main mirror with a diameter of 40 cm and a rotating secondary mirror. The particular advantage of the applied spiral scanning-technique is the possibility to vary easily the compromise between image rate and pixel density.

#### 3EPA05

##### **Large-Format Superconducting Bolometer Array Development for the SAFIRE Instrument for SOFIA**

*D.J.Benford, NASA/GSFC; J.G.Staguhn, NASA/GSFC & U.MD; C.A.Allen, S.H.Moseley, NASA/GSFC*

The Submillimeter and Far-InfraRed Experiment (SAFIRE) on the SOFIA airborne observatory will employ a large-format, two-dimensional, close-packed bolometer array. SAFIRE is an imaging Fabry-Perot spectrometer operating at wavelengths between 100 $\mu$ m and 700 $\mu$ m. The low backgrounds achieved in spectroscopy require very sensitive detectors, with NEPs of order 1E-19 W/ $\sqrt$ Hz. Our group has been developing a kilopixel, filled bolometer array for SAFIRE with a 32x40 pixel format, using a SQUID multiplexer developed by NIST/Boulder. The array consists of three individual components, to be merged into a single, working unit; 1) a transition edge sensor (TES) bolometer array, operating at  $\sim$ 100 milliKelvin, 2) a per-pixel broadband absorbing backshort array, and 3) a SQUID multiplexer readout array. The detector array is a filled, square-grid of suspended, silicon membrane bolometers with superconducting transition edge sensor thermistors. Mechanical models of large-format detector grids have been indium bump-bonded to dummy multiplexer readouts to study electrical continuity and have been mated to a backshort grid. A detector array of this general type has been used in an astronomical instrument, GISMO. Based on its performance, we can extrapolate to the necessary sensitivity for airborne spectroscopy. We report on the progress achieved toward kilopixel arrays suitable for SAFIRE.

### 3EPA06

#### **TES Development at ANL for a Frequency Selective Bolometer Camera**

*A.Datesman, G.Wang, V.Yefremenko, J.Pearson, V.Novosad, R.Divan, ANL; L.Bleem, C.Chang, A.Crites, T.Downes, J.McMahon, S.Meyer, J.Carlstrom, Univ of Chicago; G.Wilson, T.Perera, Univ of MA*

We discuss the development of a four-pixel camera, with four spectral channels per pixel, operating at 150, 220, 270, and 360 GHz. The scientific motivation involves photometry of distant dusty galaxies located by Spitzer and SCUBA, as well as the study of other millimeter-wave sources. The camera incorporates Frequency Selective Bolometer (FSB) and superconducting Transition-Edge Sensor (TES) technology. ANL TES devices utilize proximity effect superconducting bilayers of Mo/Au, Ti, or Ti/Au, located along with frequency selective absorbing structures on membranes of silicon nitride. The detector incorporates lithographically patterned structures designed to address both TES device stability and detector thermal transport issues. The membrane is not perforated, resulting in a detector which is comparatively robust mechanically. We report on the development of the superconducting bilayer TES technology, and on our approach to achieving thermoelectrical stability. This includes control of the superconducting transition temperature and transition width, the design and testing of the detector thermal transport and device stability control structures, optical and thermal test results, and the use of new materials, including palladium. Pd possesses a high heat capacity at cryogenic temperatures, and its use for a Mo/Pd TES bilayer is examined.

### 3EPA07

#### **Microstrip Filters with TES Bolometers For CMB Polarimetry**

*D.T.Becker, N.W.Halverson, University of Colorado; K.W.Yoon, S.Cho, NIST, Boulder*

Ground-based cosmological observations require tight control of passbands to avoid atmospheric lines. We will describe the design, fabrication, and testing of microstrip filters feeding TES bolometers. These filters operate at the 90 and 150 GHz passbands, with 25% bandwidth and > 30 dB out of band rejection up to 700 GHz.

### 3EPA08

#### **Fabrication of an Antenna-Coupled Bolometer for Cosmic Microwave Background Polarimetry**

*K.L.Denis, N.T.Cao, MEI Technologies; D.T.Chuss, W.T.Hsieh, S.H.Moseley, T.R.Stevenson, NASA Goddard Space Flight Center; D.E.Travers, K.U.Yen, MEI Technologies; E.J.Wollack, NASA Goddard Space Flight Center*

We describe the design and fabrication of a prototype detector for precise measurements of the cosmic microwave background polarization. The detector employs a waveguide to coupled the light between bolometers and the circular feedhorn, which produces highly symmetric beams resulting in very low cross-polarization. Input power is detected with a pair of Mo/Au superconducting transition edge sensors (TES) that are thermally well isolated and operate under 100mK. The waveguide, which couples the light to a planar superconducting microstrip circuit operating in the 29–43 GHz band, is micromachined separately from the TES and the microstrip circuit, allowing optimization of both processes. We describe micro-fabrication processes for the superconducting planar circuit, micromachining technique and angle evaporation for forming the waveguide, and a low temperature wafer bonding process for assembling the final structure.

### 3EPA09

#### **Microwave Kinetic Inductance Device (MKID) Applied in a Strip Array Detector**

*B.Bumble, B.A.Mazin, H.G.LeDuc, JPL; S.Gowala, D.Moore, Caltech*

A single drive line is used to read out an array of microwave resonators. Photon detection from optical to X-ray wavelengths is possible due to Cooper Pairs breaking causing quasiparticle generation in the superconductor. This changes the surface inductance in the resonator resulting in a shift of the frequency and amplitude of a microwave probe signal. Calibration of the photon energy is possible from signal amplitude or phase. Position is determined by relative signal strength from MKID detectors on either end of an absorber strip. We will discuss materials and fabrication techniques. UV strip detectors have demonstrated a resolving power of 6 at 254 nm wavelength.

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#### **3EPB - Transition Edge Sensors IX – Applications** **2:00pm - 4:00pm**

### 3EPB01

#### **Robust Passive Alignment of Optical Fibers to Transition-Edge Sensors by Silicon Micromachining**

*A.J.Miller, Department of Physics, Albion College, Albion MI, USA; A.E.Lita, S.Nam, Optoelectronics Division, NIST, Boulder CO, USA*

Photon counting transition-edge sensors (TESs) have recently been demonstrated to have intrinsic device efficiencies as high as 99% at near-infrared wavelengths. To properly capitalize on these high device efficiencies the optical system must be carefully designed to minimize losses between the room-temperature optical input and the cryogenic device. In particular, a major source of variability and reduction in the end-to-end optical efficiency is the fiber-to-device coupling. In this paper we present results from the design, fabrication, and measurement of a new generation of TES devices in which the silicon substrate has been micromachined to enable the passive alignment of the TES device to the fiber in a way that is repeatable and cryogenically stable with alignment losses below 1%.

### 3EPB02

#### **A Multi-Pixel TES Microcalorimeter Spectrometer for X-Ray Microanalysis**

*R.Cantor, J.A.Hall, STAR Cryoelectronics*

We describe a cryogen-free multi-pixel TES microcalorimeter spectrometer for applications in X-ray microanalysis. Cooling to typical operating temperatures around 0.1 K is provided by a pulse tube cryocooler mounted on the spectrometer cryostat and an adiabatic demagnetization refrigerator. The detector array consists of 16 Mo/Cu microcalorimeters located at the end of a 25-mm diameter cold finger along with 16 channels of first-stage SQUID readouts. Sixteen second stage SQUID array amplifiers are located at the 3 K stage of the pulse tube cryocooler. The SQUID amplifiers are read out using PC-based wideband locked-loop feedback electronics capable of tracking fast pulses of up to several hundred microamperes. This system has been installed on a Hitachi S-4800 FE-SEM for energy dispersive X-ray microanalysis. *This work was supported in part by the U.S. Department of Commerce Advanced Technology Program under Grant 70NANB4H3056.*

### 3EPB03

#### **Micro-X, the TES X-ray Imaging Rocket: First Year Progress**

*P. Wikus, M. Bautz, K. Flanagan, S. Kissel, S.W. Leman, A. Levine, N. Schulz, MIT Kavli Institute for Astrophysics and Space Research; J. Adams, S.R. Bandler, M. Loewenstein, NASA Goddard Space Flight Center & University of Maryland, Dept. of Astronomy; K. Boyce, U. Hwang, T. Kallman, R.L. Kelley, C.A. Kilbourne, R. Mushotzky, R. Petre, F.S. Porter, P. Serlemitsos, R. Smith, NASA Goddard Space Flight Center; G. Brown, High Energy Density Physics and Astrophysics Div., Lawrence Livermore National Laboratory; S. Deiker, D. Martinez-Galarce, Lockheed Martin Solar and Astrophysics Laboratory; W.B. Doriese, G.C. Hilton, K.D. Irwin, C.D. Reintsema, J.N. Ullom, National Institute of Standards and Technology; E. Figueroa-Feliciano, Dept. of Physics, Massachusetts Institute of Technology & MIT Kavli Institute for Astrophysics and Space Research; M. Galeazzi, University of Miami, Dept. of Physics; D. McCammon, Dept. of Physics, University of Wisconsin-Madison; T. Saab, Dept. of Physics, University of Florida*

Micro-X is a sounding rocket experiment that will combine a transition-edge-sensor (TES) microcalorimeter array with an imaging mirror to obtain high-spectral-resolution images of astronomical X-ray sources. The instrument's resolution across the 0.3-2.5 keV band will be 2 eV. Our first flight will target the region of the Bright Eastern Knot of the Puppis A supernova remnant and is slated for January 2011. The obtained high resolution X-Ray spectra will be used to ascertain the temperature and ionization state of the X-Ray emitting gas and to determine its velocity structure. The 121 pixels of the TES array are read out by a 4x32 channel time-division SQUID multiplexing (MUX) system. The detector front end assembly and the SQUID MUX circuit are cooled to the operating temperature of 50 mK with an adiabatic demagnetization refrigerator (ADR). The design of this refrigerator is tailored to the requirements of rocket flight. Stable operation of the TES array close to the ADR magnet will be achieved with a magnetic shielding system, which will be based on a combination of passive high permeability and superconducting materials and an active system using bucking coils to cancel out residual fields. We describe the progress made in developing the Micro-X instrument, and focus on the TES array, the read-out electronics, the magnetic shielding and the cryogenic system.

### 3EPB04

#### **Heat sinking, cross-talk, temperature stability for large close-packed array of microcalorimeters**

*N. Iyomoto, The University of Tokyo; S.R. Bandler, R.P. Brekosky, A.-D. Brown, J.A. Chervenak, M.E. Eckart, F.M. Finkbeiner, R.L. Kelley, C.A. Kilbourne, F.S. Porter, J.E. Sadleir, S.J. Smith, NASA/GSFC*

In large close-packed arrays of microcalorimeters, such as transition-edge-sensor (TES) x-ray microcalorimeter arrays for NASA's Constellation-X mission, sufficient heat sinking is important to minimize thermal crosstalk between pixels and to stabilize bath temperature of all pixels. We have measured crosstalk on our 8x8-pixel arrays. The shapes of the thermal crosstalk pulses are well reproduced as a convolution of heat input from the source pixel and decay in the receiver pixel. The amount of thermal crosstalk is dependent upon the efficiency of electrothermal feedback. We have compared the amount of thermal crosstalk with and without a heat-sinking copper layer on the backside of the silicon frame as a function of distance between the source and receiver pixels. Using the results, we have estimated the degradation of energy resolution as a function of count rate. Also, we have studied the temperature distribution within an array due to continuous heating from the TES bias and estimated its impact on the uniformity of the pixel performance.

*This research was supported in part by an appointment (A. -D. Brown and S. J. Smith) to the NASA Postdoctoral Program at NASA Goddard Space Flight Center administered by Oak Ridge Associated Universities through a contract with NASA.*

### 3EPB05

#### **Fabrication of Position Sensitive TES X-ray Detectors**

*L.R. Vale, J.N. Ullom, G.C. Hilton, K.D. Irwin, National Institute of Standards and Technology; S.W. Deiker, R.A. Stern, Lockheed Martin Space Systems*

We have fabricated linear position-sensitive TES x-ray detectors based on Mo-Cu bilayers that also includes both Cu and Pd absorbers. In this poster we will present details of device design and fabrication. We will discuss the fabrication challenges caused by the small area (12 um x 12 um) transition edge sensors. Lastly we will present preliminary data on device characterization.

### 3EPB06

#### **Finite Element Modeling of Thin Magnetic Shields Consisting of a Combination of Superconducting and High-Permeability Materials**

*T.C. Chui, J. Young, Jet Propulsion Laboratory; S. Golwala, Caltech*  
Most SQUID and TES based sensors require magnetic shielding to operate. For space applications, due to the severe constraint on mass, it is rather important to optimize the design, which often combines superconducting and high-permeability materials. We will present a way to optimize such mixed shields using a finite element method (FEM) modeling technique. The tool we used is COMSOL, which is capable of modeling high permeability shields of arbitrarily thin thickness. This aspect is particularly important for minimization of the mass of the shield. The FEM model for the SPIDER and BICEP2 projects will be presented. SPIDER and BICEP2 are, respectively, balloon-borne and ground-based bolometric receivers designed to measure the polarization anisotropy of the cosmic microwave background.

*Work carried out at the Jet Propulsion Laboratory, California Institute of Technology, was supported by a contract with the National Aeronautics and Space Administration.*

### 3EPB07

#### **Superconducting films for absorber-coupled MKID detectors for sub-millimeter and far-infrared astronomy**

*T.R. Stevenson, W.T. Hsieh, NASA Goddard Space Flight Center, Detector Systems Branch; S.H. Moseley, NASA Goddard Space Flight Center, Observational Cosmology Laboratory; D.E. Travers, NASA Goddard Space Flight Center, Detector Systems Branch; K.U. Yen, NASA Goddard Space Flight Center, Microwave Instrument Technology Branch; E.J. Wollack, NASA Goddard Space Flight Center, Observational Cosmology Laboratory; J. Zmuidzinas, California Institute of Technology, Department of Physics*

We describe measurements of the properties, at dc, gigahertz, and terahertz frequencies, of thin superconducting films with relatively high normal state sheet resistance. Such films can be applied to construct microwave kinetic inductance detector sensor arrays for submillimeter and far-infrared astronomical applications in which the incident power excites quasiparticles directly in a superconducting resonator that is configured to present a matched-impedance to the high frequency radiation being detected. For several materials, and a range of thicknesses down to 10 nm, we present measurements of normal state sheet resistance, resistance-temperature curves for the superconducting transition, quality factor and kinetic inductance fraction for microwave resonators made from patterned films, and terahertz measurements of the sheet impedance measured with a Fourier Transform Spectrometer.

### 3EPB08

#### Microwave Resonators for Detector Applications

*S.Wuensch, G.Hammer, K.Ilin, E.Crocoll, M.Siegel, University of Karlsruhe*

Superconducting transmission line resonators offer the possibility for different sensor readout methods, e.g. flux qubit, kinetic inductance detectors. Both applications require a high loaded quality factor of the microwave resonators to detect small deviations in the resonance frequency which is equal to a high sensitivity. Various superconducting niobium coplanar waveguide resonators of quarter and half wavelength for 3 GHz and 6 GHz with different layouts were developed. The different resonator samples were designed, simulated and measured on common silicon and sapphire substrates at 4.2 K. We achieved a very good agreement between simulation and measurement results in respect of the quality factor. Different layout structures have been studied, changing their layout from straight to folded structures. A strong dependence between the loaded quality factor and the complex folded structure of the transmission line resonators was observed. The achieved values of the quality factor for the half wavelength resonators were in the range of 10,000 - 100,000 and for the quarter wavelength resonators up to 1,000,000 at helium temperatures. The presented results showed the dependency of the quality factor from the chosen cross section geometry, the coupling factor, the applied microwave power and the complex layout of the transmission line.

### 3EPB09

#### Invited

#### Integrated on-chip refrigeration: an X-ray transition-edge sensor with 10 eV resolution at 260 mK, 80 mK above T<sub>c</sub>.

*G.C.O'Neil, K.D.Irwin, N.A.Miller, D.R.Schmidt, J.N.Ullom, NIST*  
We present data from a X-ray transition-edge sensor (TES) cooled by on-chip normal-metal/insulator/superconductor (NIS) junctions. NIS junctions are solid-state refrigerators whose cooling mechanism is the selective removal of the hottest electrons from the normal electrode. We operate with the cryostat temperature above the critical temperature (T<sub>c</sub>) of the TES, and cool the TES below T<sub>c</sub> with the NIS junctions. We demonstrate an energy resolution better than 10 eV FWHM at 6 keV with the cryostat temperature at 260 mK and a TES T<sub>c</sub> of 180 mK. The saturation energy of the TES is well above 6 keV, indicating that significant further resolution improvements are possible. NIS refrigerators open up new options for operating cryogenic detectors at higher temperatures than previously possible.

### 3EPC - Digital – III 2:00pm - 4:00pm

### 3EPC01

#### Study on the Single-flux-quantum Signal Generation by Millimeter Wave for Driving SFQ Circuits at Sub-terahertz Frequencies

*M.Inoue, Y.Horii, T.Kimura, K.Kajino, Nagoya University / CREST-JST; H.Andoh, Toyota National College of Technology; A.Fujimaki, Nagoya University / CREST-JST*

We investigated the generation of single-flux-quantum (SFQ) signals by millimeter wave. SFQ circuit technology has been developing using Nb junctions. In addition, we recently confirmed the operation of toggle flip-flop circuit using YBCO vertically-stacked junctions up to 500 GHz. Generation of sub-terahertz SFQ signals tunable from outside of the cryocooler is helpful for further development of SFQ circuit technology. For such high frequencies,

electric cables can not be used. As we have ever demonstrated, the photomixing technique will become a candidate for this purpose. In this report, we introduce another research for generating sub-terahertz SFQ signals. In this method, we used millimeter wave to induce high-frequency signals. As the first trial, we fabricated a short Josephson transmission line (JTL) equipped with an antenna to one junction at the end of JTL to generate SFQs at this junction. YBCO ramp-edge junctions were used for this circuit. We prepared the measurement setup and checked its performance. When 100GHz millimeter wave irradiated the whole circuit, we observed Shapiro steps in the current-voltage characteristics of the circuit. Thus we have confirmed correct receiving of the millimeter wave. Improvements of the test circuit to limit the irradiation area only to the antenna are in progress.

### 3EPC02

#### SFQ Propagation Properties in Passive Transmission Lines Based on a 10-Nb-Layers Structure

*K.Takagi, M.Tanaka, I.Kataeva, S.Iwasaki, R.Kasagi, Nagoya Univ., CREST JST; S.Nagasawa, T.Sato, SRL/ISTEC, CREST JST; H.Akaike, A.Fujimaki, Nagoya Univ., CREST JST*

We evaluated propagation properties of a single-flux-quantum (SFQ) pulse in passive transmission lines (PTLs) formed based on a new 10-kA/cm<sup>2</sup> 10-Nb-layers structure, aiming to increased SFQ circuit density and improved wiring flexibility. Two dedicated PTL layers are placed below a thoroughly planarized ground plane (GP), while junctions are formed above the GP in the new structure. The raised critical current density leads to narrowed PTLs of about 5 μm together with a higher operating speed. These features increase flexibility in placement of logic gates made up of junctions because PTLs can be routed by using the dedicated layers. However, there is a possibility to increase attenuation and dispersion in the new structure because of narrowed lines and more complicated via holes. We have experimentally examined frequency dependence of those in the PTLs including driver/receiver circuits and via holes, which are designed carefully by using several tools such as an electromagnetic wave simulator HFSS. The bias margins are obtained to be +20% even at the resonant frequencies of the PTLs when the PTLs under test have no via hole. On the other hand, the bias margin is reduced by a few % in a PTL with two via holes. We currently reoptimize the structure of via holes to keep enough margins even for PTLs having 10 via holes.

### 3EPC03

#### Picosecond precision time measurement with RSFQ circuits

*X.Zhou, University of Science and Technology of China; M.J.Feldman, University of Rochester*

To meet the challenge of real time verification of RSFQ circuits, we study a technique to measure the input-output delay of RSFQ cells with an all-RSFQ setup. This is based on the sharp transition of the output voltage of a confluence buffer when its inputs get close to each other in time. By splitting SFQ pulses from a common source, feeding them into three bias-controlled delay lines, and bringing them together with two confluence buffers, we can calibrate the delays of the three paths against each other and measure their delay times as functions of their biases. This calibration result can then in turn be used to measure the input-output delay of one of the confluence buffers as a function of the time separation between its input pulses, with picosecond precision. Comparing to simulation, the result provides a quantitative experimental test ground for the device models. Such tests will be essential before small high-current-density Josephson junctions can be used with confidence for RSFQ integrated circuits.

### 3EPC04

#### Invited

#### Reduced probability of noise introduced malfunction in RSFQ circuits by implementing intrinsic pi-phaseshifter

*O.Mielke, T.Ortlepp, Ilmenau University of Technology, Germany; P.Febvre, University of Savoie, France; F.H.Uhlmann, Ilmenau University of Technology, Germany*

The Rapid Single Flux Quantum electronics family is based on the magnetic flux quantum which is exchanged between adjoining superconducting loops by a switching event of a Josephson junction. This digital circuit family is characterized by a low switching energy, which makes it susceptible to noise introduced bit errors. For industrial applications a certain noise immunity is required which is still a challenge especially for circuits of higher complexity. Our theoretical analysis showed a significant impact of the phase offset caused by a pi-phaseshifter. It can be utilized as a kind of noiseless current source increasing the robustness of RSFQ electronics even for circuits fabricated in mature Nb-technology. We experimentally investigate the influence of the pi-phaseshifter on the bit error rate of a toggle flip-flop. We designed dedicated test circuits with and without a phaseshifter for a stability comparison. Our presented experiments show significant variances in the bit error rate confirming the improved immunity against noise. There are only slight difference in the layout of both cells, thus it can be concluded that this advantage is based on the influence of the phaseshifter. Design and fabrication were performed by FLUXONICS Foundry.

### 3EPC05

#### Implementation of high-speed single flux-quantum up/down counter for the neural computation using stochastic logic

*T.Onomi, K.Nakajima, RIEC, Tohoku University*

Artificial neural networks are promising for parallel and intelligent information processing. We have proposed superconducting neural circuits using stochastic logic. The circuit elements have been based on a single flux-quantum(SFQ) logic. In the stochastic logic, the data is represented by the generation rate of random pulses for a certain period on time domain. The neural computation must accumulate the pulses in order to generate the membrane potential of a neuron. We have proposed an improved asynchronous up/down counter for accumulation of stochastic pulses. In this counter, up and down signals are counted by two independent counters, respectively. The up/down counter has two operation phases which are the accumulation of signals and the access of accumulation result. Even if the number of bit increases, the operation speed of the accumulation does not decrease in this method. We report a design and an experimental result of an SFQ up/down counter for the accumulation of stochastic signals. A 4-bit up/down counter are fabricated using SRL Nb/AIOx/Nb standard process and successfully demonstrated. The numerical simulation shows that the up/down counter can operate at 50GHz with an enough bias margin in the accumulation phase.

*This research was supported by the Strategic Information and Communications R&D Promotion Programme from the Ministry of Internal Affairs and Communications of the Japanese Government.*

### 3EPC06

#### Standardization of RSFQ logic cell libraries: Functionality,latency and leakage current

*L. C.Müller, C. J.Fourie, H. R.Gerber, Stellenbosch University, Dept. E&E Engineering*

The standardization of RSFQ logic cell libraries is important for the fast and reliable creation of complex RSFQ digital logic circuits. In a step towards standardization, an automated technique is proposed that can unambiguously test a logic cell's functionality and latency.

This is done by state diagram extraction from raw Spice decks, which will be shown not only to be feasible but also faster and more reliable than user-specified input techniques used today. An algorithm is demonstrated to verify the implementation of the technique for several RSFQ logic cells. Leakage currents of logic cells are also extensively investigated and a standardized approach to inter-cell connection and cell loads are proposed to minimize the influence of stray currents in large scale logic circuit designs.

### 3EPC07

#### Invited

#### Superconductive Random Number Generator Using Thermal Noises in SFQ Circuits

*Y.Yamanashi, N.Yoshikawa, Yokohama National University*

Demands for information security have increased with developments of information processing technologies. In the applications of cryptographic security, high-quality random numbers, which have no periodicity and no correlation between each bit, are required. Semiconductor random number generators, which use randomness of physical phenomena such as thermal noises in resistors, have been developed. However, the generation frequency of the random number remains less than 10 MHz because magnitude of noises is too small for semiconductor circuit and amplification process is indispensable. In this paper, we propose a novel high-speed random number generator using superconductive single-flux-quantum (SFQ) circuits and thermal noises in the circuit. The proposed SFQ random number generator is similar to an SFQ comparator. Because of the high-sensitivity of SFQ circuits, real random numbers can be generated without amplification of the noises. Generation of real random numbers at the frequency of several tens GHz can be expected using the proposed circuit. We have designed the test circuit using the standard 2.5 kA/cm<sup>2</sup> Nb process and estimated the quality of the generated random numbers experimentally. We have examined 2<sup>20</sup> bit random number train at low frequency and no periodicity is observed. The paper will show the operation principle, the circuit design, and experimental results.

### 3EPD - Nanowire Detectors – IV 2:00pm - 4:00pm

### 3EPD01

#### Invited

#### Development of Superconducting StripLine Detectors (SSLDs) for Time-of-Flight Mass Spectrometers (TOF-MS)

*N.Zen, K.Suzuki, Y.Chen, M.Ohkubo, National Institute of Advanced Industrial Science and Technology; S.Miki, Z.Wang, National Institute of Information and Communications Technology*

We have succeeded in obtaining mass spectra of proteins with a mass spectrometer (MS) using NbN Superconducting StripLine Detectors (SSLDs) which have the same nanostructure as so called Superconducting Single Photon Detectors (SSPDs) for ultrafast photon detection. Encouraged by the previous results, we have been developing some other SSLDs constructed from Nb or YBCO-type high temperature superconductors. Due to the small London penetration depth, the Nb-based SSLD is expected to show rapid response time. Another YBCO-type material is a superconductor with high critical temperature around 90 K. Operation at higher temperatures will make a noticeable impact on the application. The optimum SSLD design for MS should be totally different from that of SSPD in order to realize meaningful sensitivity and reasonably fast response time for high mass resolution. In this study, the relationship between SSLD geometry and their performance is reported, and TOF-MS spectra of biomolecules is presented.

*This work was supported by the JST-SENTAN Project (Japan Science and Technology Agency), and a part of micro-fabrication processes was conducted in AIST Nano-Processing Facility (NPF).*

### 3EPD02

#### *Invited*

#### **Optical Response and Fabrication of MgB<sub>2</sub> Nanowire Detectors**

*H. Shibata, M. Asahi, T. Maruyama, T. Akazaki, H. Takesue, T. Honjo, Y. Tokura, NTT Basic Research Laboratory*

Today, the superconducting single photon detector (SSPD) based on NbN shows a highest performance among the single photon detectors for the quantum cryptography at the telecommunication wavelength. If we can replace NbN to MgB<sub>2</sub> in SSPD, it may become an ultrafast single photon detector with higher operating temperature. MgB<sub>2</sub> has a highest T<sub>c</sub> among intermetallic compounds and has a shorter inelastic electron-phonon relaxation time and a shorter phonon escape time than that of NbN. Here we study the nanowire detector based on MgB<sub>2</sub>. The 10 nm-thick MgB<sub>2</sub> films with the T<sub>c</sub> s of 20 K are synthesized by the molecular beam epitaxy method. The film is formed to the meander line with the width of 200 nm and the 10 micron square size using the standard e-beam lithography and Ar-ion beam milling. The detector is put at the end of the optical fiber, and the laser pulses are illuminated at 4 K. The output signals of the laser pulse are detected when appropriately biased, which reveals that MgB<sub>2</sub> is an attractive candidate for the fast single photon detector.

### 3EPD03

#### **Semiempirical Modeling of Dark Count Rate and Quantum Efficiency of Superconducting Nanowire Single-Photon Detectors**

*M.K. Akhlaghi, A.H. Majedi, University of Waterloo*

We present our studies on the dark count and quantum efficiency performance of NbN superconducting nanowire single-photon detectors (SNSPDs). The curves of detection probability vs. optical attenuation of our single-element SNSPDs were measured in a variety of different operating conditions. Assuming Poisson distribution of the number of photons in the laser pulses, a semiempirical model based on treating a single-element SNSPD as a combination of several non-ideal N-photon detectors is developed. Using the experimental data, the parameters of the model which are essentially the total dark count rate and quantum efficiencies of the N-photon detectors are determined. We show our model can predict the experimental data very accurately and also it can uniquely specify the details of the performance of the SNSPD in each operation condition. The proposed model is further examined when the random partitioning of coherent state is produced by means of beam splitters. Providing parameters that each specifies a different detection mechanism of the device, the model can shed more light on the physical operation principles of SNSPDs. In addition, we think the measured parameters of this model can be used as a standard gauge for comparing the dark count rate and the quantum efficiency performance of different SNSPDs.

### 3EPD04

#### **Superconductive three-terminal amplifier/discriminator**

*O. Quaranta, S. Pagano, Department of Physics "E. R. Caianiello" - University of Salerno; M. Ejrnaes, R. Cristiano, C. Nappi, C.N.R.- Institute of Cybernetics "E. Caianiello"*

We have studied the properties of an innovative three-terminal device that works as a fast superconductive pulse amplifier or discriminator. The device is based on several parallel nano-wires biased near their critical current. When a current pulses enough amplitude reaching one of the wires, it could induce a transition to the normal state, this generates a cascade switch to the normal state of the remaining wires. When all the wires are in the normal state the bias current is deviated on the reading load. The net effect is an amplification of the original pulse. The different thresholds for the original pulse are determined by different bias current value. This could be used in applications such as an amplifier of the signal generated by nano-wire detectors or RSFQ circuits.

The parallel nano-wire structure could be realized by the same fabrication process of an NbN Superconducting Single Photon Detector (SSPD) [1], so its integration into the existing technology is very simple. Here we have presented numerical simulations of this device, with special attention to circuit required for the correct operation of the device. [1] M. Ejrnaes et al, Appl. Phys. Lett., Vol 91, 262509 (2007)

### 3EPD05

#### **Excitations in Superconducting Nanostripes: Resistive States and Noise.**

*M. Bell, A. Sergeev, J. Bird, V. Mitin, A. Verevkin, University at Buffalo SUNY*

We investigate competition between one- and two-dimensional topological excitations - phase slips and vortices - in formation of resistive states and noise generation in ultrathin superconducting NbN nanostripes with 100-nm width in a wide temperature range below the mean-field transition temperature T<sub>c</sub>. The resistivity below T<sub>c</sub> is produced by one-dimensional excitations, - thermally activated phase slip strips (PSSs) overlapping the sample cross-section. We determine the scaling phase diagram, which shows that even in wider samples the PSS contribution dominates over vortices in a substantial region of current/temperature variations. The above fluctuations generated by topological excitations provide a sensitivity limit to superconducting detectors operating in a resistive state, e.g. for dark counts in single-photon nanostripe-based detectors. Our universal phase diagram represents a whole picture of competition between electron heating, vortices, regular phase slips and PSSs within a broad range of temperatures and bias currents in nanostripe devices.

*We are thankful to NY STAR (AS and VM) and NSF IGERT (MB) for support.*

### 3EPE - Superconducting Junction Detectors - 12:00pm - 4:00pm

### 3EPE01

#### *Invited*

#### **Numerical Comparison of Practicable Terahertz SIS Mixers with Epitaxial and Hybrid Coupling Circuits**

*S.V. Shitov, NAOJ / IREE RAS; M.A. Bukovski, A.V. Uvarov, O.V. Koryukin, IREE RAS; Y. Uzawa, M. Krough, T. Noguchi, M. Takeda, NAOJ; Z. Wang, NICT; A.N. Vystavkin, IREE RAS*

To provide a basis for optimum choice of a SIS mixer for ALMA Band-10 (787-950 GHz), numerical simulations are performed based on properties of both the experimental SIS junction and the possible design of its coupling circuit. The "traditional" Nb-AlO<sub>x</sub>-Nb and epitaxial NbN-AlN(MgO)-NbN junctions are studied within either NbN(NbTiN)/Al or all-epitaxial NbN circuit. The calculations are based on Tucker's theory and on experimentally defined properties of metal films of NbN, NbTiN and Al. The extra noise associated with multiple Andreev reflection in NbN-based SIS junctions is also taken into account. The numerical simulations are finally fitted to the best experimental data available from the literature and from our own experimental study. We conclude that, in spite the relatively leaky IV-curve, the performance of epitaxial NbN mixer embedded into a low-loss epitaxial NbN tuning circuit can be about the same as the performance of a high-quality Nb-AlO<sub>x</sub>-Nb junction embedded into a NbTiN/Al tuning circuit - the solution known as a hybrid circuit. The abovementioned conclusion is supported by the most recent experiments, which demonstrated receiver noise temperature below 300 K (DSB) at about 900 GHz for the circuits made from the epitaxial NbN. A report on the most recent experimental results of ALMA Band-10 is also expected at this conference.

*The research supported by ALMA-Japan Office, Japan, and by Program of Leading Scientific Schools, Russia.*

### 3EPE02

#### Invited

#### **An Octave-bandwidth SIS Mixer as a Tool of Optimization of Photonic Oscillators in Terahertz Range**

S.Kohjiro, K.Kikuchi, M.Maezawa, AIST; T.Furuta, A.Wakatsuki, NTT PH Labs.; N.Shimizu, T.Nagatsuma, Y.Kado, NTT MI Labs.; H.Ito, NTT PH Labs.; A.Shoji, AIST

We are developing a heterodyne receiver for 0.2-0.5 THz based on an octave-bandwidth SIS mixer pumped by a widely-tunable photo-mixing CW oscillator (Ph-OSC). A Ph-OSC consists of several optical components and its noise characteristics have not fully been studied yet. For its study, however, conventional detectors such as Schottky diodes at room temperature do not provide enough sensitivity. In this paper, we demonstrate a SIS mixer as a measurement tool of amplitude noise of a Ph-OSC. Receiver noise temperature (Trx) was measured with a Ph-OSC under the test as the local oscillator (LO). The result was compared to Trx with a reference LO. Trx consists of two components. One is the intrinsic noise dominated by the mixer noise. The other is the amplitude noise of LO. The latter contribution is pronounced by adopting a low noise mixer which couples to LO more tightly than the optimum value. Using a SIS mixer with Trx~200 K, the variation of Trx in the range of 1-100 K above the reference value was experimentally found as a function of parameters of the Ph-OSC. This result indicates a SIS mixer is useful for the optimization of a Ph-OSC, and suggests its possible application for a diagnostic tool of optical sources in terms of the noise.

*This work was supported in part by the Grant 10704 of the National Institute of Information and Communications Technology, Japan.*

### 3EPE03

#### Invited

#### **Development and Characterization of the Superconducting Integrated Spectrometer for TELIS.**

V.P.Koshelets, A.B.Ermakov, L.V.Filippenko, A.V.Khudchenko, O.S.Kiselev, A.S.Sobolev, M.Y.Torgashin, G.de Lange, Institute of Radio Engineering and Electronics, Moscow, Russia;

P.A.Yagoubov, R.W.M.Hoogeveen, W.Wild, SRON Netherlands Institute for Space Research, the Netherlands

The first flight of the balloon borne instrument TELIS (Terahertz Limb Sounder) is scheduled for May 2008. The main objective of this mission is to study spectral lines of the stratospheric trace gases at submm and THz frequencies. The IREE/SRON contribution to TELIS is the 500-650 GHz Superconducting Integrated Receiver (SIR) channel. This is a unique on-chip heterodyne receiver, consisting of a double dipole antenna, a SIS mixer, a flux-flow Local Oscillator, and a harmonic SIS-mixer to phase lock the LO. As a result of recent receiver's optimization the DSB noise temperature was measured as low as 140K for the SIR with intermediate frequency band 4-8 GHz. We will also present preliminary results of the first flight.

*The work was supported by the projects: RFBR 06-02-17206, ISTC # 3174, NATO SFP 981415*

### 3EPE04

#### **Epitaxial AlN tunnel barriers suitable for SIS mixers at frequencies around 700 GHz**

C.F.J.Lodewijk, E.van Zeijl, T.Zijlstra, D.N.Loudkov, Delft University of Technology; F.P.Mena, A.M.Baryshev, SRON; T.M.Klapwijk, Delft University of Technology

Superconductor-insulator-superconductor (SIS) junctions with an AlN barrier have been shown to maintain a high quality current-voltage characteristic up to a much higher critical current density than reachable with the commonly used AlOx barriers. We attribute this to a better spatial uniformity of the barrier transmissivity, associated with the crystalline nature of the AlN barrier. High critical current density, lower specific tunnel resistance, devices have a lower RC time, allowing a larger bandwidth for high frequency mixers. We have developed a new fabrication process for AlN barriers with excellent reproducibility and control compared to previous work, enabling the exploitation of these barriers in SIS mixers. We report results with Nb/AlN/Nb SIS mixers for 700 GHz demonstrating their wide bandwidth behavior with Fourier Transform Spectrometer (FTS) measurements. These measurements have been performed in air and show that the bandwidth of the AlN devices is no longer limited by the barrier. Instead, the electromagnetic environment, through both the atmospheric absorption of radiation (due to the presence of water) and the antenna impedance, limits the frequency response. We also present noise temperature measurements of AlN SIS mixers that complement the FTS results. The noise temperature reaches record low values over an unprecedented broad frequency range around 600 to 720 GHz.

### 3EPE05

#### **Properties of a novel THz SIS mixer with NbTiN-groundplane and SIS micro-trilayers directly grown on a quartz substrate**

A.Endo, Univ. of Tokyo; T.Noguchi, M.Kroug, S.V.Shitov, NAOJ; H.Inoue, Univ. of Tokyo; T.Kojima, Osaka Pref. Univ.; W.Shan, T.Tamura, PMO; Y.Uzawa, T.Sakai, NAOJ; K.Kohno, Univ. of Tokyo

A new structure and fabrication process for multi-material THz-SIS mixers will be presented. In this design, both the micrometer-sized SIS trilayers (MTL: micro-trilayer) and the groundplane are deposited directly onto the substrate. This structure is expected to possess a number of unique features, e.g., (1) the quality of the SIS junction is not affected by the physical nature of the groundplane film; (2) the heat can escape directly from the junction into the substrate. We have investigated the influence of the MTL-structure on the junction quality and circuit characteristics. Numerical calculation suggests that the effect of the extra resistance around the junction is tolerable in terms of extra rf losses, if the separation between the junction and the groundplane is less than 1 micrometer. Such MTL-SIS mixers have been fabricated using Nb/Al-AlOx(or AlNx)/Nb SIS junctions and NbTiN/Al microstriplines. The leakage current is comparable to that of the best all-Nb devices, suggesting that the junction quality is not affected by the groundplane properties. The gap voltage of the junctions was found to decrease when the diameter of the trilayers was less than about 10 micrometers. The degree of back-bending of the I(V) curves was identical to that of all-Nb devices, which indicates that the cooling of the junction is not degraded by the MTL structure.

### 3EPE06

#### Performance of terahertz waveguide SIS mixers employing epitaxial NbN films and Nb junctions

*T.Kojima, National Astronomical Observatory of Japan/Osaka Prefecture University; M.Kroug, National Astronomical Observatory of Japan; M.Takeda, National Institute of Information and Communications Technology; W.-L.Shan, Purple Mountain Observatory; Y.Fujii, Y.Uzawa, National Astronomical Observatory of Japan; Z.Wang, S.-C.Shi, National Institute of Information and Communications Technology*

We have developed waveguide SIS mixers with Nb/AlO<sub>x</sub>/Nb tunnel junctions and NbN/SiO<sub>2</sub>/Al microstriplines for the terahertz band. The ground plane is a 250-nm thick epitaxial NbN film grown on a single crystal MgO substrate. Two Nb junctions are connected in parallel by a 400-nm-thick Al wiring to form a tuning circuit, which is placed directly on the feed point of the bow-tie waveguide probe without impedance transformers. Nb junctions with a current density of 6.5 kA/cm<sup>2</sup> showed good I-V characteristics yielding a subgap-to-normal-state-resistance ratio of more than 20. The heterodyne receiver noise measurements were made using the standard Y-factor method with room-temperature (295 K) and liquid-nitrogen-cooled (77 K) loads. The local oscillator (LO) power was quasi-optically introduced into the signal path through a 12.5-micron-thick Kapton film. Preliminary results of the mixer performance showed a receiver noise temperature of 460 K (DSB) at 1 THz, corrected for losses in the beam splitter and the vacuum window. More mixers are now under test and the results will be included in the presentation.

### 3EPE07

#### Development of Nb/Al-AlN/NbTiN SIS Junctions with ICP Nitridation

*T.W.Cecil, M.E.Cyberey, R.E.Matthews, A.W.Lichtenberger, University of Virginia*

Increasing the operating frequency of SIS receivers requires a shift from Nb/Al-AlO<sub>x</sub>/Nb junctions to new material stacks. Two major limiting factors of higher frequency operation are the increase in subgap leakage that occurs in AlO<sub>x</sub> barriers as current densities approach and exceed 10kA/cm<sup>2</sup> and the increased loss in Nb electrodes above ~ 700 GHz. A promising alternative structure is the hybrid Nb/Al-AlN/NbTiN junctions. Realization of these devices has been difficult due to the challenge of fabricating devices with repeatable current densities and electrical characteristics. We present on the fabrication and dc testing of Nb/AlN/NbTiN junctions. The AlN barrier is formed using an inductively coupled plasma (ICP) source which allows for independent control of ion energy and current density. This improved control enables the repeatable synthesis of high quality barriers. Nb and NbTiN electrodes are deposited by unbalanced dc magnetron sputtering. A new fabrication process was developed to enable fabrication of junctions with diameters as small 600nm. The relationship between barrier thickness and plasma conditions is determined by in-situ discrete ellipsometry. Ellipsometry results were verified by comparison with measured current-voltage characteristics. Curves for a range of current densities and junction sizes are presented. Plans for in-situ Farady monitoring of the energy and current density of the ICP nitridation plasma will also be discussed.

### 3EPE08

#### THz Spectroscopy Using Superconducting Tunnel Junction Detectors

*T.Taino, H.Ishii, Y.Watanabe, K.Aoki, N.Yamashita, H.Myoren, S.Takada, Saitama University, Japan; S.Ariyoshi, C.Otani, H.Sato, RIKEN, Japan*

We have been developing terahertz (THz) electromagnetic-waves detectors using superconducting tunnel junctions (STJs). Nb-based STJs were fabricated on LiNbO<sub>3</sub> substrate absorbers, which have high absorption efficiency for the THz region. We used a ring THz parametric oscillator (R-TPO) as THz source. R-TPO can generate THz electromagnetic-wave range from 1 THz to 2 THz. This region is very useful for various applications because many substances have fingerprint spectra and transparency. We have successfully obtained different THz spectra of maltose and fructose using the STJ detectors. We will discuss characteristics of THz spectroscopy using the STJ detectors.

### 3EPE09

#### SFQ Multiplexed Signal Processing Circuits for Superconducting Tunnel Junction Photon Detectors Arrays

*H.Myoren, Y.Yoshizawa, T.Taino, S.Takada, Saitama University, Japan*

We have been studying SFQ digital signal processing (DSP) circuits for a superconducting tunnel junction (STJ) photon detectors array. We assumed that STJ responses for Photon irradiations is increase of quasi-particle's tunnel current and the tunnel current is converted to SFQ pulses whose densities modulated by current signal. A proposed DSP circuit consisted of a binary tree of multiplexer, a time counter, a binary counter, and a read-out memory. The multiplexer was designed that first-arrived bundle of SFQ pulses to connect to the binary counter until the time counter is count-up. The time counter will be set to long enough time compare to the response time of STJ photon detector. After processing the multiplexer, SFQ pulses will be integrated by the binary counter. The integrated number of SFQ pulses is proportional to the number of quasi-particles generated by a photon irradiation in a STJ. After count-up of the binary counter, the binary counter generate a reset SFQ pulse to reset the multiplexer, send the integrated value to the read-out memory and reset the binary counter. The binary tree of multiplexer could be extended to have address bits for photon imaging using STJ array. The part of the proposed DSP circuit was fabricated by using SRL 2.5kA/cm<sup>2</sup> Nb/AlO<sub>x</sub>/Nb standard process, and successfully demonstrated its operations using an on-chip clock generator. Details will be presented at conference.

**3EPF - LTS SQUID Fabrication and Characterization**  
**2:00pm - 4:00pm**

**3EPF01**

*Invited*

**Optimization of dc-SQUID amplifiers with tightly coupled input coils for the readout of a high-Q load in the mK temperature range**

*J.Pleikies, Low Temperature Division, University of Twente; O.Usenko, G.Frossati, Kamerlingh Onnes Laboratorium, Leiden University; J.Flokstra, Low Temperature Division, University of Twente*

Dc-SQUID amplifiers with integrated input coils are being developed for the readout of the resonant mass gravitational wave antenna MiniGRAIL. The important properties for the optimization of the amplifier are the additive and back-action noise, an input inductance in the micro-H range with a high coupling factor, and the dynamic inductance and resistance reflected to the input. Using numerical simulations, we are able to derive all those parameters from realistic models of SQUID sensors including thermal noise, the capacitance of the Josephson junctions, damping resistors as well as parasitic elements for example introduced by integrated coils. Our approach was verified by reproducing the results of a large number of papers on SQUID simulations. The simulation system was used to explain the behavior of the two sensors we presented on the ASC 2006. Most features in the distorted characteristics, including a hysteresis due to the coil resonance, as well as the for one of the designs measured sensitivity could be reproduced. Using the gained experience we are at the moment working on the next design step to improve the performance of the sensors. We will present the actual progress.

*This work has been supported by the dutch technology foundation STW (tm5879).*

**3EPF02**

**DC SQUID modulation electronics for operation with HTS DC SQUID magnetometers in the unshielded environment**

*E.V.Burmistrov, MSU, Faculty of Physics; V.Y.Slobodchikov, V.V.Khanin, Y.V.Maslennikov, IRE RAS; O.V.Snigirev, MSU, Faculty of Physics*

The new variant of DC SQUID modulation electronics for functioning with HTS DC SQUID magnetometers in the unshielded environment, was designed, manufactured and tested. The electronics, was optimized for operation with new ultrasensitive HTS DC SQUID magnetometer with magnetic field resolution of about 15 fT/Hz<sup>1/2</sup> at frequencies above 10 Hz and 30 fT/Hz<sup>1/2</sup> at 1 Hz. The central commutation core of electronics was based on EPLD (Electronic Programmable Logic Device) and allowed to include into the channel the system of a bias reversal and the system of compensation of modulation signal in the feedback, in the bias supply, and in the main signal nets circuits. Such variant provides the stable work independently of configuration of supplying wires in the dipstick or cryostat and configuration of HTS DC SQUID. The electronics was manufactured in one compact box with size 110 mm x 60 mm x 15 mm. The channel has standard bandwidth of about 100 kHz with greatly increased dynamic range due to high coupling (8 mV/Hz<sup>1/2</sup>) of feedback signal with main SQUID's loop.

**3EPF04**

**Extremely Sensitive, Very Long Baseline Planar SQUID Gradiometer**

*R.Cantor, J.A.Hall, STAR Cryoelectronics; A.N.Matlachov, P.L.Volegov, Los Alamos National Laboratory*

We have developed an extremely sensitive, low-T<sub>c</sub> first-order planar gradiometer with a very long baseline of 9 cm. The thin-film gradiometric pickup loop consists of two series-configured 3 cm x 6 cm pickup loops with center-to-center spacing of 9 cm fabricated on a 150 mm Si wafer. The pickup loop is connected to the input circuit of a separate dc SQUID chip using superconducting wire bonds. The measured magnetic field sensitivity of the gradiometer referred to one pickup loop is 0.105 nT/Φ<sub>0</sub>, and the intrinsic noise of the dc SQUID coupled to the thin-film pickup loop typically is 3 μΦ<sub>0</sub>/Hz<sup>1/2</sup>. This results in a magnetic field noise of 0.3 fT/Hz<sup>1/2</sup> and a magnetic field gradient noise of 0.033 fT/cm-Hz<sup>1/2</sup>. Measurements carried out in a magnetic shielded room to characterize gradiometer performance are described.

*This work supported by the U.S. Dept. of Energy, Contract No. DE-FG02-04ER84079*

**3EPG - HTS SQUID Fabrication and Characterization**  
**2:00pm - 4:00pm**

**3EPG02**

**The investigation of the voltage-current and voltage-flux characteristics of high TC DC SQUIDs: the role of the junctions asymmetry in current density and resistivity**

*I.L.Novikov, Y.S.Greenberg, Novosibirsk State Technical University; V.Schultze, R.IJsselsteijn, H.G.Meyer, Institute of Photonic Technology*

We studied 20 purposely asymmetrically made high T<sub>c</sub> DC SQUIDs. All of these SQUIDs were fabricated using standard high T<sub>c</sub> thin film technology and they were single layer ones, having 140 nm thickness of YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7-x</sub> film deposited by laser ablation onto MgO bicrystal substrates with 24° misorientation angle. Measurements have been carried out in two steps. First, for every SQUID we have measured its voltage-current (VCC) and voltage-flux (VFC) characteristics. Second, one of the two junctions in the loop was measured directly. For that, all SQUID loops have been cut to allow the independent measurements of the characteristics of one junction per SQUID. It allows us to determine for the first time independently and directly the current density and resistivity for every junction in the interferometer loop and its influence on the SQUID characteristics. We found the main reason for the asymmetry of VCC and VFC to be the different values of the resistivity and the critical current density for two junctions in the SQUID loop. Furthermore, even for a geometrically symmetric design of the interferometer the critical current densities of the two junctions may be substantially different.

### 3EPG03

#### Characteristics of High-Tc SQUID by focused ion beam and ion damage

*C.H.Wu, Department of Physics, National Chung Hsing University; Y.T.Chou, W.C.Kuo, Department of Physics, Tunghai University; J.H.Chen, L.M.Wang, Department of Electrical Engineering, Da-Yeh University; H.C.Yang, Department of Physics, National Taiwan University; H.E.Horng, Institute of Electro-Optical Science And Technology, National Taiwan Normal University*

We have fabricated high-Tc Josephson junction array and SQUID by focused ion beam (FIB) milling and 110 keV oxygen ion implantation. We have used a single Au mask with a small aperture of 28–50 nm defined by direct milling with FIB. Single junction, 15 junction arrays in series and SQUID have been investigated. We measured the I-V, V-B and noise characteristics of high-Tc YBa<sub>2</sub>Cu<sub>3</sub>O<sub>y</sub> Josephson junctions and array in series under microwaves. The SQUID show the resistive shunted junction (RSJ) behavior. The Shapiro steps were observed in junction. The V-B was measured in SQUID.

*The authors would like to thank the National Science Council of the Republic of China, Taiwan, for financially supporting this research under Contract No. NSC95-2112-M005-016- MY3.*

### 3EPG04

#### Spreads in critical current and normal conductance of high-Tc dc SQUID

*J.T.Jeng, Department of Mechanical Engineering, National Kaohsiung University of Applied Sciences; C.C.Lu, C.C.Wang, Institute of Mechatronic Engineering, National Taipei University of Technology, Taipei 10608, Taiwan.; C.H.Wu, Department of Physics, National Chung Hsing University, Taichung 40227, Taiwan.*

The statistical behaviors of the critical current and the normal conductance of the high-Tc dc SQUID were investigated experimentally. The voltage-current and voltage-flux curves were measured by using a switching electrical cryostat, which can characterize up to 45 elements in a series array. It was found that the spatial correlation between the adjacent SQUIDs is low, which simplifies the statistical analysis. Both the critical-current and normal-conductance histograms of the SQUID follow the gamma distribution. In addition, there is a statistical correlation of about 0.6 between the critical current and the normal conductance. The fluctuations of the effective barrier thicknesses for super- and normal- currents are at the same level, in agreement with the prediction of the intrinsically-shunt-junction model.

*This work is financially supported by the National Science Council of the Republic of China under grant no. NSC95-2112-M-027-003-MY3.*

### 3EPG06

#### Higher order HTSL gradiometers for measurements in unshielded environment

*P.Seidel, A.Steppke, U.Schinkel, V.Grosse, S.Engmann, C.Becker, Institut für Festkörperphysik, FSU Jena; L.Redlich, F.Schmidl, Institut für Photonische Technologien, Jena*

New higher order gradiometer layouts based on high-temperature superconducting thin film bicrystal Josephson junctions are presented. Our single layer gradiometers are suitable for the simultaneous measurement of magnetic field gradients with different spatial orientations. The sophisticated technology for bicrystal Josephson junctions is combined with custom substrates with two crossing 30 degree grain boundaries.

We present the technological challenges focusing on the low ohmic contact resistance using gold nanoparticles embedded in the thin film. The sensor performance is characterized using different SQUID electronics, the main parameters e.g. the critical current, IcRn-product and temperature dependences are compared with single dimension first order 30 degree bicrystal Josephson junction gradiometers. Special emphasis is put on the optimization of the noise properties in unshielded environment.

### 3EPG07

#### SQUIDs based on the superconducting MgB<sub>2</sub> thin films prepared by AFM scratching and FIB.

*M.Gregor, T.Plecenik, R.Micunek, Department of Experimental Physics, FMPI CU, Bratislava, Slovakia; S.Beloshapkin, Materials and Surface Science Institute, University of Limerick, Limerick, Ireland; T.Roch, Department of Experimental Physics, FMPI CU, Bratislava, Slovakia; M.Stefecka, Biont a.s., Bratislava, Slovakia; M.Zahoran, V.Gasparik, M.Grajcar, P.Kus, A.Plecnik, Department of Experimental Physics, FMPI CU, Bratislava, Slovakia*

Superconducting quantum interference devices have been prepared on MgB<sub>2</sub> thin films by AFM scratching technique and FIB lithography. Superconducting MgB<sub>2</sub> thin films were prepared by magnetron sputtering and ex-situ annealing in vacuum chamber. The critical temperature of the MgB<sub>2</sub> thin film was 32 K. Critical temperature of the nanobridge was Tc=18 K and critical current was 0.35 x 10<sup>-6</sup> A at 4.2 K. Phase shift between voltage across the tank and driving current as a function of magnetic flux have been measured. Current-phase characteristics and critical current vs. temperature have been calculated.

#### 3EPH - Qubit Control, Readout, and Characterization – I 2:00pm - 4:00pm

### 3EPH01

#### Microwave Reflectometry Readout of a dc SQUID Phase Qubit

*B.K.Cooper, R.M.Lewis, S.K.Dutta, T.A.Palomaki, A.Przybysz, H.Kwon, H.Paik, J.R.Anderson, C.J.Lobb, F.C.Wellstood, University of Maryland*

Several groups have recently used microwave reflectometry as a measurement technique for qubit readout [1,2]. These measurements are high speed, typically taking place in tens of nanoseconds and allowing for many measurements per second due to low heating of the system. They are also highly sensitive and projective, meaning that the final state of the qubit remains in the logical basis. We will discuss progress towards implementing reflectometry techniques for the readout of a dc SQUID phase qubit. One step along the path includes reflectometry measurements of the flux state of the qubit. Since quick (~2-3 ns) current pulses can be used to preferentially shift qubits in the 1 state to a different flux well, such a technique could be used for readout. Data taken at 55 mK from our Nb/AlO<sub>x</sub>/Nb SQUID (fabricated by Hypres) with symmetric junction critical currents of approximately 5 microamps and qubit frequencies of 5-7 GHz will be presented. [1] Siddiqi et al., Phys. Rev. B 73, 054510 (2006). [2] Lupascu et al., Phys. Rev. Lett. 96, 127003 (2006).

### 3EPH02

#### **SFQ Single-Shot Readout Circuit for a Flux Qubit Based on Current-to-Time Conversion**

*S.Nakamura, H.Numabe, A.Fujimaki, Nagoya Univ., CREST-JST*  
We have evaluated a single-flux-quantum (SFQ) readout circuit for flux qubits based on current-to-time conversion. The most important quality parameter of the readout circuit is current resolution, which determines whether a single-shot readout is possible or not. The readout circuit studied here is composed of a splitter and a delay-flip-flop (DFF). The splitter is made up of unshunted junctions and coupled mutually with a qubit through an appropriate coil. An SFQ pulse is split into two pulses at the splitter. Each of the pulses propagates in different paths. Depending on the directions of circulating current of a qubit, one pulse accelerates/decelerates and reaches the 'data' port of the DFF, and the other decelerates/accelerates the 'clock' port. The DFF serves as a zero-cross time-discriminator of the two-pulse arrivals and judges the current direction. In the actual readout circuit, there is a finite current resolution because of time fluctuation such as a jitter. We have evaluated the time jitter and found that origin experimentally, and then we improve the circuit to reduce the effect of thermal noise. For example, we increase the subgap resistances, increase the coupling coefficient between the coil and splitter, and reduce the number of junctions. The observed current resolution is around 0.8 micro amperes at 4.2 K. This enables us to realize a single-shot readout of a qubit when the circuit is placed at lowered temperatures. We currently examine the temperature dependence of the resolution.

### 3EPH03

#### **Measurement of the excited state lifetime of a Cooper-pair box**

*Z.Kim, V.Zaretsky, Y.Yoon, Department of Physics, UMD;  
J.F.Schneiderman, M.D.Shaw, Department of Physics, USC;  
P.M.Echternach, Jet Propulsion Laboratory, California Institute of Technology; F.C.Wellstood, B.S.Palmer, JQI, CNAM, Department of Physics, UMD*

We have used a radio-frequency superconducting single-electron transistor (rf-SET) to measure the lifetime ( $T_1$ ) of the excited state of an Al/AlOx/Al Cooper-pair box (CPB) qubit. The CPB had a charging energy  $E_c/k_B = 0.58$  K and a Josephson energy  $E_J/k_B$ , which could be tuned by an external magnetic flux between 0.1 and 1 K. To measure the lifetime of the excited state of the box, we applied a small voltage perturbation to the gate of the CPB at the ground to first excited state transition frequency and then turned the microwaves off. By averaging many measurements we observed an exponential decay to the ground state from a mixed state. We found that by decreasing  $E_J/k_B$  from 1 K to 0.1 K, we could increase  $T_1$  from less than 50 ns to 5  $\mu$ s, which suggests that charge noise is the dominant noise source. Additionally by varying the operating point (gate voltage) of the qubit we have observed several narrow peaks in the decay rate. We note the location of those peaks coincided with the location of anomalous avoided level crossings measured by spectroscopy, suggesting the interaction with microstates is another source of dissipation for the CPB.

*This research was supported by the National Security Agency.*

### 3EPH04

#### **Single qubit state tomography of phase qubits**

*J.D.Whittaker, F.Altomare, K.Cicak, R.W.Simmonds, NIST Boulder*  
We have performed single qubit state tomography of superconducting phase qubits. By applying microwave control pulses of particular phase, amplitude, and duration just before state measurement, we can effectively determine all three components of the qubit's state or Bloch vector. The rotation of the state basis allows us to essentially project the planar components of the state vector along our single measurement z-axis. Thus, two additional rotations (microwave pulses) along with our standard measurement pulse provides a complete description of the qubit state.

### 3EPH05

#### **Temperature Dependence of the Energy Relaxation Rate in an RF SQUID Flux Qubit**

*B.Mao, W.Qiu, Univ. of Kansas; Y.Yu, Nanjing Univ.; S.Han, Univ. of Kansas*

From microwave and resonant tunneling spectroscopy measurements we independently obtained all device parameters needed to reconstruct the Hamiltonian of an rf SQUID which is a macroscopic quantum system promising for quantum information processing. The energy relaxation of the rf SQUID as a function of flux bias and temperature were investigated experimentally. It is found that the energy relaxation rate at different flux biases can be scaled to universal temperature dependence. This universal T-dependence of  $T_1$  time can be obtained from a theoretical model in which the thermal equilibrium population of the excited states is considered.

*This work is supported in part by NSF Grant No. DMR-0325551, the State Key Program for Basic Research of China (2006CB921801), and the 111 project under Grant No. B07026.*

### 3EPH07

#### **Size Dependence of Local 1/f Flux Noise in Superconducting Flux Qubits**

*B.Mao, W.Qiu, S.Li, S.Han, Dept. of Physics and Astronomy, Univ. of Kansas; Y.Yu, Dept. of Physics, Nanjing University, China*

Excessive low frequency local flux noise has been identified as the dominant decoherence mechanism in experiments involving flux qubits. Recently, a model for 1/f flux noise in flux qubits based on spin-locked hopping of electrons between local material defects has been proposed which shows that the total amount of low frequency noise is proportional to the perimeter rather than the area of flux qubits. To investigate the size-dependence of local 1/f flux noise we measured the low frequency flux noise in SQUID flux qubits with inductance ranging from about 30 pH to 1 nH. It is found that for Nb SQUIDs fabricated with similar trilayer process the measured rms low frequency flux noise depends linearly on the inductance of the SQUIDs. Implications of the result on design of flux qubit will be discussed.

*This work was supported in part by NSF Grant No. DMR-0325551.*

### 3EPH08

#### **Macroscopic Resonant Tunneling in a RF-SQUID Superconducting Flux Qubit**

*G.Z.Sun, Research Institute of Superconductor Electronics, Department of EE, Nanjing University; Y.Yu, National Laboratory of Solid State Microstructures, Department of Physics, Nanjing University; J.Chen, P.H.Wu, Research Institute of Superconductor Electronics, Department of EE, Nanjing University*

author list: Sun Guozhu 1\*, Wang Yiwen 2, Cong Shanhua 1, Chen Jian 1, Ji Zhengming 1, Kang Lin 1, Xu Weiwei 1, Yu Yang 2, Siyuan Han 1, 3 and Wu Peiheng 1 affiliations: 1 Research Institute of Superconductor Electronics, Department of Electronic Science and Engineering, Nanjing University, Nanjing 210093, China 2 National Laboratory of Solid State Microstructures, Department of Physics, Nanjing University, Nanjing 210093, China 3 Department of Physics and Astronomy, University of Kansas, Lawrence, KS 66045, USA. Abstract: By preparing the initial state, we measured macroscopic resonant tunneling of magnetic flux between macroscopically distinct quantum states in a superconducting qubit, the bistable RF-SQUID flux qubit. The macroscopic resonant tunneling depends on the barrier of the potential well, the flux bias and the initial state. Detailed measurements of the probability as a function of the flux bias revealed that there is a resonant peak or dip at the vicinity of resonance point. This observation indicates that the dominant low frequency (1/f) flux noise in our qubit is quantum mechanical in nature.

## WEDNESDAY LATE AFTERNOON ORAL SESSIONS

4:00pm - 6:00pm

### 3EX - Transition Edge Sensors X – Applications

4:00pm - 6:00pm

4:00pm

#### **3EX01 - Development of Ir TES for the large array of rhenium detectors of the MARE experiment.**

*F.Gatti, D.Bagliani, University and INFN of Genoa; D.Bogorin, University of Miami; L.Ferrari, University and INFN of Genoa; M.Galeazzi, University of Miami; G.Gallinaro, R.Vaccarone, R.Valle, University and INFN of Genoa*

The compelling evidences of finite neutrino mass have renewed the interest in developing new methodologies for the direct measurement. Presently TES based detector appear to be one of the most advanced and robust solutions for building large arrays that are needed for a calorimetric measurement. An energy resolution at the eV level, fast response in the us range and large integration are requirements that could be properly addressed with the TES technology. We present the status of the development of a possible detector with a superconducting Re-absorber for the MARE experiment. with respect to the TES film production processes and the Re-absorber to TES thermal coupling.

4:15pm

#### **3EX02 - Detector Development for the SuperCDMS Experiment**

*C.N.Bailey, Case Western Reserve University*

The Cryogenic Dark Matter Search (CDMS) is searching for Weakly Interacting Massive Particles (WIMPs) with the ability to discriminate between candidate (nuclear recoil) and background (electron recoil) events by collecting both phonon and ionization energy from recoils in the detector crystals. As CDMS aims to achieve greater WIMP sensitivity, it is necessary to increase the detector mass and discrimination against backgrounds. CDMS is engaged in ongoing fabrication and development of new detector designs in order to meet these criteria for the proposed SuperCDMS experiment. Results from continuing laboratory tests will be presented.

4:30pm

#### **3EX03 - Alpha particle spectroscopy using superconducting microcalorimeters**

*R.D.Horansky, J.N.Ullom, J.A.Beall, G.C.Hilton, K.D.Irwin, NIST; D.E.Dry, E.Hastings, S.P.Lamont, C.R.Rudy, M.W.Rabin, LANL*

Alpha spectroscopy is the preferred technique for analyzing trace samples of radioactive material because the alpha particle flux can be significantly higher than the gamma-ray flux from nuclear materials of interest. Traditionally, alpha spectroscopy is performed with Si detectors whose resolution is at best 8 keV FWHM. Here, we describe the design and operation of a microcalorimeter alpha detector with an energy resolution of 1.4 keV FWHM at 5 MeV, the highest resolving power to date. The microcalorimeter consists of a 1.7 mm by 1.7 mm

square of superconducting Sn resting on 8 epoxy posts. The posts are located on a thin film of Cu that connects to a Mo/Cu bilayer transition-edge sensor. The Cu and Mo/Cu films are deposited on a micromachined SiN membrane. We demonstrate the ability of the microcalorimeter to clearly resolve the alpha particles from Pu-239 and Pu-240, whose ratio differentiates reactor-grade Pu from weapons-grade. We also show the first direct observation of the 4.885 MeV alpha decay of Po-209 to the ground state of Pb-205 which has traditionally been obscured by a much stronger alpha line 2 keV away. Finally, the 1.4 keV resolution observed for alpha particles is far worse than the 0.12 keV resolution predicted from thermal fluctuations and measurement of gamma-rays. The cause of the resolution degradation may be ion damage in the tin. Hence, alpha particle microcalorimeters may provide a novel tool for studying ion damage and lattice displacement energies in bulk materials.

4:45pm

#### **3EX04 - High-Efficiency Transition-Edge Sensors for visible and near-infrared wavelengths**

*A.E.Lita, Optoelectronics Division, NIST; A.J.Miller, Physics Department, Albion College; S.Nam, Optoelectronic Division, NIST*

Single-photon detectors operating at visible and near-infrared wavelengths with high detection efficiency and low noise are a requirement for many quantum-information applications. Detection of visible and near-infrared light at the single-photon level and discrimination between one- and two-photon absorption events place stringent requirements on transition edge sensors (TES) design in terms of heat capacity, thermometry, and optical detection efficiency. We have explored two different material systems such as tungsten and hafnium for our TESs. We describe the design, fabrication and evaluation of our fiber coupled photon-number-resolving detectors optimized for absorption at 1550 nm, 860 nm and 710 nm.

5:00pm

#### **3EX05 - Array-scale performance of TES x-ray calorimeters suitable for Constellation-X**

*C.A.Kilbourne, S.R.Bandler, A.D.Brown, J.A.Chervenak, M.E.Eckart, F.M.Finkbeiner, N.Iyomoto, R.L.Kelley, F.S.Porter, S.J.Smith, NASA Goddard; W.B.Dorise, K.D.Irwin, NIST Boulder*

Having developed a transition-edge-sensor (TES) calorimeter design that enables high spectral resolution in high fill-factor arrays, we now present array-scale results from 32-pixel arrays of identical closely packed TES pixels. Each pixel in such an array contains a Mo/Au bilayer with a transition temperature of 0.1 K and an electroplated Au or Au/Bi x-ray absorber. The pixels in an array have highly uniform physical characteristics and performance. The arrays are easy to operate due to the range of bias voltages and heat-sink temperatures over which resolution better than 3 eV at 6 keV can be obtained. Resolution better than 3 eV has also been obtained with 2x8 time-division SQUID multiplexing. We will present the detector characteristics and show spectra acquired through the read-out chain from the multiplexer electronics, through the demultiplexer software, to real-time signal processing. We are working towards demonstrating this performance over the range of count rates expected in the observing program of the Constellation-X observatory. We will discuss the impact of increased counting rate on spectral resolution, including the effects of crosstalk and optimal-filtering dead time.

5:15pm

### **3EX06 - Transition-Edge Sensor Development for Gamma-Ray Spectroscopy**

*J.Ullom, J.Beall, W.Dorise, G.Hilton, R.Horansky, K.Irwin, C.Reintsema, E.Sassi, L.Vale, NIST; B.Zink, Denver University; M.Bacrania, A.Hoover, M.Rabin, Los Alamos National Laboratory; C.Kilbourne, J.King, NASA Goddard*

We are presently developing multiplexed arrays of gamma-ray microcalorimeters based on transition-edge sensor (TES) thermometers. The unmatched resolution of these devices allows improved analysis of nuclear materials based on X- and gamma-ray spectroscopy below 200 keV. We have demonstrated resolutions as good as 22 eV FWHM at 103 keV in a single pixel and 47 eV at 103 keV across a 14 pixel array. We use absorbers made of bulk superconducting Sn to stop the highly penetrating gamma-rays. Typical absorber sizes are 1-2.25 mm<sup>2</sup> and 0.25 mm thick. We have recently installed a cryogen-free spectrometer with capacity for 256 pixels at Los Alamos National Laboratory.

We present high-statistics spectra of Pu isotopic mixtures obtained with this unique instrument and discuss the analysis of these spectra. We also discuss ongoing efforts to improve the resolution, area, and efficiency of the TES detectors. In particular, we discuss early experiments with absorbing materials other than Sn that offer significantly higher efficiency.

5:30pm

### **3EX07 - Development of a gamma-ray detector using iridium transition edge sensor coupled to a lead absorber**

*R.M.T.Damayanthi, H.Takahashi, The University of Tokyo, Japan; M.Ohno, The University of Tokyo & PRESTO, Japan; N.Iyomoto, The University of Tokyo, Japan; S.W.Leman, Massachusetts Institute of Technology, Cambridge; K.Nishimura, Y.Minamikawa, The University of Tokyo, Japan*

We are developing a gamma-ray detector for use in Coincidence Doppler Broadening (CDB) Positron Annihilation Spectroscopy (PAS) studies. Transition edge sensor (TES) based gamma-ray detectors have been reported upto energies of ~100 keV, whereas we are developing a detector to measure annihilation gamma rays at 511 keV. Commercially available HPGe detectors for PAS measurements are limited to ~1 keV energy resolution. TES based gamma-ray detectors do not suffer from this limitation and 27 eV energy resolution at 103 keV has been reported which scales to ~60 eV for a detector saturates at 511 keV. Thus we aim at ~100 eV resolution at 511 keV. Our detector is a microcalorimeter consisting of a bulk lead (Pb) absorber coupled to an iridium TES. Pb has a very short attenuation length and a predominance of photoelectric absorptions at 511 keV gamma-ray photons. We use 1 mm cubic Pb absorber, which has ~10% absorption efficiency at 511 keV. Our detector is composed of 300 μm x 300 μm Ir-TES film with niobium electrical leads. Pb absorber is glued to TES detector to make the composite gamma-ray detector. We hope to present the first result of this gamma ray detector in the workshop.

5:45pm

### **3EX08 - Noise characteristics of superconducting multilayer Gamma-ray microcalorimeter arrays.**

*M.Velázquez, O.B.Drury, J.G.Dreyer, S.Friedrich, Advanced Detector Group at Lawrence Livermore National Laboratory*

We have developed cryogenic Gamma-ray microcalorimeters based on arrays of superconducting transition edge sensors (TESS) operated at temperatures of ~0.1 K. Each pixel consists of a bulk Sn absorber attached to a superconducting Mo/Cu multilayer thermistor that is weakly coupled to a cold bath through a SiN membrane. These sensors can improve the energy resolution by an order of magnitude over conventional HPGe detector.

We have achieved an energy resolution of 50 – 90 eV FWHM at 100 keV and count rates above 100 counts/s per pixel. We present a two-mass model to describe the physics of our devices and simulate their response and noise characteristics. This model allows us to describe the detector in terms of its heat capacities and thermal conductances, and optimize its response. We also discuss the homogeneity of the pixels in large arrays over 4” diameter wafers. *This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344*

### **3EY - Qubit Control, Readout, and Characterization – II** **4:00pm - 6:00pm**

4:00pm

*Invited*

#### **3EY01 - RSFQ Readout of Single-Qubit Coherent Oscillations**

*T.A.Ohki, Microtechnology & Nanoscience Dept., Chalmers University of Technology; J.Lisenfeld, S.Poieto, A.Ustinov, Physikalisches Institut III, Universitaet Erlangen-Nuernberg; A.Savin, Low Temperature Laboratory, Helsinki University of Technology; J.Hassel, L.Grönberg, VTT; A.Herr, Microtechnology & Nanoscience Dept., Chalmers University of Technology*

RSFQ has been targeted as a suitable technology for the readout of superconducting qubits. We have made measurements of a Josephson junction phase qubit using an RSFQ flux comparator. The qubit was fabricated with relatively large junctions and also with a SiO<sub>x</sub> dielectric. As a consequence, the coherence times were short compared to the better coherence times measured in similar systems with different topologies and materials. Measurements of the coherent oscillation of the inductively isolated phase qubit with a weakly coupled RSFQ flux comparator showed no degradation of the coherence times that were measured via the “conventional” method of using a dc-SQUID magnetometer. The circuit provides ultra-fast sampling times of 50 ps and contributes negligible on-chip dissipation at 30 mK.

*This work has been supported by the RSFQubit EU FP-6 project.*

4:30pm

#### **3EY02 - Superconducting integrated microwave I-Q modulator for qubit control**

*M.R.Raihan, T.Ohki, A.Y.Herr, Chalmers Univ. of Technology*

We present a microwave I-Q modulator developed for control of superconducting qubits. The I-Q modulator performs the same functions as a conventional modulator - generating microwave pulses of desired frequency, pulse-width, amplitude and phase. The solution is completely in the superconducting domain. By utilizing miniaturized and tunable microwave components we make the integrated system scalable for many channels. We have experimentally demonstrated operation of all building blocks designed and fabricated in the Hypres 4.5 kA/cm<sup>2</sup> fabrication process: miniaturized bandpass filters, tunable filters, modulator, and phase shifter. The tunable components are based on series of SQUIDs used as a tunable inductance. Currently, the I-Q modulator can provide an output signal frequency between 3-5 GHz with 5 ns width of the microwave pulses at maximum power level of -52 dBm. Currently, we are able to measure phase shifting of 32° for 3-5 GHz and a 17 dB On-Off ratio at 3.16 GHz for the modulator limited by the sensitivity of the measurement equipment. We are going to present current results and solution for wider bandwidth multi-channel system.

**4:45pm**

**3EY03 - Reciprocal Quantum Logic**

*Q.P.Herr, Northrop Grumman Systems Corp.; A.Y.Herr, University of Maryland College Park*

Signal energy levels in superconductor digital gates are incredibly small, within a few orders of magnitude of the Boltzman limit. However, the established RSFQ logic family uses bias resistors that dissipate at least a factor of ten more power than the active devices themselves, even in a gate that is running at 100% utilization. Such high static power dissipation squanders much of the power advantage of superconductor technology for digital signal processing applications, and is incompatible with the requirements of qubit control circuitry operating in the 10-100 milliKelvin regime. We propose a new logic family called Reciprocal Quantum Logic (RQL) that completely eliminates bias resistors and static power dissipation. The gates are instead powered by inductive coupling to an ac clock source, which provides a stable timing reference. The gates are effectively powered in series, leading to a relatively high voltage, low current power supply. Initial results show device count and operating margins of basic gates such as And, Or, Inverter, Nor, Xor, and the shift register to be favorable compared to RSFQ.

*This work was supported in part by the Office of Naval Research*

**5:00pm**

**3EY04 - Characterization of the Environment Influencing RF-SQUID Flux Qubits**

*M.W.Johnson, R.Harris, A.J.Berkley, J.Johansson, T.Lanting, P.Bunyk, E.Ladizinsky, M.H.S.Amin, C.J.S.Truncik, D-Wave Systems, Inc.; S.Han, Department of Physics and Astronomy, University of Kansas; B.Bumble, A.Fung, A.Kaul, A.Kleinsasser, Jet Propulsion Laboratory, California Institute of Technology; D.V.Averin, Department of Physics and Astronomy, SUNY Stony Brook*

Measurements of macroscopic resonant tunneling between the two lowest lying states of single and multiple bistable RF-SQUIDs are used to characterize noise in flux qubits. Analysis indicates that the noise originates from a quantum mechanical environment in thermal equilibrium that couples primarily to the flux degree of freedom of the qubits. The noise spectral density of the environment is sharply peaked at low energy and potentially possesses an ohmic density of states at high energy. These conclusions are shown to be consistent with measurements of the low frequency flux noise power spectral density obtained from the same devices.

**5:15pm**

**3EY05 - Amplitude Spectroscopy of a Superconducting Qubit**

*W.D.Oliver, MIT Lincoln Laboratory; D.Berns, S.Valenzuela, M.Rudner, L.Levitov, T.P.Orlando, MIT*

We introduce and demonstrate amplitude spectroscopy in a superconducting qubit. In contrast to frequency spectroscopy, in which one sweeps frequency at a fixed amplitude to probe the energy spectra of a quantum system, with the amplitude spectroscopy technique, quantum state transitions between energy levels are induced by varying the driving-field amplitude at a fixed frequency. In our qubit, the resulting spectroscopy patterns assume the shape of "diamonds," and their constituent quantum interference patterns, including population inversion, correspond directly to the qubit energy spectrum. We observe and analyze four such spectroscopy diamonds, and extract energy spectra for an entire manifold of states with energies from 0.01 GHz to 120 GHz for a driving frequency near 0.1 GHz.

The amplitude spectroscopy technique, a dual to frequency spectroscopy, provides a means to access, manipulate and characterize quantum systems over broad bandwidths using a single probe frequency, which can be orders of magnitude smaller than the energy scales being probed.

*The work at Lincoln Laboratory was sponsored by the Air Force under Air Force Contract FA8721-05-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the author(s) and are not necessarily endorsed by the United States Government.*

**5:30pm**

**3EY06 - Measurements of macroscopic resonant tunneling of magnetic flux in a rf SQUID**

*L.Longobardi, D.Bennett, D.Bluhm, V.Patel, J.Lukens, Stony Brook University*

We report studies of macroscopic resonant tunneling (MRT) between fluxoid states in a rf-SQUID qubit. The modified rf SQUID has independent, in situ, controls for the relative positions of levels in different fluxoid wells and the barrier height between the wells. The ability to independently control the barrier height allows tunneling to be observed over a large range of eigenstates. The measured tunneling rates as a function of flux bias exhibit evidence of energy level quantization up to a temperature (900 mK) well above the crossover temperature ( $T_x$ ) between the quantum and the thermal regime. The data agree with the level structure calculated using independently measured circuit parameters. The shape of the MRT peaks, measured over range of tunneling rates between  $10^{-1}$  1/s and  $10^9$  1/s, is affected by both the lifetime of the excited states and anomalous low frequency flux noise. The MRT is a useful probe of decoherence-inducing flux noise in the rf SQUID since the measurements are much simpler and give values for flux noise related to those obtained from  $T_2$ . *This work has been supported in part by NSF and by AFOSR and NSA through a DURINT program.*

**5:45pm**

**3EY07 - Dynamical Behaviour of Intrinsic Josephson Junctions**

*P.A.Warburton, J.C.Fenton, S.Saleem, University College London; M.Korsah, C.R.M.Grovenor, University of Oxford*

Measurements of macroscopic quantum tunnelling (MQT) in intrinsic Josephson junctions (IJJs) suggest that they may be suitable as qubits. An advantage of using IJJs over trilayers is the absence of any artificial barrier and hence the possible absence of decohering two-level fluctuators. A disadvantage is that it is difficult to fabricate single IJJs. Hence all IJJ MQT experiments have been carried out on arrays of many IJJs in series. Since MQT is suppressed by dissipation, it is important (a) to understand the role of dissipation on the dynamics of IJJs and (b) to consider how the dissipation and the dynamics change as a function of the number of junctions in the array which are in the voltage state. We have measured distributions of the switching current on the  $n$ th branch in TlBaCaCuO IJJ arrays. The junctions show conventional underdamped behaviour below some temperature  $T^*$ , with a suppression of the width of the distribution above  $T^*$ . We find that  $T^*$  depends upon  $n$ . For  $n = 0$  (i.e. switching from the supercurrent branch),  $T^*$  is less than 4.2 K. For  $n > 0$ , we measured  $T^*$  values between 20 K and 40 K. Calculations and simulations show that a change in  $T^*$  results from a change in damping  $Q$ . Analysis suggests that this  $Q$  is determined by the environmental impedance when all junctions in the array are in the zero-voltage state, whereas having one junction or more in the voltage state isolates the array from the environment leading to a higher  $Q$ . We discuss our data in the context of possible qubit applications.

**3EZ - Junction and SQUID Systems and Applications**  
**4:00pm - 6:00pm**

**4:00pm**

**3EZ01 - A SQUID-based nondestructive evaluation system for testing wires at room temperature**

*M.Mueck, University of Giessen; F.Schoelz, W.C.Heraeus GmbH*

A growing use of SQUIDs is in the nondestructive detection of defects, such as cracks, inclusions, or holes, in a variety of materials and structures. Besides testing flat samples, such as aircraft parts or metal sheets, the testing of wires at room temperature is a promising application. When passing an ac current through a wire to be tested, or exciting eddy currents in the wire, defects in the wire will locally change the conductivity, and thus lead to a distortion of the ac or eddy-current flow in the vicinity of the defect. The defect-induced change in conductivity can be detected from the outside by measuring the magnetic field produced by the currents flowing in the wire with a SQUID. For testing certain types of wires, such as aluminum-bond-wire precursors, we developed a special cryostat, which allows for pulling a wire of arbitrary length (which is kept at room temperature) through a niobium flux transformer connected to a niobium dc SQUID. This cryostat is made from a stainless steel inner vessel; the outer tube is from fiberglass, and the gradiometric pickup loops are wound on a German-silver tube through which the wire is pulled. The measured flux noise of the system is about 65 femtotesla per root hertz. With this system, we could detect in a 2-mm-dia. aluminum wire small holes, foreign inclusions, and surface scratches with a length of 50 microns and a depth of less than 10 microns.

**4:15pm**

**3EZ02 - STM-SQUID Probe Microscope**

*H.Itozaki, Osaka University; T.Hayashi, Sendai National College of Technology; M.Tachiki, D.F.He, National Institute of Materials Science*

Scanning SQUID Probe Microscope has been developed using a fine needle. It has high special resolution such as micrometer scale. This special resolution was limited by the distance between the top of the needle and the surface of the sample, because this distance was detected in the order of micrometer by optical microscope. In a while, STM method can control this distance in the order of nanometer. We introduce the STM technique to the SQUID microscope with a fine needle. Bias voltage was applied to the fine needle to obtain tunneling current between the needle and the sample. This current was controlled to be constant to keep the gap between the needle and the sample to be order of nanometer. There was no influence to SQUID microscope by this tunneling current in order to observe magnetic image. Magnetic field of a hard disk was observed and obtained fine image of surface roughness by STM and fine magnetic image by SQUID microscope simultaneously. Magnetic Force Microscope has also high special resolution of magnetic imaging. MFM could be disturbed by the atomic force from the surface when its probe is very near the sample, because MFM detects forces between the probe and the sample such as not only magnetic force but also atomic force. STM-SQUID does not affected by this kind of surface effect, because it detects not force but magnetic field directly.

**4:30pm**

**3EZ03 - Plug-and-Play Cryogen-free Josephson Voltage Standards**

*R.E.Schwall, C.J.Burroughs, P.D.Dresselhaus, S.P.Benz, National Institute of Standards and Technology*

The increasing cost of liquid helium, particularly in developing countries, is providing additional impetus for the development of cryogen-free Josephson Voltage Standard (JVS) systems. Cryogen free operation, however, impacts many aspects of the system design

including the choice of substrate material, chip and wiring configurations, and operating temperatures. We have successfully operated both programmable and ac JVS chips that were cooled by a small (100 mW at 4.2K) cryocooler and present results of the thermal and electrical performance. More importantly, we successfully cooled and operated our circuits in the same flip-chip-on-flex package used for liquid-helium operation. This allows the circuits to operate interchangeably in both cryogenic environments. We also outline those areas requiring additional effort before such systems can be deployed, so that in the near future, all JVS systems may become cryogen-free.

**4:45pm**

**3EZ04 - Highly sensitive measurement of moisture content using HTS-SQUID**

*K.Tsukada, T.Kiwa, H.Tahara, E.Miyake, H.Yamada, Okayama Univ.; A.Tsukamoto, A.Kandori, Hitachi Ltd., Adv. Research Lab.*

We previously reported the AC magnetic properties of a large volume of water as new magnetic phenomenon. Using the phenomenon, the magnetic measurement of the moisture content of grain using a magnetic resistance (MR) sensor became possible. However, higher resolution was desired because magnetic field strength from the sample was insufficient compared with the magnetic resolution of the MR sensor. In this study, we developed a highly sensitive magnetic measurement system for moisture content using a HTS-SQUID sensor. The system consisted mainly of an exposure coil, a Dewar containing HTS-SQUID immersed in liquid nitrogen, a cancellation coil, a lock-in amplifier, magnetically shielded box, and FLL circuit. The cancellation coil was used to eliminate the exposure magnetic field in the sensor position, and then a cancellation ratio of -40dB was obtained. By the high performance, the subject can be exposed to a strong magnetic field strength greater than the order of  $\mu\text{T}$ , and a weak magnetic signal of less than tens of pT can be detected from the subject. However, the exposure magnetic field was not completely removed from the detection signal; therefore, the magnetic vector analysis was adapted to obtain the true magnetic signal. Using these cancellation techniques, more precise measurement of the moisture content was realized.

**5:00pm**

**3EZ05 - High Tc SQUID System for Detection of Small Metallic Contaminant in industrial products**

*S.Tanaka, T.Akai, Y.Hatsukade, Toyohashi Univeristy of Technology; T.Otani, S.Suzuki, Advance Food Technology Co., Ltd.*

3ch High-Tc SQUID system for detection of magnetic foreign matters in industrial products was developed. Finding ultra-small metallic foreign matters is a big issue for a manufacturer, which produces commercial products such as lithium ion batteries. If it happens, the manufacture of the product suffers a large amount of loss to recall for the products. Outer dimension of metallic particles less than 100 micron can not be detected by an X-ray imaging, which is commonly used as the inspection. Therefore a high sensitive detection system for small foreign matters is required. We developed a detection system based on 3ch high-Tc SQUID microscope with a high performance magnetic shield. Three SQUIDs were installed in one microscope-type cryostat with a 3" sapphire vacuum window which separates the SQUID and atmosphere. This design enables the SQUID to approach an object to be measured as close as 1 mm. The minimal detectable size of the foreign matter is also highly dependent on the magnetic field noise of the SQUID. Therefore, we employed double transformer coupling, which lowers the noise. One transformer was placed at 77K and the other was at room temperature. As a result, the magnetic field noise of the SQUID was reduced by 36 %. Finally we could successfully measure small iron particles less than 100 micron. This detection level was hard to be achieved by a conventional X-ray detection method.

5:15pm

**3EZ06 - A full tensor magnetic gradient (FTMG) system for geophysical exploration**

*R.Stolz, M.Schulz, V.Zakosarenko, A.Chwala, L.Fritzsche, Institute of Photonic Technology, P.O. Box 100239, D-07702 Jena, Germany; M.Meyer, Supracon Ltd., Wildenbruchstr. 15, 07745 Jena, Germany; H.-G.Meyer, Institute of Photonic Technology, P.O. Box 100239, D-07702 Jena, Germany*

Airborne geophysics is a commonly used for the geophysical prospecting of large areas with high spatial resolution. Especially the mapping of anomalies of the Earth's magnetic field is well suited for airborne operation. Up to now the measurement of the total field and gradients with Cs vapor magnetometers is the most widely used method. But there are advantages of using the gradient tensor instead of total field gradients. We present the recent results achieved with the FTMG developed by IPHT in collaboration with Supracon Ltd. The tensor components are measured by 6 LTS SQUID gradiometers with a base length of 3.5cm and an intrinsic noise of better than 50fT/m/Hz<sup>1/2</sup> which are further balanced using a reference magnetometer. Signals are recorded by a sophisticated data acquisition unit containing the ADC, INS, and pressure regulator. We report on tests where the system was towed by a helicopter and showed a noise of below 10pT/m (RMS) in a signal bandwidth of 4.5 Hz in flight.

5:30pm

**3EZ07 - HTS SQUID systems for geophysical exploration**

*A.Chwala, R.IJsselsteijn, R.Stolz, F.Bauer, N.Ukhansky, H.-G.Meyer, Institute of Photonic Technology (IPHT), P.O. Box 100239, D-07702 Jena, Germany*

Rising commodity prices are pushing the demands on new technologies for geophysical exploration. IPHT focussed in the last few years on developing Low Temperature SQUID systems for Transient Electromagnetics. They are now used on a routine basis in mineral exploration. The next logical step is to implement latest technologies into HTS SQUID systems. Most important task is to achieve low noise (also at low frequencies) as well as a high dynamic range and slew rate. Hence, a new ac bias flux locked loop electronics has been developed and tested. First field experiments with a single component have proven that such an HTS SQUID system will achieve significant improvements compared to conventional induction coils, especially for deep ore bodies. A sensor triple will allow to measure vertical and horizontal field components simultaneously. Since HTS SQUIDS can show different behaviour if not cooled down in zero magnetic field it is important to characterize the systems in the Earth's magnetic field. Measuring the noise of such a sensitive sensor outside magnetic shielding is the most demanding task and will be demonstrated.

5:45pm

**3EZ08 - Minimum-Norm Source Reconstructions for large-area geomagnetic SQUID Measurements**

*R.Eichardt, D.Baumgarten, J.Hauelsen, TU Ilmenau; S.Linzen, R.Stolz, V.Schultze, H.G.Meyer, IPHT Jena*

Geomagnetic prospection of the underground using highly sensitive SQUID devices is of great interest in many fields, e.g. archaeology, building industry or landmine clearing. In this study we perform a minimum-L2-norm source analysis based on geomagnetic SQUID gradiometer data. The measuring system consists of a non-magnetic vehicle, carrying up to three liquid helium filled cryostats, each containing one or more highly balanced planar first order gradiometers and a magnetometer triplet. The vehicle can be pulled by a car or truck over ground. During measurement, the magnetic signatures of buried objects and anomalies in the underground are sampled with 1 kHz.

An inertial system and a differential GPS provide position and orientation of the measurement device for each sample. For the source analysis we generate a regular 3D grid covering the whole measurement area with variable depths. At each grid point a magneto-static dipole is assumed. Dipole strengths and orientations are estimated by the minimum norm approach. This inverse analysis typically involves at least several tens of thousands of measurement values and dipoles. To reduce the computational complexity, the source reconstruction problem is spatially decomposed and separately solved. As result we achieve a three dimensional dipole distribution, providing information on positions (x,y,z), magnetic moments and extensions of objects or anomalies. The feasibility of the approach is demonstrated on different test data sets.

**THURSDAY, AUGUST 21, 2008**

**THURSDAY MORNING POSTER SESSIONS**

**10:00am - 12:00pm**

**4EPA - Hot Electron Bolometers and Junction Detectors**

**10:00am - 12:00pm**

**4EPA01**

*Invited*

**HTS detectors based on Josephson nano Junctions**

*T.Wolf, LPEM, CNRS-ESPCI-UPMC; P.Febvre, IMEP-LAHC CNRS UMR5130; J.Lesueur, M.Sirena, LPEM, CNRS-ESPCI-UPMC; G.Faini, LPN, CNRS; J.Briatico, R.Bernard, N.Bergeal, UMP, Thales-CNRS*

There is a strong need of highly sensitive photons detectors in the range of a few 100 GHz to a few THz for security systems, airborne vision or molecule detection for instance. Josephson Junctions are potentially a very attractive solution since they can reach very high efficiencies close to the quantum limit. High Tc Superconductors (HTS) have the advantages of a wide gap which allows detection far in the THz range, and rather simple cryogeny (77 K). HTS Josephson nano-Junctions made by ion irradiation exhibit interesting features for these applications, such as easily tunable parameters, high critical current densities, reasonable IcRn products, but, above all, good reproducibility and scalability. Starting from a c-axis YBCO film, a device including a wide band antenna coupled to a microbridge is designed using a first step of 100 keV oxygen irradiation with a fluence of 5 10<sup>15</sup> at/cm<sup>2</sup>. A nano-Junction is then made in the middle of the bridge using a fluence of a few 10<sup>13</sup> at/cm<sup>2</sup>. The fluence is chosen for an operating temperature ranging from 4 K to 77K. The size of the antenna corresponds to frequencies in the 100 GHz range. Direct detection of photons with a single junction is presented, together with noise performances. Extension to arrays of junctions will be shown.

*Acknowledgements to MPPU-CNRS for support through a post-doctoral grant, and to DGA for a PhD grant*

#### 4EPA02

*Invited*

##### **Semiconducting vs superconducting YBaCuO thin film bolometers: sensitivity and crosstalk investigations for future far-infrared imagers**

*V.Jagtap, M.Longhin, V.Michal, A.F.Degardin, P.Teste, A.J.Kreisler, LGEP Supelec; G.Klisnick, G.Sou, M.Redon, LISIF Univ. Paris 6*

YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7-x</sub> compounds are well known to exhibit superconducting properties for x smaller than 0.6 and semiconducting properties for lower oxygen content. In order to migrate from superconducting to semiconducting far-infrared bolometer technologies, we have compared the performance of 2x2 pixel arrays elaborated from both YBaCuO families. YBaCuO was deposited on MgO substrates by high temperature (700 to 800°C) magnetron sputtering with adequate oxygenation to obtain a superconducting phase, whereas the semiconducting material was deposited at lower temperature (200 to 400°C). Pixel responsivity and noise level were studied in the 1 Hz to 100 kHz modulation frequency range by using either a 10 micrometer wavelength CO<sub>2</sub> laser or a 850 nm VCSEL solid state laser. Thermal crosstalk was studied and discussed as a function of the modulation frequency, so to evaluate the adequate frame frequency. The readout circuitry was designed by aiming at low level and large bandwidth amplifiers to allow multiplexing of the pixel signals. CMOS ASIC circuitry was designed to cover the whole 80 K to 300 K temperature range. Preliminary tests exhibited 40 dB gain, 15 MHz bandwidth and 4 nV/root-Hz at 80 K (7 nV/root-Hz at 300 K). The technological and design issues to switch from a cooled to an uncooled YBaCuO device concept will be presented.

#### 4EPA03

*Invited*

##### **Temperature resolution of an HEB receiver at 810 GHz**

*S.Ryabchun, Department of Physics, Moscow State Pedagogical University; C.Y.E.Tong, S.Paine, R.Blundell, Harvard-Smithsonian Center for Astrophysics; G.Gol'tsman, Department of Physics, Moscow State Pedagogical University*

We present the results of temperature resolution measurements for an HEB receiver operating at 810 GHz. In the continuum mode, the input of the receiver was switched between two black bodies with different physical temperatures, while its output was connected to a continuum detector operating over a 380 MHz bandwidth. With a system temperature of ~ 1100 K, the receiver was able to resolve loads which differ by 1 K in physical temperature over an integration time of 5 s, which is significantly higher than the 0.03 K resolution given by the radiometer equation. In the spectroscopic mode, a gas cell filled with carbonyl sulphide gas was employed and its emission line at 813.353 GHz was measured using the receiver connected to a digital spectrometer. From the observed spectra, we could determine the measurement uncertainty of the equivalent emission temperature. With an integration time of 0.25 s, the receiver was able to resolve 2.8 K for a spectral resolution of 12 MHz, compared to a 0.6 K resolution given by the radiometer equation. These experimental results confirm that the HEB receiver is more effective in the spectral line mode of operation than in the continuum one. In both modes, the temperature resolution was improved by ~ 40% using a feedback loop which adjusted the level of a superimposed microwave radiation so as to maintain a constant operating bias current of the HEB mixer.

#### 4EPA04

##### **The design, fabrication and test results of a 1.6 THz superconducting hot electron bolometer mixer on SOI.**

*J.Schultz, D.Herald, H.Xu, L.Liu, R.M.Weikle, II, A.W.Lichtenberger, University of Virginia*

Interest in THz technology is growing, with projects such as the

Atacama Large Millimeter Array (ALMA) astronomical observatory, biohazard remote detection, high frequency radar and other detection systems. This paper presents the design, fabrication and test results of a 1.6 THz superconducting phonon-cooled NbN hot electron bolometer. Elements of the mixer design, including simulation results and s-parameters, are presented. Our novel fabrication process, the Suspended Sidewall Nano Patterned Stencil (SSNaPS) procedure, along with unique thin silicon backside processing, is used to create these THz mixers. DC characterization and RF test results, including Y-factor and noise temperature, are discussed.

*This work was funded through the National Ground Intelligence Center (NGIC) contract number W911W5-06-C-0001*

#### 4EPA05

##### **Design and Fabrication of Superconducting NbN Hot-Electron Bolometer at Terahertz Frequencies**

*L.Kang, J.P.Wang, Y.B.Li, J.Chen, B.B.Jing, Y.Jiang, M.Liang, W.W.Xu, P.H.Wu, Nanjing University*

It is well known that superconducting hot electron bolometer (HEB) is superior as far as receiving at THz frequencies is concerned. An HEB used at THz band mainly consists of two parts, i.e., a planar antenna for receiving THz signal and a bolometer as a sensor. Superconducting NbN with high T<sub>c</sub> and J<sub>c</sub> is an ideal material for HEB. In our design the antenna is a planar equiangular spiral antenna working in the frequency range from 0.4 THz to 3.2 THz, while the bolometer is of the sizes of 0.4 μm × 4 μm. We shall show in this paper the THz response of the antenna in the HEB which is experimentally studied using time-domain THz spectroscopy (THz-TDS). Also discussed will be the relationship between the direct current properties of the NbN HEB and its high frequency behavior.

*Supported by National Basic Research Programme of China No 2006CB601006 and 2007CB310404, National High-tech R&D Programme of China No 2006AA12Z120.*

#### 4EPA06

##### **Development of 0.85 THz and 1.5 THz Waveguide NbTiN HEB Mixers**

*L.Jiang, K.Shimbo, S.Shiba, Department of Physics, The University of Tokyo; P.G.Ananthasubramanian, Raman Research Institute, Bangalore, India; H.Maezawa, STE Laboratory, Nagoya University; N.Sakai, S.Yamamoto, Department of Physics, The University of Tokyo*

In this paper we will present the development of 0.85 THz and 1.5 THz waveguide hot-electron bolometer (HEB) mixers with superconducting NbTiN ultra-thin film deposited on quartz substrate under the circumstance of a 4-K close-cycled refrigerator. This investigation is targeted toward potential use in a 1.5 THz NbTiN superconducting HEB receiver for observing the fine structure line of NII and rotational line of the molecule of CH. The NbTiN and Au bilayers are sputtered on the quartz substrate without breaking vacuum, which minimizes natural oxidation of the NbTiN surface. The fabricated NbTiN film has a 12 nm thickness. We measured a double sideband receiver noise temperature (uncorrected) of 550 K and a single sideband conversion loss of 13 dB at 800 GHz for the 2 μm (width) × 0.2 μm (length) HEB mixer, which is pumped by the optimum LO power of 300 nW. We found the optimum LO power requirement monotonously increases with the device volume represented by the product of the NbTiN microbridge length by its width. Currently we are optimizing the sputtering condition to obtain thinner NbTiN film. We are focusing on the investigation of the relationship of the IF gain bandwidth of HEB mixer with the thickness of the NbTiN ultra-thin film at 0.85 THz and 1.5 THz.

#### 4EPA07

##### **Fabrication and characterization of quasi-planar epitaxial NbN nano-bridges**

*A.Kawakami, T.Matsui, H.Ohta, Z.Wang, National Institute of Information and Communications Technology*

For improvement of the performances of HEB mixers and SQUID magnetometers, we developed a new fabrication process of a quasi-planar NbN nano-bridge. In this process, the bridge length is decided by MgO inter-layer thickness, and it leads high controllability in the nanoscale. The bridges were fabricated on single-crystal MgO substrates. TEM images and electron diffraction patterns of the bridge showed that all films including the NbN nano-bridge were grown epitaxially. The bridge width, thickness, and length were about 300 nm, 10 nm, and 50 nm, respectively. The dc-characteristics of the nano-bridges show good uniformity and the dispersion of  $I_c$  was within 10 %

#### 4EPA08

##### **Microwave-Photonics Interactions in Optically Illuminated Superconductive Weak-links**

*B.G.Ghamsari, A.H.Majedi, University of Waterloo*

The peculiar sensitivity of Josephson phenomenon to the electromagnetic radiation, proposes superconductive weak-links as a promising platform for optoelectronic and microwave-photonics applications. In particular, illumination of superconductive weak-links can modulate electrical properties of the structure such as its I-V characteristics and microwave signal propagation. This paper studies the effect of illumination of visible and IR optical signal on two different types of superconductive weak-links, namely the Dayem bridge and the proximity-effect bridge, both theoretically and experimentally. The Bogoliubov-de Gennes (BdG) method along with proper boundary conditions, accounting for the inhomogeneity of the structures and the proximity effects, is employed to model the influence of light exposure on the two weak-links. Moreover, the results of experiments performed on the very two weak-links made out of Niobium integrated with a CPW microwave transmission line are presented and compared to the theoretical modeling. Their potential applications as microwave-photonic devices such as photomixers and parametric amplifiers are also addressed.

#### 4EPB - Electronic Device Fabrication IV – LTS

10:00am - 12:00pm

#### 4EPB01

##### **Pentalevel Resist Process for the Precise Fabrication of SIS Junctions**

*A.W.Lichtenberger, T.W.Cecil, G.S.Stronko, J.Wang, J.Z.Zhang, University of Virginia*

We have fabricated high quality m1/barrier/m2/Au Superconductor-Insulator-Superconductor junctions with Au over-layers using a new multilayer pentalevel resist process. The substrate/nfr/polyimide/SiO<sub>2</sub>/Cr/imaging-resist pentalevel structure

enables precise definition of submicron junction features in a self aligned insulation process. The Cr layer, defined with chlorine based RIE, serves as an excellent mask for the subsequent fluorine and oxygen based RIE etches of the remaining pentalevel stack and m2 electrode. We present a detailed description of the pentalevel process and electrical characteristics of Nb and NbTiN SIS junctions fabricated with diameters down to 0.6 $\mu$ m.

#### 4EPB02

##### **Submicrometer Nb/Al-AIOx/Nb Integrated Circuit Fabrication Process for Quantum Computing Applications**

*B.Bumble, A.Fung, A.B.Kaul, A.W.Kleinsasser, G.L.Kerber, JPL / Caltech*

We have developed a submicrometer Nb integrated circuit fabrication process for SQUID-based quantum computing applications. The baseline process consists of 7 masking steps including Pd-Au resistor, Nb/Al-AIOx/Nb trilayer, two Nb wiring layers and two sputtered SiO<sub>2</sub> dielectric layers. We have also fabricated wafers with an Nb groundplane. Using deep-UV lithography, inductively coupled plasma etch tools, and self-aligned lift-off for device definition, we routinely achieve micrometer lines and spaces with 400 nm minimum junction dimensions. Room temperature testing is used to screen wafers in process and junction annealing has been calibrated for trimming current density. We will describe the process and a variety of results obtained with it, including functional RSFQ and qubit circuits with over 100 junctions.

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#### 4EPB03

##### **Submicrometer-sized Josephson tunnel junctions with low parasitic capacitance**

*M.Schmelz, S.Anders, L.Fritzsche, T.Schoenau, R.Stolz, V.Zakosarenko, H.-G.Meyer, Institute of Photonic Technology (IPHT), P.O. Box 100239, D-07702 Jena, Germany*

We report on the fabrication and the properties of submicrometer-sized Josephson tunnel junctions in Nb-technology. They are realized as cross-type junctions where the junction area is defined by the overlap of the Nb/Al/AIOx/Nb trilayer and the superconducting wiring. In this scheme, a low parasitic capacitance in parallel with the junction is expected. Further, no etch process is required to open a via to the wiring. Sidewall passivation of the junctions is achieved by anodizing as well as by planarizing the trilayer with SiO in a self-aligned deposition step. We are able to fabricate junctions with linear dimensions from 10 down to 0.6 micrometer. The critical current density is about 1.5 kA/cm<sup>2</sup> for all junction sizes. The measured  $R_s/R_n$  ratio (where  $R_s$  is the subgap resistance measured at 2 mV and  $R_n$  the normal resistance) is about 35 independent of junction size. Both, the subgap behaviour as well as the expected low parasitic capacitance make such junctions well suited for application in high resolution SQUIDS.

#### 4EPB04

##### **SNS Josephson junction meander arrays for the Josephson arbitrary waveform synthesizer**

*O.Kieler, R.Iuzzolino, J.Kohlmann, L.Palafox, F.Müller, Physikalisch-Technische Bundesanstalt*

A system for the realization of a Josephson arbitrary waveform synthesizer (JAWS) was optimized to generate AC voltages with fundamental accuracy. Josephson junction series arrays, consisting of sub- $\mu\text{m}$  SNS type junctions (S...superconductor, N...normal conductor), were fabricated using a technology which combines electron-beam lithography and chemical-mechanical polishing. The chips are mounted by a flip-chip technique without bonding wires, allowing easy array changes. The probe-head and the experimental setup are configured to ensure a ground free operation of the array. The arrays are driven by short current pulses delivered by a pulse pattern generator. Bipolar pulses are realized by superposition of positive pulses from the pulse pattern generator and a continuous sinusoidal microwave provided by a signal generator. A second order delta-sigma modulator with a cascade of integrators in a feedback form was used to generate high quality pulse codes enabling a calculated signal-to-noise ratio of at least 115 dB. Bipolar sinusoidal AC voltages were generated with different peak-to-peak amplitudes and different signal frequencies. These generated AC waveforms were analyzed by means of a battery driven spectrum analyzer. The harmonics are suppressed by about -100 dBc indicating the high quality of the voltages synthesized by the JAWS.

#### 4EPB05

##### **Engineering overdamped niobium-based Josephson junctions operating above 4.2 K**

*V.Lacquaniti, INRIM Torino; D.Andreone, N.De Leo, M.Fretto, A.Sosso, INRIM; T.Khachaturova, M.Belogolovskii, National Akademie of Science Ukraine*

Niobium-based junctions are still the best candidates for small-scale applications of superconductivity, where a large number of junctions with small parameter spread are to be used. In particular, for the design and the fabrication of programmable voltage standards and D/A converters of fundamental accuracy nonhysteretic junctions with a large current density  $J_c$  and a reasonable characteristic voltage  $V_c$  are required. In this work we report our results achieved on Nb/Al-AlO<sub>x</sub>/Nb junctions whose properties are studied in order to optimize the mentioned features. We have measured the temperature dependence of electrical parameters for different electrode configurations (Al thickness and oxidation time), extracting the junction intrinsic characteristics. Using the scattering matrix approach, we have calculated a deviation of superconducting current-phase relation in S/N-I/S Josephson junction from sinusoidal one. On the base of the resistively shunted overdamped junction model, we have studied numerically its effect on the current amplitudes of Shapiro steps with the goal to get a maximal response on external microwave radiation. First measurements of the quantized steps at temperatures as high as 7 - 8 K on single junctions and small arrays pave the way to employ the Nb/Al-AlO<sub>x</sub>/Nb junctions in simpler cryocooler setups.

#### 4EPB06

##### **Deposition of MoSi<sub>2</sub> films as a barrier for Nb-based Josephson junctions**

*Y.Chong, S.I.Park, K.T.Kim, KRISST*

Sputter-deposited MoSi<sub>2</sub> films have been successfully used as a barrier material in Nb/MoSi<sub>2</sub>/Nb Josephson junction fabrication. In this report, we will present a study on the deposition condition for an optimal MoSi<sub>2</sub> film for electronics application. We investigated the film stress and sheet resistance as a function of deposition conditions. We also studied the structural change in the film according to the deposition conditions using transmission electron microscope. We found that there is a quite wide parameter margin for the deposition of this amorphous metal-silicide film.

*Y. C. Thank to Sam Benz and Paul Dresselhaus of NIST Boulder.*

#### 4EPB07

##### **Quick and Clean: Stencil Lithography for Wafer-Scale Fabrication of Superconducting Tunnel Junctions**

*V.Savu, Ecole Polytechnique Federale de Lausanne; J.Kivioja, VTT Technical Research Centre of Finland, Micro and Nanoelectronics; J.Brugger, Ecole Polytechnique Federale de Lausanne; J.Ahopelto, VTT Technical Research Centre of Finland, Micro and Nanoelectronics*

This paper presents a full-wafer, resist-less process for parallel fabrication of sub-micron Al/AlO<sub>x</sub>/Al superconducting tunnel junctions (STJs). A stencil is fabricated out of a Si wafer on which 200 nm low-stress SiN has been deposited. The STJ apertures in the SiN are defined by e-beam lithography on the front side of the wafer, and the Si is etched from the backside for opening SiN membranes. Using a customized full-wafer stencil aligner, the stencil is aligned and clamped to a substrate wafer which contains Au contact pads. The clamped system is placed in a thermal evaporator equipped with two Al sources, from which two Al evaporations are performed, with an intermediate in-situ oxidation step. Once out of the evaporator, the stencil is unclamped from the substrate and d.c. measurements are performed down to 0.3 K. One challenge of this technique is the clogging of the stencil, which is due to the material deposited on the side walls of the nanoapertures. The Al deposited on the stencil is removed using wet-etching, making thus the stencil reusable. This technique provides a cheaper and cleaner fabrication of STJs than present fabrication techniques, e.g. e-beam lithography. The advantages of this process are now being investigated in nanojunctions.

*This work was supported by the EC-funded project NaPa (Contract No NMP4-CT-2003-500120).*

#### 4EPB09

##### **Study of stress and morphology of superconducting niobium thin films**

*J.S.Liu, J.L.Wang, W.Chen, Tsinghua University*

The intrinsic stress plays an important role in determining the quality of superconducting properties of Nb thin films and Superconducting-Insulator-Superconducting Josephson junctions. Nb films with thicknesses of 5-150nm and Nb/Al<sub>2</sub>O<sub>3</sub>/Nb tri-layer structures were deposited by DC magnetron sputtering on oxidized Si and Sapphire substrates with different deposition conditions. We studied the surface morphology of these thin films with atomic force microscopy and corresponding superconducting properties of the films and Josephson junctions. The role of sputtering pressure, gun operating parameters, pre-deposition treatment, and substrate materials on film morphology and intrinsic stress are investigated. Experimental results will be presented.

*Partial financial support from State Key Program for Basic research of China under Grant No. 2006CB921801 and No. 2006CB921106 acknowledged.*

**4EPC01**

**Realization of adiabatic geometric gates with superconducting qubits**

*Z.H.Peng, H.Deng, J.Li, D.N.Zheng, Institute of Physics, Chinese Academy of Sciences, Beijing 100080, China*

We have proposed feasible experimental schemes to demonstrate the geometric phase in superconducting qubits. For flux qubits, this could be realized by means of a detuning coherent microwave pulse technique whereas, in a phase qubit, the Berry phase in the designed adiabatic evolution may be detected directly via the quantum state tomography. Furthermore we show that the universal quantum gates including single qubit logic gates and controlled two-qubit gates could be constructed. The fidelity of the designed adiabatic geometric quantum gates are evaluated in the presence of simulated current fluctuations for superconducting phase qubit circuits and the results show that the gates are robust against the random noise. The effect of control parameter fluctuations on the experimental detection of the Berry phase is also analyzed.

*The work is supported by the National Natural Science foundation of China and the Ministry of Science and Technology, China*

**4EPC02**

**DC SQUID Phase Qubit with LC filter**

*H.Kwon, A.J.Przybysz, H.Paik, R.M.Lewis, T.A.Palomaki, S.K.Dutta, B.K.Cooper, J.R.Anderson, C.J.Lobb, F.C.Wellstood, University of Maryland, College Park*

We investigate the use of an inductor-capacitor (LC) network to increase the isolation of a dc SQUID phase qubit from its current bias leads and thereby increase the dissipation time  $T_1$  and coherence time  $T_2$ . One junction in the SQUID acts as an ideal phase qubit while the second junction and the SQUID loop inductance act as a broadband filter to isolate the first junction from the current bias leads. With a loop inductance of 1.2 nH and an isolation junction critical current of 10 microamps, this provides a maximum isolation factor of about 1600. The LC-isolation network provides an additional isolation factor and allows flexibility in the choice of SQUID parameters. For the thin-film on-chip LC-isolation network, a 10 nH inductor and 80 pF capacitor would provide a maximum isolation factor of  $10^7$  at a plasma frequency of about 10 GHz and transform a 50 Ohm lead impedance into an effective shunting resistance of 8 MOhm across the junction. To reduce dielectric loss and two-level systems in the qubit junction, we use a relatively small area (4 square micron) Al/Al<sub>2</sub>O<sub>3</sub>/Al junction on sapphire and add external capacitors with 100 nm thick SiNx dielectric layers.

*This work is funded by JQI, CNAM and the DOD.*

**4EPC03**

**Reversible and Quantum Computation with nSQUID**

*V.K.Semenov, J.Ren, Stony Brook University*

We achieved an essential progress in understanding of the computational aspects of prospective complex quantum computing devices. Let us start with a set of artificial long Josephson junctions, where each of them is engineered as a large number of discrete Josephson junctions. It is important for us that flux solitons could stay and freely move along such long Josephson junctions. If for an illustrative purpose the discrete junctions are replaced by symmetric two-junction SQUIDs then those currently located near the soliton centers are naturally biased by a half of flux quantum and therefore at proper inductances could provide a symmetric two-minimum potential required for “conventional” flux qubits.

However, in contrast with conventional flux qubits the new ones can move along the circuit together with the flux soliton. Of course this illustrative model for moving or “flying” qubits has flaws. But these flaws are eliminated if SQUIDs are replaced by coupled nSQUIDs suggested and investigated at past ASC conferences. A quantum computer in our approach is a set of nSQUID “strings” that could be considered as “rails” for moving flux solitons with flux qubits “sitting” on tops of each soliton. The quantum logic operations (rotations) here are reduced to interactions between qubits travelling along different rails. We will present our experiments with new classical prototypes of the suggested QC that, in particular, should demonstrate extremely low energy dissipation.

*This work was supported in part by the National Security Agency (NSA) under Army Research Office (ARO) contract number W911NF-06-1-217 and by CREST/JST.*

**4EPC04**

**Eigenstates of nSQUID and “flying” qubit**

*V.K.Kornev, N.V.Klenov, A.V.Sharafiev, Department of Physics, Moscow State University*

Recently Semenov et al. [1] have suggested “flying” qubit, which clears new approach to the quantum computer architecture. This flying qubit is implemented using array of nSQUIDs characterized by negative mutual coupling between their inductances in different shoulders. The flying qubit architecture seems very promising from viewpoint of quantum data transferring in multi-qubit systems. The work is aimed at investigation of eigenstates of single nSQUID and the eigenstate changes upon galvanic and magnetic coupling with neighbor elements. Requirements to negative coupling and inductances for a double-well potential formation have been determined. Influence of applied magnetic field on quantum behavior of the system has been studied in detail. The obtained results are discussed from viewpoint of the flying qubit interactions and accomplishment of single- and two-qubit logic operations. [1] V. K. Semenov and Jie Ren, “Stimulus and read-out interfaces for nSQUID arrays”, Extended abstracts of Int. Supercond. Electronics Conf. (ISEC’2007), Washington DC, USA, June 2007, P-PU07.

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**4EPC07**

**Modeling Three- and Four- Coupled Phase Qubits**

*Z.E.Thraillkill, S.T.Kennerly, R.C.Ramos, Drexel University Department of Physics*

The Josephson junction phase qubit has been shown to be a viable candidate for quantum computation. In recent years, the two coupled phase system has been extensively studied theoretically and experimentally. We have analyzed the quantum behavior of three and four capacitively-coupled phase qubits with different possible configurations, using a harmonic oscillator model with an anharmonic perturbation. Energy levels and eigenstates have been calculated as a function of biasing current and detuning.

**4EPC08**

**Engineering quantum states of multi-qubit-cavity system**

*J.I.Park, R.Simmonds, NIST, Boulder*

We consider the possibility of preparing and verifying various nonclassical states of a system consisting of one or more superconducting phase qubits coupled via a superconducting transmissionline cavity. The methods described apply technologies recently demonstrated in experiments carried out at NIST.

#### 4EPC09

##### **Phase-Locking Transition in a Chirped Superconducting Josephson Resonator**

*O.Naaman, Quantum Nanoelectronics Lab., Dept. of Physics, Univ. of California, Berkeley; J.Aumentado, National Institute of Standards and Technology; L.Friedland, Racah Institute of Physics, Hebrew Univ.; J.S.Wurtele, Dept. of Physics, Univ. of California, Berkeley; I.Siddiqi, Quantum Nanoelectronics Lab., Dept. of Physics, Univ. of California, Berkeley*

We observe a new dynamical effect in a high-Q transmission line resonator embedded with a Josephson tunnel junction, driven with a purely ac, chirped microwave signal. When the drive amplitude is below a critical value, the resonator is only slightly excited when the drive frequency is near the linear resonance frequency. For larger amplitude, the resonator phase-locks to the chirped drive and its amplitude grows until a deterministic maximum is reached. These two outcomes are separated in parameter space by a sharp threshold that scales with the chirp rate and is sensitive to the junction critical current. Throughout its evolution, the system tracks a single basin of attraction—no switching occurs. This device, which we call the Josephson chirped amplifier (JCA), can be used to read out the state of a qubit, with the advantage of avoiding potential backaction associated with switching dynamics and transient oscillations. The observed critical behavior agrees well with theory and suggests a new modality for quantum state measurement.

#### 4EPC10

##### **Dynamical Bifurcation of an Aluminium Nanobridge Resonator**

*R.Vijay, Quantum Nanoelectronics Lab., Dept. of Physics, University of California, Berkeley; M.Hatridge, Dept. of Physics, University of California, Berkeley; V.Bouchiat, Institut Néel, CNRS-Grenoble; J.Clark, Dept. of Physics, University of California, Berkeley; I.Siddiqi, Quantum Nanoelectronics Lab., Dept. of Physics, University of California, Berkeley*

The Josephson junction is the key nonlinear element used in many amplifiers working near the quantum limit of sensitivity. Recent work has shown that a nonlinear Josephson oscillator can exhibit a dynamical bifurcation when driven with a microwave frequency current. Switching between the two non-dissipative, metastable states of the oscillator has a sharp, critical current ( $I_0$ ) dependent threshold—thus amplifying any signal coupled to  $I_0$ . Bifurcation amplification has thus far been observed in tunnel junctions. Here we experimentally demonstrate this phenomenon in a weak-link aluminum nanobridge embedded in a microwave resonator. Our measurements of the dispersive nonlinearity in a nanobridge junction define a new class of superconducting microwave devices. In particular, we describe a two junction nanoSQUID for fast, dispersive readout of a nanomagnet placed in close proximity of the weak-link for enhanced flux coupling. Other potential applications include parametric amplifiers and quantum coherent devices.

#### 4EPD - Pi Shift Devices and NanoSQUIDS – II 10:00am - 12:00pm

#### 4EPD01

##### **Crossed Andreev reflection in nanoscale ferromagnet-superconductor devices**

*J.L.Webb, B.J.Hickey, G.Burnell, University of Leeds*

Andreev reflection (AR) is a charge transfer process occurring at a normal metal - superconductor interface whereby an incident electron (hole) of energy less than the superconducting gap may be converted to supercurrent with reflection of a hole (electron) of opposite momentum and spin. Recent interest has focused on nonlocal or crossed Andreev reflection (CAR) in a nanoscale device consisting of

two normal metal leads contacting a superconductor with spatial separation of the order of the superconducting coherence length. CAR presents a possible source of solid state quantum entanglement, via the reflection of a hole (electron) produced by AR of an electron (hole) at one N/S junction at the second, forming an entangled Andreev pair and equivalent to transmission of two opposite spin quasiparticles into the separate leads. By use of ferromagnetic leads strongly spin dependent CAR and competing electron cotunneling (EC) may be controlled in a practical device. Based on design studies, micromagnetic simulation and computer modeling we have fabricated such nanoscale devices consisting of sputter deposited Co leads patterned by electron beam lithography ranging in size from 100 nm-3  $\mu$ m, with in-plane separation of 100-200 nm, in point contact with an optically patterned 5  $\mu$ m Al superconducting electrode. These devices were cooled to 50-300mK using an adiabatic demagnetization refrigerator to detect nonlocal voltages characteristic of CAR and differentiable under applied magnetic field from competing EC. Here we present our initial results.

#### 4EPD02

##### **Geometric pi Josephson junction based on d-wave superconducting thin films**

*A.Gumann, Institute for Theoretical Physics, University of Tuebingen; C.Iniotakis, Institute for Theoretical Physics, ETH Zurich; N.Schopohl, Institute for Theoretical Physics, University of Tuebingen*

In a recent publication, we have proposed a novel way to realize a pi Josephson junction, based on a weak link in an unconventional d-wave superconductor with appropriately chosen boundary geometry (Appl. Phys. Lett. 91, 192502 (2007)). Calculations based on microscopic Eilenberger theory of superconductivity clearly show, that a transition to a pi Josephson junction occurs for both low temperatures and small sizes of the geometry. The proposed device opens up interesting possibilities for application since it is based on a single layer technique and allows for close packaging of a large number of zero and pi Josephson junctions on a single substrate. Self-consistent solutions of microscopic Eilenberger theory as well as results of a simple toy model will be presented and discussed, including current-phase relation and critical current as functions of geometry and temperature. Possible SQUID and SQIF applications of the device will be analysed.

#### 4EPD03

##### **Josephson effect in superconductor/ferromagnet/superconductor junctions**

*A.A.Golubov, A.S.Vasenko, University of Twente, The Netherlands; M.Y.Kupriyanov, Moscow State University, Russia; M.Weides, Research Centre Juelich, Germany*

Superconductivity and ferromagnetism are two competing orders, however their interplay can be realized when the two interactions are spatially separated. In this case the coexistence of the two orderings is due to the proximity effect. Experimentally this situation can be realized in superconductor/ferromagnet (SF) hybrid nanostructures. Josephson junctions with ferromagnetic interlayer (SFS junctions) recently attracted a lot of interest and have been proposed as potentially useful elements in superconducting logic circuits and Josephson phase qubits. In this work we provide quantitative model of electronic transport in SFS Josephson junctions, using the quasiclassical theory of superconductivity. The model describes the oscillations of the critical current as a function of thickness of the ferromagnetic layer and materials parameters. The results are used to explain recent experimental data in practically interesting SIFS junctions, where I is a tunnel barrier. We also calculate the quasiparticle density of states in this type of junctions and compare its oscillations with those of the critical current. Our study provides a tool to explain the existing experimental data in SFS junctions and to design new experiments.

#### 4EPD04

*Invited*

##### **Direct observation of a $\sin(2\phi)$ component in the current-phase relation (CPR) of superconductor-ferromagnet-superconductor (SFS) Josephson junctions**

*M.J.A.Stoutimore, University of Illinois at Urbana/Champaign; A.Y.Rusanov, Laboratory of Superconductivity, ISSP-RAS; D.J.Bahr, University of Illinois at Urbana/Champaign; V.A.Oboznov, V.V.Bolginov, A.N.Rossolenko, V.V.Ryazanov, D.J.Van Harlingen, Laboratory of Superconductivity, ISSP-RAS*

SFS  $\pi$ -junctions have been proposed as a building block in superconducting qubits. In addition, intrinsic second-order Josephson tunneling, if present, could open up more applications for these junctions. We present direct measurements of the CPR of SFS Josephson junctions in an rf-SQUID geometry as well as isolated-junction diffraction measurements. The junctions are fabricated from Nb-CuNi-Nb trilayers with a junction area of  $2 \times 2$  microns and a CuNi thickness of 7nm. We observed transitions between an ordinary 0-junction state and a  $\pi$ -junction state - characterized by a ground state phase difference of  $\pi$  - at a temperature of  $\sim 2.2$ K. Near this crossover, we observed period-doubling of the CPR, indicating a term proportional to  $\sin(2\phi)$ . We also observed zeros in the junction critical current at applied fields proportional to multiples of half of a flux quantum. Work is underway to measure Shapiro steps and to determine if these results signify an intrinsic second-order tunneling mechanism or junction inhomogeneities.

#### 4EPD05

##### **Superconducting Proximity Effect In Non-Homogeneous Ferromagnets**

*A.S.Jenkins, C.H.Marrows, G.Burnell, University of Leeds*  
Superconductivity and ferromagnetism are two naturally competitive phenomena which will both be intrinsic to a new wave of spintronic technology and the advancement of quantum computing. The interplay between superconductivity and inhomogeneous ferromagnetism has recently come under both theoretical and experimental study, although the exact relationship between the two is still not totally understood. The better understanding of this relationship would be essential in the fabrication of a superconductor/ferromagnet hybrid switch and other devices which previously assume a single domain structure. The aim of this work is to investigate the proximity effect of inhomogeneous ferromagnetism on superconductivity. This is being attempted by controlling domain walls in devices that consist of niobium and cobalt bilayers. Using focussed ion beam technology, notch structures can be introduced into the bilayer which will cause pinning of domains and the direct effect of this on the superconductive transport properties can be observed using both critical current and resistance measurements. Here we will present initial results in device fabrication, some critical current and resistance measurements and domain structure modeling attempts using the OOMMF code.

*EPSRC*

#### 4EPE - Superconducting Junction Detectors – II 10:00am - 12:00pm

#### 4EPE01

*Invited*

##### **Characterization of the Mixing Performance of all-NbN Superconducting Tunnel Junctions at 0.5 THz**

*J.Li, S.C.Shi, Purple Mountain Observatory, CAS*  
With a gap frequency double that of Nb-based superconducting tunnel junctions ( $\sim 0.7$  THz), all-NbN junctions are of particular interest for the development of heterodyne mixers at frequencies beyond 1THz. To develop NbN superconducting SIS (superconductor-insulator-superconductor) mixers at THz frequencies, we firstly investigate the mixing performance of all-NbN superconducting tunnel junctions incorporating with two kinds of integrated junction tuning circuits,

namely, parallel-connected twin junctions and half-wavelength resonant junction. All-NbN superconducting tunnel junctions for this study are made up of NbN/AlN/NbN tri-layer fabricated on an MgO substrate and have a critical current density of  $10 \text{ kA/cm}^2$ , while the junction's thin-film tuning circuit has two choices (i.e., NbN/MgO/NbN and NbN/SiO<sub>2</sub>/NbN). The mixing performance of all-NbN superconducting twin and half-wavelength resonant junctions are thoroughly characterized at 0.5 THz. Preliminary testing has demonstrated a noise temperature below 190 K at 0.5 THz, including an RF noise temperature of around 100 K. Detailed simulation and experimental results will be presented in this paper.

#### 4EPE02

*Invited*

##### **Modelling of local trapping states in superconductor tunnel junctions with Kondo impurities**

*R.A.Hijmering, Advanced Studies and Technology Preparation Division, ESA; A.G.Kozorezov, Department of Physics, Lancaster University; A.A.Golubov, Department of Applied Physics, University of Twente; J.K.Wigmore, Department of Physics, Lancaster University; P.Verhoeve, D.D.E.Martin, I.Jerjen, R.Venn, Advanced Studies and Technology Preparation Division, ESA*  
Superconducting Tunnel Junctions (STJs) are being developed as spectrometers for wavelengths ranging from the NIR to X-rays. A STJ consists of two thin layers of superconducting material separated by an insulating layer. Due to the small energy gap, absorption of a photon will produce a large amount of quasiparticles (qps) proportional to the absorbed energy which in the presence of a DC bias voltage can be detected as a tunnel current across the barrier. In order to model the charge output and quasiparticle lifetimes adequately trapping of qps by local traps has been proposed. Not much was known about the actual nature of these local traps, but recent theoretical work suggests they could be related to the presence of discrete intra-gap states bound to Kondo impurities and electronic transitions between the continuum and these levels<sup>1</sup>. In this work we discuss the results of fitting the experimental data in Ta and Al STJs within this impurity model. <sup>1</sup> Kozorezov et al, submitted for publication in Phys. Rev. Lett.

#### 4EPE03

*Invited*

##### **Understanding Thermal Management in High-Tc THz Sources**

*C.Kurter, Argonne National Laboratory; Illinois Institute of Technology; K.E.Gray, Argonne National Laboratory; J.F.Zasadzinski, Illinois Institute of Technology; Q.A.Li, Argonne National Laboratory; L.Ozyuzer, Izmir Institute of Technology; A.E.Koshelev, Argonne National Laboratory; T.Yamamoto, K.Kadowaki, University of Tsukuba; W.-K.Kwok, U.Welp, Argonne National Laboratory*

We present tunneling characteristics for a c-axis stack of about 600 intrinsic Josephson junctions isolated in a mesa on a Bi-Sr-Ca-Cu-O (Bi-2212) crystal designed as a THz source. Despite the large mesa volume of  $300 \times 40 \times 1$  micro-m<sup>3</sup> and backbending in the I-V curve, there are accessible voltages for which self-heating does not exceed T<sub>c</sub> and significant polarized THz-wave emission can be observed. We reproduce the I-V curve using a model based on the measured low-current quasiparticle c-axis resistance, R<sub>c</sub>(T), of the mesa and a temperature increase proportional to power, IV. The mesa temperature determined along the nonlinear I-V track the observed unpolarized thermal radiation, thus supporting the model. As such, backbending results from the temperature dependence of R<sub>c</sub>(T) as first discussed by Zavaritsky. It is not due to a decreased energy gap at high current densities and its disappearance above  $\sim 60$  K is also consistent with the measured R<sub>c</sub>(T).  
*Supported by U.S. DOE Basic Energy Science, Contract No. DE-AC02-06CH11357.*

#### 4EPE04

##### **Nb SIS Mixers at 0.65 Terahertz Frequency Band**

*M.Liang, Y.Jiang, J.Chen, P.H.Wu, Research Institute of Superconductor Electronics, Nanjing University, China; S.Ariyoshi, C.Tani, RIKEN, Japan; T.Taino, Saitama University, Japan*

Quasi-optical superconducting niobium (Nb) SIS mixers have been measured at 0.6 terahertz (THz) frequency band for THz applications in astronomy and cosmology. A Gunn oscillator with its multipliers was used as the local oscillation (LO) source. The mixers consist Nb linearly distributed SIS junctions integrated on the two wings of a planar complementary log-periodic antenna. Using a Si hyper-hemispherical lens with the diameter of 12 mm and no anti-reflection (AR) coating on its surface, the radiation is focused onto the SIS mixer. The DC and THz response properties of mixers, as well as the receiver noise temperature will be discussed in detail in the presentation.

#### 4EPE05

##### **An 85-115GHz Superconductor-Insulator-Superconductor Mixer Demonstrating Nearly Constant Dynamic Resistance**

*W.L.Shan, Z.Q.Li, J.Q.Zhong, S.C.Shi, Purple Mountain Observatory*

Fixed-tuned Superconductor-Insulator-Superconductor (SIS) mixers are widely used in astronomical observations because of their ultra-low intrinsic noise and simplicity of operation. For most cases the geometric capacitance of the tunnel junction is designed to be perfectly tuned out at the center of frequency band. Below and above this frequency there will be residual inductance and capacitance respectively. The effect of residual reactance is reflected on the slope of the photon-assisted steps. In particular, at lower half of frequency band, the first photon-step below voltage gap turns out to be flat (showing high dynamic resistance) and it results in bias instability. In order to improve the stability at lower half of frequency band, we designed a W-band mixer tuning circuit that composes of an impedance transformer and a tuning microstrip line followed by a low impedance quarter-wave open-end microstrip line. The overall reactance of above frequency dependent elements is approximately a constant inductance parallel connected with the junction over a wide frequency range. If the inductance is set to be slightly smaller than what is needed for perfect compensating the junction capacitance, much improved stability can be achieved. We have carried out experiments to verify above design and observed good noise performance as well as nearly constant dynamic resistance of about 50 Ohm from 85GHz to 115GHz at the center of first photon steps.

#### 4EPE06

##### **Mixing properties of NbN-based SIS mixers with NbTiN wirings**

*M.Takeda, NiCT; W.L.Shan, PMO; T.Kojima, Y.Uzawa, NAOJ; S.Saito, NiCT; Y.Fujii, M.Kroug, J.Li, NAOJ; S.C.Shi, PMO; Z.Wang, NiCT*

We have successfully developed waveguide SIS mixers with all-NbN structures on MgO substrates. The structure consists of NbN-AlN-NbN tunnel junctions and NbN-MgO-NbN microstrips, and the NbN is epitaxially grown on the MgO. The mixers have achieved a DSB noise temperature of 345 K at 833 GHz, which corresponds to seven times as large as the quantum-limited noise. However, the fluctuation of the receiver performances seems a little larger in run-to-run process.

The high-frequency properties of NbN films are strongly dependent on the quality of the underlying MgO. To reduce such this dependence we introduced an NbTiN technology for the wiring of our mixers. A DSB receiver noise temperature of 287 K was obtained for a mixer with NbTiN wiring at 820 GHz. This value is five times as large as the quantum-limited noise. The device fabrication and detailed experimental results will be presented and discussed.

*This work was supported in part by the ALMA Band-10 Entrusted Research Fund of the National Astronomical Observatory of Japan. This work supported in part by the National Nature Science Foundation of China under contract No. 10303008.*

#### 4EPE07

##### **Sub-THz Sensitivity and Frequency Dependence of High-Tc Josephson Junction Detectors**

*K.Nakajima, A.Saito, S.Ohshima, Yamagata Univ.; H.Sato, K.Sawaya, Tohoku Univ.*

Sensitivities of High-Tc Josephson junction detectors for sub-THz wave ranging from 120 to 160GHz are investigated. The detectors consist of YBCO grain boundary Josephson junctions integrated with planar log-periodic (LP) antennas as well as slot dipole (SD) antennas on MgO substrates extended by hemispherical silicon lenses. The effect of extended hemispherical silicon lenses are studied for various diameter lenses. Frequency dependence of sensitivities are measured and compared with the simulation results for both LP and SD antennas. SD antennas exhibits sharp frequency dependences and improves sensitivities at resonance frequencies although LP antennas indicates broadband dependences for whole frequency range within a few dB deviation. Impedance mismatch between the LP antenna and the YBCO grain boundary Josephson junction gives an account of the improvement of sensitivity for SD antenna. The high-Tc Josephson junction detectors show good performance of in terms of sensitivities as well as frequency dependence and can be used in broadband sub-THz systems.

#### 4EPE08

##### **Subgap biasing of Superconducting Tunnel Junctions without a Magnetic field**

*K.Segall, J.Moyer, Colgate University, J.J.Mazo, University of Zaragoza*

Superconducting tunnel junctions (STJs) have been successfully used as single-photon detectors, but require the use of a magnetic field to operate. A recent paper [1] has proposed the idea to use a circuit of three junctions in place of a single junction in order to achieve the necessary biasing without applying a magnetic field. The nonlinear interaction between the different junctions in the circuit causes the existence of a stable subgap state for one of the junctions, which acts as the detector junction. We present the first measurements demonstrating the existence of such a biasing state feasible for STJ detectors. [2] Single-junction measurements with an applied magnetic field help determine the functional form of the subgap current versus voltage; then the operating point of a 3-junction circuit is measured and fit to theory. The excellent match between theory and experiment demonstrates the existence of the subgap biasing state. The outlook for possible use in detector applications is discussed.

*[1] K. Segall, J.J. Mazo and T.P. Orlando, Appl. Phys. Lett. 86, 153507 (2005) [2] K. Segall, J.Moyer and J.J. Mazo, J. Appl. Phys. to appear.*

**4EPF01**

*Invited*

**Superconductive Traveling-Wave Photodetectors**

*B.G.Ghamsari, A.H.Majedi, University of Waterloo*

The high intrinsic quantum yield and the fast photoresponse of superconducting thin films make them a promising detecting element for ultra-sensitive and fast photodetection. One fundamental challenge in this regard, is to effectively couple the light into the superconducting thin film in order to achieve efficient photodetectors. One possible remedy to this problem is to integrate the superconductive thin film with an optical waveguide which enables efficient coupling of optical power to the detecting element. However, the resulting device is not a lumped-element one anymore, but rather a travelling-wave device, in which the photodetection is performed in a distributed fashion. This paper investigates superconductive traveling-wave photodetectors (STWPD's), as a novel photodetection scheme, based on the kinetic-inductance of superconducting thin-films integrated with a multilayer optical waveguide and a microwave transmission line. Principles of the operation of STWPD's such as the distributed photodetection and optical-to-electrical signal conversion are discussed and the key considerations about the modal propagation characteristics of the optical signal through the device and their influence on the device performance are highlighted. Moreover, two different STWPD designs based on the HTS and LTS materials, TBCCO-on-LaAlO<sub>3</sub> and Niobium-on-Sapphire respectively, are studied in some details and experimental results regarding the overall photodetector performance are given and compared to the theory.

**4EPF02**

*Invited*

**Novel superconducting optical switch based on a Josephson vortex flow transistor**

*I.Kawayama, Y.Doda, H.Murakami, M.Tonouchi, Osaka Univ.*

Novel superconducting optical switch based on a Josephson vortex flow transistor Iwao Kawayama, Yasushi Doda, Hironaru Murakami, Masayoshi Tonouchi Ultrafast optical devices with very low power consumption are strongly desired to process large-capacity data-traffic on expanding information networks. Tonouchi et al. demonstrated that magnetic flux was optically generated in superconducting loops by femtosecond laser irradiation [1], and we have proposed to utilize this phenomenon for advanced superconducting opto-electronic devices, e. g. a memory, an interface and a switch. In this study, we have fabricated a novel superconducting optical switch based on a Josephson vortex flow transistor (JVFT) with a YBCO thin film. This device consists of a vortex flow channel and a control line for applying a magnetic field. We considered that the density of the flowing flux in the channel could be modulated by irradiation of femtosecond laser pulses and output voltage can be controlled by the laser pulses. Actually, we could observe the clear modulation of the output voltage by laser irradiation and revealed that the optical response time of the JVFT switch was less than 5 ps. We will show the details of experimental results and discuss the mechanism and potential of the novel optical switch. [1] M. Tonouchi et al., Appl. Phys. Lett. 71 (1997) 2364.

*This work was supported in part by Grant-in-Aid for Young Scientists (B) from the Ministry of Education, Culture, Sports, Science and Technology (MEXT).*

**4EPF03**

*Invited*

**Hot-Electron Nano-Bolometers: Cooling via Single Electron-Phonon Scattering Events**

*A.Sergeev, V.Mitin, SUNY at Buffalo; B.Karasik, Jet Propulsion Laboratory, California Institute of Technology*

In order to obtain a sensitive bolometric detector, the thermal coupling between the sensor and its surrounding should be suppressed. As it has been shown in recent works (e.g., [1]), the quantum character of phonon and photon thermal conductances strongly limits the minimum achievable decoupling in the geometrically isolated bolometers. In the hot-electron sensors, the electrons heated by radiation relax via electron-phonon scattering and the corresponding electron-phonon thermal conductance,  $G_{e-ph}$ , is proportional to the volume of the sensor. Using nanodevices, conductance  $G_{e-ph}$  can be reduced far below the quantum  $G_q$ , which corresponds to the conductance via a single phonon or photon mode [2]. We will address several questions associated with the fundamental limit for  $G_{e-ph}$ , its achievability in practical nano-bolometers, parameters of the corresponding devices, and any potential applications of such ultrasensitive detectors. We will show that the limiting  $G_{e-ph}$  corresponds to the relaxation of electron subsystem via single electron-phonon scattering events, which do not overlap in time. The corresponding noise has quantum character and can be described in the way analogous to the photon noise in photon counters [3]. [1] M. Meschke et al., Nature 444, 9 (2006). [2] J. Wei et al, arXiv:0710.5474 (2007). [3] B. Karasik and A. Sergeev, IEEE Appl. Supercond. 15, 618 (2005). *Work of AS and VM was supported by NYSTAR and NATO Program.*

**4EPF04**

*Invited*

**Ultrafast photoresponse of superconductor/ferromagnet hybrid nanostructures**

*G.P.Pepe, V.Pagliarulo, L.Parlato, N.Marrocco, C.De Lisis, G.Peluso, University of Naples Federico II and CNR-INFM Coherentia, ITALY; A.Barone, D.Pan, University of Naples Federico II and CNR-INFM, ITALY; J.Kitaygorsky, R.Sobolewski, University of Rochester, Rochester NY 14627, USA*

Interactions of superconducting nanostructures with external optical radiation represent a very interesting topic in the framework of nonequilibrium physics. Heterogeneous structures, such as proximized superconductor/normal and superconductor/ferromagnet (S/F) nanobilayers, are very promising in the quest for the ultrafast quasiparticle dynamics. We have characterized Nb/NiCu, Nb/PdNi, and YBaCuO/Au/NiCu proximized superconducting S/F bilayers using time-resolved, all-optical 100-femtosecond spectroscopy and optoelectronic photoimpedance measurements down to 4 K. These bilayers are very promising for novel ultrafast photodetection and spintronics devices.

*This work was supported in part by the US AFOSR grant FA9550-06-1-0348.*

#### 4EPF05

##### **Microfabrication of Metallic Magnetic Calorimeter Detectors for X-ray Astronomy**

*W.T.Hsieh, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, USA; J. A.Adams, S.R.Bandler, K.L.Denis, H.Rotzinger, T.R.Stevenson, D.E.Travers, J.Beyer, NASA/GSFC; G.M.Seidel, Physics Department, Brown University, Providence, RI 02912, USA*

Metallic magnetic calorimeter is one of the most promising devices to provide very high energy resolution needed for future astronomical x-ray spectroscopy. At Goddard Space Flight Center, we have been developing magnetic calorimeters for potential future space flight missions. Each magnetic calorimeter consists of an overhanging mushroom absorber and beneath it, a sputter deposited paramagnetic sensor, which is read out inductively by a superconducting meander-shaped coil. The paramagnetic sensor changes in magnetization when heated by an absorbed x-ray. The meandering superconducting pickup coil not only couples the sensor to a low noise dc-SQUID magnetometer, it also provides the magnetic field for the paramagnetic sensor. One of our design criteria is to build the calorimeter using fully integrated micro-fabrication processes, so that the process can be extended to build large focal plane detector arrays. We will discuss the principle detector design, fabrication process, and structural considerations for implementing a membrane support of each pixel.

#### 4EPF06

##### **HEB sensor using MgB<sub>2</sub>**

*D.B.Northeast, C.J.Fourie, Stellenbosch University, Dept. E&E Engineering*

Terahertz electromagnetic radiation provides material information that common imaging methods, such as X-ray transmission, cannot provide. This information allows new possibilities in defense and security detection and imaging, and opens research avenues in fields such as astronomy. A sensor that can detect a wide frequency band with high sensitivity and energy resolution is needed to exploit THz detection and imaging, and hot electron bolometers are prime candidates. We created HEBs using MgB<sub>2</sub>, and operated them in a heterodyne mixing mode. The structures were designed to detect EM radiation spanning the THz range. Signal intensity at various sub-T<sub>c</sub> temperatures and sub-critical currents was investigated to determine the optimal sensitivity. Targets were illuminated to allow detection above the thermal noise of the system. Results indicating EM detection from MgB<sub>2</sub> HEBs will be shown.

#### 4EPG - Novel Detectors and Sensors – II 10:00am - 12:00pm

#### 4EPG01

##### **Precise 3-axis measurement of weak dc magnetic fields with SQUID magnetometers**

*A.Schnabel, D.Drung, S.Knappe-Grueneberg, M.Burghoff, PTB-Berlin Germany*

One important requirement for a magnetically shielded room is a low residual magnetic field. A moveable SQUID system was developed to measure the static field distribution inside our heavily magnetically shielded room BMSR-2. This vector magnetometer system consists of a plexiglas cube with 30 mm side length in a liquid He-Dewar. Six integrated dc SQUID magnetometers are mounted at the six faces of the cube. Inside BMSR-2 the system noise level is <1 pT for dc (0-1 Hz) measurements. The cube design allows one to deduce all vector components at the center of the cube by averaging the SQUID signals at opposite sides. To this end, we determine the dc offset of a sensor pair by a 180° rotation of the cube around the cube center.

The average of the measured field values in both positions is the dc offset of the pair. To determine the x and y offset we rotate the whole Dewar around the vertical z-axis of the cube. Since it is not possible to turn the Dewar upside down, the rotation for the z-direction is replaced by a single tilt of 40°. Together with the results of the 180° rotation the z-axis offset can be calculated. Prerequisite for the calibration and the following measurements is that all SQUIDs remain permanently locked. Using a special dewar holder the SQUID system can be offset corrected in less than 5 minutes with an uncertainty of +/-20 pT. The magnetic field vector distribution inside BMSR-2 was measured after offset calibration in a volume of 2m x 2m x 1m. By this we could optimize the demagnetization of the canister resulting in a residual field <1 nT.

#### 4EPG02

##### **Superconducting Detectors for Mass Spectrometry**

*B.V.Estey, J.A.Beall, G.C.Hilton, K.D.Irwin, D.R.Schmidt, J.N.Ullom, R.E.Schwab, National Institute of Standards and Technology*

Mass Spectrometry is widely used for protein characterization, structural virology, drug discovery, and clinical chemistry. However, the detection efficiency of existing detectors for mass spectrometry degrades rapidly as mass is increased and is only ~10<sup>-5</sup> at 10<sup>6</sup> Da. Superconducting detectors provide detection efficiency which is essentially mass independent and previous efforts have explored the use of superconducting tunnel junctions (STJ's) and normal-insulator-superconductor (NIS) microcalorimeters as detectors. Both STJ and NIS detectors, however have active areas limited to ~0.01cm<sup>2</sup>, well below the ~1 cm<sup>2</sup> required to contain the beam of a typical mass spectrometer. Superconducting micro-stripline meander detectors have the potential to provide the necessary area. We have fabricated simple prototype detectors, mounted them on a cryocooler interfaced to a commercial mass spectrometer, and obtained spectra of representative biological molecules. We present quantum efficiency comparisons to conventional multichannel plate detectors and outline the steps remaining to develop a commercially viable system.

#### 4EPG03

##### **Fabrication and Characterization of Superconducting Probe Coil for High-Sensitive NMR Spectroscopy**

*H.Yamamoto, Advanced Research Laboratory, Hitachi Ltd.; M.Takahashi, Hitachi Research Laboratory, Hitachi Ltd.; K.Saitoh, Advanced Research Laboratory, Hitachi Ltd.; K.Kawasaki, Y.Fukuda, Hitachi Research Laboratory, Hitachi Ltd.; H.Tanaka, Mechanical Engineering Research Laboratory, Hitachi Ltd.; M.Okada, H.Kitaguchi, Hitachi Research Laboratory, Hitachi Ltd.*

We have been developing an NMR spectrometer having a unique structure, which consists of split-pair superconducting magnet, solenoidal-shaped probe coil, and cryogenic probe system. Sensitivity of NMR measurement depends on a quality factor (Q) of probe coil. Superconductor is a promising material for fabrication of high-Q probe coil. In this work, we fabricated superconducting probe coil using Bi-2212, and evaluated its advantage for NMR measurement. Superconducting probe coil was prepared by using dip-coat process. Its quality factor was measured by a network analyzer. As the measurement result, quality factor of about 2 times higher than the normal metal probe coil was obtained. This result suggests that the present superconducting probe coil has a great advantage to normal metal coils for high-sensitivity measurement. Preliminary result of NMR measurement using the superconducting probe coil is also given.

*This work was supported by Research Promotion Bureau, Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan, under the contract No.19-199.*

#### 4EPG04

##### **Embedding and ageing issues for YBCO-based hot-electron bolometers dedicated to THz detection and imaging**

*A.J.Kreisler, I.Turer, M.Aurino, V.Jagtap, A.F.Degardin, LGEP; N.Ribiere Tharaud, Supelec; J.-C.Villegier, M.Redon, CEA Grenoble; G.Klisnick, LISIF*

Superconducting Hot Electron Bolometer (HEB) mixers are a competitive alternative to conventional superconducting technologies in the THz frequency range because of their ultrawide bandwidth, high conversion gain, and low intrinsic noise level, even at 77 K. A technological process to fabricate YBaCuO ultra-thin films (in the 15 to 40 nm thickness range) etched to form 0.4x0.4 sq-micrometer constrictions has been previously described. Ageing effects were observed, with the consequence of increased electrical resistance, significant degradation of the regular bolometric response, preventing HEB mixing action as well. Several measures have been attempted to address these problems, mainly by considering the embedding technological issues related to the YBaCuO nanobridge coupling to the antenna and the intermediate frequency (IF) circuitry. For this purpose, the nanobridge impedance was analyzed at both THz and IF frequencies, and mismatch to IF strip and antenna was studied. In particular, extensive antenna simulations were performed and validated against experiments on scaled models at GHz frequencies. Electromagnetic coupling to the incoming radiation was also studied with these models, including crosstalk between neighbor antennas forming a linear imaging array. Further characterizations concern the device bolometric response in the direct and heterodyne detection modes at 2.5 THz.

#### 4EPG05

##### **The Quantum Capacitance Detector: a pair-breaking detector readout based on the single Cooper-pair box**

*P.M.Echternach, Jet Propulsion Laboratory, California Institute of Technology; M.D.Shaw, Dept. of Physics and Astronomy, University of Southern California; J.Bueno, P.Day, C.M.Bradford, Jet Propulsion Laboratory, California Institute of Technology*

We propose a pair-breaking submillimeter radiation detector based on the single Cooper-pair box (SCB), and discuss preliminary results. Non-equilibrium quasiparticles generated in a superconducting absorber by incident radiation are measured with an SCB, which is exquisitely sensitive to the quasiparticle density in the leads. We discuss the theoretical sensitivity and response of the detector in the presence of several noise mechanisms. The detector promises sensitivity in excess of  $10^{-20}$  W/Hz<sup>1/2</sup> at submillimeter wavelengths, which is essential to meet scientific goals in submillimeter astronomy. The detector is naturally scalable to large frequency-multiplexed arrays.

#### 4EPH - Passive Microwave Devices – I 10:00am - 12:00pm

#### 4EPH01

##### **Design, fabrication and testing of microwave filter using Yttrium Barium Copper oxide on Ytria stabilized Zirconia buffered silicon substrate**

*J.M.Vargas, Y.S.Hijazi, Universidad del Turabo; Y.A.Vlasov, G.L.Larkins, Florida International University*

The microwave performance of high temperature superconducting (HTS) Yttrium Barium Copper-oxide (YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7</sub>) on a 15 mm x 15 mm silicon (Si) substrate is investigated. Ytria stabilized Zirconia (YSZ) is used as a buffer layer on (100) oriented Si-substrate. A YSZ film of approximately 80-100 nm thick is

deposited by the rf magnetron sputtering method. X-ray diffraction and AFM are used to characterize the buffer layer. YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7</sub> film, 300-500 nm thick is then grown using the method of pulsed laser deposition (PLD) in an atmosphere of 0.5 Torr O<sub>2</sub> at 760 °C with critical temperature, T<sub>c</sub>, of 77 K. The YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7</sub> thin film is patterned into a microwave hairpin filter using standard photolithographic methods. Fabrication details of the hairpin filter with nominal center frequency of 3GHz and bandwidth of 30 MHz are discussed along with simulation data and the most recent test results.

#### 4EPH02

##### **Fabrication and Characteristics of Miniaturized Dual-Band High-Tc Superconducting Filters: Using Quarter-Wavelength Stepped-Impedance YBa<sub>2</sub>Cu<sub>3</sub>O<sub>y</sub> Resonators**

*L.-M.Wang, M.-C.Chang, S.-F.Li, J.-W.Liou, C.-Y.Shiau, C.-I.G.Hsu, Department of Electrical Engineering, Da-Yeh University*

A step-impedance microstrip band-pass filter is presented for the applications of IEEE 802.11b/g ( 2.4 GHz ~ 2.48 GHz) and IEEE 802.11a ( 5.15 GHz ~ 5.35 GHz) on the multimode wireless local area networks. The designed filter can be miniaturized by using quarter-wavelength stepped-impedance resonators (SIR) and shows a dual-passband response. The simulation results show the dual-band feature of two pass bands at 2.4 and 5.2 GHz with an insertion loss of 0.02 dB and bandwidths of 14 and 24 MHz, respectively. For fabrication, high-Tc superconducting YBa<sub>2</sub>Cu<sub>3</sub>O<sub>y</sub> (YBCO) films were deposited on double-side-polished 0.5-mm-thick LaAlO<sub>3</sub> (LAO) (100) substrates by a radio-frequency sputtering system. The filter was fabricated by double-sided depositing patterned YBCO films on a 10-mm-square LAO substrate and by putting it in a gold-coated copper housing. The measured results show a good performance of high-Tc superconducting dual-passband filter. The temperature-dependent microwave properties are also discussed.

#### 4EPH03

##### **Superconducting Coplanar Waveguide Resonators for Applications in QIP and single photonics.**

*J.E.Healey, T.Lindstrom, C.Muirhead, M.S.Colclough, University of Birmingham; C.Webster, A.Y.Tzalenchuk, National Physical Laboratory*

We have designed and measured 6 GHz lambda/2 coplanar waveguide (CPW) resonators. We have studied the effect of temperature, choice of dielectric substrate and coupling capacitance of the resonators to the external circuitry in order to optimize the quality factor for subsequent circuit quantum electrodynamics (CQED) experiments with CPWs coupled to flux qubits. So far superconducting niobium CPW resonators on sapphire substrates have demonstrated the highest loaded quality factors, Q, of about 500,000 at 1.2 K and 900,000 at 50 mK. We have also demonstrated trimming of the coupling capacitors to the desired value using focused ion beam without sacrificing Q. We have measured resonators in the range of 50 mK to 4.2 K as a function of magnetic field and field angle relative to the plane of the film. Frequency shifts up to 2 MHz with a magnetic field applied perpendicular to the plane of the film have been observed for the fundamental, first and second harmonics, with only a small change in the Q factor at low temperatures. This has applications for engineering, such as filters and signal processing and physical applications for circuit-QED experiments.

#### 4EPH04

##### **Power-Handling Capability of Transmit Filters using Bulk Single Crystal Resonators**

*A.Saito, Yamagata University; H.Teshima, Nippon Steel Corporation; S.Ono, J.H.Lee, S.Ohshima, Yamagata University*

We investigated the frequency responses and power-handling capability of transmit bandpass filters (BPFs) by using superconducting bulk single-crystal resonators with dielectric trimming rods at a 5.0 GHz center frequency with a 100 MHz bandwidth. A 3-pole strip-line BPF was designed using a Chebyshev function with three pairs of resonators and dielectric trimming rods having the same dimensions and by adjusting the positions of the trimming rods. We simulated the frequency response with a low loss and passband ripple for the BPF. The strip-line BPF was fabricated using Dy-Ba-Cu-O QMG bulks and a pair of Al<sub>2</sub>O<sub>3</sub> substrate in a Cu cavity attached to the dielectric trimming rods. In this paper, we present the frequency response including tuning and trimming properties and power-handling capability of the transmit filters using Dy-Ba-Cu-O QMG bulk resonators.

*This work was supported in part by "Research and development of fundamental technologies for advanced radio frequency spectrum sharing in mobile communication systems" from the Ministry of Internal Affairs and Communications of Japan, intelligent cosmos foundation, JTS, and Okawa foundation.*

#### 4EPH05

##### **Development of High-Speed Tuning System for HTS Filters**

*S.Ohshima, M.Ohsaka, S.Takeuchi, H.Kinouchi, S.Ono, J.H.Lee, Yamagata University; Y.Takano, M.Yokoo, TSI; A.Saito, Yamagata University*

We developed a high-speed tuning system for HTS microstrip line (MSL) filters using a dielectric tuning plate, dielectric trimming rods, and conducting trimming rods. The tuning plate has windows through which the dielectric and conducting trimming rods pass. It was designed for a 3-pole filter with 5 GHz center frequency ( $f_c$ ) and 100 MHz bandwidth (BW) using a 3-dimensional electromagnetic simulator. We simulated the shift of the  $f_c$  to frequencies below 500 MHz using the tuning plate with a dielectric constant of 45 and improving the insertion loss (IL), the pass-band ripple, and the BW of the filter responses by adjusting the positions of the ceramic and copper (Cu) trimming rods. In the experiment, the positions of the plate and the rods above the filter were adjusted by using high-resolution stepping motors, which were operated at room temperature in the air. The minimum step of moving the plate and the rods was 0.001 mm. We experimentally evaluated that the  $f_c$  was shifted to 500 MHz while retaining the IL, pass-band ripple, and BW. The time taken by the 500 MHz tuning was less than 1 second. These results indicate that our method and system will be useful for the next generation of wireless communication systems.

*This work was supported in part by "Research and development of fundamental technologies for advanced radio frequency spectrum sharing in mobile communication systems" from the Ministry of Internal Affairs and Communications of Japan.*

#### 4EPH06

##### **Self-equalized linear-phase superconducting filters for the applications in the mobile and satellite communications**

*T.Zou, H.H.Xia, C.X.Zhou, M.He, X.J.Zhao, S.L.Yan, L.Fang, Department of Electronics, Nankai University, Tianjin, China*

Two kinds of linear phase superconducting filter are presented. The first one is designed for mobile communication applications and has a fractional bandwidth of 1.03% centering at 1950 MHz. In the coupling structure of the filter, two pairs of transmission zeros locating on the real-axis and imaginary-axis respectively are introduced, which make the filter exhibit a linear phase characteristic together with a quasi-elliptic function response. The second filter has a dual-band. Complex conjugate quadruplet of transmission zeros with quadrantal symmetry on the complex S-plane are introduced in the filter structure, which make the two bands of the filter exhibit a linear phase performance. Both of the filters were fabricated by double-sided Ti<sub>2</sub>Ba<sub>2</sub>CaCu<sub>2</sub>O<sub>8</sub> films. The substrates are LaAlO<sub>3</sub> and Sapphire respectively.

*This work was supported in part by the 973 Project of China (2006CB601006), 863 Project of China (2006AA03Z213) and Specialized Research Fund for Doctoral Program of Higher Education in China (20050055028).*

#### 4EPH07

##### **A dual mode narrow-band 4-pole HTS filter with high-power handling for TD-SCDMA mobile base station**

*Y.H.Wang, X.Q.Zhang, Y.S.He, Institute of Physics, Chinese Academy of Sciences*

A dual mode narrow-band 4-pole high-power handling HTS filter was developed for third generation (3G) mobile communications, which will be used in the transceiver of the TD-SCDMA base station. This filter was designed to endure high-power microwave signals (more than 2-3 watts). ACLR (Adjacent Channel Leakage power Ratio) test, which is defined as the ratio of the transmitting power in the major channel (within the pass band) and the leakage power in the adjacent channel (outside the pass band), were carried out in DaTang Mobile Equipment Inc. Results of the test showed that by introducing our HTS filter into the system, no obvious increase can be seen in the ACLR ratio between the major channel and the 1st adjacent channel (channels closest to the pass-band-edges), with powers up to 5 Watts. More over the ratio to the 2nd adjacent channel showed remarkable reduction, demonstrating the superiority of employing high performance HTS filter to reduce the non-linearity of other devices in the system and achieve high EMF compatibility. For further examination of power handling ability of this filter, power dependent transmission (S<sub>21</sub>) response curves were measured and no noticeable change can be seen up to 10 watts. This filter was integrated with other devices as front end of the transceiver of TD-SCDMA base station. Field trail in a 3G network will be carried out in this spring. Results of field trail will be reported in the conference.

#### 4EPH08

##### **Theoretical Investigations on THz and Optical Superconductive Surface Plasmonic Waveguides**

*H.Majedi, University of Waterloo*

Negative dielectric constant of superconductors is used to investigate the possibility of surface plasmon excitations for Transverse Magnetic (TM) modes of electromagnetic waves for superconductor/dielectric waveguides. BCS complex conductivity and Drude-type complex permittivity have been used for LTS and HTS, respectively, to arrive at the negative complex permittivity that has to be coupled to Maxwell's Equations. The modal electromagnetic field analysis has been carried out for interface, trilayer and five-layer superconductor/dielectric waveguide structures to find the propagation constant of the propagating electromagnetic waves. Swihart and surface plasmon regimes are derived and the possibility of having surface plasmon regime for both LTS and HTS materials will be discussed. Specific applications in THz waveguiding and superconducting optoelectronic devices will be highlighted at the end.

#### 4EPJ - Active Microwave and Terahertz Devices – I 10:00am - 12:00pm

#### 4EPJ01

##### **High-Tc dc SQUID Radiofrequency Amplifier Operated with a Mechanical Cryocooler**

*O.V.Snigirev, M.L.Chukharkin, A.V.Ryazanov, Department of Physics, M.V. Lomonosov Moscow State University; A.S.Kalaboukhov, D.Winkler, Chalmers University of Technology, SE-412 96 Goteborg Sweden*

We report a first operation of a high-Tc dc SQUID amplifier with a mechanical cryocooler at temperatures down to 40 K. The SQUID is fabricated on the r-plane sapphire bicrystal substrate with a misorientation angle of 24 degrees. It consists of the single layer of YBCO film and 7-turn Nb/Au input coil separated from the SQUID washer by amorphous YSZ layer. The dc and microwave properties of the fabricated amplifier have been measured in the temperature range of 40 - 77 K. The power gain of order of 15 dB has been found at frequency of 2.3 GHz with 50 MHz bandwidth at 40 K. The obtained results are compared to 3-D numerical simulations of the surface current distribution in the input coil and the distribution of the magnetic field coupled to the SQUID washer. S-parameters of the SQUID amplifier have also been simulated in the frequency range 1- 8 GHz.

*Work was supported by the Royal Swedish Academy of Sciences via KVA grant and by the ONR via CRDF Grant Assistance Program (project RUE1-1610-MO-05)*

#### 4EPJ02

##### **Eck resonances in high-T<sub>c</sub> long faceted Josephson junctions.**

*G.Rotoli, Università dell'Aquila; F.Tafari, Università di Napoli 2; D.Stornaiuolo, D.Born, Università di Napoli; T.Bauch, F.Lombardi, MC2 Chalmers Technical University*

By means of numerical simulations we study the dynamics of the phase difference in faceted long Josephson junctions. We compare our simulations with experiments on different samples of high quality high-T<sub>c</sub> biepitaxial junctions. Adjusting junction length and dissipation to reproduce the observed data we found a significant agreement which permits to identify these resonances mostly as Eck steps. Some considerations is also made on the requirements to observe flux-flow or Fiske resonances in these junctions. Effects of pi-shift and random faceting are also considered.

*PRIN MIUR 2006 "Sistemi Quantistici Macroscopici-Aspetti Fondamentali ed Applicazioni di strutture Josephson Non Convenzionali"*

#### 4EPJ03

##### **Advantages and disadvantages of SQIFs for microwave applications**

*V.K.Kornev, I.I.Soloviev, Physics Department, Moscow State University, Moscow, Russia; N.V.Klenov, Physics, Department, Moscow State University, Moscow, Russia; O.A.Mukhanov, Hypres, Inc., 175 Clearbrook Road, Elmsford, NY, USA*

We consider different applications of SQIFs as amplifiers for gigahertz frequency range. SQIF is able to provide much higher dynamic range and linearity than dc SQUID and therefore could be used in input circuits of ADCs to improve their characteristics or even as an active electrically small superconducting antenna because SQIF eliminates high external interference due to nonperiodic structure. Dynamic range increases as square root of number of SQIF elements N, as well as high linearity voltage response may be achieved using specific structure of the SQIF [1]. The main problem is to keep entirely the specific structure functioning in spite of influence of surrounding environment and directly coupled circuits. Possible ways to overcome the problem are suggested and discussed in detail. [1] V. K. Kornev, I. I. Soloviev, N. V. Klenov, and O. A. Mukhanov, Superconducting Science and Technology (SUST), v. 20, 2007, p. S362-S366. *This work was supported in part by CRDF GAP Grant 1493*

#### 4EPJ04

##### **Synchronized High-Tc Josephson Junction Arrays in Fabry-Perot Resonator System**

*M.He, Dept. of Electronics, Nankai Univ., Tianjin, P. R. China; A.M.Klushin, N.Klein, Forschungszentrum Jülich GmbH, Germany; X.J.Zhao, S.L.Yan, T.G.Zhou, Dept. of Electronics, Nankai Univ., Tianjin, P. R. China*

In this report, we explored high-temperature superconductor (HTS) Josephson junction arrays embedded in a hemispherical Fabry-Perot resonator. Numerical field simulations were also made to investigate the coupling mechanism of the system. We found optimal design of arrays to achieve steps at higher voltage with a better coupling to the millimeter wave irradiation power than our former design, which enables us to achieve a maximum Josephson voltage of about 0.1V for an array of 620 bicrystal junctions at a temperature of 79.2K and a frequency of 77.465 GHz. In addition, we demonstrated that Shapiro steps of a bicrystal junction array at a voltage of 70 mV were flat within 4 parts in 10 to order of 8 over the current range of 150  $\mu$ A.

#### 4EPJ05

##### **Simulation and measurement of HTS Josephson heterodyne oscillator**

*J.C.Macfarlane, Strathclyde University, UK; J.Du, CSIRO, NSW 2070, Australia; R.Taylor, M&MD Pty Ltd, Qld, Australia; C.M.Pegrum, FieldSolutions, Glasgow G12 9SD, UK*

Practical applications of the ac Josephson effect as the basis for a voltage-tunable radio-frequency oscillator have been hindered both by the low available oscillator power levels, and by the inherently large thermal linewidth broadening of the signal. We have previously demonstrated experimentally [1] that useful power levels (10s of nW) and linewidths of a few kHz can be achieved in the heterodyne output from a High-Temperature-Superconducting Resistive SQUID (HTS-RSQUID) operating in the frequency range 1 – 50 MHz. Those results were achieved with 2-junction R-SQUIDS incorporating current-biased shunt resistors of a few micro-ohms. With appropriate modifications to the fabrication procedure, and by adjustment of the resistors and bias current values, higher frequencies can be achieved. Step-edge Josephson junction technology has been employed to fabricate such a heterodyne oscillator. In the present paper, we report numerical simulations and experimental measurements we have carried out to assess the feasibility of extending the range of operation of such a device to 1 GHz. [1] J.C. Macfarlane et al., Linewidth of a resistively-shunted high-temperature-superconductor Josephson heterodyne oscillator, Appl. Phys. Lett. Vol. 76, 1752-1754, 2000.

#### 4EPJ06

##### HTS Antennas for THz submillimeter Radiation

*D.C.Chung, Dept. of EE Woosuk Univ; H.S.Choi, Dept. of EE Chosun Univ.; M.H.Kwak, G.Y.Kang, ETRI; S.H.Lim, Dept. of EE Soongsil Univ.*

High-Tc superconducting (HTS) antennas for 3 THz submillimeter radiation were designed and fabricated by photolithographic method. HTS thin films used in this work was YBCO thin film deposited on MgO substrate. The radiation patterns of our antennas were measured for 3 THz CH<sub>3</sub>OH laser radiation. Measured radiation patterns were well agreed with calculated antenna patterns. The efficiency and power gain were measured and compared with theoretically calculated value. Those were several times higher than normal conducting counterparts. We think that our superconducting antennas fabricated in this work will be useful for NMR, medical spectroscopy and so on in future application.

#### 4EPJ07

##### Higher Harmonics of the THz Electromagnetic Emission from Intrinsic Josephson Junction Bi<sub>2</sub>Sr<sub>2</sub>CaCu<sub>2</sub>O<sub>8</sub> Single Crystals

*H.Yamaguchi, K.Yamaki, GS-PAS, Univ. Tsukuba; I.Takeya, H.Minami, T.Yamamoto, K.Kadowaki, IMS, Univ. Tsukuba; S.Hashimoto, GS-PAS, Univ. Tsukuba; M.Tachiki, L.Ozyuzer, Univ. of Tokyo; A.E.Koshelev, C.Kurter, K.E.Gray, W.-K.Kwok, U.Welp, MSD, ANL*

Generation of electromagnetic waves with THz frequencies is currently a hot topic in science and technology fields since they have a versatile applications in all kinds of research fields. We have succeeded in generating intense, continuous and monochromatic electromagnetic radiation at frequencies from a few 100 GHz to 1 THz region by making use of high temperature superconductor single crystals of Bi<sub>2</sub>Sr<sub>2</sub>CaCu<sub>2</sub>O<sub>8</sub>+d. As reported (L. Ozyuzer et al., Science 318, 1291 (2007)) previously, it is shown that the radiation frequency,  $f$ , follows the simple relations of  $f=c/2nw=2eV/hN$ , where  $c$  is the light velocity in vacuum,  $n$  the refractive index,  $w$  the width of the mesa,  $V$  the voltage appearing in the mesa,  $N$  the number of the intrinsic Josephson junctions,  $e$  and  $h$  are the elemental charge and the Planck constant. Associated with the intense fundamental emission line, we recently found higher harmonics up to the 4th order. We will show the detailed experimental results concerning the intensity ration as well as the angular dependence of the higher harmonics in comparison with the recent theoretical analyses.

*This work has been supported by the Grant-in-Aid for Scientific Research (A), CREST-JST, JSPS CTC program, WPI-MANA project in MEXT of Japan.*

## THURSDAY AFTERNOON ORAL SESSIONS

### 3:00pm - 5:00pm

#### 4EA - Quantum Computing – II 3:00pm - 4:45pm

##### 3:00pm

##### 4EA01 - Controlled quantum logic gates between low-frequency fluctuators in a Josephson junction

*L.Tian, Stanford University*

Two-level systems (TLSs) in the tunnel barrier of a Josephson junction have recently been observed as energy splittings in the spectroscopic measurements of the superconducting phase qubit. With their strong coupling to the Josephson junction and the relatively long coherence time, the TLSs can be treated as qubits themselves and demonstrate coherence quantum dynamics. In a previous work (L. Tian and R. W. Simmonds, Phys. Rev. Lett. 99, 137002, (2007) ), we proposed a cavity QED approach to characterize the coupling between the TLSs and a Josephson junction by measuring the microwave transmission in the Josephson junction

which behaves as a high-Q microwave resonator. Various properties of the TLSs can be studied in this scheme. Here, we show that the coupling between the Josephson junction resonator mode and the TLSs can serve as an effective tool to control the quantum dynamics and the coupling between the TLSs. Controlled quantum logic gates can be performed on TLSs through the manipulation of the resonator mode.

*This work is supported by the Urbanek Postdoc Fellowship in the Department of Applied Physics at Stanford University.*

##### 3:15pm

##### 4EA02 - Probing anomalous two-level systems with a Cooper-pair box

*Z.Kim, V.Zaretsky, Laboratory for Physical Sciences; J.F.Schneiderman, M.D.Shaw, Dept. of Physics, University of Southern CA; P.M.Echternach, Jet Propulsion Laboratory, California Institute of Technology; F.C.Wellstood, Joint Quantum Institute and Center for Nanophysics and Advanced Materials; B.S.Palmer, Laboratory for Physical Sciences*

We have used an Al/AlO<sub>x</sub>/Al Cooper-pair box (CPB) qubit to detect coupling to anomalous “two-level” quantum systems. By measuring the excitation spectrum and lifetime of the first excited state from 15 GHz to 50 GHz of the CPB at a temperature of 40 mK, one can identify anomalous levels and ascertain the magnitude of the quantum noise that is coupled to the qubit. It was found that the frequency of a distinct avoided level crossing depends on gate voltage and the size of the splitting depends on the effective Josephson energy. Both the gate voltage and Josephson energy dependence are consistent with coupling to extraneous charged two-level systems formed by point charges that can tunnel between two positions in the oxide of the Josephson junction. By fitting a model Hamiltonian to our data, we are able to extract microscopic information about the charge fluctuator such as the well asymmetry (~130 micro-eV), tunneling rate (~ 8 GHz) and a maximum hopping distance for the charge fluctuators (~ 0.8 Angstroms). *This research was supported by the National Security Agency. FCW would like to acknowledge support from the Joint Quantum Institute and State of Maryland through the Center for Nanophysics and Advanced Materials.*

##### 3:30pm

##### 4EA03 - Study of two-level systems in superconducting microwave resonators

*J.Gao, California Institute of Technology; M.Daal, University of California at Berkeley; A.Vayonakis, California Institute of Technology; B.A.Mazin, H.G.Leduc, P.K.Day, Jet Propulsion Laboratory; S.Gawala, B.Sadoulet, J.Zmuidzinas, California Institute of Technology*

Excess frequency noise in superconducting microwave resonators has long been observed and can be a limiting factor for device performance. It is suggested that two-level systems (TLS) in dielectric materials may be responsible for this noise. Here we report results of two recent experiments. In the first experiment, we deposited 1 micron thick silicon nitride on the surface of Al on sapphire CPW resonators. We find that the temperature dependence of resonance frequency and quality factor agrees well with the TLS theory. We also observed an increase by a factor of 20 in the frequency noise after the deposition of silicon nitride, which demonstrates that a surface layer of TLS loaded material is able to produce excess frequency noise. In the second experiment, we measured the temperature-dependent frequency shift of five niobium on sapphire CPW resonators, with center strip widths  $s$  ranging from 3 micron to 50 micron. Again, we find that the frequency shift can be well explained with the TLS theory. The amplitude of the frequency shift has a strong geometry dependence and scales roughly as  $1/s$ . This result strongly implies that the TLS are distributed on the surface of the CPW but not in the bulk substrate.

**3:45pm**

**4EA04 - Non-equilibrium quasiparticle kinetics in superconducting charge qubits**

*M.D.Shaw, University of Southern California; P.Delsing, Chalmers University of Technology; P.M.Echternach, Jet Propulsion Laboratory, California Institute of Technology*

We directly observe the statistics of non-equilibrium quasiparticle tunneling in a pair of Al charge qubits based on the single Cooper-pair box. Incoherent tunneling processes are a significant problem in single-charge devices, which must be understood and engineered away for applications in quantum computing. We measure the odd-to-even and even-to-odd transition rates as a function of gate voltage, temperature, and RF readout power and interpret these results using the kinetic theory of Lutchyn and Glazman, which demonstrates that low-temperature quasiparticles are out of thermal as well as chemical equilibrium. This theory successfully predicts a number of interesting features at low temperatures.

**4:00pm**

**4EA05 - Sisyphus Heating and Cooling of a Resonator Coupled to a Flux Qubit Under Microwave Irradiation**

*S.H.W.van der Ploeg, Institute of Photonic Technology, Jena, Germany; M.Grajcar, department of experimental physics, Comenius university, Bratislava, Slovakia; A.Izmalkov, T.Wagner, U. Huebner, E.Ilichev, H.-G.Meyer, Institute of Photonic Technology, Jena, Germany*

The results of spectroscopic measurements on flux qubits coupled to a low frequency resonator will be presented. This resonator can be used to measure the curvature of the qubit's ground state. Also it can detect the response of microwave excitation and therefore be used for spectroscopy. Both methods allow to determine the values of the persistent current and tunnel splitting of the qubit and, therefore, to reconstruct the qubit Hamiltonian. The results of both methods are completely consistent. In the spectroscopic measurements we observed energy transfer between the microwave field and the resonator. We attribute this effect to a Sisyphus mechanism where the tank, depending on the sign of the microwave detuning, always increases or decreases the total energy of the qubit.

**4:15pm**

**4EA06 - Experimental Results on the Engineering of Photon States with Phase Qubits**

*F.Altomare, K.Cicak, J.I.Park, J.D.Whittaker, R.W.Simmonds, National Institute of Standards and Technology*

Two key tools used in quantum information systems are superconducting quantum bits and resonant cavities. At present, a considerable amount of research has been devoted to manufacturing and studying the properties of superconducting qubits. Recently, we have inserted a superconducting transmission line cavity between two phase qubits (Sillanpaa et al, Nature 449, 438 (2007)). A resonant cavity can be used as a quantum memory, a bus for transferring individual qubit states, and, in another experiment, a virtual interaction space for entangling qubits (Majer et al, Nature 449, 443 (2007)). In addition, due to the large number of non-classical photon or "Fock" states available, a resonant cavity can exhibit interesting quantum dynamics of its own. We have taken the first steps towards engineering specific Fock states in a cavity using the phase qubits as control and readout devices. Generating these cavity states offers us a new resource for manipulating and processing quantum information.

**4:30pm**

**4EA07 - Effect of Isolation on dc SQUID Phase Qubit Lifetimes**

*A.J.Przybysz, T.A.Palomaki, H.Kwon, R.M.Lewis, B.K.Cooper, K.Mitra, J.R.Anderson, C.J.Lobb, A.J.Dragt, F.C.Wellstood, University of Maryland, JQI*

The dc SQUID phase qubit has been plagued by relatively short coherence times  $T_2$ , and relaxation times  $T_1$  (tens to hundreds of ns). Defects in the tunnel barrier, dielectric loss, and dissipation from the impedance of the bias leads have all been implicated. Our phase qubits consist of a dc SQUID with Al/AlO<sub>x</sub>/Al junctions on a sapphire substrate and a loop inductance of order 1-2 nH. One junction has a small area (typically 2-4 microns on a side) with a 0.7-1.2 microamp critical current and acts as a phase qubit. The other junction in the SQUID is about 10 times larger and can be used as the low inductance branch of an inductive divider that isolates the qubit from its bias leads. In order to determine the importance of dissipation due to the bias leads as a source of decoherence, we vary the current through the isolation junction in order to increase or decrease the amount of noise that reaches the qubit and measure its effect on  $T_1$  and the Rabi decay time. We measured three different devices at 20 mK; one device showed the  $T_1$  dependence on isolation, while the other two did not. We will discuss these results and also present results from additional experiments that are still in progress.

*Funding by JQI, CNAM, DOD*

**4EB - Digital IV - Circuit Design 3:00pm - 4:45pm**

**3:00pm**

*Invited*

**4EB01 - Design and Implementation of SFQ Half-Precision Floating-Point Adders**

*H.Park, Y.Yamanashi, K.Taketomi, N.Yoshikawa, Yokohama National University; M.Tanaka, K.Obata, Y.Itou, A.Fujimaki, N.Takagi, K.Takagi, Nagoya University; S.Nagasawa, Superconductivity Research Laboratory*

We have been developing a large-scale reconfigurable data-path (LSRDP) based on single flux quantum (SFQ) circuits to establish a fundamental technology for future high performance computing systems. The LSRDP is composed of a large number of floating point units which are connected each other by reconfigurable network switches. In the LSRDP, reputation loops in the source program are directly mapped to hardware. Its main advantage is the reduction of the memory wall problem. In the LSRDP, SFQ floating-point adders (FPA) are one of main and the most complicated circuit blocks. We designed and implemented an SFQ half-precision FPA. The floating-point addition is performed by three steps: adjustment of exponent's positions and rounding, calculation of fractions, and normalization. We have implemented an SFQ half-precision FPA using the SRL 2.5kA/cm<sup>2</sup> Nb process. The size and total junction number are 4.96 x 6.76 mm<sup>2</sup> and 11700. Simulated dc bias margin is  $\pm 20\%$  at 20GHz operation, which corresponds to the performance of 1GFLOPS. We have successfully confirmed the correct operation of the 11-bit fraction calculation block. We will present on-chip high-speed test results of the whole FPA system.

*This research was supported by CREST, Japan Science and Technology Agency.*

**3:30pm**

**4EB02 - RSFQ baseband DSP**

*A.Y.Herr, I.Kataeva, H.Éngseth, R.Rafique, B.Sarabi, Chalmers University of Technology*

Ultra fast switching speed of superconducting digital circuits enable realization of Digital Signal Processors with performance unattainable by any other technology. Based on rapid-single-flux technology (RSFQ) logic, these integrated circuits are capable of delivering high computation capacity up to 30 GOPS on a single processor and very short latency of 0.1 ns. There are two main applications of such hardware for practical telecommunication systems: filters for superconducting ADCs operating with digital RF data and recursive filters at baseband. The later of these allows functions such as multiuser detection for 3G WCDMA, equalization and channel precoding for 4G OFDM MIMO, and general blind detection. The performance gain is an increase in the cell capacity, quality of service, and transmitted data rate. The current status of the development of the RSFQ baseband DSP is discussed. Major components with operating speed of 30 GHz have been developed. Designs, test results, and future development of the complete systems including cryopackaging and CMOS interface are reviewed.

*This work was supported in part by SSF INGVAR grant, EU FP6 "RSFQubit", VR N2003-10990-17764-11, STINT, ONR. Dr. A. Herr (Kidiyarova-Shevchenko) is supported by The Royal Swedish Academy of Sciences by a grant from the Knut and Alice Wallenberg Foundation.*

**3:45pm**

**4EB03 - SFQ Circuits in Magnetic Field**

*V.K.Semenov, S.Narayana, Stony Brook University*

A great variety of unique SFQ circuits have been suggested and demonstrated during the last two decades. The data in these circuits are presented by presence or the sign of magnetic flux quanta. It is natural that the circuits are highly sensitive to ambient magnetic field caused either by frozen magnetic flux or induced by an electric current required for circuit operation. Many efforts have been made to reduce magnetic field surrounding SFQ circuits. However, dramatically less has been reported about direct investigations of parasitic effects caused by magnetic field. We investigated many circuits affected by magnetic fields of different intensities and orientation. Most of SFQ circuits developed and fabricated earlier for different projects successfully "passed" through our magnetic test. However, we discovered also some bad cells especially those with internal magnetic coupling that are highly sensitive to magnetic field. At the conference we will compare the experimental results with our theoretical expectations. We hope that our investigation could help to improve many superconductor ICs. But our results are much more important for larger multi-chip projects where an extra design/fabrication cycle could easily kill a supposedly great project.

*The project has been supported in part by Office of Naval Research.*

**4:00pm**

**4EB04 - Flux Trapping in Superconducting Circuits**

*S.Narayana, V.K.Semenov, Y.A.Polyakov, Stony Brook University*

We already discussed many aspects of flux trapping in superconductor circuits at the last ASC. Later we designed and measured a great variety of circuits with similar functionality but different flux-trapping environment. Our observations could be generalized in several statements. Similar cells in the array usually demonstrate statistically similar trapping sensitivities. However,

occasionally we have deal with strange "fabrication" defects when one cell in the array is dramatically more sensitive than the others. Flux moats are probably the most important way to protect circuit components from flux trapping. Overwhelmingly the protection quality is reversely proportional to the second power of the distance between the moat and protected circuit component. The next important recommendation is to check the shielding quality in as real environment as possible. In plain words, we discovered that the quality of used magnetic shields is not as good as we expected. *The work is supported in part by office of Naval Research.*

**4:15pm**

**4EB05 - Impedance matching of microstrip inductors in digital superconductive electronics**

*T.Ortlepp, F.H.Uhlmann, Ilmenau University of Technology*

The topology of state-of-the-art RSFQ circuits consists of Josephson junctions, inductances and bias current sources, whereat the inductances are practically used as functional elements. Even more, their value defines the functionality and therefore the conventional design process requires strict conditions for the wiring between Josephson junctions. The present design and optimization process does not take into account their parasitic capacitances to ground. This becomes an important issue for ultra fast applications above 100 GHz, but also for circuits dedicated to control quantum electronics. We report on a theoretical and experimental investigation of the influence of ground capacitances to the operation of RSFQ circuits with reduced current densities. The impedance matching between the connecting microstrip-lines and the Josephson junction is a key issue for the correct operation of these circuits. We performed circuit simulations and collected experimental data of correct and incorrect operating circuits to derive a design criteria. The critical reflection coefficient is 0.35 and the particular design must use a smaller value for transfer and a larger value for storage of SFQ pulses, respectively.

*The circuit design and fabrication were supported by FLUXONICS Foundry.*

**4:30pm**

**4EB06 - SFQ pulse transfer circuits using inductive coupling for current recycling**

*M.Igarashi, K.Churei, N.Yoshikawa, Yokohama National University; K.Fujiwara, Y.Hashimoto, SRL-ISTEC*

Recent development of single-flux-quantum (SFQ) circuit technology enabled us to make large-scale SFQ digital systems including more than ten of thousands of Josephson junctions. The total bias current for such large SFQ circuits is now well over one ampere. The increasing bias current causes several problems to the circuits operation, such as large magnetic fields and unexpected ground return currents. One way to solve this problem is a current recycling technique called series-biasing, where some SFQ circuits placed on separated floating grounds are biased in series to reduce the total bias current. The key component for the current recycling is an SFQ pulse transfer circuit, which transfers an SFQ pulse between the SFQ circuits on different ground planes. In this paper, we examined two types of inductively coupled pulse-transfer circuits. One is composed of an SFQ driver based on a delay flip-flop and a SQUID receiver. The advantage of this circuit is that the coupling time between the driver and the receiver can be increased and well controlled. The other is composed of a simple JTL pulse driver and a SQUID receiver whose junctions are slightly under-damped to reduce SQUID switching time, resulting in large operating margins. We have implemented the two types of pulse transfer circuits using SRL 2.5 kA/cm<sup>2</sup> Nb process and demonstrated their correct operations.

**3:00pm**

**4EC01 - A HIGH SELECTIVE HTS FILTER WITH GROUP DELAY SELF-EQUALIZATION FOR 3G MOBILE TELECOMMUNICATION SYSTEMS**

*C.G.Li, Q.Zhang, X.Q.Zhang, H.Li, Y.S.He, Institute of Physics, Chinese Academy of Sciences*

A recent development of a twelve-pole high-temperature-superconducting (HTS) bandpass filter with group delay self-equalization for 3G wireless applications is reported. The filter is designed to have a 5.425MHz pass-band at a centre frequency of 2121.5MHz. The filter exhibits a quasi-elliptic function response implemented with a cascaded quadruplet (CQ) coupling structure. Two pair of complex frequency transmission zeros placed at  $\omega = \pm 0.5 \pm 0.3i$  have been introduced to implement linear phase for group delay self-equalization, where  $\omega$  is the normalized frequency related to the real frequency variable  $f$  and fractional band width (FBW) as  $\omega = \text{FBW} * (f/f_0 - f_0/f)$ . A pair of image frequency transmission zeros placed at was introduced to improve the selectivity. The filter was fabricated on a 0.5mm-thick MgO wafer with double-sided YBCO films. The filter displayed a minimum insertion loss of 0.2 dB in the passband and a return loss better than 14 dB over the pass-band. Out-of-band rejection at both sides is higher than 57dB with the skirt-slope as high as 100dB/MHz. The filter shows a 60ns fluctuation of group delay within 78% pass-band which matches the requirement of TD-SCDMA standard of 3G mobile telecommunication.

**3:15pm**

**4EC02 - Submillimeter-wave, lumped-element, superconducting bandpass filters for multicolor imaging**

*S.Kumar, IBM; A.Vayonakis, J.Zmuidzinas, California Institute of Technology*

The opacity of Earth's atmosphere obscures portions of the sub-THz sky to ground based astronomical observation. This requires that band defining filters be used in conjunction with a broad band antenna and submillimeter photon detectors to construct pixels working at these wavelengths. These filters reduce the load on the detectors from the atmospheric emission thereby preventing their sensitivity from degrading. This paper presents the design and measurements of superconducting, lumped-element, on-chip bandpass filters placed inline with the microstrip connecting the antenna and the detector. Four filters were designed to be used in different pixels. Filter passbands were 209-265 GHz, 274-315 GHz, 335-361 GHz and 397-416 GHz, corresponding to the windows in the Earth's atmospheric transmission spectrum. Fourier transform spectroscopy (FTS) was used to verify that the spectral response of the filters is well predicted by the computer simulations. The on-chip, lumped element design also allowed us to construct two-color pixels by connecting the output of a single broadband antenna to two different filters in parallel. The output of each filter was detected by a separate photon detector. These pixels were used to implement a 16-pixel, two-color camera. The FTS results from the lab testing of the camera are presented. The paper also discusses a new pixel design allowing four-color operation for future camera designs.

**3:30pm**

**4EC03 - Linear and Nonlinear Superconducting Transmission Line Periodically Loaded with Normal Conductor and Dielectric Gap**

*H.R.Mohebbi, A.H.Majedi, University of Waterloo*

Linear and nonlinear microwave signal propagation analyses are carried out in periodically-loaded superconducting transmission line either with normal metal, (S-N TL) or insulator gap (S-I TL).

Both analyses are based on the combination of Floquet theorem and the ABCD matrix method when the kinetic inductance of the superconducting segments is either in linear or in nonlinear regime. We derive the dispersion and impedance equations for both structures, S-N and S-I TLs, with infinite and finite length. Dispersion and impedance equations are solved numerically under various boundary conditions in order to find the propagation characteristics such as complex propagation constant and group velocity. Band gap formation in S-I TL is highlighted and its potential applications in the design of passive filters and resonators are discussed. The role of kinetic inductance nonlinearity in band gap engineering of the SI-TL is highlighted and its potential benefit to tune the resonant frequency and the filtering properties of the structure is discussed. By introducing some CPW prototype design of the two structures the experimental results of the HTS-based S-I TL will be demonstrated.

**3:45pm**

**4EC04 - A Superconducting Array of Scatterers Embedded in a Coplanar Waveguide**

*N.Orloff, University of Maryland, Physics Department; D.Gu, A.Lewandowski, J.C.Booth, National Institute of Standards and Technology; I.Takeuchi, University of Maryland, Physics Department*

We investigate experiments on conventional coplanar waveguide transmission lines loaded with arrays of small lithographically-patterned yttrium barium copper oxide superconducting scatterers. Since there is no DC transport between scatterers, when the material is in the superconducting state the large imaginary conductivity term in the permittivity overwhelms the permittivity of the substrate, yielding a negative permittivity metamaterial. Our experiments explore the effects of lattice orientation, filling fraction, and the suppression superconductivity with an applied DC magnetic field. We also look at the effects of kinetic inductance on nonlinear excitations in this metamaterial.

**4:00pm**

**4EC05 - NbTiN superconducting high Q microwave resonators**

*R.Barends, H.L.Hortensius, Delft University of Technology; J.R.Gao, Delft University of Technology and SRON Netherlands Institute for Space Research; J.N.Hovenier, T.M.Klapwijk, Delft University of Technology; J.J.A.Baselmans, S.J.C.Yates, SRON Netherlands Institute for Space Research*

Kinetic inductance photon detectors [1] as well as experiments in circuit quantum electrodynamics [2] demand low noise, high Q superconducting resonators. Currently available resonators show, at low temperatures, excess frequency noise [3], a saturation of the quality factor and a non-monotonic temperature dependence of the resonance frequency [4], all incompatible with the expected high-frequency response of the superfluid and quasiparticles [5]. We have realized and studied NbTiN coplanar waveguide microwave resonators. We find a monotonic resonance frequency temperature dependence, a normalized frequency noise as low as -200 dBc/Hz, and Q factors up to  $10^6$  down to 300 mK. After adding a sputtered SiO<sub>2</sub> dielectric layer on top of the resonators, we observe a non-monotonic temperature dependence of the resonance frequency as well as an increase in the frequency noise, without changing the spectrum. These observations suggest that processes associated with the dielectric layers may play a strong role in NbTiN resonators. [1] P. K. Day et al., Nature 425, 807 (2003) [2] A. Wallraff et al., Nature 431, 162 (2004) [3] J. Gao et al., APL 90, 102507 (2007) [4] R. Barends et al., IEEE TAS 17, 263 (2007) [5] D. C. Mattis and J. Bardeen, PR 111, 412 (1958)

**4:15pm**

**4EC06 - Cryogenic Actuators and Motors for Tunable Superconducting Devices**

*X.Jiang, TRS Technologies, Inc.; S.Dong, Virginia Tech; W.S.Hackenberger, TRS Technologies, Inc.; D.Viehlend, Virginia Tech; W.Cook, NASA Langley Research Center*

Single crystal PMN-PT is known with unprecedented high piezoelectric properties at both room temperature and cryogenic temperatures. The piezoelectric coefficients of PMN-PT at 30 K are equivalent to the values of conventional PZT ceramics at room temperature. In this paper, the design, fabrication and characterization of novel single crystal piezoelectric actuators will be presented for cryogenic positioning control in tunable superconducting devices. Single crystal stack actuators with dimension of 10mmx10mmx50mm showed the stroke of 65-80  $\mu\text{m}$  at room temperature, and  $> 30 \mu\text{m}$  at 77K under  $\sim 150\text{V}$ . A flexensional stack actuator with dimension of 10mmx5mmx50mm exhibited stroke of  $\sim 300 \mu\text{m}$  at room temperature and  $> 100 \mu\text{m}$  at 77K under driving of 150 V. A Single crystal stepping motor developed recently is expected to achieve 15 mm stroke at the resolution of 80 nm at 77 K. The initial tuning experiments on YBCO thin film resonator using a flexensional actuator with stroke of 150  $\mu\text{m}$  at room temperature showed promising results. Further study will focus on precise and broadband tuning using cryogenic stepping motors. The cryogenic actuators presented in this paper also hold promising for space active and passive optics applications.

*The support from NASA under contracts NNL06AA09C and NNL07AA94P for cryogenic actuators development is greatly acknowledged. The initial HTS resonator tuning was performed by STI under the Air Force/MDA contract #F49620-03-C-0012.*

**4:30pm**

**4EC07 - Nonlinear Compensation in Combined HTS/Ferroelectric Devices at Microwave Frequencies**

*J.C.Booth, N.D.Orloff, NIST; J.Mateu, Universitat Politecnica de Catalunya*

Nonlinear effects such as intermodulation distortion and harmonic generation can be detrimental for microwave applications of high temperature superconductor devices in communications systems. While nonlinear effects can be mitigated somewhat by modifying circuit designs to reduce high rf current densities, these approaches compromise one of the principle benefits of superconducting circuits, namely compact device size. We explore the possibility of canceling nonlinear effects in HTS microwave devices by incorporating nonlinear capacitances, in order to compensate for the nonlinear inductance inherent in superconducting devices. We have designed and fabricated a number of different planar transmission line and resonator devices using thin-film bilayers of SrTiO<sub>3</sub>/YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7-x</sub>. We combine accurate linear on-wafer calibrations and measurements with nonlinear techniques to obtain a quantitative measure of the nonlinear impedance, which quantifies the nonlinear response and which can be analyzed in order to evaluate how effects due to nonlinear inductances and nonlinear capacitors interact in distributed structures.

**4:45pm**

**4EC08 - A Novel Planar Design for an "Intrinsically Detuned" MRI Coil**

*J.Wosik, TcSUH and Electrical and Engineering Dept., University of Houston, Houston, TX 77204, USA; K.Nesteruk, Institute of Physics PAS, 02-668 Warsaw, Poland; F.Ip, L.-M.Xie, TcSUH and Electrical and Engineering Dept., University of Houston, Houston, TX 77204, USA*

When Faraday coil noise is the governing source of MRI system noise, it has long been recognized that cooling of normal metal and/or using HTS can drastically reduced such noise. Implementation of HTS coils in MRI is challenging, thus most reports refer to coils with inductive coupling and without any detuning circuit from the transmit coil. Due to high Q of HTS coils and, in addition, the prohibitive use of normal metal for crossovers, new designs are required. Therefore, we report a coil, which in principle is intrinsically isolated from the whole body scanner transmit coil. In the uniform rf field, this coil should not require special circuitry when the transmit is used for excitation. Our design consists of two modified double-sided split-ring resonators connected on one end by two narrow strips. The coil was patterned using standard patterning process on 2" YBCO films deposited on both sides of a 0.5 mm thick LAO dielectric substrate. Both copper and HTS were positively tested for coil detuning performance. Unloaded Qs were measured as 380 and 15,000 for Cu and HTS, respectively. The additional advantage of such a design, is also the relatively smaller eddy current losses. MRI images acquired in a 3 Tesla (128 MHz) scanner will be presented and discussed.

*This work was supported by NIH AR053156.*

**THURSDAY LATE AFTERNOON ORAL SESSIONS**

**5:30pm - 7:30pm**

**4EX - Electronic Device Fabrication – V 5:30pm - 7:30pm**

**5:30pm**

**4EX01 - Operation of toggle flip-flop circuits up to 500 GHz based on vertically-stacked high-temperature superconductor Josephson junctions**

*T.Kimura, Nagoya Univ., CREST JST, JSPS Research Fellow; M.Watanabe, K.Kajino, Y.Horii, M.Inoue, A.Fujimaki, Nagoya Univ., CREST JST*

We report the 500 GHz operation of toggle flip-flop (TFF) based on high-temperature superconductor vertically-stacked Josephson junctions (VSHTSJJJs). To the authors' knowledge, this is the first time success in the circuit operation using VSHTSJJJs. We have fabricated the VSHTSJJJs, because VSHTSJJJs have several advantages such as low parasitic inductances compared with ramp-type JJs. As the first trial of the circuit operation, we fabricated TFF circuits, because TFF is used as a benchmark circuit to indicate potential of the circuit operation speed. The TFF circuit was composed of 7 JJs. We utilized YBCO as a base and a counter electrode and PGO as an insulator. They were deposited by the RF magnetron sputtering method. To simplify the fabrication process for contact holes, we utilized the counter YBCO layer as a wiring layer. The junction barrier was formed by the interface treatment based on an Ar ion bombardment in an ECR plasma etcher. We observed I-V characteristics at the input port and the output port of the TFF, and confirmed that the input voltage coincided with twice the output voltage up to 1 mV at 4.2 K, which corresponds to the correct operation up to 500 GHz. This frequency is the highest value in HTS circuits ever observed, which suggests the high potential of the VSHTSJJJs for the circuit operation. We expect the TFF operation above 1 THz after choosing appropriate process parameters.

5:45pm

#### **4EX02 - Hydrogen-Inclusion-Induced Critical Current Deviation of Niobium Josephson Junctions in Superconducting Integrated Circuits**

*K.Hinode, T.Satoh, S.Nagasawa, M.Hidaka, Superconductivity Research Laboratory*

We observed a type of test structures had about 20% larger critical current densities than the conventional ones. The test structures consist of serial 1000 Josephson junction arrays of the same areas wired with Nb electrode partly covered with Pd exposed to the chip surface. The conventional ones are almost similar but wired with electrodes without Pd-coverage. We found the occurrence of hydrogen inclusion into Nb electrodes and its influence on the critical current of the Josephson junctions. During the fabrication process hydrogen incorporates and desorbs when the Nb surface is made clean and held in a vacuum. Incorporation or desorption processes proceed depending on the ambient hydrogen partial pressure even in an atmosphere if the Nb is covered with Pd. The decrease in hydrogen concentration causes an increase in the critical current of JJs, which is the case happened in the larger  $I_c$  test structures. As hydrogen diffuses fast in Nb and stops in Al and Mo (resistor in our circuits), hydrogen concentration differences can happen within a circuits, which result in the difference in the critical current density. We confirmed critical current deviations caused by the hydrogen concentration difference.

*This work was supported by the New Energy and Industrial Technology Development Organization (NEDO) as Development of Next-Generation High-Efficiency Network Device Technology Project.*

6:00pm

#### **4EX03 - Fabrication Process for Superconducting Devices operating at milli-Kelvin Temperatures**

*L.Gronberg, J.Hassel, P.Helisto, VTT Technical Research Centre of Finland*

A fabrication process for superconducting Josephson junction based devices operating at mK temperatures was developed in the EU project RSFQubit. The goal was to enable control and readout of quantum circuits such as superconducting qubits. The Josephson junctions are formed in the Nb/Al-AlO<sub>x</sub>/Nb stack. Up to four Nb layers can be used. Two of the SiO<sub>2</sub> insulator layers are CMP planarized (Chemical Mechanical Planarization). Palladium is used as resistor material, to allow operation at very low temperatures. Massive Cu cooling fins enhance electron-phonon coupling to the shunt resistors. Successful multichip processing has been carried out with the process. In the paper improvements to the process will be described and process characterization data will be presented. Example on the devices realized with the process will be presented.

6:15pm

#### **4EX04 - Protection against plasma-induced damage of tunnel barrier**

*A.F.Kirichenko, S.K.Tolpygo, D.Yohannes, D.Amparo, HYPRES; J.M.Meckbach, University of Karlsruhe, Germany*

We have investigated various phenomena leading to damage of tunnel barrier in Nb/AlO<sub>x</sub>/Nb trilayer during fabrication. The damage results in enhancement of critical current and quality reduction of tunnel Josephson junctions. We have designed and extensively tested numerous test structures fabricated at various technological regimes. As a result, we have gained better understanding of the physics of the phenomenon and developed methods that allow us to avoid the plasma-induced barrier damage, which we are going to present in this paper.

6:30pm

#### **4EX05 - Characterization of nanometer step structure formation during the fabrication of large-scale superconducting-tunnel-junction array detectors**

*M.Ukibe, A.Kurokawa, M.Ohkubo, AIST*

We are developing superconducting-tunnel-junction (STJ) array detectors with an effective sensitive area of 4 mm<sup>2</sup> for mass spectrometry and energy-dispersive X-ray spectrometry. The array detectors are constructed from one hundred Nb/Al junctions of 200 micrometer square. Large sensitive area is an issue to realize practical analyzing instruments equipped with superconducting detectors. In the course of fabrication process optimization for the STJ array detectors, we have found that anomalous nanometer-step structure appears on the junctions located at specific sites after some steps in the fabrication processes. The anomalous steps cause an increase of leakage current from ~ 5 nA to a few 100 nA or sometime more. In order to characterize and prevent the step formation, we performed structural analysis with atomic force microscopy, interference microscopy, differential interference microscopy, and transmission electron microscopy. The effects of residual stress and young modulus of substrates were investigated. We have found that no obvious steps occur in case of using the Nb film with a residual stress below 10 Mpa. It has been suggested that the anomalous step formation can be avoided by the accurate stress control of the sputtered metal film.

*This work was supported by the JST-SENTAN Project ( Japan Science and Technology Agency).*

6:45pm

#### **4EX06 - Stacked Amorphous NbSi Barrier Junctions for Voltage Standard and Digital Applications**

*D.Olaya, P.D.Dresselhaus, S.P.Benz, National Institute of Standards and Technology*

The use of amorphous Nb-Si as a barrier has been previously demonstrated for voltage standard circuits, including both dc programmable and ac Josephson voltage standards. This barrier material was chosen so that the junctions could be thin-film fabricated in vertical stacks, increasing the number of junctions in an array which, in turn, increases the output voltage of the circuits. Although tall stacks of 10-junctions have been demonstrated for short arrays, the circuits that have produced the highest voltage have used stacks with 3 junctions. The performance and operating margins of taller stacks was degraded by a number of effects, including heating of the stack and the propagation of roughness throughout the stack. By smoothing the interface and optimizing the heat flow out of the stacks, we hope to make taller stacks that result in circuits with higher output voltage and better operating margins. This work is also synergistic with our effort to create higher-speed and higher characteristic voltage ( $I_c R_n$ ) junctions, because the same factors that lead to improved stacks lead to more reproducible junctions with thin, insulating barriers. These high-speed junctions are suitable for digital superconductive electronics and for 75 GHz programmable voltage standards.

7:00pm

**4EX07 - Study of NbN Josephson Junctions with Barrier Tuned to the Metal-Insulator Transition**

*R.Setzu, S.Bouat, V.Michal, J.-C.Villegier, INAC CEA-Grenoble; D.Renaud, LETI CEA-Grenoble*

We have studied and compared two kinds of self-shunted NbN Josephson junctions operating at 10K based on different semi-insulating barriers compositions and transmission mechanisms, one based on diffusive TaN and the other on tunnel type MgO-AlN-MgO hetero-structures. High resistivity has been induced in metallic TaN diffusive barrier by control of high nitrogen flow during sputter deposition for developing SNS NbN-TaN-NbN Josephson junctions operating in a relaxed cryogenic environment. Typically the junctions show current densities in the  $\sim 10\text{kA}/\text{cm}^2$  range and a  $RnI_c$  product of 0.3 mV at 10K when the TaN barrier layer sputtered at 300 °C is 7nm thick and low roughness of only 0.2nm as characterized by the mean of X-rays reflectivity. Josephson behavior is observed up to 14.5K. The NbN-MgO-AlN-MgO-NbN hetero-structures are sputtered at 250°C in a very similar way as we optimized high  $J_c$  NbN-MgO-NbN and NbN-AlN-NbN SIS tunnel junctions, except that we deposit sequentially each layer, total barrier thickness being estimated to 2.5nm. Junctions show controllable  $J_c$  values and low hysteresis in the I-V for 4-14K temperature range with  $J_c \sim 5\text{-}10\text{kA}/\text{cm}^2$  and  $RnI_c \sim 0.1\text{mV}$  at 10K. The two kind of barrier transmission As NbN tri-layers have been recently sputtered on 8 inch silicon wafers, we will present their strong potential for making RSFQ circuits taking advantage of self-shunted junctions with barriers tuned in a controllable way close to the metal insulator transition.  
*Partly supported by ANR06 TCOM023 HyperSCAN*

7:15pm

**4EX08 - All MgB2 in-situ native oxide trilayer Josephson junction development**

*B.H.Moockly, Superconductor Technologies, Inc.*

Owing to the great difficulty of producing simple HTS digital circuits and the limitation of operating LTS circuits at very low temperatures, the promise of medium-temperature superconductive digital electronics operating at  $\sim 20$  K is exciting indeed. The seeming simplicity and forgiveness of MgB2 in comparison with YBCO provides hope that device and circuit formation may be far less complex. We report on the development of an all-MgB2, all in-situ native oxide Josephson junction technology. MgB2 thin films are deposited using a reactive evaporation deposition technique developed at STI. Native oxides are formed on these films either naturally or via oxygen introduction at selected pressures and temperatures. These oxide layers are intended as the barrier layer in Josephson tunneling devices. We have studied the thickness and composition of these oxide layers using XPS. We are able to tailor the thickness and composition of these native oxide layers via changes in growth conditions and oxygen treatments. These oxide layers have been used to form trilayer junctions with an in-situ MgB2 thin film as the counterelectrode. We discuss the transport characteristics of these structures.

**4EY - SQUIDS Fabrication and Characterization**

**5:30pm - 7:30pm**

5:30pm

*Invited*

**4EY01 - Novel SQUID current sensors with high linearity at high frequencies**

*D.Drung, J.Beyer, M.Peters, T.Schurig, PTB Berlin*

For some of today's demanding SQUID applications, a high linearity and thus a high system slew rate is required even at high signal frequencies. For example, for the frequency-domain multiplexed readout of transition-edge sensors, SQUID current sensors with slew rates above  $10\text{Phi}^0/\text{us}$  at signal frequencies above 1 MHz are needed. The bandwidth and hence the slew rate of SQUIDS operated in a flux-locked loop (FLL) is usually limited by the delay in the transmission lines between SQUID and room temperature electronics. The slew rate can be increased considerably by using a cold FLL electronics built with semiconductor devices. However, such circuits dissipate power of the order of mW which is problematic in multichannel systems and makes operation at mK temperatures impossible. Furthermore, semiconductors at 4.2 K usually exhibit a very high  $1/f$  noise level. We have developed novel SQUID current sensors consisting of a sensitive 16-SQUID input stage followed by an output stage of 40, 160, or 640 low-inductance SQUIDS. The output signal is fed back to the input stage in order to increase the linear signal range. The devices can be read out directly using a low-noise room temperature preamplifier, or embedded into a room temperature feedback loop to further increase the linearity. The input flux noise level is  $0.4\text{uPhi}^0/\text{rtHz}$  at 4.2 K or  $0.2\text{uPhi}^0/\text{rtHz}$  at 100 mK, respectively. The device with 160 output SQUIDS has a power dissipation of about 50 nW and achieves a slew rate of  $25\text{Phi}^0/\text{us}$  at frequencies up to 10 MHz. In the paper, the design, noise performance, and dynamic behavior of our novel sensors will be presented.

6:00pm

*Invited*

**4EY02 - Magnetism in SQUIDS at Millikelvin Temperatures**

*R.McDermott, S.Sendelbach, D.Hover, Department of Physics, University of Wisconsin, Madison; M.Mueck, Institut fur Angewandte Physik, Justus-Leibig-Universitat Giessen; J.M.Martinis, Department of Physics, University of California, Santa Barbara; A.Kittel, Institut fur Physik, Carl von Ossietzky Universitat Oldenburg*

We have characterized the temperature dependence of the flux threading dc Superconducting QUantum Interference Devices (SQUIDS) cooled to millikelvin temperatures. The flux through the SQUIDS increases as  $1/T$  as temperature is lowered; moreover, the flux change is proportional to the density of trapped vortices. The data is compatible with the thermal polarization of unpaired surface spins in the trapped fields of the vortices. Careful analysis of field-cool experiments allows us to extract the surface density of spins. In the absence of trapped flux, we observe evidence of spin interactions and spin-glass ordering at low temperature. These results suggest a microscopic explanation for the "universal"  $1/f$  flux noise in SQUIDS and superconducting quantum bits ("qubits"), a dominant source of dephasing.

*We gratefully acknowledge funding from BBN Technologies.*

6:30pm

**4EY03 - Self-induced structure in the current-voltage characteristics of RSQUIDs**

*C.M.Pegrum, FieldSolutions; J.C.Macfarlane, University of Strathclyde*

Resistive two-junction SQUIDs (RSQUIDs) made from high-temperature superconductors are being developed as narrow-linewidth tunable oscillators in the GHz frequency range, as is reported elsewhere at this meeting. We present here our results of numerical simulation of RSQUIDs of this type. These studies have identified certain conditions where sub-harmonic steps, step tails and the onset of chaos are all apparent in the current-voltage characteristics, driven by the internally-generated heterodyne frequency when this is well above 10GHz. The behavior is sensitive to the frequency (set by the voltage across the resistive element in the RSQUID), the temperature and also the parasitic inductance. We have studied the effects of thermal noise on these features and on the self-induced Shapiro steps that are apparent at low temperatures for all frequencies. We also assess how these effects might be observed, and consider how they can be avoided for practical applications of very high frequency heterodyne RSQUID oscillators.

6:45pm

**4EY04 - Development of integrated HTS SQUIDs with a multilayer structure and ramp-edge Josephson junctions**

*H.Wakana, S.Adachi, K.Hata, T.Hato, Y.Tarutani, K.Tanabe, Superconductivity Research Laboratory, ISTE*

We have fabricated HTS SQUIDs with a multilayer structure and ramp-edge Josephson junctions. For stable operation above 77K, it is necessary to raise the  $T_c$  of junctions and electrode layers. We employed La-ErBCO and SmBCO as materials for the upper-electrode and base-electrode layers, respectively. Both the films exhibited superconducting properties with a transition above 90 K. Junctions were fabricated by employing a Cu-poor La-ErBCO layer as a precursor of the barrier. The fabricated parallel SQUID gradiometers with a base line of 1-3 mm exhibited the field-induced modulation voltage of 20-50 $\mu$ V at 77K, and a clear modulation up to 86.8 K. Noise measurements at 77 K revealed a white flux noise of  $4.5\text{-}10\mu\Phi_0/\text{Hz}^{1/2}$  at 1 kHz. No significant degradation of the flux noise due to flux trapping was observed after applying ac magnetic field up to several mT, which is due to the gradiometer structure without weak links. We also fabricated magnetometers with an integrated flux transformer and series gradiometers with a cross-over structure, and examined their properties. The magnetometer with an effective area of about 1.8 mm<sup>2</sup> exhibited the field noise of 25 fT/Hz<sup>1/2</sup> or less at 1 kHz.

*This work was supported by the NEDO.*

7:00pm

**4EY05 - Graphene Superconducting Quantum Interference Devices**

*O.Naaman, Department of Physics, Univ. of California at Berkeley; Ç.Girit, Center of Integrated Nanomechanical Systems, Univ. of California at Berkeley; V.Bouchiat, Institut Neel, CNRS/UJF, BP 166, 38042 Grenoble Cedex 9, France; A.Zettl, Center of Integrated Nanomechanical Systems, Univ. of California at Berkeley; I.Siddiqi, Department of Physics, Univ. of California at Berkeley*

We present transport measurements on superconducting quantum interference devices constructed from aluminum/graphene/aluminum Josephson junctions. Graphene based Josephson devices have many attractive features such as a gate tunable critical current, the absence of an oxide tunnel barrier, and direct access to the junction barrier—a potentially powerful probe of the electric and magnetic properties of submicron sized particles. We investigate the current-phase relation, intrinsic dissipation, and microwave properties of graphene weak-link junctions.

7:15pm

**4EY06 - A practical SQUID sensor for dc currents**

*J.Beyer, D.Drung, F.Ruede, M.Peters, T.Schurig, PTB Berlin*

SQUIDs are detectors of changes in magnetic flux and are used in precision measurement systems to sense changes in various physical quantities, e.g. magnetic field, electric current or mechanical displacement, which can be transformed into changes in the magnetic flux threading the SQUID loop. A SQUID based sensor able to detect a dc signal can be formed by a series array of individual SQUIDs with different sensitivities to the signal of interest, for instance a series array of SQUID magnetometers with different sensitive areas[1]. Based on this concept we have developed practical and highly sensitive sensors for dc current based on SQUID series arrays. In these devices, the SQUID loops of all array elements are identical. However, the input signal current is coupled tightly but non-uniformly to the individual array elements. This leads to a single-valued overall voltage-vs.-current response and, therefore, allows a dc input signal to be measured. The response would be compromised by random as well as by equal flux offsets in the individual array elements, which can occur during cooldown or operation. Our design ensures that such flux offsets are avoided or can be compensated for by the readout electronics. We have realized sensors with 18 and 36 array elements. The expected single-valued overall voltage response and white noise levels down to 7.5 pA/rtHz at 4.2 K are achieved. We present the realized sensor design and simulations of the device characteristics. Locked mode operation and noise performance of our novel dc current sensors are discussed. [1] P.Carelli et.al., Europhys.Lett. 39, 569 (1997)

**4EZ - Active Microwave and Terahertz Devices – II**

**5:30pm - 7:30pm**

5:30pm

*Invited*

**4EZ01 - Emission of Terahertz Waves from Stacks of Intrinsic Josephson Junctions**

*K.E.Gray, A.E.Koshelev, Argonne National Laboratory; L.Ozyuzer, Izmir Institute of Technology; C.Kurter, Argonne National Laboratory; K.Kadowaki, T.Yamamoto, H.Minami, H.Yamaguchi, University of Tsukuba; W.-K.Kwok, U.Welp, Argonne National Laboratory*

Compact solid-state sources of THz-radiation are being sought for sensing, imaging and spectroscopy applications across the physical and biological sciences. We demonstrate that coherent continuous-wave THz-radiation of sizable power can be extracted from stacks of intrinsic Josephson junctions in the layered high-temperature superconductor, Bi<sub>2</sub>Sr<sub>2</sub>CaCu<sub>2</sub>O<sub>8</sub>. In analogy to a laser cavity, the excitation of an electromagnetic cavity resonance inside the sample generates a macroscopic coherent state in which a large number of junctions are synchronized to oscillate in phase. We report that more than 500 junctions can be made to oscillate in phase producing continuous wave coherent radiation power up to ~0.5 microW at frequencies up to 0.85 THz. The available power is potentially much larger, as there is evidence that 20 microW of power are pumped into the observed THz cavity resonance. The emission persists up to temperatures of ~50 K.

*Supported by U.S. DOE Basic Energy Science, Contract No. DE-AC02-06CH11357*

**6:00pm**

**4EZ02 - Anisotropic Emission of THz Electromagnetic Waves from Intrinsic Josephson Junction Bi<sub>2</sub>Sr<sub>2</sub>CaCu<sub>2</sub>O<sub>8</sub> Single Crystals**

*K.Yamaki, H.Yamaguchi, S.Hashimoto, GS-PAS, Univ. Tsukuba; H.Minami, I.Takeya, IMS, Univ. Tsukuba; T.Yamamoto, K.Kadowaki, M.Tachiki, IMS, Univ. Tsukuba; L.Ozyuzer, Dep. Phys. Izmir Inst. Technol.; A.E.Koshelev, MSD, ANL; C.Kurter, Phys. Div. IIT and MSD, ANL; K.E.Gray, W.-K.Kwok, U.Welp, MSD, ANL*

There has been a growing interest in generation of electromagnetic waves at THz frequencies, because of large area of potential applications in all kinds of different science and technological fields. As is reported previously (L. Ozyuzer et al., Science 318, 1291 (2007).) we have succeeded in generation of strong, continuous and coherent THz electromagnetic waves at frequencies from several 100 GHz to 1 THz from mesas of intrinsic Josephson junctions made of single crystal Bi<sub>2</sub>Sr<sub>2</sub>CaCu<sub>2</sub>O<sub>8</sub>. The power estimated is fairly strong and to be as high as 5 microwatt, which is about 10<sup>6</sup> times stronger than the one observed in single junctions. Furthermore, recent our study reveals that the emission takes place anisotropic manner into the space, i.e., there is a preferred directional orientation in space, which is about 30 degree off from the polar direction (c-axis). This can be interpreted by the modes standing inside the mesa and the interference effect of the reflected waves due to the sample geometry. The experimental results is argued in comparison with the recent theoretical calculations.

*This work has been supported by the Grant-in-Aid for Scientific Research (A), CREST-JST, JSPS-CTC program and WPI-MANA project under MEXT of Japan.*

**6:15pm**

**4EZ03 - Detection of THz emission from intrinsic Josephson junctions**

*H.B.Wang, National Institute for Materials Science, Japan; S.Guenon, Universität Tübingen, Germany; J.Yuan, A.Ishii, S.Arisawa, T.Hatano, National Institute for Materials Science, Japan; D.Koelle, R.Kleiner, Universität Tübingen, Germany*  
Many researchers have been exploring the possibilities to develop terahertz (THz) oscillators based on Bi<sub>2</sub>Sr<sub>2</sub>CaCu<sub>2</sub>O<sub>8</sub> (BSCCO) intrinsic Josephson junctions (IJJs), due to the high collective plasma frequencies (up to THz region), the uniformity in junction properties, the easiness to make a large junction array, and the low loss at high frequencies. Quite recently, THz emissions observed in mesas with large lateral sizes are stimulating more researches in this field. From the viewpoint of practical applications, it is necessary to phase-lock the emissions from IJJs, couple the THz oscillations into a finite space, guide them in a controllable way, and monitor the frequencies and power levels. With a quasi-optical system and a small IJJs stack as a detector, we have been making extensive efforts to realize these ideas; and preliminary experimental results are quite promising.

**6:30pm**

**4EZ04 - Novel Self-Sustained Oscillations and Giant Nonlinearity in Superconducting Resonators**

*E.Segev, B.Abdo, O.Shtempluck, E.Buks, Technion*

We study microwave superconducting stripline resonators made of NbN on Sapphire substrate. A section of the resonator is made of a narrow and thin meander microbridge. A monochromatic wave at frequency close to one of the resonances is injected into the resonator and the reflected power off the resonator is measured. Novel, self-sustained oscillations of the reflected power are observed. Near the onset of these oscillations the device exhibits giant nonlinearity. Intermodulation characterization performed in this region yields extremely high intermodulation gain (about 30dB), which is accompanied by a very strong noise squeezing (about 45dB squeezing factor) and sub-harmonic generation of various orders. We also study the response of the device to infrared (1550 nm wavelength) illumination impinging on the meander strip. To characterize the response time of the system we modulate the impinging optical power with a varying frequency. We observe extremely fast (modulation frequencies of up to 8GHz) [4] and sensitive (optical power below 100 fW) response near the onset of the self-sustained oscillations. To account for our findings we propose a theoretical model, which attributes the self-sustained oscillations to thermal instability in the meander strip. A comparison to the experimental results yields a good quantitative agreement.

**6:45pm**

**4EZ05 - Modeling of Discrete Josephson Junction Transmission Line with Finite Difference Time Domain Technique**

*H.R.Mohebbi, A.H.Majedi, University of Waterloo*

We study the nonlinear wave propagation in a Discrete Josephson Junction Transmission Line (DJJTL). DJJTL consists of a finite number of unit cells each including a segment of superconducting transmission line with a single or stack of N identical lumped element Josephson junctions (JJs). Employing a generalized RCSJ model of JJs, accounting for the nonlinear inductance and resistance of the single or stack of N identical JJs, the nonlinear wave propagation in the DJJTL is investigated. As the governing nonlinear wave propagation is a system of nonlinear partial differential equations with mixed boundary conditions, the method of Finite Difference Time Domain (FDTD) is used to solve the equations numerically. Two regimes of wave propagation and diffusion are discussed in the structure. By this tool, the behavior of wave propagation along the DJJTL can be monitored in both time and space domains across each unit cell. We will briefly investigate the various operating conditions to acquire microwave traveling-wave devices such as Josephson oscillators, mixers and amplifiers.

7:00pm

**4EZ06 - Measurements of the Scattering Parameters of Radio Frequency Amplifiers based on SQUIDs**

*D.Hover, S.Sendelbach, R.McDermott, Department of Physics, University of Wisconsin-Madison; M.Mueck, Institut für Angewandte Physik, Justus-Leibig-Universität Giessen*

A dc SQUID can be used as a sensitive radio frequency amplifier if the rf signal to be amplified is suitably coupled to the SQUID. We have made rf amplifiers for which a coil integrated on top of the SQUID is operated as a half-wavelength-microstrip resonator. Such amplifiers have a power gain of up to 100 at 1 GHz, and 4 at 8 GHz. When cooled to millikelvin temperatures, sensitivities close to the quantum limited could be obtained at 500 MHz. For practical applications of such amplifiers, besides sufficient gain and low noise, their input and output impedances are important parameters. We have carried out measurements of the scattering parameters S11 and S22 of a number of amplifiers between 300 MHz and 3 GHz. By applying negative feedback and adding a few passive components, the input and output impedances of such amplifiers can be brought close to 50 ohms, with slightly lower gain than available without the feedback.

7:15pm

**4EZ07 - Cryogenic Phase Locking Loop System for Superconducting Integrated Receiver**

*A.V.Khudchenko, V.P.Koshelets, P.N.Dmitriev, A.B.Ermakov, Institute of Radio Engineering and Electronics, Moscow, Russia; P.A.Yagubov, SRON Netherlands Institute for Space Research, Groningen, the Netherlands; O.M.Pylypenko, State Research Center of Superconducting Electronics*

Recently a cryogenic phase detector (CPD) based on a superconductor-insulator-superconductor junction has been proposed and preliminary tested. A model describing coupling between a CPD and an FFO has been developed and experimentally verified. This model takes into account dependence of the CPD current on the input power and differential resistance of the CPD. Design of the Cryogenic Phase Locking Loop (CPLL) system for the Superconducting Integrated Receiver will be presented along with results of its implementation. An effective bandwidth of the CPLL system exceeds 25 MHz at operation frequency of 400 MHz (bandwidth of the room-temperature PLL system is limited to 12 MHz by unavoidable delays in the long cables and semiconductor PLL system). Novel CPLL synchronizes more than 50% of the FFO power for free-running FFO linewidth of about 10 MHz, compare to 20% in the case of regular PLL system. Details of the phase noise measurements and results of development of the CPLL with operation frequency 4 GHz will be discussed.

*The work was supported by the projects: RFBR 06-02-17206, ISTC # 3174, NATO Sfp 981415, and Grant for Leading Scientific School 5408.2008.2*

**FRIDAY, AUGUST 22, 2008**

**FRIDAY MORNING ORAL SESSIONS**

**10:00am - 12:00pm**

**5EA - Roger Koch Memorial Session 10:00am - 12:00pm**

**10:00am**

*Invited*

**5EA01 - Roger Koch: A Scientific Legacy**

*J.Clarke, Dept. of Physics, University of California and Materials Sciences Div., Lawrence Berkeley National Laboratory*

In his remarkable career, Roger Koch made seminal contributions to many diverse fields of physics, including Josephson junctions and SQUIDs (fabricated from both high- and low-transition temperature superconductors), 1/f noise ( $f$  is frequency), geophysics, chaos, electromigration, scanning tunneling microscopy, neural networks, vortex glasses, magnetism and flux-gate magnetometers. His earliest papers were concerned with quantum noise and 1/f noise in Josephson junctions and SQUIDs. I briefly review Roger's contributions to these topics, both of which are highly relevant to today's research on the limitations of SQUIDs and quantum bits. I describe SQUID amplifiers operated at millikelvin temperatures that are close to the quantum limit of detection and find applications such as searching for cold dark matter and the readout of superconducting quantum bits (qubits). One of Roger's last contributions was a theory for the ubiquitous 1/f flux noise that afflicts both SQUIDs and qubits, and I give an overview of the current state of this research.

*This work was supported by US DOE Basic Energy Sciences.*

**10:30am**

*Invited*

**5EA02 - The Search for Complex Order Parameter Symmetry in Unconventional Superconductors**

*D.J.Van Harlingen, Department of Physics, University of Illinois at Urbana/Champaign*

In the course of his remarkable career, Roger Koch made many contributions in the study of fluctuations, nanomagnetism, high temperature superconductivity, quantum information, and particularly dc SQUIDs. All of these topics come together in the application of Josephson interferometry to probe the pairing symmetry and phase dynamics of unconventional superconductors. In this talk, I will review this powerful experimental technique and how we are using it to study the symmetry of superconducting materials suspected to exhibit odd-symmetry and/or complex order parameters. In Sr<sub>2</sub>RuO<sub>4</sub>, we see direct evidence for dynamical chiral domains of the form  $px \pm ipy$ , making Sr<sub>2</sub>RuO<sub>4</sub> a possible candidate for non-Abelian anyon statistics that could enable topologically-protected quantum computation. Another potential candidate is the heavy fermion superconductor UPt<sub>3</sub>, which exhibits two superconducting phases, the lower temperature one likely complex. I will present recent experiments designed to elucidate the symmetry and quantum dynamics of these exotic superconductors.

**11:00am**

*Invited*

**5EA03 - Quantum information storage using tunable flux qubits**

*M.Steffen, F.Brito, D.DiVincenzo, A.Engineer, M.Farinelli, K.Fung, G.A.Keefe, S.Kumar, R.Koch, F.Milliken, M.B.Rothwell, J.Rozen, M.Ketchen, IBM*

The quest towards building a practical quantum computer using superconducting materials and Josephson junctions has made rapid progress over the past several years. Experimental demonstrations ranged from high fidelity single qubit gates to elementary two-qubit gates. One major step towards continued progress consists of understanding all major sources of decoherence that destroy the fragile quantum states. In this talk we provide an overview of our experimental efforts using superconducting qubits. Our qubit is a tunable flux qubit coupled to a high quality transmission line resonator. We show quantum information storage in the resonator with lifetimes of a few microseconds. The qubit itself is shown to have short coherence times, which are presently not well understood theoretically. Possible decoherence mechanisms include junction losses, dielectric losses, or other losses related to the qubit loop geometry. To help shed light on these issues we test Josephson resonators as well as lumped LC resonators with varying loop sizes and geometries all made using the same fabrication techniques as those used for the qubits.

**11:30am**

*Invited*

**5EA04 - Measurements of the Dynamics of Magnetic Nanoparticles**

*J.R.Kirtley, IBM T.J. Watson Research & Center for Probing the Nanoscale, Stanford University*

Roger Koch was a pioneer in the measurement and modeling of the dynamics of magnetic nanoparticles. In this talk I will describe some of this work, including that in which Roger, Solomon Woods, Shouheng Sun, and I measured thermally activated magnetic noise from self-assembled arrays of Co nanoparticles using a variable sample temperature scanning SQUID microscope [1]. The SQUID microscope allowed the sensing of relatively small numbers of particles and the straightforward subtraction of the background noise by lifting the SQUID sensor tip away from the sample. From these measurements we could infer the anisotropy energy distribution of an array of nanoparticles. Such characterization is critical to optimizing the magnetic properties of nanoparticle devices and media. I will discuss recent advances in SQUID microscope sensors that could allow such measurements to be made on individual nanoparticles in sufficiently sparse arrays. [1]. S.I. Woods, J.R. Kirtley, Shouheng Sun, and R.H. Koch, Phys. Rev. Lett. 87, 137205 (2001)

**5EB - Bolometric Detectors 10:00am - 12:00pm**

**10:00am**

**5EB01 - Time-Resolved Terahertz Spectroscopy with an Antenna-Coupled Superconducting Bolometer**

*D.F.Santavicca, A.J. Annunziata, J.D. Chudow, Y. Yin, L. Frunzio, Dept. of Applied Physics, Yale University; A.B. True, C.A. Schmuttenmaer, Dept. of Chemistry, Yale University; D.E. Prober, Dept. of Applied Physics, Yale University*

We have developed antenna-coupled niobium bolometers as sensitive direct detectors for applications in time-resolved terahertz spectroscopy. The fast response time of the niobium microbridge enables measurements on nanosecond to microsecond timescales, which are too fast for standard commercial bolometers and too

slow for optical delay line techniques. Our detectors have been integrated into a custom Fourier transform spectrometer. We report here the characterization of different planar antenna geometries, including a comparison of electromagnetic simulations with measured performance. We also describe the initial demonstration of this system in a time-resolved spectroscopy application in which we measure the free carrier lifetime in photoexcited zinc oxide films.

*This work is supported by NSF-CHE and Yale University.*

**10:15am**

**5EB02 - Technology and Performance of Hot-Electron Bolometers for THz Mixers**

*K.S.Ilin, A.Stockhausen, A.Scheuring, Institute for Micro- and Nanoelectronic Systems, University Karlsruhe (TH), Karlsruhe, Germany; A.Semenov, H.W.Huebers, DLR Institute of Planetary Research, Berlin, Germany; M.Siegel, Institute for Micro- and Nanoelectronic Systems, University Karlsruhe (TH), Karlsruhe, Germany*

Hot-Electron Bolometer (HEB) detectors are a complex multi-layer thin film structure containing an ultra-thin superconducting film of NbN as a detecting element and a thick normal metal layer as an antenna structure. We have optimized the fabrication process starting with ultra-thin NbN films, Au films for antenna structures and their patterning using e-beam lithography and lift-off. The coupling between normal conducting antenna and NbN detector has been improved by introducing an intermediate NbN film to reduce proximity suppression of superconductivity in the detecting element. Further, the antenna design for better matching between detector and antenna was improved. Results on fabrication and properties of NbN ultra-thin films and multi-layer structures will be presented. The performance of HEB detectors was studied and will be discussed. So far, we achieved a noise temperature of 1050 K at 2.5 THz and helium temperatures.

*This work was supported partly by German BMBF and DFG-Center for Functional Nanostructures.*

**10:30am**

**5EB03 - Noise of NbN hot electron bolometer mixers above 3 THz**

*P.Khosropanah, SRON, Groningen, the Netherlands; W.Zhang, Purple Mountain Observatory, Nanjing, China; W.M.Laauwen, SRON, Groningen, the Netherlands; J.R.Gao, SRON & TU Delft; J.N.Hovenier, T.M.Klapwijk, Kavli Institute of NanoScience, Delft University of Technology, Delft, the Netherlands*

NbN superconducting hot electron bolometer (HEB) mixers are the most sensitive detectors for heterodyne spectroscopy above 1.5 THz. Today HEB mixers are considered to be a rather mature technology when operated below 2 THz as they are used in the HIFI instrument on the Herschel space observatory. Future space instruments will focus on the higher frequency range between 2-6 THz, which holds crucial information on astronomical objects as well as on chemical composition of Earth's atmosphere. However, the noise contribution of a HEB mixer at such high frequencies has not been well understood. It has been suggested that the quantum noise (QN) becomes increasingly important as the frequency goes up until it plays a dominant role beyond 3 THz. Therefore, the receiver noise temperature should also increase steeply above 3 THz. Here we report experimental results that suggest otherwise. Recently we published a DSB receiver noise temperature of 1300 K at 4.3 THz, which is unexpected low (P. Khosropanah et al, APL, 91, 221111(2007)). Our experimental data obtained at 1.9, 3.4 and 4.3 THz shows that the receiver noise temperature increases roughly linearly with local oscillator frequency. In all these cases the mixer output noise is about 50 K, suggesting negligible contribution of the QN.

10:45am

**5EB04 - Superconducting Terahertz Hot Electron Bolometer Mixers**

*P.H.Wu, J.Chen, L.Kang, B.B.Jin, W.W.Xu, Research Institute of Superconductor Electronics, Nanjing University; W.Zhang, L.Jiang, N.Li, Purple Mountain Observatory, CAS; S.C.Shi, Purple Mountain Observatory, CAS.; G.N.Gol'tsman, Moscow State Pedagogical University*

Quasi-optical superconducting niobium nitride (NbN) hot electron bolometer (HEB) mixers have been measured in the terahertz (THz) frequency range of 0.5~2.5 THz for THz applications in astronomy and cosmology. An optically pumped far-infrared (FIR) gas laser was used as the local oscillation (LO) source at frequencies higher than 0.76 THz, while a Gunn oscillator with its multipliers were used at frequencies lower than 0.76 THz. The NbN HEB mixers consist of a planar complementary antenna and several nanometer thick NbN bridge connecting across the antenna's inner terminals. Using a Si hyper-hemispherical lens with the diameter of 12mm and no anti-reflection (AR) coating on its surface, the radiation is focused onto the HEB mixer via the antenna integrated with it. A receiver noise temperature of 2000 K at 1.6 and 2.5 THz has been obtained for the mixers without corrections.

11:00am

**5EB05 - Integrated Terahertz Broadband Detectors Utilizing Superconducting Hot-Electron Bolometers**

*L.Liu, H.Xu, R.Percy, D.Herald, UVA; J.Hesler, VDI; A.W.Lichtenberger, R.M.Weikle, UVA*

Terahertz detection technology is becoming more attractive for its applications in astronomy, imaging and bio-sensing. Although waveguide detectors employing Schottky diodes are widely used, they tend to have narrow bandwidths and relatively low sensitivities. Moreover, the impedance mismatch between zero-bias Schottky diodes and waveguide embedding structures are substantial, resulting in a limited power coupling efficiency. Superconducting HEBs have been shown to exhibit higher sensitivity than Schottky diodes at terahertz frequencies. Because HEB devices are purely resistive and frequency-independent, they have the potential for broadband operation when integrated with self-complementary planar antennas. In this work, planar sinusoidal antennas covering 50 to 900GHz have been designed and fabricated on silicon substrates. To maintain a self-complementary structure, four antenna arms are used, leading to a frequency-independent input impedance of  $74\Omega$ . Two squares of superconducting niobium HEB's (10nm thick niobium,  $R_s=35\Omega/\square$ ) are required at the feed point of the antennas. Two sizes of HEB's (120nm X 240nm, 2um X 4um) have been fabricated using EBL, and standard photo-lithography processes, respectively. A quasi-optical mount with high-resistivity silicon lens has been employed for power coupling. With a close-cycled cryocooler, the detectors will be tested at 100, 200 and 585 GHz. Detector characteristics (responsivity, NEP's) will be presented and compared to waveguide Schottky diode detectors.

11:15am

**5EB06 - Superconductors at the airport? – Towards passive video rate terahertz camera**

*M.Leivo, L.Grönberg, P.Helistö, VTT Technical Research Centre of Finland, Espoo, Finland; A.Luukanen, Millimeter-wave Laboratory of Finland, Espoo, Finland; J.S.Penttilä, Aivon Oy, Espoo, Finland; T.Perälä, A.Rautiainen, C.R.Dietlein, VTT Technical Research Centre of Finland, Espoo, Finland; E.N.Grossman, National Institute of Standards and Technology, Optoelectronics Division, Boulder, CO, USA*

Superconducting microbolometers are utilized in a novel terahertz (THz) imaging system. Development of ultra-sensitive bolometer

arrays together with innovative room-temperature electronics and a commercial cryogen-free refrigeration system enables us to take a gigantic leap towards passive video rate THz camera. Such an imaging system, that is capable of concealed object identification at a stand-off distance of several meters, has been identified as one of the key technologies to benefit security applications. In the paper we will describe the overall architecture of the 128 pixel imaging system. Detector array comprises antenna-coupled vacuum-bridge NbN microbolometers arranged in 8 pixel modules. Electrical and optical performance characteristics of the detectors and passive imagery of test objects are presented.

*Supported by TEKES, the Finnish Funding Agency for Technology and Innovation.*

11:30am

**5EB07 - MgB2 mixers at terahertz frequencies**

*S.Cherednichenko, V.Draskinskiy, Chalmers University of Technology; H.Shibata, NTT Basic Research Laboratories*

Superconducting bolometric mixers made of low Tc materials (such as Nb, NbN, NbTiN) have very high sensitivity and a gain bandwidth adequate for the majority of radio astronomical application below 2 THz. The resulting 3dB gain bandwidth can be made up to 3-4GHz. For extragalactic radio astronomy the required mixer gain bandwidth increases with the signal frequency (e.g. due to the Doppler effect). For the broad band spectral line surveys as large bandwidth mixers as possible are also required. Therefore, novel devices with greater characteristics are demanded by the future astronomical instruments. Recently, we demonstrated that a gain bandwidth of 2GHz can be achieved with relatively thick (20nm) MgB2 film bolometer mixers [1]. Using the acoustic film-to-substrate matching approach a gain bandwidth up to 8-10GHz was predicted. We will present the results of study of MgB2 bolometers made of 5-10nm thick films. The mixer gain bandwidth was measured at both millimeter wave and terahertz wave ranges. Moreover, theoretical and experimental investigation of sensitivity of such devices (both as mixers and direct detectors) will be reported. We foresee that such devices could be of interest for applications besides astronomy, such as terahertz imaging systems. A great advantage of our devices is that they require cooling only to 20K, i.e. the cooling systems could much simpler and cheaper than for low Tc detectors. [1] S.Cherednichenko et al., Appl.Phys.Lett.90,023507(2007)

11:45am

**5EB08 - The fastest MgB2 neutron detector**

*T.Ishida, Y.Fujita, K.Arai, Osaka Pref Univ; M.Machida, T.Kano, JAEA; T.Koyama, Tohoku Univ; M.Kato, H.Shimakage, Osaka Pref Univ; S.Miki, Z.Wang, NICT; K.Satoh, T.Yotsuya, TRI-Osaka; S.Okayasu, M.Katagiri, JAEA*

The era of the high-intensity pulsed neutron source requires the development of the high-counting rate neutron detector. Conventional neutron detectors such as BF3 gas counters typically work on the time scale of ms while our novel MgB2 neutron detector works on the ns operation speed. To our knowledge, this is the fastest among all existing neutron detector. The MgB2 superconducting detector uses high-quality 10B-enriched MgB2 thin films. An resistance change induced by the nuclear reaction of neutron and 10B in MgB2 causes a partial deterioration of superconductivity. This is similar to the principle of so-call TES detectors. Neutrons are irradiated in a research reactor (JRR-3M) of JAEA (Tokai, Japan) and output signals were in a 1 ns pulse width. The experimental data are in good agreement with super-large-scale calculations of the time-dependent Ginzburg-Landau equation, the Maxwell equation, and the heat diffusion equation.

*This work was partially supported by a JST-CREST grant and by a Gant-in-Aid for Scientific Research from MEXT(19206104).*

## 5EC - Invited Session: Josephson Voltage Standards

10:00am - 12:00pm

10:00am

Invited

### **5EC01 - 1V and 10V-SNS Programmable Josephson Voltage Standards for 70 GHz**

*F.Mueller, R.Behr, T.Weimann, PTB Braunschweig; D.Olaya, P.D.Dresselhaus, S.P.Benz, NIST Boulder*

PTB and NIST, in close collaboration, have realized the first 13 bit 1 V Programmable Josephson Voltage Standard (PJVS) on the basis of SNS junctions which can be operated at 70 GHz. NIST has grown the SNS-trilayer using co-sputtered amorphous NbSi-alloy as a normal-metal barrier. PTB has taken this trilayer and fabricated 15 mm x 5 mm chips (array field: 1.7 mm x 4.5 mm) by adapting the 70 GHz microwave design used for analogous SINIS circuits. Driven with 70 GHz microwaves, all segments of the binary-divided array with 8192 junctions which are distributed over 64 parallel connected microstriplines, showed quantized dc voltage levels with an operating margin greater than 1.3 mA. In contrast to the SINIS arrays, the 1 V SNS-chips were fabricated with a conventional self-aligned window process. With the exception of the ground plane and the load resistors that were deposited on top of the dc circuit, all of the metallic and insulating layers were patterned using e-beam lithography. Compared to the PTB SINIS circuit technology, which suffers from plasma-induced damage during processing, arrays with SNS junctions appear to be more robust and exhibit a higher yield. These encouraging results motivate further effort to realize a 10V PJVS using 70 GHz, which is the typical frequency used by the metrology community for the conventional SIS Josephson Voltage Standard.

10:30am

Invited

### **5EC02 - Microwave-induced Characteristics of (NbN/TiNx)N /NbN Stacked Josephson Junction Arrays**

*N.Koda, A.Shoji, H.Yamamori, T.Yamada, National Institute of Advanced Industrial Science and Technology*

We have measured microwave-induced characteristics of (NbN/TiNx)N /NbN (N = 2, 3, and 4) stacked Josephson junction arrays for a programmable Josephson voltage standard (PJVS). The measurement was carried out using samples with the same circuit design as that of the 1-V PJVS chips previously reported. The temperature of the samples was set to be about 10 K at which the product of the critical current and the normal resistance became 34 microvolt corresponding to the frequency (16 GHz) of the microwave. The amplitude of the first constant-voltage step (n=1) was measured for junction arrays with different numbers (32, 64, 128, 256, 512, 1 024, 2 048, and 4 096) of stacks. It was found that constant-voltage steps with amplitudes greater than 1 mA were obtained for an array of 2 048 (NbN/TiNx)<sup>2</sup> /NbN junctions, that of 1 024 (NbN/TiNx)<sup>3</sup> /NbN junctions, and that of 256 (NbN/TiNx)<sup>4</sup> /NbN junctions. Discussions will be made on the origin of reduction in the step amplitude with increase in the number of junctions in the array.

11:00am

Invited

### **5EC03 - Tapered Transmission Lines with Dissipative Junctions**

*P.D.Dresselhaus, National Institute of Standards and Technology; M.M.Elsbury, University of Colorado at Boulder; S.P.Benz, National Institute of Standards and Technology*

One of the main drawbacks of using over-damped Josephson junctions for voltage standards is that the dissipation of the junctions limits the total number which may be in a single array. If there is too much dissipation in the array, the junctions at the end receive too little microwave excitation power compared with the junctions at the beginning of the array. Tapered transmission lines minimize this effect because the microwave power is transformed to maintain a nearly constant microwave current as the transmission line impedance decreases, thus compensating for the transmission-line attenuation caused by the junctions. Microwave simulation and testing have improved our transmission line designs for tapers with impedances from 85 Ohms and decreasing down to 5 Ohms. Low-leakage bias tees for various characteristic impedances were also designed so that sub-arrays could be measured within long arrays. For a 10V chip with 16-way microwave division, each array will produce 625 mV. Using this technique, single arrays have demonstrated a bandwidth of (14 to 22) GHz and a constant voltage step nearly 30% of the critical current, which is necessary for an efficient use of on-chip power. This is a two-fold increase in the operating current range of the device compared to our previous designs. These microwave designs will form the basis for the planned NIST 10V programmable Josephson voltage standard.

11:30am

Invited

### **5EC04 - Automated 10 Volt Josephson voltage standard system operating with liquid helium and with a cryocooler**

*M.Meyer, M.Starkloff, M.Schubert, Supracon Ltd., Wildenbruchstr. 15, 07745 Jena, Germany; G.Wende, S.Anders, B.Steinbach, T.May, H.-G.Meyer, Institute of Photonic Technology (IPHT), P.O. Box 100239, D-07702 Jena, Germany*

A commercially available complete microprocessor controlled, fully automated 10 Volt Josephson voltage standard system has been developed in cooperation between IPHT and Supracon. The system operates with an array of altogether 19,700 SIS Josephson tunnel junctions. A direct comparison between two such systems showed an uncertainty of  $2 \times 10^{-10}$ . Furthermore, a novel cryocooler based system is described.

## FRIDAY AFTERNOON ORAL SESSIONS

12:30pm - 2:30pm

### 5EX - Special Session: Quantum-Limited Amplification of Microwave Signal 12:30pm - 3:30pm

12:30pm

*Invited*

#### **5EX01 - Parametric Amplification of Quantum Signals with a Josephson Ring Modulator**

*N.Bergeal, F.Schakert, M.Metcalf, V.Manucharyan, R.Vijay, M.Devoret, Yale University Applied Physics*

Quantum Mechanics puts a limit on how small the degradation of information passing through an amplifier can be. It is known theoretically that the minimum noise added by the amplifier to the signal amounts at least to half a photon at the signal frequency. Is it possible to construct a practical amplifier working at microwave frequencies that would reach this quantum limit? We will present recent results by our group aiming at answering this question, which is of practical importance for the readout of solid state qubits, and more generally, for the measurement of very weak signals in various areas of science. The device we have developed is based on a ring of four Josephson junctions biased at half flux quantum. The ring connects two microwave resonators corresponding to the signal and idler modes.

1:00pm

*Invited*

#### **5EX02 - A tunable parametric amplifier based on a SQUID array resonator with nearly quantum-limited sensitivity**

*M.A.Castellanos-Beltran, K.W.Lehnert, JILA, NIST and the University of Colorado, and the Department of Physics, University of Colorado*

Recently, there has been an increasing number of compelling applications for quantum-limited amplifiers at microwave frequencies. These include the readout of superconducting qubits and ultrasensitive measurements of the motion of nanomechanical beams. Although quantum-limited microwave amplifiers have already been demonstrated, they have suffered from both limited bandwidth and dynamic range. We create a Josephson parametric amplifier from a transmission line resonator whose inner conductor is made from a series SQUID array. By changing the magnetic flux through the SQUID loops, we are able to adjust the circuit's resonance frequency and, consequently, the center of the amplified band over an octave (4-8 GHz). This tunability circumvents some of the problems related to a limited bandwidth. We will discuss recent results that include demonstration of large gain (30 dB), nearly quantum-limited sensitivity and noise squeezing.

1:30pm

*Invited*

#### **5EX03 - Parametric amplifier using a superconducting cavity**

*T.Yamamoto, NEC; K.Inomata, M.Watanabe, RIKEN; K.Matsuba, Tokyo institute of technology; T.Miyazaki, JST; W.Oliver, MIT; Y.Nakamura, J.S.Tsai, NEC*

The degenerate parametric amplifier is a phase sensitive amplifier, which can amplify one of the two quadratures of the signal without introducing extra noise. The parametric amplifier based on the nonlinear inductance of a Josephson junction had been studied extensively in 1970's and 1980's. Recently, there is a demand for

amplifiers that operates at the quantum limit in the superconducting qubit experiment, and the interest in the parametric amplifiers have been revived. In this talk, I would like to show the experimental data on a new kind of parametric amplifier. It is based on a superconducting coplanar-wave-guide resonator, whose center conductor is terminated by a dc-SQUID to the ground. By modulating the flux inside the SQUID loop in time, the resonant frequency of the cavity is also modulated, which causes the parametric amplification if the modulation frequency is the double of the resonant frequency of the cavity. We have operated the parametric amplifier at 10.8 GHz and observed the amplification and the deamplification depending on the phase between the pump and the signal. The maximum gain is 14 dB.

2:00pm

*Invited*

#### **5EX04 - Progress at NIST on DC SQUID Microwave Amplifiers**

*L.F.Spitz, K.D.Irwin, J.A.Aumentado, NIST*

We report on the development at NIST of microwave amplifiers using DC SQUIDS. Our design approach is to use small SQUIDS which can be modeled as lumped element circuits, thus separating the design process for the SQUID from that of the microwave impedance transformers. We present our model of the impedance, gain and noise of such a SQUID and measurements of the characteristics of our amplifiers. Furthermore, we discuss how our modular hardware design allows for easy deployment in labs around the world where there is a need for lower noise microwave measurement.

*We thank Konrad Lehnert, Rob Schoelkopf, and Michel Devoret for useful discussions.*

2:30pm

*Invited*

#### **5EX05 - Optimizing the Gain and Noise Temperature of Microstrip SQUID Amplifiers**

*D.Kinion, Lawrence Livermore National Laboratory; J.Clark, U.C. Berkeley and Lawrence Berkeley National Laboratory*

Microstrip SQUID amplifiers (MSA) offer near quantum-limited sensitivity and gains greater than 20 dB at frequencies around 1 GHz. These properties make them desirable for applications ranging from dark-matter axion detection to dispersive readout of superconducting qubits. The input of the MSA is a microstrip transmission line in the shape of a square spiral coil surrounding the hole in the SQUID washer that serves as the ground plane. Near the fundamental resonance, there is strong flux coupling between the input coil and SQUID. To obtain maximum performance it is necessary to know the complete set of complex scattering parameters. We present measurements of the scattering parameters of MSAs cooled to 4.2 K and 300 mK. The input impedance is found by measuring the reverse scattering parameter (S11), and is described well by a low-loss transmission line model. We map the low-loss transmission line model into an equivalent parallel RLC circuit that accurately predicts the observed gain given by the forward scattering parameter (S21). This information is used to optimize the input and output matching circuitry to achieve optimal noise temperature and gain. We present results for the gain and noise temperature of these optimized MSAs at 30-500 mK as a function of frequency and SQUID bias. We compare the results to the prediction of the circuit model and to the theoretical expectation that the lowest noise temperature occurs off-resonance.

*This work partially supported by DOE.*

**3:00pm**

**Invited**

**5EX06 - Development of dc SQUID RF amplifiers**

*T.Miyazaki, JST; T.Yamamoto, Y.Nakamura, NEC, Riken, JST; S.Yorozu, NEC, JST; M.Hidaka, ISTE, JST; J.S.Tsai, NEC, Riken, JST*

We have designed and fabricated dc SQUID RF amplifiers (SQAs) to amplify 10 GHz signals of superconducting quantum bits. An SQA consists of a dc SQUID and a resonant circuit (microstrip line or LC) couples to a dc SQUID. Compared to a semiconductor amplifier, an SQA consumes several orders of magnitude less power and shows less noise temperature. Power consumption of an SQA is the order of 100 nW and can be operated at the same temperature stage as quantum bits (typically below 100 mK). This small power consumption is a very useful feature to integrate many quantum bits. By fabricating SQAs and quantum bits on a same chip or packaging them as a multi-chip-module they can be integrated in a small system. Regarding the noise performance, it has been reported that an SQA can achieve a noise temperature a few times of quantum limit. Our SQAs are fabricated with NEC standard process and the critical current of a Josephson junction is 20  $\mu$ A. We designed SQAs to achieve more than 10 dB gain and 1 GHz bandwidth and noise temperature as close as possible to quantum limit ( $\sim 0.5$  K at 10 GHz). So far, our SQA have achieved 12 dB gain,  $\sim 5$  K noise temperature and 400 MHz bandwidth at 9.5 GHz with 4.2 K dip probe measurements.

**5EY - SQUID Applications in Biomagnetism 12:30pm - 2:30pm**

**12:30pm**

**5EY01 - Development of a cryogen-free, ultra low field SQUID MRI system**

*B.H.Eom, K.Penanen, P.Day, Jet Propulsion Laboratory/Caltech; M.S.Cohen, UCLA; I.Hahn, Jet Propulsion Laboratory/Caltech*  
Magnetic Resonance Imaging (MRI) at ultra low fields using Superconducting Quantum Interference Device (SQUID) magnetometry, using pre-polarization field cycling technique has been demonstrated recently and many advantages have been discussed. Earlier work, we used a liquid helium Dewar and a relatively small second order gradiometer to image and characterize, in-vivo, low-field magnetic relaxation in human hand and arm. We are currently developing a new cryogen-free SQUID MRI prototype that will enhance imaging volume and will reduce the cost and inconvenience of operating a liquid helium based system. The major sensor elements, a second order gradiometer and a SQUID sensor, are both cooled by a commercial pulse tube cryocooler. A relatively large size ( $\sim 8$  cm diameter) second order gradiometer design is chosen for imaging a human brain. The superconducting pick up coil is specially designed such that the wire is cooled below the superconducting transition temperature by thermal conduction and it still provides a superconducting loop with an input coil of a SQUID. The resolution of our liquid helium based system was limited by the intrinsic noise of the commercial SQUID sensor. To improve overall signal-to-noise ratio of the new SQUID MRI system, we also designed a custom SQUID with lower junction capacitance. We present our progress towards the construction of a practical SQUID MRI instrument for human clinical imaging.

**12:45pm**

**5EY02 - Human brain imaging by SQUID-based microtesla MRI and MEG**

*V.S.Zotev, A.N.Matlashov, P.L.Volegov, I.M.Savukov, M.A.Espy, J.C.Mosher, J.J.Gomez, R.H.Kraus, Jr., LANL*

Magnetic resonance imaging at ultra-low fields (ULF MRI) has developed significantly since the first results were reported four years ago. This imaging method uses SQUID sensors to measure the spatially encoded nuclear spin precession at microtesla-range magnetic fields. Unlike conventional MRI, microtesla MRI is compatible with SQUID-based techniques for biomagnetic measurements, such as magnetoencephalography (MEG). This allows development of combined MEG/ULF-MRI systems for brain imaging. Such systems can directly provide anatomical maps for MEG-localized sources and thus greatly facilitate integration of MEG with other imaging modalities. Here we present 3D images of the human brain acquired at a 46 microtesla measurement field, as well as auditory MEG data recorded using the same system. The system includes seven SQUID gradiometers and five sets of magnetic field and gradient coils for 3D Fourier imaging with pre-polarization at 30 mT. Images of the right side of the human head and of the forehead area were acquired with 3 mm x 3 mm x 6 mm resolution. Using the multiple-echo technique, we demonstrated T2-weighted contrast and estimated T2 values for different tissues. We also carried out preliminary experiments to estimate T1 relaxation times in the brain. Auditory MEG measurements were performed immediately after the ULF imaging of the right side of the head. Our results demonstrate that SQUID-based microtesla MRI can be successfully used for human brain imaging in combination with MEG.

**1:00pm**

**5EY03 - Harmonic Analysis of Neuronal Membranes Using SQUIDS**

*J.R.Claycomb, Houston Baptist University/ Department of Mathematics and Physics; V.Vajrala, J.Fang, J.H.Miller, Jr., University of Houston/ Department of Physics and Texas Center for Superconductivity (TcSUH)*

We report the nonlinear response of nerve fibers in the earthworm *Lumbricus terrestris* to sinusoidal and pulsed excitations using a High-Tc SQUID magnetometer. SQUID signals are processed on a Fast Fourier Transform (FFT) spectrum analyzer. Use of the SQUID eliminates low frequency polarization impedance and field distortion that would be present near pickup electrodes. The earthworm's harmonic response to electrical excitation is attributed to gap junctions and ion channels in the medial giant nerve fiber. Harmonic response measurements are compared to Hodgkin-Huxley active and passive transport models. Harmonic and impedance spectroscopy measurements are compared to a Finite Element Method (FEM) model of the passive electrical response of gap junctions to sinusoidal and pulsed excitations.

*This work was supported in part by grants from the State of Texas through the Texas Center for Superconductivity (TcSUH) at the University of Houston, the Robert A. Welch Foundation (E-1221), the National Heart, Lung and Blood Institute (R21CA122153), the National Cancer Institute, the National Institute of Health and the National Science Foundation*

**1:15pm**

**5EY04 - Magnetic Bioassay Applications using a Cryocooled Bench Top High-Tc SQUID Instrument**

*M.S.DiIorio, K.-Y.Yang, T.R.Pisanic, MagneSensors, Inc.*

We have developed a new bench top high-Tc SQUID system for ultra-sensitive magnetic bioassays. A SQUID magnetometer is used to measure the binding of antibodies, labeled with magnetic nanoparticles, to various targets. Of substantial importance for applications, the throughput of the new instrument is increased by over two orders of magnitude, enabling the measurement of over 50 samples per minute at high sensitivity using conventional microplate wells. Key design innovations also allow the use of a cryocooler without adding noise to the SQUID (150 fT per root Hz down to 1 Hz). The SQUID can be operated from 60-77K with a temperature stability better than a few mK. The instrument is being delivered into a hospital laboratory to measure clinical samples for sepsis diagnostics. To date we have demonstrated cell assays on *E. coli* bacteria (important O157:H7 strain) and *S. aureus*. We have detected a concentration less than 2,000 CFU per ml for both types of bacteria in buffer. Detection in serum is slightly higher, namely 2,700 CFU per ml for *E. coli*. Significant effort has been expended on various conjugation methods to couple antibodies to 50-150 nm size magnetic nanoparticles to permit assays to be performed in complex media such as blood and serum. Progress in other applications, including cell surface receptor assays of biomarkers for the detection of minimal residual disease in leukemia as well as intracellular assays for drug delivery and drug interactions, will be discussed.

*Work supported by NIH (1U01AI066578-03, 1R43DK080634-01)*

**1:30pm**

**5EY05 - Fast Detection of Biological Targets with Magnetic Marker and SQUID**

*K.Enpuku, H.Tokumitsu, Y.Sugimoto, Kyushu University; H.Kuma, N.Hamasaki, Nagasaki International University; A.Tsukamoto, T.Mizoguchi, A.Kandori, Hitachi, Ltd; K.Yoshinaga, Kyushu Institute of Technology; H.Kanzaki, N.Usuki, Hitachi Maxell, Ltd.*

We have been developing a SQUID system for the detection of biological targets. In this system, magnetic markers are bound to the targets, and the magnetic signal from the bound marker is detected with the SQUID. In order to realize fast detection of the target, we developed a new measurement procedure. First, we used large polymer beads as material to capture the target, which is in contrast to the conventional case where the target is captured to the base of chamber. Since the polymer beads are dispersed in liquid, biological targets on the surface of the polymer bead can easily couple to the markers, which results in the fast reaction time. Next, we detected the bound markers without using the washing process to separate the bound and unbound markers, which was realized by using the difference in the Brownian relaxation time between them. Using this procedure, we demonstrated the detection of the target called IgE. We obtained good relationship between the amount of IgE and the magnetic signal in the range from 4 to 4000 atto-mol of IgE. The result was the same as that obtained using the conventional procedure. The reaction time for the coupling of the magnetic marker was 3 min, which was an order of magnitude shorter than the conventional method. These results show the validity of the present method.

**1:45pm**

**5EY06 - Biologically Functionalized Magnetic Nanoparticle Characterization with High-Tc SQUID Gradiometer**

*F.Oisjoen, J.F.Schneiderman, K.Shunmugavel, Chalmers University of Technology; P.Magnelind, Chalmers, Los Alamos National Lab; A.Kalabukhov, D.Winkler, Chalmers University of Technology*

We have set up a high-Tc SQUID gradiometer measurement system for determination of the magnetic characteristics of biologically functionalized magnetic nanoparticles (MNPs) suspended in solution. The single layer YBCO SQUID was fabricated in house on an STO bicrystal substrate and mounted in a non-magnetic LN2 cryostat. The cryostat allows for a 1 mm separation between the room temperature MNP solution and the 77K gradiometer. The MNPs are coated with streptavidin, a commonly used biomolecule which serves as a substrate for more interesting biochemical reactions. We extract relaxation and susceptibility information of the MNPs from our experiments. A Helmholtz coil that surrounds both the sample and the gradiometer is used to excite the MNPs. Determination of the magnetic characteristics of the particles enables further experiments with antigen-antibody reaction kinetics for specific detection of biomolecules in a fashion similar to that used in ELISA. This measurement serves as a benchmark for comparison with an array of technologies based on MNPs in conjunction with the EU Biodiagnostics Project.

*The authors would like to thank Staffan Persson for hardware development, Jakob Blomgren for experimental setup, Karolina Petersson for providing the MNPs, Christer Johansson for fruitful discussions, and Imego for the LN2 cryostat.*

**2:00pm**

**5EY07 - Hyper-high-sensitivity Wash-free Magnetoreduction Assay on Bio-molecules Using High-Tc Superconducting Quantum Interference Devices**

*H.E.Horng, J.J.Chieh, National Taiwan Normal University; S.Y.Yang, Global Applied Biomedical Corporation; H.C.Yang, National Taiwan University; C.C.Wu, National Taiwan University Hospital*

In this work, we develop a platform for assaying bio-molecules involving the measurement of ac magnetoreduction of magnetic reagent mixed with a detected sample. The magnetic reagent contains magnetic nanoparticles coated with a given kind of antibody, which associates with conjugated bio-molecules. Then, the bio-molecules can be quantitatively detected by measuring the ac magnetoreduction of magnetic reagent. To achieve hyper-high-sensitivity assay, a system utilizing a high-transition-temperature rf superconductive quantum interference device (SQUID) as a sensor to probe the magnetoreduction of reagent due to the association between bio-molecules and magnetic nanoparticles. Examples to assay multi-active-epitope, single-active-epitope, and small molecules are given to demonstrate the validity of the assay platform, as well as the hyper-high sensitivity.

*This work is supported by the National Science Council of Taiwan under Grant Nos. 95-2120-M-003-001, 95-2112-M-003-017-MY2, and 95-2752-M-002-016-PAE.*

**2:15pm**

**5EY08 - Development of a SQUID system using field reversal for rapidly detecting bacteria**

*A.Tsukamoto, T.Mizoguchi, A.Kandori, Hitachi, Ltd.; H.Kuma, N.Hamasaki, Nagasaki International University; H.Kanzaki, N.Usuki, K.Yoshinaga, Hitachi Maxell, Ltd.; K.Enpuku, Kyushu University*

We have developed a SQUID system for rapidly detecting bacteria based on our previous magnetic immunoassay system. Samples are prepared by simply mixing bacteria in a suspension with magnetic markers. They are then passed through above a magnet and a SQUID sensor alternately by rotating a sample holder. When the magnetic moment of both bound and unbound markers is aligned by the magnet, the bound markers can be distinguished from the unbound markers by the SQUID sensor due to their difference in Brownian relaxation time. Thus, simple and rapid bacteria detection is possible without separating the bound marker and immobilizing the target material. For use in this system, we also developed a field reversal measurement scheme in which a difference signal was obtained by subtracting the magnetic signals measured by applying a magnetization field in both directions. The signal-to-noise ratio was significantly improved by this scheme.

**5EZ - Mixers and Junction Detectors 12:30pm - 2:00pm**

**12:30pm**

**5EZ01 - Development of low noise THz SIS mixer using an array of Nb/AlN/NbTiN junctions**

*A.Karpov, D.Miller, California Institute of Technology; J.A.Stern, B.Bumble, H.G.LeDuc, MDL, JPL, California Institute of Technology; J.Zmuidzinas, California Institute of Technology*

We present the development of ultra low noise SIS mixers aimed for the Terahertz channels of the heterodyne Caltech Airborne Submillimeter Interstellar Medium Investigations Receiver (CASIMIR) designed for the Stratospheric Observatory for Far Infrared Astronomy, (SOFIA). The observatory is based at a 747 Boeing flying at 14 km altitude. A high cost of SOFIA operation and the limited observation time is making the speed of detection, and thought the sensitivity of the detectors, a vital priority. Here we report the development of 1 THz SIS mixer. The mixer uses an array of 0.24  $\mu\text{m}^2$  Nb/AlN/NbTiN SIS junctions with critical current density of 30-50 KA/cm<sup>2</sup>. The junctions are shaped in order to optimize the suppression of the Josephson DC currents. We are using a double slot planar antenna to couple the mixer chip with the telescope beam. The RF matching microcircuit is made using Nb and gold films. The mixer IF circuit is designed to cover 4 - 8 GHz band. A test receiver with the new mixer has a low noise operation in 0.87 – 1.12 THz band. The minimum DSB receiver noise in optimized receiver may be as low as 200 K. The combination of a broad operation band of about 250 GHz with a low receiver noise is making the new mixer a useful element for application at SOFIA.

*This work is supported by the USRA SOFIA instrument development program*

**12:45pm**

**5EZ02 - Superconductive Parallel Junctions Arrays for Submm-Wave Astronomy Applications**

*F.Boussaha, M.Salez, LERMA, Observatoire de Paris; L.Loukitch, Laboratoire de Mathématique, INSA de Rouen, B.P.8, Mont-Saint-Aignan cedex - France; J.G.Caputo, Laboratoire de Mathématique, INSA de Rouen; B.Lecomte, LERMA, Observatoire de Paris; C.Chaumont, Pôle Instrumental, GEPI, Observatoire de Paris; F.Dauplay, A.Feret, J.M.Krieg, LERMA, Observatoire de Paris; M.Chaubet, CNES - BP 2220, 18 avenue Edward Belin, Toulouse Cedex 4 - France*

Observation and analysis of submillimeter-wave radiation in astronomy and atmospheric sciences requires increasingly performant receivers. Thanks to its high sensitivity, able to approach the limited quantum, the SIS (Superconductor-Insulator-Superconductor) junction became a standard and inescapable component, widely used in the submillimeter waves detection ranging from 0.3 to 1 THz. We are developing Submillimeter-wave fully Integrated superconducting Receivers (SIR) based on SIS mixer and SIS Multijunction operating as local oscillator. Multijunction array may be an interesting alternative to the standard Long Josephson Junction (LJJ) in SIR, allowing wide LO tunability, wide impedance matching bandwidths, and increased design flexibility and control of technological parameters. We present a detailed comparison of measurements and numerical simulations of model devices where we varied the number, sizes and positions of the junctions in the arrays. These show that such circuits can be tailored for different specific applications.

**1:00pm**

**5EZ03 - Gain Expansion and Compression of SIS mixers**

*C.Y.E.Tong, A.Hedden, R.Blundell, Harvard-Smithsonian Center for Astrophysics*

It is a well known fact that SIS mixers exhibit gain compression due to saturation effects when the output IF voltage swing becomes non-negligible compared to the width of the photon step. In this report, we show that under certain circumstances, SIS mixers can also exhibit the inverse phenomenon -- gain expansion. This non-linear behavior has been observed experimentally when the output power-voltage curve of an SIS mixer has a double peak feature over the photon step. The IF output power of the mixer is no longer a linear function of the incident signal power if the device is biased at the valley position between the two peaks of the P-V curve. At this setting, the apparent conversion gain of the mixer is not constant, in fact it increases with the input signal power. Consequently, the noise temperature of the mixer deduced from a Y-factor measurement, using 2 black bodies at different temperatures, will be artificially lower. We will present our experimental measurements and provide an explanation of such a phenomenon.

**1:15pm**

**5EZ04 - Effect of Al trapping layer thickness on the Ta-based Superconducting Tunnel Junctions detectors**

*H.S.Yoon, Y.S.Park, J.H.Park, S.H.Lee, Korea Astronomy and Space Science Institute; M.K.Yang, J.K.Lee, Korea Institute of Science and Technology; S.H.Kim, Y.U.Chong, Yonsei University; Y.H.Lee, S.K.Lee, Korea Research Institute of Standards and Science; D.L.Kim, Korea Basic Science Institute*

Superconducting Tunnel Junctions (STJs) technique offers next generation photon detectors exhibiting high energy resolution, high quantum efficiency and photon counting ability over the broad wavelength range from X-ray to NIR. We report a Ta/Al-AlO<sub>x</sub>-Al/Ta structure deposited on sapphire substrates using various techniques including UV photolithography, DC Sputtering, RIE, and PECVD technique. The characterization experiment was undertaken in an Adiabatic Demagnetization Refrigerator at an operating temperature below 50mK. The details of experimental investigations for variable Al thicknesses (2~40nm) as a trapping layer and STJ side-lengths (20~80μm) are discussed. The detector performance indicators such as energy gap, energy resolution, normal resistance, normal resistivity, dynamic resistance, dynamic resistivity, and quality factor were estimated from the measured I-V curve.

*This work has been supported by a grant (KRCF-CRND-2006-02-KASI) from Korea Research Council of Fundamental Science & Technology.*

**1:30pm**

**5EZ05 - Superconducting YBCO Step-edge Josephson Junction Detector for THz Imaging**

*J.Du, J.C.Macfarlane, K.E.Leslie, CSIRO CMSE, Lindfield, NSW 2070, Australia; A.D.Hellicar, L.Li, S.Hanham, CSIRO ICT Centre, Marsfield, NSW 2122, Australia*

Due to its unique characteristics, the terahertz (THz) electromagnetic spectrum offers a wide range of potential applications in areas of security, medicine, food processing and non-destructive testing. However, the lack of cost effective high performance components such as sensitive detectors and high power sources has delayed the development and application of THz technology for many decades. In recent years, there has been a growing interest in THz development due to advances in new components. We have recently developed a superconducting detector using an YBCO step-edge Josephson junction coupled with a ring-slot antenna for a THz imaging system. The antenna-coupled superconducting detector was mounted on a silicon substrate hyper-hemispherical lens and cooled in a liquid N<sub>2</sub>/He cryostat. The junction and antenna were illuminated with a 600 GHz source through a THz-transparent window on the cryostat. A quasi-optical scheme was set up to focus the THz wave generated by a backward wave oscillator onto a sample and the detector. We obtained THz images on various samples using the superconducting detectors. The images clearly demonstrate a number of THz features, the sensitivity to water content and the ability to penetrate cardboard, cloth and plastic materials.

**1:45pm**

**5EZ06 - High-resolution high-speed superconducting tunnel junction X-ray detector arrays**

*S.Friedrich, Lawrence Livermore National Laboratory; L.Fritzsche, Institute for Physical High Technology Jena; O.B.Drury, Lawrence Livermore National Laboratory; R.Stolz, Institute for Physical High Technology Jena*

Superconducting tunnel junctions (STJs) are being developed as X-ray detectors because they combine the high energy resolution of cryogenic detector technologies with the high count rate capabilities of athermal devices. We are developing STJ spectrometers for chemical analysis of dilute samples by high-resolution soft X-ray spectroscopy at the synchrotron. The instruments use 36 pixels of 200 μm × 200 μm Nb-Al-AlO<sub>x</sub>-Al-Nb STJs with 165 nm thick top Nb absorber films. They have achieved an energy resolution of ~10 - 20 eV FWHM for X-ray energies below 1 keV, and can be operated at a total count rate of ~10<sup>6</sup> counts/s. For increased sensitivity and operation at higher energies, we are currently developing larger STJ arrays with higher quantum efficiency. Initial results show extremely low leakage currents in the subgap region and correspondingly low electronic noise. We will discuss the performance of the instrument in fluorescence-detected X-ray absorption spectroscopy, and the most recent results on detector upgrades. We will also present speciation measurements on dopants in novel scintillator materials to illustrate the potential for STJ spectrometers at the synchrotron.

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