Microresonator Workshop July 28-29, 2011 Abstracts

Thursday July 28, 2011
Session 1 : Physical Effects in Microresonators 1

1. Pieter de VISSER, SRON – The Netherlands

Title: Counting quasiparticles: generation-recombination noise in microwave resonators

The density of quasiparticles in a superconductor should vanish when approaching zero temperature. In the fields of superconducting qubits and high sensitivity radiation detectors, this property should lead to long decoherence- and relaxation times. However, decoherence and relaxation times both saturate at low temperatures. Our measurements on resonators now enable counting the quasiparticles in a superconducting film, showing that their presence limits the relaxation time.
In thermal equilibrium, the number of quasiparticles fluctuates around an average value that increases exponentially with temperature. We report on a measurement in which these fluctuations show up as fluctuations in the complex conductivity of a thin Al superconducting film, probed with a microwave resonator. These fluctuations provide a direct measure for both the number of quasiparticles and the quasiparticle lifetime in the superconductor. We show that the saturation in quasiparticle lifetime at 2.2 ms below 160 mK is due to the saturation in the quasiparticle density at around 50 µm-3.
From a (kinetic inductance) detector perspective, measuring these fluctuations means that we have reached the intrinsic generation-recombination noise limit for the first time. The saturation in the number of quasiparticles limits the NEP to 3.3x10-19 W/Hz-1/2. Understanding and lowering the number of remnant quasiparticles will be crucial to improve the sensitivity of these detectors, which will ultimately form arrays of thousands of pixels.

We have recently published part of these results in: PRL 106, 167004 (2011).

2. Stephen YATES, SRON – The Netherlands

Title: Measurement of photon noise limited detection with lens-antenna coupled. Microwave kinetic inductance detectors using phase readout

Sub-mm astronomy requires detectors with a high optical efficiency limited by the noise fluctuations associated with the incoming radiation, the photon noise. Recently, we demonstrated high efficiency photon noise limited detection with hybrid lens-antenna coupled Microwave Kinetic Inductance Detectors (MKIDs) using dissipation readout. But for most applications MKID phase readout is preferred since it relaxes the requirements on the readout electronics noise contribution so aiding multiplexing. However, this adds a large extra noise contribution with a $sim 1/f^{0.5}$ spectral shape originating from the dielectric environment. Here we present photon noise limited detection in phase readout, using the response in radius readout to determine the remaining excess dielectric contribution. We also discuss how the photon noise signal can be used to measure the optical efficiency, so effectively calibrating the MKIDs.

3. Jochen BASELMANS, SRON – The Netherlands

Title: Background limited antenna coupled MKID arrays for ground based imaging

Background limited radiation detection implies a sensitivity greater than the limits imposed by the sky photon noise background in combination with device specific, fundamental noise sources. For MKIDs the fundamental limit is given by the photon noise from the sky, in combination with intrinsic generation-recombination noise from the superconducting film. To reach this limit the MKIDs need to be have a high responsivity, low noise and quasiparticles created by the sky radiation should be effectively confined and detected. Additionally the optical efficiency should be as high as possible. We will discuss the fundamental limits and non-fundamental issues of antenna coupled MKID arrays. Additionally we will sketch the complications encountered in a full system design based upon these detector arrays in combination with a 2 GHz bandwidth digital readout system developed in collaboration with MPIfR, Bonn.

4. James SCHLAERTH, CALTECH - USA

Title:

In superconducting MKID resonators, the complex conductivity, and the change in conductivity with the creation of quasiparticles, determines the measurable parameters of the resonator quality factor and frequency. In Mattis-Bardeen theory, the conductivity depends on the superconducting gap parameter, the resonance frequency, and the physical temperature of the quasiparticles. The change in conductivity due to quasiparticles is a strong function of temperature, decreasing at high temperature. The frequency and dissipation response have different dependances on these parameters, such that the ratio of frequency-to-dissipation response is a good measure of the physical temperature. We have used this ratio to diagnose the temperature of our arrays under large optical loads, and thus to solve problems of array heating under optical load. In addition, we have seen some evidence that at low substrate temperatures, antenna-coupled millimeter-wave MKIDs experience higher effective quasiparticle temperatures, which slightly decreases the responsivity. Finally, we have found evidence of anomalous behavior of this ratio in temperature sweeps under "dark" conditions (i.e. no optical load). While this is not entirely understood, we discuss the steps taken to find the difference between thermally and optically-created quasiparticles. We discuss what steps are being taken to fully understand this behavior and its implications for sub/millimeter MKIDs.

Session 2 : Physical Effects in Microresonators 2

1. Reinier JANSSEN, Delft Univ. of Technology – The Netherlands

Title: Power handling and responsivity of narrow superconducting coplanar-waveguide resonators

R.M.J. Janssen, A.Endo, J.J.A. Baselmans, P.J. de Visser, R. Barends, and T.M. Klapwijk

The sensitivity of kinetic inductance detectors (KIDs) based on coplanar waveguides (CPWs) needs to be improved by at least an order of magnitude to satisfy the requirements for space-based terahertz astronomy. Our aim is to investigate if this can be achieved by reducing the width of the CPW to much below what has typically been made using optical lithography ({$>$ }1 {μ}m). It has been shown for these resonators that for reducing width the gain in responsivity is greater than the loss in noise and power handling, yielding a net improvement in sensitivity. CPW resonators with a central line width as narrow as 300 nm were made in NbTiN using electron beam lithography and reactive ion etching. In a systematic study of quarter-wave CPW resonators with various widths it is shown that the behavior of responsivity, noise and power handling as a function of width do not change down to 300 nm. This encourages the development of narrow KIDs using materials such as Al and TiN in order to improve their sensitivity.

2. Loren SWENSON, CALTECH – USA

Title: Performance of a far-infrared kinetic inductance detector operating in the non-linear regime

The proposed Cerro Chajnantor Atacama Telescope (CCAT) was recently recommended in the Astro2010 decadal survey by the National Research Council. This sub-mm telescope is projected to provide a 1 degree field-of-view requiring, for example, ~10^6 photon-noise limited detectors at a wavelength of 35 mm. A leading device candidate for realizing this unprecedented pixel count and exhibiting a sufficiently low noise-equivalent power (NEP) is the kinetic inductance detector (KID). Previously demonstrated by DEMOCAM at the CSO and by NIKA at the IRAM 30 meter telescope, KIDs are frequency-multiplexed detectors based on superconducting resonators. In operating KIDs it has frequently been observed that the intrinsic KID noise, primarily due to coupling to quantum two-level systems in the substrate, is suppressed at high electrical readout powers. However due to the underlying superconducting electrodynamics, non-linear behaviour and an eventual bifurcation in the device response has been observed at even modest readout powers. The onset of non-linearity is well below the necessary readout power for optimal device performance and therefore an understanding of

this effect is crucial for achieving an ultra-low detector NEP. Here we present a theoretical model and experimental data of a KID optimized for far-infrared radiation detection and operated at electrical readout powers both well below and significantly above the onset of bifurcation.

3. Masato NARUSE, NAO - Japan

Title: The properties of MKID made of crystal Al films and amorphous-Al films

We investigate the effect of film qualities in superconductors on the properties of Microwave Kinetic Inductance Detectors (MKID) [Day, et al, 2003]. We compare the sensitivity of MKID between crystal Al films and amorphous Al films. The electrical NEP of the crystal-Al MKID is around 10^(-17) W/Hz^(1/2) and comparable that of the amorphous-Al MKID. The properties of these MKID may be restricted by the stray light through coaxial cables and the narrow gaps of sample holders, as the previous work reported [Baselmans, et al. 2009].
We prepared good quality and crystallized Al films by using Molecular-Beam Epitaxy (MBE). The Al film with a thickness of 150 nm were deposited on a high resistivity (>15 kilo Ohm cm) Si(111) substrate in an ultrahigh vacuum (UHV) chamber with pressures less than 2 $*10^{-7}$ Pa. Before the Al deposition process, the Si wafers were immersed in an HF solution and annealed at 650 degree Celsius in the UHV chamber, in order to make the surface of the wafers clean and reconstructed. The Al films were characterized by X-ray diffraction and in-situ reflection high-energy electron diffraction measurements. Epitaxial Al(111) films were grown on the Si(111) substrate. The residual resistivity ratio (RRR) of the MBE-Al film was about 18.
For comparison, a 150 nm thick Al film on the Si(111) substrate was prepared by using Electron Beam (EB) deposition. Before the deposition process, the wafer was passivated by hydrogen, but was not annealed. The RRR of the amorphous film was about 10.
The Al films were patterned into standard, 1/4 wave length, Coplanar Waveguide (CPW) resonators by a wet etching process. The CPW resonators have a 3 micro meter wide center line and 2 micro meter wide gaps. MKID samples were surrounded with magnetic shields, and put on the top load of a 0.1 K dilution refrigerator. The quasiparticle lifetime was estimated from the responses of MKID against LED pulses [Barends, et, al. 2008].
The quasiparticle lifetime of the MBE-Al film and the EB-Al film were comparable and about 450 micro second at 0.1 K. Noises and quality factors of both films were also indistinguishable. In our measurement system, unexpected sub-mm wave photons might invade a sample holder and limit the lifetime in the superconductors. In order to isolate the unexpected-photon problem, we are reconstructing the measurement system into a light-tight setup.

Session 3 : Optics and System aspects 1

1. Omid NOROOZIAN, CALTECH – USA

Title:

We have investigated resonator designs suitable for direct absorption of far infrared (FIR) photons using lumped element kinetic detectors. Our FIR detectors are made from a 20-50 nm thin layer of TiNx with a tunable Tc (0-4.5K) that exhibits very high surface inductance and very low microwave loss (internal quality factors as high as $3x10^7$). These resonators have meandered or spiral inductors and use interdigitated capacitors to reduce two-level system noise. We have made tightly packed arrays with 256 pixels using a new resonator design that shows minimal crosstalk. Resonator design details, measurements of detector and array properties including crosstalk, and circuit simulations of large arrays will be presented.

2. Markus ROESCH, IRAM Grenoble - France

Title: Simulations and measurements to optimize the optical coupling of LEKIDs

One advantage of lumped element kinetic inductance detectors (LEKID) is the highly sensitive direct detection area of the resonator geometry. There are no lenses or antennas necessary to couple photons into the resonator, which makes the fabrication process relatively easy.
Measurements at cryogenic temperatures are very time consuming considering the characterization of the optical absorption of a series of samples. Therefore we decided to use a room temperature reflection measurement setup. The sample geometry has been adapted to be comparable to the low temperature case. The results of these measurements will be presented and compared to a transmission line model and simulations.
To increase the responsitivity of the detectors we are testing a LEKID geometry that is sensitive to two polarizations. Properties, such as optical absorption, quality factors and sensitivity will be discussed for this type of geometry

3. Alessandro MONFARDINI, Institut Néel – France

Title: The Néel IRAM KID Arrays (NIKA)

We present the recent results and the future plans of the NIKA collaboration, developing LEKID and antenna-coupled KID for ground-based millimeter-wave astronomy. In particular, we describe in detail the results of the last technical run at the IRAM 30-m telescope. NIKA has demonstrated for the first time a KID sensitivity comparable to existing bolometer-based instruments.

4. Simon DOYLE, Cardiff University – United Kingdom

Title: Optimisation of Aluminium Lumped element Kinetic Inductance detectors under high optical loading

The Lumped Element Kinetic Inductance Detector (LEKID) is a simple to fabricate single layer kinetic inductance detector that incorporates both detecting and absorbing elements in a single structure. Like other kinetic inductance detectors the LEKID has the potential to be both a very sensitive detector while being easily integrated into multiplexed large format arrays. The LEKID device has already been tested and proven as a viable technology on two observing runs at the IRAM telescope observing at both 2mm and 1.25mm. Current arrays tested on IRAM have fallen slightly short of the photon noise limit by around a factor of 3 in the best pixels tested. This presentation will discuss how the LEKID can be optimised to meet the photon noise limit under typical sky loading conditions at IRAM (typically 1-10pW per pixel) using simulation and test data.

Session 4 : Optics and System aspects 2

1. Tomu NITTA, NAO – Japan

Title: Development of silicon lens array for MKID camera

We have been developing a large format submillimeter camera using microwave kinetic inductance detectors (MKIDs) at National Astronomical Observatory of Japan-Advanced Technology Center (NAOJ-ATC).
We plan to install the camera on a submillimeter telescope that will be constructed at the Japanese Antarctic station, Dome Fuji station. The Dome Fuji station is located at an altitude of 3810 m on a plateau halfway between the South Pole and the ocean. By measurements of atmospheric-transparency at 220 GHz, it has been indicated that the optical depth at the Dome Fuji station in summer is comparable to that at the Atacama Desert in winter (Ishii et al, 2010). Under the best condition in winter at the Dome Fuji station, we expect that pwv=50 um and high transparency, better than 80% at atmospheric windows up to 1 THz. Therefore, the Dome Fuji station is one of the best site on earth for submillimeter astronomy. Optical design of our MKID camera is based on double slot antennas and a synthesized elliptical lens array (e.g. D.Filipovic et al, 1993). The lens array is made of a high-purity polycrystal silicon with a low absorption coefficient at submillimeter waveband and the large refractive index. The property of silicon at 12 K was measured using Fourier Transform Spectrometer (FTS). Loss tangent derived from FTS was less than 5×10^(-4) between 200 GHz - 1.6 THz, and refractive index was 3.388 between 200 GHz - 1.6 THz. The silicon lens array was designed to achieve symmetrical beam pattern and low side-lobe level. A prototype 220 GHz silicon lens array has

3×3 pixel with the radius of 2.045 mm and extension thickness of 0.35 mm. It was machined with a high-speed spindle at NAOJ-ATC. The shape error was measured to be less than 20 um (P-V) and the surface roughness was 0.5 um (Ra) at the top of the lens. The fabrication of a hundred pixel silicon lens array has already been done. It takes about 1 hour for machining 1 pixel. We have measured the beam pattern and the dynamic range of Al MKIDs with the prototype silicon lens array at 220 GHz. The Al MKIDs were operated under the temperature of 300 mK cooled by a He-3 sorption cooler.

2. Akira Endo, Delft Univ. of Technology – The Netherlands

Title: A Submillimeter Imaging-spectrograph Based on Superconducting Resonators

A. Endo(1), P. van der Werf(2), R. M. J. Janssen(1), T. M. Klapwijk(1), J. J. A. Baselmans(3), L. Ferrari(3), A. M. Baryshev(3), and S. J. C. Yates(3)

(1) Kavli Institute of NanoScience, Faculty of Applied Sciences, Delft University of Technology
(2) Leiden Observatory, Leiden University
(3) SRON Netherlands Institute for Space Research

DESHIMA (Delft SRON High-z Mapper) is a project to build an imaging spectrograph to instantaneously cover the entire bands of multiple submillimeter telluric windows in the range of 300-950 GHz with a modest frequency resolution (f/df ~ 1000). In parallel to the grating optics design, we seek an alternative design which utilizes the rapidly advancing technology of superconducting microresonators twofold. The signal received by the antenna enters different channels according to their frequency by using lossless NbTiN resonators as band pass filters. At the exit of each channel is another resonator with a lossy Al center strip, making the resonator act as a Microwave Kinetic Inductance Detector (MKID). By simulation, we show that a frequency resolution of f/df = 1000 can be achieved with a coupling loss of 3dB, assuming that dissipation in the filters is negligible. The antennas will be arrayed to obtain a full-2D spatial sampling. While the primary aim is to cover multiple telluric windows from ground-based observatories, the extreme compactness and flexibility of such a configuration makes it suitable for space- and air-born missions as well.

3. Peter Barry, Cardiff University – UK

Title: **Design and simulation of various KID geometries used to readout elements of a mm-wave filter bank spectrometer**

Superspec is a concept for an on-chip mm-wave spectrometer using half-wave resonators coupled to a planar transmission line as filter elements. I shall describe simulations of different

KID geometries coupled to individual filter elements designed to read out the signals in the different bands.

Friday July 29, 2011
Session 1 : Microresonator applications 1

1. Stefan Filipp, ETH Zürich – Switzerland

Title: Distributing Quantum Information with Microwave Resonators in Circuit QED

Superconducting quantum circuits can couple strongly to microwave photons in coplanar transmission line resonators, an architecture known as circuit QED. It provides a versatile platform for quantum computation and quantum optics experiments, where resonator photons are used to mediate interactions and transfer coherent quantum information between multiple distant qubits. In recent experiments, highly entangled qubit states have been prepared for quantum algorithms and teleportation. Cooperative effects such as the enhancement of the coupling between photons and multiple qubits and the formation of dark states have been observed. Moreover, microwave resonators can be used to interface different quantum systems such as highly-excited Rydberg atoms and superconducting circuits to form hybrid quantum systems as future platform for quantum computation.

2. Marta KRAWCZYK, Walther-Meisser Institute – Germany

Title: Distributed (ultrastrong) coupling of two superconducting microstrip resonators

Coupled superconducting transmission line resonator systems have potential applications in quantum information processing and fundamental quantum mechanics. Experimentally, high coupling strengths are desirable for a clear demonstration of quantum effects. We achieve coupling strengths between 10% and 20% of the resonator frequency (ultrastrong coupling) by distributed coupling. We find that, differently from the case of punctiform coupling, the normal modes of the coupled system are no longer arranged symmetrically with respect to the single resonator frequency. Nevertheless, a detailed theoretical analysis shows that the system can still approximately be described by a beam splitter Hamiltonian for two effective resonators. We expect that this result will allow for straightforward experimental access to exciting effects such as thermal entanglement in our samples.
Furthermore, our preliminary studies indicate that the coexistence of capacitive and inductive coupling, which is well controlled by the sample geometry, allows for the construction of interesting Hamiltonians in a seemingly simple system.

We acknowledge support from the SFB 631 of the Deutsche Forschungsgemeinschaft, the German Excellence Initiative via NIM, and the EU FP7-people network CCQED.

3. Alexander BAUST, Walther-Meisser Institute – Germany

Title: Superconducting coplanar waveguides for experiments with flux quantum circuits

Superconducting coplanar waveguide (CPW) structures are widely used in experiments with superconducting thin-film circuits acting as artificial two-level atoms or, equivalently, quantum two-level systems (qubits). More specifically, CPW resonators can serve as qubit readout instrument, as quantum bus between multiple qubits, or as a "box" confining microwave photons for light-matter experiments with previously unprecedented coupling strengths. Here, we present recent results of CPW resonators coupled to superconducting flux quantum bits. In the strong coupling regime, the study of two-photon excitations allows for the direct observation of controlled symmetry
breaking [1] and the vacuum coupling strength. Furthermore, a qubit-resonator coupling of up to 12% of the resonator self energy is reached by means of the nonlinear inductance of a Josephson junction. Making use of the multimode structure of the resonator, the breakdown of the Jaynes-Cummings model is observed in this ultrastrong
coupling regime [2]. Finally, we discuss superconducting hybrid ring beam splitters [3, 4] made of microstrip waveguides and their applicability for experiments with propagating quantum microwaves [5].

We acknowledge support from the SFB 631 of the Deutsche Forschungsgemeinschaft, the German Excellence Initiative via NIM, and the EU FP7-people network CCQED.

[1] F. Deppe et al., Nature Physics 4, 686 (2008)
[2] T. Niemczyk et al., Nature Physics 6, 772 (2010)
[3] E. Hoffmann et al., Appl. Phys. Lett. 97, 222508 (2010)
[4] M. Mariantoni et al., Phys. Rev. Lett. 105, 133601 (2010)
[5] E. P. Menzel et al., Phys. Rev. Lett. 105, 100401 (2010)

4. Jonathan BURNETT, NPL/RHUL – United Kingdom

Title: Interrogating superconducting lumped element resonators by Pound locking

J. Burnett (1,2), T. Lindström (1,2), M. Oxborrow(1), A.Ya. Tzalenchuk1, G. Ithier(2), P Meeson(2) Y. Harada(3) and Y. Sekine(3)

(1) National Physical Laboratory, Hampton Road, Teddington, TW11 0LW, UK
(2) Royal Holloway, University of London, Egham, TW20 0EX, UK

(3) NTT Basic Research Laboratories, 3-1 Morinosato Wakamiya, Atsugi, Kanagawa 243-0198 Japan

We present an adaptation of Pound frequency locking – a technique well known within frequency metrology for stabilising precision oscillators – which we use for the characterisation of superconducting micro-resonators.

At millikelvin temperatures the resonant frequency of superconducting resonators undergoes fluctuations due to coupled noise sources. These are suspected to originate within dielectrics about the resonator and can be parameterised as a bath of two level fluctuators. By recording the feedback signal, we probe fluctuations of the resonance frequency and obtain qualitative and quantitative information on noise coupled to the superconducting resonator.

Several benefits are gained from the adapted Pound frequency locked loop: The measurements are performed above the amplifier corner frequency, while the feedback eliminates sensitivity to amplitude fluctuations. This feedback also allows the resonance frequency to be tracked in real time (within the bandwidth of the loop).

Measurements have been performed using the Pound locking scheme at microwave powers between –80dBm and –100dBm. A frequency resolution at the 10 Hz level (limited by noise intrinsic to the resonator) is possible within 10 ms, corresponding to a line splitting factor (resolution/resonator bandwidth) of order 105. After 10 ms random walk frequency noise (1/f2 noise) becomes the dominant drift mechanism, limiting the frequency stability, while flicker frequency (1/f) noise is only observed at frequencies less than 5 Hz.

[1] T. Lindström, J. Burnett, M. Oxborrow and A. Ya. Tzalenchuk arXiv:1106.5396v1
[2] T. Lindström, J. E. Healey, M. S. Colclough, C.M. Muirhead and A. Ya. Tzalenchuk Phys. Rev. B , vol 80, 132501, 2009

Session 2 : Microresonator Applications 2

1. David MOORE, CALTECH - USA

Title: Phonon mediated microwave kinetic inductance detectors

D. Moore, S. Golwala, B. Bumble, B. Cornell, B. Mazin, J. Gao, P. Day, H.G. LeDuc, J. Zmuidzinas

We are developing athermal-phonon mediated particle detectors using microwave kinetic inductance detectors (MKIDs) as the phonon sensing elements. Since MKIDs are easily multiplexed, hundreds of sensors patterned on a single dielectric substrate can be read out simultaneously, leading to a precise, time-resolved measurement of the phonon flux at each point on the detector surface. In addition to providing a high-resolution measurement of the location of the interaction, the energy deposited by the particle can be reconstructed with an expected baseline resolution of 10s of eV. The complexity of the cryogenic readout electronics is significantly reduced relative to designs based on multiplexed transition edge sensors. We present results from initial proof-of-principle devices which demonstrate energy resolutions as good as 1.2 keV at 30 keV, dominated by the position dependence of the phonon signal. New designs aimed at improving this resolution by more than an order of magnitude will be discussed. Such high-resolution phonon mediated detectors would have applications including direct detection of dark matter, hard X-ray/soft gamma-ray astrophysics, and neutrinoless double beta decay.

2. Christopher McKenney, CALTECH – USA

Title: Superconducting Microresonators for Bolometer Readout

We are investigating radio-frequency (RF) superconducting microresonators for use as kinetic inductance thermometers (KITs). As pointed out by McDonald in 1987, the temperature-dependent kinetic inductance of a superconductor provides the basis for a thermometer with very low power dissipation and noise. While these properties are very advantageous for bolometer readout, today most superconducting bolometer arrays use resistive readout of transition-edge sensors (TES) because of the availability of SQUID-based multiplexed readout schemes. In comparison, RF-KITs are quite attractive since they are easy to fabricate and offer a much simpler frequency-domain multiplexing scheme. Superconducting microresonators are typically operated at microwave frequencies; we are exploring the feasibility of fabricating radio-frequency (RF; ~100 MHz) resonators using parallel-plate thin-film capacitors in order to achieve very high multiplexing density. A key issue will be frequency noise due to capacitance fluctuations from two level systems (TLS) in the dielectric material, as has been observed in microwave kinetic inductance detectors (MKIDs). However, the RF-KITs will operate in a different regime ($hf \ll kT$) where thermal saturation of the TLS becomes important, and TLS noise in this regime has not been investigated in detail. We are therefore designing, fabricating, and testing microresonators in order to study the signal and noise properties of KITs operated at RF frequencies.

3. John MATES, NIST – USA

Title:

Transition-edge sensors are by some figures of merit the most sensitive detectors of electromagnetic signals over more than nine orders of magnitude in energy. As new scientific

applications demand larger and larger arrays of these detectors, there is a need for a large scale multiplexing solution.
We have developed a microwave frequency multiplexer of dissipationless SQUIDs to read out TES detectors with low added noise. We have demonstrated multiplexed readout of the microwave SQUIDs with low crosstalk. Using a flux modulation scheme, we circumvented the excess low-frequency noise due to two-level systems on the resonator surfaces. This multiplexer enables readout of the next generation of TES arrays.

5. **Julien SALORT, Institut Néel – France**

Title: Miniature velocity probe for superfluid turbulence

We present an original application of superconducting micro-resonators for low-temperature local velocity measurements in superfluid helium : we use a niobium LC resonator to measure the deflection of a micro-cantilever located inside a highly turbulent 4He flow. Fast demodulation of the resonance leads to the velocity fluctuations, which is a quantity of interest in the field of quantum turbulence.

Session 3 : TiN Microresonators

1. **Peter DAY, JPL – USA**

Title: Nonlinearity of TiN/ NbTiN resonators and transmission lines

We have measured the nonlinearity of microresonators and transmission lines made of TiN and NbTiN. By sweeping the microwave excitation tone downward in frequency, we are able to drive the resonators at much higher than the critical power at which the resoance curves become hysteretic. We observe that at low enough temperature and for a wide range of excitation power, the nonlinearity produced by the strong driving tone is purely reactive. Large values of reactive nonlinearity can be produced before nonlinear dissipation is observable. Long transmission lines made from the same materials show similar nonlinearity, leading to the possibility of their use as traveling wave parametric amplifiers. We present initial results on amplification in devices of this type.

2. Pascale DIENER, SRON – The Netherlands

Title: Design and testing of Kinetic Inductance Detectors made of highly resistive materials

The use of highly resistive material for KIDs is promising because it increases drastically their responsivity through the high kinetic inductance Lk and allows a more efficient direct optical coupling. In this context, titanium nitride (TiN) appears particularly well suited because its critical temperature and Lk varies with the nitrogen content.
To develop and optimize TiN-based KIDs, we need to have a comprehensive view of the variations of the intrinsic properties with Lk. Furthermore, new designs have to be done, in part due to the impedance match needed between the chip containing the detectors and the whole 50Ω readout circuit.
Here we firstly present and demonstrate a new design, with the main part of the chip in aluminum and only small areas in TiN containing the resonators. Electromagnetic 2D simulations with SONNET have been compared to experimental results. We find that the chip transmission does not exhibit any box resonance and less than 2dB loss in the readout frequency range 3 to 9 GHz.
We also report our first results on TiN chips with different nitrogen contents. The intrinsic parameters appear to vary widely with Lk: internal factors Qi up to 106 are measured in a chip with Lk≈5pH, but the lifetime is only 50μs; in contrast, another chip with Lk≈50pH exhibits Qi's of 104 but a huge responsivity and a lifetime up to 5ms, giving rise to a minimum electrical Noise Equivalent Power of 1.2 10-19 W√Hz.

3. Pieter-Jan COUMOU, Delft University of Technology – The Netherlands

Title: Electrodynamics of strongly disordered superconducting TiN films

P.C.J.J. Coumou, E.F.C. Driessen, R.R. Tromp, M.R. Zuiddam, P.J. de Visser, A. Endo, and T.M. Klapwijk

Kavli Institute of NanoScience, Faculty of Applied Sciences, Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, The Netherlands

Resonators of (sub)stoichiometric superconducting TiN films are of great interest for use as kinetic inductance detectors, because of their expected high sensitivity. However, TiN films are highly resistive in the normal state leading to competition between localization and superconductivity. This may lead to large scale electronically disordered behaviour in atomically uniform disordered materials. Therefore, the standard analysis of the electrodynamics, such as applied for aluminium resonators, may reveal deviations if applied to TiN films. We study the electrodynamics of atomic layer deposited and sputter deposited TiN films with varying disorder. The films have k_Fℓ values between 2.6 and 11 indicative of strong disorder approaching the superconductor-insulator transition. Very thin layers of TiN, with high resistance per square, can be grown by atomic layer deposition (ALD), possibly with superior properties compared to sputtered materials. We measure the electromagnetic response of these films using microwave resonators. The internal quality factor and the shift in the resonance frequency as a function of temperature are used as probes for the real and imaginary part of the complex conductivity. The response of the films with relatively low disorder can be described fairly well with Mattis-Bardeen theory, provided that a broadening of the BCS density of states is introduced. For increasing disorder, the needed broadening parameter increases. This suggests that the broadening is directly related to the increase in disorder in agreement with numerical simulations of disordered superconductors.