

ED2-1-INV

Micro-fiber coupled superconducting nanowire single-photon detector for near infrared wavelengths

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High-performance superconducting nanowire single-photon detectors (SNSPDs) have enabled numerous experiments and applications especially in modern quantum optics and quantum communication. Two kinds of optical coupling methods for SNSPDs have been developed so far. One is the standard-fiber-coupled SNSPD with the fiber vertically illuminating the meandered nanowires, the other is waveguide-coupled SNSPD with the nanowires fabricated on the surface of the waveguide which guides photons while the fiber is coupled to the waveguide. Here we report a new type of SNSPD coupled with micro-fiber (MF). The photons are guided by an MF and evanescently absorbed by the nanowires of SNSPD when the MF is atop the superconducting NbN nanowires. The room-temperature optical experiments indicated a coupling efficiency of up to 90% with a 1.3- μm -diameter MF for the wavelength of 1550 nm. We were able to demonstrate that the MF-coupled detector achieved system detection efficiency of 50%/20% at the wavelength of 1064/1550 nm with a 2- μm -diameter MF at 2.2K. We expect the MF-coupled high-efficiency SNSPDs may extend to various novel applications such as micro/nano optics.

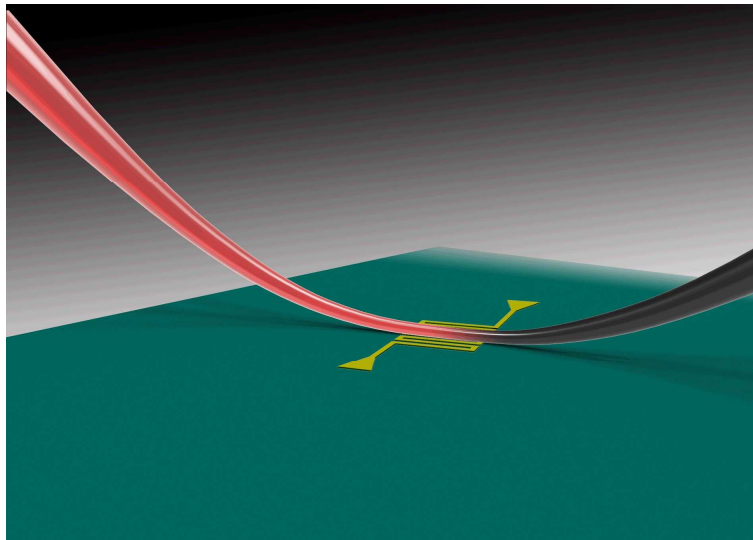


Figure Caption: Schematic of MF-coupled SNSPD.

Keywords: Micro-fiber, superconducting single-photon detector

ED2-2

Microscope imaging with an optical transition edge sensor sensitive to a single photon

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Optical transition edge sensor (TES) detectors which can resolve an energy of a single optical photon have proven desirable in quantum information and biological imaging. We have developed confocal imaging system with a gold-titanium bilayer TES embedded in cavity structure designed to detect photons in a few eV range and lower than this [1]. The TES is formed on a mirror, covered by an anti-reflection coating. The detector has achieved high detection efficiency, nearly 100 % at 1,550 nm (0.8 eV), and an energy resolution of 0.1 eV for 0.8-eV photons. The TES is coupled with the microscope through a fiber which is placed at the confocal plane of a lens and acts as a pinhole. A two-dimensional image can be obtained by scanning a sample. Figure 1 shows an image of blue, yellow and red ink spots scanned by the TES-coupled microscope. The intensity of light source illuminating the sample was set to a level where commercially available CMOS cameras are not usable. The color of each spot was determined based on red-green-blue (RGB) model. We will also show the recent status of development of optical TESes.

[1] K. Niwa et al., Sci. Rep. 7, 45660, (2017).

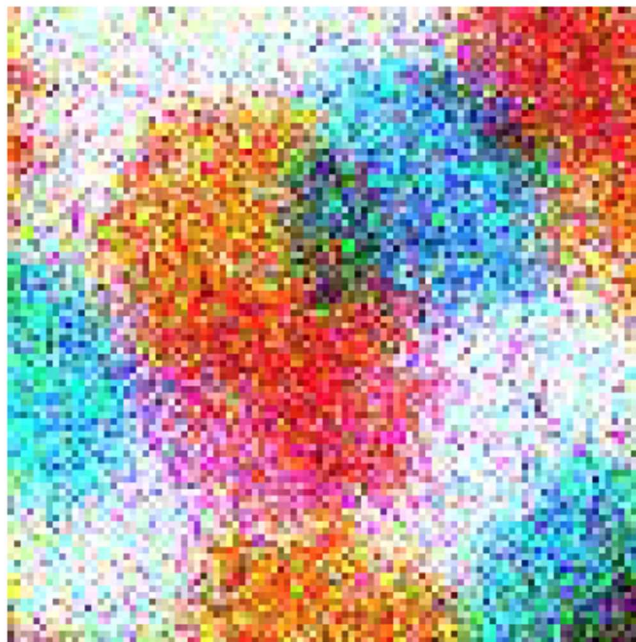


Fig. 1 Blue, yellow and red ink spots illuminated by a faint light source. The gate time was 50 ms for each pixel and the pixel pitch was 2 μm .

Keywords: transition edge sensor, confocal microscopy, two-dimensional imaging

ED2-3

Microwave SQUID Multiplexing for Ti/Au bilayer TES X-ray microcalorimeter

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We are developing a microwave superconducting quantum interference device (SQUID) multiplexer (MW-Mux) aimed to realize more than 10^4 pixels large format superconducting transition edge sensor (TES) X-ray microcalorimeter array, which is larger than that of the Athena X-ray astronomical space mission (i.e., 3840 pixels planned to launch around 2028) in an order of magnitude, for future space missions required large angle and high-resolution spectroscopy such as an Diffuse Intergalactic Oxygen Survey (DIOS). MW-Mux is a multiplexing technique capable of reading out potentially hundreds to thousands of TES pixels in a single coaxial pair because of that three orders of magnitude larger bandwidth than those of conventional multiplexing methods (i.e., TDM, CDM and FDM) with several MHz bandwidths. It consists of a number of superconducting resonators in the GHz range, each employing a unique resonance frequency, terminated by dissipationless rf-SQUID magnetically coupling to a TES pixel. Each SQUID acts as a flux-variable inductor responding to the magnetic flux threading the SQUID loop in a flux-quantum Φ_0 ($= 2.07 \times 10^{-15} \text{Wb}$) cycle. Therefore, a TES signal is read out by monitoring the shift of the resonance frequency depending on the magnetic flux activated by change of current though TES at energy irradiation. For multiplexing, those elements are capacitively coupled to a microwave feedline.

Since the output resistance of Ti/Au TES is generally larger than that of Mo/Cu TES or Mo/Au TES reported from U.S.A., our MW-Mux should have lower current noise than MW-Mux developed in U.S.A. In our condition, the current noises of Ti/Au TES and MW-Mux were respectively $\sim 30 \text{ pA/Hz}^{0.5}$ and $\sim 100 \text{ pA/Hz}^{0.5}$. In order to realize the signal to noise ratio higher than one, the coupling between TES and SQUID should be larger than 200 pH, which is about three times as large as our first design.

For this purpose, we are investigating how large the coupling between TES and SQUID can be in our MW-Mux.

In this presentation, we will first describe this result as well as the multiplexing of X-ray TES arrays.

Keywords: Microwave SQUID multiplexer, Transition edge sensors (TES), Microwave resonators

ED2-4

Evaluation of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ based microwave kinetic inductance detector array with rewound spiral resonators

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A microwave kinetic inductance detector (MKID), which is one of the superconducting photon detectors, is a promising candidate to realize highly sensitive terahertz imaging due to easy fabrication of large format arrays^[1]. However, currently developed MKIDs in other groups utilize low critical-temperature materials for astronomical applications, and they require sizable and expensive cooling systems.

We propose an MKID array using $\text{YBa}_2\text{Cu}_3\text{O}_{7-d}$ (YBCO) thin film that can be easily operated at 77 K. We deposited the YBCO film on a MgO substrate and then patterned a 25-pixels array. The array consists of 25 spiral resonators with the microstrip linewidth of 10 μm as shown in Fig.1(a)^[2]. Each pixel is designed to resonate in the microwave band, and the lengths of the resonators were varied for every 30 μm .

We evaluated the microwave characteristics by measuring one of the scattering matrix elements (S_{21}) using a vector network analyzer. 25 resonant dips were clearly observed at around 5 GHz with intervals of about 15 MHz as shown in Fig.1(b). The average amplitude was 9 dB, and the loaded quality factor (Q_L) was approximately 1300 at 11 K. Each resonant frequency was shifted by 170 MHz by changing the operating temperature from 11 to 50 K. In addition, the arrays with linewidth of 20 and 40 μm were also prepared to compare the detector performance. As for these two resonators, the amplitudes were 12 dB and 18 dB, and the Q_L values were 950 and 600 in average, respectively. As a first step of the optical evaluation, we irradiated a pulsed visible light to the array. The resulting noise equivalent power (NEP) was of the order of 10^{-9} W/sqrt(Hz), and the response time was less than 30 ms at 13 K. We think that the performances of the detector will be improved by optimizing our YBCO film quality as well as the resonator design. The latest results will be given in this presentation.

[1] P. K. Day, et al. Nature **425** 817 (2003)

[2] K. Hayashi, et al. Physics Procedia **45** 213 (2013)

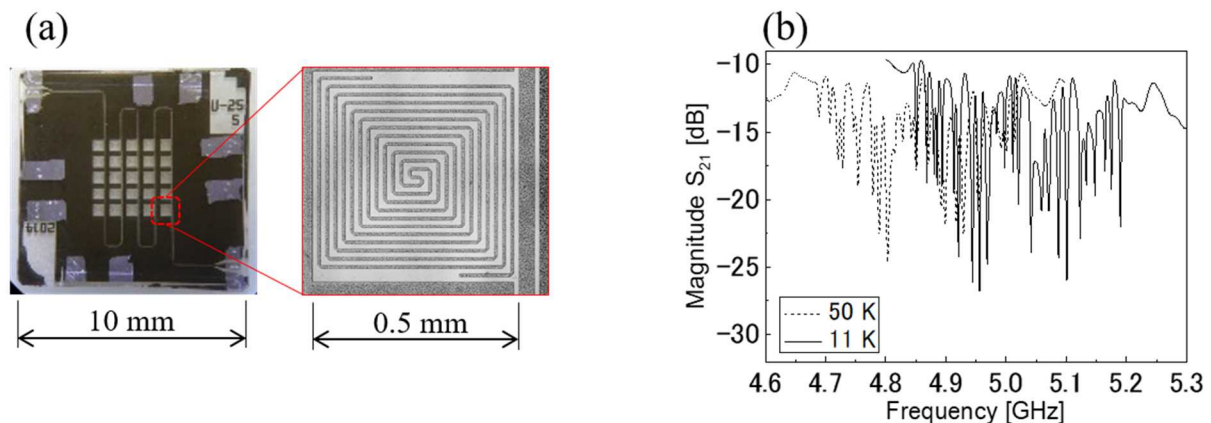


Fig1. (a) MKID array fabricated on a MgO substrate, (b) Microwave characteristics of the array measured at 11 and 50 K.

Keywords: YBCO, MKID, kinetic inductance, microwave resonator