EDP1-1

A Study of the HTS Josephson Junction Formed by a Ga Focused Ion Beam

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High Temperature Superconductor Josephson Junctions (HTS-JJs) are based on artificial grain boundaries. However, the layout of HTS Superconducting Quantum Interference Devices (SQUIDs) on a bi-crystal substrate is restricted. Therefore, we explored the use of low noise nano-bridge JJs formed by Ga-Focused Ion Beam (FIB) irradiation.

We have studied properties of HTS films by irradiated Ga-FIB in previous paper [1]. In this paper, we report the fabrication method of HTS nano-bridge JJs and its properties. We deposited 100 nm thick $YBa_2Cu_3O_{7-d}$ (YBCO) films on an MgO substrate by pulsed laser deposition, and 20 nm thick gold thin film as a protection layer was deposited in-situ. After that, we fabricated a 4 µm wide micro-channel by photolithography and an Ar ion milling. Then, we patterned a nano-bridge by FIB irradiation (Acceleration voltage: 40 kV, Beam diameter: ~30 nm, Fluence: 2×10^{15} ions/cm^2) on the micro-channel. As a result, the YBCO layer was normalized leaving a width of 500 nm or 1000 nm as a nano-bridge after FIB process. A SEM image of the typical nano-bridge is shown in Fig.1. The critical current of the 500 nm wide nano-bridge was decreased from 1700 µA to 170 µA at 77 K. The nano-bridge was irradiated by a micro-wave to observe Shapiro steps.

Fig.2 shows the V-I characteristics when the nano-bridge was irradiated by a micro-wave with a frequency f_{RF} of 2 GHz and a power of -13 dBm. A step height of 4.1 µV was observed, consistent with the theoretical value $\Delta V = (h/2e) \times f_{RF}$. This result suggested that the nano-bridge behaved as a Josephson junction. In the future, we plan to apply this fabrication method of the JJ to a low noise SQUID.

[1] K. Hayashi *et al.*, Extended Abstracts of 14th International Symposium on HTSHFF2018, p.p.56-57, 2018.

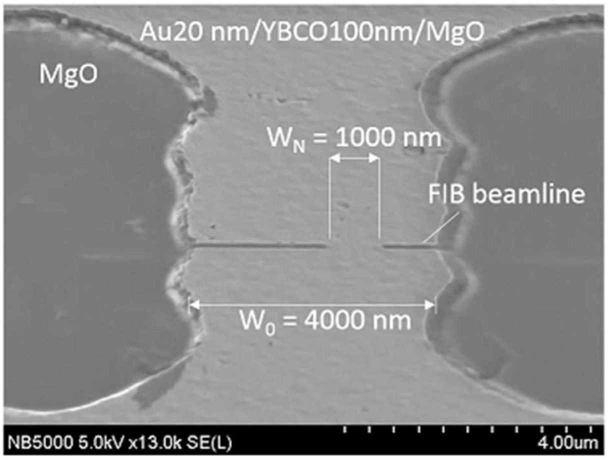

Fig.1 A SEM image of the typical nano-bridge.

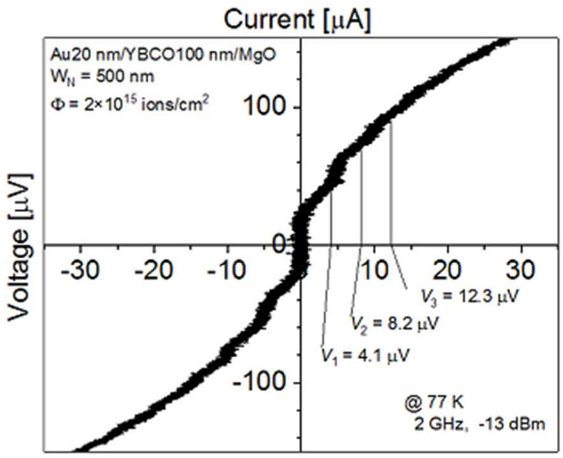

Fig.2 Shapiro-step of the formed nano-bridge.

Keywords: HTS Josephson junction, HTS-SQUID, FIB, Nano-bridge

EDP1-2

Non-contacting ultrasonic guided wave testing for ferromagnetic pipes using HTS-SQUID gradiometer

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In this work, we investigated non-contacting ultrasonic guided wave testing technique based on magnetostriction method and HTS-SQUID. Magnetization method to transceive T(0, 1) mode guided waves on nickel thin pipe was studied by both electromagnetic field simulator and experiments utilizing magnetostriction method and HTS-SQUID gradiometer. In the both studies, a pair of electromagnets sandwiching a Ni pipe was used to magnetize the pipe, while rotating the pipe between the electromagnets. Both studies demonstrated that the magnetization method enabled us to magnetize the Ni pipe roughly uniformly in the whole circumference and also generate T(0, 1) mode guided waves on the pipe. All-round guided wave testing around the magnetized nickel pipe with artificial defect was also conducted using the HTS-SQUID gradiometer and compared with simulation result using ultrasonic wave simulator. The both results agreed well.

Keywords: HTS-SQUID, T(0, 1) mode ultrasonic guided wave, ferromagnetic pipe, magnetostriction

EDP1-3

Performance of Digital SQUID with Sub-Flux Quantum Feedback Resolution fabricated using 10 kA/cm^2 Nb process

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The digital SQUID with Single Flux Quantum (SFQ) feedback operates as a delta-type oversampling A/D converter. Magnetic flux resolution at Nyquist frequency can be improved by taking sub SFQ feedback resolution and large oversampling ratio. Using high critical current density Nb process for fabricating SFQ circuits, we expect more higher operation speed of 13 GHz for the digital SQUID and resulting to higher magnetic flux resolutions. In this study, we report on the expected performance of the digital SQUID magnetometer fabricated using 10 kA/cm^2 Nb process based on CAD layout, with an up/down counter using T^{2}FF cells and parallel SFQ feedback. For the clock frequency of 13 GHz and the Nyquist frequency of 0.793 MHz, the magnetic field noise is lower than 1.5 fT/Hz$^{1/2}$ and the slew rate is exceeded 0.5 T/s. The most promising application of the digital SQUID will be the SQUID transient Electromagnetics (TEM) and these valuses satisfied the requirements.

Acknowledgement

This study has been partially supported by the VLSI Design and Education Center (VDEC) at the University of Tokyo, in collaboration with Cadence Design Systems, Inc. Circuits were fabricated in the clean room for analog-digital superconductivity (CRAVITY) of the National Institute of Advanced Industrial Science and Technology (AIST) with the standard process 2 (STP2) and the high-Jc standard process (HSTP). The AIST-STP2 and HSTP process are based on the Nb circuit fabrication process developed by the International Superconductivity Technology Center (ISTEC).

Keywords: digital SQUID, Single flux quantum circuit, high-Jc Nb process, sub-SFQ feedback

EDP1-4

Implementation of interface circuit for Digital SQUID with sub-Flux Quantum Feedback Resolution

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Digital SQUIDs with the single flux quantum (SFQ) feedback have attracted much attention because of the feasibility of realizing a wide dynamic range and high slew rate for digital magnetometers. In order to realize higher resolution, we have studied a digital SQUID with sub-flux quantum feedback. In this presentation, we will discuss implementation methods for an interface circuit considering circuit size, power consumption and signal processing in order to realize high-resolution and high-speed operation of the digital SQUID magnetometer. Assuming the decimation filter and the up/down counter implemented on a FPGA board, a 1-bit to 16-bit deserializer with output frequency of 500 MHz can be used for interface circuit. This would drastically reduce bias current for the digital SQUID with SFQ feedback operating at 4.2 K.

Acknowledgement

This study has been partially supported by the VLSI Design and Education Center (VDEC) at the University of Tokyo, in collaboration with Cadence Design Systems, Inc. Circuits were fabricated in the clean room for analog-digital superconductivity (CRAVITY) of the National Institute of Advanced Industrial Science and Technology (AIST) with the standard process 2 (STP2) and the high-Jc standard process (HSTP). The AIST-STP2 and HSTP process are based on the Nb circuit fabrication process developed by the International Superconductivity Technology Center (ISTEC).

Keywords: digital SQUID, Single flux quantum (SFQ) circuit, sub-SFQ feedback, digital filter

EDP1-5

Theory for the Response of a Superconducting Kinetic Inductance Detector to an Electromagnetic Wave Packet

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We construct a theory for the response of a superconducting kinetic inductance detector to an electromagnetic (EM) wave packet with a small spatiotemporal extension on the basis of our previous theory for the operation principle of CB-KID [1]. An EM wave packet incident on the superconducting nanowire induces an AC quasi-particle current in the small region where the EM wave packet is irradiated. It is shown that this quasi-particle current generates voltage pulses inductively, which propagate towards both ends of the superconducting nanowire. In the current-biased case the kinetic inductance of the detector is also varied by a hot spot originating from the damping of the quasi-particle current. As a result, a pair of voltage pulses with opposite polarities are generated. The possibility to detect single-photons in this detector is also discussed.

Keywords: kinetic inductance detector, superconducting nanowire

EDP1-6

Reduction of the leakage current for embedded STJ

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Superconducting tunnel junction (STJ) is expected as a next-generation photon detector because of high energy resolution, high counting rate and wide energy range. However, the detection area of single STJ is limited to 0.01 mm^2. One of the solutions is the expansion of the detection area by the array of the STJ. The conventional array format of the STJ also has a problem. Large format arrays will reduce the detection efficiency because of its larger number of the contact wires. To solve this problem, we have proposed an embedded STJ (e-STJ) with through Si via as shown in Fig. 1 (a). The detection efficiency of the e-STJ is not affected by the number of the wires. A simple e-STJ in Fig. 1(b) has shown good I-V characteristic at 4.2 K.
So far, the I-V characteristics of the simple e-STJ showed large leakage current at 0.3 K. In this research, we fabricated a conventional STJ and three types of e-STJ : simple e-STJ and e-STJ where the side surface of the STJ is not in contact with the Si substrate and e-STJ where only the side surface of the base electrode layer is in contact with the Si substrate. Then, the cause of the large leakage current at 0.3 K was investigated. We will present about the fabrication methods and the experimental results.

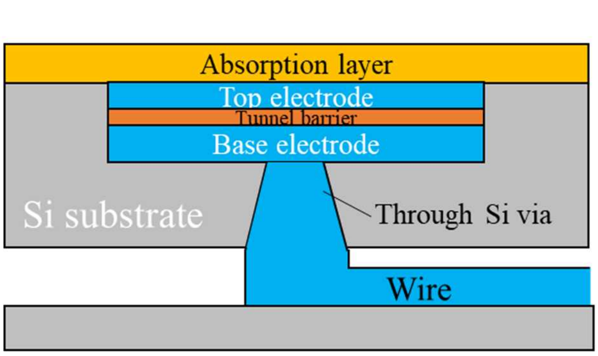

Fig.1 (a) Cross view of e-STJ with through Si via and (b) Cross view of a simple e-STJ

[1] T. Ishizuka et al., The 74th Japan Society of Applied Physics Autumn Meeting, 17p-C10-20 (2013).

EDP1-7

Improvement of spatial resolution using Substrate Absorption type STJ

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An electromagnetic wave having a frequency range from 0.1 to 10 THz is called a THz (terahertz) wave. It is expected to find applications in various fields since it has both radio wave and light wave. We have proposed a substrate absorption type superconducting tunnel junction (STJ) for the THz detector that absorbs the THz waves by the substrate and detects phonons generated in the substrate [1].

The phonon isotropically diffuses in the substrate when the THz waves are illuminated from the opposite side of the STJ across the substrate. It causes the degradation of the spatial resolution. To solve this problem, we have proposed a new THz detector which restricts the phonon diffusion by trenches on the back side of the substrate as shown in Fig 1. The trenches have Al layer which prevents the absorption of the THz wave at the trenches. The formation of the trenches and the deposition of the Al layer do not affect the quality of the STJ [2]. In this research, we demonstrate the phonon restriction using the trenches. The fabrication method and the measured results will be presented.

[1] C. Otani *et al.*, IEEE Trans. Appl. Supercond., Vol. 15, No. 2, pp. 591- 594 (2005).
[2] M. Sone *et al.*, Journal of Physics: Conf. Series, 871, 012069 (2017).

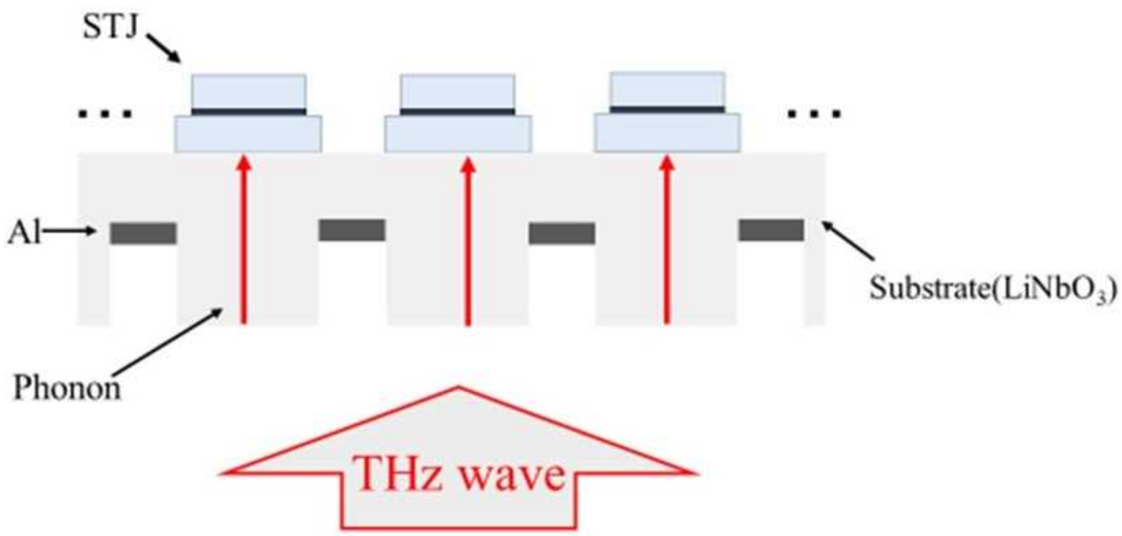

Figure 1. A schematic view of our proposed STJ

Keywords: Superconducting tunnel junctions, Terahertz wave

EDP1-8

Develipment of STJ with large detection area for neutron detector

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Since neutron is permeable to metals and sensitive to light elements such as hydrogen, lithium and boron, it can nondestructively evaluate a bulk texture of metallic materials. Therefore, it has been expected as a new imaging tool in the industrial fields such as automobile industry and construction industry and so on. However, conventional neutron detectors can realize indeed a large sensitive area (> cm^2), but they only have poor spatial resolution of the order of millimeters. On the other hand, superconducting tunnel junctions (STJs) on a single crystal $Li_2B_4O_7$ (LBO) substrate have proposed as a next generation neutron detector because of its high detection efficiency [1]. In case of STJs, a high spatial resolution (< 50 mm) can be possible but it is fairly difficult to satisfy the required sensitive area (10 cm × 10 cm) of the detector for industrial applications, because the area of single STJ is limited to 0.1 mm × 0.1 mm due to its own characteristics and then at least 1 million pixels are necessary to cover the whole required sensitive area, which leads to a quite large heat load to cryostats through 2 million wires. That is not realistic. Therefore, it is necessary to introduce another approach for realizing such a large sensitive area and a high spatial resolution, simultaneously.

In this research, we proposed and fabricated a new substrate absorption type STJ for neutron detection with 1 pixel size of 5 mm × 5 mm, which can be expected to achieve large detection area by using a small number of STJs. Fig. 1 shows our proposed neutron detector. Neutron is irradiated from the substrate. 4 STJs detect phonons generated in the substrate by nuclear reactions of neutron with Li and B. Theoretically, the position of the neutron absorption can be determined precisely from the each pulse height of STJ[2]. The geometric configuration of STJs should be decided to realize a high special resolution as well as a large detection area. In order to determine the above configuration, it is necessary to evaluate the phonon diffusion length in the substrate. As a first step, we have tried STJs on LBO substrates and determined the phonon diffusion length to design the appropriate neutron detector based on STJs. The fabrication method and the evaluation results will be presented.

[1]T.Nakamura et al., Nucl. Instr. and Meth.,m A 529, 402-404 (2004).
[2]H.Kraus et al., Phys Lett. B 231, 195 (1989).

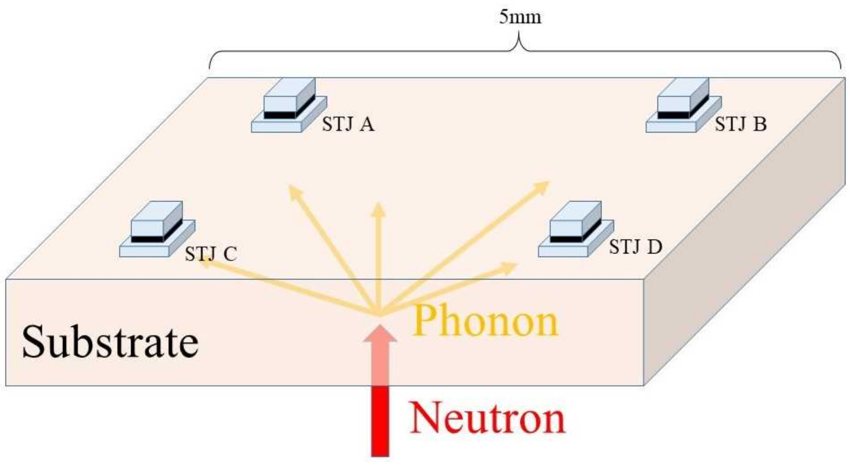

Fig.1 Our proposed neutron detector

Keywords: Superconducting Tunnel Junction, Neutron detector

EDP1-9

Development of Superconducting Single-Photon Detector(SSPD) using molybdenum nitride thin film

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In recent years, there is an increasing demand for high-performance single photon detectors in a wide range of research fields including quantum information communication and quantum optics. Among them, SSPD is a detector having a single photon sensitivity from the ultraviolet region to the mid-infrared region (0.3 µm to 0.5 µm). Furthermore, its excellent performance of high sensitivity and high speed response is expected to be applied to future communications. The superconducting material used greatly affects the detector performance. Currently, niobium nitride (NbN) is often used as a superconducting material for SSPD. However, this study focused on molybdenum nitride (MoN) as a new material. The reason is that MoN has a maximum Tc slightly lower than NbN, but has an electron-lattice relaxation time that is one order of magnitude longer. As a result, a detector with higher internal detection efficiency than that using NbN is obtained. Furthermore, we succeeded in developing the SSPD using MoN with high system detection efficiency by adding a cavity structure and an anti-reflection coating layer.
This work is supported in part by JSPS KAKENHI 18K04255 and by the Cooperative Research Program of “NJRC Mater. & Dev.”.

Keywords: SSPD, MoN

EDP1-10

Improvement of detection efficiency by reducing shunt resistance of SSPDs

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Superconducting single-photon detectors (SSPDs) are based on nano-scaled width strips. This is because it has been empirically known that SSPDs can't detect single-photons with the wider strips. Even if it's possible, the detection efficiency is low. Recently, it has been reported that when a bias current (I_{bias}) is applied close to the depairing current (I_{dep}), it can detect single-photons even with the micron-scaled bridges [1]. Here, we report our results using the micron-scaled bridges as well as the nano-scaled stripes with various shunt resistances (R_{sh}). We found that the single-photon detection is possible even with a micron-scaled bridges by applying R_{sh}, and the system detection efficiency (η_S) of the micron-scaled bridges increases by reducing R_{sh}. We also report the improvement of η_S with nano-scaled strips by further reducing R_{sh}.
This work is supported in part by JSPS KAKENHI 18K04255 and by The Telecommunications Advancement Foundation.
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[1] Y. Korneeva et al. Phys. Rev. Appl. 9, 064037 (2018).

Keywords: SSPD, SNSPD, shunt resistor

EDP1-11

Iridium-based superconducting optical transition edge sensor for single-photon detection

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Optical quantum imaging or information processing is expected to be a new technology to surpass classical noise and resolution limit by fully exploiting the characteristics of non-classical photon sources. In such applications, photon-number resolving capability and high detection efficiency is required for the photon detector. The superconducting transition edge sensor (TES) is the ideal detector for this application, since it has the nearly 100 % detection efficiency with optical cavity structure and the almost linear response to simultaneously absorbed multi-photons. A TES consists of a superconducting thin film which is biased with a constant voltage. When optical photons are absorbed in the film, the photon energies are transformed into a very small increase of temperature in the film and hence the increase of its resistance, causing small current signal which is measurable with superconducting quantum interference device (SQUID).

To enhance the energy resolution of optical TES and hence its photon number resolving capability in near infrared regions, we are developing optical TES based on single-layer iridium film by exploiting its very low transition temperature (140 mK in bulk). We fabricated optical TES with iridium film with the minimum size of 7×7 μm^2. The iridium film was deposited on SiN/Si/SiN substrate, and Nb contact electrodes were formed. We confirmed the response to optical photons in near infrared wavelengths (860 nm and 1310 nm) using iridium optical TESs. The design of optical cavity structure for iridium TES is ongoing, and its performance will be discussed too.

EDP1-12

Kinetic inductance neutron detector operated at near critical temperature

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Superconducting detectors have the advantages of high sensitivity, fast response, and high energy resolution such as a transition edge sensor [1], a superconducting nanowire single-photon detector [2], and a microwave kinetic inductance detector [3]. We first proposed a superconducting neutron detector using an MgB_2 superconductor [4]. Later on, we extended the idea to a current-biased kinetic inductance detector (CB-KID) [5] which consists of two orthogonal superconducting Nb meanderlines with a ^{10}B neutron conversion layer. The CB-KID neutron imager detects high spatial resolution neutrons transmission images by using a delay-line technique. We reported a spatial resolution of 22 μm [6]. The physical characteristics of a CB-KID detector have been studied systematically [7,8]. The theoretical basis of CB-KID was studied by means of the Maxwell-London theory [9]. Prior to this study, we found that the number of events was remarkably increased with increasing the detector temperature until close to the critical temperature T_c [10]. In the present study, we investigated the properties of CB-KID at near T_c.

We observed systematic changes of neutron signals as a function of the detector temperature from 4 K to T_c.

We evaluated the detection efficiency of the CB-KID detector and compared with PHITS Monte Carlo simulations. The simulations modeled the sequential physical processes for 10B(n,α)7Li reactions and energy deposition by particles within CB-KID, including neutrons, ^{4}He particles, ^{7}Li particles, photon and electron transport [11].

This work was partially supported by a Grant-in-Aid from the Japan Society for the Promotion of Science (JSPS) (No. 16H02450).

[1] K. D. Irwin, Appl. Phys. Lett. **66** (1995) 1998. [2] G. N. Gol'tsman *et al.,* Appl. Phys. Lett. **79** (2001) 705. [3] J. Zmuidzinas, Annu. Rev. Cond. Matter Phys. **3** (2012) 169. [4] T. Ishida *et al.*, J. Low Temp Phys **151** (2008) 1074. [5] S. Miyajima *et al.*, Nucl. Instrum. Meth. Phys. Res. A. **842** (2008) 71. [6] H. Shishido *et al.*, Phys. Rev. Appl. **10** (2018) 044044. [7] Y. Miki *et al.*, J. Phys. Conf. Ser. **1054** (2018) 012054. [8] Y. Iizawa *et al.,* J. Phys. Conf. Ser. **1054** (2018) 012056. [9] T. Koyama and T. Ishida, J. Phys.: Conf. Series, **1054** (2018) 012055. [10] T. D. Vu *et al.,* J. Phys. Conf. Series, (2019) in press. [11] A. Malins *et al.,* submitted to.

Keywords: Superconducting detector, neutron detector, CB-KID, pulsed neutron

EDP1-13

Design and fabrication of Programmable Josephson Voltage Standard Circuit for 100 V ac-voltage standard

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The Programmable Voltage Standard (PJVS) Circuit having the output voltage of 32 V has been designed and fabricated for ac voltage standard. While our PJVS chip for primary dc voltage standard at NMIJ has the maximum output voltage of about 16 V, the voltage for commercial power in Japan is 100 Vrms and 141 Vpp.
We plan to generate 141 Vpp by combining 5 chips of 32 V PJVS circuit.
Thus, twice higher integration density of Josephson junction and the uniform power distribution for them are necessary to generate such high out put voltage with practical operating margin.

To integrate a million of Josephson junctions on the 15 mm x 15 mm chip, the junction size has been changed from 3.4 um x 3.4 um to 1.2 um x 4.0 um.
Although vertically stacked double barrier Josephson junctions are used to integrate such large number of Josephson junctions, the poor uniformity of the critical current between the upper and lower junction significantly decreased the Shapiro step height. We have found that the grain sizes of the barrier layer of TiN film for the upper junction is larger than that for the lower junction. The surface flatness of the NbN film nearly proportional to the thickness.

We experimentally confirmed that the critical current of the NbN/TiN/NbN Josephson junction depends on the thickness of the base electrode.
This suggests that the difference of the critical current between the upper and lower junction caused from the difference of the crystalline nature such as grain size of the barrier TiN. The lower Josephson junction has smaller critical current and the upper Josephson junction has higher one. And this provides a clue to improve the uniformity of the critical currents between the lower and upper junction, which may significantly increase integration density for Josephson junctions.

Keywords: ac voltage standard, double barrier Josephson junction, NbN, grain size

EDP1-14

Optical Ppulse-Driven Integrated Quantum Voltage Noise Source for Johnson Noise Thermometer

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We have developed an integrated quantum voltage noise source (IQVNS) as a reference signal source for the Johnson noise thermometer. The Josephson effect ensures that the power spectral density of the output signal of IQVNS is described by a combination of Planck's constant h, elementary electric charge e, clock frequency of IQVNS f_c, and numerical coefficient. One of the features of IQVNS is that it has a random number generator on the superconducting device. Therefore, it is not necessary for IQVNS to use a pulse pattern generator that can be an unwanted electrical noise source for the Johnson noise thermometer. However, IQVNS is coupled with a microwave oscillator for supplying a clock signal using a metallic coaxial cable, and there is still a possibility of picking up unwanted noise signals.
In this study, we tried to eliminate the metallic wiring to IQVNS completely by using optical pulse as clock signal to IQVNS. The light pulse transmitted through the optical fiber is converted into a current pulse by a photodiode mounted on the IQVNS probe head. Using this optical pulse driven IQVNS, the thermal noise of the resistor placed at the triple point of water was measured, and the temperature of the triple point of water was derived.

Keywords: Johnson noise thermometry, quantum voltage noise source, rapid single flux quantum circuit, Optical pulse

EDP1-15

Investigation of Thermal Resistance in a Cryopackage for Programmable Josephson Voltage Standard Device

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Since 2016, a programmable Josephson voltage standard (PJVS) system based on a liquid-helium-free cryocooler has been in practical use at NMIJ. In this system, however, there is a problem that the chip temperature slightly rises with the output voltage level, narrowing the bias-current margin for the PJVS device operation.

In our previous study, it was found that many voids existed in the solder layer used in our cryopackage and might be one of the possible causes for the temperature rise in the PJVS chip [1]. We investigated the void-ratio dependence of the thermal resistance both in the numerical simulations and the experimental measurements, and showed that the thermal resistance rapidly increases with the void ratio of greater than 80 %.

In this study, we are investigating more details of the void-ratio dependence and other measurements for the thermal resistance of our cryopackage for the PJVS device. Up to now, we found that the obtained data for the void-ratio dependence cannot be fitted by the simulated dependence, indicating the existence of a large residual thermal resistance of the order of 1 K/W or more (Fig. 1). We are now trying to reveal the cause for such the large thermal resistance.

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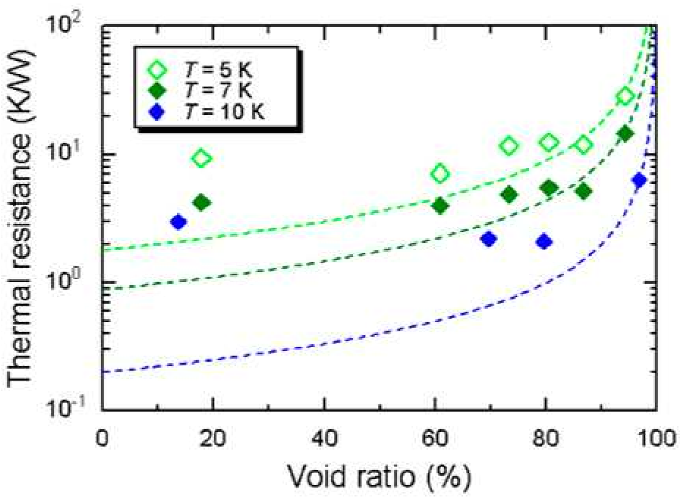

Fig. 1 Measured thermal resistances of the cryopackage for the PJVS device versus the void ratio in the solder layer. The broken lines indicate the fitting lines based on a simulation.

Keywords: Cryopackage, Josephson voltage standard, PJVS, Thermal resistance

EDP1-16

Estimation of Electricity Storage Density of Compact SMESs Composed of Si-wafer Stacks Loaded with Superconducting Thin Film Coils in Spiral Trenches under the Constraint of Critical Magnetic Flux Density

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We have been developing a superconducting thin film coil in a spiral trench on a Si wafer [1]. Having completed in fabrication of a NbN superconducting thin film coil on 76.2 mm-diameter Si wafer [2], we have replaced NbN with $YBa_2Cu_3O_{7-\delta}$[3]. The high critical current density of $YBa_2Cu_3O_{7-\delta}$ is possible to impose high magnetic flux density as well as electromagnetic hoop stress on the coil. In the constraint of the upper limit of critical magnetic flux density of 20 T for $YBa_2Cu_3O_{7-\delta}$ and hoop stress of one third of 4 GPa for Si wafer, the design of the spiral coil must be optimized. For this purpose, estimation of magnetic field generated by the superconducting current in the spiral coil was performed based on Biot-Savart low [4]. The spiral coil was approximated to be multiple loops with the same current in a 101.6 mm Si wafer and 600 wafers were supposed to be stacked. The sum of the generated magnetic fields was obtained at the innermost loop in the trench to obtain the maximum magnetic flux density and hoop stress in the 600 wafers. A typical result in Figure 1 shows the maximum electricity storage density of 13.8 Wh/*l* appeared at the innermost coil radius about 45.4 mm. The hoop stresses were well below the one third of 4 GPa.

[1] Sugimoto N et al., 2017, Supercond. Sci. Technol. 30, 015014
[2] Suzuki N et al., **2017,** IOP Conf. Series: Journal of Physics: Conf. Series 897, 012019
[3] Ichiki Y et al., 2018, IOP Conf. Series: Journal of Physics: Conf. Series 1054, 012065
[4] Ichiki Y et al., 2018, EDP1-17 in ISS2018, Tsukuba, Japan.

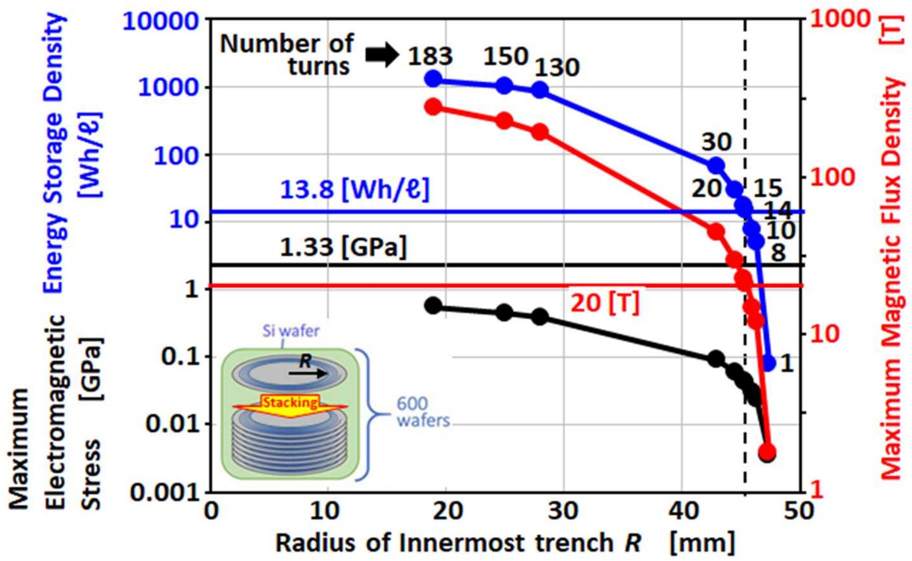

Fig. 1 A typical result of estimations of energy storage, maximum magnetic flux density and maximum electromagnetic stress as a function of the radius of the innermost trench radius.

Keywords: Electricity storage density, SMES, Si wafer, Critical magnetic field

EDP1-17

Evaluation of surface morphology of Pb-In alloy films for superconducting bumps utilized in a three-dimensional packaging structure of X-ray detector

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Superconducting tunnel junction (STJ) is one of the candidates as an x-ray detector because of high energy resolution. In order to obtain a two-dimensional image of detected x-ray, it is necessary to array a large number of STJs on a chip. However, the integration density of STJs is limited by the wiring area when the STJ-array is enlarged. To solve this problem, we have proposed an “embedded STJ” (e-STJ) with a three-dimensional packaging structure [1].

A Pb-In alloy bump is one candidate for using the superconducting connections in the three-dimensional packaging structure. We found some roughness on the bump surface in the previous research. In order to realize multi-pin connection technology, it is necessary to flatten bump surface to reduce bonding force. Thus, we investigated the surface of superconducting Pb-In alloy bumps to clarify the effect of surface morphology on the superconducting Flip-chip Bonding (FCB) connection.

A Pb and In films were deposited on an oxidized Si wafer by evaporation sequentially to make Pb-In stacking films with various mass concentration of In in Pb. Total thickness of the stacking film was made to be 4 µm. The calculated average roughness (Ra) and the maximum height (Rz) of Pb-In stacking film surfaces were measured at room temperature after annealing time of over 100 hours for alloying. Ra and Rz of the Pb-In stacking films are plotted as a function of the mass concentration of In in Pb in Fig. (a) and (b), respectively. The roughness of Pb-In stacking film surfaces increased after alloying than the pure Pb and In films as shown in the figures. The details will be presented.

[1] T. Ishizuka et al., 74th the Japan Society of Applied Physics, 17 p-C10-20 (2013).

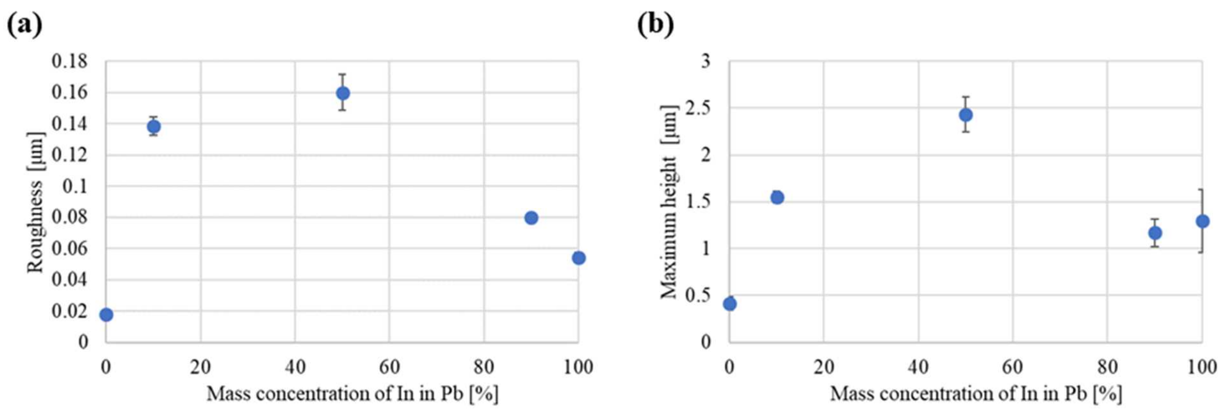

Fig.(a) Ra of Pb-In stacking film surface (b) Rz of Pb-In stacking film surface

Keywords: Superconducting tunnel junctions, Flip-chip bonding, Bump

EDP1-18

Micro-Fabrication of NdFeAs(O,F) Thin Films and Evaluation of the Transport Properties for Future Particle-Detector Application

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Photon and ion detectors based on superconducting nanowires have been attracting substantial attention because they are superior to conventional detectors in terms of high-speed operation, high sensitivity, and low noise characteristics. To realize these excellent performance, the superconductor has to be fabricated into narrow wires with a width of about 300 nm for an ion detector and 100 nm or less for a photon detector. Detectors based on conventional BCS superconductors such as Nb and NbN have been already extensively studied [1]. However, the operating temperature is low due to their low transition temperature (T_c). As for the high-T_c superconductors, there are several attempts to fabricate detectors from MgB_2 and copper-oxides [2-4], yet they suffer from a notable degradation of the superconducting characteristics when the wires become narrow. On the other hand, little is known about the performance of nanowires based on iron-based superconductors. In this work, we fabricated narrow wires from thin films of NdFeAs(O,F), which has the highest T_c (= 56 K) among iron-based superconductors, and evaluated their transport properties.

High-quality single crystalline thin films of NdFeAs(O,F) were grown on MgO substrates by a molecular beam epitaxy method [5]. The film was patterned into a two-island structure connected by a narrow wire (40-nm-thick x 0.35-µm-wide x 10-µm-long) using i-line lithography and Ar ion milling. The as-grown film exhibited a zero T_c of 40 K, whereas the fabricated wire still kept T_c = 38 K as displayed in Fig. (a). The critical current density (J_c) was 1.3 MA/cm^2 at 4 K as shown in Fig. (b). These results indicate that degradation of the superconducting properties of NdFeAs(O,F) due to nano-processing might not be as serious as other high-T_c superconductors.

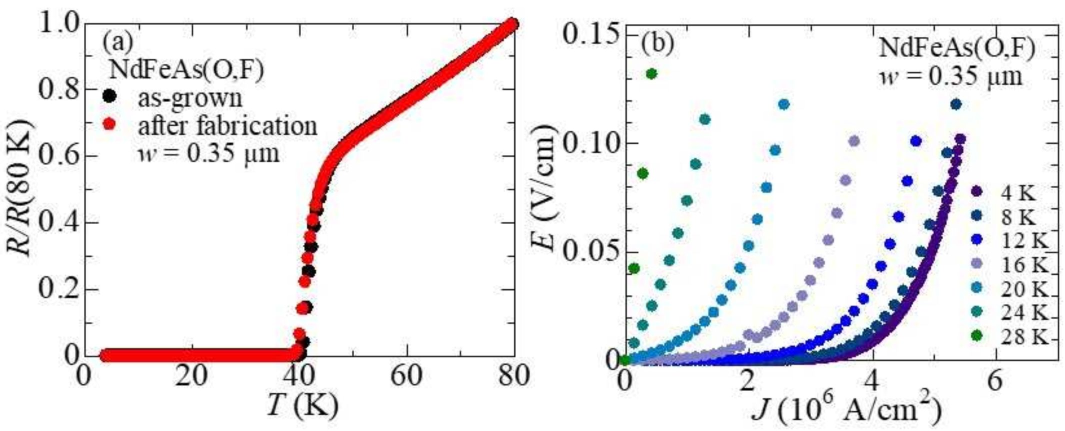

Fig. (a) Temperature dependence of the resistivity, and **(b)** current density (*J*) dependence of the electric field (*E*) of the fabricated wire. The data of the as-grown film are also shown in (a).

[1] C. M. Natarajan *et al.*, *Supercond. Sci. Technol.* **25**, 063001 (2012). [2] H. Shibata *et al.*, *Appl. Phys. Lett.* **97**, 212504 (2010). [3] N. Zen *et al.*, *Appl. Phys. Lett.* **106**, 222601 (2015). [4] R. Arpaia *et al.*, *Phys. Rev. B* **96**, 064525 (2017). [5] T. Kawaguchi *et al.*, *Appl. Phys. Lett.* **97**, 042509 (2010). T. Kawaguchi *et al.*, *Appl. Phys. Express.* **4**, 083102 (2011).

Keywords: Micro-fabrication, Epitaxial thin film, Iron-based superconductor, Particle detector

EDP1-19

Prototyping new type $Bi_2Sr_2CaCu_2O_{8+x}$ devices using a consumer-oriented inkjet printer

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We are attempting to prepare planar type intrinsic Josephson oscillator devices. These new type devices can be prepared by a combination of orientation control technique of $Bi_2Sr_2CaCu_2O_{8+x}$ (Bi2212) thin film by solution method and printing method using inkjet printer. In order to prepare these planar type devices, it is necessary to form a current path parallel to the substrate, so that the *c*-axis of Bi2212 is required to be parallel to the substrate.

We have prepared (010) (or (100)) oriented Bi2212 thin films by metal-organic decomposition (MOD) method which is one kind of solution method [1]. When using vicinal (100) substrates, the Bi2212 (020) (or (200)) peak appeared clearly in the X-ray diffraction patterns. From the scanning electron microscope (SEM) image, it was found that elongated plate-like crystal grains of Bi2212 were grown. From the viewpoint of lattice matching, this elongated crystal grain is considered to be (010) (or (100)) oriented Bi2212 crystal grains.

Since we have succeeded in forming crystal grains that the *c*-axis is parallel to the substrate, we are now attempting on prototyping device using a consumer-oriented inkjet printer. The main component of the solvent in the Bi2212 raw material solution is xylene. Some inkjet printer components have low resistance to xylene, such as the packing of the printer head. Therefore, the Bi2212 raw material solution cannot be used by filling in the ink cartridge. In this report, microfabrication is performed by lithography and chemical etching. The printing method using an inkjet printer is applied to the lithography process. The device fabrication procedure is as follows.

(1) Using a spin coater, the raw material solution is applied to the entire surface of the substrate.
(2) The substrate coated with the solution is heat-treated using an electric furnace.
(3) Photoresist is applied to the sample in a desired pattern using an inkjet printer.
(4) Etching with acid is performed.
(5) The photoresist is removed.

We are using an EPSON inkjet printer capable of CD label printing. The samples will be evaluated based on SEM images and electrical characteristics. Details will be discussed in the presentation.

[1] Yamada Y et al., Journal of Physics: Conference Series (to be published)

Acknowledgments: This work was supported by JSPS KAKENHI Grant Number JP17K06377.

Keywords: BSCCO, metal-organic decomposition method, orientation control, printing method

EDP1-20

Design of High Quality Factor RF Coil Using Superconducting Bulk

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It is main problem that improvement of the power transfer efficiency of Wireless Power Transfer (WPT) system. The power transfer efficiency depends on the quality factors of the transmitting and receiving coils. However, it is difficult to improve the quality factors of them due to the limitation of conductivity of the normal conductor such as copper used for the coils. To overcome this problem, we designed a high-quality factor coil using the superconducting bulk. Figure 1(a) shows the structure of superconducting bulk simulated with 3D electromagnetic simulator. Figure 1(b) shows the quality factor of the coil versus the gap between lines with each line width. The resonant frequency is 40 MHz. The quality factor of the superconducting bulk coil is 30 times higher than that of the copper coil when gap between lines and line width are 1.5 mm and 1.5 mm.

We also simulated the coil quality factor with dielectric supporting material because the superconducting bulk coil can't maintain the spiral coil structure without it. We will show the detail of the preliminary experiments using superconducting bulk coil at the conference.

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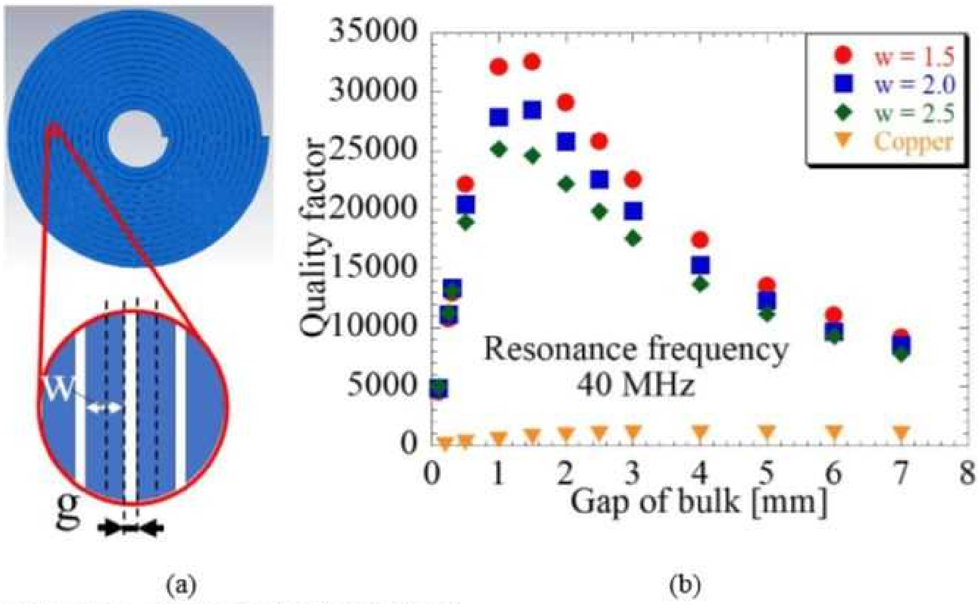

Figure 1. (a) Structure of superconducting bulk coil,
(b) Quality factor dependences on gap between lines with each line width

Keywords: Wireless Power Transfer (WPT), Superconducting bulk coil, RF coil, Quality factor

EDP1-21

Development of Superconducting Filter for Deep Space Exploration Ground Station Receiving System

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We have developed a superconducting filter for deep space exploration receiving system. JAXA (Japan Aerospace eXploration Agency) is currently developing new antenna for deep space exploration. New antenna requires high performance filter which has compact size, low insertion loss and high selectivity. In this study, we developed a superconducting filter which satisfied these requirements and design specification accurately. The filter was fabricated using $YBa_2Cu_3O_7$ thin film on r-Al_2O_3 substrate. An r-Al_2O_3 substrate has strong mechanical strength, high chemical stability and low cost. However, there is the problem that it is difficult to agree well with the simulated and measured result, because of dielectric anisotropy, so that there is no practical superconducting filter using r-Al_2O_3 substrate. Therefore, we proposed the design method which consider dielectric anisotropy of the substrate. In addition, to improve the degradation of the frequency response due to the discrepancy of the substrate thickness and dielectric constant difference between design and fabrication we used dielectric rods. Figure 1 shows the simulated and measured frequency responses of the filter. The measured results agree well with the simulated ones. We used the dielectric rods to reduce the return loss. Finally, our filter was adopted for the receiving system of the JAXA Ground Station for Deep Space Exploration and Telecommunication (GREAT).

Acknowledgment
This work was executed in the development of low noise amplifier equipment for JAXA GREAT project.
We would like to thank the member of GREAT project team.