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LOWER CRITICAL FIELD MEASUREMENT SYSTEM OF THIN FILM SUPERCONDUCTOR

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Abstract

The superconducting thin film is one of the key technology to increase the RF performance of SRF cavities. The lower critical field H_{c1}, which is one of the important physical parameters characterizing a superconducting material, will be enhanced by coating thin film superconductor such as NbN to the bulk Nb. We developed the H_{c1} measurement system using the third harmonic voltage response of applied AC magnetic field from the solenoid coil. In order to control the temperature of the superconducting sample, we installed heaters and thermal anchors which could be moved by the vertical mover. By this temperature control the sample state can be easily transferred from Meissner state to mixed state. The result of temperature control and the first measurement result of bulk Nb sample are discussed. In addition, we report the measurement result of the critical temperature T_c of NbN-SiO_2 multilayer thin film sample.

INDRODUCTION

S-I-S (Superconductor-Insulator-Superconductor) thin film multilayer structure has been proposed by Gurevich and Kubo to enhance the effective H_c [1,2]. Antoine has measured effective H_{c1} with third harmonic voltage method and shows the possibility of H_{c1} increase [3]. The third harmonic measurement system was also constructed by Iwashita, Katayama, and Tongu in Kyoto University [4,5]. Another measurement system is necessary for parameter search of multilayer thin film structure. KEK also set up the third harmonic measurement system. In this paper, detail of measurement system and the first measurement result of bulk Nb sample are reported. On the other hand, T_c and Residual Resistivity Ratio (RRR) measurement system, which consists of a small-sized cryostat and a GM refrigerator to cool down samples without using liquid Helium (LHe), has already been constructed in KEK [6]. Since 200 nm NbN thin film and 30 nm SiO_2 thin film were sputtered on a bulk Nb sample by ULVAC, Inc., the T_c measurement result of the sample is also reported.

MEASUREMENT SETUP

Cryostats

This experiment is carried out by cooling the sample with LHe stored in the bottom of cryostat. LHe is supplied from Helium dewar using transfer tube and the liquid level of LHe is monitored by the LHe level monitor. This cryostat is equipped with two GM refrigerators to reduce consumption of liquid Helium and is precooled by these GM refrigerators before LHe transfer. vacuum pumps for thermal insulation vacuum tank and for air substitution to He gas are installed. The heater for evaporating LHe is installed at the bottom inside the cryostat (see Fig. 1).

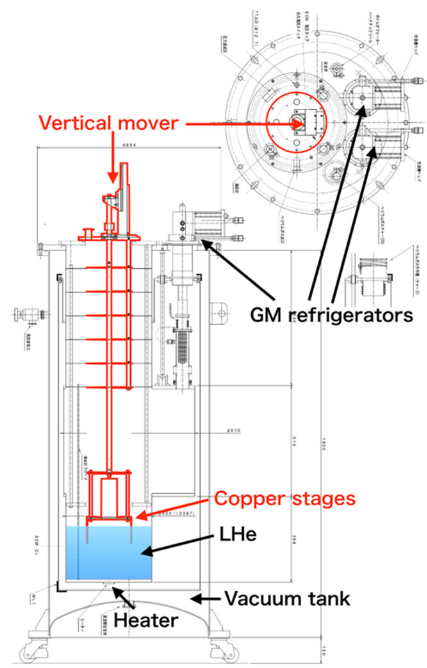

Figure 1: Drawing of the cryostat. Red highlights are the measuring equipment newly fabricated for the third harmonic measurement.

Sample Stage and Coil Stage

Figure 2 shows the copper stage for third harmonic measurement, which has two copper stages for the sample and the exciting coil. The sample stage has two copper anchors which are equipped with heater for increase sample temperature. The coil stage has two copper anchors whose bottom ends are immersed in LHe to decrease the sample temperature. By controlling the whole stage up and down by the vertical mover which movable scope is 100 mm, it is possible to control the degree of immersion of the copper anchors in to the LHe. One of the tempera-

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ture sensors is directly contact with backside of the sample and the remaining three temperature sensors could monitor the temperature of any part of the stage. The sample put between the two stages. The gap distance of 1.5 mm between sample surface and the coil stage is kept by SiN balls embedded in the coil stage (see Fig. 3). The 1 kHz magnetic field from the coil is applied to the sample surface.

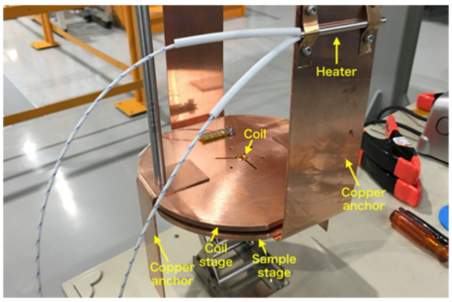

Figure 2: The copper stage setup for third harmonic measurement.

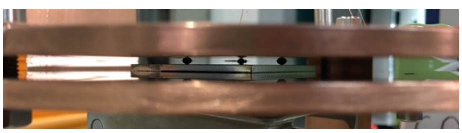

Figure 3: The gap distance of 1.5 mm between sample surface and coil stage is kept by SiN balls embedded in the coil stage.

Circuit

Figure 4 shows the block diagram of the measurement circuit. The signal generator (S.G.) generates 1 kHz sinusoidal waveform with amplitude 1 V_{pp}. The 1 kHz signal passes through 1kHz band-pass-filter (BPF) with bandwidth of +/- 20 Hz. Another 1 kHz signal passes through the three-multiplier and phase shifter, then fed into the mixer. The amplified 1 kHz signal is applied to the coil in the cryostat to generate magnetic field on the sample. The amplified 1 kHz signal is picked up and fed into 3 kHz BPF with bandwidth of +/- 30 Hz. The detected 3 kHz signal is amplified with gain, 10, 100, and 1000, then fed into the mixer. The mixer detects their phase. The phase signal is fed into the 1 Hz low-pass-filter (LPF). The output of the 1Hz LPF is DC signal and is the third harmonic components in the coil voltage.

Data Acquisition System

The output of the 1Hz LPF is digitised by the 24 bits ADC and transmitted to the host computer by Raspberry Pi computer. The oscilloscope monitors 3 kHz SIG MON, 1 kHz REF MON, PD MON, and DC MON. Their waveforms are recorded by the host computer. Four temperature sensor and voltmeter that monitors the amplified 1 kHz signal are recorded by the host computer. The waveforms are recorded once in 10 seconds and the other data are recorded once in 1 second.

THERMAL SIMULATION

To confirm the temperature controllability of the sample by the heaters, the thermal simulation in transient state has been performed with CST (see Fig. 5). Material properties such as thermal conduction and specific heat were implemented in the solver. To reproduce the experiment conditions, the He gas is filled in the space, the initial temperature of assembly is 4.2 K, and the LHe temperature is fixed at 4.2 K. The simulation was repeated for various power of the heaters. Then the temperature rise of the sample was confirmed (see Fig. 6).

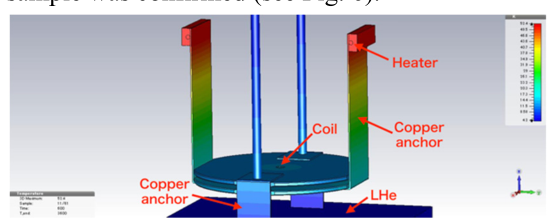

Figure 5: The result of thermal simulation.

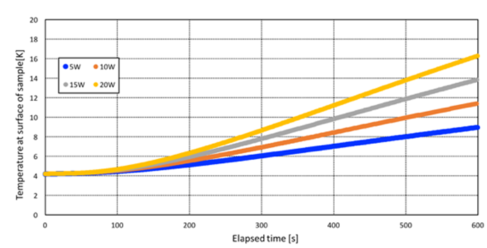

Figure 6: The plot of sample surface temperature change with various heaters power.

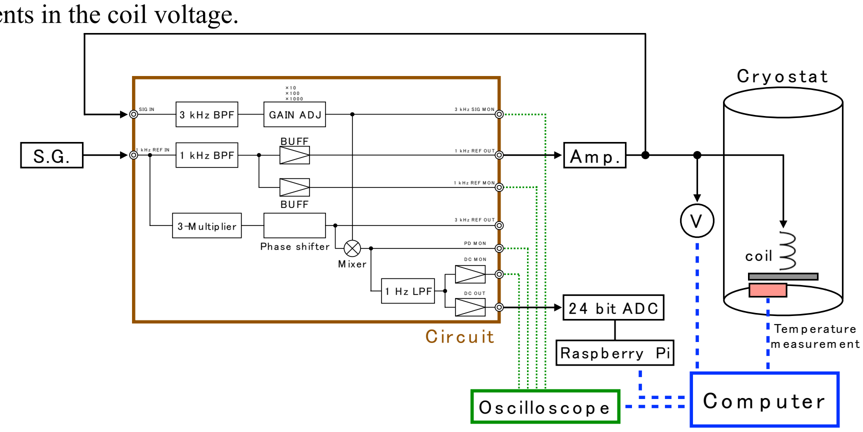

Figure 4: The block diagram of the measurement circuit.

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EXPERIMENT

LHe transfer was performed after precooled cryostat by GM refrigerators. After LHe level of 25 % was filled and temperature of copper stage was reached to 4.2 K, third harmonic measurement was started. The 1 kHz magnetic field was applied by the coil before rising of the temperature. The third harmonic components were measured during the rising of the temperature of the sample stage by the heaters. The powers of heaters were optimized, so that the temperature variation speed was 0.1 K/min. In this experiment, amplitude of applied 1 kHz signal of coil was varied from 0.2 V_{pp} to 0.5 V_{pp}.

RESULT

The third harmonic components had typically 655 μV DC offset and 20 μV_{pp} fluctuation. The DC offset had a drift of 10 μV_{pp} in 2.5 hours. The significant change of the third harmonic components at around T_c of Nb was not detected (see Fig. 7). The possible reasons of no detection are the insufficient applied magnetic field, invasion of electric noise. The reason of drift can be considered as thermal sensitivity of the circuit. The Improvement of the detection circuit should be considered.

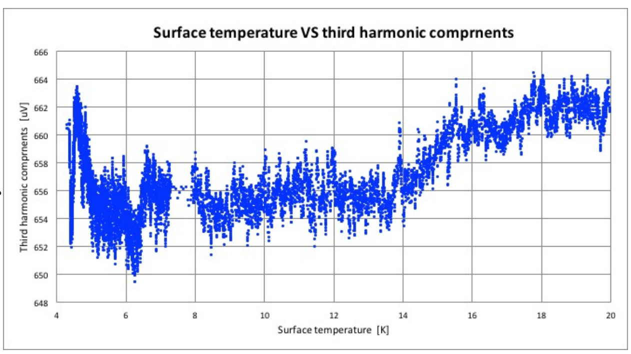

Figure 7: The result of the third harmonic measurement.

T_C MEASURMENT

The temperature dependence of the resistance of the NbN-SiO_2 multilayer thin film sample made by ULVAC, Inc. was tested. This sample was obtained by magnetron sputtering 200 nm NbN and 30 nm SiO_2 on a bulk Nb (sample No.180409-1-A) [7]. Figure 8 shows the measurement result of four current conditions. The peaks at around the T_c of NbN were observed. This temperature dependence behaves differently from the result of NbN thin film on silicon wafer which has no peak and smooth change of resistance at T_c. The reason of peaks can be related to current path at the boundary between thin film and bulk Nb. To investigate this phenomenon in detail, we will make the various sample, such as NbN on bulk Nb, and retest them. The T_c of 13.8 +/- 0.1 K is obtained by the usual T_c definition ignoring the peaks.

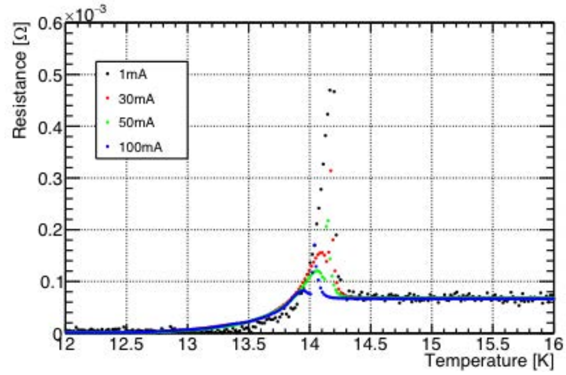

Figure 8: The T_c measurement result of NbN-SiO_2 multilayer thin film sample. The T_c of 13.8 +/- 0.1 is obtained.

CONCULUSION

The third harmonic measurement system is constructed and the first cooldown test using Nb sample is performed. The temperature variation speed of 0.1 K/min was obtained. However, the significant change of the third harmonic components at around T_c of Nb was not detected. The improvement of the detection circuit should be considered.

The temperature dependence of the resistance of the NbN-SiO_2 multilayer thin film on bulk Nb was tested. The peaks at around the T_c of NbN were observed. The T_c of 13.8 +/- 0.1 K is obtained by the usual T_c definition ignoring the peaks. Further measurement to understand the peak will be done.

ACKNOWLEDGEMENT

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REFERENCES

[1] A. Gurevich, "Enhancement of rf breakdown field of superconductors by multilayer coating", Appl. Phys. Lett. 88, 012511 (2006).

[2] T. Kubo et al., "Radio-frequency electromagnetic field and vortex penetration in multi-layered super-conductors", Appl. Phys. Lett. 104, 032603 (2014).

[3] C. Z. Antoine, M. Aburas, A. Four, et al., "Progress on characterization and optimization of multilayers", SRF2017 Proceedings, Lanzhou, China.

[4] Y. Iwashita, H. Tongu, H. Hayano, et al., "Measurement of thin film coating on superconductors", Proceedings of IPAC2017 Proceedings, Copenhagen, Denmark.

[5] Y. Iwashita, H. Tongu, H. Hayano, et al., "R&D of Thin Film Coating on Superconductors", SRF2017 Proceedings, Lanzhou, China.

[6] T. Saeki, H. Hayano, T. Kubo, et al., "Construction of Measurement System for Superconducting Characteristics on Thin-film Samples at KEK", IPAC2016 Proceedings, Busan, Korea.

[7] R. Ito, T. Nagata, et al., "Development of Coating Technique for Superconducting Multilayered Structure", IPAC2018 Proceedings, Vancouver, Canada.