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LOWER CRITICAL FIELD MEASUREMENT OF THIN FILM SUPERCONDUCTOR

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Abstract

The superconducting thin film is the promising technology to increase the 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 Nb with thin film superconductor such as NbN. To measure the H_{c1}, we developed the measurement system using the third harmonic response of applied AC magnetic field from solenoid coil. In order to control the temperature of the sample, we installed heaters and thermal anchors which could be moved by the motor. By this temperature control the sample state can be easily transited from the Meissner state to the mixed state. By raising the temperature of the sample with applying AC magnetic field, H_{c1} and transition temperature, which is point of transition from the Meissner state to the mixed state, can be determined at when the third harmonic response appears in the voltage of solenoid coil. By repeating the measurement for various applied AC magnetic field, the H_{c1} vs temperature can be plotted. In this report, measurement result of the bulk Nb sample and NbN-SiO_2 multilayer thin film sample are presented.

INTRODUCTION

S-I-S (Superconductor-Insulator-Superconductor) thin film multilayer structure has been proposed by Gurevich to enhance the effective H_{c1}, and Kubo made advanced theoretical study [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, and improvement of effective H_{c1} has been confirmed by the measurement of NbN-SiO_2 multilayer thin film sample which has been produced by ULVAC, inc. [4-6]. In order to increase H_{c1} measurement capability in our research group and to measure a large number of samples, KEK also set up the third harmonic measurement system. In this report, development status of the measurement system and the measurement result of bulk Nb sample and NbN-SiO_2 multilayer thin film sample are reported.

MEASUREMENT SYSTEM

This experiment is carried out by cooling the sample with liquid helium (LHe) stored in the bottom of cryostat, and LHe is supplied from Helium dewar using transfer tube. The 1kHz AC magnetic field is applied to the superconducting sample using solenoid coil, and the third harmonic components (3 kHz) induced in the solenoid coil when the magnetic field penetrate into the sample is detected. At this time, from the magnetic field strength applied to the sample and the temperature of the sample, the effective H_{c1} of the sample at that temperature (transition temperature) is measured. In addition, by repeating the measurement with various applied magnetic fields, the temperature dependence of H_{c1} is measured.

Sample Stage and Coil Stage

The measurement setup consists of the two copper stages for the sample and the exciting coil. The sample stage has two copper thermal anchors which are equipped with heater for increase sample temperature. The coil stage has also two copper thermal anchors whose bottom ends are immersed in LHe to decrease the sample temperature. By controlling the whole stage position up and down by the vertical mover which movable range is 100 mm, it is possible to control the immersion depth of the copper thermal anchors into the LHe. One of the temperature 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 0.85 mm between sample surface and the coil stage is kept by three small SiN balls embedded in the coil stage (see Figs. 1 and 2).

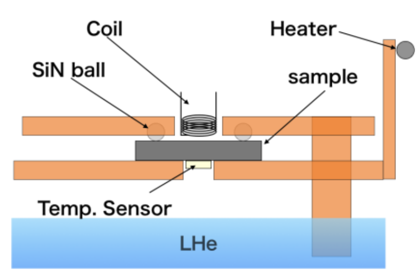

Figure 1: Cross-sectional Schematic of setup.

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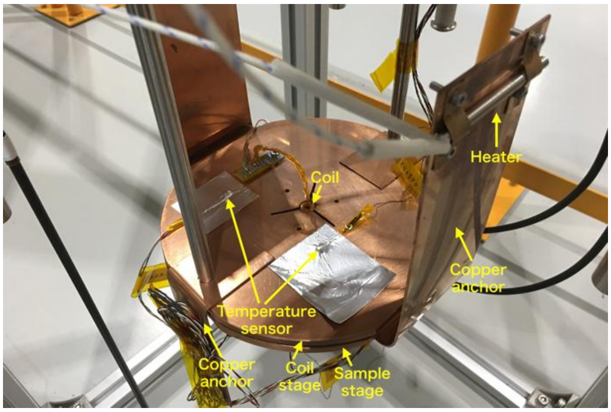

Figure 2: The picture of the copper stage setup for third harmonic measurement.

Circuit

Figure 3 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 1 kHz 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.

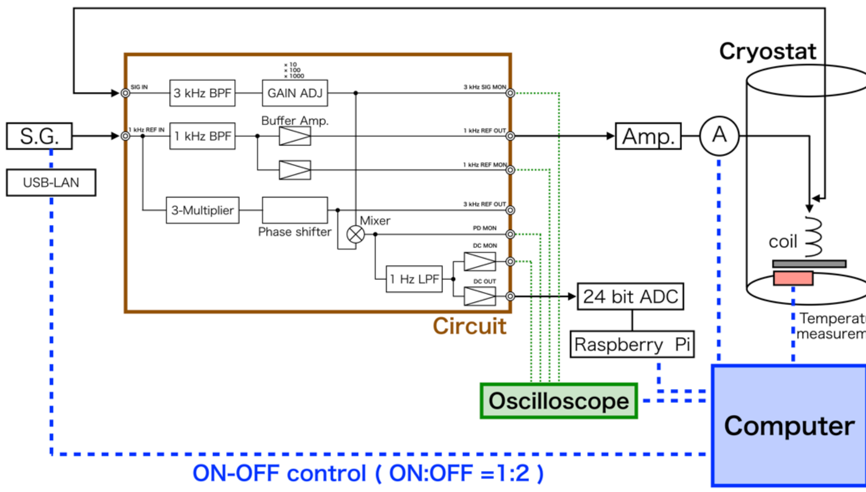

Figure 3: The block diagram of the measurement circuit.

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 ammeter that monitors the amplified 1 kHz signal are recorded by the host computer.

H_{c1} Definition

The magnetic field strength from the coil at the moment when the third harmonic signal is significantly changed is defined as the H_{c1} and the temperature at that moment is defined as transition temperature. In order to know the applied magnetic field strength on the sample from the coil, calibration was performed using the measurement result of bulk Nb sample assuming that following function $H_{c1}(t)$ is the temperature dependence of H_{c1} of bulk Nb:

$$H_{c1}(t) = 180 \times \left\{1 - (\frac{t}{T_c})^2\right\} \tag{1}$$

where T_c which is the critical temperature of the Nb is free parameter.

MASUREMENT RESULTS

The third harmonic components have the offset proportional to the current in the coil (blue line) (see Fig. 4). Since there is a negative offset of third harmonic components at the point where the current is zero, the offset of third harmonic components was corrected against the negative offset when the magnetic field strength from the coil was calculated (red line).

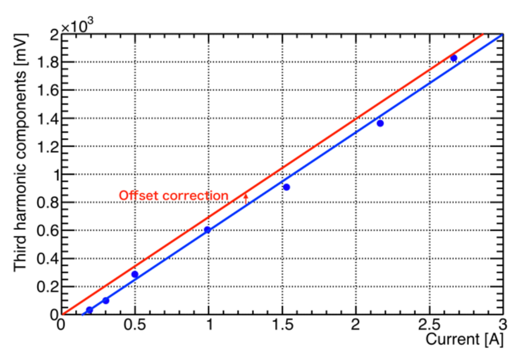

Figure 4: The third harmonic components vs current in the coil at gain 10.

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Result of Bulk Nb

Figure 5 shows the typical measurement result of bulk Nb. The vertical axis shows the third harmonic components detected by the 24 bits ADC and the horizontal axis shows the bulk Nb sample temperature. The significant change of the third harmonic components at around T_c of Nb was detected. The intersection point of the two linear fitting curves (red lines) was defined as transition point.

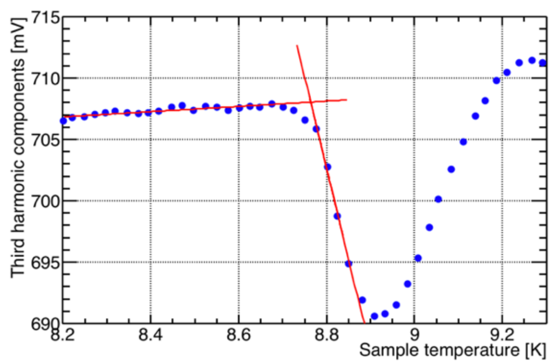

Figure 5: Third harmonic components vs sample temperature at 1 A coil current.

Figure 6 shows the amplitude of the third harmonic component as a function of the transition points obtained in the various applied AC magnetic field. The temperature dependence of H_{c1} of bulk Nb was obtained by relating the amplitude of the third harmonic component of Fig. 6 to the magnetic field using Eq. (1).

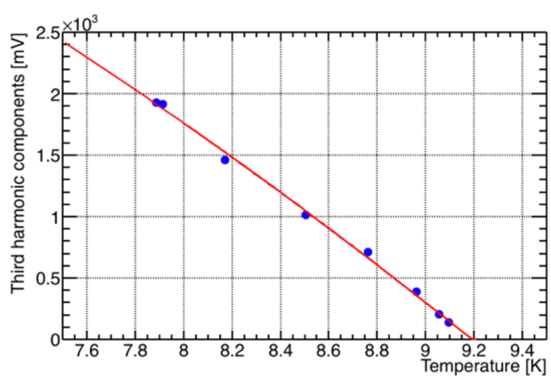

Figure 6: Plot of the transition points in case of the bulk Nb.

Result of NbN-SiO$_2$ Multilayer Thin Film

Figure 7 shows the measurement result of NbN-SiO$_2$ multilayer thin film sample. The red line is the Eq. (1) which is used for the calibration of the bulk Nb result. The blue points show calibrated result of bulk Nb. The green dashed line is fitting curve obtained by two triangle points (transition point of NbN-SiO$_2$ multilayer thin film sample). The third harmonic response of NbN-SiO$_2$ multilayer thin film sample was detected with only two points at high temperature region at which bulk Nb substrate is normal conducting state (> 9.2 K). At low temperature region at which both bulk Nb substrate and NbN thin film are superconducting state (< 9.2 K), the transition point could not be estimated due to large fluctuation of third harmonic components.

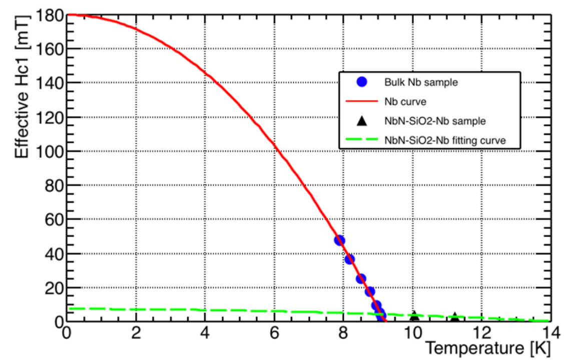

Figure 7: Critical magnetic field vs temperature.

IMPROVEMENTS

After these experiment, we found that the ammeter caused high third harmonic components offset. The offset was suppressed by two orders by replacement of the ammeter. In order to apply strong magnetic field to the sample, the distance between the coil and the sample surface was changed 0.85 mm to 0.45 mm. But fluctuation of third harmonic components became large, distance was restored back.

CONCULUSION

The third harmonic measurement system is constructed and commissioned in KEK. The bulk Nb sample was measured and calibration of magnetic field strength was performed. The measurement of NbN-SiO$_2$ multilayer thin film sample succeeded in high temperature region. In order to suppress the fluctuation of third harmonic components and make strong magnetic field, the improvements are ongoing.

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