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R&D OF THIN FILM COATING ON SUPERCONDUCTORS

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Abstract

A measurement system for superconducting thin film coating is constructed, in order to investigate performances of superconducting thin film coatings. It is based on the third order harmonic measurement, which measure the nonlinear behaviour of an inductance of a coil put on a superconducting film around the critical magnetic field B_{c1}. Samples are cooled down through a copper plate tab whose bottom end is immersed in liquid Helium. The tab is fixed under a sample stage and the temperature of the stage is controlled by a heater on the stage. The temperature is monitored by Cernox sensors. We could obtain a preliminary results using the system

INTRODUCTION

Multilayer thin film coating of superconducting materials is a promising technology to enhance performance of superconducting cavities. Until recently, principal parameters to achieve the sufficient performance had not been known, such as the thickness of each layer. We proposed a method to deduce a set of the parameters to exhibit a good performance [1,2] (see Figure 1). In order to verify the scheme, we prepared the third order harmonic measurement system at Kyoto University[3].

MEASUREMENT METHOD

In order to evaluate the performance of the thin film coated material, we selected the third order harmonic detection method [4,5,6]. Figure 2 shows the schematic diagram of the prepared system, where the FPGA controls the generation of a sinusoidal wave and the amplified current excites the coil to generate the AC magnetic field. The FPGA is controlled by a PC through USB. The magnetic field is applied to superconducting samples and the excitation current and the self-induced voltage of the coil are monitored. The third harmonic component is measured through a high pass filter (HPF) cutting the fundamental frequency component. Figure 3 shows the measurement system for the third order harmonic component. When the applied magnetic field is less than B_{c1} of the superconducting film material, the Meissner effect completely repels the magnetic flux and the magnetic field flux does not penetrate the superconducting films (see Fig. 4). The self-induced voltage of the coil is proportional to the time derivative of the coil current as long as the Meissner effect is maintained. This linear behavior is

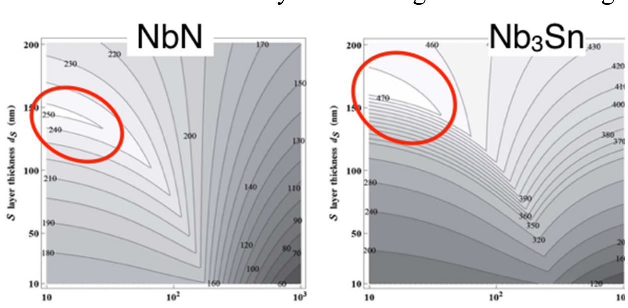

Figure 1: Parameters for enhancing a gradient limit by the multilayer thin film coating on superconducting bulk surface. A thin S layer pushes up B_v, but it cannot protect the bulk SC from an applied field if d_S << London depth. Not only B_v, but also the shielded magnetic field on the bulk SC must be considered simultaneously.

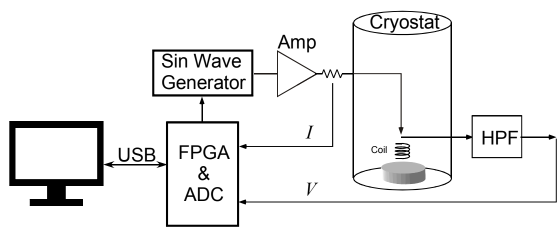

Figure 2: Block diagram of the measurement system of the third order harmonic component.

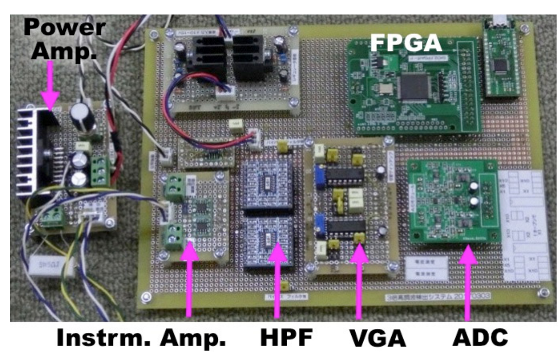

Figure 3: Circuits of the measurement system for the third order harmonic component.

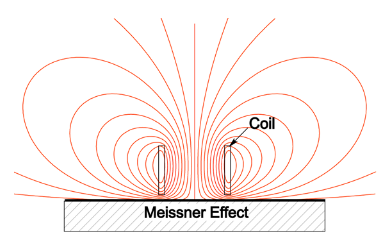

Figure 4: Meissner effect completely repels the magnetic flux from the superconductor film and the magnetic stored energy around the coil is reduced compared with the coil without the film.

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broken when the magnetic field level exceeds B_{c1}, and the self-induced voltage of the coil becomes distorted. Then the third order harmonic appears in the voltage signal. When the temperature is higher than the critical temperature, this nonlinear behavior disappears hence the third harmonic component vanishes (see Fig. 5). The tiny third harmonic component is picked up among the large fundamental component by the HPF (8th order Butterworth). In order to reduce the heat generated by the coil current, the AC excitation current is applied intermittently with duty factor of less than 10%. The frequency of around 5kHz is used in this system and the ADC has 20-Bit resolution at 250ksps. The obtained data is Fourier transformed in the PC and analyzed.

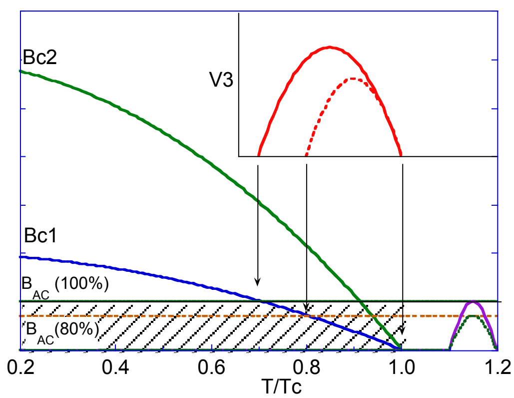

Figure 5: The third order harmonic component appears when the magnetic field level B_{AC} crosses the B_{c1} at the temperature. The magnetic vortexes start to penetrate the film and the inductance of the coil changes when the external AC magnetic field level exceeds the B_{c1}.

THE CRYOGENIC STAGE

The cryogenic environment is prepared to have temperature sensors, liquid helium quantity monitors, and a magnetic shield [3]. Figure 6 shows the cryogenic stage for the third order harmonic measurement configuration, which has two copper cryogenic stage plates for the samples and the exciting coil. Both the plates have copper tabs whose bottom ends are immersed in the liquid helium independently.

The temperature of the sample stage is controlled by a heater installed on the plate and the heat flow of thermal conduction through the copper tab. Since a sample is put on the bottom stage plate, the sample temperature should follow the bottom plate (see Fig. 7). One Cernox sensor directly touches the sample from the backside to measure the sample temperature. The temperatures of both plates are also measured by Cernox sensors.

The coil is embedded in the upper plate whose bottom surface coincides with the bottom surface of the upper plate. Since the wire of the excitation coil is normal conducting copper, it generates heat when it excites the magnetic field. Although the coil is cooled through the upper plate, the heat transfer from the coil to the sample should be reduced as small as possible.

There is a gap between the sample and the coil, which is kept by ceramic balls embedded in the upper plate. The ceramic balls protruding 0.2mm from the plate surface make the gap distance 0.2 mm (see Fig. 8). Although the thermal conduction between the two plates should be limited through the ceramic balls, the temperature of the coil plate goes up when the sample stage is heated up with the heater. This thermal conduction may be caused by the existence of He gas between the two stages. We are planning to improve the thermal insulation between the two plates by inserting insulating sheets.

The stage can be pulled up to adjust the depth of the

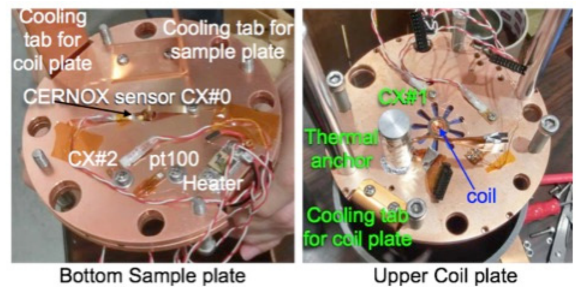

Figure 6: Stage setup. The temperature sensor directly contacts to the sample from the backside. Tabs are immersed into Liquid Helium to be cool down. Heater raises the temperature.

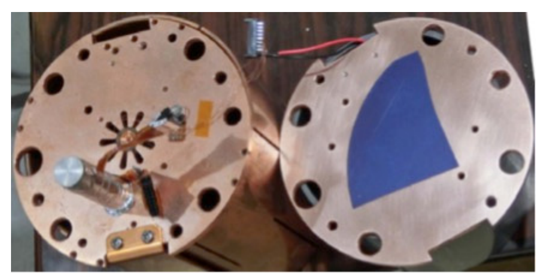

Figure 7: Cryogenic stage. Right: 100nm NbN thin film on Si Wafer is put on the sample stage plate. Left: coil stage plate.

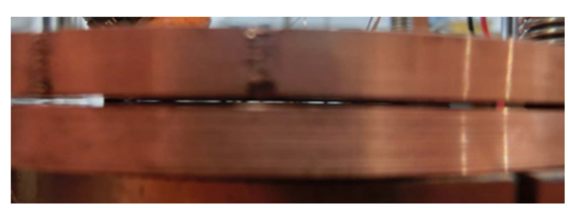

Figure 8: The sample put between the two plates. The gap between the coil plate and the sample put on the bottom plate is seen. The gap distance of 0.2 mm is kept by ceramic balls embedded in the upper plate, which protrude 0.2mm from the surface.

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immersion to the liquid helium. All the devices except heater are wired for the four terminal method through the thermal anchor.

PRELIMINARY RESULT

The sample shown in Fig. 7 is 100nm NbN thin film made by ULVAC, Inc., which is magnetron sputtered on a Si Wafer. The resistances measured at three currents and three different places from the sample wafer are shown in Fig. 9. The deviations of the transition temperatures were about 0.1 K among the points, although the sample wafer was not the best one, which was selected just for the test of this system.

The preliminary result of the third order harmonic measurement is shown in Fig. 10. They were measured with five different coil excitation levels. Although the calibration between the voltages shown in the figure and the magnetic field is not performed yet, the magnetic field amplitude should be proportional to the voltage shown.

The third order harmonic components were measured during the cooling down of the sample stage plate. They were not observed beyond the transition temperature ~ 11.5K. They started to appear at the transition temperature at any excitation levels, as expected. Then they showed the peaks at different temperatures. They return to zero, when the amplitudes of the AC magnetic field become less than the critical field level, which is a function of the temperature. Each intersection point of the third harmonic component curve and the x-axis should indicate the B_{c1} at the temperature.

SUMMARY

The measurement setup for the third harmonic component is ready. It includes the electric circuits, cryogenic system, and magnetic field shields. The last one, magnetic field shields may have to be added further after the measurement starts up. We are planning to reduce the heat transfer from the upper coil stage plate to the bottom sample stage. We tested the system using a 100-nm thick NbN thin foil sample that was magnetron sputtered on a Si wafer. While the sample was an early stage premature product, it allowed for us to observe the peculiar appearance of the third harmonic component. Then we conclude that the system is working while some adjustments would be needed such as gains. After the proper calibration experiments, we will be able to evaluate many samples, which are expected come soon. In order to improve the measurement efficiency, we will improve the data acquisition system to automate it.

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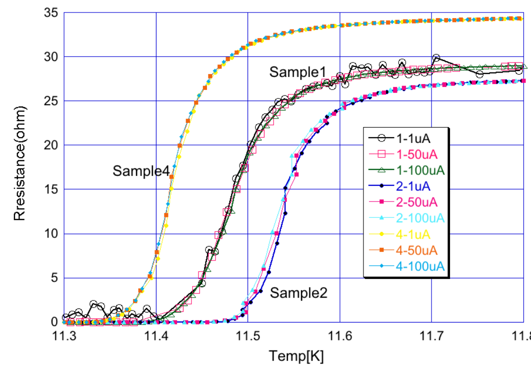

Figure 9: The resistances measured at three currents and three different places from the sample wafer. The deviations of the transition temperatures were about 0.1 K among the points, although the sample wafer was not the best one, which was selected just for the test of this system.

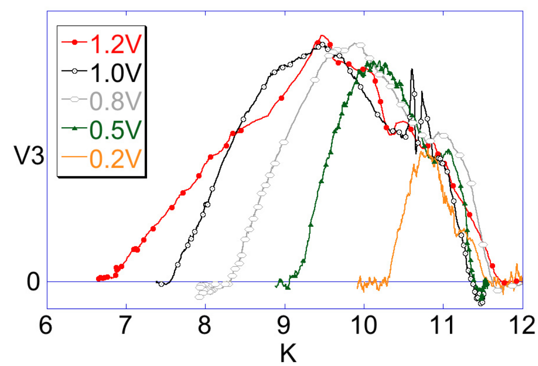

Figure 10: The preliminary result of the third order harmonic measurement.

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