CONSTRUCTION OF MEASUREMENT SYSTEM FOR SUPERCONDUCTING CHARACTERISTICS ON THIN-FILM SAMPLES AT KEK*

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Abstract

We set up a measurement system for Superconducting (SC) characteristics on thin-film samples at KEK. The system includes small-sized and middle-sized cryostats, where critical temperature, critical magnetic field, Residual Resistivity Ratio (RRR), Superconducting RF (SRF) resistivity can be measured on thin-film samples. A small-sized cryostat has a compact refrigerator to cool down samples for the measurements of critical temperature and RRR. On the other hand, we can cool down various setups with a middle-sized cryostat by using liquid helium (He). A SC sample is set into the bore-center of superconducting solenoid magnet and the magnetization of sample is measured with external magnetic field around the critical temperature. In another setup, a thin-film sample is set with a small coil and the third harmonic measurement is done on the sample. Finally, a thin-film sample is set into a mushroom-shaped cavity and the SRF characteristics of the sample can be measured. This article presents the details of the system and some measurements of samples by the system.

INTRODUCTION

The thin-film coating technology of inner surface of the Superconducting RF (SRF) cavity has a big impact on the future accelerator projects and also on the industrialization of compact accelerators. We are interested in the technology and firstly considered the theory of the thin-film effect on the Superconducting (SC) characteristics [1]. In the next step, we started constructing the experimental setups to test the thin-film SC samples to verify our considerations on the thin-film effects. This article reports the small-sized experimental setup with a compact refrigerator tube for quick measurements of SC samples and larger experimental setups with a middle-sized cryostat for detailed tests of SC samples.

SMALL-SIZED CRYOSTAT WITH A COMPACT REFRIGERATOR TUBE

Because the operation of liquid He to cool down Superconducting (SC) samples is sometimes complicated and safety issues should be considered for operators, a system with a compact all-in-one refrigerator tube is convenient for quick experiments. We made a compact experimental setup with a small-sized cryostat and a compact refrigerator tube to measure SC characteristics of samples.

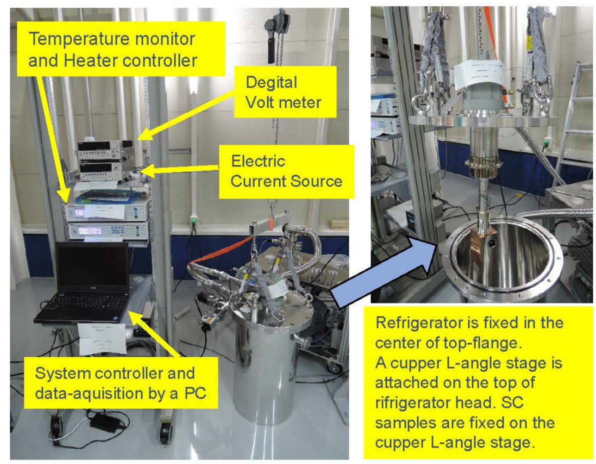

Figure 1: Experimental setup with a small-sized cryostat and a compact refrigerator tube to measure SC characteristics of samples. Left-had side: a picture of the system. Right-hand side: a picture of a compact refrigerator tube on the top flange of the small-sized cryostat.

Figure 2: Left-hand side: a picture of He compressor for the refrigerator tube. Right-had side: a picture of cooling-water chiller for the He compressor.

Figure 1 shows pictures of the experimental setup. The top flange of small-sized cryostat has a compact refrigerator tube and the head of the tube is cooled down to low temperature. A cupper L-angle stage is fixed onto the head of the tube and the stage is covered by a cupper box to insulate thermal radiation from inner wall of cryostat. Several SC samples can be fixed on the stage to be cooled down. Handling of the system is easy because no need of

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complicated liquid-He operation. The refrigerator starts cooling samples just by switching on the refrigerator tube. The liquid He is supplied to the refrigerator tube by a compact He compressor. Pictures of the He compressor and the water-chiller of the He compressor are shown in Fig. 2. After low-temperature experiments, the warming-up operation of the samples is done without complicated operation of He-gas recovery, where you can just switch off the refrigerator and the samples are warmed up naturally. The SC samples on the L-angle cupper stage are connected to an electric current source and a digital voltage meter outside the small-sized cryostat as shown in Fig. 1. The temperature of SC samples and the stage is measured by temperature sensors. The history-log of 8 temperature-sensors are recorded in the system. As a heater is set on the L-angle stage, the temperature of SC samples can be controlled by a heater-controller. Data acquisition and the temperature controlling can be done by a Personal Computer (PC) as shown in Fig. 1.

Figure 3 shows some examples of resistance measurements for a Nb sample. The dimension of the Nb sample is 2.8 x 5 x 150 (mm^3). The electric current of 50 mA is applied between the both ends of the sample, and the voltage is measured. As shown in the Fig. 3, the critical temperature of the Nb sample is clearly measured to be 9.56 K. If you measure the resistance at the room temperature, you can estimate the Residual Resistivity Ratio (RRR) of the sample. If a thin-film sample has an insulator layer below the first outer SC layer, the resistance and RRR of the first outer SC layer can be measured in the same method.

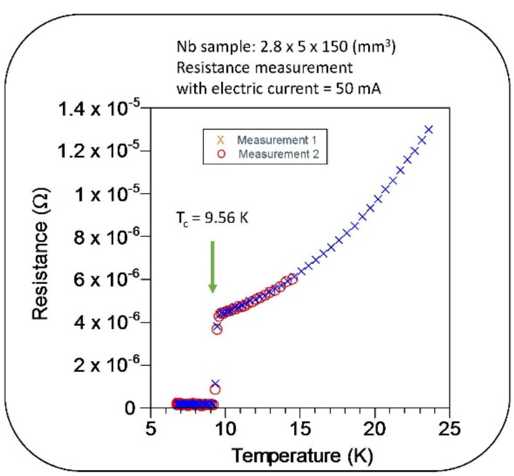

Figure 3: Some examples of resistance measurements for a Nb sample.

MIDDLE-SIZED CRYOSTAT WITH TWO COMPACT REFRIGERATORS

The system with a small-sized cryostat and a compact refrigerator tube is convenient for quick experiments, but there are some limitations of cooling capacity and dimension of experimental setups. In order to perform experiments of more complicated and larger setups, we made the system with a middle-sized cryostat with two refrigerator tubes to keep cooling down the liquid He inside the cryostat.

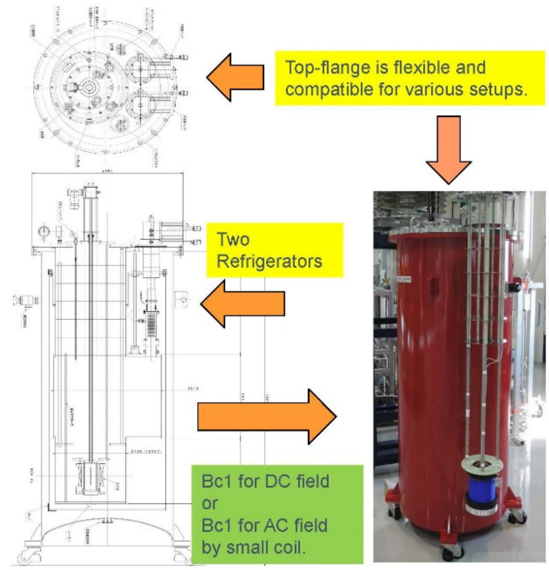

Figure 4: An example of experimental setup to measure the critical magnetic field (Bc1) of SC samples with the middle-sized cryostat. The operation of Liquid He is necessary for experiments by the system.

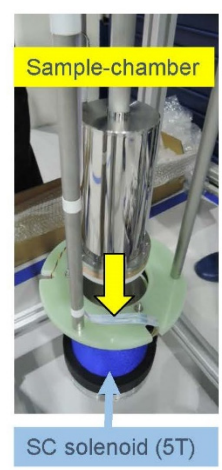

Figure 5: A picture of sample-chamber and SC solenoid (5T) before insertion of sample-chamber into the bore-center of the solenoid.

Figure 4 shows the drawings and a picture of example setup to measure the critical magnetic field (Bc1) of SC samples by the system with a middle-sized cryostat. The top flange of the cryostat is flexible and compatible to several setups. In the example setup in Fig. 4, the top flange is supporting a sample-chamber and Superconducting (SC) solenoid which creates DC magnetic field of 5 T at maximum surrounding the sample-chamber. Figure 5 shows a picture of the sample-chamber and the SC solenoid before inserting the sample-chamber into the bore-center of solenoid. SC samples can be set inside the sample-chamber and the sample-chamber is set at the bore-center of the solenoid, and the sample-chamber and solenoid can be set in the cryostat. Liquid He is poured into the cryostat to cool down the system. If the critical temperature Tc is measured with changing the external magnetic field of samples, you can measure the dependence of the Tc on the external magnetic field for the samples. Magnetization measurement of sample is also possible. The middle-sized cryostat has two compact refrigerators to keep cooling the He gas inside the cryostat. The refrigerators can liquefy the He gas and the temperature can be reached below 4 K. The achievable lowest temperature depends on the setup inserted in the cryostat which introduces the thermal path. When warming up the samples, the operation of He-gas recovery is necessary.

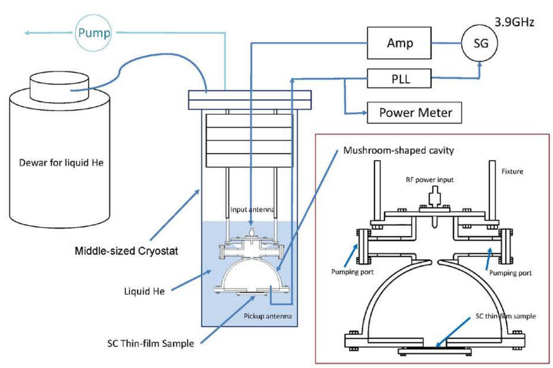

Figure 6: Experimental setup to measure the RF critical magnetic field (Bc1) of thin-film SC sample.

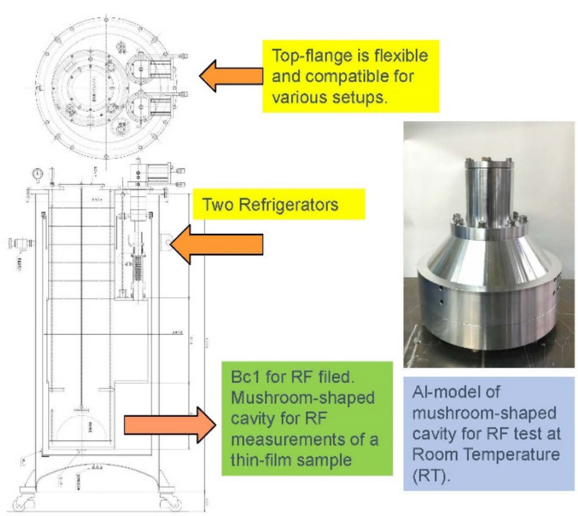

Figure 7: Left-hand side: Drawings of experimental setup to measure the RF critical magnetic field (Bc1) of thin-film SC sample by the middle-sized cryostat. Right-had side: Aluminium model of mushroom-shaped cavity for the RF test at the room temperature.

If you insert a larger sample-chamber into the cryostat with a thin-film SC sample and a small coil on the sample, you can measure the SC characteristics of the thin-film sample by the method of third harmonics analysis [2, 3] in AC magnetic field around kHz region. In this experiment, you do not need the SC solenoid and you have more space for the sample-chamber. We are trying to make the small coil and the experimental setup for the third harmonic analysis.

Finally, the SC characteristics of thin-film sample can be measured by a Nb mushroom-shaped cavity where the sample is set inside the cavity and RF filed at the frequency of 3.9 GHz is applied to the cavity and on the sample. A schematic illustration of the experimental setup for the measurement is shown in Fig. 6. A Nb mushroom-shaped cavity is set in the middle-sized cryostat and liquid He is filled inside the cryostat. The RF power at the frequency of 3.9 GHz is supplied into the cavity where the thin-film SC sample is set on the inside bottom of the cavity. The temperature of the sample is measured outer bottom of the cavity to estimate the power consumption on the sample. Figure 7 (left-hand side) shows the drawings of the experimental setup for the middle-sized cryostat. The top flange is optimized for this measurement. Figure 7 (right-hand side) shows the aluminium model of mushroom-shaped cavity for the RF test at the room temperature. We are going to fabricate the Nb mushroom-shaped cavity based on the test results from the aluminium model.

SUMMARY

A small-sized cryostat with a compact refrigerator is successfully installed and commissioned at KEK. The system with a small cryostat is cooled down without complicated liquid-He operation and is used for the measurements of critical temperature Tc and RRR of Superconducting (SC) samples.

A middle-sized cryostat with two compact refrigerators are designed and fabricated. The experimental setup in the cryostat is cooled down by liquid He. The middle-sized cryostat is used for the measurements of SC critical magnetic field (Bc1) for thin-film samples by DC, AC, and RF fields. DC field is created by SC solenoid magnet (5T). AC field is created by a small coil for the third harmonic analysis. And RF field (3.9 GHz) is created by a Nb mushroom-shaped cavity. The Al-model of mushroom-shaped cavity for 3.9-GHz RF field is fabricated for RF test at the room temperature.

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