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Fabrication of RRR Measuring System for Disseminating IEC International Standard

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IEC국제규격을 보급하기 위한 RRR측정장치 제작

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Abstract

In order to disseminate the IEC international standard of RRR measurement of Cu/Nb-Ti composite superconductors, a measuring system was developed at KRISS. The system consisted of helium reservoir, base plate, thermometer, voltmeter and current source. The helium reservoir and base plate provided a stable temperature of a range from 4.2 K to 300 K and the voltmeter measured several order of μV on specimen for obtaining RRR of the Cu/Nb-Ti composite superconductor. Three specimens of the Cu/Nb-Ti composite superconductors were measured using this system for characterizing their RRR. The resistance-temperature curves of the specimens showed 10^{-6} to 10^{-5} Ohms near transition temperature and 10^{-4} to 10^{-3} Ohms at 293 K. The RRR values of the specimens were 145, 71 and 140, respectively.

Keywords : RRR, Nb-Ti composite superconductor, Cu matrix, Standardization.

I. Introduction

The Cu/Nb-Ti composite superconductors consist of Nb-Ti multifilaments and Cu or Cu-Ni matrices and are widely used for electric power application or MRI magnet. The matrix materials work as an electrical shunt and disperse a heat generated in the Nb-Ti multifilaments to the surrounding coolant when the superconductors are quenched(1). To improve the performance of matrix material as a stabilizer, their resistance at cryogenic temperature should be as low as possible.

The RRR(Residual Resistance Ratio) is defined as a ratio of the resistance of the superconductor at room temperature to that just above the superconducting transition. One of the international organization, IEC(International Electrotechnical Commission), published an international standard concerning the test method of RRR of Cu/Nb-Ti composite superconductors in 2001. The standard named "IEC international standard 61788-4" describes preparation of specimen, apparatus, measurement procedure and correction of bending strain besides of the definition of RRR(2).

Recently, many research institutes and universities have developed superconducting system for

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application of superconductors in Korea. In order to disseminate the new IEC international standard 61788-4, a measurement system was fabricated and test method for RRR measurement of Cu/Nb-Ti composite superconductor was studied at KRISS.

II. Definition of RRR

The IEC 61788-4 international standard defines the RRR of Cu/Nb-Ti composite superconductors as a ratio of the resistance at room temperature(R_1) to that just above the superconducting transition(R_2)

$$RRR = \frac{R_1}{R_2} \qquad (1)$$

The value of R_1 is measured at 20 °C(293 K). If resistance of the specimen is measured at 0°C $\leq T_m < 35$ °C, the value shall be corrected to the value on 20°C. A test current with 0.1 ~ 1 A/mm^2 of current density should be applied for measuring the R_1.

The value of R_2 at cryogenic temperature is obtained from analyzing a resistance-temperature (R-T) curve measured near transition as shown in Fig. 1.

For obtaining the R_2, a line (a) is drawn at region where the voltage sharply increases. Another line (b) is also drawn at region where the temperature increase but the resistance remains almost the same. The resistance at the intersection of these two lines, A, is defined as R_2 just above the superconducting transition. To measure R_2, a test current with the current density in the range of 0.1 ~ 10 A/mm^2 based on the total cross-sectional area should be applied to the specimen. In order to keep the signal to noise ratio high enough, the resulting voltage near transition should exceed about 10 μV.

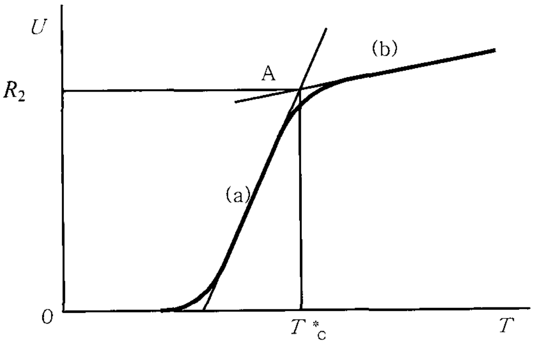

Fig. 1. R-T curve for defining R_2.

III. Fabrication of Measurement System

To satisfy requirement of the IEC 61788-4 international standard, we designed and fabricated a RRR measurement system as shown in Fig. 2. The system consisted of helium reservoir, base plate for mounting a linear specimen, thermometer, voltmeter and stable current source.

The helium reservior(MVE Cryogenics E4) holds 10 liter liquid helium for about 7 hours. The current source(HP 6642 A) supplies a constant current of 0.05 A to 5 A with the 0.18%-accuracy and 0.01%-stability. The voltmeter(Keithley 181) measures the produced voltage from the specimen with the 0.01%-accuracy and 10 nV-sensitivity. The thermometer consists of a temperature indicator(Lakeshore 218) and two sensors (Lakeshore DT470 SD and CU). Measurement range of the thermometer is 1.4 K to 475 K with accuracy of ±0.5 K at 4.2 K, ±0.15 K at 77 K and 300 K, respectively.

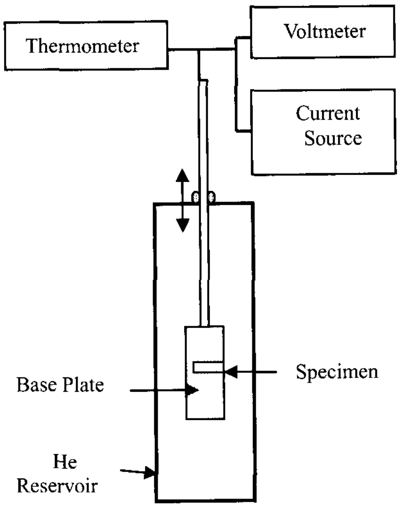

Fig. 2. Experimental setup for measurements of RRR.

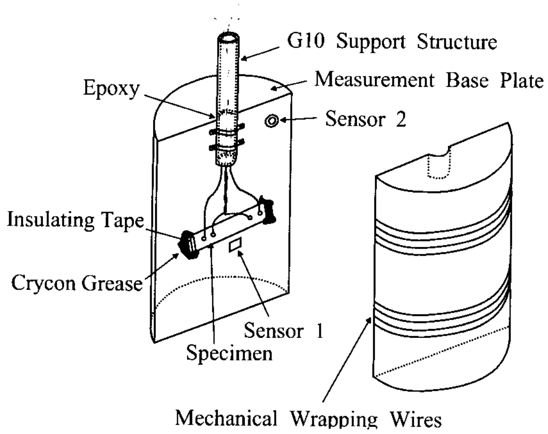

Fig. 3. Schematic diagram of the base plate for mounting a specimen.

A specimen of Cu/Nb-Ti wire is mounted on the base plate as shown in Fig. 3. For helping thermal equilibrium at a measurement temperature, a pair of base plate was fabricated with copper block. The dimensions of base plate are 46 mm-diameter, 50 mm-height and 400 g-mass. A straight specimen is mounted on the base plate attached two temperature sensors. The base plate was affixed to a support structure of 85 cm-long tube to allow to be lowered or raised to the helium reservoir. The support structure was made of G10 and bonded to the base plate with epoxy. Current, voltage, and temperature sensing wires were passed through the support structure.

The specimen was instrumented with current contacts near each end of the specimen and a pair of voltage contacts between the current contacts of the specimen. After wiring, the specimen was mounted on the base plate with crycon grease. For thermal equilibrium, the specimen mounted to the base plate was covered with another semi-cylinder by wiring and then wrapped with overlapping aluminum foils.

IV. Characteristics of Measurement System

The target precision of the IEC 61788-4 international standard for RRR measurement of Cu/Nb-Ti composite superconductors is 5% or less(3). To satisfy the precision, the standard requires some accuracy of instruments. Specifications of our system are listed in Table 1. As shown in Table 1, all of specifications of the system satisfy for requirements of the standard. Most of the instruments used for the system were periodically calibrated to the national standard at KRISS.

Table 1. Requirements of the international standard and specifications of our system.

Requirements of International Standard		**Specifications of Our System**
Accuracy of voltage measurement : 0.5%		0.01%
Current	Accuracy : 0.5%	0.18%
	Stability : 0.5%	0.01%
Temperature	300 K : ± 1 K	± 0.15 K
	4.2 K : not specified	± 0.5 K
Material of Base Plate	Thermal conductivity : 100W/(m·K) : Cu, Al, Ag (recommended)	Cu -base plate
	Length : at least 30mm	46mm
Rate of Temperature Increase	0.1 K/min to 10 K/min	0.05 K/min to 1 K/min

In the case of temperature measurement, Sensor 1 showed 3.9 K at liquid helium temperature(4.2 K) whereas Sensor 2 showed 4.2 K. However, Sensor 1 showed accurate temperature at other temperature such as 77 K or 300 K. If we correct Sensor 1 as much as +0.3 K at 4.2 K range, difference between two sensors becomes nearly zero for whole measurement range. Furthermore, accuracy of the thermometer is not so important because our purpose is to measure more exact resistance of a specimen near superconducting transition

The temperature of the base plate is controlled by lowering or raising the support structure to the liquid helium level. In Fig. 4, the relation between temperature and position above the liquid helium is shown. The data in Fig. 4 were collected for August 12 through 14. Temperature was approximately raised 10 K per 10 mm of the position. Especially, near 10 ~ 11 mm of the position, temperature of the base plate showed 9 ~ 10 K where the Cu/Nb-Ti composite superconductor showed superconducting transition.

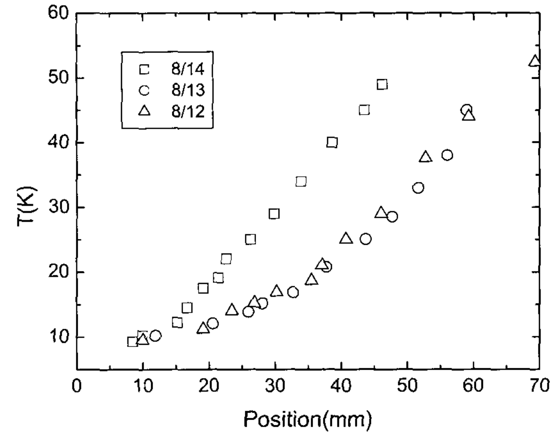

Fig. 4. Relation of temperature to position of base plate above liquid helium level.

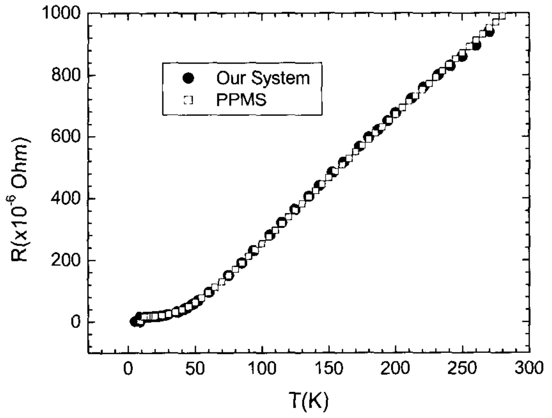

Fig. 5. Comparison of resistance values by our measurement system with those by PPMS.

After investigating the characteristics of our system, we measured the resistance of a Cu/Nb-Ti composite wire from 4.2 K to 300 K. For justification of measurement of our system, we compared measurement data with those measured by PPMS(Physical Property Measurement System: Quantum Design Inc.). The result is presented in Fig. 5.

As well as around superconducting transition, the measured data of our system are nearly same as those of PPMS from 4.2 K to 300 K. Therefore, we could verify that our system was not only simple but also acceptable for measuring the RRR of Cu/Nb-Ti composite superconductors

V. RRR Measurements of Cu/Nb-Ti Specimens

After we verified the performance of the measurement system, we applied our system to measure R-T curves of three Cu/Nb-Ti composite wires to acquire their RRR values. The specimens had round cross-section and diameters were 1.0, 0.75, and 0.50 mm, respectively. Each specimen was instrumented with current contacts near each end of the specimen and a pair of voltage contact over a central portion of the specimen. A specimen was mounted on base plate and some mechanical method by wiring was used to hold the specimen against the base plate. Measurement procedures were as follows.

First, R_l at room temperature was measured by flowing a test current of 1 A or 2 A corresponding to current densities of 0.1 A/mm^2 ~1 A/mm^2. Next, the specimen was slowly lowered into the liquid helium and cooled to 4.2 K for 5 minutes. When the specimen was in a superconducting state, a test current of 0.1 A/mm^2 to 10 A/mm^2 current density was applied and then initial voltage was measured to compensate thermoelectric voltage. For measuring the resistance at superconducting transition, the base plate was slowly raised to about 10mm-position above the liquid helium level. When the specimen reached at appropriate temperature, we measured the voltage of specimen.

Successive data for obtaining R-T curve were acquired with increasing temperature. The measured R-T curves of three specimens from 4.2 K to 300 K are shown in Fig. 6.

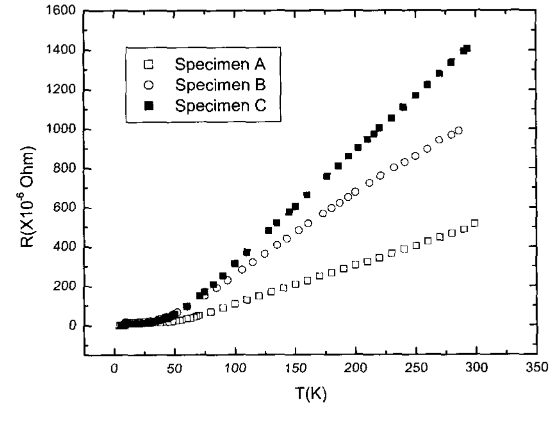

Fig. 6. R-T curves of three specimens from 4.2 K to 300 K.

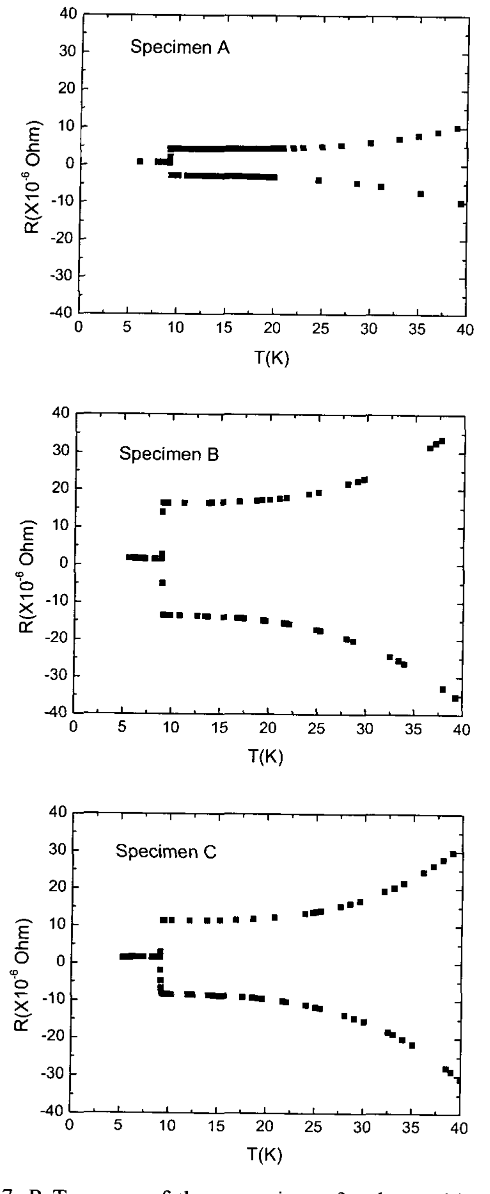

Fig. 7. R-T curves of three specimen for the positive and negative polarity.

From Fig. 6, R_1 values of three specimens at 293 K(20 °C) are 5.16×10^{-4}, 1.07×10^{-3} and 1.40×10^{-3} Ohms, respectively.

To obtain the R_2 values, more precise R-T curves of both positive and negative polarity were measured in the range of 4.2 K to 40 K. The R-T curves of negative polarity were measured by applying a negative current to the specimens after completing a measurement of positive polarity. The results of R-T measurement of three specimens from 4.2 K to 40 K are illustrated in Fig. 7.

All of specimens show sharp superconducting transition for both polarity around 9.3 K. Above superconducting transition, resistances of three specimens are nearly constant with increasing temperature up to 15 K. Thus, R_2 values at the intersection of the (a) and (b) lines shown in Fig. 1 are easily determined from each R-T curve. However, R_2 values due to polarity for each specimen are quite different. In the case of specimen A, positive R_2 value is 4.25×10^{-6} Ohm whereas negative R_2 value is 2.87×10^{-6} Ohm. This large difference is presumed to cause from the thermoelectric voltage due to large temperature difference, i.e., specimen at cryogenic temperature and voltmeter at room temperature.

During measurements, all the specimens showed thermoelectric voltages of +1.37 μV to +1.57 μV in superconducting state. These values did not depended on test currents, polarity or specimen. Even when the test current was zero, the thermoelectric voltage showed nearly the same value. We compensated the thermoelectric voltage for measured data. After compensating, R_2 values of Specimen A become 3.54 $\times10^{-6}$ Ohm for positive polarity and 3.57×10^{-6} Ohm for negative polarity. These values are consistent within 1%.

The same compensation procedures as the specimen A were done for specimen B and C. Results of RRR measurements for three specimens are summarized in Table 2.

In Table 2, R_2 values of the specimens were averaged with the positive and negative polarity. R_1 values are in the range of from 10^{-4} to 10^{-3} Ohms. R_2 values show from 10^{-6} to 10^{-5} Ohms. By using equation (1), the RRR values of three specimens

Table 2. Results of RRR measurements

Test Report	**Specimen A**	**Specimen B**	**Specimen C**
Test current	± 2.0 A	± 1.0 A	± 1.0 A
R_1 at 293 K	$5.16\times10^{-4}\Omega$	$1.07\times10^{-3}\Omega$	$1.40\times10^{-3}\Omega$
R_2(averaged)	$3.55\times10^{-6}\Omega$	$1.50\times10^{-5}\Omega$	$9.99\times10^{-6}\Omega$
RRR values	145.3	71.3	140.1

were calculated to be 145.3, 71.3 and 140.1, respectively. Except for 71.3 of specimen B, other RRR's values are acceptable for practical application such as magnet system.

VI. Conclusion

To disseminate the IEC 61788-4 international standard, we designed and fabricated a simple RRR measurement system for Cu/Nb-Ti composite superconductors. The system provided a good experimental environment for measuring R-T curves of Cu/Nb-Ti composite superconductors.

We characterized three specimens of Cu/Nb-Ti composite wires for obtaining RRR values. The specimens showed meaningful R-T curves from 4.2 K to 300 K and precise RRR values were calculated according to the international standard. The calculated RRR values were 145.3, 71.3 and 140.1, respectively. The RRR measurement system and research result will be useful to provide a new KS on RRR measurement of Cu/Nb-Ti composite superconductor in the near future.

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