MICROWAVE SURFACE RESISTANCE MEASUREMENT TECHNIQUE FOR CYLINDRICAL HIGH-Tc SUPERCONDUCTOR

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ABSTRACT

A surface resistance measurement method is investigated using an open-circuit terminated cavity constructed from a shielded pair comprising two cylindrical conductors as a specimen. The accuracy is confirmed by measuring copper specimens. High-Tc YBaCuO superconductor surface resistances are evaluated from 1 to 8 GHz.

INTRODUCTION

In order to design microwave circuits using high-critical-temperature superconductor, it is important to evaluate microwave surface resistance of the superconducting materials. Microwave resistance measurement methods are required which do not incur error due to contact resistance, because it is difficult to make low and stable resistance contacts between specimens and instruments using current high-Tc superconductor manufacturing technologies. The main disadvantage of the previous measurement methods(1)-(2) on disk samples is that the superconducting material occupies only a small part of the resonator. Therefore, the uncertainties in the Q measurement of the resonator make it difficult to obtain meaningful quantitative information. The resonant measurement technique using low-impedance disk resonators showed relatively good results, but the radiation loss limits the accuracy(3).

In this paper, a method of measuring surface resistance applied in the GHz region using the Q factor of an open-circuit terminated cavity formed by a pair of cylindrical superconductor specimens, is investigated experimentally. The accuracy is confirmed by measuring copper specimens. Thus, the surface resistance of the high-Tc YBaCuO superconductors from various sources are evaluated as a function of frequency from 1 to 8 GHz at 77 K.

MEASUREMENT METHOD

Configuration of the surface resistance measurement method is shown in Fig. 1. A cylindrical superconductor pair used as a specimen is placed inside a long piece of waveguide which provides the appropriate cutoff frequency. The waveguide prevents radiation loss in the frequency range below the waveguide TE_{11} mode cutoff frequency(4). Capacitive couplings are realized by probes. Gaps between the probe couplings and the cavity are adjustable to obtain unloaded Q factor. Thus, the Q factor of the TEM mode resonance of the shielded cylindrical pair is measured.

The ohmic loss of the shielded pair is given by(5);

$$\alpha = \frac{\frac{2R_{S1}}{d}\{1+\frac{1+2p^2}{4p^4}(1-4q^2)\} + \frac{8R_{S2}}{D}q^2\{1+q^4-\frac{1+4p^2}{8p^4}\}}{\eta\{\ln[2p(\frac{1-q^2}{1+q^2})]-\frac{1+4p^2}{16p^4}(1-4q^2)\}} \quad (1)$$

where $\eta=\sqrt{\mu/\varepsilon}$, $p=s/d$, $q=s/D$ and

Rs1: surface resistance of each cylindrical conductor,
Rs2: surface resistance of waveguide.

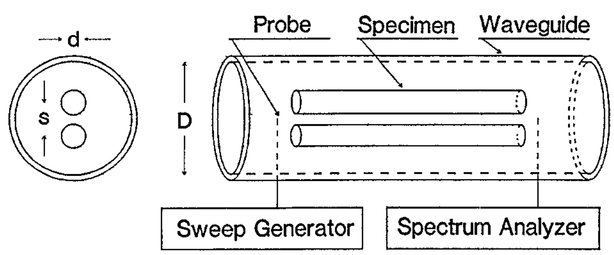

Fig. 1 Arrangement of measurement circuit

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Using eqn. 1, and the expression $Q=\beta/2\alpha$, it is possible to calculate the surface resistance of the specimen from the measured unloaded Q factor.

The shielded cylindrial pair loss is almost determinded by the cylindrical pair loss by choosing appropriate values for the cylindrical specimen radius, the cylindrical pair width and the waveguide radius. Therefore, this technique can provide a highly accurate surface resistance measurement of the specimen.

EXPERIMRNTAL RESULTS

There are two different TEM resonant modes which present close resonant frequencies in this measurement arrangement: the shielded pair mode and coaxial mode. Fortunately, the difference of the fringe capacitance at the cylindrical pair open ends between the two modes separate these resonant frequencies enough to evaluate the Q factor of the shielded pair mode, as shown in Fig. 2.

Figure 3 shows the Q factor of the cylindrical copper pair resonator with and without the waveguide. The radiation loss is effectively prevented by the waveguide so that the cylindrical pair resonator Q factor with the waveguide agrees with the theoretical value. No resonance was observed above the waveguide TE_{11} mode cutoff frequency.

In order to confirm the accuracy of this method, the surface resistance of a cylindrical copper conductor pair was measured at 77 K and 300 K. The specimen was about 16 cm long and 1.6 mm diameter. As the waveguide is 20 mm in diameter, the measurable frequency is less than 8.8 GHz: the cutoff frequency of the TE_{11} mode. The specimen

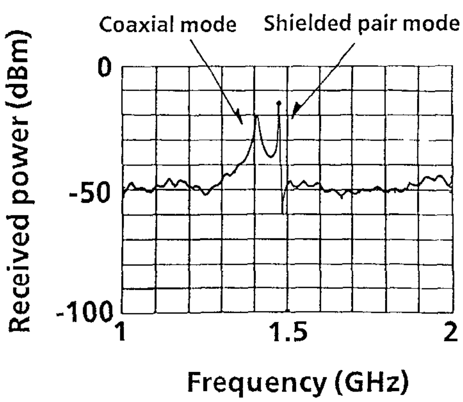

Fig. 2 Received power versus frequency around resonant frequencies

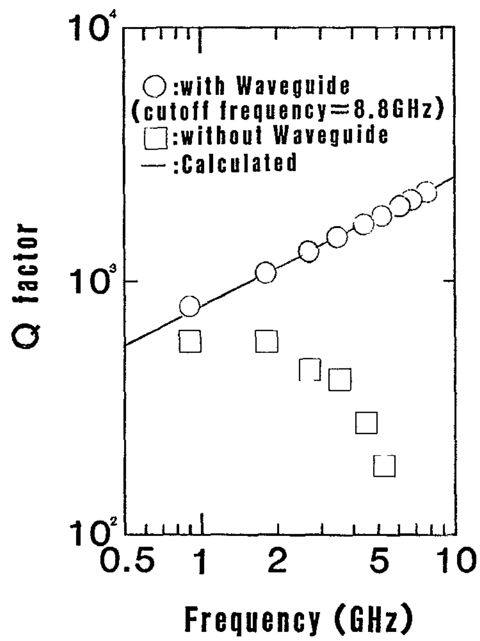

Fig. 3 Q factor of cylindrical copper pair versus frequency with and without waveguide

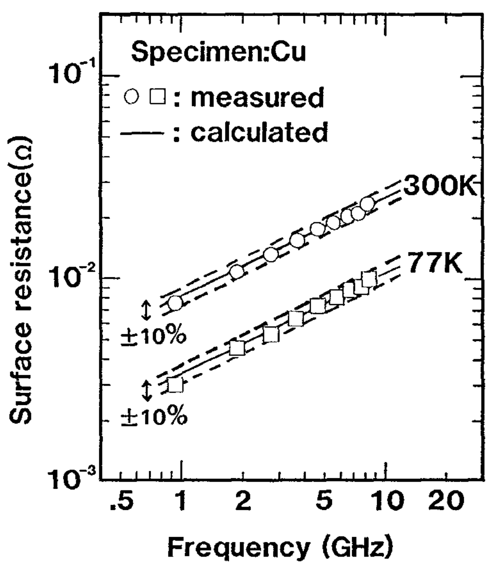

Fig. 4 Surface resistance of copper versus frequency

was cooled by circulated nitrogen gas to maintain it at a constant temperature. Figure 4 shows the surface resistance of the copper specimen. Measured and theoretical values were within 10% of each other.

The frequency characteristics of bulk YBaCuO superconductors from various sources are measured between 1.5 GHz and 8 GHz at 77 K. The cylindrical specimens are 8-10 cm long and 1-2 mm in diameter.

Below a certain cavity excitation level at a particular resonant frequency, the Q factor was not a function of excitation level, as shown in Fig.5. However, at a high excitation level, the Q factor decreased with excitation level. Thus, in this experiment the excitation level was kept low enough to maintain the Q factor at a constant value.

The frequency characteristic of the surface resistance at 77 K is shown in Fig.6. The surface resistance of one sample pair becomes lower compared to that of copper at 300 K below 7 GHz. It is apparent that the surface resistance of other samples is lower than that of copper at 300 K below 1 GHz. The empirical equation of the surface resistance frequency characteristic of the three bulk YBaCuO pairs at 77 K are given by:

$$Rs = 1.5 \times 10^{-14} f^{1.3} \quad (\Omega) \qquad (2)$$

$$Rs = 1.4 \times 10^{-15} f^{1.4} \quad (\Omega) \qquad (3)$$

$$Rs = 4.8 \times 10^{-19} f^{1.7} \quad (\Omega) \qquad (4)$$

where f is in Hz.

The power-low behavior of bulk YBaCuO surface resistance with frequency is similar to that of Nb and Pb superconductors(6). However, the bulk YBaCuO surface resistance at 77 K is about 10^3-10^4 times that of Pb at 4.2 K.

CONCLUSION

A surface resistance measurement method in the GHz region is presented. The shielded cylindrical superconductor pair resonator is easy to fabricate and realizes accurate measurements. Its validity is confirmed by the experiment with copper specimens from 1 to 8 GHz. Measured and theoretical values of copper specimens were within 10% of each other.

Microwave surface resistance of the bulk YBaCuO superconductors from various sources was evaluated at 77 K. The power-low behavior of surface resistance with frequency ranges from 1.3 to 1.7.

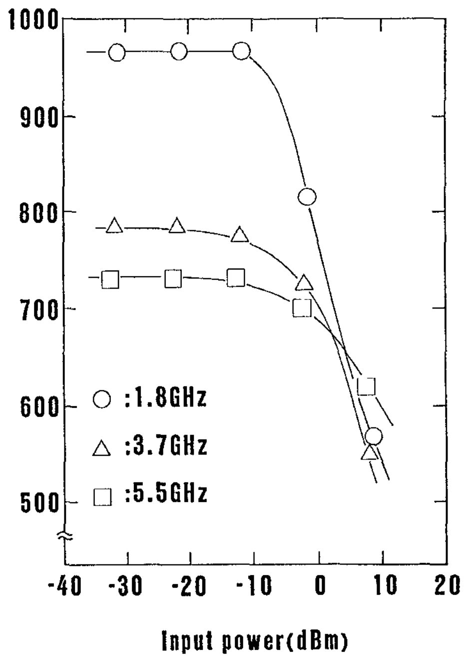

Fig.5 Q factor of cylindrical YBaCuO superconductor pair versus input power to excitation probe

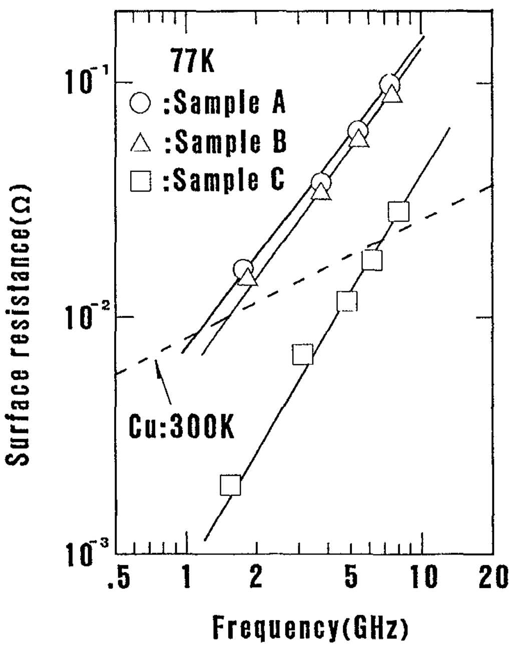

Fig.6 Surface resistance of YBaCuO versus frequency at 77 K

ACKNOWLEDGMENTS

We thank Dr. Sadakuni Shimada , Dr. Hidetoshi Kimura and Dr. kiyoshi Nakagawa for their help and encouragement.

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