

MEASUREMENT OF SURFACE RESISTANCE OF HIGH-Tc SUPERCONDUCTOR
($(\text{Bi,Pb})_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_x$) AT 10.5GHZ

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Abstract

Temperature and current dependences of the surface resistance of high-Tc superconductor have been studied at 10.5GHz by measuring quality factors of a TM010 cavity resonator (10 mm H x 11 mm R) made of a bulk $(\text{Bi,Pb})_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_x$. The surface resistance increases from 1.8 mΩ to 80 mΩ at 22 K as the surface current from 4 A(peak)/m to 61 A/m, also increases as the temperature increases, and reaches 200 mΩ at 90 K for the surface current of 45 A/m.

Introduction

From recent studies of ceramic superconductors with high critical temperature(T_c)^{1)~4)}, it seems difficult to apply the high-Tc ceramics for an rf cavity of a particle accelerator because the surface resistance becomes too high in the electro-magnetic field required for the accelerator. However, a lot of researchers have been studying, and developing new materials and methods to make films since the high-Tc ceramics is invented in 1986. Furthermore, most studies were done on ceramics of YBaCuO and a experimental method is different from each others. Then we studied a rf characteristics of a TM010 cavity made of a bulk $(\text{Bi,Pb})_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_x$ by measuring reflection coefficients with a waveguide system.

- This method has following advantages:
- 1) We can measure the characteristics of the actual cavity without any disturbance by normal conductor or dielectric inside the cavity.
 - 2) The measurement can be made in a full range of excitable power level in the cavity, that is, from near noise level of a detector to the maximum output level of a microwave source; on the other hand, in a weak coupled two antennas(source and detector) method the range is reduced by a factor due to insertion loss of each antenna.
 - 3) The electro-magnetic field in the cavity is analytically solved.

Experimental method

Figure 1 shows cross-sectional views of the cavity and the copper housing. Material of the cavity* consists of $(\text{Bi,Pb})_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_x$ having a density of 80~85%. The cavity is composed of a flat end plate and a hollow body

*The cavity was made by DOWA kogyo Co. Ltd.

machined with bulk ceramic blocks. Then they are joined by heat treating with high-Tc superconductor paste on their contact surfaces. The cavity is set on a cooling head in a vacuum chamber and is cooled down to about 20K with a refrigerator. Figure 2 shows a block diagram of the experimental setup. The cavity is connected to a waveguide system outside vacuum with a 40 cm low thermal conductance waveguide made of silver plated cupro-nickel. An rf signal is fed into the cavity through a small coupling hole and a reflected signal is detected with a directional coupler. A coupling adjustor adjoining the cavity makes impedance matching by minimizing a reflected signal at the center

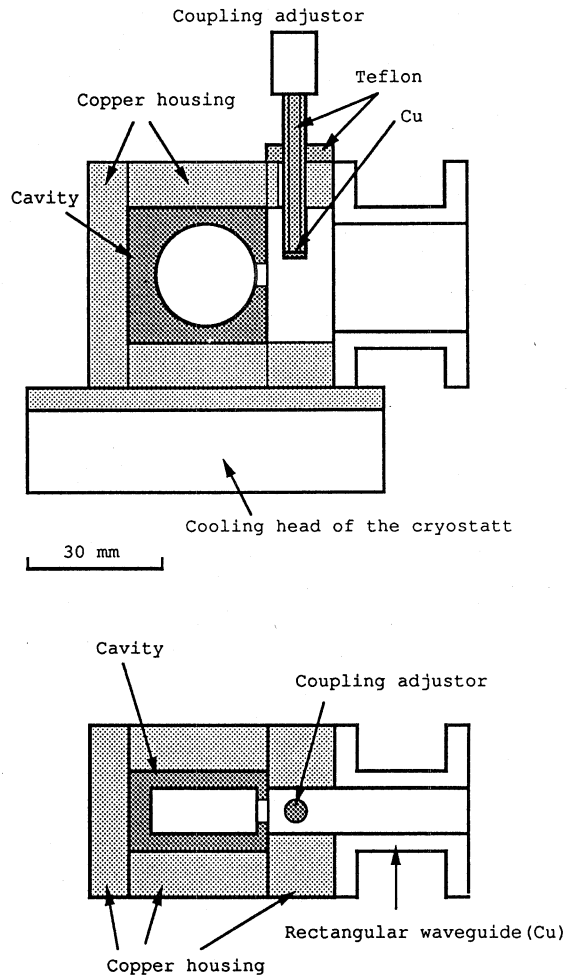


Fig.1 Cross-sectional views of the cavity and the copper housing.

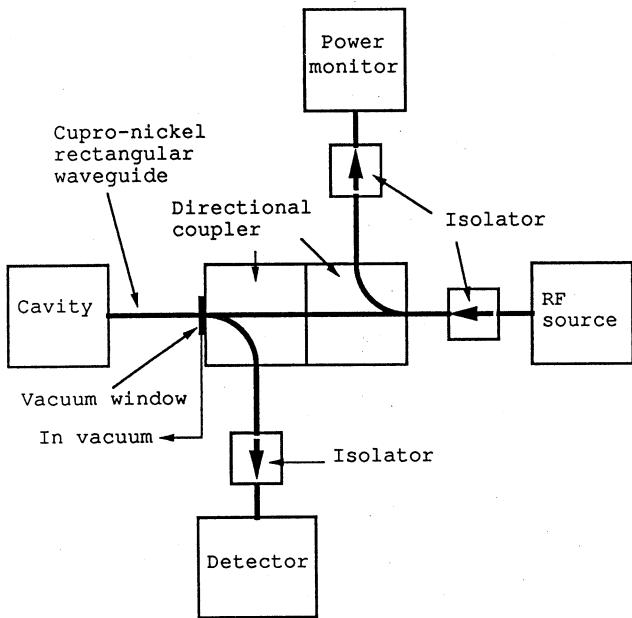


Fig.2 Block diagram of the experimental setup.

of resonance. In most case the reflected signal can be reduced below the noise level of the detector. A resonant absorption curve is measured in the best impedance matching and absolute values of reflection coefficient (Γ) around the resonant frequency are deduced from the curve.

Experimental result

Figure 3 shows an typical resonant absorption curve. The ordinate is voltage amplitude of reflected signal in linear scale. At the resonant frequency, the input power is absorbed completely by the cavity. In this case the unloaded quality factor (Q_u) is given by the following equation:

$$Q_u = f_0 / \Delta f,$$

where f_0 is a resonant frequency and Δf is a frequency width of a resonance curve at $\Gamma = 0.447$.

A surface resistance of the cavity (R_s) is deduced from Q_u by the following equation:

$$R_s = \pi f_0 \mu / (Q_u (1/a + 1/h)),$$

where μ is permeability of vacuum, a and h are radius and height of a cavity, respectively.

The maximum surface current density (I_s) takes place along a circle of radius of $0.765a$ on a circular base of a cavity and is given by

$$I_s = 2.77 \times 10^{-6} (Q_u P f_0 / h)^{1/2} \text{ (A/m)}$$

where P is a input power to the resonator. P is determined from a calibrated output level of the microwave source and is corrected by a measured insertion loss of the measuring system.

Temperature dependence of R_s in three input power levels are shown in Fig. 4

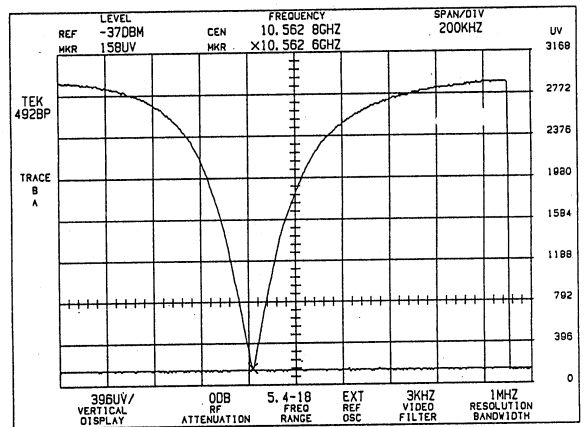


Fig.3 Typical resonant absorption curve. Frequency: 10.5626GHz, Temperature: 50.5K, Maximum surface current: 3 A/m.

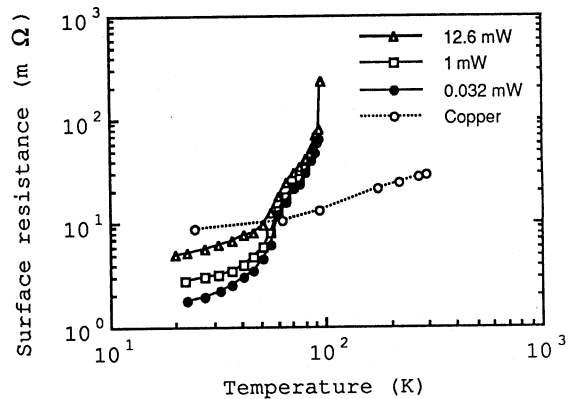


Fig.4 Temperature dependence of surface resistance.

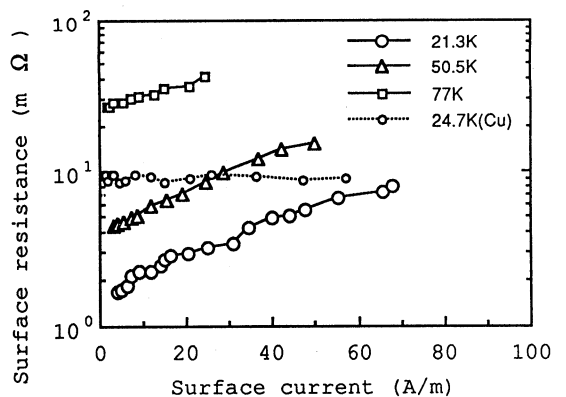


Fig.5 Surface current dependence of surface resistance.

together with a result of the copper cavity which has the same geometry as the high-Tc superconducting cavity. The obtained R_s of copper is consistent with calculation within 5%. The R_s of this high-Tc superconductor has a strong temperature dependence below the T_c as those of YBaCuO_3 . The values of R_s are about one tenth of those obtained by Delayen¹).

Figure 5 shows surface current dependences of R_s at temperatures of 21.3K, 50.5K, and 77K. The surface current density shown is I_s above. In such a low current density as 3.8 A/m (RF magnetic field is 0.05 Gauss), the R_s depends on the field.

Conclusion

Surface resistances of high-Tc superconducting cavity (TM010) made of a bulk $(\text{Bi,Pb})_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_x$ have been studied and it is clear that this material can not be applied for an accelerator cavity. However, the present results is useful for theoretical study of high-Tc materials and the experimental method will be useful to study new materials which will be developed in the future.

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