Measurements of Microwave Cavities Made of Bulk Superconductor $YBa_2Cu_3O_{7-x}$

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The cylindrical microwave cavities designed to be resonant in the TE_{011} mode at 24 GHz have been fabricated by $YBa_2Cu_3O_{7-x}$ bulk sample. The unloaded quality factor Q_U up to 10^5 is attained at 77 K. This value seems to be the top data in the world at this moment.

1. INTRODUCTION

As is well known, the $YBa_2Cu_3O_{7-x}$ (YBCO) superconductor can exhibit superconductivity with a high-T_c above 90 K. The fundamental physical properties and the applications for electronic devices of YBCO are studied by many workers. It is very important to examine RF properties in YBCO. Moreover, particulary, the high-Q superconducting cavities operated at 77 K (liquid nitrogen temperature) have potential applications to linear accelerators. Zahopoulos et al.[1] measured the TE_{011} mode cavity made of YBCO. However, their cavity operated at 8 GHz was dielectrically loaded with sapphire, and the Q values of the cavity were 10^4 at 77 K and nearly 10^5 at 4.2 K. Recently, the cavity made of YBCO without any dielectric interior, which was resonant at 7 GHz in the TM_{010} mode, was measured and the Q of around 10^5 was obtained at 25 K.[2)]

In the present paper, the cylindrical microwave cavities designed to be resonant in the TE_{011} mode at 24 GHz are made of YBCO bulk sample. The Q of the cavities are measured.

2. EXPERIMENTAL

The samples used in the present work are prepared from the stoichiometric mixture of usual commercial powders, Y_2O_3, $BaCO_3$ and CuO with purities of 99.99%. The nominal composition is $YBa_2Cu_3O_{7-x}$. The ground powder mixture in an alumina crucible is calcined at 900°C for 8 hours in air and then slowly cooled to room temperature in a furnance. The reacted mixture is repeatedly ground and calcined at 900°C for 8 hours. Afterwards, the reacted mixture was ground sufficiently and pressed into a disk with a 60-mm diameter at a pressure of 200 kg/cm^2. The disk sample is sintered at 900°C for 6 hours in air and then slowly cooled to room temperature. In both the calcining and the sintering, it takes 1.5 hours for the heating to 900°C and about 10 hours for the cooling to room temperature.

The superconducting cavities are designed to be resonant at 24.5 GHz in the cylindrical TE_{011} mode, and are made using three YBCO disks with a 60-mm diameter. Figure 1 shows the assembly of the microwave cavity using two disks and one ring made of YBCO. The inner diameter and length of the cavity are 30 mm and 7 mm,

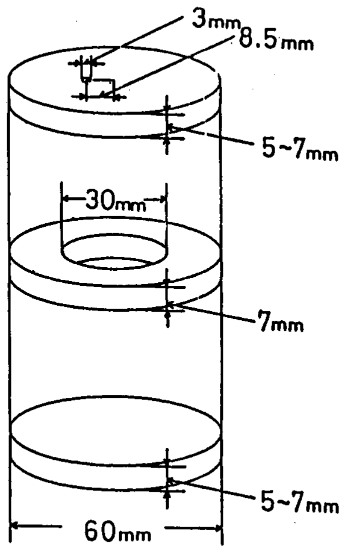


Fig.1 Assembly of a TE_{011} mode cavity using $YBa_2Cu_3O_{7-x}$ disks and ring.

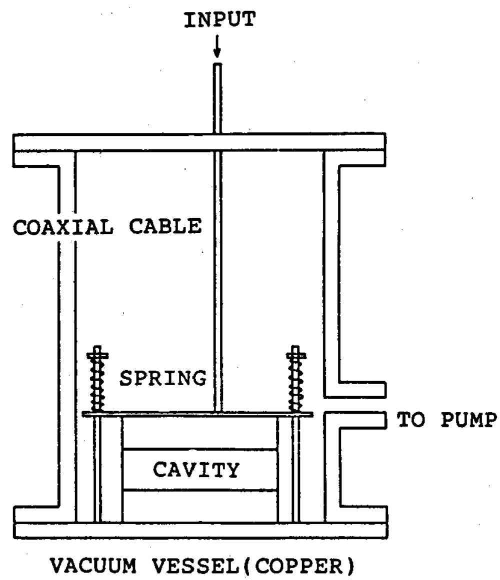


Fig.2 An experimental setup.

respectively. The orifice with a 3-mm diameter of the top disk is drilled for the incidence of microwaves. The coupling is obtained by a loop antenna. As shown in Fig.2, the cavity made of YBCO disks and ring is set into the vacuum vessel made of copper, and is fixed using springs. The temperature of the cavity is controlled by liquid nitrogen and mesured by a thermocouple set between the top disk of the YBCO cavity and the copper plate.

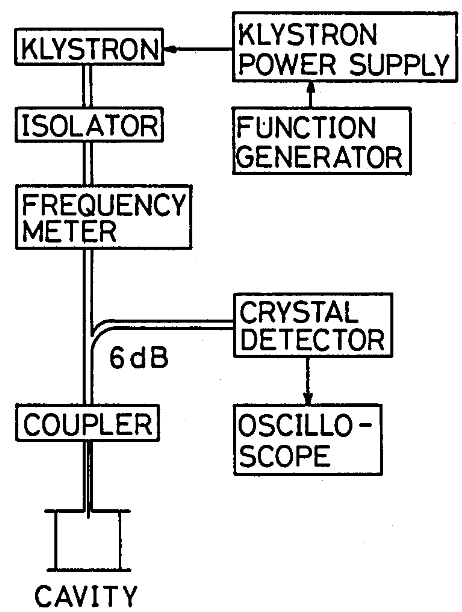


Fig.3 Schematic diagram of microwave measuring system.

Figure 3 shows our microwave measuring system. The unloaded quality factor Q_U of the cavity is measured using the standard transient method by modulating the incident microwaves to a square waveform. The pulse-modulated CW microwaves are fed to the port of the cavity using a semi-rigid coaxial cable, and the reflected microwave signals are measured by a coaxial detector with 50-Ω terminating resistance. The voltage from the crystal detector is calibrated by a microwave power meter. From the loaded quality factor Q_L determined from the decay time and the coupling constant β, the unloaded quality factor Q_U is calculated by the relation $Q_U = (1 + \beta) Q_L$.

3. RESULTS AND DISCUSSION

Figure 4 shows an X-ray diffraction pattern for a YBCO bulk sample. The majority phase of the sample is similar to usual orthorhombic structure observed for the high-T_c materials. Figure 5 shows the temperature dependence of the DC resistance of the YBCO bulk sample prepared under the same conditions as the cavity materials. The measurements are carried out using the standard four-probe technique with silver paint contacts and the voltage is measured at a current of 100 mA during heating of the sam-

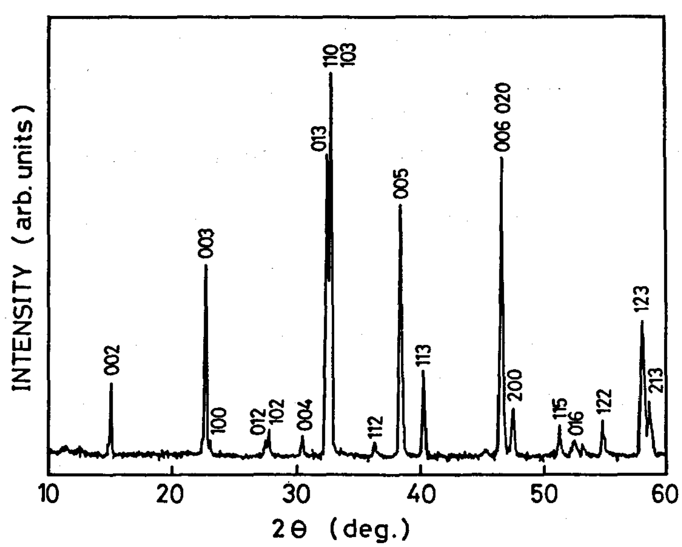


Fig.4 X-ray diffraction pattern for a $YBa_2Cu_3O_{7-x}$ bulk sample.

ple under a pressure of about 10^{-4} Torr in the cryostat. From this figure, it is found that a sharp drop of resistance starts at about 98 K and the resistance become zero at about 90 K.

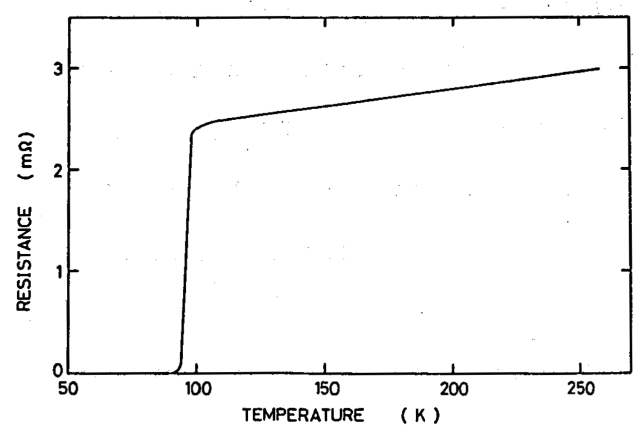


Fig.5 Temperature dependence of the DC resistance of a $YBa_2Cu_3O_{7-x}$ bulk sample.

Figure 6 shows the result of the unloaded quality factor Q_U measurements of the cavities made of YBCO. The data at 77 K represented by an open circle in Fig.6 is obtained for another cavity and the reflected signal in this case is shown in Fig.7. From Fig.7, the coupling constant β = 2.1 and the loaded quality factor Q_L = 3.3 x 10^4 are obtained, and the unloaded quality factor Q_U is calculated to be 1.0 x 10^5. This value seems to be the top data. However, other data of Q_U around 80 K are 5 x 10^3. Figure 8 shows the surface resistance of the cavity obtained from Fig.6. The surface resistance R_s is calculated using

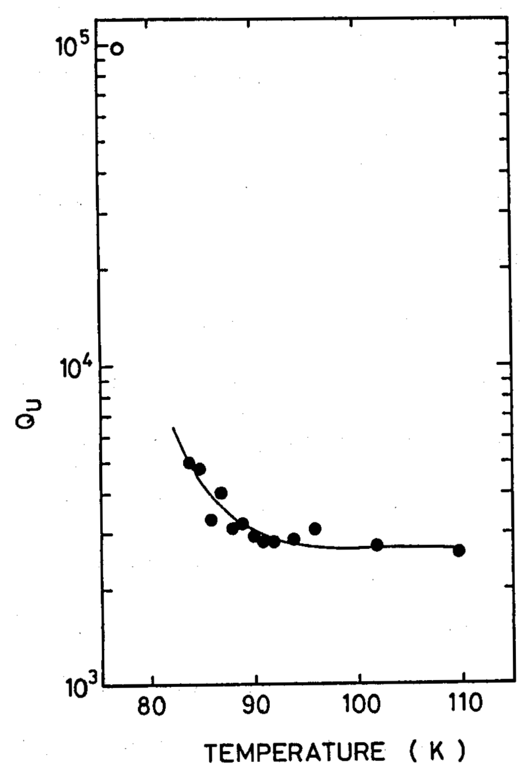
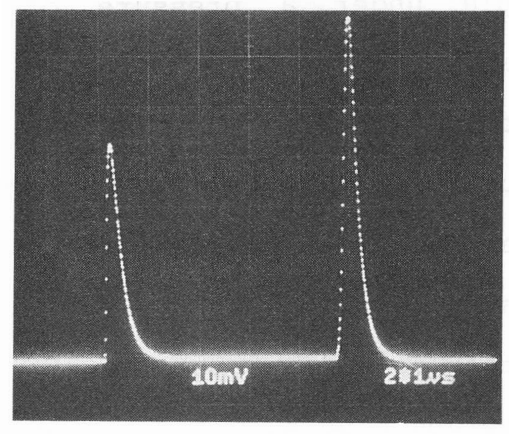


Fig.6 Results of unloaded quality factor measurements of the TE_{011} mode cavity made of $YBa_2Cu_3O_{7-x}$.

the relation $Q_U = \Gamma/R_s$, where Γ is a geometric factor of the mode. In our TE_{011} cylindrical mode cavity, Γ is 417 Ω. At 77 K, the surface resistance is 4.2×10^{-3} Ω.

Figure 9 shows the schematic diagram of the Q_U measurements of a TM_{011} mode cylindrical cavity operated at 2.86 GHz with and without the YBCO sample.[3)] The YBCO disk sample with a 20-mm diameter and 1-mm thickness is placed in the field of the cavity made of copper. The inner diameter and length of the cavity are 9.0 cm and 11.4 cm, respectively. The sample is much smaller than the cavity volume. Figure 10 shows the result of the Q_U measurements of the cavity with and without the YBCO disk sample.[3)] The value of Q_U with the sample is smaller than that without the sample, and this is due to the Joule loss in the



TIME (1μs/div.)

Fig.7 Reflected microwave signal measured at 77 K.

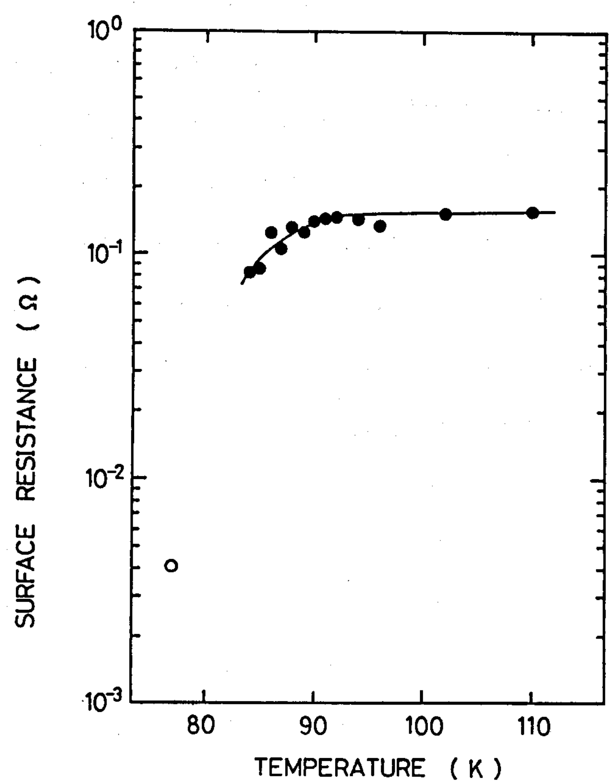


Fig.8 Surface resistance obtained from Fig.6.

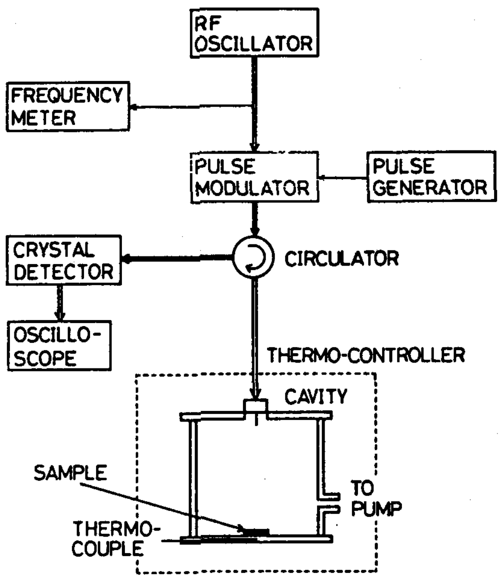


Fig.9 Schematic diagram of the quality factor measurements of the TM_{011} mode cavity with a $YBa_2Cu_3O_{7-x}$ disk sample.

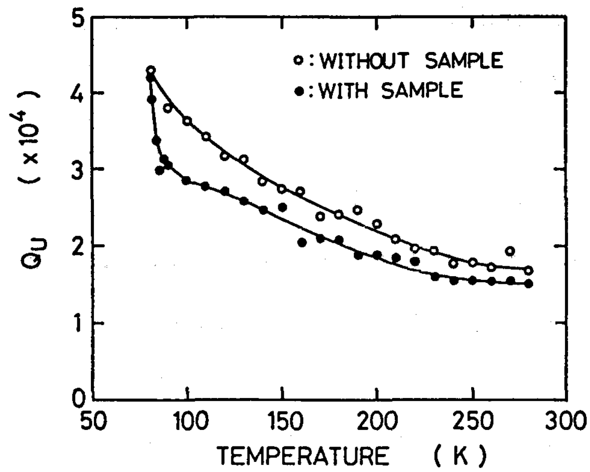


Fig.10 Temperature dependence of the unloaded quality factor of the cavity with or without the sample.

sample. It is found that a sharp reduction of the Joule loss in the sample begins at an onset temperature of about 90 K. Near 80 K, the value of Q_U with the sample is almost same as that without the sample. Therefore, the surface resistance of the YBCO sample seems to be the same as the cavity wall material, i.e., copper.

4. CONCLUSION

The cylindrical microwave cavities designed to be resonant in the TE_{011} mode at 24 GHz are made of $YBa_2Cu_3O_{7-x}$ bulk sample. The unloaded quality factors Q_U were measured. The Q_U values are measured above 77 K and the value up to 10^5 was obtained at 77 K. This value seems to be the top data. However, the Q_U of other cavities made in the same way were, in usual, not reached to 10^5.

Further detail examinations for the reproducibility are under way.

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