

# MICROWAVE SURFACE RESISTANCE OF YBaCuO SUPERCONDUCTING FILMS LASER-ABLATED ON COPPER SUBSTRATES

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Abstract

In order to apply high- $T_c$  material to a real accelerator cavity, it may be indispensable that the material is deposited on metal substrate. It is now possible to align the  $c$  axis of  $\text{YBa}_2\text{Cu}_3\text{O}_y$  (YBCO) film perpendicular to a metal surface. Furthermore, the constituent crystals can be in-plane aligned with a laser ablation technique following the formation of yttria-stabilized-zirconia (YSZ) buffer layer of controlled grain orientation. Using a demountable copper cavity operated at 13 GHz in the  $\text{TE}_{011}$  mode, the microwave surface resistance was measured over a temperature range from 11 K to 300 K.

## I. INTRODUCTION

Since the discovery of a high- $T_c$  superconductivity, the possibility to use a high- $T_c$  material to an accelerator cavity has been discussed. For high-power accelerator cavities, not only must high- $T_c$  films be deposited onto large-area substrates of complex shape, but the use of metallic substrates of high thermal conductivity is also essential. As the thermal conductivity of high- $T_c$  materials is rather low[1], heat must be released to keep the film in a superconducting state even under a high field.

In KEK we have been involved[2] in developing thick high- $T_c$  films of YBCO or  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_y$ . The YBCO films were prepared through a low-pressure plasma-spraying technique and melt-reaction process either on silver substrate or nickel-plated copper substrate. The  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_y$  films were prepared either by a screen-printing or spraying method either on silver substrate or silver-plated copper substrate. The microwave surface resistances were measured using a demountable cylindrical cavity made of copper at 3 GHz in the  $\text{TE}_{011}$  mode. The surface resistance of YBCO film on a silver end plate was 0.2 m $\Omega$  at 20 K. However, the preparation of well-controlled surface of this size (the diameter and length is 150mm and 84mm, respectively) is expensive, time-consuming and not necessarily successful.

Therefore we made another demountable cavity operated at 13 GHz of the same mode. It was cooled by a compact refrigerator and temperature-controlled from 11 K up to the room-temperature. The high- $T_c$  films were formed by a laser-ablation method on well-controlled YSZ layer. The surface resistances of the samples were found from the measured quality factors following the same procedure as before[2]. However, as the reflection at 13 GHz was more severe and temperature-dependent than that at 3 GHz, we were required to be more cautious in measuring the rf parameters.

## II. FABRICATION OF FILMS

An YSZ/Cr film was used as buffer layer for the deposition of YBCO on copper substrates. The Cr underlayer was found to be essential to protect copper against oxidation, resulting in good adhesion of the YSZ layer on copper. Copper substrates, 36-mm dia. disk with a thickness of 3 mm, were polished to a mirror finish. They were then ion-plated with the Cr layer of about 0.5  $\mu\text{m}$ , subsequently sputter-deposited with the YSZ buffer layer of as thick as 0.8  $\mu\text{m}$ .

The grain orientation of YSZ layer was controlled using a modified bias sputtering technique. The technological fundamentals of this method were reported elsewhere [3], [4], [5].

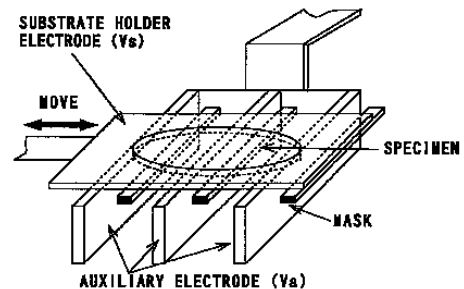


Figure 1. The configuration of electrodes.

Figure 1 shows a pair of specially devised electrodes installed in the sputtering system. Using this equipment, we made an attempt to obtain YSZ films with in-plane texturing over the whole surface of the sample. In brief, the films grown without the biased electrodes showed a poor crystallinity and random orientation. In contrast, when a negative d.c. bias of 200 V was applied both to the substrate holder and auxiliary electrodes, an apparent in-plane texture occurred in the films. However, the degree of in-plane texturing varied depending upon the sample position; films grown on the part of the substrate located directly above the center between the two auxiliary electrode plates, showed comparatively poor texture. This is because glancing angle ion bombardment during deposition is one of the requirements for the achievement of in-plane texturing. However, at this area,  $\text{Ar}^+$  ions impinge on a film not obliquely but at almost right angles. In order to avoid the growth of this poorly-oriented film, masks made of zirconium tape were placed at these positions, as illustrated in Fig.1. In addition, we incorporated a movable substrate holder electrode which enabled us to slide the substrate

horizontally during deposition. After a definite time of deposition, the substrate was moved horizontally so that a film with in-plane texturing could grow on the masked area. Consequently the whole area of the substrate was successfully covered with in-plane textured YSZ thin films. We call this method "masked and moved" deposition mode. In contrast to this, the films grown under "maskless and fixed" mode exhibited poor texturing from place to place. In the present paper, we characterize YSZ buffer layers as "untextured", "partially in-plane textured", and "in-plane textured", each corresponding to the films grown under (1) unbiased-sputtering mode, (2) "maskless and fixed" deposition mode, and (3) "masked and moved" deposition mode, respectively.

The copper substrates thus precoated with YSZ/Cr buffer layer were used for deposition of YBCO films using the laser ablation technique[5]. In order to obtain uniform large area YBCO films, the mirror was oscillated so that an excimer laser beam reflected from the mirror could be scanned on the rotating target surface. However, the film thickness was distributed on the entire substrate between 1.5 and 2  $\mu\text{m}$ . Figure 2(a) shows the pole

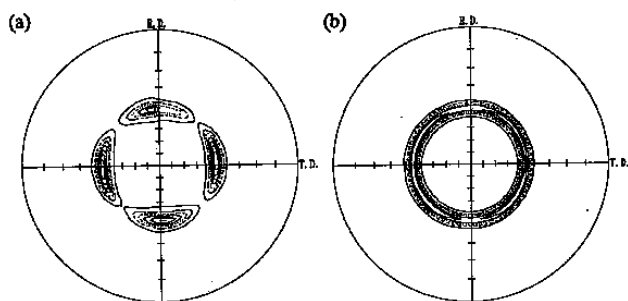


Figure 2. Pole figure for (a) in-plane aligned YBCO, (b) in-plane non-aligned YBCO films.

figure for (103) peaks of the YBCO films deposited on the in-plane textured YSZ buffer layer. From this figure, we can see that the c axis of the YBCO films was oriented normal to the substrate, and the a and b axes were aligned to the YSZ [110] axis at the interface of the films (designated as in-plane aligned YBCO). Figure 2(b) shows the pole figure for the YBCO film grown on untextured YSZ buffer layer. The c axis of the YBCO film was aligned perpendicular to the surface, but the others were distributed randomly (designated as in-plane non-aligned YBCO). Figure 3 shows resistance-vs-temperature

curves of YBCO films deposited on (a) untextured- and (b) textured-YSZ buffer layers, together with that (c) of YBCO film grown on (100)MgO for comparison. This figure reveals that both YBCO films on the YSZ buffer layers have zero-resistance temperature  $T_{c0}$  of about 86 K. On the other hand, YBCO film on (100)MgO exhibited the  $T_{c0}$  of 88.5 K and the resistance curve can be extrapolated to the origin. These results indicate that the formation of the proper buffer layer can further improve the superconducting properties of polycrystalline YBCO films on copper substrates. Transport  $J_c$  was measured using a four-point probe technique. The film grown on in-plane textured YSZ buffer layer gave  $J_c$  of  $1.0 \times 10^5$  A/cm<sup>2</sup>, whereas a comparable

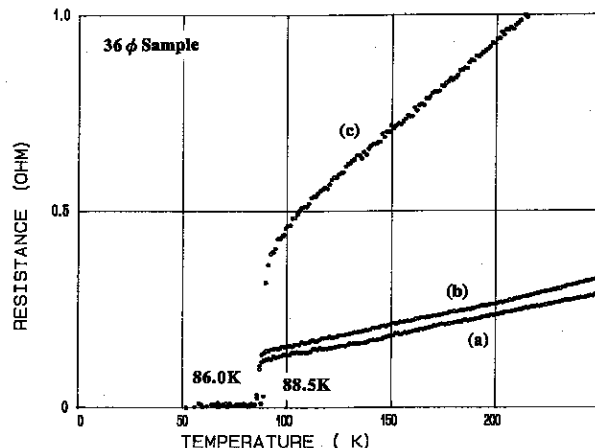


Figure 3. Resistance  $R$  vs  $T$  of YBCO films grown on (a) in-plane textured, (b) untextured, YSZ buffer layers and (c) (100)MgO.

film on a partially in-plane textured YSZ buffer layer had a  $J_c$  of  $5.2 \times 10^4$  A/cm<sup>2</sup> at zero field and 77K. This result indicated that the growth quality of YSZ buffer layers was found to determine the texture of subsequently grown YBCO films.

### III. MEASUREMENT OF THE SURFACE RESISTANCE

Figure 4 shows the experimental set-up for microwave surface impedance measurements using a 13 GHz cavity. The diameter  $2a$  is 30 mm and the length  $l$  is also 30 mm. It consists of a copper host cavity and a copper end-plate. The end-plate is a disk with 36 mm diameter and 3 mm thickness and is substituted with one covered with high- $T_c$  film. The temperature of the cavity is controlled from 11 K to 300 K with a closed-cycle refrigerator and a 50 W heater. As the coupling constants change dramatically during temperature rise, we can adjust them from outside the vacuum chamber. With a constant temperature step, we measure the resonant frequency, quality factor  $Q_L$  and coupling constant  $\beta_1$  and  $\beta_2$  of the two coupling ports. As the reflections from components change during the temperature increase, the reflection coefficients are calculated by fitting their background with an order-two polynomial.

Initially the unloaded quality factor  $Q_{0,c}(T)$  of the copper cavity is measured as a function of temperature  $T$ , and the surface resistance of copper  $R_{s,c}(T)$  is calculated. Then the end-plate is replaced by one covered with a YBCO film, and the unloaded quality factor  $Q_{0,s}(T)$  is measured. Using these quality factors and two geometrical factors  $k$  and  $c$ , the surface resistance  $R_s(T)$  of the film at temperature  $T$  is given by

$$R_s(T)/R_{s,c}(T) = k(Q_{0,c}(T)/Q_{0,s}(T) - c). \quad (1)$$

For  $a = 15\text{mm}$  and  $l = 30\text{mm}$ , we have  $k = 13.903$  and  $c = 0.92808$ .

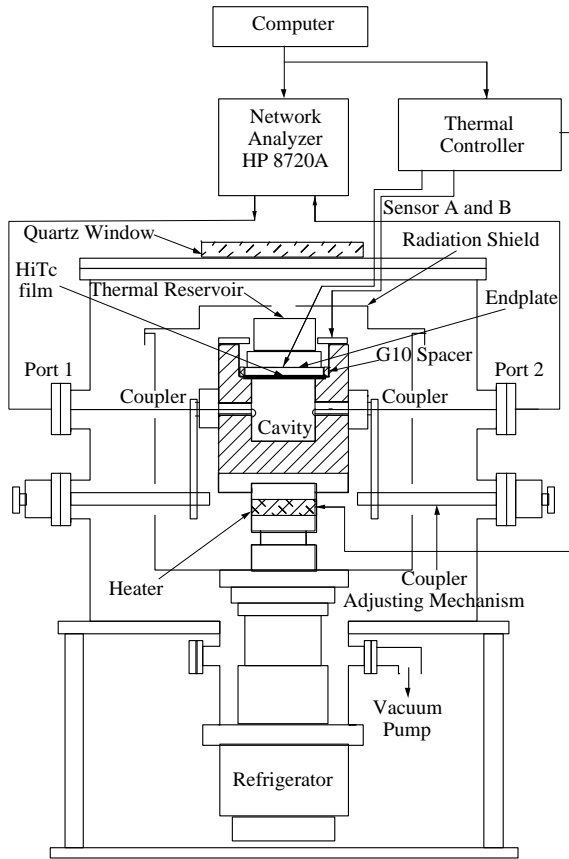


Figure 4. Experimental set-up for microwave surface resistance.

#### IV. EXPERIMENTAL RESULTS AND DISCUSSION

Fig.5 shows the surface resistance of the copper  $R_{s,c}(T)$  composing the host cavity. The value below 32.7 K falls less than 10 m $\Omega$  and remains almost constant. The value measured for the 3 GHz cavity is also shown.

As the input power to the cavity is small, the rf losses observed in high- $T_c$  materials are explained by a model of Josephson coupling between the superconducting grains. The thick solid line in Fig.6 shows the surface resistance of the in-plane aligned YBCO film and the thick dotted line shows that of the copper. The surface resistance of the sample below 71.5 K is lower than that of copper and around 1 m $\Omega$  below 45 K. As the surface resistance of the material decreases below than that of the copper, the relative error increases as described in Ref.2. Thus with a copper host cavity, the absolute measurement of a low surface resistance is substantially inappropriate. Meanwhile it has an advantage in measuring a surface resistance with the same order of copper and for a wide temperature range. Note that the situation can be improved to some extent, if we change the geometrical factors.

Before long the properties of the samples would be clarified through the analysis of the data and will be reported elsewhere. We can also obtain the complex impedance through the data analysis.

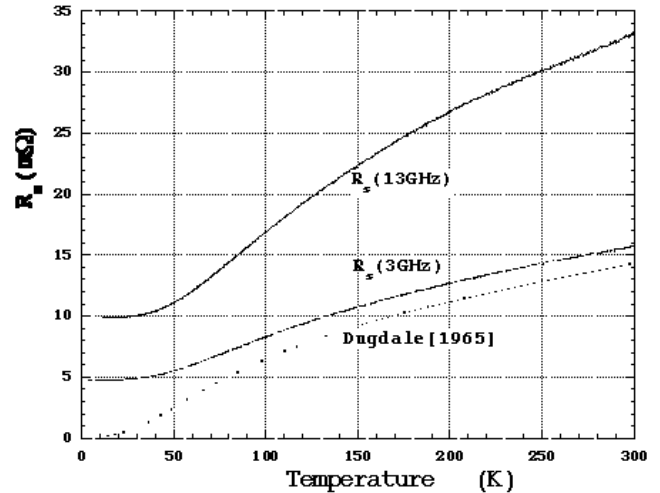


Figure 5. Microwave surface resistance of copper at 3 and 13 GHz.

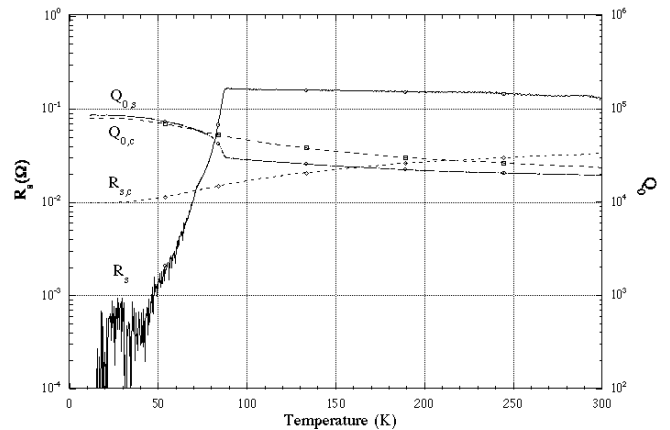


Figure 6. Microwave surface resistance and quality factor of the in-plane aligned YBCO film as well as those of the copper.

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