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Insulation of Y_2BaCuO_5 Thin Films in $YBa_2Cu_3O_{7-\delta}/Y_2BaCuO_5/Au$ Layered Films

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The effects of annealing on insulation of Y_2BaCuO_5 layers in $YBa_2Cu_3O_{7-\delta}/Y_2BaCuO_5/Au$ layered films were investigated. It was found that the dielectric strength of the Y_2BaCuO_5 layer increases from 5 kV mm^{-1} to 25 kV mm^{-1} as a result of a thermal annealing at 800 ℃ for 1 hr. In addition, the diffusion coefficient of Y in $Y_2BaCuO_5/ErBa_2Cu_3O_{7-\delta}$ layered films was evaluated from Rutherford backscattering spectra. The activation energy Q for diffusion and the frequency factor D_0 are 1.1×10^2 kJ mol^{-1} and 2.8×10^{-14} m^2 s^{-1}, respectively.

1. INTRODUCTION

It is indispensable to fabricate SIS Josephson junctions using the high-T_c oxide superconductors such as $YBa_2Cu_3O_{7-\delta}$ for both fundamental research and device applications. The attempts to fabricate tunnel junctions using MgO or $SrTiO_3$ as insulators have been reported.[1,2] The high-T_c oxide superconductors have short coherence lengths. Since a tunneling barrier is necessary to be very thin, it is required to have sufficient dielectric strength. Moreover, the interface between a superconductor and an insulator must be abrupt to fabricate SIS junctions. $YBa_2Cu_3O_{7-\delta}$ and Y_2BaCuO_5 have thermodynamical relations to be segregated according to the equilibrium phase diagram. Therefore, the abruptness of the interface and Josephson characteristics are expected to progress as a result of a thermal annealing.

In this report, the effects of annealing on the dielectric strength of the Y_2BaCuO_5 insulating layer were studied. In addition, the interdiffusion between Y_2BaCuO_5 and $ErBa_2Cu_3O_{7-\delta}$ was investigated quantitatively.

2. EXPERIMENT

The layered films were prepared by rf magnetron sputtering. The sputtering targets used in this study were made by a solid-state reaction for nominal compositions of $YBa_2Cu_{4.8}O_\delta$, $Y_2Ba_{1.5}Cu_4O_\delta$ and $ErBa_2Cu_{4.8}O_\delta$. The substrates were heated at 650 ℃ during deposition. Table I shows the sputtering conditions. $YBa_2Cu_3O_{7-\delta}$ (3000 Å)/Y_2BaCuO_5 (100-1000 Å)/Au layered films were prepared on (100) MgO to measure current-voltage (I-V) characteristics. A schematic configuration of the layered film

Table I. Sputtering conditions.

Target	$YBa_2Cu_{4.8}O_\delta$, $Y_2Ba_{1.5}Cu_4O_\delta$ and $ErBa_2Cu_{4.8}O_\delta$ sintered disks
Sputtering gas	Ar 6 mTorr + O_2 20 mTorr
Substrate temperature	650 ℃
Rf input power	100 W
Substrate-target distance	35 mm

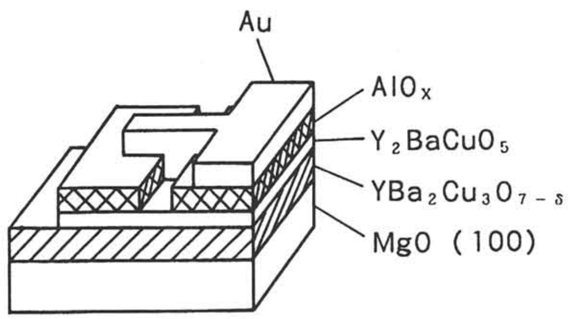

Fig. 1. Schematic configuration of an $YBa_2Cu_3O_{7-\delta}/Y_2BaCuO_5/Au$ layered film on MgO (100).

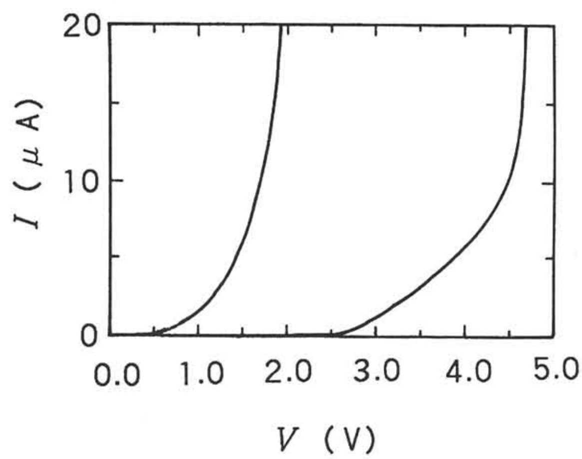

Fig. 2. Current-voltage characteristics of a $YBa_2Cu_3O_{7-\delta}/Y_2BaCuO_5/Au$ layered film with a 1000-Å-thick Y_2BaCuO_5 layer at room temperature.

is shown in Fig. 1. The $YBa_2Cu_3O_{7-\delta}/Y_2BaCuO_5$ layered films were annealed at 800 ℃ for 1 hr in an oxygen atmosphere. AlO_x thin films with a thickness of 3000 Å were sputtered on the layered films except the junction area to insulate the counter-electrodes from the $YBa_2Cu_3O_{7-\delta}$ layer. Finally, the counterelectrodes of Au thin films with a thickness of 4000 Å were evaporated. The junction area was about 1.0×10^{-3} cm^2. *I–V* measurements were carried out for the layered films at room temperature.

Y_2BaCuO_5 (1500 Å)/$ErBa_2Cu_3O_{7-\delta}$ (4500 Å) layered films were prepared on (100) MgO to investigate the interdiffusion. Since Y and Er have nearly equal ionic radii and the same valence, Y in $YBa_2Cu_3O_{7-\delta}$ is replaced with Er. The $Y_2BaCuO_5/ErBa_2Cu_3O_{7-\delta}$ layered films were annealed at 700-850 ℃ for 1 hr in an oxygen atmosphere in an infrared furnace. After annealing, the films were cooled at a rate of about 1 K s^{-1}. Rutherford back-scattering spectrometry (RBS) measurements were carried out for the resulting layered films using 1.5 MeV $^4He^+$.

3. RESULTS AND DISCUSSION

Figure 2 is *I–V* characteristics of the $YBa_2Cu_3O_{7-\delta}/Y_2BaCuO_5/Au$ layered film with the 1000-Å-thick Y_2BaCuO_5 layer at room temperature. Before annealing, drastic increase in the current through the Y_2BaCuO_5 layer occurs when the voltage is applied beyond 0.5 V. On the other hand, after annealing, it does not occur below 2.5 V. The resistivity of the Y_2BaCuO_5 layer is larger than 1.0×10^{-10} Ω cm below 2.5 V. The dielectric strength of the Y_2BaCuO_5 layer increases from 5 kV mm^{-1} to 25 kV mm^{-1}, which is as large as typical dielectric materials: quartz and alumina. Furthermore, a dielectric strength of 10 kV mm^{-1} was obtained for the annealed layered film with a 100-Å-thick Y_2BaCuO_5 layer. Although the reason for the increase of the dielectric strength is not clear, it may be due to improvement of crystal quality and/or elimination of pinholes.

Figure 3(a) shows an RBS spectrum of the as-deposited $Y_2BaCuO_5/ErBa_2Cu_3O_{7-\delta}$ layered film. It is in good agreement with a simulated spectrum (Fig. 3(b)). Figure 4 shows RBS spectra of the layered films annealed at 700-850 ℃. The interdiffusion of Y and Er becomes evident with increasing temperature, while there are no obvious changes of the spectra corresponding to elements except Y and Er at the interface. Therefore, it was turned out that the

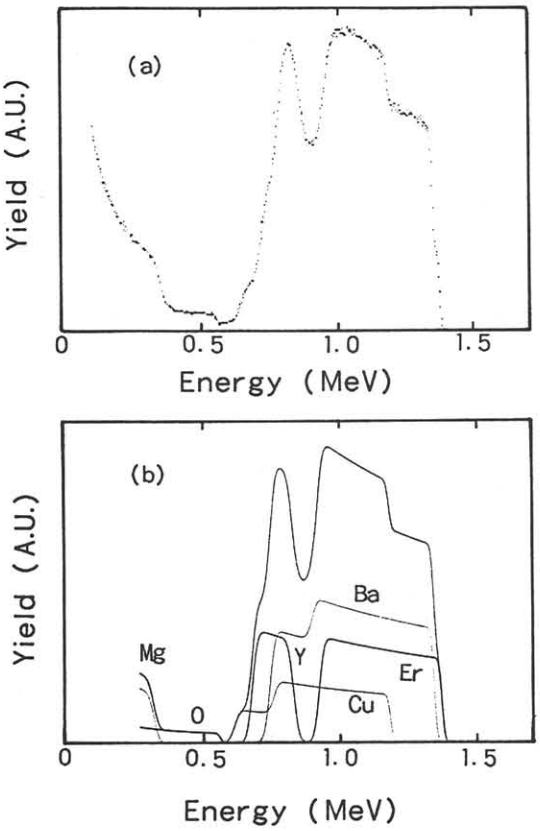

Fig. 3. (a) Backscattering spectrum for an as-deposited $Y_2BaCuO_5/ErBa_2Cu_3O_{7-\delta}$ layered film and (b) simulated spectrum.

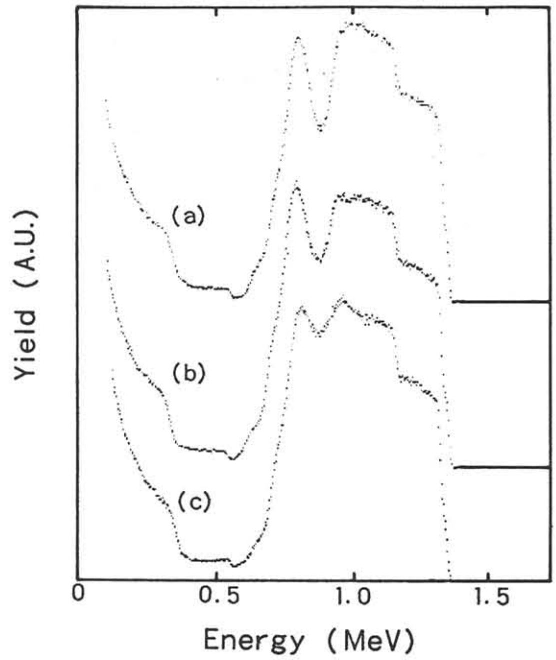

Fig. 4. Backscattering spectra for $Y_2BaCuO_5/ErBa_2Cu_3O_{7-\delta}$ layered films annealed at (a) 700 ℃, (b) 800 ℃ and (c) 850 ℃.

interface remains abrupt though the atoms at the interface diffuse during thermal annealing.

The diffusion coefficient D of Y was evaluated from RBS spectra. RBS has widely been used for determination of diffusion coefficients in solid.[3] D is determined in the following way. The energy scale in the RBS spectrum is converted into the depth scale using the energy loss values.[4] The intensity of the back scattering yield is converted into the concentration of each element. Then, the diffusion-penetration profile can be obtained. The diffusion-penetration profile conforms well to the solution of the diffusion equation for a pair of semi-infinite solids,

$$C(x,t) = C_0/2 \ \mathrm{erfc}[x/(2\sqrt{Dt})], \qquad (1)$$

where $C(x,t)$ is the concentration at a

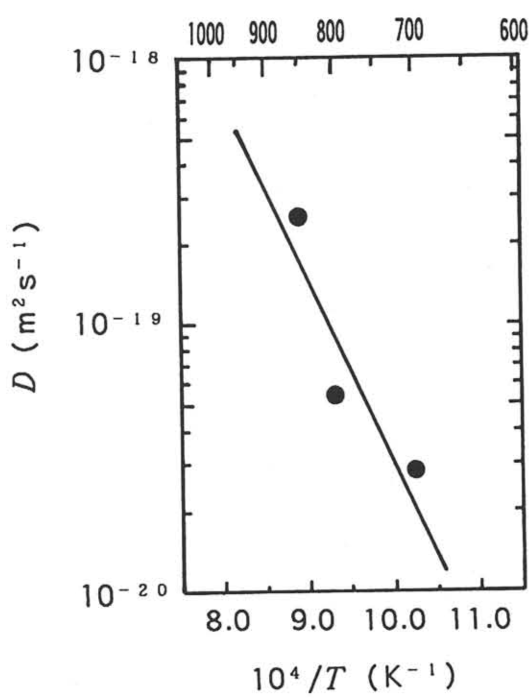

Fig. 5. Temperature dependence of the diffusion coefficient of Y in $Y_2BaCuO_5/ErBa_2Cu_3O_{7-\delta}$ layered films.

depth x after a diffusion interval t, C_0 is the initial concentration and D is the diffusion coefficient. The diffusion coefficient was evaluated from Eq. (1). Figure 5 shows the temperature dependence of the diffusion coefficient of Y into the $ErBa_2Cu_3O_{7-\delta}$ layer. The frequency factor D_0 and the activation energy Q for the diffusion can be evaluated from Fig. 5 using the Arrhenius equation,

$$D = D_0 \exp(-Q/RT). \qquad (2)$$

In this way, the activation energy Q and the frequency factor D_0 were evaluated to be 1.1×10^2 kJ mol^{-1} and 2.8×10^{-14} m^2 s^{-1}, respectively.

4. CONCLUSIONS

The effects of annealing on the insulation of the Y_2BaCuO_5 layer in the $YBa_2Cu_3O_{7-\delta}$/Y_2BaCuO_5/Au layered films were investigated. It was found that the dielectric strength of the Y_2BaCuO_5 layer increases from 5 kV mm^{-1} to 25 kV mm^{-1} as a result of the thermal annealing at 800 ℃ for 1 hr. In addition, the diffusion coefficient D of Y in the Y_2BaCuO_5/$ErBa_2Cu_3O_{7-\delta}$ layered films was evaluated from the RBS spectra. The penetration distance for diffusion at 800 ℃ for 1 hr is $\sqrt{Dt}$ ~ 200 Å. Therefore, within about 200 Å at the interface region, $YBa_2Cu_3O_{7-\delta}$ and Y_2BaCuO_5 are expected to separate each other.

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