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Preparation of $YbBa_2Cu_3O_{7-x}$ Films on Si(100) Substrates Using $SrTiO_3$ Buffer Layers

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Formation of superconducting $YbBa_2Cu_3O_{7-x}$(YBCO) films on $SrTiO_3$/Si(100) structure is described, in which $SrTiO_3$ films were deposited on Si substrates using a focused electron beam evaporation method, while YbBCO films were deposited using a DC arc discharge evaporation method. It has been found that the $SrTiO_3$ buffer layer is effective to transmit the crystalline property of a Si(100) substrate to the YbBCO film, as well as to block diffusion of Si atoms to the YbBCO film. The critical temperature of zero resistivity of the film was 73K.

§ 1. Introduction

Preparation of high-Tc superconducting films on Si substrates is very interesting from viewpoints of device applications. However, it has been found difficult to grow superconducting films directly on Si substrates, because of interdiffusion of constitution atoms of the film and substrate as well as formation of the surface SiO_2 layer on Si. So far, excellent epitaxial films have been grown on Si substrates using Y_2O_3/YSZ buffer layers[1]. However, no successful growth of superconducting films has been reported on $SrTiO_3$/Si structures, although bulk $SrTiO_3$(STO) crystals are often used as excellent substrates for growing them.

In this paper, we demonstrate for the first time that C-axis-oriented $YbBa_2Cu_3O_{7-x}$ (YbBCO) superconducting films are formed on (100)-oriented STO films on Si(100). STO is considered to be one of the best buffer layers on Si, since the lattice mismatch between the film and substrate is only 1.7% for both (100) and (110) substrates when a unit cell of STO is rotated around the surface normal axis by 45° and 90°, respectively, and since STO acts as a degenerate semiconductor as well as an insulator by doping of Nb atoms or by control of oxygen content.

§ 2. Experimental Procedure

STO films were deposited on Si(100) substrates using a focused electron beam evaporation method, while YbBCO films were deposited on them using a DC arc discharge evaporation method. The focused e-beam apparatus which composed of a gun room, a transport column and a deposition chamber is shown in Fig. 1. Typical acceleration energy, current, and diameter of the beam are 12KV, 8mA, 0.5mm, respectively. Prior to deposition of a STO film, a Sr layer about 10nm thick was deposited on a Si(100) substrate kept at 750 ℃ in order to deoxidize the SiO_2 layer on Si. Then, an STO

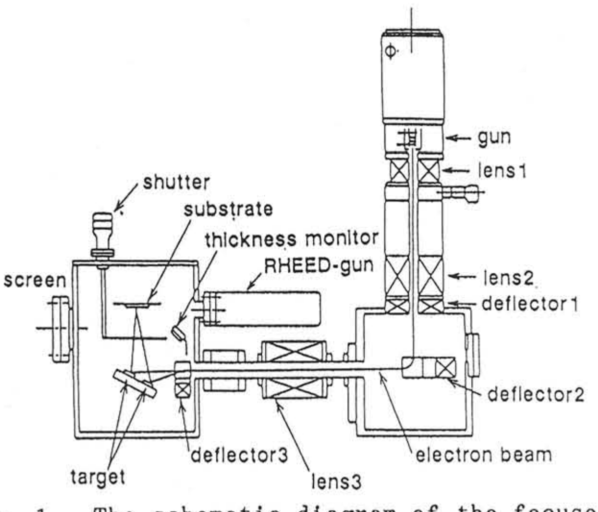

Fig. 1. The schematic diagram of the focused e-beam system.

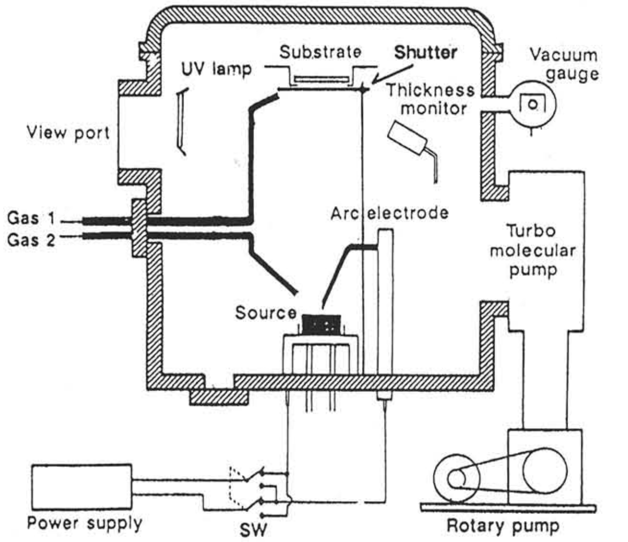

Fig. 2. The schematic diagram of the arc discharge evaporation system.

film was successively deposited on that structure at 750 ℃ by evaporating a single crystal STO grain. The deposition rate of STO films was 1 to 2 nm/min and a typical film thickness was 80 nm. After the deposition, the samples were annealed at 800 ℃ for 1 hour in O_2 atmosphere in order to improve crystalline quality of the film.

A DC arc discharge evaporation apparatus is shown in Fig. 2. Details of the preparation method of YbBCO films are described elsewhere[2]. Briefly, the vacuum pressure during deposition was kept at $2 \sim 4 \times 10^{-2}$ Torr by introducing O_2 gas into the chamber. UV light was illuminated to produce ozone gas. The electrode for arc discharge was made of Yb metal, while the evaporation source were made of $Y_xBa_yCu_3O_z$(x=2.4,y=2.1) ceramics. The substrate temperature during deposition was kept in the range between 600 and 750 ℃. The deposition rate was $2 \sim 3$ nm/min, and a typical film thickness was approximately 100 nm. During the deposition, the direction of the discharge voltage was changed with appropriate intervals in order to adjust the composition of the films. After the deposition, oxygen gas was introduced in the chamber to an atmospheric pressure, and the samples were annealed at 600 ℃ for 1 hour and at 450 ℃ for 1 hour. The crystalline quality of the films was characterized by X-ray diffraction analysis, the composition ratio was analyzed by secondary ion mass spectrometry (SIMS), and the electrical properties were measured by a DC four-point probe method.

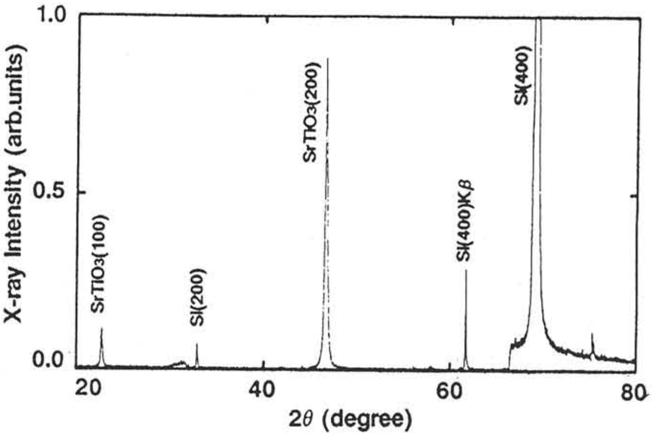

Fig. 3. The X-ray diffraction pattern of a $SrTiO_3$ film on Si(100).

§ 3. Result.

An X-ray diffraction pattern of an STO film on Si(100) is shown in Fig. 3. In this figure, only (100) and (200) peaks of the STO film can be seen besides the peaks of Si substrate, which indicates that the film is preferentially oriented along the (100) direction. On the other hand, STO films deposited without Sr layers were amorphous or polycrystalline and YbBCO films deposited on them showed no superconductivity. These results indicate that an STO buffer layer plays a role not only to block inter-diffusion of constitutional atoms, but also to transmit the crystalline property of the Si substrate to the films.

Figure 4 shows the temperature dependence of the X-ray diffraction patterns of YbBCO films on STO/Si(100) structures. We can see that the diffraction peaks are strong when the deposition temperature is between 650 ℃ and 700 ℃. However, when the deposition temperature is higher than 725 ℃, an Yb_2O_3(400) peak appears in the pattern and superconductivity of the film is destroyed. On the other hand, deposited films are hardly crystallized below 650 ℃. Figure 5 shows the ρ -T measurement of the films, which reflects the result of the Fig. 4. The highest critical temperature (73K) is observed in the sample deposited at 675 ℃. However, we speculate from X-ray diffraction analysis that the variation of Tc among the samples deposited at temperatures ranging from 650 ℃ to 700 ℃ is not essential.

Depth profile of the YbBCO/STO/Si(100) structure which was deposited at 700 ℃ is shown in Fig. 6. Because of the difference of sputtering rate, depth scale among layers

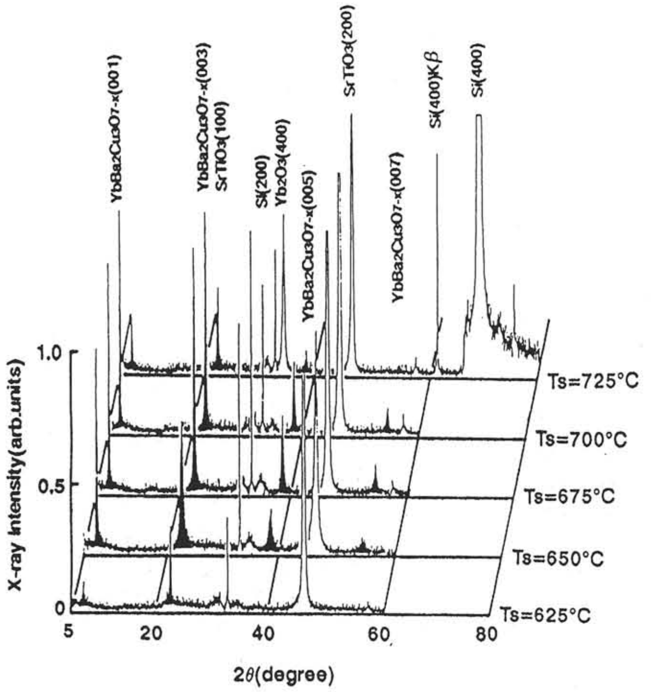

Fig. 4. The X-ray diffraction pattern of $YbBa_2Cu_3O_{7-x}$ films on $SrTiO_3$/Si(100) structures.

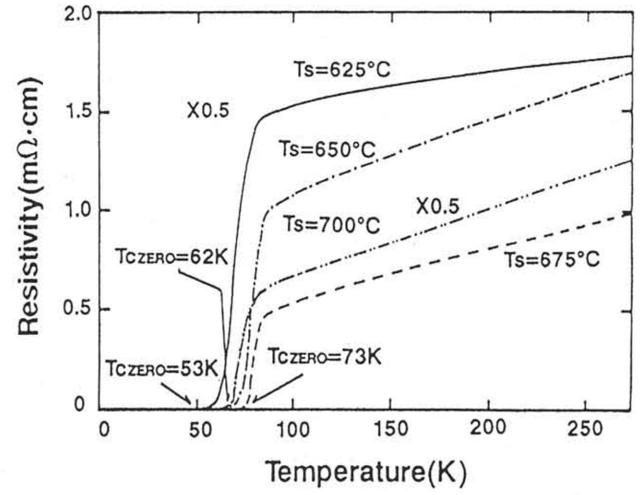

Fig. 5. Temperature dependence of resistivity of $YbBa_2Cu_3O_{7-x}$ films

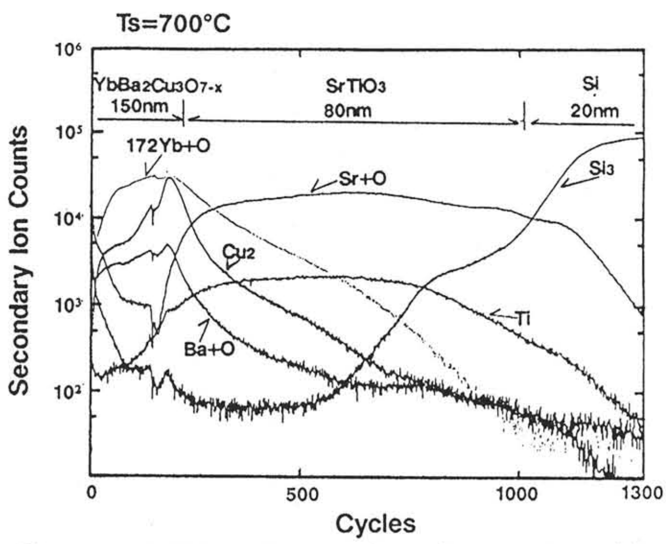

Fig. 6. SIMS analyses of a $YbBa_2Cu_3O_{7-x}$ film on $SrTiO_3$/Si(100) structure.

is not identical. It can be seen that the STO film reacts with Si substrate, but Sr atoms in the film do not diffuse in the YbBCO film. It can also be seen that Yb atoms diffuse in the STO film and that the concentration of Cu increases around the interface between the YbBCO film and the STO buffer layer. Although, we can not explain the origin of Cu-rich layer, we think that this problem is one of the reasons why the critical temperature is lower than 80K in these films.

§ 4. Conclusion

Superconducting YbBCO films were prepared on Si(100) substrates using $SrTiO_3$ buffer layers 80nm thick. It was found that the best deposition temperature of YbBCO films was between 650 ℃ and 700 ℃. It was also found that the STO buffer layer was effective to transmit the crystalline property of a Si(100) substrate to the YbBCO film, as well as to block to the diffusion of Si atoms to the YbBCO film. Tc(zero) of the film so far obtained was 73K. Consequently, we judged that the STO films were effective for buffer layer when superconducting thin films were deposited on Si(100) substrate. Recently,we succeeded in growing STO films epitaxially on Si(100) substrates, in which the chanelling minimum yield in Rutherford backscatterring spectroscopy was 28% near the surface of the film[3]. Better superconducting properties will be obtained by use of the epitaxial buffer layer.

REFERENCES

[1] H.Myoren, Y.Nishiyama, N.Miyamoto, Y.Kai, Y.Yamanaka and Y.Osaka: Jpn.J.Appl.Phys. 29(1990).L955

[2] H.Nohira and H.Ishiwara: Jpn.J.Appl.Phys. 29(1990).L2466

[3] H.Mori and H.Ishiwara: Jpn.J.Appl.Phys. (in press)