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The Temperature Dependence of Critical Current in $YBa_2Cu_3O_{7-d}$ Thin Films Deposited on MgO by an Eclipse PLD

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$YBa_2Cu_3O_{7-d}$ thin films were deposited on MgO single crystals by means of an eclipse pulsed laser deposition (PLD) method. A deposited film exhibited the critical temperature of 74 K. The dependence of critical current on temperature was well explained by the Ginzburg-Landau theory. Although the theory is described only near critical temperature, experimental results are well fitted in a wide range between 25 K and 74 K. It stems from the strongly Josephson-coupling regime.

I Introduction

Recently the $YBa_2Cu_3O_{7-d}$ (YBCO) thin films have been applied to superconducting devices such as Josephson junctions [1,2], flux flow transistors [3,4], superconducting quantum interference devices (SQUID) [5]. YBCO thin films are more and more significant for electronic devices nowadays. It is of importance to investigate fundamental properties of YBCO thin films: the critical temperature and the critical current.

Researchers have challenged a variety of fabrication techniques to deposit YBCO thin films since the discovery of the material. Among these deposition techniques, sputtering and pulsed laser deposition (PLD) are possibly the most promising deposition methods. In sputtering, there is a problem in principle; resputtering. The resputtering is caused by oxygen anions generated in a sputtering chamber. The generation of oxygen anions is inevitable because YBCO is an oxide material. On the other hand, PLD is free from resputtering because of the absence of electric field in the chamber, but another problem of a droplet should be considered. A droplet, a big cluster of atoms or ions, deteriorates a deposited film. In order to avoid the deterioration, an eclipse PLD method is effective [6].

In this article YBCO thin films were deposited on MgO substrates by an eclipse PLD. The dependence of critical current on temperature was investigated after patterning of the YBCO films was performed.

II Experimental details

A commercially available stoichiometric single target was used; 25 mm in diameter with a thickness of 2 mm. The target was rotated at 100 r.p.m. for a uniform irradiation. A KrF excimer laser was used for the ablation, which oscillates at 246 nm. The output energy and repetition frequency was 100 mJ and 8 Hz, respectively.

A (100) MgO single crystal was used as a substrate. The substrate was prepared in the form of a square of 100 mm^2 with a thickness of 2 mm. MgO have been widely used as a substrate for YBCO thin films regardless of large misfit of 7.7%, because the dielectric properties are excellent; low dielectric constant and loss tangent. The substrate was cleansed in acetone and in ethanol one after another repeatedly using an ultrasonic cleaner. A cleansed substrate was dried in air and put in the deposition chamber in such a way that the substrate was parallel to the target (on-axis configuration). The substrate was gripped with a sample holder on which an SiC heater was mounted. The substrate temperature was elevated up to 740 °C during the deposition, which was monitored with a thermocouple attached to the sample holder.

The deposition chamber was evacuated to $3*10^{-6}$ Torr with a turbo pump. The deposition was performed under an oxygen atmosphere for an hour. The deposition time corresponds to the film thickness of 90 nm. After the deposition the chamber was filled with oxygen gas. The substrate was cooled down in the chamber slowly to 400 °C for 30 min. and then to room temperature naturally. The treatment makes us to omit a post-deposition anneal in an oxygen atmosphere.

Deposited films were patterned to be in the form depicted schematically in Fig. 1. The patterning was performed by a chemical etching with a phosphoric acid with the help of a photolithography with an Az resist and a photo mask.

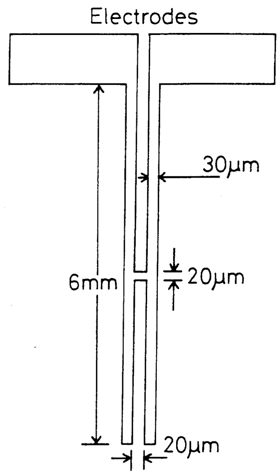

Figure 1. An illustration of patterned YBCO films. Chemical etching was performed with phosphoric acid.

The resistivity and I-V characteristic of the deposited film were obtained by an ordinary four-port method. The temperature dependence was obtained using a liquid helium cryostat and a computer controlled heater attached to the sample holder. The critical temperature was defined as that where the gradient of the resistance to temperature is at maximum.

III Results and discussion

An x-ray diffraction pattern of the deposited YBCO films showed ten (00I) peaks from YBCO as well as a strong peak (2θ=42.8 degree) corresponding to an MgO substrate. The results indicated that the film is preferably oriented in the manner that c axis is normal to the surface. The film thickness was 90 nm, which was determined by a needle-contact-type thickness profiler.

The temperature dependence of the resistivity is shown in Fig. 2. The resistivity is calculated including the dimension of the etched film. The figure shows that the transition occurs steeply at 74 K. It indicates the existence of only one phase. The oxygen deficiency is estimated to be 0.37 based on the data reported previously [7].

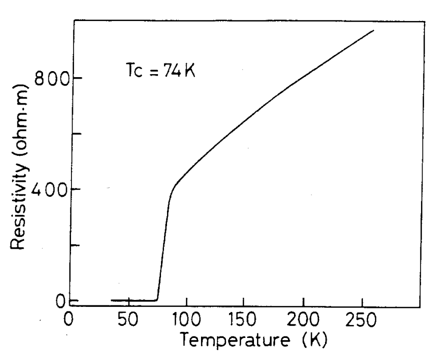

Figure 2. A temperature dependence of resistivity. The superconducting transition temperature (Tc) is 74 K.

The I-V characteristic was measured between 25 K and 72 K. Typical results (T=25 K, 50 K, 65 K, and 72 K) are shown in Figs. 3-6. Each figure shows that when the current is small the voltage is zero. The feature indicates that the superconducting current occurs. If the current reaches a critical current, for example 42 K for T=50 K, a voltage increases without the current increase. The occurrence of voltage drop indicates the break of the superconducting state. The feature is of the case regardless of the direction of the current from the fact that the data is symmetrical at the origin.

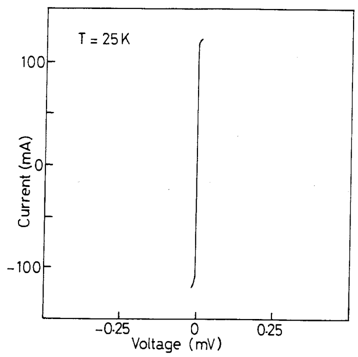

Figure 3. The I-V characteristic at T=25 K.

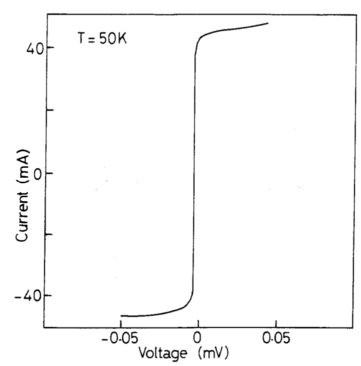

Figure 4. The I-V characteristic at T=50 K.

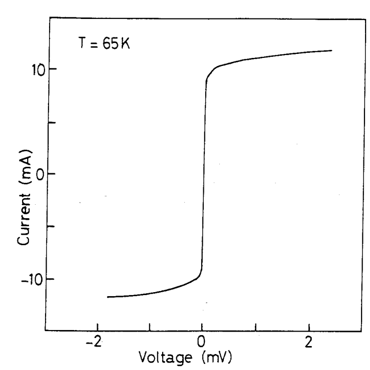

Figure 5. The I-V characteristic at T=65 K.

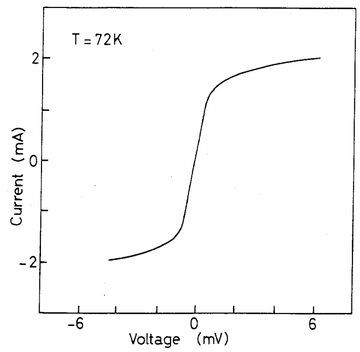

Figure 6. The I-V characteristic at T=72 K.

As the temperature becomes higher, the critical current becomes smaller as is obtained from the figures. The relation between the critical current and temperature is plotted with closed circles in Fig. 7. It clearly shows that the critical temperature monotonically decrease with the temperature. A solid line in the figure is drawn on the basis of the Ginzburg-Landau (GL) theory, which states that the critical current is in proportion to $(1\text{-}T/Tc)^{3/2}$. Tc means the critical current and a coefficient is an adjustable parameter. The observed data agree well with the theory, when the coefficient is 225 mA.

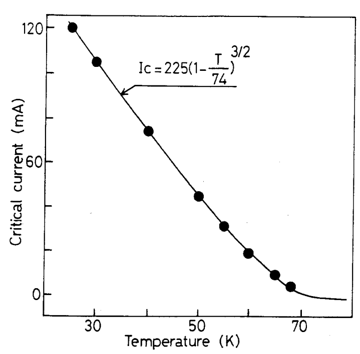

Figure 7. The temperature dependence of the critical current. Closed circles are obtained from the experiment. A solid line was drawn on the basis of the Ginzburg-Landau theory.

J.R. Clem *et al.* have reported that granular superconductors show the crossover effect between Ambegaokar-Baratoff (AB) and GL temperature dependence on critical current density [8]. The AB temperature dependence, that the critical current is in proportion to (1-T/Tc), is based on the weakly Josephson coupled regime and observed in granular superconductors. The AB dependence shows convex one in the critical current density as a function of temperature. The dependence is observed under the crossover temperature. From the crossover temperature up to the Tc, GL dependence is observed where current - induced gap suppression is dominant.

The crossover has been also reported in YBCO ceramics and films [9]. The literature shows the decrease in the crossover temperature with the decrease of the Tc. When the Tc is under 80 K the crossover occurs no higher than 10 K. The Tc is determined by the oxygen deficiency. As the oxygen deficiency is strong, the coherence length becomes small followed by the decrease of the crossover temperature. For instance, an YBCO sample with the oxygen deficiency between 0.2 and 0.25 showed the superconducting transition at 80 K where the crossover temperature was situated between 10 and 20 K. The coherence length was 1 nm and the size of superconducting domain is around 1nm.

The literature treated the YBCO films deposited on $SrTiO_3$ and $LaAlO_3$ substrates. The lattice mismatch with YBCO films is less than 3%. In this article the MgO substrate was used whose lattice mismatch is 7.7%. The discussion in the literature is consistent with our results that YBCO films with Tc of 75 K showed Ginzburg-Landau temperature dependence in a wide range. It implies a strongly Josephson-coupling regime where the size of superconducting domain is less than 1nm.

IV Conclusions

YBCO thin films are deposited on MgO substrates by means of an eclipse PLD method. The YBCO films were patterned by means of chemical etching by phosphoric acid with the help of photolithography. The I-V characteristic was measured, from which temperature dependence of the critical current was obtained. The dependence is in an excellent agreement with the Ginzburg-Landau theory over a range between 25 K and 72 K. It stems from the strongly Josephson-coupling regime.

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