EFFECT OF SUBSTRATE TEMPERATURES ON THE PROPERTIES OF $YBa_2Cu_3O_{7-\delta}$ THIN FILMS

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Abstract: $YBa_2Cu_3O_{7-\delta}$ thin films have been deposited by pulsed laser deposition (PLD) on single crystalline $SrTiO_3$ (001) substrates. The deposition was carried out at different substrate temperatures T_S=660-740°C. The result shows that the films are strongly oriented with the *c*-axis. The optimal critical temperature (T_C) and critical current density (J_C) are obtained at T_S=690-700°C, with values of T_C=91K and J_C=1.1 MA/cm^2 at 77K and in zero magnetic field.

1. Introduction

The discovery of high-temperature superconductivity set off an explosion of research on the development of high-temperature superconducting (HTS) devices based on $YBa_2Cu_3O_{7-\delta}$ thin films, including microwave devices, Josephson junctions and transistors [1].

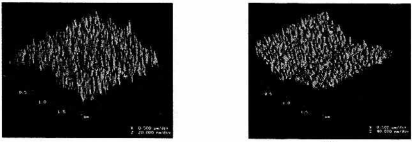
The films employed in this study were deposited by pulsed laser deposition (PLD). The duration of a laser pulse can range between nanoseconds and femtoseconds, which can create extremely energetic pulses in very localized areas [2]. Ablated species from a target come into oxygen environment and transfer to the substrate. A relatively high oxygen background pressure can be used with this technique. This allows for the fabrication of oxide and superconductor films with a nearly perfect stoichiometry.

2. Experiment procedure

The $YBa_2Cu_3O_{7-\delta}$ (YBCO) thin films were prepared by PLD. Before deposition, the single crystalline $SrTiO_3$ (001) substrates were washed with 5% HNO_3 solution in an ultrasonic cleaner and subsequently by deionized water, acetone and ethanol. The excimer laser (λ = 248 nm) was operated at 250 mJ/pulse for 30 min for each deposition.

The substrate is mounted on the heater in the cross-area of the PLD plume caused by the beam and its temperature (T_S) was in the range of 660-740°C. The ambient oxygen pressure was kept at 0.2 mbar. The films were annealed at 400°C for about 1 h and cooled down to room temperature for about 2-3 h in the ambient oxygen pressure of 1 atm. The films thickness is about 260 nm. The 1×1 cm^2 samples were patterned, yielding bridges 50 μm long and 20 μm wide.

The microstructures of the samples were analysed by means of X-ray diffraction with CuK_α radiation, atomic force microscopy (AFM). DC electrical resistance measurements were carried out using the standard four-probe method with silver alloy solders as electrical contacts. The transport critical current densities (J_C) of the samples were measured at 77K using the four-probe method with the 1 μV/cm criterion with microbridge of 20 μm × 50 μm patterned by photolithography.



(a) (b)

Fig.1. AFM side-view images of YBCO/STO films at T_S=680^{0}C (a) and T_S=700^{0}C (b).

3. Results and discussion

In AFM experiments, we observed a surface morphology characteristic of island growth, with occasional out-growths, see Fig. 1. Mixed growth consists of island after the first monolayer forms successfully (Stranski-Kranstanov mode) [3]. The growth islands had a typical lateral size of about 50-60 nm. This is very similar to the results found by other authors under the same deposition conditions [4].

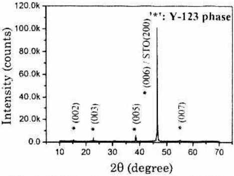


Fig.2. XRD θ-2θ patterns of the YBCO thin film on STO substrate

The presence of the *(00l)* peaks in the XRD pattern of the films corresponds to a well-crystallized single orthorhombic phase and *c*-axis-oriented film, as shown in Fig. 2. The *c*-axis of the film has a normal value of 11.68Å. The rocking curves of the (005) YBCO reflection showed a narrow shape with similar FWHM of 0.2^0 for the film. It shows that the YBCO thin films of high structural quality have been epitaxially grown on STO substrates.

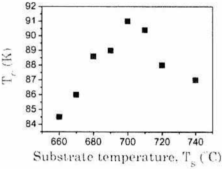


Fig.3. Transition temperature of YBCO films vs. substrate temperature.

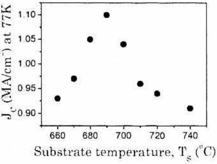


Fig.4. Critical current density of YBCO films (77K & 0T) vs. substrate temperature

The dependence of substrate temperatures on the transition temperature (T_C) and critical current density (J_C) of YBCO thin films is shown in Fig. 3 & Fig. 4. It is shown that the optimal transition temperature (T_C=91K) was obtained at a T_S of around 700°C, while the highest J_C (1.1 MA/cm^2 at 77K) was achieved at 690°C. It is shown that the substrate temperatures of T_S=690-700°C are enough high to allow sufficient surface migration and interdiffusion of the atoms for the formation of the desired orthorhombic YBCO crystal structure. In application of HTS thin films, critical current density is more important than transition temperature in coated conductors, a deposition temperature of 690°C was chosen.

The field-dependent J_C measured at liquid nitrogen temperature is plotted in Fig. 5. In this configuration, the Lorenz force is perpendicular to the *ab*-plane and vortices induced by the applied magnetic field have to cross the superconducting CuO_2 planes for flux flow to occur. It is shown that J_C decreases rapidly when the field is applied parallel to the *c*-axis of the film. The sudden drop in J_C as soon as a magnetic field is applied (B<0.25 T) is due to the effect of Josephson weak links at the grain boundaries [5].

The macroscopic pinning force $F_P=J_C \times B$ for thin film is shown in small picture (Fig. 5). In the F_P vs. B curve, the broad peak in a rather low-field region (B is about 0.35 T) and the long tail in the high-field region suggest an unconventional pinning behavior. The fact that the pinning force peak appears in a quite low field region indicates that the pinning of the pinning centers in this film is not so weak. The low macroscopic pinning force is due to the weak elastic properties of the flux-line lattice that is possibly related to the highly anisotropy layered structure of this material.

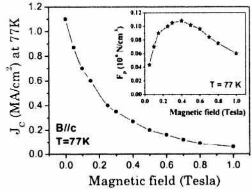


Fig.5. J_C value as a function of applied magnetic field at 77 K for a 20 μm wide bridge patterned into the YBCO film at T_S=690°C.

4. Conclusions

The successful preparation of high quality YBCO superconducting thin films by pulsed laser deposition is shown. Films deposition on single crystalline $SrTiO_3$ (001) substrate at deposition temperature of 690°C present transition temperature, T_C=90K and critical current density, J_C=1.1 MA/cm^2 at 77K. These films have a sufficiently good quality to make the high-performance microwave components.

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References

1. U. Brinknrann, *Lambda Highlights* No.**19/20** (1989).
2. Q. Y. Ying, H. S. Kim, D. T. Shaw and H. S. Kwok, *Appl. Phys. Lett.* **55** (1989) 1041-1043.
3. H. -U. Habermeier, *Journal of Superconductivity: Incorporating Novel Magnetism* **13** (2000) 871-875.
4. C. J. van der Beek, M. Konczykowski, A. Abal'oshev, I. Abal'osheva, P.Gierlowski, S. J. Lewandowski, M.V. Indenbom and S.Barbanera, *arXiv:cond-mat/0202243 v2-22 Aug* (2002) 1-11.
5. L. Hua, J. Yoo, H. Kim, H. Chung, G. Qiao and G. Yuan, *Physica C* **337** (2000) 165-168.