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Off-axis pulsed laser deposited $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ thin films for device applications

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Abstract

$\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (YBCO) thin films deposited by off-axis pulsed laser deposition could be used for fabricating multilayer devices. Growing YBCO films with high critical current density and high T_c (T_c is around 90 K and J_c is above 10^7 A/cm² at 77 K), there was a tendency that the surface morphology of YBCO films is rough. This causes problems in fabricating multilayer devices that require a smooth surface. In this work, we have developed two-step procedures of growing YBCO thin films with high critical current and a smooth surface for multilayer device applications. In the two-step procedure, we first grew YBCO film with higher T_c (T_c is around 90 K, but usually the surface is with defects like holes), next we planarized the film by growing the film with lower T_c (T_c is around 83 K and the surface is smooth). YBCO films deposited at low temperatures have critical current densities (J_c) around 10^6 A/cm² at 77 K in zero magnetic field. These films are almost free from laser droplets and outgrowth-free surface. In two-step procedures, we could grow films with a smooth surface and high critical current density. Methods for growing smooth surfaces in two-step procedures will be presented.

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Keywords: YBCO thin films; Off-axis pulsed laser deposition; Surface roughness

1. Introduction

Multilayer thin film is a very important part in electronic device applications. One main requirement in multilayer devices is that each layer must have smooth surface. Nevertheless, it is not easy to grow smooth $\text{YBa}_2\text{Cu}_3\text{O}_y$ (YBCO) film with high current density and high T_c (T_c is around 90 K and J_c is above 10^7 A/cm² at 77 K) in multilayer pro-

cedures because there is a tendency that the surface morphology of YBCO films is rough [1–4].

The pulse laser deposition (PLD) is one of the most suitable techniques to fabricate high temperature superconducting thin films. But the most serious problem of the laser deposition, concerning device application, is the moderate surface quality. To obtain high-quality thin film with smooth surface and electrical properties, in the work we develop two-step procedures of growing YBCO thin films. Under such procedures, the as grown YBCO films are almost absence of laser droplets and outgrowth-free surface. The root mean square (rms) roughness is below 4 nm over a scanned area

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of $20 \times 20 \mu\text{m}^2$. Besides, the YBCO films possess high critical current density.

2. Experimental

YBCO films were prepared onto $\text{SrTiO}_3(100)$ substrates by the off-axis PLD [5] technique. Our off-axis PLD system consists of a Lambda Physik ArF excimer laser operated at 193 nm and 10 Hz, with the beam focused onto a stoichiometric YBCO target. The energy fluence of the laser beam was about 1.35 J/cm^2 . Instead of manipulating target, we controlled the laser beam path to scan over the surface of the target to provide for uniform erosion. This way can also improve the thickness uniformity of film. The target was repolished after every film deposition.

The substrate was heated by radiation method. The heaters were two halogen lamps and each one is 1000 W. To increase temperature uniformity around the substrate, the substrate holder was kept rotating during deposition. The deposition temperature was measured on substrate holder by a thermocouple. The temperature measured by thermocouple is a little different from the effective temperature of YBCO thin film because they have different radiation absorptions. But it still can be used to be a deposition parameter to reveal relative temperature. The oxygen pressure was kept at 400 mTorr in each deposition. All the films were $200 \pm 20 \text{ nm}$ thick. The atomic force microscopy (AFM) was used to determine the surface morphology of films.

3. Results and discussion

Fig. 1 is the AFM micrograph of a typical YBCO film deposited at 620°C . It is obvious that the surface of film grown at this temperature is filled with holes with typical diameters of $0.2\text{--}2 \mu\text{m}$ and depths of $200\text{--}800 \text{ \AA}$. These holes are probably resulting from incomplete film coalescence [4]. The average roughness and rms roughness of the surface are 156.0 and $194.9 \text{ \AA}$, respectively. Although the surface is rough, the transport properties are good. The critical temperature T_c is above

Fig. 1. The surface micrograph of YBCO thin film deposited at 620°C . The average roughness and rms roughness of the surface are 156.0 and $194.9 \text{ \AA}$, respectively.

89 K and the critical current density J_c is over 10^7 A/cm^2 at 77 K . The reason for high critical current density should be that magnetic vortices are pinned by holes as the pinning centers [6].

To obtain smoother YBCO films, we can deposit films at lower temperatures. Nevertheless, the transport properties of these films are degraded. This can be seen from the AFM micrograph of a film deposited at 560°C shown in Fig. 2. It is very clear that holes have disappeared completely and the surface is very smooth. The average roughness

Fig. 2. The surface micrograph of YBCO thin film deposited at 560°C . The average roughness and rms roughness of the surface are 21.9 and $35.7 \text{ \AA}$, respectively.

and rms roughness are only 21.9 and 35.7 Å, respectively.

Nevertheless, T_c is reduced to 83 K and J_c is degraded to about 10^6 A/cm² at 77 K. For electronic applications, having good electrical properties is a basic requirement. Losing good electrical properties to improve the surface morphology is not a good choice.

To possess both good electrical properties and smooth surface at the same time, we adopted two-step procedures to grow YBCO films. First we deposited the film, which has high T_c and J_c but rough surface, at 620 °C as the bottom YBCO buffer layer of about 150 nm thick. Then we deposited the YBCO film, which has smooth surface but low T_c and J_c , of about 50 nm thick at 560 °C onto the bottom layer. The finished film is consisted of the first bottom YBCO layer with good electric properties, and the upper YBCO film with smooth surface. The whole processes were completed in situ and only the deposition temperatures were varied. Fig. 3 shows the surface morphology of the YBCO film deposited by two-step procedures. The surface is quite smooth that average roughness and rms roughness are 39.2 and 48.6 Å, respectively. Moreover, the electrical properties are pretty good that the T_c is about 89 K and the J_c is above 10^7 A/cm² at 77 K. The behavior of re-

Fig. 3. The surface micrograph of YBCO thin film deposited by two-step procedures. The average roughness and rms roughness of the surface are 39.2 and 48.6 Å, respectively.

sistance versus temperature plot of the two-step processed YBCO film is similar to that of the YBCO film deposited at 620 °C because the dominant part of the two-step YBCO film is deposited at 620 °C as shown in Fig. 4. Hence, we have successfully grown YBCO film with smooth surface and high J_c .

To confirm the properties of the two-step processed YBCO film, we used SQUID system to measure the hysteresis loop of the bilayer film. The change of the magnetization, ΔM , in the hysteresis loop is related to the strength of pinning force of film and the critical current density. Fig. 5 clearly shows that the pinning force of two-step processed film is greater than the film deposited at lower temperature. It is due to the pinning sites of smooth film smaller less than two-step processed film to cause the result. We considered that some holes of the bottom film were not “filled up” but “covered” by the smooth film. And those unfilled holes act as the pinning sites to pin the vortices. So the two-step processed film could possess wider hysteresis loop show high critical current density.

Fig. 4. Resistance versus temperature plots for YBCO films deposited at different conditions.

Fig. 5. The hysteresis diagrams of YBCO films deposited at 560 °C and by two-step procedures at 77 K.

4. Conclusion

We have developed the two-step off-axis procedures of growing smooth YBCO films with good transport properties. These YBCO films possess both high critical temperature and high critical current density at 77 K. Off-axis arrangements can reduce the droplets and precipitates on the film, so the films we made are almost droplet-free and

precipitate-free. The surface morphology is quite smooth. The two-step procedures are quite simple and easy to use. We therefore conclude that the two-step off-axis procedures would be one of the suitable choices for multilayer superconducting electronic applications.

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