Manipulation of $G_1Ba_2Cu_3O_{7-x}$ Film Properties by Simply Changing Growth Temperature with RF Sputtering Method

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Abstract. We have investigated the relationship between $J_c$ (the critical current density) and $H$ (applied magnetic field magnitude) for $Gd_Ba_Cu_O_{7-x}$ (GdBCO) films grown from 750°C to 850°C by RF sputtering. Measurements of $J_c(H, \theta)$ (the magnetic-field angular dependence of the critical current density) reveal that film B (800°C) shows enhanced pinning compared with C (850°C), A (750°C) (Gd)BCO films. The film C (850°C) is the most anisotropic. We speculate that a lot of stacking faults exist in film C (850°C), based on a broad peak along ab-plane and no peak along c axis from the $J_c$ angular measurements together with the small anisotropy parameter $\gamma = 3$. The speculation is proved by angular dependence measurement of film C (850°C) after high temperature process in oxygen.

1. Introduction

Higher critical current carrying ability ($J_c$) in applied magnetic fields are very important for (Re) BCO films. Flux pinning improvement in (Re) BCO films is one basic way to improve $J_c$ in applied magnetic fields. Up to date, anisotropic pinning analysis of (Re) BCO films has been of much interest [1-3]. Low angular anisotropy of $J_c$ value is needed for many applications with (Re) BCO films. A variety of means have been proposed to introduce Nano structural defects into (Re) BCO films for the improvement of $J_c$ values in $H$. These methods include secondary phase impurities [4-6], substrate surface modifications [7-11], and multilayers[1]. Many researchers have investigated the angular, fields, and temperature dependency of $J_c$ for (Re) BCO samples by new artificial flux pinning methods. But little attention was paid to researching flux pinning properties for pure (Re) BCO samples at different deposition conditions.

In this research, we analyze the flux pinning properties for (Gd) BCO films deposited with RF sputtering with different growth temperature, based on the $J_c(H, \theta)$ values.
2. Experiment
All (Gd) BCO films were deposited with RF Sputtering. CeO$_2$/YSZ/CeO$_2$/NiW substrates were used for (Gd) BCO films. The same stoichiometric Gd$_x$Ba$_{1-x}$Cu$_2$O$_y$ target was used in the experiment. The CeO$_2$/YSZ/CeO$_2$/NiW substrates’ quality is as follows: The in-plane and out-plane texture was 6.5° and 3.9°. The RMS value over 1x1 μm$^2$ was smaller than 3 nm. The power was 50W. The total pressure of O$_2$ and Ar mixture gas is 30 Pa. Oxygen-argon partial pressure ratio was 1:1. The target and substrate distance were about 50mm. The growth temperature for sample A, B, C was 750°C, 800°C, 850°C, respectively. The deposition time was 300 minutes. In this study, the only changed parameter was growth temperature. Other parameters were fixed. The three samples are 3-centimeter-long and 1 centimetre wide. The thickness of three points was measured by the step profiler for every sample. The thickness homogeneity is very well. The average thickness for A, B and C was 510nm, 520nm and 550nm.

A four-probe method was use for meaning the $J_c$, and the voltage criterion was 1 μv/cm.

XRD and AFM were used to study the structure and morphology of (Gd) BCO films. The step profiler was used to obtain the (Gd) BCO film thicknesses.

3. Results and Discussion

3.1. Microstructure and Surface Morphology

![Figure 1. 0-2θ XRD measurement for (Gd) BCO samples.](image)

The 0-2θ XRD measurement for (Gd) BCO samples are shown in Fig. 1. Aside from the peaks attributed to the CeO$_2$/YSZ/CeO$_2$/NiW substrate. All peaks belong to the c-axis (00$l$) of (Gd)BCO. No a-axis-oriented peak was found.

According to nucleation theory, crystal nucleation first forms at lower barrier place. Thus, lower low-index planes with low surface free energy will first form. As to (Gd) BCO unit cell, 001 surface should be the lowest free energy, so it will appear more easily. And the film will favour growth along c-axis (00$l$). We suggest using $I$ (001) / $I$ (002) (the intensity ratio) as a distinct indication for the grain’s orientation fraction between the c-axis and a-axis. The higher $I$ (001) / $I$ (002) value indicates the higher c-axis fraction.

The $I$ (001) / $I$ (002) values are 0.84, 2.03, and 4.22 for A (750°C), B (800°C) and C (850°C) films, respectively. Lower $I$ (001) / $I$ (002) ratio in film A (750°C) implies more a-axis grains occurring, although they are hardly identified through the XRD measurement. The a-axis grains are certified by SEM studies in the following text. It is well known that lower deposition temperature favours a-axis grains of (Re) BCO, and higher deposition temperature favours the growth of c-axis grains of (Re) BCO. The conclusion is consistent with our analysis.
Figure 2. Top row: AFM images of all the three (Gd) BCO films [(a) (b) (c) are corresponding to A (750°C) , B (800°C) , C (850°C)]; Bottom row: SEM images of all the three GBCO films [(d) (e) (f) are corresponding to A (750°C) , B (800°C) , C (850°C)]

From AFM pictures, we observe an island growth mode for the films [see Fig. 2(a) (b) (c)]. The corresponding RMS of the three films is 3.57 nm, 13.65 nm, and 19.39 nm, respectively. Higher deposition temperature leads to higher roughness.

Two-dimensional nucleation and island growth are the two mainly growth modes for YBCO films. Two-dimensional nucleation happens with lower temperature, which leads to flat film with lower roughness (A (750°C)). While island growth appears with higher temperature, which leads to rough film with higher roughness. The island sizes increases with growth temperature, which is certificated in our experiment (comparing B (800°C) and C (850°C) films).

In order to get much more details, SEM measurement was used for our samples. Figs. 2(d), (e) and (f) corresponding to Figs. 2(a), (b) and (c), respectively. It is clearly shown in Fig. 2(d) that a-axis grains of (Gd) BCO appear in film A (750°C), and disappear in films (800°C) and C (850°C). At the same time, pinholes appear in films (800°C) and C (850°C). The size of pinhole becomes bigger in C (850°C). Pinholes are due to the grains having stronger orientation in the c-axis. All of these indicate that the good structure for (Gd) BCO films when enhancing growth temperature.

3.2. Field and Angular-Dependent $J_c$

The $J_c(0)$ at 0.3T for all samples is shown in Fig. 3(a). The value of $J_c(77K, 0.3T)$ is enhanced by increasing deposited temperature. The biggest $J_c$ is obtained at 800°C. To compare the relative increase in $J_c$ in H//ab as compared to $J_c$ in H//c for all the three samples, angular dependence data of normalized $J_c$ with respect to $J_c$ in H//c are presented in Fig. 3(b). It can be seen that the ratio of ($J_c$ in H//ab)/ ($J_c$ in H//c) is about 2.72 for C (850°C), whereas it is around 2.38 and 2.22 for B (800°C) and A (750°C) samples. The result indicates more strong anisotropy for C (850°C) film, which will be discussed carefully in the next part.
Figure 3. Angular dependence of $J_c$ for all films at 77K, 0.3 T. (b) Normalized $J_c$ with respect to $J_c$ in $H//ab$ of all the three samples.

Figure 4. Angular dependence of $J_c$ for all films at 77K, 0.3 T. (b) Normalized $J_c$ with respect to $J_c$ in $H//ab$ of all the three samples.

A board peak in ab-plane direction and no peak at c axis from the $J_c$ angular measurements together with the small anisotropy parameter $\gamma = 3$ indicate that the film defect structure in film C (850 $^\circ$C) maybe like the MOD (Re) BCO films. In the MOD (Re) BCO films, stacking faults play a main role in pinning centres, which lead to a board peak along ab-plane and a small anisotropy value. Thus, we speculate that stacking faults exist in film C (850 $^\circ$C). In order to prove our speculation, film C is heated at 800 $^\circ$C for one hour in 500ppm $O_2$. It is found that the board peak along ab-plane become small and narrow, as shown in Fig. 4. It is sure that a lot of stacking faults exist in film C (850 $^\circ$C), which lead to the largest $\delta J_c$($\theta$) in film C (850 $^\circ$C). Because high temperature process in oxygen will let stacking faults disappear.[12].

4. Conclusions
In summary, we have found that the B(800 $^\circ$C) film exhibits the enhanced pinning properties compared with A(750 $^\circ$C), C(850 $^\circ$C) (Gd)BCO films. Samples deposited with different substrate temperature, exhibit different pinning mechanisms. the film C (850 $^\circ$C) exhibits a bigger anisotropy when H is applied parallel to ab-plane, which implies strong sources of pinning along ab-plane, which is proved to be stacking faults. A lot of randomly distributed spherical defects are observed by cross-section SEM study in our films. This result is consistent with the low value for $\gamma = 3$, which implies enhanced pinning of random pinning on $J_c$ in our films.
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