

Origin of the thickness dependence of critical current densities in YBCO films prepared by pulsed laser deposition

This article has been downloaded from IOPscience. Please scroll down to see the full text article.

2008 J. Phys.: Conf. Ser. 97 012142

(<http://iopscience.iop.org/1742-6596/97/1/012142>)

View [the table of contents for this issue](#), or go to the [journal homepage](#) for more

Download details:

IP Address: 38.107.179.212

The article was downloaded on 16/02/2012 at 01:32

Please note that [terms and conditions apply](#).

Origin of the Thickness Dependence of Critical Current Densities in YBCO Films Prepared by Pulsed Laser Deposition

K Ohki, K Develos-Bagarinao, H Yamasaki and Y Nakagawa

National Institute for Advanced Industrial Science and Technology, 1-1-1 Umezono,
Tsukuba, Ibaraki 305-8568 Japan

kotaro.ohki@aist.go.jp

Abstract. Introducing porosity allows us to increase film thickness of the $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ (YBCO) films on sapphire substrates without microcracking. However, we have observed that porous films possess relatively low values of J_c , especially in thick film region (> 500 nm). In order to find out the cause of the degradation of J_c , we examined the depth profiles of the magnetic-field angular dependence of critical current density $J_c(t, \theta)$ and other properties for YBCO films ($t \leq 1550$ nm). The YBCO films were deposited by a large-area pulsed laser deposition system on CeO_2 -buffered r-cut sapphire. Depth profiles were obtained for YBCO films successively milled with an Ar ion beam irradiation. In the as-grown film, the $J_c(\theta)$ exhibits a broad J_c peaks at $\mathbf{H} \parallel c$, and smaller one centered at $\mathbf{H} \parallel ab$. After the milling, the $J_c(\mathbf{H} \parallel ab) / J_c(\mathbf{H} \parallel c)$ ratio increases with decreasing film thickness. The YBCO (005) peak of x-ray diffraction shifts towards higher angle with decreasing film thickness. The depth profiles reveal that the oxygen deficit is one of the causes of the decrease of the J_c of the large-area PLD YBCO/ $\text{CeO}_2/\text{Al}_2\text{O}_3$ films with increasing film thickness.

1. Introduction

High temperature superconductor films are expected for use in electric power applications, such as fault current limiters [1] and coated conductors used for various power devices [2]. These electric power applications require a high critical current I_c . We have been fabricating large-area $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ (YBCO) films on CeO_2 -buffered sapphire substrates by a pulsed laser deposition (PLD) method [3], since sapphire has good thermal and mechanical properties with relatively low costs. However, significant reduction of the critical current density J_c with increasing film thickness has often been observed [2-5]. The reduction is generally observed in typical YBCO films, but the YBCO films deposited on sapphire substrates exhibited decay to very low level with increasing film thickness [3]. The J_c decreases more likely to be caused by porosity, which is introduced to suppress micro-cracks [6], but the detailed causes remains unclear.

To clarify the cause of the J_c decrease from point of view of the flux pinning mechanism, several studies have been performed on the large-area PLD (LA-PLD) YBCO thick films with the magnetic-field angular dependence of J_c measurements [7]. The previous study showed that the J_c of the LA-PLD YBCO thin film (< 200 nm) exhibits a maximum centered at $\mathbf{H} \parallel ab$, but the peaks at $\mathbf{H} \parallel c$ became more prominent than the $\mathbf{H} \parallel ab$ peaks with increasing film thickness [7]. The angular dependence is peculiar to our films since typical YBCO films show only J_c peaks at $\mathbf{H} \parallel ab$. Several

studies have investigated the association between these peaks and the pinning sources. $\mathbf{H} // ab$ peaks are associated with (i) the intrinsic pinning [8,9], (ii) random pinning due to point-like defects [10,11] and (iii) extended planar defects parallel to the ab -planes [12]. On the other hand, the $\mathbf{H} // c$ peaks are proved to be due to c -axis correlated pinning centers such as dislocations, planar defects parallel to the c -axis, and nano-precipitates elongated along the c -axis [7,13,14]. These results imply that the lack of the pinning centers correlated along the ab plane is one of the causes of the J_c decrease. However, the details remain unanswered.

In this study, we obtained the depth profiles. We thinned the YBCO thick films by Ar ion milling and measured the angular dependent J_c and obtained x-ray diffraction data.

2. Experimental details

2.1. Sample preparation The YBCO films, with thickness up to 1550 nm, were prepared on CeO₂-buffered (1 $\bar{1}$ 02) Al₂O₃ (r -cut sapphire) substrates by an LA-PLD system utilizing a KrF excimer laser source (248 nm) operated at an energy density on the target surface of ~ 1 J/cm². The target-to-substrate distance of the LA-PLD system is 14 cm, much longer than standard small-area PLD system. Since the preferential scattering of Ba and Cu occurs, YBCO films deposited from stoichiometric targets are always yttrium-rich. In order to compensate for the deficiency in the films, we used off-stoichiometric targets [6]. The depositions were carried out at an oxygen pressure of 175 mTorr and the substrate temperature of 750 °C. After the deposition, the films were cooled to room temperature in O₂ at 250 Torr.

For comparison, we also prepared YBCO films on (100) SrTiO₃ by a standard PLD system (S-PLD) utilizing an ArF excimer laser source (193 nm). The target-to-substrate distance of the S-PLD system is 3 cm. The YBCO films were deposited at an oxygen pressure of 300 mTorr and the substrate temperature of 760 °C. After the deposition, the film was annealed at 420 °C in O₂ at 700 Torr for 1 h.

The critical temperature T_c was measured by using a standard four-probe method and magnetic susceptibility measurements. Typical T_c values of the YBCO/CeO₂/Al₂O₃ and the YBCO/SrTiO₃ films were around 88 K and 90 K, respectively. The c -axis oriented growth was confirmed by x-ray diffraction analysis.

2.2. Depth profiling The depth profiles of J_c were obtained for YBCO films that were successively milled with an Ar ion beam. The ion beam was produced with an electron cyclotron resonance ion source, and the ion beam irradiation was performed with an acceleration voltage of 500 V. To avoid irradiation damage the samples were cooled by liquid nitrogen during the milling process. The J_c of the films was measured by an inductive method using third-harmonic voltages [15,16] in liquid N₂ bath (77.3 K). This nondestructive measurement by the inductive method has the advantage that we do not need to make narrow bridges such as necessary in transport measurements. This allows us to make x-ray analysis for each milled films more easily.

2.3. Angular dependence of J_c The angular dependent J_c measurement is a very useful tool to investigate pinning sources [7,10,11]. In this study, the angular dependence of J_c of the YBCO films is also measured by the inductive method [15,16]. A small coil, an outer diameter $D = 2.2$ mm, was mounted on a film, and both were fixed on a rotating sample holder. Figure 1 shows the schematic diagram of the coil setup. The angular studies were performed in a liquid N₂ bath (77.3 K) at $\mu_0 H = 0.5$ T. The angle θ is defined as the angle between \mathbf{H} and the normal to the film. This inductive method corresponds to the transport measurement with the field applied perpendicular to the current direction (maximum Lorenz force configuration) [17].

3. Results and discussion

The J_c of the YBCO films as a function of film thickness up to 1550 nm is shown in Fig. 2. The thickness dependence of as-grown films (filled-circle), which was measured for many different films,

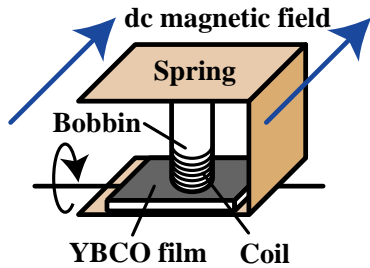


Fig. 1 Schematic diagram of the coil setup.

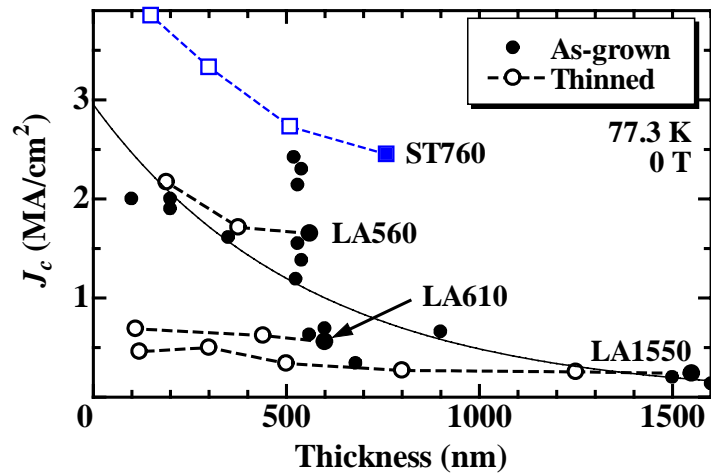


Fig. 2 Thickness dependence of J_c for YBCO films at 77.3 K, self-field: (a) LA560, (b) LA610, (c) LA1550 and (d) ST760. The solid line and broken line indicate the as-grown films and the etched films, respectively.

shows a typical degradation of J_c with increasing film thickness. Especially, in thick film region (>500 nm), the J_c exhibits decay to very low values.

In order to investigate inner region of the films, we milled three LA-PLD as-grown films by Ar ion beam irradiation. Two of the three samples are low J_c films and another is relatively high J_c film. Broken lines for samples LA1550, LA610 and LA560 show the thickness dependence of J_c of the thinned films, which were milled from 1550 nm, 610 nm and 560 nm, respectively. After the successive milling, these three films showed only a slight increase of J_c with decreasing film thickness. The J_c of LA1550 increased from 0.24 MA/cm² to 0.46 MA/cm², which is much lower than the J_c expected for as-grown thin films.

For comparison, we measured the thickness dependence of J_c in milled ST760 films as shown in open-square. In this sample, the J_c increased with decreasing film thickness and such a recovering phenomenon has been already observed and reported [2]. These results show that the J_c of inner region of the S-PLD film remained high and there is no obvious ion-milling damage. It is suggested that the inner region of LA-PLD films was degraded with further film deposition process possibly due to the growth of large pores.

Figure 3(a), (b) and (c) show the depth profile of the angular dependent J_c of LA1550, LA560 and ST760, respectively. The angular dependent J_c of the LA610 was not shown here because it showed similar tendency to that of LA1550. Basically, the J_c enhanced for the entire angular range with decreasing film thickness, with exception of LA560. The $J_c(\mathbf{H} // ab) / J_c(\mathbf{H} // c)$ ratio of the LA-PLD films increases with decreasing film thickness. Further, for the thin film region (< 200 nm), J_c peaks at $\mathbf{H} // ab$ become prominent. The changes of the $J_c(\mathbf{H} // ab) / J_c(\mathbf{H} // c)$ ratio are one of the features of the LA-PLD films. Typical YBCO films show J_c peaks at only $\mathbf{H} // ab$ as shown in Fig. 3(c), and the characteristic shape of $J_c(\theta)$ of the ST760 did not change for each thickness, except for the film thinned to 150 nm.

We investigated the lattice constant c of the LA-PLD film by YBCO (005) x-ray diffraction peaks. Figure 4 shows the YBCO (005) peaks of the milled film in Fig. 3. As shown in Figs. 4(a) and (b), the YBCO (005) peaks of LA1550 and LA560 shifted towards higher angle with decreasing film thickness. This indicates that the lattice constant c contracted. This contracting of the lattice constant c means the increasing of the oxygen content of the film [18,19]. It is interesting to note that the results indicate that the oxygen content at the interface region is higher than at the surface region. We have also

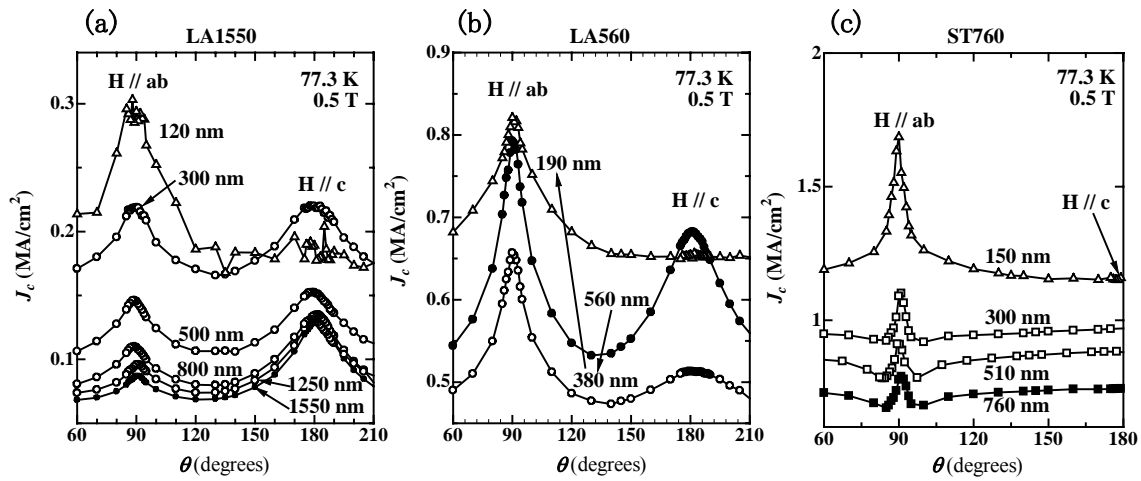


Fig. 3 Angular dependence of J_c for YBCO film at 77.3 K and $\mu_0 H = 0.5$ T. The solid line indicates the data for as-grown films and the broken lines show the data for the milled films LA1550, LA560 and ST760.

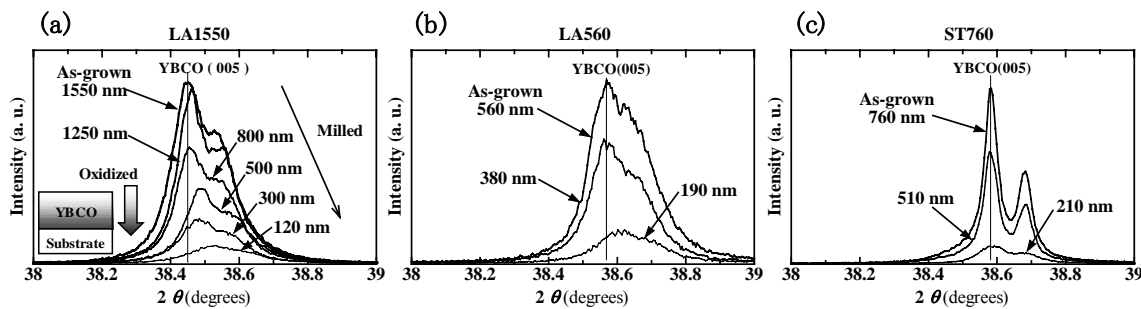


Fig. 4 2θ - θ XRD scans around YBCO (005) peaks of (a) LA1550, (b) LA560 and (c) ST760.

observed that the J_c ($H // ab$) peak associated with the random pinning increases with oxygenation of the film, which will be described elsewhere [17].

The lattice constants c , which are calculated from the YBCO (005) peaks are 11.65 nm, 11.66 nm and 11.70 nm for as-grown ST760, LA560 and LA-PLD 1550, respectively. According to the report [19], there is almost no oxygen deficit in ST760 and very low-level oxygen deficit in LA560. On the other hand, it is estimated that the oxygen deficit δ of LA1550 is 0.25. It is to be noted that the YBCO (005) peak of the ST760, which correspond to almost no oxygen deficit, did not change with decreasing film thickness (Fig. 4(c)). These results lead us to the conclusion that the oxygen deficiency of the films is one of the causes of the degradation of J_c with increasing film thickness.

In order to increase J_c of the thick films, we tried to increase oxygen content for the YBCO films deposited using the LA-PLD system with the same condition as LA1550 by typical oxygen annealing. However, we could not increase oxygen content of the YBCO films to the level of ST760. The origin of the oxygen deficiency is under investigation.

4. Summary and conclusions

We have studied the depth profiles of the magnetic field angular dependence of J_c and the lattice constant c of the YBCO/CeO₂/Al₂O₃ films deposited by the large-area pulsed laser deposition system. The depth profiles revealed that the oxygen content at the surface region is lower than at the interface region. The oxygen deficiency is one of the causes of the decrease of J_c .

References

- [1] Yamasaki H, Furuse M and Nakagawa Y 2004 *Appl. Phys. Lett.* **85** 4427
- [2] Foltyn SR, Jia QX, Arendt PN, Kinder L, Fan Y and Smith JF 1999 *Appl. Phys. Lett.* **75** 3692
- [3] Develos-Bagarinao K, Yamasaki H, Nie JC and Nakagawa Y 2005 *Supercond. Sci. Technol.* **18** 667
- [4] Foltyn SR, Wang H, Civale L, Jia QX, Arendt PN, Maiorov B, Li Y, Maley MP and MacManus-Driscoll JL 2005 *Appl. Phys. Lett.* **87** 162505
- [5] Emergo RLS, Wu JZ, Aytug T and Christen DK 2004 *Appl. Phys. Lett.* **85** 618
- [6] Develos-Bagarinao K, Yamasaki Nie J C, Murugesan M, Obara H and Nakagawa Y 2005 *IEEE Trans. Appl. Supercond.* **15** 2962
- [7] Develos-Bagarinao K, Yamasaki H, Murugesan M, Mawatari Y, Nakagawa Y and Nie J C 2005 *Supercond. Sci. Technol.* **18** S266
- [8] Tachiki M and Takahashi S 1989 *Solid State Commun.* **70** 291
- [9] Tachiki M and Takahashi S 1989 *Solid State Commun.* **72** 1083
- [10] Civale L, Maiorov B, Serquis A, O Willis J, Y Coulter J, Wang H, X Jia Q, Arendt PN, MacManus-Driscoll JL, Maley MP and Foltyn SR 2004 *Appl. Phys. Lett.* **84** 2121
- [11] Civale L, Maiorov B, MacManus-Driscoll JL, Wang H, Holesinger TG, Foltyn SR, Serquis A and Arendt PN 2005 *IEEE Trans. Appl. Supercon.* **15** 2808
- [12] Grigis Ch, Schamm S and Dorignac D 1999 *J. Mater. Res.* **14** 2732
- [13] Diaz A, Mechin L, Berghuis P and Evetts J E 1998 *Phys. Rev. Lett.* **80** 3855
- [14] Yamada H, Yamasaki H, Develos-Bagarinao K, Nakagawa Y, Mawatari Y, Nie J C, Obara H and Kosaka S 2004 *Supercond. Sci. Technol.* **17** 58
- [15] Claassen JH, Reeves ME, J Soulen R and Jr 1991 *Rev. Sci. Instrum.* **62** 996
- [16] Yamasaki H, Mawatari Y and Nakagawa Y 2003 *Appl. Phys. Lett.* **82** 3275
- [17] Ohki K, Yamasaki H, Develos-Bagarinao K and Nakagawa Y 2007 *unpublished*
- [18] Gallagher P K, O'Bryan H M, Sunshine S A and Murphy D W 1987 *Mat. Res. Bull.* **22** 995
- [19] Ueda Y and Kosuge K 1988 *Physica C* **156** 281