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Effect of Y_2O_3 Nanoparticles on Critical Current Density of $YBa_2Cu_3O_{7-x}$ Thin Films

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Y_2O_3 나노입자가 $YBa_2Cu_3O_{7-x}$ 박막의 임계전류밀도에 미치는 영향

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Abstract

Introduction of proper impurity into $YBa_2Cu_3O_{7-x}$ (YBCO) thin films is an effective way to enhance its flux-pinning properties. We investigate effect of Y_2O_3 nanoparticles on the critical current density J_c of the YBCO thin films. The Y_2O_3 nanoparticles were created perpendicular to the film surface (parallel with the *c*-axis) either between YBCO and substrate or on top of YBCO, YBCO/Y_2O_3/LAO or Y_2O_3/YBCO/STO, by pulsed laser deposition. The deposition temperature of the YBCO films were varied (780 ^oC and 800 ^oC) to modify surface morphology of the YBCO films. Surface morphology characterization revealed that the lower deposition temperature of 780 ^oC created nano-sized holes on the YBCO film surface which may behave as intrinsic pinning centers, while the higher deposition temperature produced much denser and smoother surface. J_c values of the YBCO films with Y_2O_3 particles were either remained nearly the same or decreased for the samples in which YBCO is grown at 780 ^oC. On the other hand, J_c values were enhanced for the samples in which YBCO is grown at higher temperature of 800 ^oC. The difference in the effect of Y_2O_3 can be explained by the fact that the higher deposition temperature of 800 ^oC reduces intrinsic pinning centers and J_c is enhanced by introduction of artificial pinning centers in the form of Y_2O_3 nanoparticles.

Keywords : YBCO thin film, critical current density, pinning centers, Y_2O_3 nanoparticle

I. Introduction

The discovery of high temperature superconductors (HTS) have opened a new era for the applications of HTS at higher temperatures. For electrical power application purpose, the critical

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current density (J_c) is one of the most important parameters [1].

Many efforts have been devoted to enhance J_c values of YBCO thin films by doping various kinds of impurities into YBCO at nano-scale as artificial pinning centers [2-6]. Requirements for effective artificial pinning centers include size and density of dopants [7]. The size of artificial pinning centers should be in the range of few times of the coherence length of YBCO (ξ~ 1.5-2 nm) [8], and the defect density should be equivalent to the order of (H/2) × 10^{11}/cm^2 [8], where H is the magnitude of the applied magnetic field.

In this work, we investigate the critical current density of the YBCO thin films with introductions of Y_2O_3 nanoparticles. Y_2O_3 was chosen as artificial pinning centers because it is chemically nonreactive with YBCO, and has a simple cubic structure of a = 1.06 nm [4] with a small lattice mismatch with YBCO, which will allow epitaxial growth of nanoparticles in YBCO matrix. The superconducting properties of YBCO thin films with Y_2O_3 nanoparticles are compared with those of the pure YBCO.

II. Experiment

All of pure YBCO, YBCO thin films with Y_2O_3 nanoparticles were fabricated by using a pulsed lased deposition (PLD) technique. YBCO thin film was deposited at 780 ^oC with oxygen pressure of 150mTorr and laser energy of 250 mJ. Y_2O_3 layer was deposited at 800 ^oC with oxygen pressure of 200 mTorr and laser energy of 250 mJ [9, 10].

Two sets of YBCO thin films with Y_2O_3 nanoparticles deposited at different temperatures were prepared: Y_2O_3(800 ^oC)/YBCO(780 ^oC) and Y_2O_3(800 ^oC)/YBCO(800 ^oC). YBCO and Y_2O_3 layer were deposited on single crystal (100) $SrTiO_3$ (STO) and (100) $LaAlO_3$ (LAO) substrates, respectively. Each set consisted of a pure YBCO (YBCO/STO) and YBCO with Y_2O_3 nanoparticles (Y_2O_3/YBCO/STO and YBCO/Y_2O_3/LAO). The thickness of YBCO layer was 300 nm while Y_2O_3 was deposited as pseudo layer of nanoparticles.

Structural properties of the samples and the existence of impurity phases were characterized by X-ray diffraction (XRD), atomic force microscopy (AFM) measurement [4]. The magnetization curves M(H) were taken by using magnetic property measurement system (MPMS) for the applied field up to 5 T parallel to the *c*-axis of films.

III. Results and Discussion

First, properties of Y_2O_3 nanoparticles deposited on LAO substrate using 160 laser pulses were analyzed. Figure 1 shows the AFM pictures of Y_2O_3/LAO samples representing a uniform distribution of Y_2O_3. Mean height and diameter of Y_2O_3 nanoparticles calculated from 2-dimensional (2D) and 3-dimensional (3D) AFM pictures were about 2 nm and 14 nm, respectively.

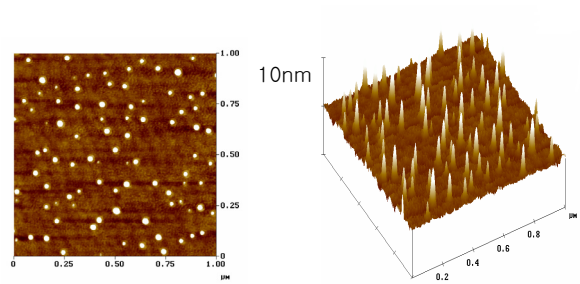

Fig. 1. 2D and 3D AFM pictures of Y_2O_3 nanoparticles deposited on LAO substrate using 160 laser pulses.

XRD patterns of Y_2O_3(800 ^oC)/YBCO(780 ^oC)/STO and pure YBCO(780 ^oC)/STO samples are shown in Fig. 2. All peaks of YBCO (*00l*) where l = 2 to 7 appeared for both samples and the (400) peak of Y_2O_3 in the double layer sample suggest textured growth of both the materials and confirm the existence of Y_2O_3 impurity in the YBCO film.

The second set of samples in which the YBCO layer is deposited at higher temperature of 800 ^oC is analyzed by the same procedures. The XRD patterns of Y_2O_3(800 ^oC)/YBCO(800 ^oC)/STO and pure

YBCO(800 °C) samples revealed that all of the peaks of YBCO and Y_2O_3 appear at the same positions with those in Fig. 2. The existence of textured Y_2O_3 impurity on the YBCO film surface at deposition temperature of 800 °C is also confirmed.

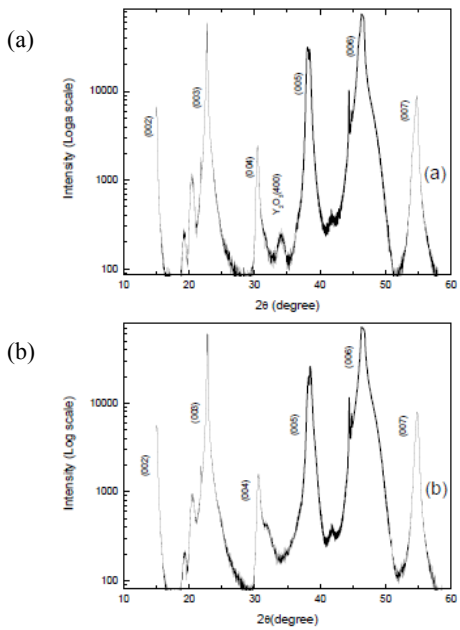

Fig. 2. XRD patterns of (a) Y_2O_3(800 °C)/YBCO(780 °C)/STO and (b) undoped YBCO(780 °C)/STO. Appearance of Y_2O_3 (400) peak in (a) indicates Y_2O_3 nanoparticles are produced perpendicular to the film surface.

Figure 3(a) and (b) exhibit AFM pictures of the surface morphology of the Y_2O_3(800 °C)/YBCO(780 °C)/STO and Y_2O_3(800 °C)/YBCO(800 °C)/STO samples, respectively. For the YBCO layer deposited at 780 °C, the film surface is not smooth and covered with many deep holes. Properties of the holes are listed in Table 1. Y_2O_3 impurity is coated on top of YBCO in the form of a random distribution of nanoparticles exhibited by the white dots on yellow background. The distribution of Y_2O_3 is not as regular as that of Y_2O_3 on LAO substrate in Fig. 1 due to rough surface of the YBCO layer. For the YBCO deposited at 800°C, the surface of the YBCO layer looks smoother and has smaller number of deep holes than that of the YBCO deposited at 780 °C. Y_2O_3 nanoparticles are still randomly mounted on the YBCO surface. Properties of the holes are compared with the Y_2O_3 particles in Table 2.

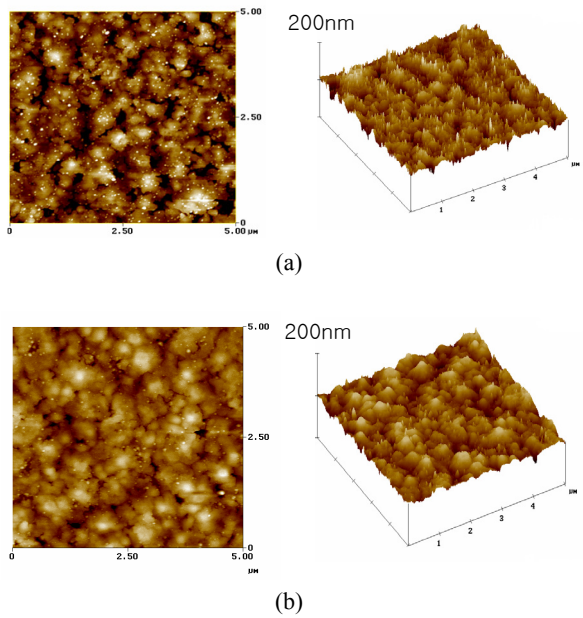

Fig. 3. AFM pictures of (a) Y_2O_3(800 °C)/YBCO(780 °C)/STO and (b) Y_2O_3(800 °C)/YBCO(800 °C)/STO for 160 laser pulses at scale of 5 x 5 μm^2.

Table 1. Comparison of Y_2O_3 particles and holes existed on Y_2O_3(800 °C)/YBCO(780 °C)/STO film surface.

	Mean diameter	Mean height (depth)	Density
Y_2O_3	14.0 nm	1.8 nm	167 /μm^2
Holes	30.4 nm	4.6 nm	78 /μm^2

Table 2. Comparison of Y_2O_3 particles and holes existed on Y_2O_3(800 °C)/YBCO(800 °C)/STO film surface.

	Mean diameter	Mean height (depth)	Density
Y_2O_3	14.0 nm	1.8 nm	167 /μm^2
Holes	15.4 nm	2.4 nm	18 /μm^2

Flux pinning properties of the samples were compared by evaluating J_c from the magnetization measurement. Figure 4 represents the field dependence of J_c values of the set of YBCO samples with Y_2O_3

nanoparticles in which the YBCO layer was deposited at 780 °C compared to that of the pure YBCO. The magnetization curves were taken with the magnetic field parallel to the *c*-axis of the samples. The inset of Fig. 4 shows the magnetization M(H) versus the field H at T = 5 K. The critical current density J_c was calculated by using a Bean model, J_c = 30ΔM/VR [11], where ΔM is the difference of M, V is the sample volume and R is the and R is the mean radius of samples which was taken as one fourth of sample length and width. It could be seen that the J_c value of the Y_2O_3(800 °C)/YBCO(780 °C)/STO sample is slightly larger than that of the pure YBCO at zero field and decreases little faster than the pure one as the field is increased. On the other hand, J_c of the YBCO(780 °C)/Y_2O_3(800 °C)/LAO sample decreases much faster than that of the pure YBCO and as a result, the value of J_c became nearly a half of that of the pure at H = 5 T. These results suggest two things. First, the Y_2O_3 nanoparticles deposited on top of the YBCO layer do not significantly change pinning property of the sample. It indicates that the Y_2O_3 nanoparticles on top of the YBCO layer do not serve as effective pinning centers. Second, the Y_2O_3 nanoparticles deposited in between the YBCO layer and the substrate drastically degrade pinning property of the sample. The reason for this might be not only due to the Y_2O_3 nanoparticles but also due to the surface morphology of the YBCO layer. We will discuss this later.

In order to understand the decrease of J_c of the YBCO(780 °C)/Y_2O_3(800 °C)/LAO sample in magnetic field, J_c was measured for the set of the samples in which the YBCO layer was deposited at 800 °C and plotted as a function of magnetic field as shown in Fig. 5. Similar to the result observed in the first set, the value and the field dependence of J_c of the Y_2O_3(800 °C)/YBCO(800 °C)/STO sample is almost the same with that of the pure YBCO. The value of J_c of the YBCO(800 °C)/Y_2O_3(800 °C)/LAO sample, contrary to the previous result, is about 3 times larger than that of the pure YBCO at zero field and this enhancement is maintained in all range of fields.

The opposite behaviors of J_c of Y_2O_3(800 °C)/YBCO(780 °C)/STO and Y_2O_3(800 °C)/YBCO(800 °C)/STO in fields might come from the difference in the surface morphology of the YBCO layer deposited at different temperatures. As shown in Fig. 3 and summarized in Table 1, the YBCO layer deposited at 780 °C has relatively rough surface and many deep holes of which dimensions and density

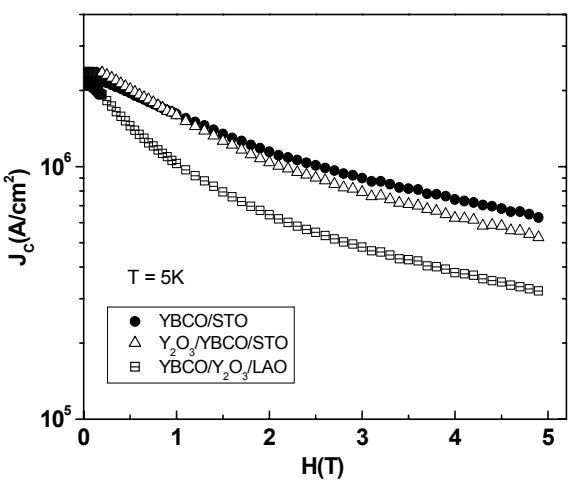

Fig. 4. Comparison of J_c values of YBCO(780 °C)/STO, Y_2O_3(800 °C)/YBCO(780 °C)/STO and YBCO(780 °C)/Y_2O_3(800 °C)/LAO measured at T = 5 K.

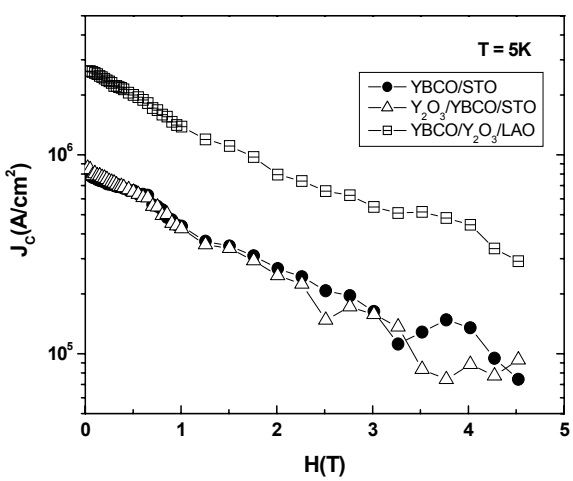

Fig. 5. Comparison of J_c values of YBCO(800 °C)/STO, Y_2O_3(800 °C)/YBCO(800 °C)/STO and YBCO(800 °C)/Y_2O_3(800 °C)/LAO measured at T = 5 K

are comparable with those of Y_2O_3 nanoparticles. These holes seem to behave as intrinsic pinning centers. Since there exist enough intrinsic pinning centers already, introduction of artificial pinning centers in form of Y_2O_3 nanoparticles leads to reduction in superconducting areas and J_c decreases as the field is increased as shown in Fig. 4. On the other hand, the holes on the YBCO layer deposited at 800 ^oC are much less and smaller than those on the YBCO layer deposited at 780 ^oC. This indicates that less numbers of intrinsic pinning centers exist in the set of samples deposited at 800 ^oC manifested by smaller J_c of the undoped YBCO sample at zero field than that of sample deposited at 780 ^oC. As artificial pinning centers in the form of Y_2O_3 nanoparticles were added to YBCO films, pinning property is greatly enhanced, and the value and the field dependence of J_c become comparable with those of the pure YBCO deposited at 780 ^oC.

IV. Summary

Two sets of samples of YBCO thin films with Y_2O_3 nanoparticles were prepared by PLD at different deposition temperatures of YBCO (780 ^oC and 800 ^oC) in order to see the change in flux pinning property of the YBCO thin films. The number of laser pulse of 160 was chosen to deposite Y_2O_3 nanoparticles. The existence of textured Y_2O_3 nanoparticles was confirmed by the XRD and AFM analyses. Changes in flux pinning property were probed by evaluating J_c of the two sets of samples from the magnetization measurements. At lower deposition temperature of YBCO of 780 ^oC, the YBCO layer has rough surface with large density of deep holes which serve as intrinsic pinning centers, so introduction of artificial pinning centers in the form of Y_2O_3 nanoparticles leaded to reduction in J_c of the YBCO thin films in fields. But the results were different for the YBCO thin films deposited at higher temperature of 800 ^oC. The smoother film surface contained less amount of intrinsic pining centers and consequently the addition of Y_2O_3 nanoparticles effectively enhanced flux pinning property of YBCO leading to increase in J_c.

Acknowledgments

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References

[1] T. P. Orlando, K. A. Delin, Foundations of applied superconductivity, Addison-Wesley (1990).

[2] J. L. Macmanus-Driscoll, S. R. Foltyn, Q. X. Jia, H. Wang, A. Serquis, L. Civale, B. Maiorov, M. E. Hawley, M. P. Maley, D. E. Peterson, Nature materials **3**, 393 (2004).

[3] T. J. Haugan, P. N. Barnes, T. A. Campell, A. Goyal, A. Gapud, L. Heatherly, S. Kang, Physica C **425**, 21-26 (2005).

[4] P. Mele, K. Matsumoto, T. Horide, O. Miura, A. Ichinose, M. Mukaida, Y. Yoshida, S. Horii, Physica C **426-431**, 1108-1112 (2005).

[5] S. K. Viswanathan, A. A. Gapud, M. Varela, J. T. Abiade, D. K. Christen, S. J. Pennycook, D. Kumar, Thin solid film **515**, 6452-6455 (2007).

[6] M. Sparing, E. Backen, T. Freudenberg, R. Huhne, B. Rellinghaus, L. Schultz, B. Holzapfel, Supercond. Sci. Technol. **20**, S239-S246 (2007).

[7] P. Mele, K. Matsumoto, T. Horide, A. Ichinose, M. Mukaida, Y. Yoshida, S. Horii, Physica C **463-465**, 653-656 (2007)

[8] T. Haugan, P. N. Barnes, I. Maartense, C. B. Cobb, J. Mater. Res. **18**, 11 (2003).

[9] RJ. Gaboriaud, F. Pailloux, J. Perriere, Applied surface science **186**, 477-482 (2002).

[10] XCheng, Z. Qi, G. Zhang, H. Zhou, W. Zhang, M. Yin, Physica B **404**, 146-149 (2009).

[11] TA. Campbell, T. J. Haugan, I. Maartense, J. Murphy, L. Brunke, P. N. Barnes, Physica C **423**, 1-8 (2005).

[12] JAlbrecht, S. Leonhardt, H. U. Habermeier, S. Bruck, R. Spolenak, H. Kronmuller, Physica C **404**, 18-21 (2004).