Microstructural and Pinning Properties of $YBa_2Cu_3O_{7-\delta}$ Thin Films Doped with Magnetic Nanoparticles

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***Abstract*— In this paper, we report a strong enhancement in the in-field transport properties of the $YBa_2Cu_3O_{7-\delta}$ (YBCO) thin films doped with magnetic Fe_2O_3 nanoparticles. We incorporated magnetic Fe_2O_3 nanoparticles with two different architectures by laser ablation of the YBCO and dopant targets. YBCO film thickness was controlled at around 1 µm for all the samples. We conducted a detailed microstructural characterization on all the doped samples by X-ray diffraction (XRD) and cross-sectional transmission electron microscopy (TEM) and compared with the pure YBCO films. The pinning properties of these doped YBCO films were explored at different temperatures (5K, 40K, and 65K) and correlated with their microstructural characteristics.**

I. Introduction

The introduction of nanoparticles into YBCO films has been demonstrated using a variety of methods to enhance the flux pinning properties of YBCO coated conductors. [1]–[4] In addition to acting as flux pinning centers by themselves, the nanoparticles can also create defects, such as strain fields surrounding the particles, stacking faults, and dislocations, which could potentially enhance the flux pinning. Depending upon the processing method, the composition, pinning material content, size, and distribution all determine the effectiveness of the nanoparticles for the flux pinning enhancement.

Recently, efforts have been made to incorporate different magnetic nanoparticles with various architectures, either by laser ablation of a composite target through premixing the superconductor and dopant powders, or by alternative growth of the superconductor and dopant targets to enhance the in-field flux pinning properties. [5]–[8] In this work, we observe a strong improvement on the Fe_2O_3 doped YBCO thin films by alternative growth of pure YBCO and pure Fe_2O_3 layers. We conducted a systematic study on the microstructural and physical properties of these Fe_2O_3 doped samples and explored the correlation between their flux pinning properties and their microstructural characteristics at three different measurement temperatures.

II. Results and Discussion

The detailed sample information, including the doping architecture, T_c and J_c self-field values, are listed in Table I. The Fe_2O_3 nanoparticles deposited on YBCO layer (sample 1) only slightly lowered the T_c; while, the case with a Fe_2O_3 buffer layer (sample 2) indeed lowered the T_c about 6K. XRD normal scans (not shown here) and TEM study (Fig. 1a and 1b) both confirmed that the high quality growth of YBCO films. In Fig. 1a, it is obvious that a very thin (~10nm) but distinguishable Fe_2O_3 layer coated (marked by dashed line) on the top of high quality YBCO thin film. In Fig. 1b, it clearly shows several small Fe_2O_3 nanoparticles (~2-5nm in diameter, marked as arrows) randomly distributed inside the epitaxial YBCO matrix. The insets are the corresponding selected area electron diffraction (SAED) patterns, which indicate the high quality epitaxial growth of both YBCO films on STO substrate.

TABLE I transport data for the samples (1–3)

Sample ID	Sample information	T_c	J_c^{sf} @ 65K
1	Fe_2O_3 deposited on YBCO/STO	88K	1.58 MA/cm^2
2	YBCO on Fe_2O_3 buffer layer on STO	84K	1.18 MA/cm^2
3	Pure YBCO on STO as a reference sample	90K	3.50 MA/cm^2 1.00 MA/cm^2 (75K)

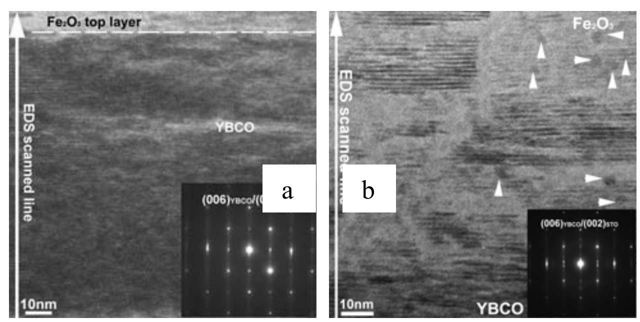

Fig. 2 Cross-sectional TEM images of (a) sample 1 and (b) sample 2. The insets are the corresponding SAD patterns.

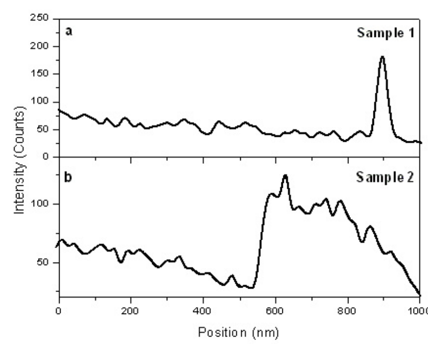

Fig. 2 The EDS Fe-K line profiles for Sample 1 and 2

We conducted detailed chemical analysis using EDS line scans. Fig. 2 a and b show the EDS Fe-K line profiles for sample 1 and sample 2, respectively. It confirms the distribution of Fe_2O_3 on the top of the YBCO thin film in sample 1 and Fe_2O_3 dispersed in YBCO thin films (especially 500nm or above) in sample 2.

The normalized critical current density as a function of the applied magnetic field ($J_c^{in\text{-}field}$ measured at 5K, 40K and 65K, H//*c*) for the doped sample 1 and 2 are plotted in Fig.3, 4, and 5, respectively, and compared with the reference sample (sample 3, pure YBCO film).

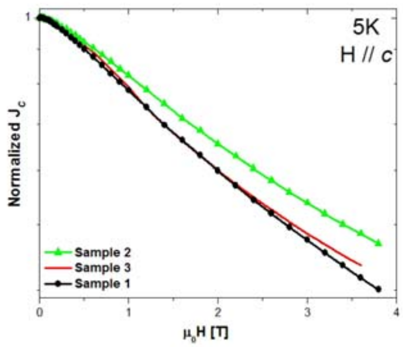

Fig. 3 Normalized critical current density as a function of the applied magnetic field ($J_c^{in\text{-}field}$) measured at 5K for all three samples.

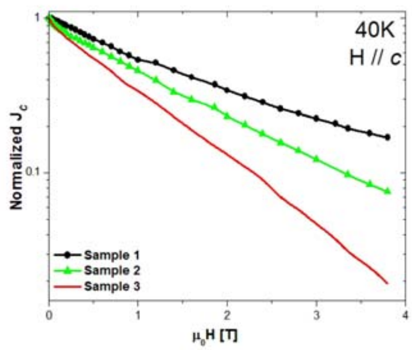

Fig. 4 The normalized critical current density as a function of the applied magnetic field ($J_c^{in\text{-}field}$) measured at 40K for all samples.

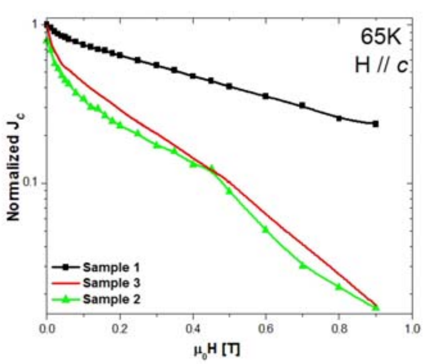

Fig. 5 The normalized critical current density as a function of the applied magnetic field ($J_c^{in\text{-}field}$) measured at 65K for all samples.

Overall, both doping architectures (sample 1 and 2) demonstrate better pinning properties than the pure YBCO film, however at different temperature regimes. At low temperatures, the YBCO film uniformly doped with Fe_2O_3 shows better in-field performance. At high temperature range, the YBCO film with Fe_2O_3 on top shows a much better in-field performance than the pure YBCO film. This might be directly related to the different vortex line structures and pinning mechanisms at different temperature regimes. The buffer layer approach introduces a very uniform distribution of Fe_2O_3 nanoparticles in YBCO matrix. It is possible that these uniformly distributed magnetic particles interact well with the closely spaced vortex lines at low temperatures and therefore demonstrate a better performance than the surface doping case. While at high temperatures, the magnetic particles on the YBCO top surface pin the vortex lines better. Further study on the interaction between the magnetic nanoparticles and the YBCO vortices is needed to fully understand the pinning mechanisms of these systems.

III. Conclusion

High quality YBCO thin films doped with Fe_2O_3 nanoparticles were deposited on STO substrates with two different architectures to explore the flux pinning effects introduced by magnetic nanoparticles. At 65K and 40K, the sample with Fe_2O_3 nanoparticles deposited on top of the YBCO matrix shows a significantly enhanced pinning performance than pure YBCO film. At 5K, the sample with uniformly doped Fe_2O_3 nanoparticles demonstrates a better pinning property than the surface doping architecture.

Acknowledgement

This work was supported by the Air Force Office of Scientific Research (Contract No. FA9550-0701-0108).

References

[1] T. J. Haugan, P. N. Barnes, R. Wheeler, F. Meisenkothen, and M. Sumption, "Addition of nanoparticle dispersions to enhance flux pinning of the $YBa_2Cu_3O_{7-x}$ superconductor," Nature (London), vol. 430, pp. 867, 2004.

[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, and D. E. Peterson, "Strongly enhanced current densities in superconducting coated conductors of $YBa_2Cu_3O_{7-x}$ + $BaZrO_3$," Nat. Mater., vol. 3, pp. 439, 2004.

[3] H. Wang, S. R. Foltyn, Q. X. Jia, P. N. Arendt, and X. Zhang, "Microstructures and transport properties of Y-rich $YBa_2Cu_3O_{7-\delta}$ thin film processed by pulsed laser deposition", Journal of Applied Physics., 100, 053904, (2006).

[4] S. R. Foltyn, H. Wang, L. Civale, Q. X. Jia, P. N. Arendt, B. Maiorov, Y. Li, M. P. Maley, and J. L. MacManus-Driscoll, "Overcoming the barrier to 1000 A/cm width superconducting coatings," Appl. Phys. Lett., vol. 87, pp. 162505, 2005.

[5] N. B. Rizzo, J. Q. Wang, D. E. Prober, L. R. Motowidlo and B. A. Zeitlin, "Ferromagnetic artificial pinning centers in superconducting Nb0.36Ti0.64 wires," Appl. Phys. Lett., vol. 69, pp. 2285, 1996.

[6] K. T. Lau, S. Y. Yahya and R. Abd-Shukor, "Enhanced flux pinning in Ag-sheathed Bi-Pb-Sr-Ca-Cu-O superconductor tapes with addition of magnetic nanorods Fe2O3," Appl. Phys. Lett., vol. 89, pp. 123904, 2006.

[7] L. N. Bulaevskii, E. M. Chudnovsky and M. P. Maley, "Magnetic pinning in superconductor-ferromagnet multilayers," Appl. Phys. Lett., vol. 76, no. 18, pp. 2594, 2000.

[8] D. B. Jan, J. Y. Coulter, M. E. Hawley, L. N. Bulaevskii, M. P. Maley, Q. X. Jia, B. B. Maranville, F. Hellman, and X. Q. Pan, "Flux pinning enhancement in ferromagnetic and superconducting thin-film multilayers," Appl. Phys. Lett., vol. 82, no. 5, pp. 778, 2003.