2009

YBCO films with Zr4+ doping grown by MOD method

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YBa2Cu3O7-delta (YBCO) films with Zr doping have been prepared successfully by the trifluoroacetate metal-organic deposition (TFA-MOD) method through dissolving Zr acetylacetonate into the precursor solution. Yttria-stabilized zirconia (YSZ) nanoparticles were detected in the doped YBCO films by XRD. From the analysis of XRD omega and phi scans, the doped films have better out-of-plane and in-plane textures than those of the un-doped YBCO film. Although the doped YBCO films have lower T-c than that of the un-doped YBCO film, a very significant enhancement of normalized J(c) is displayed as compared to the undoped film at applied fields, indicating that an effective pinning force was created by Zr doping.

Keywords
YBCO, films, Zr4, doping, grown, MOD, method

Disciplines
Engineering | Physical Sciences and Mathematics

Publication Details

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This journal article is available at Research Online: http://ro.uow.edu.au/aiimpapers/253
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Grown by MOD Method
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Abstract—YBa\(_2\)Cu\(_3\)O\(_{7-\delta}\) (YBCO) films with Zr doping have been prepared successfully by the trifluoroacetate metal-organic deposition (TFA-MOD) method through dissolving Zr acetylacetonate into the precursor solution. Yttria-stabilized zirconia (YSZ) nanoparticles were detected in the doped YBCO films by XRD. From the analysis of XRD \(\omega\) and \(\varphi\) scans, the doped films have better out-of-plane and in-plane textures than those of the un-doped YBCO film. Although the doped YBCO films have lower \(T_c\) than that of the un-doped YBCO film, a very significant enhancement of normalized \(J_c\) is displayed as compared to the undoped film at applied fields, indicating that an effective pinning force was created by Zr doping.

Index Terms—Nanoparticle doping, TFA-MOD, YBCO film.

I. INTRODUCTION

FOR practical applications, especially power applications, high temperature superconductors (HTS) such as YBa\(_2\)Cu\(_3\)O\(_{7-\delta}\) (YBCO) need to carry a high critical current density \(J_c\) under high magnetic fields. However, due to vortex motion, the capability of YBCO to carry currents is significantly reduced at higher applied magnetic fields. There is an effective way to improve the in-field performance of coated conductor by introducing various kinds of pinning centers using a variety of techniques, including interlayers of non-superconducting materials [1], [2], mixed rare-earth doping [3], [4], and doping with self-aligned Ba\(_2\)Zr\(_2\)O\(_7\) (BZO) nanodots and nanorods [5]–[7], as well as the use of nanoparticle-modified substrate surfaces [8], [9]. Among these approaches, BZO nanoparticles [7], [9] grown heteroepitaxially within laser-ablated YBCO films are the most popular, because these particles are easily incorporated into the films from a source target composed of a ceramic BZO/YBCO mixture. Using a pulsed laser deposition (PLD) process, Goyal [7] et al. have succeeded in producing long, nearly continuous vortex pins along the \(c\)-axis in YBCO, in the form of self-assembled stacks of BZO nanodots and nanorods, which led to an improvement in \(J_c\) in magnetic fields. Recently, a new strategy for introducing BZO nanoparticles into YBCO films has also been developed by J. Gutierrez et al. [10], [11] on the basis of easily scalable chemical solution deposition techniques. The random crystalline orientation is the essential feature distinguishing chemically prepared nanocomposite films from those prepared through vacuum deposition methods. The quasi-isotropic character of the pinning has demonstrated that this new strategy is very effective in preventing vortex motion at high fields and high temperatures for all magnetic-field orientations. In this work, epitaxial YBCO/YSZ nanocomposite thin films were grown from a non-vacuum, low cost, and easily scalable metal-organic deposition method, and their microstructures and physical properties were investigated.

II. EXPERIMENTAL

The trifluoroacetate precursor solution was prepared by a standard TFA-MOD process with a cation ratio of Y : Ba : Cu = 1 : 1.5 : 3. A Zr acetylacetonate precursor in stoichiometric proportions was added to obtain the TFA precursor solution with 6 mol.% Zr doping. The solution was coated on \(10 \times 10 \text{mm}^2\) LaAlO\(_3\) single-crystal substrates with (001)-orientation by spin coating at a speed of 4000 rpm for 2 min at room temperature. The wet films were decomposed to amorphous precursor films by slowly heating them up to 400°C in a humid oxygen atmosphere. The amorphous precursor film was heated up to 800°C in humid Ar/O\(_2\) (100 ppm O\(_2\)) atmosphere and held for 90 minutes. An oxygenation process was carried out at 550–450°C for 90 min to achieve the superconducting phase.

X-ray diffraction measurements were carried out to examine the phase of the YBCO films. X-ray \(\omega\)-scans and \(\varphi\)-scans were used to evaluate the out-of-plane and in-plane textures of the YBCO films, respectively. The film thickness after growth was determined, by profilometer analysis, to be 250–300 nm. The DC magnetization measurements were carried out with a physical properties measurement system (PPMS) in magnetic fields parallel to the \(c\)-axis of the specimens. The \(J_c\) values of the YBCO films in magnetic fields were determined by application of the Bean critical state model formula, 

\[ J_c(H) = 20 \cdot M(H)/a(1 - (a/3b)), \]

where \(M\) is the vertical width of the magnetization hysteresis loop (emu cm\(^{-3}\)), and \(a\) and \(b\) (cm) are the cross-sectional dimensions of the sample perpendicular to the applied field, with \(b \geq a\).
The overall increase in $T_C$ of the doped YBCO film is 1.5 K lower than that of the un-doped film. The lowering of $T_C$ in the presence of the nanoparticles is consistent with other studies done on PLD YBCO films that were doped with $Y_2O_3$ nanoparticles [14]. The reason for the depressed $T_C$ may possibly be Zr substitutions into Yttrium sites, which are able to locally depress $J_c$ so they can act as flux pinning centers.

D. Analysis and Comparison of $J_c$

Devices with YBCO films are usually used at a temperature of 77 K, so we measured the $J_c$ at 77 K using PPMS. Fig. 4(a) shows the field dependence of $J_c/J_{c0}$ at 77 K, with the field parallel to the c-axis. It can be seen that the 6% Zr doped film has a very significant enhancement of normalized $J_c$ values as compared to the un-doped film for all applied fields, indicating that an effective pinning force was created by 6% Zr doping. The overall increase in $J_c$ at all magnetic fields can be more clearly seen when the magnetic-field dependence of the pinning force, $F_p = J_c(B) \times B$, is presented, as shown in Fig. 4(b). Although $J_c$ decreases monotonically with increasing field, $F_p$ increases to a maximum value $F_p\text{max}$ at the field of 0.3 T field.
then slowly decreases during further increase of the applied field. $F_{p}$ of 3.0 GNM$^{-3}$ in the 6% Zr doped YBCO film, which is a close to 500% enhancement compared with that of the un-doped sample, clearly exemplifies the appealing prospects for the present nanocomposite films.

IV. CONCLUSION

In conclusion, we have shown that the metal-organic deposition technique can be modified to be used as a cost-effective and highly versatile method for introducing nanosized pinning centers into YBCO films. The TFA-YBCO route with Zr doped
precursor solutions was utilized to fabricate YSZ doped YBCO films through an in-situ crystallization process. Investigations into the behavior of the critical current density in magnetic fields reveal a strong enhancement of \( J_c \) at high magnetic fields in the YBCO film with 6% Zr doping. Pinning centers introduced by chemical solution deposition techniques show enhanced pinning properties in all magnetic fields.

ACKNOWLEDGMENT

The authors thank Prof. S. X. Dou (University of Wollongong) for his valuable suggestions in preparing this paper.

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