Physica C 493 (2013) 104–108

Contents lists available at SciVerse ScienceDirect

Physica C

journal homepage: www.elsevier.com/locate/physc

Enhanced flux pinning properties in superconducting $YBa_2Cu_3O_{7-z}$ films by a novel chemical doping approach

W.T. Wang [a,*], M.H. Pu [a], M. Lei [a], H. Zhang [a], Z. Wang [a], H. Zhang [b], C.H. Cheng [a,c], Y. Zhao [a,c,*]

[a] Key Laboratory of Magnetic Levitation and Maglev Trains (Ministry of Education of China), Superconductivity R&D Center (SRDC), Southwest Jiaotong University, Mail Stop 165#, Chengdu, Sichuan 610031, China
[b] Department of Physics, Peking University, Beijing 100871, China
[c] Superconductivity Research Group, School of Materials Science and Engineering, University of New South Wale, Sydney, 2052 NSW, Australia

ARTICLE INFO

Article history:
Available online 10 April 2013

Keywords:
Superconductivity
$YBa_2Cu_3O_{7-z}$ films
Chemical doping
Flux pinning

ABSTRACT

Pure and cobalt-doped superconducting $YBa_2Cu_3O_{7-z}$ (YBCO) films were prepared on (00l) $LaAlO_3$ substrate by a newly developed polymer-assisted metal organic deposition method. The cobalt-doped YBCO films display much denser and smoother surface microstructures and the superconducting transition temperature T_c spans a small range of 1.7 K with the doping levels. Significantly enhanced flux-pinning properties have been obtained for dilute cobalt-doped film. This may be attributed to the good grain connections and the effective flux pinning centers introduced by cobalt doping.

1. Introduction

YBCO-based coated conductors (CCS), with high current densities and irreversibility fields, have recently become the hotspot in high temperature superconductor research field [1,2]. YBCO-based CCS is mainly applied in generator, motor, superconducting magnet, magnetic energy storage equipment and so on. However, the low current densities with increasing the magnetic fields and temperatures prevent the large scale applications of CCS. Many results have illustrated that introduction of proper artificial flux pinning centers can distinctly improve the current carrying capabilities of CCS. Among these present techniques, creation of column defects comprised of self-alighted $BaZrO_3$ nanodots and nanorods is regarded as the most effective artificial technique to significantly increase the flux pinning properties [3–5]. Meanwhile, flux pinning centers can also be introduced by rare earth substitution for yttrium [6,7], addition of second phase particles [8], YBCO multilayer with second phase materials [9,10], decoration of substrate surfaces by nanosize particles [11,12]. Whereas, most of the high performance CCS has been obtained through in situ approaches [9] with high cost and relatively low production rate. Furthermore, most of the present dopants in YBCO are complicated and expensive for the real production. Therefore, it is quite necessary to develop the novel dopants and cost-effective technique to incorporate the flux pinning centers and thus remarkably enhance the flux pinning properties of YBCO-based CCS.

In this work, dilute cobalt doping of YBCO film has been proposed to improve the in-field current densities of YBCO films by solution-derived method. The cobalt can be easily incorporated during the synthesis process of YBCO coating solution and the solution-derived method can introduce dopants under non vacuum atmosphere. So this artificial technique is cost-effective and easy to operate, thus it is favorable to realize the mass production of YBCO-based CCS. A series of cobalt-doped YBCO films with different doping levels were synthesized by a newly developed fluorine-free polymer-assisted metal organic deposition (PA-MOD) method [13,14] and the effect of cobalt doping on texture, microstructure, superconducting and magnetic properties was seriously investigated. High current densities in magnetic fields have been achieved in highly dense cobalt-doped YBCO films.

2. Experimental

Cobalt (Co)-doped $YBa_2Cu_{3-x}Co_xO_{7-z}$ films with $x = 0$, 0.0005, 0.001 and 0.005 were prepared on commercially available $LaAlO_3$ (LAO) single crystal substrate by fluorine-free PA-MOD method. The precursor solutions were synthesized by dissolving acetates of cobalt, in addition to acetates of yttrium, barium and copper, in propionic acid and stirring at 60 °C for 2 h. Then polyvinyl butyral was added into the solution with being subsequently subjected to continuously stirring to adjust the viscosity thus obtain the final coating solution. Then the coating solution was coated on LAO using a spin coater with the rotation speed of 6000 r/min and fol-

* Corresponding authors. Address: Key Laboratory of Magnetic Levitation and Maglev Trains, Superconductivity R&D Center, Southwest Jiaotong University, Chengdu, Sichuan 610031, China (Y. Zhao). Tel.: +86 28 87600786; fax: +86 28 87600787.

E-mail addresses: wtwang@swjtu.edu.cn (W.T. Wang), yzhao@swjtu.edu.cn (Y. Zhao).

0921-4534/$ - see front matter
http://dx.doi.org/10.1016/j.physc.2013.03.039

lowed by drying at 150–200 °C for 5–10 min. The YBCO films were fabricated with the following three processing steps. Firstly, the films were decomposed in the temperature range of 150–500 °C at the rate of 0.5 °C/min in humid argon and oxygen mixture gas condition. After this step, the amorphous matrix with CuO nanoparticles was obtained. Secondly, YBCO pyrolyzed films were directly inserted into the quartz tube furnace at 815–870 °C in dry argon and oxygen mixture gas for several minutes to experience a partial melting process then treated at 770 °C for 1 h to get the tetragonal YBCO phase. The humidified ambient was obtained by passing dry gas through a reservoir of water, in which the humidity can be controlled by water temperature, i.e., the dew point of water. Finally, superconducting YBCO films with orthorhombic phase were prepared by annealing in dry oxygen gas at 400–450 °C for several hours.

A Philips X'Pert MRD diffractometer with CuKα radiation was used to record the θ–2θ XRD patterns, which characterized the phase purity of the as-grown film. The texture analyses including φ-scan and ω-scan were performed using a Philips MRD equipped with a four crystal monochromator, delivering a pure CuKα1 line of wavelength λ = 0.15406 nm. The microstructure analyses as well as the cross-sectional investigation of the YBCO layer were performed by using an environmental scanning electron microscope (ESEM) equipped with EDS. Superconducting transition as well as magnetic hysteretic loop have been observed by using Quantum-Design SQUID XL(7T). The J_c value of the YBCO film in self-field at 77 K was determined by the application of the Bean critical state model formula using the M–H curve. The thickness of the YBCO film has been determined by Ambios XP-2 step profiler and cross-sectional SEM micrograph.

3. Results and discussions

Fig. 1a shows the X-ray diffraction θ–2θ patterns of Co-doped YBCO films with x = 0, 0.0005, 0.001 and 0.005. As can be seen, only (00l) YBCO reflection peaks can be detected except the peaks of single crystal substrate for pure YBCO film indicating a strong c-axis orientation. YBCO films with Co doping also exhibit excellent c-axis orientation despite of the observation of quite small Y-124 (004) peaks, and film doped with x = 0.001 has the highest (00l) YBCO peak intensity.

To further examine the texture, phi-scan and omega-scan rocking curves have been documented in Fig. 1b and c. Fig. 1b shows the phi-scan curve of YBCO (103) peak with the full width at half maximum (FWHM) of 0.9° and 1.23° for pure and Co-doped YBCO films indicating the good in-plane alignment. The lattice deformation by Co doping to the CuO chain may be responsible for relatively worse in-plane texture compared with that of pure film. The typical omega-scan rocking curves of pure and Co-doped films around the YBCO (005) peak are performed to estimate the quality of out-of-plane alignment shown in Fig. 1c. The FWHM of (005) peak is about 0.3° for the films showing the good out-of-plane alignment. The above results demonstrate that biaxially textured Co-doped and pure YBCO films have been successfully prepared.

Fig. 2a–d shows the surface morphologies of pure and Co-doped YBCO films with different doping levels. As can be seen, amount of

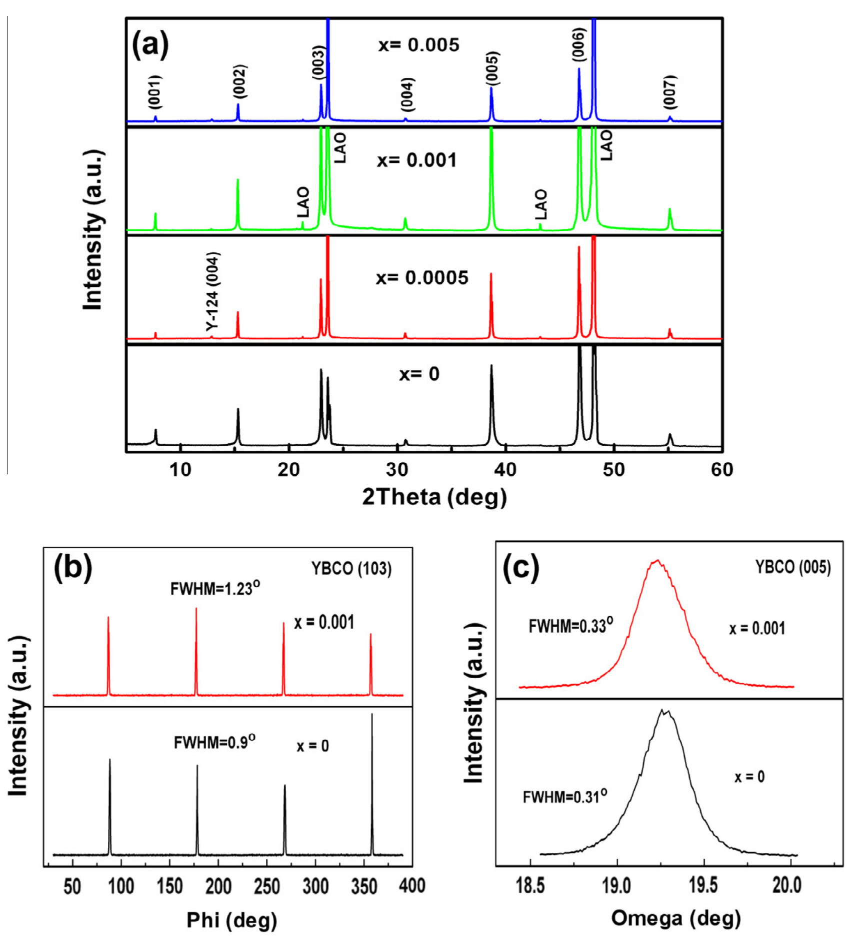

Fig. 1. (a) Typical θ–2θ X-ray diffraction patterns of pure and Co-doped YBCO films with different doping levels. A small Y-124 peak was shown in the doped films. (b) The YBCO (103) phi-scan and (c) (005) omega-scan rocking curves of pure and Co-doped YBCO films. The FWHM values are given in the figure.