Available online at www.sciencedirect.com

ScienceDirect

Physica C 468 (2008) 147–152

PHYSICA C

www.elsevier.com/locate/physc

Morphological variations on surface topography of $YBa_2Cu_3O_{7-\delta}$ thin films on $SrTiO_3$, with respect to the substrate misorientation direction

Dimitrios Vassiloyannis *, Panos M. Pardalos [1]

Department of Industrial and Systems Engineering, University of Florida, Gainesville, FL 32611-6595, USA

Received 24 April 2007; received in revised form 25 October 2007; accepted 31 October 2007
Available online 13 November 2007

Abstract

The surface topography of $YBa_2Cu_3O_{7-\delta}$ thin films deposited on $SrTiO_3$ substrates has been evaluated by atomic force and scanning tunneling microscopy. The observed correlation between the direction of the substrate misorientation and the surface morphology of the films produced is reported: when using substrates with offcut lying only along the [1 0 0] plane, smoother and highly ordered film surfaces are produced, while for substrates misoriented along both the [1 0 0] and [0 1 0] planes, island growth reappears in the resulting films. The findings demonstrate that the direction of substrate offcut influences the morphology of the films deposited, enabling better thin film engineering at nano-scale.
Published by Elsevier B.V.

PACS: 74.72.Bk; 74.78.−w; 68.55.−J; 68.55.−a; 81.15.Aa; 68.37.Ps; 68.37.Ef; 68.37.Og; 61.05.Cp; 61.72.Ff, 61.72.Hh, 61.72.Lk; 81.15.−z

Keywords: Misorientation; Offcut; Thin films; Nano-scale; Surface morphology; YBCO; STO

1. Introduction

The high temperature superconducting (HTSC) systems and their exotic physical properties have attracted great scientific interest for large scale applications in electronic devices. A plethora of articles have focused on the $YBa_2Cu_3O_{7-\delta}$ (YBCO) compound, since the strong intrinsic flux pinning observed, leads to high critical current densities J_c-s (up to $\sim10^6$ A/cm^2) without introducing artificial pinning sites [1,2]. However, its unit-cell with the triple perovskite structure [3] makes YBCO a difficult material to manufacture in applicable forms, such as wires, tapes, etc. Island mediated columnar growth and grains of various orientations generally appear after some finite thickness [4–6] as directed by the ceramic nature of the material. The resulting surfaces inhibit the production of good quality assemblies such as SQUID-s, since holes created by columnar growth between non-adjacent layers act as joins and reduce significantly the device reliability.

Highly epitaxial, *c*-axis oriented YBCO thin films can be routinely produced on $SrTiO_3$ (STO) substrates by pulsed laser deposition [7–10] due to their low mismatch parameter ($\sim$1%). The use of substrates polished at low angles off the [1 0 0] or [0 1 0] planes has been reported to lead to the generation of smoother films, favoring a more full-monolayer two dimensional growth (Frank-Van der Merwe) [11,12,15]. It has also been observed that substrates vicinally offcut along the [1 1 0] crystallographic axe exhibit a preferred twin pair for vicinal angles up to 0.60°, while detwinning occurs with increasing vicinal angle for offcut lying parallel to the [1 0 0] or [0 1 0] STO

---

* Corresponding author. Tel.: +1 352 392 1464x2033, 2017; fax: +1 352 392 3537.
E-mail address: anpote@yahoo.com (D. Vassiloyannis).

[1] Research partially supported by NIH and CRDF grants.

0921-4534/$ - see front matter Published by Elsevier B.V.
doi:10.1016/j.physc.2007.10.021

crystallographic axes ([16] and references therein). In this paper we report the effect of the offcut direction of misoriented $SrTiO_3$ substrates on the surface microstructure of YBCO thin films. We observe that a substrate misorientation along the [1 0 0] (a) or [0 1 0] (b) planes improves the texture of the resulting films, while for offcut lying close to the substrate diagonal, 3D island and terrace growth reappears.

2. Experimental details

The series of $SrTiO_3$ substrates used in the experiments consisted of five different specimens: two samples vicinally polished at angles 1.04° and 1.68° off the (0 0 1) towards the [1 0 0] plane, two samples intentionally offcut from (0 0 1) by 1° and 1.7° about both the [1 0 0] and [0 1 0] planes, and a 0° sample. All specimens were pre-annealed at 900 °C for 2 h to reveal the step-structure of their surfaces. A digital instruments nanoscope II AFM with a cantilever force of 8 nN was used in air to evaluate the samples surface. YBCO films 130–230 nm in thickness were subsequently deposited by pulsed KrF (248) excimer laser ablation from a commercial stoichiometric YBCO target under a dynamic oxygen pressure of 400 mTorr, with the STO substrates heated to 820 °C during the deposition [12]. The film surfaces were imaged using a digital instruments nanoscope II STM equipped with a PtIr tip, operating in constant current mode at a bias of 800 mV and a tunneling current of 50 pA. A Siemens D5000HR high-resolution, four circles, six axes diffractometer with a CuKa source was used for a series of X-ray diffraction experiments which were performed to evaluate the substrate misorientation, the film crystalline quality and the film orientation parallel to the substrate *c*-axis with a precision of 0.001°, as described previously [12]. The TEM-HREM studies were performed using a Philips CM-20 and a JEOL 200CX microscopes operating at 200 kV.

3. Results

3.1. X-ray analysis

Sharp superconducting transitions at 89–91 K by means of SQUID magnetometry (Fig. 1) confirmed for all samples a superconducting character near the ideal for the YBCO phase [13]. The good crystalline quality of the samples was determined by X-ray experiments: full widths at half maximum (FWHM) values measured for the (0 0 5) YBCO reflection were about ~0.3° for all samples [12], while the Φ-scan measurements performed through $(0\,1\,8)_{YBCO}$, evidenced that the good lattice matching prohibited the growth of grains of different orientation or of phase impurities (see Fig. 2). The film epitaxial growth was confirmed by XRD (θ–2θ) diffractograms (Fig. 3). Only (0 0 1) peaks were measured of both the film and the substrate, indicating that only a single crystalline phase was produced with the *c*-axis aligned along the substrate *c*-axis. That is in agreement with reports in the literature [16] whereby no discernible misorientation is detected for offcut angles >0.60°.

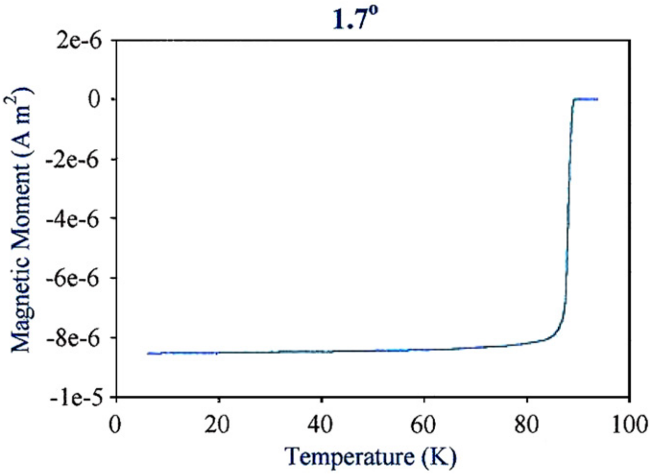

Fig. 1. Typical DC-SQUID magnetometry measurement for the superconducting transition of the 1.7° sample.

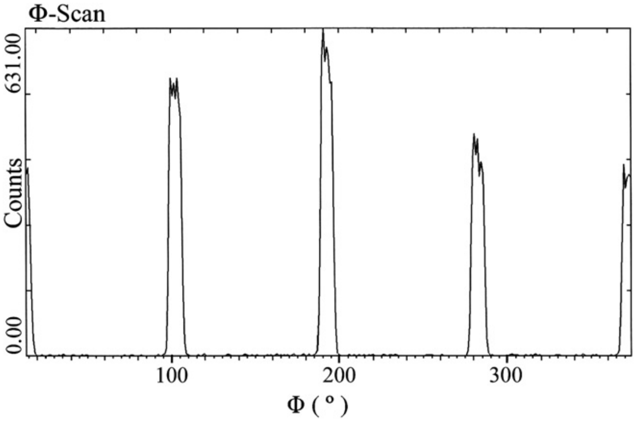

Fig. 2. Φ-scan through (0 1 8) for the 1.7° sample.

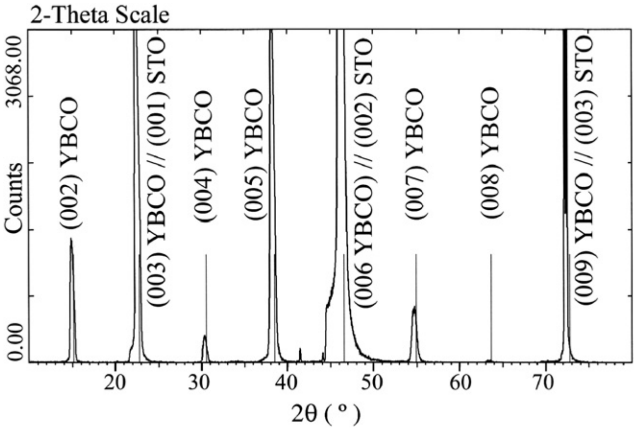

Fig. 3. XRD diagram from the 1.7° sample.