Available online at www.sciencedirect.com
SCIENCE DIRECT
Physica C 437–438 (2006) 336–340
PHYSICA C
www.elsevier.com/locate/physc

Magneto-optical investigation on $YBa_2Cu_3O_{7-x}$ thin films on $SrTiO_3$

Dimitrios Vassiloyannis *

IVON-NEWBURY High-Tech Laboratory, Esopus, NY 12429, P.O. Box 236, USA
University of Florida, Gainesville, FL 32611, USA

Available online 3 February 2006

Abstract

The vortex motion when the external field penetrates perpendicularly square $YBa_2Cu_3O_{7-x}$ thin films deposited on misoriented $SrTiO_3$ platelets has been pictured in situ by magneto-optical imaging. The visualized vortex pinning profile allows large-scale characterization of the superconducting quality of the thin film surface enabling tracing of areas of reduced superconducting properties or of various film defects. The obtained magneto-optical (M-O) images in combination with magnetization measurements can produce reliable estimations of the supercurrents flowing at each point of the film surface. The findings indicate a 40% anisotropy in the current distribution along the different [1 0 0] and [0 1 0] orientations for films deposited on substrates miscut at angles >1.69°.

Keywords: Magneto-optical; Thin films; Off-cut; Misorientation; YBCO; STO

1. Introduction

An increasing number of articles are published about the current distribution within high temperature superconducting (HTSC) thin film platelets [1–4]. It has been observed [2] that off-cutting the substrate leads to the production of thin films that are characterised by highly anisotropic current distributions along the *a* and *b* directions of the sample while a significantly enhanced current occurs along the misorientation direction. These findings are of great technological importance when integrating HTSC thin films in electronic assemblies such as the SQUID-s.

Highly mono-crystalline $YBa_2Cu_3O_{7-x}$ (YBCO) thin films can be reliably produced on $SrTiO_3$ (STO) substrates by pulsed laser ablation [5–8] maintaining the *c*-axis orientation of the substrate due to the low mismatch (~1%). The currents reported for this HTSC compound of the order of 10^8 A/cm^2 [1,2], the highest in the literature, render the material very promising for large-scale applications. In this paper an analytical description of the current distribution within misoriented YBCO thin films is attempted using a large-scale magneto-optical (M-O) investigation to allow estimation of the profile of the magnetic field that penetrated individual samples with increasing external magnetic field and/or temperature [9]. The M-O images received can be used to evaluate the quality of the whole surface of the produced platelets via magnetic field imaging of the supercurrent associated vortices, thus indicating probable weak superconducting areas or defects (like the so called *plumes* [10]). When combined with magnetization (VSM) measurements, they can offer an accurate estimation of the associated supercurrents at each point of the film surface.

2. Experimental

A series of $5 \times 5 \times 1$ mm^3 $SrTiO_3$ substrates vicinally off-cut at angles 1.69°–6.4° off the (0 0 1) towards the (0 1 0) plane were used. The substrates were pre-annealed for 2 h at 900 °C. YBCO films 130 (±10) nm thick were deposited on the substrates by pulsed laser ablation (PLD) under an oxygen pressure of 400 mT with the specimens being heated to 820 °C during deposition. Conventional Θ–2Θ scans were conducted on a Siemens D5000HR high resolution, four circle, six axis diffractometer with a CuKa

* Address: IVON-NEWBURY High-Tech Laboratory, Esopus, NY 12429, P.O. Box 236, USA. Tel./fax: +1 30 694 609 8008.
E-mail address: anpote@yahoo.com

0921-4534/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.physc.2005.12.068

source, to examine the film orientation parallel to the substrate c-axis. The films full widths at half maximum (FWHM) were measured by rocking curves experiments. Φ-scans were performed to verify in-plane alignment. The high index (0 1 8) YBCO peaks were used to direct the diffracted beam in the device detector area. A vibrating sample magnetometer (VSM) was used for a series of magnetization measurements at temperatures of 4.2, 25, 50 and 77 K. The required temperatures were firstly reached in zero field cooling mode and data were recorded with the field increasing up to 12 T at a sweep rate of 10 mT s^{-1} and then decreasing down to zero. For the M-O technique, a typical ferrimagnetic iron garnet ($Bi_xLu_{3-x}Ga_yFe_{5-y}O_{12}$) grown on a GGG garnet ($Gd_3Ga_5O_{12}$) was used [10,11], combined with a mercury arc light source and filter [12–15], with the polariser–analyser set at an extinction angle of 6° off their crossed position [11], maintaining their angle stable at all processing times. Images were received at a CCD camera using various shutter speeds (from 1/120 up to 1/4000 s^{-1}) of a Nikon Optiphot 100 S optical microscope with a ×5 objective lens and a white light of 60 W.

3. Results

3.1. X-ray analysis

The good superconducting quality of the produced YBCO thin films has been verified by sharp superconducting transitions at 89–91 K. X-ray experiments confirmed the mono-crystalline character of the films: all samples presented full widths at half maximum (FWHM) values of about ~0.3° for the (0 0 5) YBCO reflection [1]. The (Θ–2Θ) X-ray diffractogram received of the 5.33° sample is shown in Fig. 1. Only (0 0 1) peaks of the film and the substrate were detected evidencing the presence of only one mono-crystalline film phase with its c-axis aligned along the substrate c-axis. No grains of different orientation or of phase impurities were detected in any of the samples by Φ-scan measurements performed through $(0\,1\,8)_{YBCO}$ (see Fig. 2).

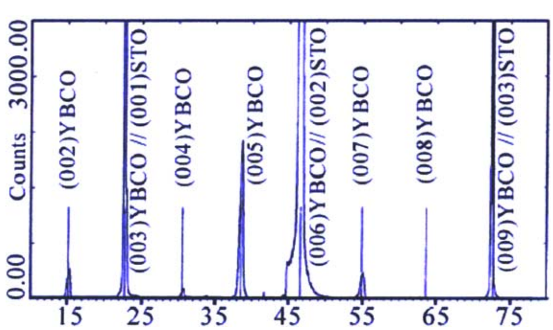

Fig. 1. (Θ–2Θ) X-ray diagram of the 5.33° sample.

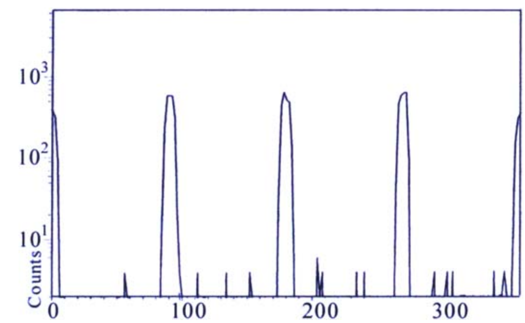

Fig. 2. Φ-scan diagram of the 5.33° sample.

3.2. VSM measurements

The magnetization half-loops received of all specimens are symmetrical about the field axis for all temperatures at fields >0.2 T, as shown in Fig. 3 (5.33° sample). The difference ΔM between the increasing and decreasing field branches of the magnetization half-loops received, can provide the average J_c flowing inside the films [16]:

$$J_c = 240 \cdot (\Delta M / t) \tag{1}$$

where ΔM is given in emu, t in cm and J_c in A/cm^2. Fig. 3(c). illustrates the J_c-s for all samples at different temperatures versus off-cut angles. A significantly increased J_c is observed for the 1.69° off-cut specimen, for which a current value $\sim 6 \times 10^{11}$ Am^{-2} was recorded at $T = 4.2$ K and $B = 0.2$ T. This value is at least an order of magnitude higher than the usually reported in the literature and comparable to the value published in [2]. Identically increased current values have been measured for the same specimen

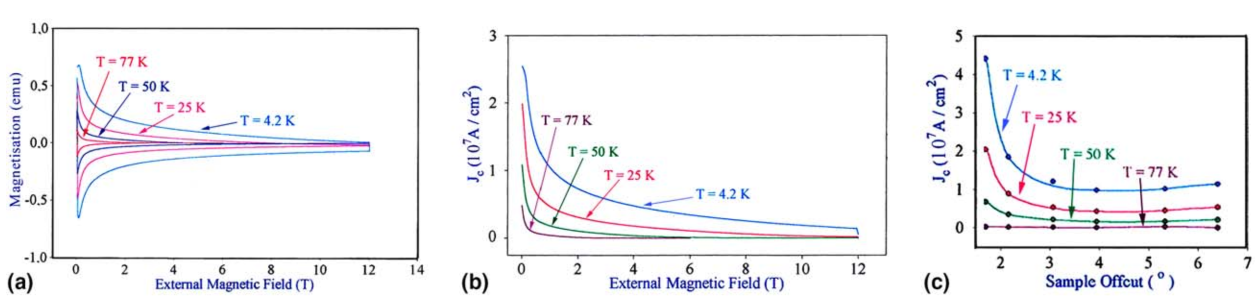

Fig. 3. (a) Magnetization hysteresis loops of the 5.33° sample, (b) corresponding currents, and (c) comparative current plot for the different angles, $B = 1$ T.