

Texture by the kilometer

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ABSTRACT

A novel x-ray diffractometer has been used to characterize the texture of 2 km of textured tape in segments up to 20 m long. Techniques have been developed for the study of the uniformity of texture and for the detection of second phases, deviations from cube texture, and the sharpness of cube texture, in metal substrates, oxide buffer layers, and YBa₂Cu₃O₇ (YBCO) superconductors.

INTRODUCTION

There is great interest in the development of superconducting tapes consisting of YBCO films grown on metal substrates (with or without buffer layers). High critical currents (J_c) have been demonstrated for such tapes over ~1 m lengths, persisting to high magnetic fields [1,2]. Most applications, however, will require production of ~km lengths. The requirements for scale-up are made particularly challenging by the intergranular transport properties of YBCO: J_c drops significantly when the grain boundary disorientation exceeds ~5°, so the texture of the YBCO must be uniform over the length of the conductor [3]. A single wall of high-angle grain boundaries could block the supercurrent.

X-ray diffraction has been widely used to characterize ~cm lengths of superconducting tape. We have developed a novel x-ray diffractometer to completely characterize the phase content and texture of longer lengths. Preliminary results suggest that processing conditions can be kept sufficiently uniform to produce long-length superconducting tapes [4]. We report the techniques we have developed, and the range of texture variations which we have observed in the first 2 km of operation.

EXPERIMENTAL DETAILS

Up to 20 m of tape, typically 1 cm in width and 0.05 mm in thickness, is spooled on reels 10 cm in diameter (Fig. 1). These reels are mounted on a four-circle diffractometer [5]. The 40 cm inside diameter of the χ circle provides clearance for full rotation of χ and ϕ , with the restriction $2\theta < 90^\circ$. One reel is controlled by a microstepping motor [6], the other is held at a constant torque of 0.2 N-m [7]. The sample slides across stainless steel guides machined to a 5 cm radius. The sample is irradiated between these guides, which hold it at a constant height. The smooth motion provided by a microstepper and the gentle bending applied by the large-radius guides prevent damage to the sample.

X rays are provided by a 50 kV / 100 mA Cu rotating anode source[8]. A sagittally bent graphite (002) crystal selects K $_{\alpha}$ fluorescence and collimates the x rays in the vertical (out-of-plane) direction. A 75 cm flight-path followed by a 2.5 mm (wide) x 5 mm (high) slit collimates horizontally (in-plane). Diffracted radiation is collimated in-

plane by soller slits (100 cm long, 0.7 mm pitch) and counted using a scintillation detector.

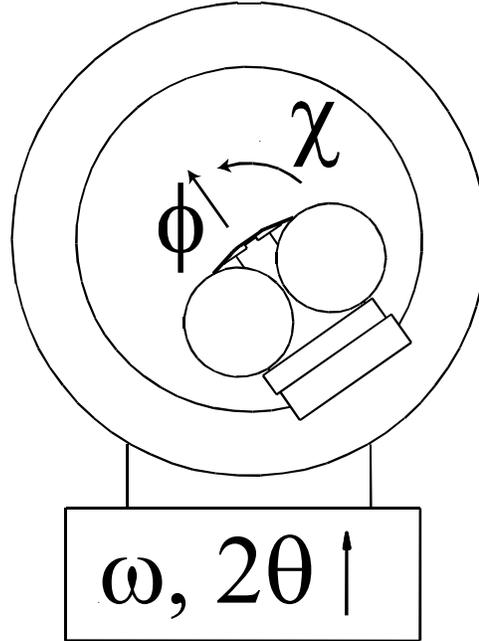


Figure 1. Reel-to-reel tape handler mounted on a four-circle diffractometer. Reel diameter is 10 cm, chi circle inside diameter is 40 cm.

Counting and control of reel motors and diffractometer stepping motors is coordinated using PC software [9]. This system was adapted from one built for another purpose, and its design is not optimum. We are currently commissioning a dedicated system in which higher intensity will be obtained from a sealed-tube x-ray source placed closer to the sample and collimated and monochromated using a meridionally bent, variable period multilayer film [10].

RESULTS AND DISCUSSION

The phase content of a tape is characterizing by collecting $\theta/2\theta$ scans at each point on the tape (Fig. 2). A complete phase analysis is obtained by collecting a scan at 1 cm intervals. Each scan takes 3 minutes, for a scan rate of 20 cm/hour. The scans show cube-textured YBCO, CeO₂, and YSZ, along with the reaction products BaCeO₃ and NiO.

Once we know what phases to expect, we can analyze the phase content much more quickly using “tape scans”. The diffractometer is set to a Bragg peak, with the tape moving while counts are read at intervals of 1 cm; the scan runs along the ridge of one of the lines of peaks seen in Fig. 2b. We can measure the uniformity of YBCO as fast as 1 m/min (Fig. 3).

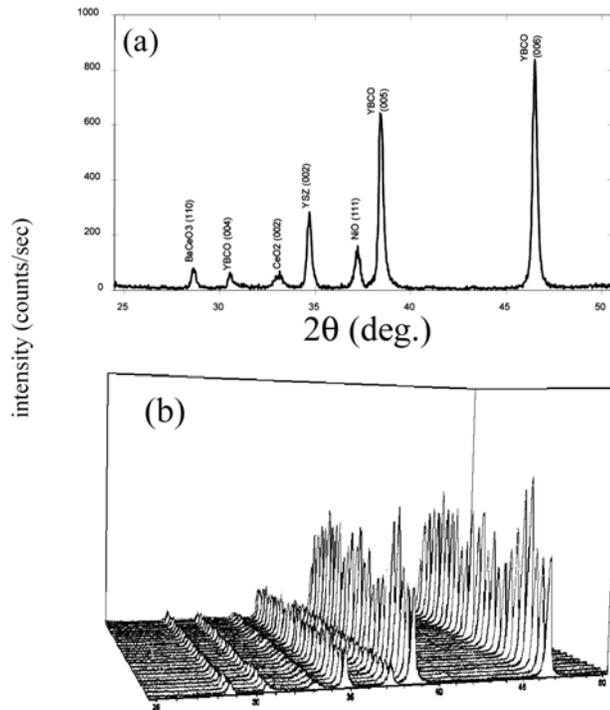


Figure 2. $\theta/2\theta$ scans from YBCO/ CeO_2 /YSZ/ CeO_2 /Ni tape **A**. (a) Conventional $\theta/2\theta$ scan. Collection time is 3 min. (b) Family of $\theta/2\theta$ scans collected at 1 cm intervals; total collection time is 90 min.

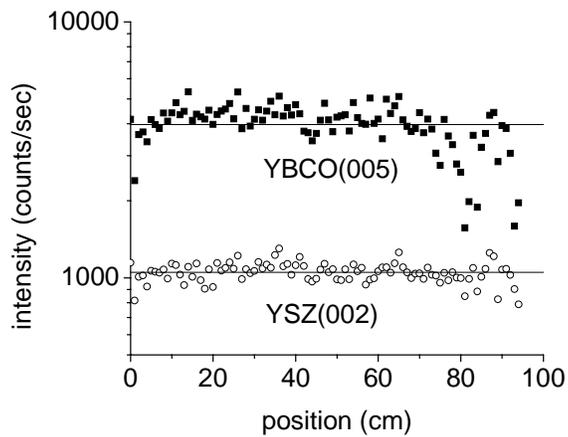


Figure 3. Intensity from cube texture Bragg reflections from YBCO/ CeO_2 /YSZ/ CeO_2 /Ni tape **B**.

These tape scans have three principle uses. Firstly, they serve to locate isolated defects for closer study; the dip in YBCO(005) intensity at 84 cm (Fig. 3), for example, corresponds to a point where the film is less well aligned. Secondly, tape scans are a convenient and rapid way to perform controlled experiments. Deposition temperature and tape speed are cycled through 10 sets of parameters as a YSZ film is continuously deposited on a moving tape, causing the YSZ texture to switch back and forth between (111) and (002) (Fig. 4). Thirdly, tape scans can reveal

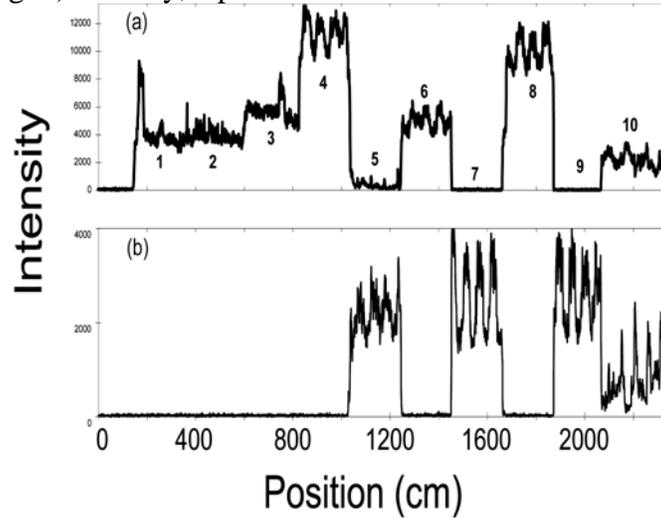


Figure 4. Tape scans of the (a) YSZ(111) and (b) YSZ(002) Bragg reflections for $\text{CeO}_2/\text{YSZ}/\text{CeO}_2/\text{Ni}$ tape C. Each scan took 8 minutes.

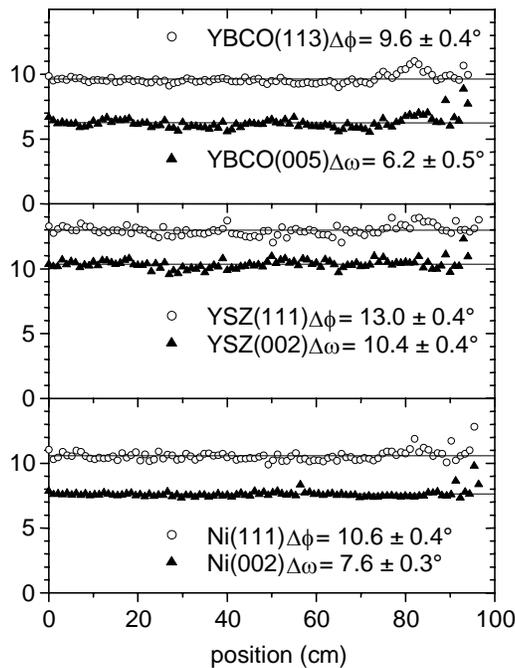


Figure 5. Phi scan and rocking curve widths from $\text{YBCO}/\text{CeO}_2/\text{YSZ}/\text{CeO}_2/\text{Ni}$ tape B.

periodic behavior: periodic variations in the sharpness of the YSZ rocking curves create dramatic fluctuations in Bragg intensity (Fig. 4).

Rocking curves, phi scans (Fig. 5) and pole figures (Fig. 6) measure the quality of film epitaxy. Widths are found by least squares fitting to a Gaussian lineshape. An increase in peak width can be seen at 83 cm (Fig. 5). The volume fraction of cube textured material by computed by integrating pole intensity using an equal-area projection; the integrated intensity of the cube texture peaks is compared to the total integrated intensity. We define “cube texture” to be

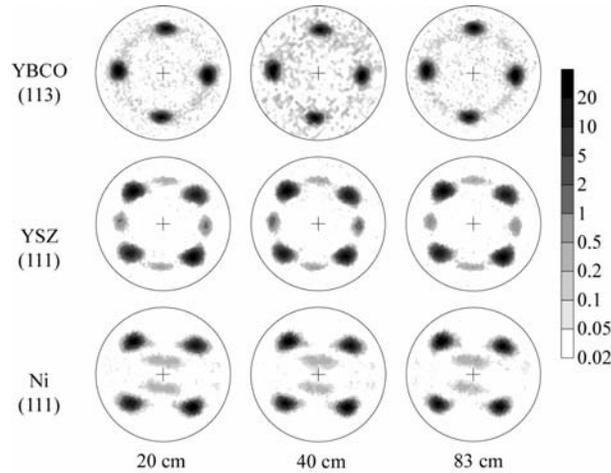


Figure 6. Background-subtracted, log-scale pole figures from selected points on a YBCO/CeO₂/YSZ/CeO₂/Ni tape **C**.

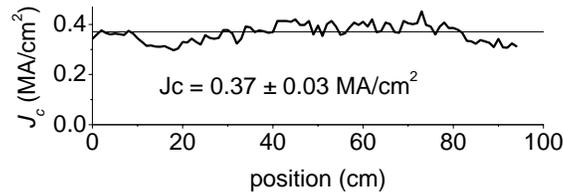


Figure 7. Critical current for YBCO/CeO₂/YSZ/CeO₂/Ni tape **B**, measured at 1 cm intervals.

orientations where $(\Delta\phi / 30^\circ)^2 + (\Delta\omega / 25^\circ)^2 < 1$; $\Delta\phi$ and $\Delta\omega$ are the in-plane and out-of-plane angular deviations from the nearest cube texture orientation. In the example shown here (Fig. 6), there is no significant variation from 96% cube texture, but retained rolling texture in Ni, {100}<110> domains in YSZ, and randomly oriented YBCO are clearly seen.

All these diffraction measurement can be correlated with J_c measurements (Fig. 7). In this example, a dip in J_c at 83 cm correlates with a broadening of the texture; a dip at 18 cm has no correlation in the diffraction data.

CONCLUSIONS

Reel-to-reel x-ray diffraction provides a rapid and detailed characterization of the texture and crystallographic phase of superconducting tapes. The techniques can be used for performing controlled experiments over the length of a tape, for locating defects, for uncovering periodic behavior and trends in film quality, and for determining the uniformity of a tape.

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