Physica C 468 (2008) 1070–1077

Contents lists available at ScienceDirect

Physica C

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

Biaxially textured $YBa_2Cu_3O_{7-x}$ films deposited on polycrystalline flexible yttria-stabilized zirconia ceramic substrates

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ARTICLE INFO

Article history:
Received 4 February 2008
Received in revised form 22 May 2008
Accepted 23 May 2008
Available online 10 June 2008

PACS:
74.72.Bk
74.78.Bz
74.78.Fk

Keywords:
YBCO coated conductors
Flexible YSZ ceramic
IBAD-MgO
Cryoelectronic applications

ABSTRACT

Biaxially textured $YBa_2Cu_3O_{7-x}$ (YBCO) films were grown on polycrystalline flexible yttria-stabilized zirconia (YSZ) ceramic substrates (Ceraflex) buffered with MgO and $LaMnO_3$ layers. These substrates were initially coated with silica glass to obtain a smooth surface and then biaxially textured MgO buffer layers were deposited by ion beam assisted deposition (IBAD-MgO). Lanthanum manganate (LMO) cap layers and YBCO layers were then deposited by the pulsed laser ablation method. Highly textured YBCO films with a full width half maximum (FWHM) of 6.75° in (1 1 0) phi scans and a FWHM ~ 5° in (2 0 0) omega scans were obtained. An initial deposition yielded samples with a $T_c > 88$ K and a self-field magnetization J_c of 2×10^5 A/cm^2 at 77 K. A secondary ion mass spectrometry (SIMS) depth profile of the samples indicated that with the present deposition condition, some La, Mn and Mg diffusion into the YBCO layers is possible and this may reduce the J_c in the self-field. The yield strength (YS) of uncoated Ceraflex substrates was compared with that of metallic substrates and it was found that Ceraflex substrates can have a YS at least 4–5 times higher than the YS of biaxially textured Ni–5 at.%W substrates and ~1.5 times that of Hastelloy^{TM} substrates.

1. Introduction

$YBa_2Cu_3O_{7-x}$ (YBCO) coated conductors are presently being developed using conductive metallic substrates such as Ni–5 at.%W or Hastelloy^{TM} [1,2]. However, losses due to eddy currents appear when these conductors are used in ac applications. Non-conducting or highly resistive substrates can avoid this issue for ac applications [3]. In addition, for cryoelectronic applications, YBCO films deposited on thermally- and electrically-insulating substrates are also of interest. Earlier work showed that $YBa_2Cu_3O_{7-x}$ coatings can be grown on highly resistive flexible polycrystalline yttria-stabilized zirconia (YSZ) substrates with ion beam assisted deposition (IBAD)-YSZ layers for RF cryoelectronic applications [4].

Polycrystalline YSZ substrates such as Ceraflex are commercially available in ultra thin, tough, flexible thin sheet form [5]. Sheets as thin as 0.05 mm thick and as large as 200 × 200 mm square are readily available. These substrates also have high hardness and fracture toughness – three times higher in bending strength, two or three times in fracture toughness than alumina. Properties such as this would make the material suitable as substrates for coated conductors if the lengths can be increased.

Gnanarajan et al. reported that IBAD-YSZ layers and YBCO with a phi scan full width half maximum (FWHM) of 19° can be grown on Ceraflex substrates when coated with an additional silica coating to reduce surface roughness [6]. However, it is known that biaxial texture can develop in IBAD-MgO faster than IBAD-YSZ [7,8]. Initial work by Lu et al. indicated that highly textured IBAD-MgO with a FWHM of 9.3° can indeed be grown on properly prepared Ceraflex substrates using particular processing conditions [9,10]. Here, we present initial results which indicate that biaxially textured YBCO can be grown on the IBAD-MgO buffered Ceraflex substrates using lanthanum manganate (LMO) cap layers deposited by pulsed laser ablation (PLD). Results on this YBCO/LMO/IBAD-MgO/Y_2O_3/SiO_2/Ceraflex architecture include biaxial texture of the layers, superconducting properties such as critical transition temperature (T_c), critical current density (J_c), microstructures and SIMS depth profile analyses of the coatings. Both Ceraflex 3Y with 3 mol% Y_2O_3 and Ceraflex 8Y with 8 mol% Y_2O_3 were used. In addition, mechanical properties of the Ceraflex substrates were measured and compared with published values of biaxially textured Ni–5 at.%W and Hastelloy^{TM} substrates.

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doi:10.1016/j.physc.2008.05.258

2. Experimental

2.1. Mechanical properties of ceraflex substrates

The Ceraflex substrates are obtained from Marketech International Inc. [5]. Ceraflex 3Y strips also have good elasticity and high flexibility and are capable of bending to a radius of 8 mm. The Ceraflex 3Y substrates were sliced to a nominal tensile specimen size of 50.8 × 3.34 × 0.09 mm. To prevent damage during the slicing operation, the substrates were hot-wax mounted and sandwiched between two microscope glass slides. The glass-sandwiched substrate was fed into a slow-speed, water cooled/lubricated, diamond-impregnated, slicing wheel rotating at ~100 rpm at a 0.25 mm/s feed rate. After slicing, the test specimens were unmounted and cleaned in toluene to remove the wax and further cleaned in acetone and methanol, and then dried. After cleaning, the tensile specimens were optically inspected at 50× for machining damage and edge chipping.

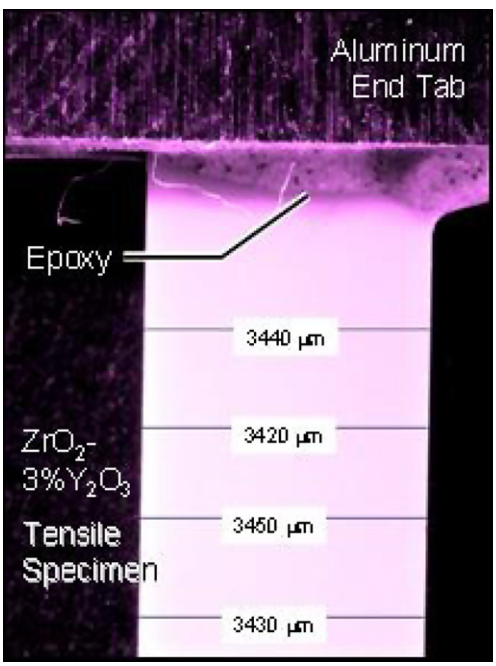

Fig. 1. Optical macrograph of a Ceraflex tensile test specimen in aluminum tabs. (Width measurements are also shown.)

The Ceraflex tensile specimens were then tabbed with 12 × 12 × 0.762 mm (nominal) aluminum plates at the ends to prevent crushing of the thin ceramic specimens in the tensile grip. Each end of Ceraflex tensile specimen was glued with a general-purpose two-part epoxy and sandwiched with two aluminum plates as shown in Fig. 1. The epoxy was allowed to cure for ~24 h to achieve maximum shear strength. The Ceraflex specimen tensile gage length after end tabbing was approximately 25 mm.

The width and thickness of the samples were measured before testing. The thickness was measured using a micrometer with debris-free flat anvils to prevent any surface damage to the tensile specimen. The width was measured optically using a calibrated microscope to prevent damage to the edge of the thin specimen. Typical variation in the sample widths is shown in Fig. 1.

The tabbed Ceraflex tensile specimens were mounted on an aligned tensile wedge grip (Instron Model 2716-015) on a Universal testing system (Instron Model 4486 SN C8825) with a 1 kN load cell (Instron Load Cell SN: UK881). The tensile extension rate was 0.0212 mm/s (0.05 ipm). A total of three tensile specimens were tested to failure. After testing, the remnants of each test specimen were photographed to show that the fracture occurred between the end tabs as shown in Fig. 2. A simple tensile testing method originally developed for textured metallic substrates [11] was used to test these thin ceramic substrates.

2.2. Buffer layers (MgO, $LaMnO_3$) and YBCO layers

The Ceraflex 8Y substrates were initially spin coated with methyl siloxane polymers to make smooth SiO_2 coatings as described in detail elsewhere [6]. A thin amorphous Y_2O_3 buffer layer (15–40 nm thickness) was deposited by e-beam deposition and pre-exposed in Ar^+ for 1–2 min on the initial SiO_2 layer. MgO of 9–11 nm thickness was deposited by IBAD at 1.5 Å/s, at room temperature using Ar^+ beam operating at 750 eV and 10 mA. An ion-to-atom ratio of ~0.9 was maintained during deposition. A homo-epitaxial MgO layer of 100–200 nm thickness was grown at 0.5–1.0 A/s, at 300–500 °C. In-situ real-time reflection high-energy electron deflection (RHEED) was used to monitor the texture development during IBAD-MgO and homo-epitaxial MgO depositions. A detailed discussion of the deposition conditions and characterization of these layers have been discussed elsewhere [10]. In the present

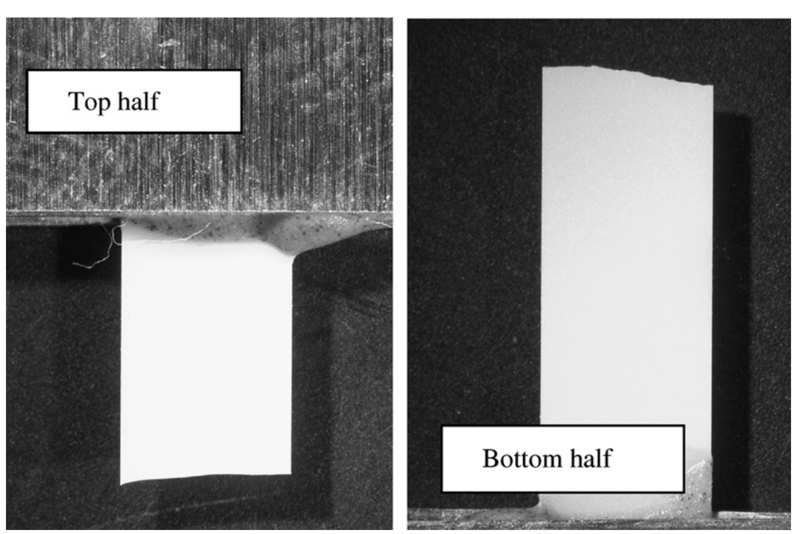

Fig. 2. Optical macrograph of a tested Ceraflex tensile test specimen at the end of the test showing the fractured tensile gage section: (a) top half and (b) bottom half.