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Y-Ba-Cu-O Film Deposition by Metal Organic Chemical Vapor Deposition on Buffered Metal Substrates

V. Selvamanickam, G. Galinski, J. DeFrank, C. Trautwein, and P. Haldar
Intermagnetics General Corporation, NY 12110, U. S. A.

U. Balachandran, M. Lanagan, and M. Chudzik
Argonne National Lab, IL 60439, U. S. A.

Abstract **— $YBa_2Cu_3O_x$ (YBCO) films have been deposited on buffered metal substrates by Metal Organic Chemical Vapor Deposition (MOCVD). Cube-textured nickel substrates were fabricated by a thermomechanical process. Epitaxial CeO_2 films were deposited on these substrates by thermal evaporation. Nickel alloy substrates with biaxially-textured Yttria-Stabilized Zirconia (YSZ) buffer layers deposited by Ion Beam Assisted Deposition were also prepared. Highly biaxially-textured YBCO films were deposited by MOCVD on both types of metal substrates. A critical current density greater than 10^5 A/cm^2 at 77 K has been achieved in YBCO films on metal substrates.**

I. INTRODUCTION

The newest type of HTS conductor that is being developed at Intermagnetics is surface-coated YBCO conductor. YBCO offers advantages of operation at substantially higher magnetic fields especially at temperatures above 40 K compared to Bi-based conductors. A 10 to 100-fold improvement in performance over Bi-based conductor has been demonstrated in short samples of YBCO tape [1]-[4]. Current densities of 1 MA/cm^2 have been demonstrated by several groups in YBCO films deposited by Pulsed Laser Deposition (PLD) on buffered nickel-based substrates. In this work, a deposition technique that is more viable for large-scale manufacturing than PLD-namely Metal Organic Chemical Vapor Deposition (MOCVD)-was developed for deposition of YBCO films on nickel-based substrates. MOCVD is used in several industries for uniform coatings of various materials on large-area substrates. Two types of metal substrates were used in this work : biaxially-textured nickel substrates with an epitaxially grown buffer layer, and nickel alloy substrates with a biaxially-textured buffer layer deposited by Ion Beam Assisted Deposition (IBAD).

II. CUBE-TEXTURED METAL SUBSTRATES

A cube-texturing technique was developed for fabrication of highly biaxially-textured nickel and copper substrates [5]. In this technique, metal rods are rolled and heat treated to form a flexible metal tape. Deformation and heat treatment conditions were developed to achieve a high degree of biaxial texture in the metal substrates. Fig. 1 shows X-ray Diffraction (XRD) theta-2theta scan and polefigure of (111) peak of a Ni substrate. A strong degree of (200) texturing as well as a good in-plane texturing is seen. The spread in the in-plane texture is typically about 10°FWHM. Essentially, polycrystalline metal substrates with a 'pseudo-single-crystal' type texture were fabricated.

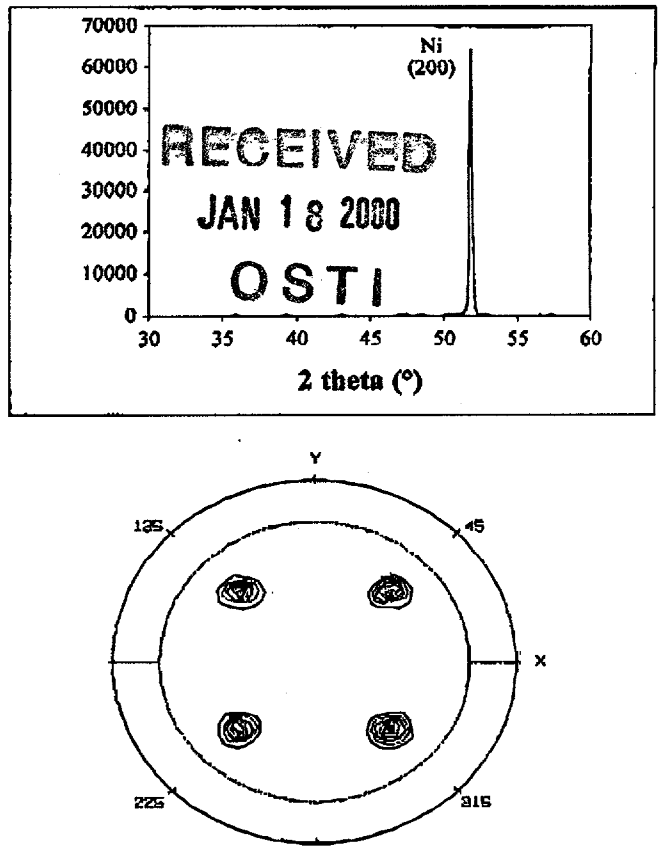

Fig. 1 X-ray theta-2theta scans and (111) polefigure of a biaxially-textured nickel substrate fabricated by thermomechanical processing.

A polishing process has been developed to achieve a very smooth metal substrates. Results from surface roughness measurements by Atomic Force Microscopy (AFM) on polished, textured Ni samples over a relatively large area of 100 μm × 100 μm indicate a very small RMS roughness of 1.4 nm.

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II. BUFFER DEPOSITION BY THERMAL EVAPORATION

Next, a thermal evaporation process was developed to deposit buffer layers such as CeO_2 on biaxially-textured nickel substrates. In this process, Ce or other metals are thermally evaporated and the vapor is condensed on biaxially-textured metal substrates held at a high temperature. Deposition conditions such as temperature, deposition rate, chamber pressure, and gas flow rate were optimized to achieve epitaxial growth of highly biaxially-textured CeO_2 buffer layers on Ni substrates. CeO_2 films with a spread in the in-plane texture as low as 5° FWHM as well as (200) texture almost as intense as that of the nickel substrate were fabricated. Fig. 2 shows XRD theta-2theta scan and polefigure of (111) peak of a CeO_2 layer on a Ni substrate. A strong degree of (200) texturing as well as good in-plane texturing can be seen in the figure. A high degree of biaxial-texture has been achieved over a wide range of film thickness (500 to 5000 A°).

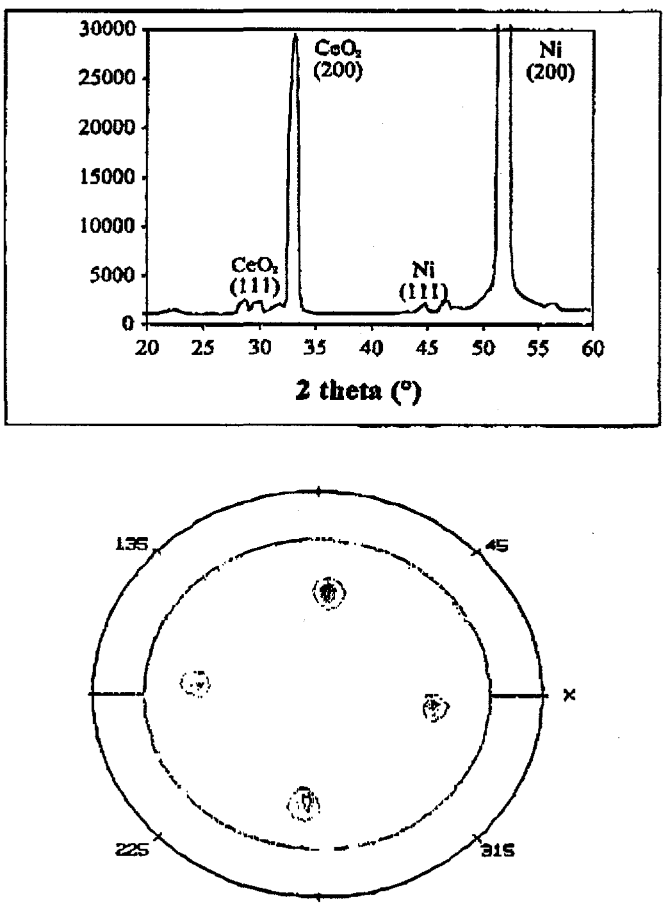


Fig. 2 X-ray theta-2theta scans and (111) polefigure of a CeO_2 buffer film deposited on a biaxially-textured nickel substrate by thermal evaporation

III. BIAXIALLY-TEXTURED BUFFER LAYERS BY IBAD

The second type of metal substrate that was used in this work was untextured Hastelloy C substrate. Yttria-stabilized zirconia buffer layers were deposited by ion-beam-assisted electron beam evaporation on unpolished Hastelloy C substrates to a film thickness of 0.65 μm [6]. A 300 eV assisting ion beam of $Ar/10\%O_2$ was incident on the substrate during film growth at an angle of 35° with respect to the substrate surface using an 8-cm Kaufman-type DC ion source. The atomic deposition rates were 1.6 Å/s and the ion flux was 200 $\mu A/cm^2$ to yield an ion-to-atom flux ratio of 2.8. Fig. 3 shows a X-ray phi-scan of a YSZ film deposited on a Hastelloy substrate. Evidence of in-plane texture is observed, although it is broad compared to the CeO_2 buffer layer on biaxially-textured nickel substrate described in fig. 2.

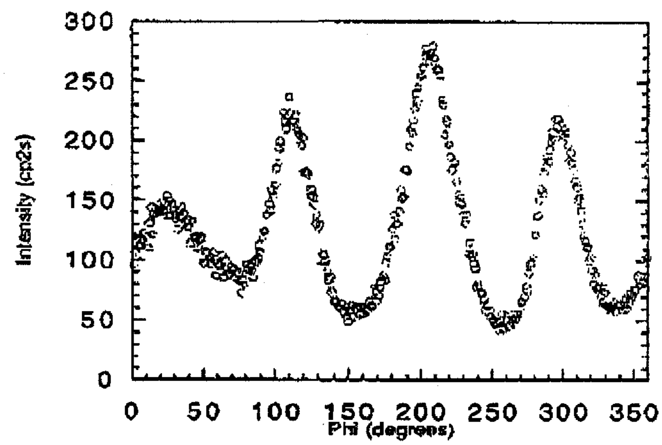


Fig. 3 X-ray phi-scan obtained from a YSZ film deposited by IBAD on an untextured Hastelloy substrate. Biaxial texturing of the buffer layer can be seen

IV. YBCO DEPOSITION BY MOCVD

An industrial type MOCVD facility was constructed at Intermagnetics for YBCO deposition on buffered biaxially textured metal substrates. In a MOCVD process, metal organics of each of Y, Ba, and Cu are individually sublimed, and the vapors are transported in a carrier gas such as Ar. The vapors are then mixed with oxidants such as O_2 and N_2O and the mixture is decomposed just above a heated substrate to yield a YBCO film. Deposition parameters such as the deposition temperature, reactor pressure, oxidant partial pressure, carrier gas flow rates, and precursor sublimation temperatures determine film features such as film morphology, uniformity, thickness, particle formation, texture, composition as well as film properties such as transition temperature and critical current density. Tailoring of the deposition process to a specific microstructure and property is possible by a proper choice of individual process variables.

The MOCVD process was first optimized for YBCO deposition on unbuffered single crystal substrates of Yttria-Stabilized Zirconia (YSZ) which is one of the most common buffer materials used with YBCO conductor. Critical currents in excess of 20 A were consistently achieved in YBCO films by optimizing the deposition process to fabricate very uniform, smooth, continuous films with no visible gradients in thickness. Also, second phase particles were reduced substantially and compositions close to stoichiometric were achieved. Fig. 4 shows a microstructure of one such YBCO film. The film is seen to be uniform with few second phase particles.

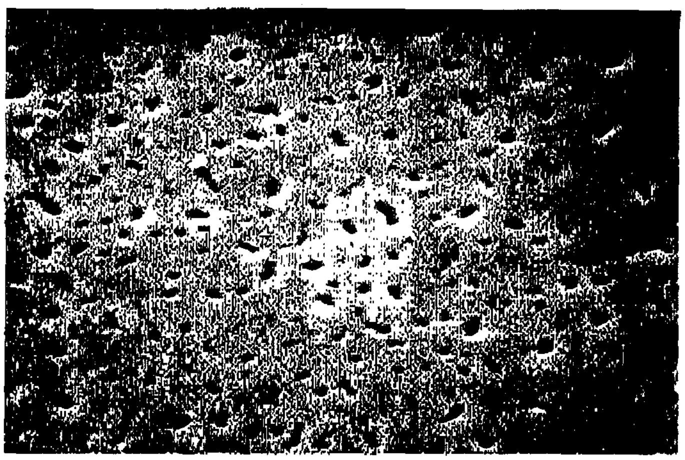


Fig. 4 Microstructure of a YBCO film deposited by MOCVD on single crystalline YSZ substrate after process optimization. The film is uniform with very few second phase particles.

Critical currents in excess of 40 A (J_c of about 1 MA/cm^2) have been achieved in YBCO films deposited on unbuffered, single crystalline YSZ substrates. A I-V curve obtained from one such film is shown in fig. 5. The measurement was conducted on a film area of 1 cm × 0.4 μm. No transition was observed up to 38 A when the film and substrate cracked. The cracking of the film and the substrate is believed to be due to heating at the current contacts in the absence of a silver overlayer on the YBCO film.

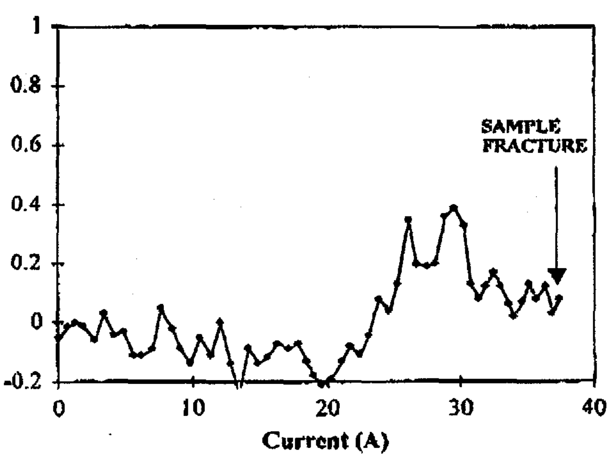
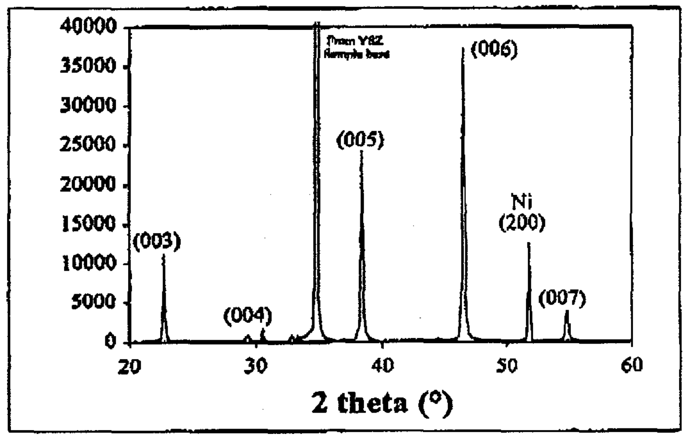


Fig. 5 Current-voltage curve obtained from YBCO film deposited by MOCVD on a single crystal unbuffered YSZ substrate. The sample fractured at 38 A before transition from superconducting state.

The performance of the YBCO film shown in fig. 5 is impressive considering that the lattice mismatch between YBCO and YSZ is about 5 %. Typically, critical current density of 1 MA/cm^2 is achieved usually in YBCO deposited on single crystal substrates of $SrTiO_3$ or $LaAlO_3$ where the lattice mismatch is about 0.2%. The achievement of high current as well as a high J_c in YBCO deposited on single crystal YSZ is very encouraging for our efforts for YBCO deposition on metal substrates.

Results from YBCO films on buffered, biaxially-textured metal substrates are also promising. Fig. 6 shows XRD theta-2theta scan and polefigure of (113) peak of a YBCO film on a CeO_2 buffered Ni substrate. The XRD measurements were obtained from the entire sample surface. A strong degree of c-axis texturing as well as a good in-plane texturing can be seen in the figure.



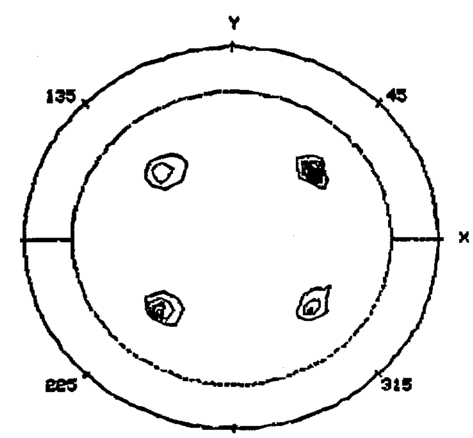


Fig. 6 X-ray theta-2theta and (113) polefigure obtained from a YBCO film deposited by MOCVD on a CeO_2-buffered nickel substrate. A high degree of biaxial texture can be seen. The YSZ peak is from a single crystal YSZ base that was used to support the sample.

Good c-axis texture and in-plane texture were also achieved in YBCO films deposited on IBAD-YSZ buffered

Hastelloy substrates. The YBCO films were however rough because the YSZ layer was deposited on unpolished metal substrates. In spite of the roughness and the very broad texture of the YSZ buffer layer, a good T_c (onset of 92 K and $T_{c,zero}$ of 87 K) was achieved as shown in fig. 7. The

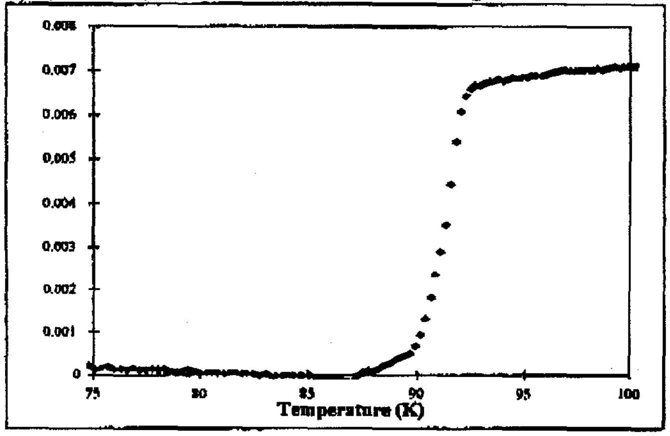


Fig. 7 T_c measurements from a YBCO film deposited by MOCVD on IBAD YSZ buffered metal substrate. A T_c onset of 92 K and a $T_{c,zero}$ of 87 K have been achieved.

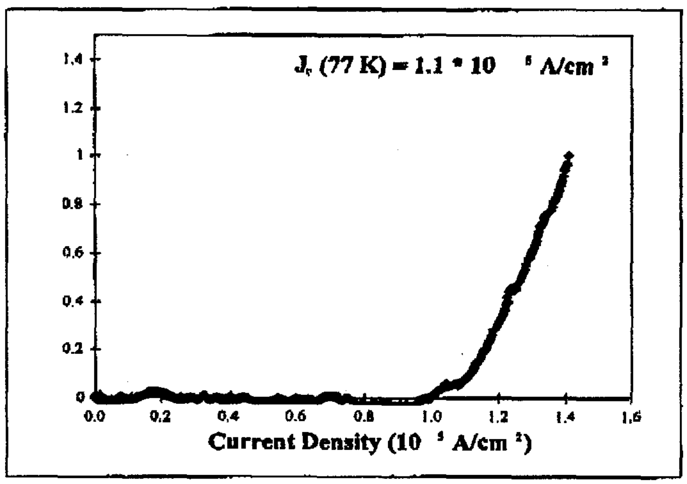


Fig. 8 J_c measurements on a YBCO film deposited by MOCVD on IBAD YSZ buffered metal substrate. A J_c greater than 10^5 A/cm^2 has been achieved.

measurements were conducted on a film of size 1 cm × 0.5 cm and 0.5 μm in thickness. J_c measurement on one of the samples is shown in fig. 8. A J_c of 1.1×10^5 A/cm^2 was achieved at 77 K. The high J_c achieved in a YBCO film on a metal substrate with a buffer layer that had a very broad texture and a very rough surface is encouraging.

V. Conclusions

YBCO films have been deposited by MOCVD on biaxially-textured nickel substrates with an epitaxially grown CeO_2 buffer layer as well as on nickel alloy substrates with biaxially-textured YSZ buffer depositedby IBAD. A high degree of biaxial texture has been achieved in YBCO films on both types of substrates. A critical current density greater than 10^5 A/cm^2 has been achieved in YBCO films deposited by MOCVD on buffered metal substrates.

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