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Title: YBa(2)Cu(3)O(7-delta) Thick Films on Ni-based Alloys

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$YBa_2Cu_3O_{7-\delta}$ Thick Films on Ni-based Alloys

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ABSTRACT

$YBa_2Cu_3O_{7-\delta}$ (YBCO) thick films were prepared on Ni based alloys with an ion beam assisted deposited and textured yttria-stabilized zirconia (YSZ) buffer layer. Transport critical current densities (J_c) over $1x10^6$ A/cm^2 at 75 K, and over $1x10^7$ A/cm^2 at 4 K were obtained in the 1 μm thick YBCO films. Zero field critical current of 198 Amps at 75 K was obtained in a 2 μm thick and 1 cm wide YBCO film. Angular dependence measurement revealed J_c peaks for both H//c and H//a-b. The peak for H//c implies additional pinning due to defects such as small angle grain boundaries or twin boundaries. It was also found that the thick films on Ni based alloys were quite flexible.

KEYWORDS: $YBa_2Cu_3O_{7-\delta}$, ion beam assisted deposition, pulsed laser deposition, Ni based alloys

INTRODUCTION

In the last few years, the oxide-powder-in-tube (OPIT) proces has been widely used to make high temperature superconducting wires and tapes. The OPIT wires or tapes will probably be the first ones available for power and magnet applications based on high temperature superconductors. However, the OPIT process can only be applied to Bi- or Tl-based oxide superconductors since both will form plate-like microstructures after mechanical rolling and drawing. In order to use $YBa_2Cu_3O_{7-\delta}$ (YBCO) as the superconductor for practical applications, an approach based on vapor deposition technologies very different from OPIT has been developed to make YBCO thick films on Ni or Ni-based alloys [1-3]. In this approach, a highly textured yttria-stabilized zirconia (YSZ) layer is deposited by an ion beam assisted deposition (IBAD) process so that the YSZ layer will serve as a template for growth of a textured YBCO thick film. Furthermore, the YSZ buffer layer will also act as a diffusion barrier to prevent elements such as Ni from diffusing into the films. Currently, only short samples have been produced, though continuous processes have been developed to coat the YSZ by IBAD, and YBCO by pulsed laser deposition or chemical vapor deposition [4].

In this report, we present our results for YBCO thick films on flexible Ni-based alloy substrates. A transport critical current density (J_c) over $1x10^6$ A/cm^2 at 75 K was obtained on a polycrystalline Ni-based substrate with a textured buffer layer. Furthermore, a critical current of 198 Amps at 75 K was demonstrated in a 2 μm thick and 1 cm wide YBCO thick film on a Ni-based alloy.

EXPERIMENTAL PROCEDURE

We used Ni-based alloys (e.g. Hastelloy C-242) as substrates, the reasons being that these materials are oxidation resistant at high temperature, they have thermal expansion coefficients very close to that of YBCO, and the materials are available in long lengths and as thin tapes. So far, we do not find any major differences in results for YBCO films on various substrates though a systematic study to find the best substrate will be appropriate. The substrate thickness ranges from 50 μm to 1000 μm depending on the availability from various commercial vendors. The metallic substrates were either electrochemically or mechanically polished; the latter gave a more reproducible surface finish. Our IBAD deposition system is very similar to the one first reported by Iijima et. al. [1]. Ion beam sputtering along with ion beam assisting was used to deposit textured YSZ buffer layers at room temperature. The detailed deposition parameters can be found in our previous publications [3,5]. The YSZ layer thickness is typically 5000 Å. After YSZ deposition, the samples were transferred to another vacuum chamber for pulsed laser deposition of YBCO thick films. A thin (~200 Å) CeO_2 buffer layer was always deposited on the YSZ for a better lattice match for the subsequent YBCO growth. The deposition conditions were the same as previously published [3,5,6]. The films were cooled to room temperature from the deposition temperature (700 °C to 800 °C) in 300 Torr of oxygen. The YBCO films were always c-axis oriented. Samples were produced in two sizes. For critical current (I_c) measurements, the sample size was 4 cm long by 1 cm wide. In this case silver was evaporated on the sample ends for electrical contact, the samples were annealed at 550 °C in flowing oxygen to reduce contact resistance, and copper leads were attached with indium solder. For measurement of J_c and its magnetic field dependence up to 18 T, the sample size was 5 mm by 10 mm with a patterned bridge 5 mm long and 100-300 μm wide. All measurements were DC transport with a 1 μV/cm criterion. For the field dependence measurements, configurations of both field parallel and perpendicular to the applied current flow were used.

RESULTS AND DISCUSSION

YSZ films deposited at room temperature without IBAD were always randomly oriented. With an optimized IBAD process, the (100) oriented YSZ films can be prepared on any substrates at room temperature. It should be noted that the substrate temperature can rise to ~ 100 °C due to the energy from the assisting ion beam though the substrates were never intentionally heated. Fig. 1 shows a x-ray diffraction spectrum for an IBAD deposited YSZ film. The data clearly indicate that the YSZ film is (100) oriented with respect to the substrate surface. X-ray rocking curve for the (200) YSZ diffraction peak is plotted in Fig. 2. The full width at half-maximum (FWHM) for the (200) peak is 5°, indicating a reasonable mosaic spread along the perpendicular direction with respect to the film surface.

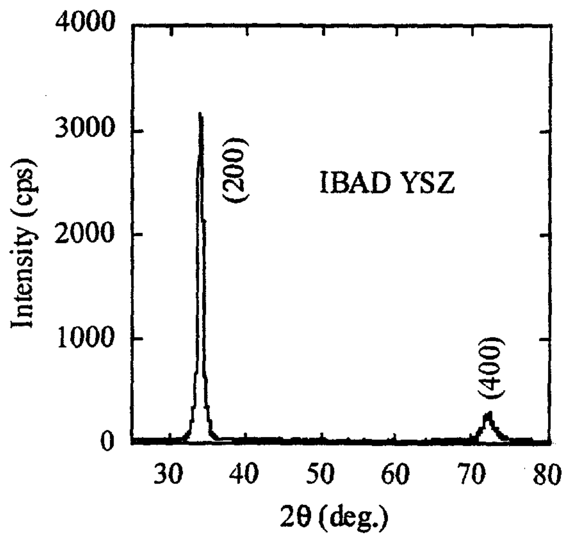

Fig. 1 X-ray diffraction pattern of a YSZ film deposited at room temperature by IBAD.

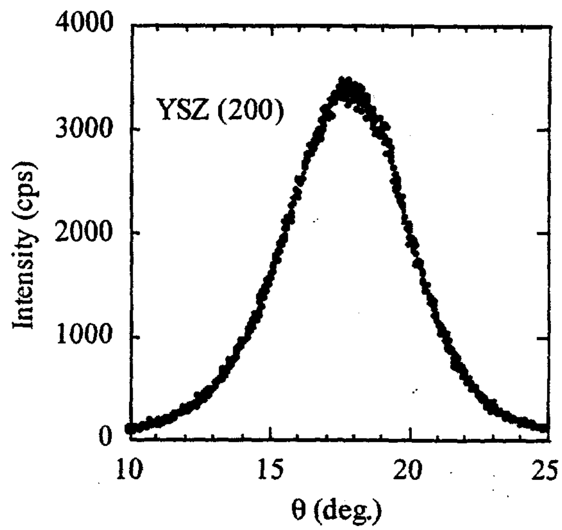

Fig. 2 X-ray rocking curve of the (200) diffraction peak of IBAD deposited YSZ.

Though the IBAD deposited YSZ films were highly oriented out-plane, it is extremely important to have films in-plane oriented so that the biaxially textured YSZ layer will serve as a template for growth of a highly textured YBCO thick film. Fig. 3 shows a X-ray phi-scan of the (202) diffraction peak of an IBAD deposited YSZ layer on a Ni-based alloy. The average FWHM of the peaks is ~12°, which is the smallest value reported to our knowledge. A thin layer of CeO_2 was inserted between the YSZ layer and YBCO film. The growth orientation between the YSZ and CeO_2 is simply cube-on-cube. The YBCO film is 45° in-plane rotated with respect to the major axes of the CeO_2 or YSZ layer as expected from a lattice match point of view. A X-ray phi-scan of a YBCO thick film on Ni-based alloy with an IBAD deposited YSZ buffer layer (Hereafter, we will refer to these samples as YBCO/Ni) is shown in Fig. 4. The average FWHM of the YBCO (103) peaks is 6.5°. Based on the result of bicrystal thin film experiments by Dimos *et al.* [7], J_C across a grain boundary is strongly dependent on the tilt angle between two superconducting grains. We found a similar trend in J_C vs. in-plane mosaic spread of the YBCO thick films [8]. It was very clear from the data that the critical current (density) correlates very well with the FWHM of the in-plane YBCO (103) peaks as expected [8,9]. It was found that one degree improvement in the lower end of the FWHM can result in 10-20% gain in the J_c or I_c (for a fixed sample width). To obtain a smaller FWHM in YBCO, it is critical to get a better textured YSZ layer by fine tuning the deposition parameters in the IBAD process. From Fig. 4 one can see that a small pecentage of 45° misoriented YBCO grains were present in the film, indicating the YBCO films have two in-plane orientation with the major one having the best lattice match with CeO_2. The misoriented YBCO grains do not appear in most of the samples. It should be also noted that the YBCO films are always c-axis oriented with a very little a-axis oriented material.

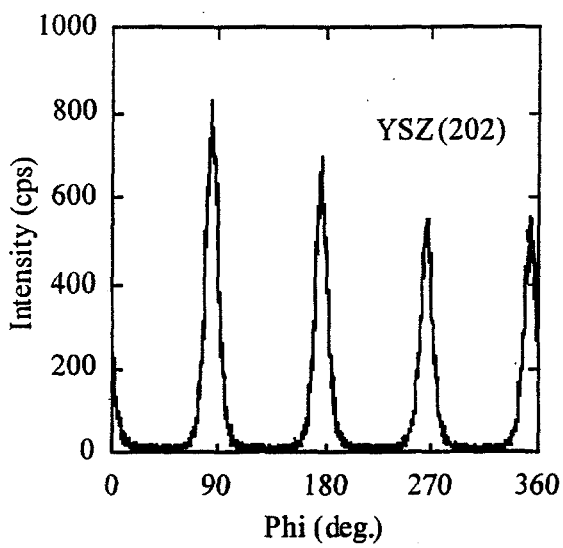

Fig. 3 X-ray phi-scan of an IBAD deposited YSZ film. The average FWHM of the peaks is 11.6°.

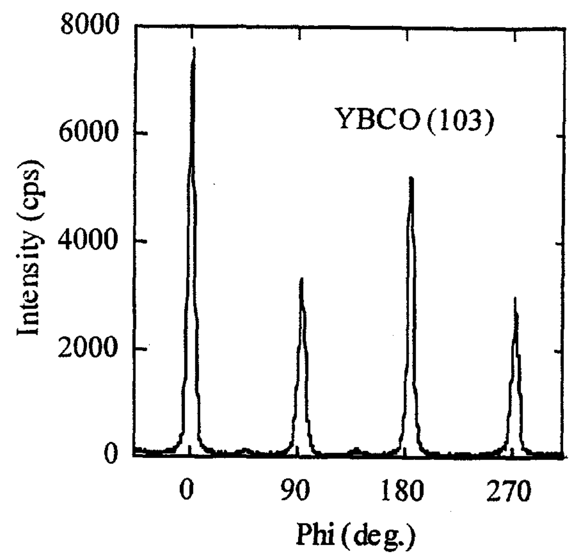

Fig. 4 X-ray phi-scan of YBCO/Ni. The average FWHM of the (103) peaks is 6.5°.

Figure 5 shows J_c as a function of magnetic field at 75 K (liquid nitrogen temperature at Los Alamos) for a 1.2 μm thick YBCO/Ni. The zero field J_c for the film is over 10^6 A/cm^2, which was only previously obtained in epitaxial high T_c thin films on single crystal substrates. We previously reported that a 1.2 μm thick YBCO on single crystal YSZ substrate with a CeO_2 buffer layer has a zero field J_c of ~ 2x10^6 A/cm^2 at 75 K [10]. It should be noted that texture alone will not guarantee a high J_c since additional factors such as oxidation, contamination, and microstructure of the films are also very critical. Primary results from a transmission electron microscopy study of the YBCO films indicate the YBCO grains are highly connected, and the grain boundaries lack secondary phase materials. Since the grain size of the YBCO on Ni is typically ~ 1-2 μm for the films, and the current path crosses 10^4-10^5 grain boundaries in the samples, it is remarkable to see that the films with a FWHM of 5-6° retain ~50% of the critical current for YBCO on a single crystal substrate. The initial quick drop for J_c for H//c (perpendicular to the film surface) or H//a-b (parallel to the substrate surface) and the magnetic field direction perpendicular to the applied current flow (H⊥I) at small fields could be due to possible existence of some weak-links in the YBCO. The J_c field dependence at high fields is very similar to epitaxial YBCO thin films on single crystal substrates [11]. Another feature from the figure is that there is a strong Lorentz force effect for H//a-b (two upper curves) [12], which was observed in epitaxial YBCO thin films and single crystals but not in OPIT materials. This result indicates that the current YBCO/Ni is highly textured as expected from the X-ray measurements.

Since the YBCO thick films on Ni have many small angle grain boundaries as compared to the YBCO films on CeO_2/(100) YSZ single crystal substrates, J_c angular dependence experiments were performed on the thick films of YBCO/Ni at different temperatures and magnetic fields to see the effect of the boundaries [12]. At high temperatures such as 65 K and 75 K (Fig. 6). J_c peaks were observed not only for H//a-b. but also for H//c for the magnetic field direction perpendicular to the applied current flow (H⊥I). similar to the effect observed on high quality YBCO thin films on (100) $SrTiO_3$ substrates [11]. The J_c peak at H//a-b is mainly due to the intrinsic pinning while the peak at H//c is believed to be the result of artificial pinning due to small angle grain boundaries, twin boundaries or stacking faults [11].

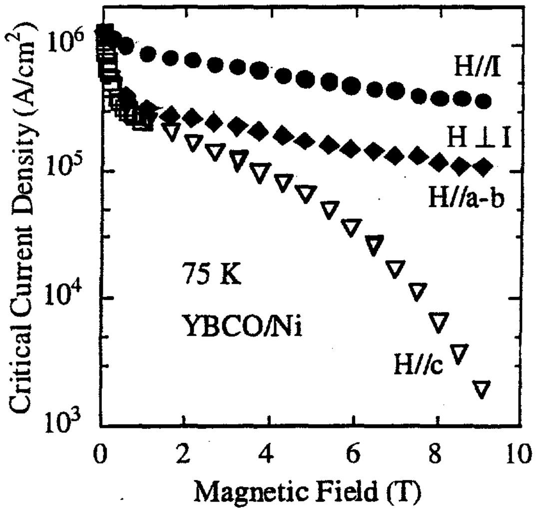

Fig. 5 J_c as a function of applied magnetic field at 75 K. Note that the two upper curves are for H//a-b.

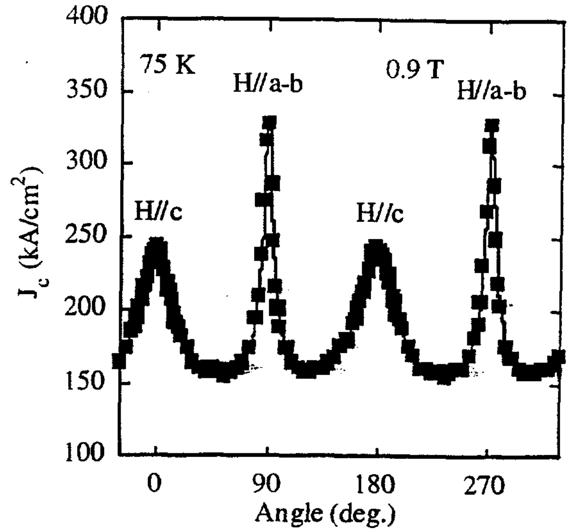

Fig. 6 J_c angular dependence for YBCO/Ni at 75 K, 0.9 T and H⊥I.

Differences were found by comparing normalized I_c as a function of magnetic field for two 2 μm YBCO thick films on two different substrates: (100) YSZ and IBAD deposited YSZ on Ni (Fig. 7). For H//a-b, the field was perpendicular to the current path. Initially, the I_c drops more rapidly with field for the YBCO/Ni, which could be due to the weakly coupled YBCO grains in the film. At a field of ~ 0.2 Tesla, the I_cs are equal for the two samples. At fields of ~ 1 Tesla, the normalized I_cs for the YBCO on IBAD YSZ are higher than those of YBCO/YSZ for both H//a-b and H//c, indicating existence of additional pinning sites in the YBCO/Ni. The result indicated that the small angle grain boundaries or twin boundaries could be partly responsible for the additional pinning. Work is under way to further clarify the role of defects in the YBCO thick films.

To demonstrate that the YBCO thick films on Ni-based alloys can carry higher critical currents, YBCO films were deposited on 1 cm wide substrates. Fig. 8 shows a current-voltage curve at zero field for a 2 μm thick and 1 cm wide YBCO films at 75 K. The YBCO film had a critical current of 198 Amps, which corresponds to a J_c of 0.99×10^6 A/cm^2 at 75 K for a such thick film. This result demonstrates that YBCO thick films have a high current carrying capability.

In order to further demonstrate that the YBCO thick films can be used as practical conductors, bending tests were performed by either fastening the samples to a series of cylindrical mandrels or a continuous tensile test system. I_c was measured by submerging the samples in liquid nitrogen. The results from both measurements were comparable. Using the mandrel method, a 1.2 μm thick YBCO on a 130 μm thick Ni-based alloy was tested in a tension mode (the film was on the outside of the substrate) [6]. The I_c was unchanged from the original value (diameter=∞) at a diameter of 1.5 inches, drops by 5% at 1 inche, and was reduced sharply at smaller diameters. The corresponding strain at 1 inch diameter is 0.5%. From the continuous tensile test, it was found that the I_c of YBCO thin films drops to 93% of the original value at a strain of 1% for the films in the compression mode [8].

The critical current recovered to the original value after the strain was released. These results clearly showed that the YBCO thick films on metallic substrates are highly flexible. Work is underway to coat YBCO on substrates thinner than 50 µm.

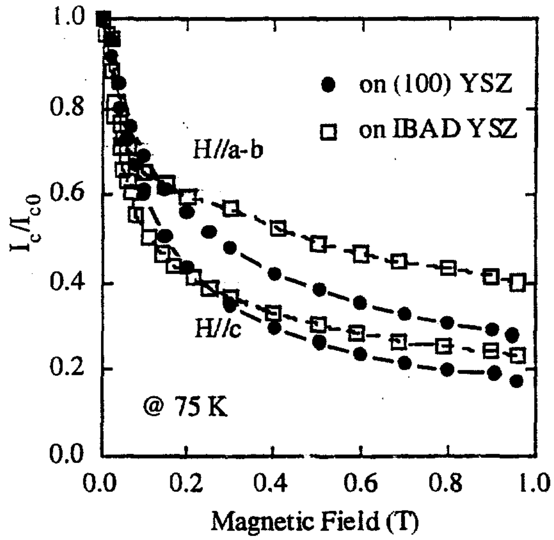

Fig. 7 Normalized I_c for two 2 µm YBCO samples on (100) YSZ single crystal, and IBAD YSZ. The two top curves are for H//a-b and H⊥I, and the bottom two are for H//c.

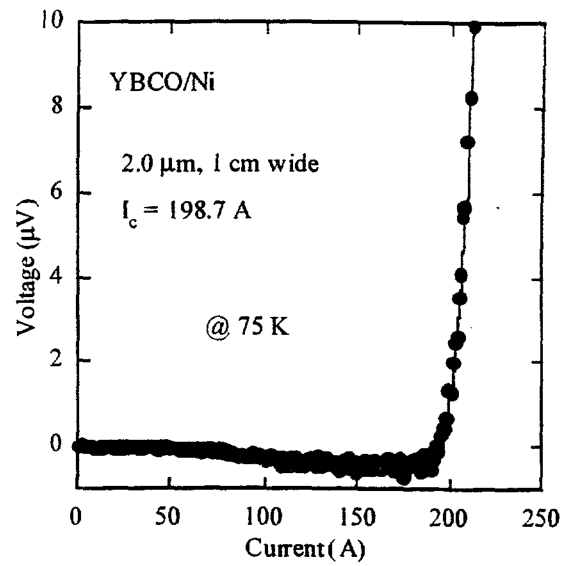

Fig. 8 IV curve at 75 K for a 2 µm thick and 1 cm wide YBCO film on Ni with IBAD deposited YSZ.

In summary, we have presented the properties of YBCO thick films on Ni-based alloys with a textured buffer layer of YSZ deposited by IBAD. The superconducting and mechanical properties of YBCO short samples presented here are adequate to realize many of the applications associated with high temperature superconductivity. But to produce long length YBCO thin films economically is still an extremely challenging task. The scaleup process will need creative thinking, time and resources.

REFERENCE

1. Iijima Y, Tanabe N, Kohno O, Ikeno Y (1992) Appl. Phys. Lett. 60: 769-771
2. Reade RP, Berdahl P, Russo RE, Garrison SM (1992) Appl. Phys. Lett. 61: 2231-2233
3. Wu XD, Foltyn SR, Arendt P, Townsend J, Adams C, Campbell IH, Tiwari P, Coulter Y, Peterson DE (1994) Appl. Phys. Lett. 65: 1961-1963
4. Kohno O, Iijima Y, Onabe K, Tanabe N, Sadakata N, Saito T, Yoshitomi J, Nagaya S (1995) In: Extended Abstracts of Inter. Workshop on Superconductivity, ISTEC & MRS, pp 210-213
5. Arendt P, Foltyn S, Wu XD, Townsend J, Adams C, Hawley M, Tiwari P, Maley M, Willis J, Moseley D, Coulter JY (1994) MRS Proc. 341: 209-212
6. Foltyn SR, Arendt P, Wu XD, Blumenthal WR, Cotton JD, Coulter JY, Hults WL, Safar HF, Smith JL, Peterson DE (1995) In: Extended Abstracts of Inter. Workshop on Superconductivity, ISTEC & MRS, pp 105-108
7. Dimos D, Chaudhari P, Mannhart J, LeGoues FK (1988) Phys. Rev. Lett. 61: 219-221
8. Yang F, Narumi E, Patel S, Shaw DT (1995) Physica C244: 299-304
9 Wu XD, Foltyn SR, Arendt PN, Blumenthal WR, Campbell IH, Cotton JD, Coulter JY, Hults WL, Maley MP, Safar HF, Smith JL (1995) Appl. Phys. Lett. Oct. 16
10. Foltyn SR, Tiwari P, Dye RC, Le MQ, Wu XD (1993) Appl. Phys. Lett. 63:1848-1850
11. Roas B, Schultz L, Saemann-Ischenko G (1990) Phys. Rev. Lett. 64: 479-481
12. Safar H, Coulter JY, Maley MP, Foltyn S, Arendt P, Wu XD, Willis JO (1995) Phys. Rev. B52: 9875