PrBa$_2$Cu$_3$O$_{7-x}$ as an Insulating Layer for YBCO Multilayer Coated Conductors

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Abstract. A study into the insulating layers for multi-layered coated conductors was undertaken in an effort to achieve high critical current density throughout the different layers of the structure. Single thin films of YBCO were grown, then covered with dielectric layers, onto single crystal and buffered, nickel, textured substrates using pulsed laser deposition. By using a combination of shadow masking and photolithography techniques, transport currents were measured through the layer to obtain its critical current density ($J_c$). Additionally electron backscattered diffraction was employed to characterise the films. PrBa$_2$Cu$_3$O$_{6+x}$ was shown to maintain high $J_c$ across the sample, thus maximising the overall engineering current density.

1. Introduction

YBa$_2$Cu$_3$O$_{7-x}$ (YBCO) thin films can potentially have many applications due to its ability to carry large currents at liquid nitrogen temperature. Of the various fabrication techniques pulsed-laser deposition (PLD) produces films with the highest current density ($J_c$), with films of the order of MAcm$^{-2}$. This is not enough, though, to justify the cost of a vacuum process and laser gasses when considering the number of laser pulses required, including in excess of 10 000 pulses for the buffer layers. An interconnected multi-layer architecture of alternate superconducting and insulating layers, patterned to form coils, represents a serious alternative to superconducting coil fabrication by the conventional winding of long lengths of pre-formed coated conductor tape. Multilayered films carry more current per cross-sectional area as the buffer layers are not required for each layer, so reduce the engineering current density ($J_E$). A widely accepted insulating material in multilayered YBCO is SrTiO$_3$ (STO) on account of high dielectric constant and lattice match. STO has been used effectively as a buffer layer [1] [2] and may reduce oxygen diffusion to the substrate [3]. It may prevent oxygen from reaching the underlying YBCO during the crucial cooling process.

PrBa$_2$Cu$_3$O$_{6+x}$ (PrBCO) is a candidate for insulating at 77K. It is isomorphic to YBCO and oxygen can diffuse through it in the same way, allowing the entire multilayered structure to oxygenate during cooling. PrBCO can be layered intermittently with YBCO to enhance the anisotropy of the YBCO film thus pinning the flux and changing the coupling strength [4] [5], although a thickness of <30nm is required for a significant effect to the YBCO [6].

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A practical development from single crystal substrates is rolling assisted biaxially textured substrate (RABiTS) [7]. It is reported [8] that the $J_c$ on RABiTS is comparable to the $J_c$ on single crystals in self-field.

2. Experimental

YBCO films have been grown by PLD on MgO single crystal and Ni RABiTS substrates. Two tracks measuring 0.7mm by 5mm were etched onto each sample using photolithography and wet etching techniques. STO or PrBCO were deposited onto one of the tracks through a shadow mask during a second PLD. The tracks were completely covered to reduce the possibility of oxygenating through the side of the YBCO track. Growth conditions for all materials were 780°C in 0.6mbar oxygen partial pressure and a fluence of 2.1Jcm$^{-2}$ operating at a 248nm wavelength. Ni RABiTS was heated in forming gas before depositing the established ceria/ytrria-stabilised zirconia/ceria buffer layers [9]. The sample was cooled rapidly in 0.6mbar $O_2$ after the deposition of YBCO and at 10°Cmin$^{-1}$ in 700mbar $O_2$ following the deposition of the STO and PrBCO cap layers.

AC susceptibility was employed to measure the critical temperature ($T_c$) of the films to check the consistency in quality of depositions. Transport measurements were performed at 77K, using a programmable HP3060A power supply, Keithly 2086 nanovoltmeter and a computer. Each data value obtained is the average of 100 measurements at each polarity. The critical current was defined by $1\mu Vcm^{-1}$. Electron backscatter diffraction (EBSD) was obtained using a JEOL 7000 SEM and INCA software.

Additional samples were produced to check that the insulating material succeeded in isolating the YBCO layers. These consisted of YBCO on buffered Ni RABiTS substrate, then using a shadow mask to conceal half of the sample and deposit STO or PrBCO and a second YBCO layer. Four-point measurements were used to discern whether a current passed between the YBCO layers.

3. Results and discussion

All films presented have $T_c=90.5K \pm 1K$. The $J_c$ of YBCO on MgO is 1.69 MAcm$^{-2}$ and with a PrBCO layer on top the $J_c$ is reduced slightly to1.24 MAcm$^{-2}$. The STO/YBCO/MgO structure renders a $J_c$ of $1.71 \times 10^4 \text{Acm}^{-2}$, suggesting that indeed oxygen was prevented from reaching the YBCO layer. STO/YBCO/Ni provides a lower still $J_c$ of $8.53 \times 10^3 \text{Acm}^{-2}$ reinstating that grain boundaries play a significant role in reducing the $J_c$. Figure 1 shows numerous grain boundaries above 10°.

Figure 1: Secondary electron image of YBCO on buffered Ni with RABiTS superimposed, EBSD derived, grain boundaries where green lines represent relative misorientations of 2°-5°, red of 5°-10°, pink of 10°-15° and yellow of 15°-30°.
EBSD derived pole figures of YBCO (001) on MgO single crystal (Figure 2) and YBCO (001) on buffered Ni RABiTS substrate (Figure 3). The stark mosaic orientation of the YBCO in Figure 2 is mostly at grain boundaries of angles greater than 5°.

The STO layer isolated the YBCO layers when voltages up to 20V were applied, re-asserting it as a good insulator. The PrBCO layer was effective to 12mV. This voltage remained approximately constant whilst the current was increased until the critical current of the lower YBCO layer was breached. Although smaller, this voltage should be sufficient to isolate the YBCO layers in multilayered structures.

4. Conclusion

STO does prevent the movement of oxygen to the underlying YBCO layer during cooling. PrBCO is more transparent to oxygen diffusion and may yet find a role as an insulating layer in multilayered HTS films. The mosaic spread of biaxially textured nickel grains appears to play a significant role in reducing the transport of electrical current.

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