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Sr_2YSbO_6 as a buffer layer for $YBa_2Cu_3O_{7-\delta}$ superconducting films

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Abstract We report the epitaxial growth of Sr_2YSbO_6 films over a MgO single crystal using magnetron sputtering technique. Sr_2YSbO_6 films were used as a buffer layer for growth of $YBa_2Cu_3O_{7-\delta}$ films by DC sputtering. It was experimentally determined that the films evidence superconducting properties, such as a critical temperature of 90 K and a self-field critical current density at 77 K of 0.8 MA/cm^2. These results, as well as good lattice matching and chemical stability between Sr_2YSbO_6 and $YBa_2Cu_3O_{7-\delta}$, suggest that Sr_2YSbO_6 is an ideal material to be applied as buffer layer for high-performance superconductor coatings. For instance, Sr_2YSbO_6 material can be used as a single buffer layer in coated conductor tapes based on ion beam assisted deposition of MgO template (IBAD-MgO).

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Introduction

During the past decade, significant advances in the performance levels of high-temperature superconducting (HTS) wire have made it suitable for commercially viable applications such as electric power cables, fault current limiters, motors, and generators [1, 2]. For instance, both the United Sates Department of Energy and private industry have been developing a key superconductor cable and fault current limiter projects [1], and there is a 5-year Japanese national project for materials and power applications of coated conductors, which was started in 2008 [2]. These power applications share a common requirement: that the superconducting material be formed into a long, strong, and flexible conductor so that it can be used like the copper wire it is intended to replace. And this is where the problems began, because the HTS materials are ceramics that are more like a piece of chalk than the ductile metal copper [3].

The first solution to this problem, the so-called first generation wire, was a tape that was made packing Bi–Sr–Ca–Cu–O (BSCCO) superconducting powder into a silver tube, following a series of rolling and heating steps [4]. In spite of successful applications, this type of conductor is expensive for most commercial applications due to the use of silver.

Further, BSCCO is not suitable for applications such as motors and magnets at liquid nitrogen temperature; it loses its ability to carry super current in a magnetic field [3, 5]. The alternative approach, known as the second generation wire, uses the epitaxial growth of a $YBa_2Cu_3O_{7-\delta}$ superconducting coating on a thin metal tape. The advantages of this wire are that very little silver is needed, making it inexpensive, and that the compound $YBa_2Cu_3O_{7-\delta}$ retains much higher current-carrying ability in a magnetic field.

Despite these advantages of superconductors, the ability to carry current without loss is limited to current densities lower than a critical value, J_c. In order to carry a higher current in a wire, the objective of research efforts is to increase J_c.

In this context, the preparation of biaxially textured substrates and subsequent epitaxial buffer layers is very important for the realization of long-length $YBa_2Cu_3O_{7-\delta}$-coated conductors. The buffer layer should not only satisfy chemical stability, but structural matching with $YBa_2Cu_3O_{7-\delta}$ as well because the alignment of the superconductor is required for high J_c values [3, 6].

Different oxide materials have been successfully used as a buffer layer to fulfill these requirements [3, 7–14]. However, most of them are really a multilayer architectures, which significantly increase the complexity as well as the cost of production [6]. Therefore, the development of a single buffer layer is of great interest, as this might simplify the preparation process and lead to a more cost-effective fabrication of coated conductors. To fabricate templates of great length, the most promising approach is, generally, with ion beam assisted deposition, IBAD yttria-stabilized zirconia (YSZ), $Gd_2Zr_2O_7$ or MgO [15–18]. Of these, the best is IBAD-MgO because very good biaxial texture can be obtained with films only 10 nm thick, which reduces production costs [3, 16, 17].

Sr_2YSbO_6 appears to be a promising material for fulfill these criteria, as it has a lattice parameter exhibiting a good lattice match with $YBa_2Cu_3O_{7-\delta}$ (mismatch between a and b $YBa_2Cu_3O_{7-\delta}$ parameters and a of Sr_2YSbO_6 is $\sim 5\%$). In this article, it has been applied effectively as a buffer layer for $YBa_2Cu_3O_{7-\delta}$ film growth by DC sputtering. Schematic representation of the resultant architecture $YBa_2Cu_3O_{7-\delta}$–Sr_2YSbO_6–MgO is shown in Fig. 1. This superconducting film has a J_c value $\sim 10^3$ times that grown on MgO. Sr_2YSbO_6 films that were deposited over MgO single-crystal substrate, because Sr_2YSbO_6 has a good match with MgO, which is the material of the IBAD-MgO tapes. Other applications for the Sr_2YSbO_6 material are in a Josephson junction because they are an insulating material for the deposition of superconductor films in microwave

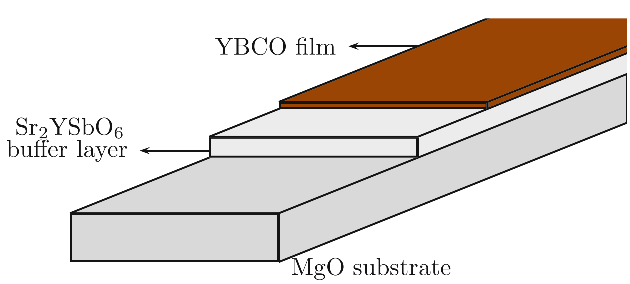

Fig. 1 Schematic representation of $YBa_2Cu_3O_{7-\delta}$ films on Sr_2YSbO_6 buffer layer

applications, and for the elaboration of crucibles for the preparation of superconductors due to their chemical non reactivity with $YBa_2Cu_3O_{7-\delta}$.

The material Sr_2YSbO_6 was chosen because we had been working to find new substrates for $YBa_2Cu_3O_{7-\delta}$ within the perovskite family $A_2BB'O_{6'}$ since by means of substitutions they permit adjusting the lattice parameters [19]. Previous studies of the material in polycrystalline form showed that it was viable as a substrate for the growth of $YBa_2Cu_3O_{7-\delta}$ films [20], which is effectively shown in this article.

Experimental details

The deposition of Sr_2YSbO_6 buffer layers, on MgO (1 0 0) substrate, was performed by magnetron sputtering (13.56 MHz, 70 W) using a polycrystalline target, which was fabricated by the solid state reaction method, based on SrO, Sb_2O_3, and Y_2O_3 powder oxides. Detailed Sr_2YSbO_6 synthesis processing conditions, and study of structural ordering, can be found elsewhere [19, 21]. $YBa_2Cu_3O_{7-\delta}$ target was prepared by the solid state reaction method such is described in reference [19].

X-ray diffraction patterns, both for the polycrystalline target and for the films, were recorded by a PHILLIPS PW1710 diffractometer using Cu-Kα radiation ($\lambda = 1.5406$ Å).

The substrate temperature and oxygen pressure for the Sr_2YSbO_6 growth were kept at 800 °C and 7×10^{-3} mbar, respectively. $YBa_2Cu_3O_{7-\delta}$ films were deposited on these buffer layers by sputtering DC ($\sim$30 W) at an optimized substrate temperature of 850 °C an O_2 pressure of 3.5 mbar for 1 h, followed by cooling up to 550 °C in 30 min at O_2 pressure of $\sim$850 mbar and, therefore, were annealed at 550 °C for 30 min at the same O_2 pressure.

The superconducting properties of $YBa_2Cu_3O_{7-\delta}$ films were determined by measurements of the transition temperature (T_c) and critical current density (J_c) at 77 K in self-field, by means of ACT measurements (bias AC current of 30 Hz) with the four-probe method, using the PPMS system of Quantum Design. These measurements were performed on $YBa_2Cu_3O_{7-\delta}$ micro bridges, with 20 μm of width and 100 nm of thickness, which were prepared by UV photolithography.

Results and discussion

The X-ray diffraction pattern of Sr_2YSbO_6 polycrystalline target is shown in Fig. 2. The Rietveld refinement, performed with the EXPGUI and GSAS programs [22, 23], reveals that the Sr_2YSbO_6 has the expected typical

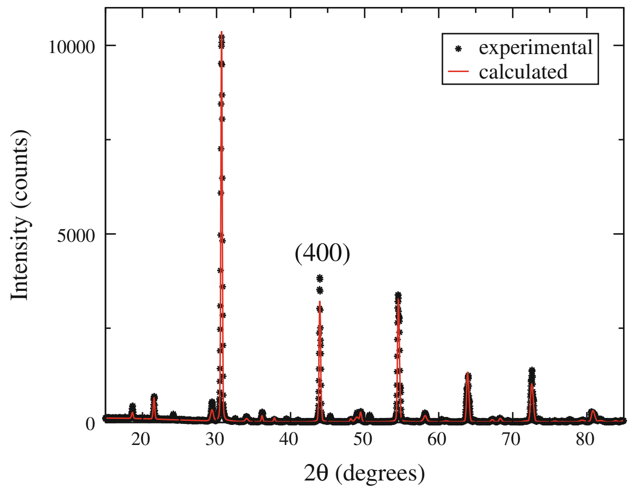

Fig. 2 XRD pattern of Sr_2YSbO_6 policrystalline target

structural ordering of a complex cubic perovskite with lattice parameter $a = 8.249$ Å.

Figure 3 shows the X-ray diffraction pattern for the film of Sr_2YSbO_6, with 2 h of deposition for 2θ between 10° and 80°. It consists of strong peaks (2 0 0) of MgO and (4 0 0) of Sr_2YSbO_6. Figure 4 shows a short detailed scan for 2θ between 41 and 46. It shows the MgO peak in $2\theta = 43°$ and the Sr_2YSbO_6 peak in $2\theta = 43.1°$. This result reveals the epitaxial growth of Sr_2YSbO_6 films on MgO (1 0 0) substrate.

The X-ray diffraction pattern for the film of $YBa_2Cu_3O_{7-\delta}$ growth over Sr_2YSbO_6 buffer layer, for 2θ between 10° and 90°, is shown in Fig. 5. It consists of peaks (0 0 *l*) of $YBa_2Cu_3O_{7-\delta}$, besides the MgO and Sr_2YSbO_6 peaks, such as is detailed in Fig. 6. These result reveals the epitaxial growth of $YBa_2Cu_3O_{7-\delta}$ over Sr_2YSbO_6/MgO buffered substrate.

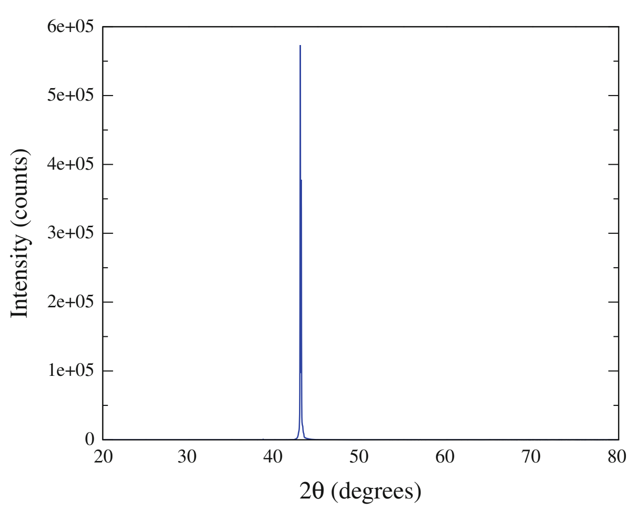

Fig. 3 XRD of Sr_2YSbO_6 films, for 2θ between 10° and 90°

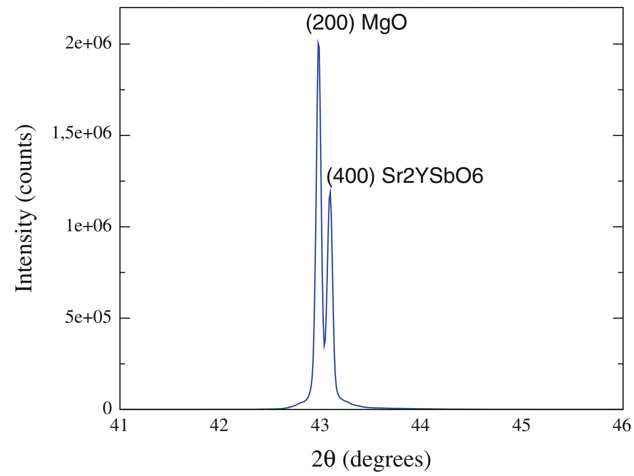

Fig. 4 Detailed XRD pattern of Sr_2YSbO_6 films

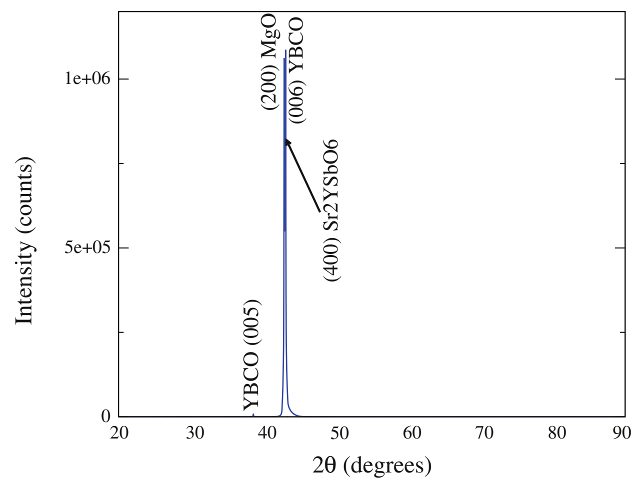

Fig. 5 XRD pattern of $YBa_2Cu_3O_{7-\delta}$ buffered films

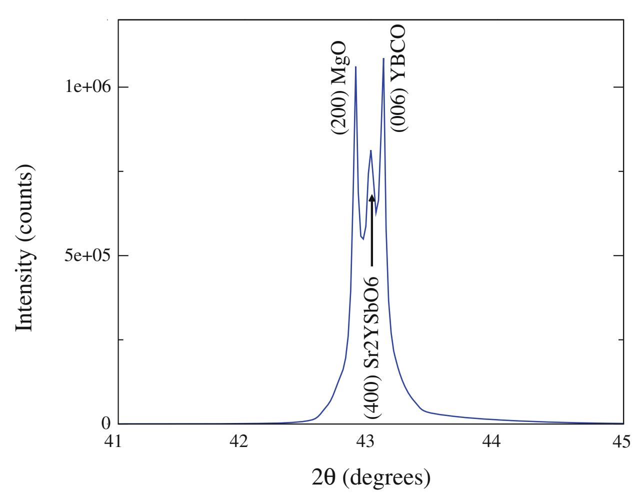

Fig. 6 Detailed XRD pattern of $YBa_2Cu_3O_{7-\delta}$ films

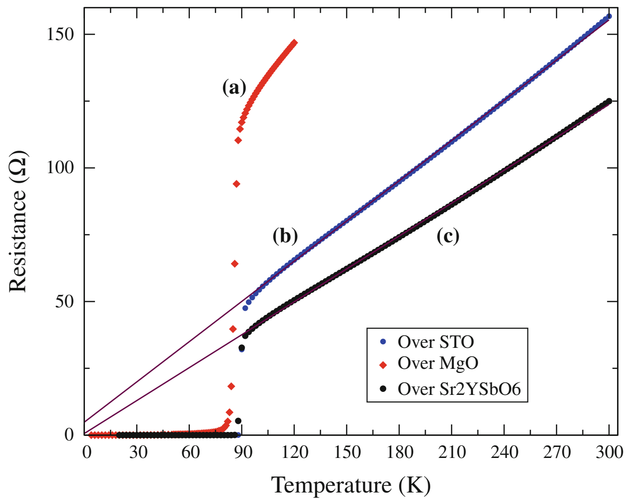

Fig. 7 Resistance in function of temperature for $YBa_2Cu_3O_{7-\delta}$ films over different substrates: (*a*) over MgO single crystal; (*b*) over $SrTiO_3$ single crystal; and (*c*) over Sr_2YSbO_6/MgO buffered substrate

Figure 7 shows the behavior of $YBa_2Cu_3O_{7-\delta}$ film's resistance as a function of temperature. For films growth over Sr_2YSbO_6 the curve exhibits linear behavior up to a transition temperature T_c of 90 K. In the same figure the measurements corresponding to a $YBa_2Cu_3O_{7-\delta}$ films growth over MgO and on $SrTiO_3$, with the same conditions, are shown. The T_c of $YBa_2Cu_3O_{7-\delta}$ films over MgO is 86 K, and over $SrTiO_3$ is 90 K. Although the T_c values are similar for films over STO and over Sr_2YSbO_6 buffer layer, the resistance in the normal zone is less for the $YBa_2Cu_3O_{7-\delta}$ growth on buffer layer; also, the extrapolated residual resistance for this film (0.62 Ω) is less than the residual resistance (4.86 Ω) of $YBa_2Cu_3O_{7-\delta}$ film growth on $SrTiO_3$.

Results of measurements for voltage V in function of current I (I–V curves) are shown in Figs. 8 and 9 for the films of $YBa_2Cu_3O_{7-\delta}$ over MgO and over buffered substrate Sr_2YSbO_6/MgO, respectively. Based on I–V data, with the 1 μV/cm criteria, the critical current values were determined in 0.013 and 16.5 mA, respectively. So, the critical current density value for $YBa_2Cu_3O_{7-\delta}$ films growth over Sr_2YSbO_6 buffer layer is $J_c \sim 0.8$ MA/cm^2, which is 1269 times the J_c of $YBa_2Cu_3O_{7-\delta}$/MgO films.

The J_c value for $YBa_2Cu_3O_{7-\delta}/Sr_2YSbO_6$/MgO films growth over buffer layer appears to be less than those reported in the literature ($J_c \sim 10^7$ A/cm^2). However, it is worth saying that the value for $YBa_2Cu_3O_{7-\delta}$/MgO is less too in comparison with references ($J_c \sim 10^6$ A/cm^2). Thus, the sputtering deposition conditions perhaps are not yet optimized, and we believe that with other methods of deposition, such as PLD, we could improve the J_c results. The results reported in the literature are for films deposited in wealthy laboratories that have optimized deposition conditions.

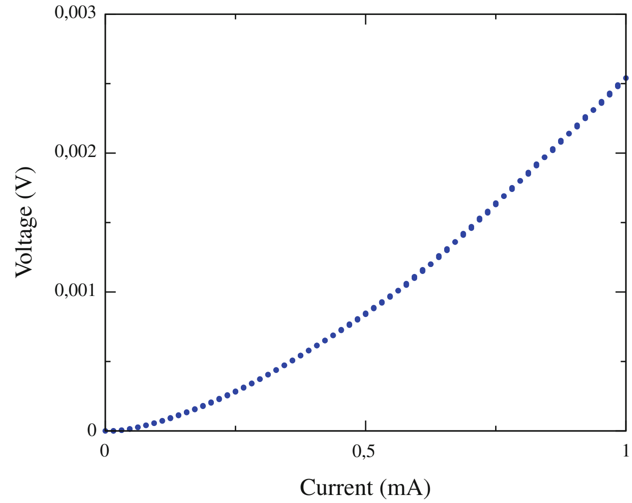

Fig. 8 *I–V* curves for $YBa_2Cu_3O_{7-\delta}$/MgO film at 77 K

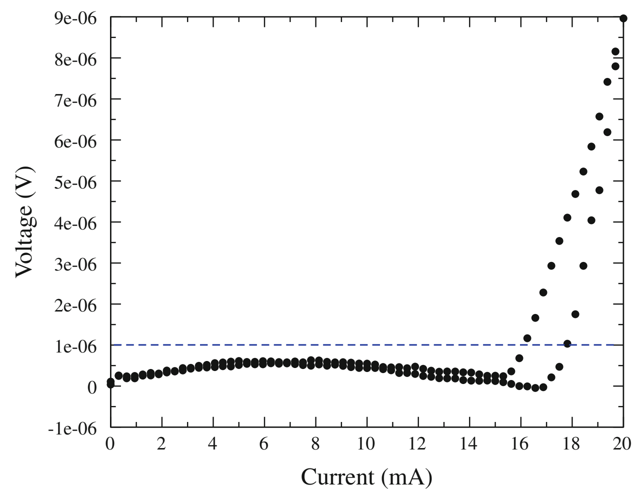

Fig. 9 *I–V* curves for $YBa_2Cu_3O_{7-\delta}$ film over Sr_2YSbO_6/MgO buffered substrate at 77 K. The *dashed line* is a guide for the eye. It shows the voltage value of 1 μV

Conclusion

Although the optimal deposition conditions for Sr_2YSbO_6 films are not yet known, we have shown that Sr_2YSbO_6 can be succesfully used as a buffer layer for the epitaxial growth of $YBa_2Cu_3O_{7-\delta}$ films with high density current value in self-field at 77 K. Taking into account that there is evidence of the effect of buffer layer thickness on J_c [9] and that the $YBa_2Cu_3O_{7-\delta}$ deposition conditions can be improved, our values of J_c could be greater than those reported in this article.

It is worth saying that the layer of Sr_2YSbO_6 material that was used plays the roll of a buffer layer because the negative effects of MgO over superconducting properties of $YBa_2Cu_3O_{7-\delta}$ films were eliminated, and because it has an excellent structural matching with $YBa_2Cu_3O_{7-\delta}$ and with MgO. These results show that Sr_2YSbO_6 can be an excellent substrate material for the $YBa_2Cu_3O_{7-\delta}$ layers in coated conductors, using the IBAD-MgO templates. Besides which, with the Sr_2YSbO_6 material the architecture of the coated conductors can be simplified, because only one buffer layer is needed with Sr_2YSbO_6.

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