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Properties of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ Superconducting Films on Sr_2YSbO_6 Buffer Layers

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1. Introduction

In a previously published work we have shown that the Sr_2YSbO_6 material can be successfully used as a buffer layer for the epitaxial growth of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films with high density current value in self-field at 77 K (Ortiz-Diaz et al., 2010). The layer of Sr_2YSbO_6 material plays the role of a buffer layer because the negative effects of MgO over the superconducting properties of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films were eliminated, and because it evidences an excellent structural matching with $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ and with MgO. These results show that Sr_2YSbO_6 can be an excellent substrate material for the $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ 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 a single Sr_2YSbO_6 buffer layer is used.

The importance of this work is the fact that during the last 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 (Maguire&Yuan, 2009; Shiohara et al., 2009). For instance, both the United States Department of Energy and private industry have been developing a key superconductor cable and fault current limiter projects (Maguire&Yuan, 2009), and there is a five year Japanese national project for materials and power applications of coated conductors, which was started in 2008 (Shiohara et al., 2009). These power applications share a common requirement: that the superconducting material is 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 (Foltyn et al., 2007). 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 (Heine et al., 1989). 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 (Foltyn et al., 2007; Heine et al., 1989). High critical current density in more successfully multifilamentary BSCCO wires, with magnetic field, happen at helium liquid temperatures (Goyal et al., 1996; Shen et al., 2010). The alternative approach, known as the second generation wire, uses the epitaxial growth of an $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ 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 $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ 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 bi-axially textured substrates and subsequent epitaxial buffer layers is very important for the realization of long-length $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ coated conductors. The buffer layer should not only satisfy chemical stability, but structural matching with $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ as well because the alignment of the superconductor is required for high J_c values (Foltyn et al., 2007; Ying et al., 2009).

Different oxide materials have been successfully used as a buffer layer to fulfill these requirements (Foltyn et al., 2007; Huhne et al., 2006; Jia et al., 2002; 2003; Nishikawa et al., 2003; Parans et al., 2003; Sathyamurthy et al., 2003; Wang et al., 2005; Wee et al., 2005). However, most of them are really multilayer architectures, which significantly increase the complexity as well as the cost of production (Ying et al., 2009). 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), $\text{Gd}_2\text{Zr}_2\text{O}_7$ or MgO (Arendt et al., 2004; Groves et al., 2002; Hanyu et al., 2007; Koa et al., 2007). Of these, the best is IBAD- MgO because very good biaxial texture can be obtained with films only 10 nm thick, which reduces the production costs (Arendt et al., 2004; Foltyn et al., 2007; Koa et al., 2007). Section 3 is extended a bit the issue of buffer layers and materials used in them.

Sr_2YSbO_6 appears to be a promising material for fulfill these requirements as a buffer layer, as it has a lattice parameter exhibiting a good lattice match with $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (mismatch between a and b $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ parameters and a of Sr_2YSbO_6 is 5%). Previously we have showed that Sr_2YSbO_6 has been applied effectively as a buffer layer for Sr_2YSbO_6 film growth by DC sputtering (Ortiz-Diaz et al., 2010). This superconducting film has a J_c value 10^3 times higher than one grown on MgO . The Sr_2YSbO_6 films 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 applications, and for the elaboration of crucibles for the preparation of superconductors due to their chemical non reactivity with $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$.

The Sr_2YSbO_6 material was chosen because we had been working to find new substrates for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ within the perovskite family $\text{A}_2\text{BB}'\text{O}_6$ since by means of substitutions they permit adjusting the lattice parameters (Ortiz-Diaz et al., 2004a). Preliminary studies of the material in polycrystalline form showed that it was viable as a substrate for the growth of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films (Ortiz-Diaz et al., 2004b; 2010).

The goal of this chapter is to show a summary of these works, which were taken from a period of 2004–2010, showing the technology of manufacturing, since synthesis and evaluation of a material as a potential substrate for superconducting films, until the effective utilization as a substrate for films with excellent superconducting properties.

Section 2 begin with definition of elementary concepts of critical temperature, critical current density J_c and critical magnetic field. One of these topics concerns about the temperature

effect on J_c , based on unpublished experimental results of curves current-voltage (I - V), which permit to calculate the critical current. Also is shown the relevancy of the critical parameters for applications of superconducting films and layers. Section 3 present a short overview of state of the art about the coated conductors (CC), relevance of the buffer layers for the increase of J_c in the second generation of superconducting wires. Special emphasis is made on importance the single buffer layers in order to simplify the fabrication process of CC. We are show the relevance of our Sr_2YSbO_6 perovskite for this goal. In section 4 We will describe details of the evaluation of the properties of Sr_2YSbO_6 polycrystalline material, such as crystallographic matching and chemical stability between Sr_2YSbO_6 and $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$; also We show details of the fabrication of Sr_2YSbO_6 films on MgO single crystal by magnetron sputtering, besides the structural matching of Sr_2YSbO_6 with MgO. Section 5 describes the fabrication of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ target and the growth process of films on MgO and SrTiO_3 (STO) single crystals and on the Sr_2YSbO_6 buffer layer. Also is shown the preparation of the conductor path, for electrical measurements, by means of photolithography, and show the results of critical temperature for all the films, and the measurements I - V based on which were determined the critical current density.

2. Superconductivity elementary notions and relevant properties for applications

A superconductor is the material that show two important properties: zero DC resistivity and magnetic induction zero inside the material when it is cooled below temperature T_c , known as critical temperature. For temperatures $T > T_c$, the superconductor it is in the normal state, and is like normal metal with poor conductivity (Cyrot & Pavuna, 1992; Pool et al., 1995). For a superconductor with a high T_c value, in the normal state, the resistance depends linearly on temperature, such as a typical conductor, as shown in figure 1(a). On the other hand, zero magnetic induction in the superconducting state means that the magnetization takes negative values below T_c and it is usually zero for temperatures above T_c , as shown in figure 1(b).

Fig. 1. Resistance and magnetization curves for a $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ samples, in function of temperature.

The second property of the superconductors is called diamagnetism. When it is perfect a superconducting material does not permit an externally applied magnetic field to penetrate into its interior. However, superconductivity disappears and the material returns to the normal state if one applies an external magnetic field of the strength greater than some critical value, B_c , called the critical thermodynamic field. It worth to say that we are calling magnetic field to the magnetic induction field B . The superconducting state can also destroyed by passing an

excessive current greater than some value I_c , called critical current, which creates a magnetic field at the surface. This limits the maximum current value that the material can sustain and it is a crucial problem for applications of superconducting materials. Those materials that totally exclude an applied magnetic flux, for $T < T_c$, are known as type I superconductors.

There are other superconductors, known as type II superconductors, that totally exclude magnetic field when the applied magnetic field is low, but only partially exclude it when the applied field is higher. For this superconductors there are two critical fields: the lower B_{c1} and the upper B_{c2} . The flux is totally expelled only up to the lower critical field B_{c1} . Then, in applied fields smaller than B_{c1} , the type II superconductor behaves like a type I superconductor below B_c . Above B_{c1} the flux penetrates into the material until the upper critical field B_{c2} is reached. Above B_{c2} the material returns to the normal state.

Between B_{c1} and B_{c2} , the type II superconductor is said to be in the mixed state. The Meissner effect is only partial. For this range of fields magnetic flux partially penetrates the superconducting sample in the form tiny filaments known as vortices. A vortex consists of a normal core in which the magnetic field is large, surrounded by a superconducting region in which flows supercurrent.

Critical magnetic field and, obviously, critical current depends on temperature. Because of that it is important to report the temperature value at which the measures of critical current are carried out. Figure 2(a) shows a typical curve of voltage V in function on applied current I at temperature of 82 K for a $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ film which was growth on Sr_2YSbO_6 buffer layer. Note that this temperature is higher than 77 K, usually reported for critical current measurements in high temperature superconductors. In these measurements one applies current I and takes a voltage value between two electrodes. In the so-called criterion of a microvolt/cm ($\mu\text{V}/\text{cm}$), the current value for which the voltage drop in a 1 cm length is $1\mu\text{V}$ is defined as a critical current value. Figure 2(b) shows an expanded region of the figure 2(a), in which the red dashed line is a visual guide to determine the current value for which the drop voltage is $1\mu\text{V}$. For this example, the critical current value is 4.14 mA, from which by dividing by the cross-sectional area of the sample, yields a relatively high value of $J_c \sim 0.2 \times 10^6 \text{ A}/\text{cm}^2$.

Fig. 2. Voltage in function of current, at 82 K for a $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ film growth on $\text{Sr}_2\text{YSbO}_6/\text{MgO}$ substrate.

Figure 3(a) shows the voltage curves as a function of current for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ film on MgO at different temperatures from 5 K to 82 K and, Figure 3(b), the behavior of the density critical

(a) I - V curves.

(b) Critical current.

Fig. 3. I - V curves for several temperatures and critical current in function of temperature for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ on MgO single crystal.

current as a function of temperature, calculated for each temperature in the same way as was done for the data in Figure 2. As the temperature increases, the current value for which the potential drop is $1\mu\text{V}$ decreases dramatically, so that at 82 K the curve approaches the linear behavior as a sign that is disappearing superconducting state. This is equivalent to the reduction of critical current density with increasing temperature as shown in Figure 3(b). In contrast, as shown in Figures 2, for this temperature of 82 K the superconductor film grown on Sr_2YSbO_6 buffer layer maintains a relatively high critical current value. From applications viewpoint, is important to determine the critical current value for at determined temperature. For HTS superconductors often the critical current is measured at the reference value of 77 K.

It worth noting that the issue of the temperature is crucial factor for the cost of practical uses of superconductors. For the called conventional superconductors is required the liquid helium coolant which have very higher cost. Nitrogen becomes liquid at 77 K; it is far less costly to liquefy this gas than to liquefy helium. For any application in which liquid nitrogen can replaced liquid helium, the refrigeration cost will be about 1000 times less (Sheahen, 2002). High- T_c oxides have critical temperatures above liquid nitrogen. For instance, the $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ has been found to be superconducting up to ~ 90 K; then liquid nitrogen is sufficient to cool $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ in the superconductor range.

The maximum current density, J_c , that a superconductor can carry without exceeding a voltage drop criterion ($1\mu\text{ V/cm}$) depends both on the superconductor temperature and the applied magnetic field. From the practical point of view the critical temperature, T_c , is the temperature at which a very small J_c may flow at zero applied field. At a fixed temperature less than T_c , J_c will usually drop very rapidly above some threshold value of applied field. Thus, it is common to see a critical B plotted as a function of T , defined at some value of J_c . For an HTS, this critical magnetic field is called the irreversibility field, B_{irr} , which is the field at which flux lines or vortices to flow and causes dissipation. This value is often considerably lower than the B_{c2} of the material (Hull, 2003). Figure 4(a) shows B_{c2} in function of temperature for some common superconductor materials. For $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ and BSCCO B_{c2} has high values at liquid nitrogen temperature. Figure 4(b) shows B_{irr} in function of temperature for some materials. The B_{irr} curve for BSCCO is noteworthy because it is relatively low at 77 K but starts to rise rapidly as temperatures drop below about 30 K. Thus, at temperatures near 77 K, applications for BSCCO will be limited to low magnetic field applications, such as transmission lines. Higher field applications, such as motors and generators, will require the expensive helium cooling of the BSCCO. This mean that the $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ is an ideal candidate for these applications at liquid nitrogen temperature, which appears as a dashed line in figure 4(b). This is the main reason why the $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ is the preferred material for applications involving high magnetic fields, and therefore, the reason why we decided to use $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ and no other superconductor material for our study.

Fig. 4. Magnetic field in function of the temperature for some superconductors. Data adapted from (Hull, 2003).

Structural and transport properties of the HTS oxide materials is highly anisotropic. For this reason it is helpful, for the understanding of the properties of the $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$, a description

of its structure. The unit crystallographic structure of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$, shown in figure 5, can be seen as a stacking of three perovskites. So, crystallographers classify the structure of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ as the perovskite type with vacancies of oxygen; the oxygen contents it is in the range 6 to 7, as indicates the subscript $7 - \delta$. The lattice parameter c is around three times larger than a and b parameters.

Fig. 5. Schematic representation of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ structure.

Thus, its structure consists of a sequence of oxide layers perpendicular to the c -axis separated by Y and Ba atoms, which can be seen in figure 6. Figure 6(a) corresponds to $\delta = 1$, that is, to $\text{YBa}_2\text{Cu}_3\text{O}_6$ and, figure 6(b) is the representation of $\text{YBa}_2\text{Cu}_3\text{O}_7$. The sequence of oxide layers are as follows:

- a Cu–O layer with two vacancies of oxygen for figure 6(b); each Cu is surrounded by 4 O. Thus the typical octahedral coordination has been replaced for a square planar coordination. So along the b -axis are formed the called chain copper oxygen connect by oxygen atoms. In the $\text{YBa}_2\text{Cu}_3\text{O}_6$ there is not chains because each copper ion has surrounded by two oxygen,
- a barium layer,
- a Cu_2O layer where each copper exhibit fivefold pyramidal coordination. The basis of pyramids linked by oxygen atoms, forms the called copper oxygen planes through the ab -plane,
- a layer of Y with for oxygen vacancies sandwiched between two Cu–O planes.

These sequence is duplicated in the upper half of the structure.

The tetragonal $\text{YBa}_2\text{Cu}_3\text{O}_6$ compound is an insulator. By increasing of oxygen concentration the ab -planes are gradually doped with holes and eventually it reaches the $\text{YBa}_2\text{Cu}_3\text{O}_7$ composition in which there are not vacancies of oxygen. The maximum $T_c = 94 \text{ K}$ is obtained for $\text{YBa}_2\text{Cu}_3\text{O}_{6.93}$ and for $\text{YBa}_2\text{Cu}_3\text{O}_7$ the critical temperature is lower (Cyrot & Pavuna, 1992;

Fig. 6. Schematic representation of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ structures, shown the planes and chains.

Pool et al., 1995). Those compounds $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ with optimally oxygen contents have orthorhombic structure and are superconductors. They are called $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ optimally doped.

Conductivity in ab -planes are around 100 times than c -axis conductivity. For this fact is accepted that superconductivity essentially takes place within quasi dimensional planes, and $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ is considered as Cu–O planes separated by a charge reservoir (the chains).

As the conductivity, the J_c of the ceramic oxide materials is too highly anisotropic. For this reason a good alignment of the crystalline axes of all the grains is essential to pass high current density from one superconducting grain to another. For polycrystalline specimens the J_c is very low, of order hundred A/cm^2 . In contrast, higher J_c values, around $\sim 10^7 \text{ A}/\text{cm}^2$, are obtained in single crystals and a good films.

To explain the low value of J_c in polycrystalline samples and understand how to improve these values by using the superconductor in the form of films, it is worth noting, as mentioned in section 4 that for the production of a polycrystalline sample in the form of pellet, one mix a precursor components, which are subjected to heat treatment and appropriate oxygenation for optimal superconducting properties. However, even the best polycrystalline samples consist of many randomly oriented polycrystalline grains, each of them with their anisotropic layered structure. It also contains grain boundaries, structural defects such as twins, voids, which act as non conducting grains. All this conspires against applications that require high critical current densities. In contrast, with single crystals and epitaxially grown films are obtained large values of J_c at 77 K and self field, because superconductivity occurs through the ab planes.

To produce films is necessary to use a substrate, which must satisfies basic requirements to promote epitaxial growth and micro structural properties to obtain high current density values: must have good matching of lattice constants with superconductor; must be chemically non reactant with $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ even under heat treatment at temperature of film deposition and; should not affect the values of critical temperature and critical current density of the superconductor. It worth to say that the recent analyses, about current limiting defects in coated conductors, have shown that the major local current-limiting defects are a -axis grains, which exert a big effect on current flow and local dissipation in the coated conductor samples studied (Li et al., 2012). By reducing the amount of grains grown along the a axis, the quality of the superconducting layers substantially improves. To achieve this purpose, besides optimizing the deposition conditions, also, the substrate plays a crucial role.

The crystallography and preparation of the substrate is of primary importance in determining the quality of the film deposition. Some of the highest critical current densities at 77 K and highest film uniformities have been achieved in $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films grown on commercially available (1 0 0) SrTiO_3 substrates (Huhne et al., 2006; Jia et al., 2002; 2003; Ortiz-Diaz et al., 2004a; Sathyamurthy et al., 2003; Varanasi et al., 2008; Wang et al., 2005; Wee et al., 2005; Wu et al., 2005; Ying et al., 2009). However, SrTiO_3 is fairly expensive, has high dielectric constant, and undergoes phase transition at ~ 110 K. LaGaO_3 with $\sim 0.5\%$ mismatch it is neither cheap nor twin free (Cyrot & Pavuna, 1992). Other commercial substrate, LaAlO_3 was reported as a problematic substrate for the deposition of thin $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films, especially when a thick substrate is required, because detrimental extended defects are developed. The use of LaAlO_3 layers of 0.5 mm is advantageous, provided the deposition temperature is kept as low as possible (Koren & Polturak, 2002).

MgO single crystal substrates have been widely used for its economy and acceptable matching of lattice constants. However, it is widely accepted that MgO affects the superconducting properties. In particular, T_c and J_c values for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ and $\text{REBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films are generally lower when are deposited on MgO than the values for films grown on other commercial substrates (Hollmann et al., 1994; Wee et al., 2005). This has been attributed to chemical reaction between the superconductor and the MgO , which causes the formation of third phases, which act as “non-superconducting dead layers” and; grains (0 0 1) growth rotated 45° with respect to MgO (1 0 0) surface.

Sapphire is another cheap substrate, free twining. However, has relatively high mismatch with $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ and reacts chemically with superconductor, thus, the interfacial BaAl_2O_4 layer is formed, which affects the epitaxial growth of the film and result in poor superconducting films (Hollmann et al., 1994).

The list of materials tested as substrates for superconducting films is broad and includes a variety of compounds and crystal structures, ranging from oxides and simple perovskites to complex perovskites and pyrochlore structures. For instance, Yttrium Stabilized Zirconium Oxide (YSZ) and cerium oxide, CeO_2 have been widely used, sometimes as a combination of layers. Among simple perovskites that have been proposed, perhaps the most successful are SrTiO_3 , LaAlO_3 and SrRuO_3 , which are commercially available as single crystals. Examples of other simple perovskites proposed as substrate materials are YAlO_3 , GdAlO_3 , EuAlO_3 , SmAlO_3 , LaGaO_3 , NdGaO_3 , PrGaO_3 . Also, were proposed to make substitutions with the idea that variation in the composition allows the lattice parameters vary, and then the matching can be improved, but question arises about the chemical compatibility with $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (Hollmann et al., 1994); thus, are tested as potential substrates, for

YBa₂Cu₃O_{7- δ} applications in microwaves and electronics, many complex perovskites with formula A₂BB'O₆, besides, some pyrochlore structures. Some examples of complex perovskites proposed are Sr₂AlTaO₆ for superconducting devices (Findikoglu et al., 1992; Ying & Hilbert, 1994); Ca₂GaNbO₆; Sr₂GaTaO₆ (Brandle, 1996); Ba₂LaNbO₆ (Pai et al., 1997); DyBa₂SnO_{5.5} (Koshy et al., 1995); DyBa₂ZrO_{5.5} (Yadava et al., 1998); HoBa₂SbO₆ (Aguiar et al., 1998) and Ba₂NdTaO₆ (Kurian et al., 2002; Kurian & Morishita, 2003).

As can be seen, the search for new substrates for the deposition of superconducting films is continuous, since it is hard to find the substrate to produce the perfect film.

3. Buffer layers for superconducting films

As was said in the previous section, there are many potential substrates for YBa₂Cu₃O_{7- δ} films deposition, but only a few commercially available in single crystal form. Also, each substrate has a problem or disadvantage to the film that has to grow on. To solve this problem without having to wait for the manufacture of new mono-crystalline substrates, some groups began to use these materials in the form of film on any of the commercial MgO and SrTiO₃ substrates for growth of superconducting films. The idea was to eliminate the negative effect of single-crystal substrate by using a buffer layer that acts as a chemical barrier that eliminates the reaction between the crystal and the superconductor. In addition, the buffer layer plays the role of template to facilitate the epitaxial growth of superconducting film with improved superconducting and microstructural properties. RF sputtered and laser ablated films of YBa₂Cu₃O_{7- δ} on a MgO single crystal substrate using a buffer layer of SrTiO₃ began to be manufactured in the 1990's.

In 1993 SrTiO₃ buffer layers were grown on MgO (100) substrates to provide a better match to RF sputtered YBa₂Cu₃O_{7- δ} films. This heterostructure allows a highly textured growth to be achieved over thickness as high as 1 μ m. The improvement of lattice matching makes the critical current density increase from 10³ A/cm² for 1 μ m films grown to 4 $\times$ 10⁵ A/cm² for films grown with a SrTiO₃ buffer layer (Lucia et al., 1993).

Laser ablated thin films of YBa₂Cu₃O_{7- δ} on a MgO substrate using a SrTiO₃ buffer layer were grown, which is perfectly oriented with respect to the MgO substrate. Superconductivity is improved in a spectacular manner with respect to YBa₂Cu₃O_{7- δ} directly deposited on MgO. A critical temperature T_c = 92 K and a critical current density of 4 $\times$ 10⁶ A/cm² at 82 K are reached for the first time for films deposited on MgO substrate (Proteau et al., 1995).

In 1996 were grown epitaxial YBa₂Cu₃O_{7- δ} films by pulsed laser ablation on SrTiO₃ buffered (100) MgO and was found that the SrTiO₃ buffer layer provides a better lattice match to the YBa₂Cu₃O_{7- δ} film and plays a crucial role to prevent the interaction between YBa₂Cu₃O_{7- δ} and MgO. Thus, were obtained YBa₂Cu₃O_{7- δ} films with $J_c \sim 10^6$ A/cm² at 77 K and zero magnetic field (Boffa et al., 1996).

A comparative study of NdBa₂Cu₃O_{7- δ} films deposited, by laser ablation, on different substrates showed that the transport J_c value of 3.5 $\times$ 10⁶ A/cm² at 77 K in self-field was obtained from the NdBa₂Cu₃O_{7- δ} on SrTiO₃ with T_c value of 91.2 K, while the NdBa₂Cu₃O_{7- δ} on MgO with T_c of 86.8 K exhibited the low J_c value of 0.25 $\times$ 10⁶ A/cm². On the other hand, J_c value of 1.55 $\times$ 10⁶ A/cm² was obtained from NdBa₂Cu₃O_{7- δ} film on SrTiO₃ buffered MgO(100) substrate with T_c of 91.5 K. The low J_c value of the NdBa₂Cu₃O_{7- δ} on MgO can be attributed to both depressed T_c value and the existence of 45° rotated grains

with (0 0 1) $\text{NdBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (1 1 0) MgO (Wee et al., 2005). $\text{NdBa}_2\text{Cu}_3\text{O}_{7-\delta}$ film properties were improved too using a buffer layer of $\text{Ba}_2\text{NdTaO}_6$ on MgO (Kurian & Morishita, 2003).

The above example is a sample of the use of compounds different to the commercial substrates as a material for buffer layers. Also, with the emergence of the second generation of superconducting wires took great importance to study and search for new buffer layers. For instance, Biaxially textured $\text{La}_2\text{Zr}_2\text{O}_7$ with CeO_2 and $\text{Ce}_{0.7}\text{Gd}_{0.3}\text{O}_3$ buffer layers were grown on Ni-RABiTS (rolling-assisted biaxially textured substrates) to obtain suitable buffer layer architectures for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ coated conductors (Knoth et al., 2005). More recently, it has been used as textured substrate for coated conductors a NiW alloy with a $\text{Gd}_2\text{Zr}_2\text{O}_7$ buffered $\text{Ce}_{0.9}\text{La}_{0.1}\text{O}_{2-y}$ for the growth of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films with $J_c \sim 1 \times 10^6 \text{ A/cm}^2$ (Zhao et al., 2012). This work is an example of current interest in improving the manufacturing process of superconducting tapes with different combinations of deposition technique and combinations of buffer layers.

Fig. 7. Schematic representation of the $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ film on Sr_2YSbO_6 buffer layer.

Film deposition	Buffer layer	$J_c (\times 10^6 \text{ A/cm}^2)$	Reference
Sputtering RF	SrTiO_3	0.4	(Lucia et al., 1993)
PLD	$\text{Sr}_2\text{AlTaO}_6/\text{LaAlO}_3$	1.3	(Findikoglu et al., 1992)
PLD	$\text{CeO}_2/\text{IBAD-YSZ}$	2.2	(Li et al., 2012)
PLD	$\text{SrO}/\text{Sr}_2\text{AlTaO}_6$	~ 0.5	(Takahashi et al., 2003)
PLD	$\text{Ba}_2\text{LaNbO}_6$	5×10^6	(Pai et al., 1997)
PLD	SrTiO_3	4	(Proteau et al., 1995)
PLD	$\text{Ce}_{0.9}\text{La}_{0.1}\text{O}_{2-y}/\text{Gd}_2\text{Zr}_2\text{O}_7$	~ 1	(Zhao et al., 2012)
Sputtering RF	$\text{Sr}_2\text{YSbO}_6/\text{MgO}$	0.86	(Ortiz-Diaz et al., 2010)

Table 1. Values of critical current density for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films on some buffer layers at 77 K and self-field. PLD means Pulsed Laser Deposition.

We have mentioned a few examples of materials used for buffer layers; a more extensive list can be consulted by the interested reader in an excellent review of coated conductors (Foltyn et al., 2007). With all this it can see two things: first, the problem of the epitaxial growth appears overcome and; second, the optimization and reduction of cost of deposition can be obtained with the uses of buffer layer sandwiched between the single substrate and superconducting film, as is shown in figure 7 (Foltyn et al., 2007; Hanyu et al., 2007; Nishikawa et al., 2003; Ortiz-Diaz et al., 2010; Parans et al., 2003).

Most promising applications of type II superconductors are in the power area, where the most advantageous superconductor material is $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$, because high critical current densities needed for this applications can be achieved with it, with acceptably low energy dissipation, even with magnetic fields, as was shown in section 2. These applications require that the superconductor be formed as a long coated conductor tape so that it can be used

like the copper wires. The architecture of the superconducting tapes is like the buffered $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films showing in figure 7, but with additional protective layer of gold or silver and with the single substrate replaced for a flexible tape of commercial alloy textured with an oxide layer. The most promising technology for the manufacture of coated conductor tape is based on Ion Beam Assisted Deposition (IBAD) (Arendt et al., 2004; Foltyn et al., 2007), where MgO and $\text{Gd}_2\text{Zr}_2\text{O}_7$ are successfully used for texturing. Intermediate oxide layers are epitaxially grown on this textured substrate. The architecture of the tapes can be simplified and, then, the cost of manufacture can be reduced if these intermediate layers are replaced with a single buffer layer. It is the principal motivation for the evaluation of new materials, such as Sr_2YSbO_6 . Also, the evaluation is made using the MgO single substrate, because the MgO is one of the oxides successfully used in IBAD technology. Generally, the route followed to evaluate a material as a possible constituent of the buffer layer in a superconducting tape begins with tests on a small sample of single crystalline substrate. That is why in our work the films are grown on single crystal, instead of on a textured tape directly.

4. Evaluation of Sr_2YSbO_6 , step by step

The evaluation of Sr_2YSbO_6 starts with the preparation, which was made by the solid state reaction method. Stoichiometric mixtures of high purity (99.99%) commercial precursor oxides Y_2O_3 , SrO and Sb_2O_3 in adequate amounts are mixed thoroughly, pelletized and calcined at 1100°C for 18 h. The calcined material was reground, pressed as circular discs and sintered at 1090°C for 135 h. All the above processing was carried out in ambient atmosphere.

For the compatibility studies, single phase $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ superconducting material was prepared by the solid state reaction method. High purity (99.99%) constituent commercial chemicals Y_2O_3 , BaCO_3 , and CuO were mixed in stoichiometric ratio. The mixed powder was finely ground and calcined at 900°C for 24 h at ambient atmosphere. The calcined material was reground, pressed as circular discs at a pressure of 1.6 ton/cm^2 . The pellets were sintered at 930°C for 24 h, followed by slow cooling up to 500°C for 13 h and annealing at this temperature for 24 h at O_2 atmosphere. Samples were finally furnace cooled to room temperature over a span of 12 h.

For the study of the structural characteristics of the materials, X Ray Diffraction (XRD) patterns of the samples were recorded by a Siemens D5000 X Ray diffractometer, using Cu-K α radiation ($\lambda = 1.5406\text{ \AA}$) and studied by Rietveld method with the programs EXPGUI and GSAS (Larson & Dreele, 2000; Toby, 2001).

Powder XRD pattern of Sr_2YSbO_6 is shown in figure 8. It consists of strong peaks which are characteristics of a primitive cubic perovskite plus a few weak line reflections arising from the superlattice. Thus, the whole XRD pattern of Sr_2YSbO_6 can be indexed in a $\text{A}_2\text{BB}'\text{O}_6$ cubic cell with the cell parameter $a = 8.2561\text{ \AA}$.

Taking into account the doubling of the basic perovskite lattice parameter, the lattice constant $a = 8.2561\text{ \AA}$ ($a/2 = 4.128\text{ \AA}$) of Sr_2YSbO_6 is comparable to lattice constants a and b of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$. Thus, Sr_2YSbO_6 has a lattice parameter a which presents a good match with the lattices parameters a and b of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ superconductors. This first result was crucial for work purposes. First, the Sr_2YSbO_6 show acceptable fit with $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$, one of the basic requirements of a substrate. On the other hand, the matching is also suitable with MgO, which would ensure the epitaxial growth of Sr_2YSbO_6 films.

Fig. 8. XRD pattern of Sr_2YSbO_6 sample after the Rietveld refinement.

For the study of chemical and physical compatibility, we have synthesized several composites of Sr_2YSbO_6 - $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ with 15 to 90 vol% of Sr_2YSbO_6 component in the composite. For synthesis of each composite, the component materials were mixed in desired vol% ratios and mixture was pelletized as circular discs at a pressure of 1.6 ton/cm^2 . These pellets were heat treated at 900°C for 10 hour in oxygen and cooled down slowly at a rate of 0.5°C/min for proper oxygenation. Chemical stability of Sr_2YSbO_6 with $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ was examined by X-ray diffractometry of Sr_2YSbO_6 - $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ composites. XRD patterns of Sr_2YSbO_6 - $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ composites are shown in figure 9. As seen from these XRD patterns, all the XRD peaks could be indexed for either Sr_2YSbO_6 or $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ and there is no extra peak corresponding to impurity phase. Within the accuracy of the XRD technique, these results show that there is no chemical interaction between these materials and Sr_2YSbO_6 is chemically compatible with $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ superconductors.

The effect of Sr_2YSbO_6 addition on the superconductivity of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ superconductors was investigated by measuring dc magnetization of Sr_2YSbO_6 - $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ composites in the temperature range 5–100 K using a Quantum Design SQUID magnetometer. Figure 10 shows the magnetization for Sr_2YSbO_6 - $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ composites for 0, 45 and 90 vol% of Sr_2YSbO_6 . As shown from these figures all the Sr_2YSbO_6 - $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ composites gave a superconducting transition temperature $T_c \sim 90 \text{ K}$ as that of the pure $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ superconductor. A saturated diamagnetic transition is clearly observed in every sample at temperatures well below T_c . However, with decreasing $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ superconductor volume fraction the magnitude of magnetization decreases in all Sr_2YSbO_6 - $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ composite samples.

These remarkable results guarantee that indeed the material does not react chemically with $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$, in spite of the severe heat treatment made to the composites at temperatures above the deposition of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films. For this reason the Sr_2YSbO_6 material can be proposed as a potential substrate for the growth of superconducting films.

It worth noting that the Sr_2YSbO_6 material has good structural matching with MgO. Thus, next step was the epitaxial growth of Sr_2YSbO_6 films on (1 0 0) MgO commercial single crystal substrate, which were performed by magnetron sputtering (13.56 MHz, 70 watt) using a polycrystalline target, which was fabricated, like the firsts samples, by the solid state reaction

Fig. 9. XRD patterns for several composites $\text{Sr}_2\text{YSbO}_6\text{--YBa}_2\text{Cu}_3\text{O}_{7-\delta}$. First plot show, as a reference, XRD patterns of single phases of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ and of Sr_2YSbO_6 .

method, based on SrO , Sb_2O_3 and Y_2O_3 , powder oxides. The substrate temperature and oxygen pressure for the Sr_2YSbO_6 growth were kept at 800°C and 7×10^{-3} mbar, respectively.

Fig. 10. Magnetization in function of temperature for composites $\text{Sr}_2\text{YSbO}_6\text{--YBa}_2\text{Cu}_3\text{O}_{7-\delta}$.

The X-ray diffraction pattern for films, were recorded by a PHILLIPS PW1710 diffractometer using $\text{Cu-K}\alpha$ radiation ($\lambda = 1.5406 \text{ \AA}$). Figures 11 show XRD pattern for 2θ between 10 and 80 degrees, and a short detailed scan for 2θ between 41 and 46 degrees. Pattern of figure 11(a) consists of strong peaks (200) of MgO and (400) of Sr_2YSbO_6 . Figure 11(b) shows the MgO peak in $2\theta = 43^\circ$ and the Sr_2YSbO_6 peak in $2\theta = 43.1^\circ$. This result reveals the successfully epitaxial growth of Sr_2YSbO_6 films on MgO (1 0 0) substrate.

Fig. 11. XRD patterns for Sr_2YSbO_6 film growth by magnetron sputtering on MgO .

In conclusion, in this section we have showed the preliminary study of structural characteristics of a complex ordered perovskite Sr_2YSbO_6 for its use as substrate material for the fabrication of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$. Sr_2YSbO_6 has a fairly good lattice match (lattice mismatch $\sim 8\%$) with this superconductor. X-ray diffractometry and magnetic measurements made on $\text{Sr}_2\text{YSbO}_6\text{--YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ composites show that Sr_2YSbO_6 is chemically and physically compatible with $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ material, even after a severe heat treatment at 900°C , processing temperature of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$. These favorable characteristics of Sr_2YSbO_6 show that it can be used as a buffer layer for deposition of superconductor $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films using MgO single substrate.

5. Sr_2YSbO_6 as a successfully buffer layer for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films

In the previous section We show that Sr_2YSbO_6 satisfies the requirements for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films deposition. For this reason, was made the growth and characterization of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ film on buffered layer of Sr_2YSbO_6 . This film, and additional films on commercial substrates of MgO and STO, for comparative studies, were carried by sputtering DC (~ 30 watt) at an optimized substrate temperature of 850°C an O_2 pressure of 3.5 mbar for 1 hour, followed by cooling up to 550°C in 30 min at O_2 pressure of ~ 850 mbar and therefore were annealed at 550°C for 30 min at the same O_2 pressure.

Figures 12 show the XRD pattern of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ film over Sr_2YSbO_6 buffer layer, for 2θ between 10 and 90 degrees. It consists of peaks (00 l) of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$, besides the MgO and Sr_2YSbO_6 peaks, such as is detailed in figure 12(b). These result reveals the epitaxial growth of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ over $\text{Sr}_2\text{YSbO}_6/\text{MgO}$ buffered substrate.

Fig. 12. XRD patterns for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ film growth on Sr_2YSbO_6 buffer layer.

The superconducting properties of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films were characterized 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 four probe method, using the PPMS system of Quantum Design. These measurements were performed on $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ micro bridges, with $20\ \mu\text{m}$ of width and 100 nm of thickness, which were prepared by UV photo lithography.

For the photolithography, the films were coated with a layer of photolack. Then, the coated surface was put over a mask and was irradiated for 12 min with UV radiation. Irradiated film was submerged and moved into mix of H_2O and NaOH , until we can saw a marks of mask. Then, the film was pasted to another recipient with 60 drops of H_2O and five drops of phosphoric acid, and move until the $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ superconductor paths that were used for electrical measurements were clears. Finally, film was retired and cleaned. Figures 13 show a $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ film after the photolithography and detailed microscopic image of the micro brigde. Films of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ were contacted by means of indium leads such as is show in figure 14, by measurements both resistance in function of temperature and voltage V in function of current I .

Figures 15 to 17 show the behavior of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films 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 . In figure 16 the measurements corresponding to a $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$

Fig. 13. $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ film after the photolithographic process for preparation of micro bridge.

Fig. 14. $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ with contacts for superconducting measurements.

films growth over MgO and on SrTiO_3 , with the same conditions, are shown. Figure 17 is shown for comparison of the resistance behavior.

It worth to say about the ways of defining the sharpness and superconducting transition temperature. There is two criteria widely used. Some authors talk in terms on the onset, 5%, 10%, midpoint, 90%, 95%, and zero resistance points (Pool et al., 1995). The onset, or 0% point is where the experimental curve begins to drop below the extrapolated linear behavior. With this criterion, the T_c value is midpoint at which the resistivity has decreases by 50% below onset. The point at which the first derivative of the resistive transition curve reaches its maximum value could be selected as defining T_c , since is the point of most rapid change from the normal to superconducting phase. Also, the width ΔT between the half-amplitude points of the first derivative curve is good quantitative measure of the width of the transition.

Fig. 15. Resistance in function of temperature for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ film on Sr_2YSbO_6 buffer layer.

Fig. 16. Resistance in function of temperature for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films on STO and MgO single crystals.

Based on the first derivative criterion, we determined the T_c values as $T_c = 86.6 \pm 6.6 \text{ K}$ for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ on MgO; $T_c = 88 \pm 3 \text{ K}$ for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ on STO and; $T_c = 88 \pm 2 \text{ K}$ for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ on Sr_2YSbO_6 buffer layer.

Linear fit for $140 \text{ K} < T < 280 \text{ K}$; $99 \text{ K} < T < 147 \text{ K}$ and $150 \text{ K} < T < 250 \text{ K}$ were made for $R-T$ data for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ on Sr_2YSbO_6 , MgO and STO, respectively. The linear fit results are

$$R = -0.11 + 0.41T, \tag{1}$$

for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}/\text{Sr}_2\text{YSbO}_6$ film,

$$R = 45.4 + 0.85T, \tag{2}$$

Fig. 17. Resistance in function of temperature for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films.

for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}/\text{MgO}$ film, and

$$R = 5.1 + 0.50T, \quad (3)$$

for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}/\text{STO}$ film.

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 $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ growth on buffer layer; also, the extrapolated residual resistance for this film is less than the residual resistance of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ film growth on SrTiO_3 .

Results of measurements for voltage V in function of current I (I - V curves) are shown in figure 18 for the films of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ over buffered substrate $\text{Sr}_2\text{YSbO}_6/\text{MgO}$. Based on this I - V data and on the I - V curves for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}/\text{MgO}$, of the figure 3, with the $1 \mu\text{V}/\text{cm}$ criterion, the critical current values, at 77 K, were determined in $\sim 0.013 \text{ mA}$ for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ on MgO and $\sim 17 \text{ mA}$ for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ on Sr_2YSbO_6 buffer layer. So, the critical current density value for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films growth over Sr_2YSbO_6 buffer layer is $J_c \sim 0.86 \times 10^6 \text{ A}/\text{cm}^2$ which is three order of magnitude times the J_c of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}/\text{MgO}$ films. The J_c value for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}/\text{Sr}_2\text{YSbO}_6/\text{MgO}$ film growth over buffer layer appears to be less than those reported in the literature ($J_c \sim 10^7 \text{ A}/\text{cm}^2$). However, it is worth saying that the value for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}/\text{MgO}$ is less too in comparison with references ($J_c \sim 10^6 \text{ A}/\text{cm}^2$). Thus, the sputtering deposition conditions perhaps are not yet optimized, and we believe that with other methods of deposition, such as laser ablation, 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.

The figure 18 also shows the voltage curves as a function of the applied current for temperatures of 82, 85 and 90 K. We observe a decrease in the value of critical current with increasing temperature and how at 90 K the linear behavior is similar to of conductors at this temperature, which is a sign that the $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ is in the normal state.

Fig. 18. I - V curves for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films on Sr_2YSbO_6 buffer layer at different temperatures.

6. Conclusion

In this chapter We have showed some relevant properties of type II superconductors for applications that requires high critical current densities even with applied magnetic fields. Special attention was dedicated to structural properties of the substrates for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films in order to improve the J_c values. In this context, in this chapter was showed a case of study: the evaluation of the Sr_2YSbO_6 as a potential material for buffer layer in growth of superconducting films, since preliminary studies of polycrystalline samples until the effective application of this material for deposition of high quality superconducting films. It worth noting that this chapter concerns only on structural issues that limits the J_c values, which is a problem practically solved. Nothing were said about the flux pinning, another property that can be improved in order to obtain J_c values higher that reported at the present.

There has been show a review of the role of substrate in the successful deposition of superconducting films for applications. Furthermore, it has illustrated the convenience of using buffer layers for the growth of superconducting layers. For these purposes also We showed the different steps in the manufacture of superconducting film on the Sr_2YSbO_6 buffer layer used, with a focus on techniques to evaluate the material as a potential substrate for the successful growth of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films.

Previous studies on a polycrystalline Sr_2YSbO_6 material showed an acceptable structural matching with the $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ and the MgO , allowing the epitaxial growth of Sr_2YSbO_6 film on MgO and subsequently, the superconducting film. Studies on chemical non-reactivity

with $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ despite the severe heat treatment applied to the two materials in contact with each other, at temperature above the deposition of the films, were crucial to ensure that the Sr_2YSbO_6 buffer layer to fulfill its role of chemical barrier to eliminate the negative effect of MgO on the superconducting properties of YBCO film. In fact, the critical current density at 77 K of the film on the Sr_2YSbO_6 buffer layer was three orders of magnitude larger than J_c of the films deposited on MgO directly under the same conditions, as has been widely mentioned in the literature.

The value of critical current density of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ film on the Sr_2YSbO_6 buffer layer is smaller than other values reported in the literature, as is shown in table 1, which can be explained by the deposition conditions not yet optimized and by use of magnetron as a technique of deposition. To support this assumption is worth mentioning, for example, that the laser ablated $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films on LaAlO_3 have $2 \times 10^6 \text{ A/cm}^2$ and the quality of this films is better than of the films grown by sputtering DC (Koren & Polturak, 2002). In this reference Koren mentions that substrate thickness influences the formation of structural defects in the superconducting film, besides the size of superconducting grains is one order of magnitude lower for films deposited by laser ablation than for deposited with DC magnetron, so that their quality improvement. The optimum temperature of deposition is another factor to review, as there is evidence that it may affect the J_c value. For example, buffered substrate $\text{SrRuO}_3/\text{MgO}$ was used for growth of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films with $J_c \sim 2.5 \times 10^6 \text{ A/cm}^2$ at temperature of 770°C , while for deposition at 790°C J_c decreased to $6 \times 10^5 \text{ A/cm}^2$ (Uprety et al., 2004). Also, in a study by Takahashi is reported the effect of buffer layer thickness on the superconducting properties of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$. There is a minimum thickness that ensures chemical isolation between $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ and other layers, but an increase of buffer layer thickness results in decreased critical current density. There is an optimum thickness of this layer that produces the films with the highest value of J_c (Takahashi et al., 2003). In our study, Sr_2YSbO_6 film was deposited with any thickness, which is not necessarily optimal.

As the emphasis was made on the application in coated conductors, it is worth noting that, once found the optimal conditions of manufacture, the Sr_2YSbO_6 could be used as a single buffer layer, thereby simplifying the manufacturing process of the superconductor tapes. Although it appears that the workhorse to discuss possible applications of our material is the field of superconducting tapes, it is interesting to note that the material could be used in other application fields such as electronic devices and Josephson junctions.

7. References

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