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Bilayer Conductive-Oxide Buffer Layer Structures for High-J_c $YBa_2Cu_3O_{7-\delta}$ Coated Conductors

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Submitted to

5th Joint ISTEC/MRS Workshop
Honolulu, HI USA
June 24–27, 2001

prepared by
SOLID STATE DIVISION
OAK RIDGE NATIONAL LABORATORY
Managed by
UT- BATTELLE, LLC
under
Contract No. DE-AC05-00OR22725
with the
U.S. DEPARTMENT OF ENERGY
Oak Ridge, Tennessee

April, 01

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ABSTRACT

Epitaxial, *conductive-oxide* buffer layers having *bilayer* configurations have been deposited on biaxially textured nickel substrates (RABiTS) by *rf* and *dc*-sputter techniques. The conductive bilayer structures comprise the layer sequences of $SrRuO_3/LaNiO_3/Ni$ and $SrRuO_3/Cu/Ni$. Systematic property characterizations of the buffer layers showed excellent electrical and structural properties. High-quality epitaxial $YBa_2Cu_3O_{7-\delta}$ (YBCO) films grown by pulsed-laser deposition on these structures exhibited critical current densities (J_c) as high as $1.3x10^6$ A/cm^2 at 77 K in self-field.

INTRODUCTION

Coated conductor applications in power technologies may require stabilization of the high-temperature superconductor (HTS) coating against thermal runaway. Conductive buffer layers can electrically couple the HTS layer to the underlying metal substrate, and consequently provide stability in the event of an overcurrent situation. For fabrication approaches that utilize high-conductivity metal tapes, development of a conductive buffer structure for coated conductors is a central issue.

Thin films of the conductive-oxides, $SrRuO_3$ (SRO) and $LaNiO_3$ (LNO) have good lattice match with HTS's which makes it possible to develop heterostructures. [1-4]. Both SRO and LNO are perovskite-type, conductive metallic oxides with pseudocubic lattice parameters of 3.96 Å and 3.86 Å and with room temperature resistivities around 300 μΩ cm and 600 μΩ cm, respectively. High-quality epitaxial YBCO thin films having high T_c=91 K and J_c=$2x10^6$ A/cm^2 at 77 K can be grown on SRO-buffered single-crystal substrates [1,2]; however, there have been no reports on the successful growth of SRO layers on textured metals for the development of coated conductors. Since, we previously showed that highly textured LNO layers can be deposited onto Ni tapes [5], we have studied the combination of SRO-LNO multilayers as a possible conductive buffer layer structure for YBCO-based coated conductors. In addition we report new approaches, such as growth of SRO films on Cu buffered textured Ni substrates, as an alternative conductive buffer layer structure.

EXPERIMENTAL APPROACH

Biaxially textured Ni substrates were obtained from randomly oriented high purity (99.99%) Ni bars, which are first mechanically deformed by cold rolling and then annealed in vacuum at 1000 °C for 1 hour to obtain the desired (100) cube texture. The thickness and the width of the textured-Ni substrates used in this study were 50 μm and 5 mm, respectively. The *dc*-magnetron sputtering method was used for the growth of Cu buffers on textured-Ni substrates. During Cu deposition, the chamber pressure was kept at 3 mTorr of forming gas (96%Ar + 4%H_2) with substrate temperature in the range of 550-600 °C. The deposition rate was ≈8 Å/sec, with the corresponding film thickness of 1μm. The *rf*-magnetron sputtering technique was used for the deposition of both base LNO and the top SRO layers. Growth of LNO was accomplished at substrate temperatures ranging from 450-500 °C. Forming gas was used at the initial stages of LNO growth (≈ 2-3 min), followed by deposition in oxidizing conditions at a total pressure of 10 mTorr. The partial pressure of O_2 was varied in the range of 0.1-1 mTorr. Subsequent SRO deposition on LNO/Ni and Cu/Ni substrates were conducted at substrate temperatures ranging from 600-700 °C under 10 mTorr of Ar. The deposition rate of both SRO and LNO was ≈0.4-0.5 Å/sec and typical film thicknesses were 200-300 nm.

The PLD technique was employed for deposition of the YBCO films, where the buffered substrates were kept at 780 °C in the presence of an O_2 pressure around 120 mTorr. After deposition, the samples were first cooled to 600 °C at a rate of 5 °C/min; then the O_2 pressure was increased to 550 Torr, and the samples cooled to room temperature at the same rate. Typical film thicknesses of YBCO coatings were 200 nm.

RESULTS AND DISCUSSION

Conductive $SrRuO_3/LaNiO_3$ Bilayers on Textured Ni Tapes

An XRD θ-2θ spectrum for a typical YBCO film on a SRO/LNO/Ni multilayer structure is shown in Fig. 1a. The pattern indicates only (00*l*) reflections from both the YBCO and SRO layers, demonstrating the presence of c-axis aligned films. The LNO(002) reflection can be seen as a shoulder in the vicinity of YBCO(006) peak from the enlargement of the boxed region, as shown in Fig. 1b. The XRD out-of-plane (ω-rocking curve) and in-plane (ϕ-scan) measurements on YBCO/SRO/LNO/Ni revealed that all oxide layers closely replicate the texture of the Ni substrate.

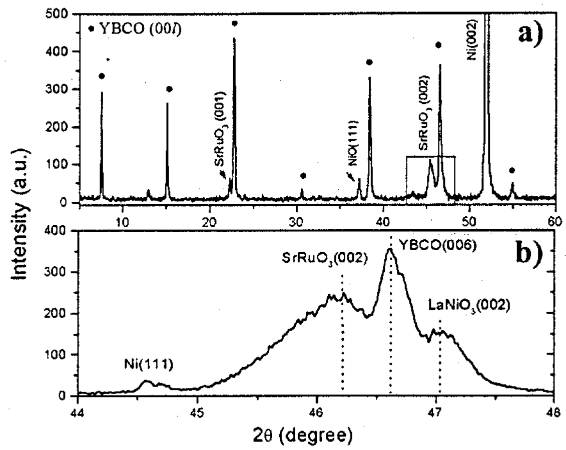

Fig. 1 XRD θ-2θ scan for (a) YBCO/SRO/LNO/Ni multilayer. YBCO (00*l*) peaks are indicated by (•). (b) Shows the LNO (002) diffraction peak from the enlargement of the boxed region of (a).

The magnetic field dependence of transport critical current density (J_c) at 77 K for the same YBCO film is shown in Fig 2. Shown also for comparison are the J_c dependence for epitaxial YBCO films on STO, on SRO/LNO buffered LAO, and on a standard insulating-oxide RABiTS architecture of $CeO_2/YSZ/CeO_2/Ni$. Data for an optimized Bi-2223/Ag PIT sample is also included. The superconducting transition temperature of YBCO/SRO/LNO/Ni is 90 K.

At zero-applied field YBCO film exhibits a J_c value of 1.25×10^6 A/cm^2, with an irreversibility field (H_{irr}) of 7.5 T. As evident from the figure, this J_c performance is comparable to that of epitaxial YBCO films on single crystal STO, SRO/LNO buffered LAO and $CeO_2/YSZ/CeO_2$ buffered Ni substrates,

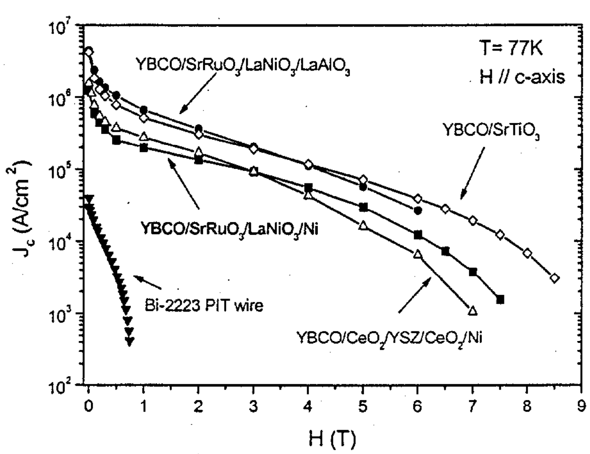

Fig. 2 Magnetic field dependence of J_c, measured at 77 K, for a YBCO film on conducting buffer structure of SRO/LNO/Ni. Data is compared with several other systems.

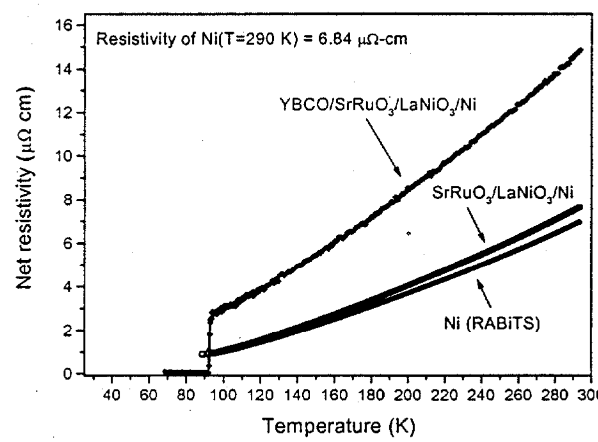

Fig. 3 Temperature dependence of resistivity of the YBCO/SRO/LNO/Ni sample shown in Fig. 2. Also shown for comparison are ρ-T data for as-made SRO/LNO/Ni and for pure Ni substrate.

and is far superior to that of optimum quality Bi-2223/PIT wire. Temperature dependent resistivity curves and electrical coupling between layers of YBCO/SRO/LNO/Ni is displayed in Fig.3. The net resistivity (ρ_{net}) is calculated from the thickness of the conductive structure (YBCO + conductive-buffers + Ni substrate). We have observed a somewhat degraded metallic conductivity for the YBCO/SRO/LNO/Ni, as evidenced by the relative increase in the ρ_{net} compared to the SRO/LNO/Ni structure. This increase is attributed to the observation of NiO (see Fig. 1) after YBCO deposition. From thermodynamic considerations, it has been found that NiO is more stable than either SRO or LNO. Nevertheless, experimentally there remains good metallic conductivity between the YBCO/SRO/LNO and the Ni substrate.

Conductive $SrRuO_3$/Cu Bilayers on Textured Ni Tape

Typical XRD θ-2θ scan for a Cu buffer layer on Ni is shown in Fig. 4. It is clear that the Cu film has an excellent c-axis orientation. There is no indication for the presence of either NiO or CuO. Texture analysis of Cu layers showed similar in-plane and out-of-plane FWHM values as those of Ni. Subsequent deposition of SRO layers on these Cu/Ni substrates also yielded c-axis oriented films. To assess the electrical coupling among layers of SRO/Cu/Ni, as a potential for conductive interface, four-terminal ρ-T measurements were carried out. The results are plotted in Fig. 5. For comparison data for Cu/Ni, as well as data for biaxially textured Ni is included. The fact that ρ_{net}-T behavior of the SRO/Cu/Ni multilayer is similar to those of the Cu/Ni and pure Ni substrate, is an indication of excellent electrical coupling among all three layers. Efforts are underway to grow epitaxial YBCO coatings on these SRO/Cu buffered Ni-tapes.

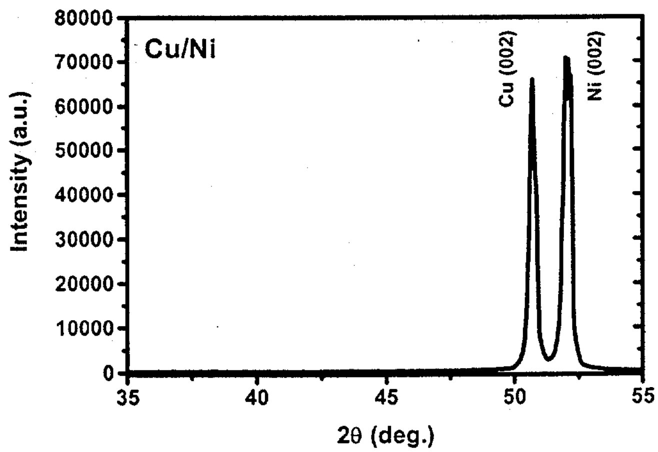

Fig. 4 An XRD θ-2θ spectrum for a 1 μm Cu on biaxially textured Ni substrates.

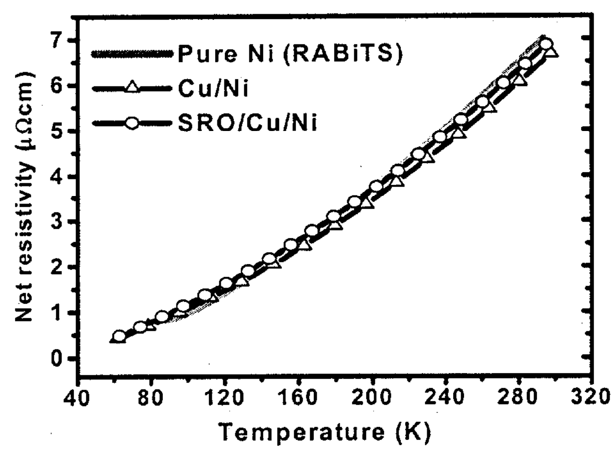

Fig. 5 Temperature dependent resistivities of SRO/Cu/Ni, Cu/Ni and pure Ni substrates.

ACKNOWLEDGMENT

This work was supported by the U.S. Department of Energy, Office of Power Technologies-Superconductivity Program, Office of EE and RE. The research was performed at ORNL, managed by U.T.-Battelle, LLC for the USDOE under Contract No. DE-AC05-00OR22725.

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