Reduced microwave losses of $YBa_2Cu_3O_{7-\delta}$ thin films on electro-optic $LiNbO_3$ crystals

L. Fàbrega,[a] R. Rubí, and J. Fontcuberta
Institut de Ciència de Materials de Barcelona (CSIC), Campus de la UAB, 08193 Bellaterra, Spain

F. Sánchez, C. Ferrater, M. V. García-Cuenca, and M. Varela
Dipartmento Física Aplicada i Òptica, Universitat de Barcelona, Diagonal 647, 08028 Barcelona, Spain

C. Collado, J. Mateu, O. Menendez, and J. M. O'Callaghan
Dipartmento Teoria del Senyal i Comunicacions, Campus Nord UPC, Jordi Girona 1-3, 08034 Barcelona, Spain

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We report on the growth of epitaxial $YBa_2Cu_3O_7$ thin films on X-cut $LiNbO_3$ single crystals. The use of double CeO_2/YSZ buffer layers allows a single in-plane orientation of $YBa_2Cu_3O_7$, and results in superior superconducting properties. In particular, surface resistance R_s values of 1.4 mΩ have been measured at 8 GHz and 65 K. The attainment of such low values of R_s constitutes a key step toward the incorporation of high T_c materials as electrodes in photonic and acoustic devices. © *2002 American Institute of Physics.* [DOI: 10.1063/1.1515372]

$LiNbO_3$ (LNO) is an essential element of many electronic components, such as electro-optical modulators and surface acoustic wave devices,[1,2] due to its excellent ferroelectric and electro-optic properties. In most of these devices, a radiofrequency (rf) field is applied by using metal electrodes, in order to suitably modify the mechanical, optical, or electrical properties of LNO. If the metal electrodes are substituted by superconductors, the performances of the devices would be significantly improved. It has been predicted[3] that an enhancement of the bandwidth, operating speed, and electrode efficiency are to be expected, due to the much lower surface resistance of superconducting materials. For such a purpose, the growth of epitaxial thin films of high temperature superconductors (HTSs) on LNO crystals, with high critical current and low rf losses, is necessary.

The growth of high quality epitaxial $YBa_2Cu_3O_{7-\delta}$ (YBCO) films on LNO crystals is a difficult problem, due to the poor structural matching of both materials, and to the unstability of the LNO surface at the high temperature and low pressure required for the epitaxial growth of HTS materials. There have been several reports of YBCO films grown on LNO, most of them using buffer layers.[4–9] Usually, the microstructure and superconducting properties of these films are rather poor, due to the mentioned growth problems. Their rf properties have been scarcely studied, in spite of being a crucial parameter to evaluate the potential applications of these films; there is only one report of surface resistance measurements: high values of 450 mΩ at 18 GHz and 70 K were measured in Ref. 8 for YBCO films grown on LNO with several buffer layers. Therefore, in spite of the promising potentiality[1–3] for improving performances of electro-optic devices, several problems related to materials properties have hampered the implementation of HTS in such devices.

In a previous work,[7] we reported the growth and properties of epitaxial YBCO films grown on X-cut LNO crystals by rf magnetron sputtering, using yttria-stabilized zirconia (YSZ) buffer layers. Below the superconducting transition, resonators made with these films displayed quality factors 2.8 times larger than those of equivalent Au resonators at 7 GHz and 55 K.[3] However, (001) YBCO thin films grown on YSZ usually display two in-plane orientations, forming 45° grain boundaries which set a limit to the superconducting performances of the films.

In this communication we report on the superconducting and rf properties of improved YBCO films, grown on CeO_2/YSZ buffer layers. The additional CeO_2 layer has been used to overcome the above mentioned difficulty; it allows a single in-plane orientation of YBCO films, and consequently better superconducting properties are obtained. Their high critical current and low surface resistance values make them very promising candidates to substitute Au electrodes in several electro-optic and electroacoustic devices operating at liquid nitrogen temperatures.

Epitaxial YBCO/CeO_2/YSZ heterostructures were grown on X-cut LNO crystals by pulsed laser deposition using a KrF excimer laser. The total thickness of the double buffer was about 110 nm; YBCO films with thickness t between 95 and 380 nm were studied. Details on the growth conditions and structural characterization may be found elsewhere.[10] X-ray diffraction patterns reveal the high quality of the buffer and superconducting layers. Specially, the ϕ scans (Fig. 1) indicate that YBCO grows epitaxially, with a single in-plane orientation.

YBCO films display good transport properties, with a resistance ratio $R(300\ \mathrm{K})/R(100\ \mathrm{K})$ of 2.8, as it may be seen in the inset on Fig. 2. The typical transition width is below 1.5 K, and zero resistance is attained usually above 85 K.

Hysteresis cycles ($5\ \mathrm{K} \leq T \leq 77\ \mathrm{K}$) were recorded with a superconducting quantum interference device magnetometer,

[a]Electronic mail: lourdes@icmab.es

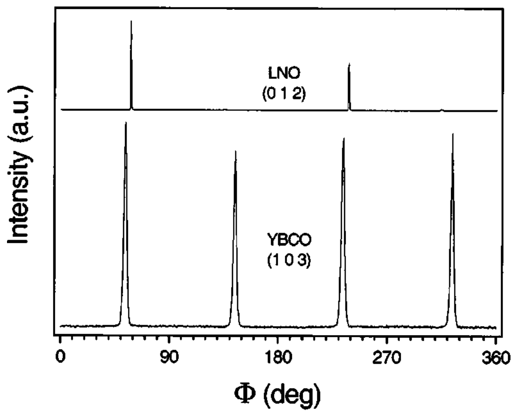

FIG. 1. ϕ scan of the (103) peak of YBCO corresponding to a YBCO/CeO_2/YSZ heterostructure grown on X-cut LNO; the scan of the (012) peak of LNO is also shown.

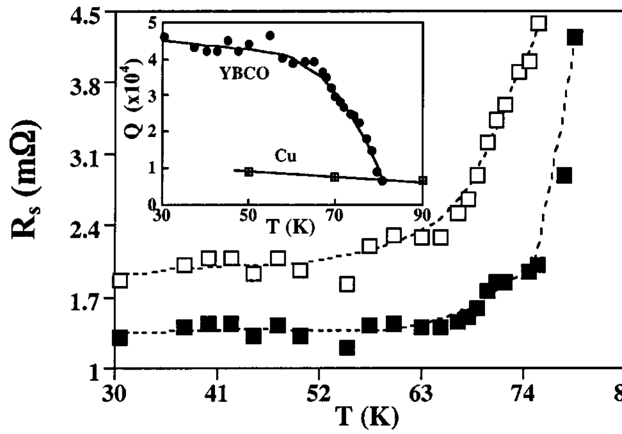

FIG. 3. Surface resistance at 8 GHz of the YBCO films, after correcting for dielectric loss of the rutile (open squares), and after a further correction, for finite film thickness (full squares). The lines are guides for the eye. Inset: Temperature dependence of the Q factor at 8 GHz for resonators with a YBCO/CeO_2/YSZ heteroestructure and with Cu.

and the critical current J_c was calculated using the critical state model. J_c is found to decay exponentially with magnetic field, as commonly reported in YBCO films.[11] Figure 2 shows the field dependence of J_c measured at 77 K, for three YBCO thicknesses. As expected, J_c of the thinner film (t $=95$ nm) displays higher values, likely due to changes in the microstructure of the films; Atomic force microscopy analyses reveal indeed a surface degradation as t increases. Thicker films display lower J_c values, weakly dependent on thickness; rf measurements described below were performed on the thicker films, since $t>\lambda$ is required.

At 5 K and zero field, J_c of the 95 nm film reaches 6×10^6 A/cm^2. This value is nearly 1 order of magnitude better than those reported for YBCO films grown directly on LNO,[6] and only a factor of 5 lower than those of optimal thin films grown on $SrTiO_3$ single crystals.[11] Low field J_c values of 3×10^5 A/cm^2 are obtained at 77 K; these are nearly 1 order of magnitude lower than those of films on $SrTiO_3$. Typical values of 2×10^5 A/cm^2 have been reported at 77 K, also from inductive measurements, for YBCO films grown on Y-cut LNO both by pulsed laser deposition and sputtering.[4,6] Only Tiwari *et al.* reported a higher value, J_c $>10^6$ A/cm^2, from transport measurements.[5]

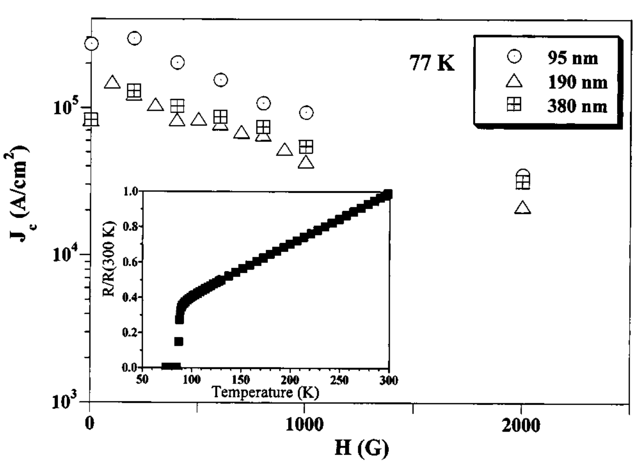

FIG. 2. Field dependence of the critical current measured at 77 K, for heterostructures with three different YBCO thicknesses (95, 190, and 380 nm). (Inset) Resistance transition of a 270 nm YBCO film.

The rf losses of the films were measured with a rutile-loaded cavity, following the procedure described in Ref. 12, with two heterostructures grown on 10×10 mm^2 LNO crystals, with YBCO thickness of 230 nm. This resonator was chosen—instead of the coplanar one used in Ref. 3—to avoid the contribution of the dielectric losses of LNO and the buffer layers. The inset in Fig. 3 displays the unloaded quality factor Q as a function of temperature. At 65 K, the resonant frequency is 8 GHz and $Q=3.7\times10^4$; this is 4.7 times better than that of an identical Cu resonator at the same temperature. Additionally, measurements have been performed on two 700 nm thick YBCO films grown on MgO by a commercial supplier to assure that, when measuring our samples, Q is dominated by the surface resistance of the YBCO and not by the dielectric loss of the rutile. Taking into account the rutile losses,[13] the measured R_s at 65 K becomes 2.3 mΩ. After correction for the finite thickness of the film, using the procedure described in Ref. 14 and assuming a temperature-dependent penetration depth with $\lambda_L(0)$ $=150$ nm,[15] the value of R_s is reduced to 1.4 mΩ (see Fig. 3). The actual R_s might be even lower, since the penetration depth can be expected to be longer, and thus the finite thickness correction would be more important. On the other hand, to rule out a significant nonlinear behavior of the rf loss in our films, we have measured the quality factor of the resonator in a 30 dB range of the source power (from -16 to 14 dB m) at 60 and 70 K and found no significant changes.[16]

We emphasize that the R_s value of our films is nearly 2 orders of magnitude lower than the previously reported one for YBCO films grown on LNO,[8] and only a factor of 4–10 higher than the R_s values of the best YBCO films grown on $LaAlO_3$.

In conclusion, we have demonstrated the epitaxial growth of high quality epitaxial YBCO thin films on X-cut LNO substrates using a double CeO_2/YSZ buffer layer. The good properties of the films, with critical currents above 3×10^5 A/cm^2 at 77 K and surface resistance of 1.4 mΩ at 65

K and 8 GHz, are extremely encouraging in order to improve the performances of LNO-based devices by using them as substitutes of metallic electrodes, operating at cryogenic temperatures. More precisely, the *X* cut of LNO crystals, used in this work, is suitable for some photonic components like electro-optical modulators, and thus the here reported results constitute a key step toward the integration of HTS in these devices.

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