Improvement of the conducting parameters of $YBa_2Cu_3O_x$ films grown on sapphire through the use of a strontium titanate buffer layer

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High-T_c superconducting films of $YBa_2Cu_3O_x$ on sapphire with an additional buffer layer of strontium titanate (actually, on heterostructures $(100)SrTiO_3/(001)YBa_2Cu_3O_x/(100)CeO_2/(1\bar{1}02)Al_2O_3$) are obtained by laser deposition, and their superconducting characteristics are investigated. It is shown that that buffering the sapphire by a strontium titanate film can raise the critical temperature of the $YBa_2Cu_3O_x$ films by two degrees and give a severalfold increase in the critical current density. © *1998 American Institute of Physics.* [S1063-7850(98)00509-6]

Strontium titanate $SrTiO_3$ (STO) is one of the best substrate materials for growing epitaxial high-T_c superconducting (HTSC) films. It has a cubic crystal lattice of the perovskite type with a lattice parameter $a=0.3904$ nm that is only slightly ($<2.5\%$) different from the lattice constants a and b of the basal plane of the HTSC $YBa_2Cu_3O_x$ (YBCO). The coefficient of linear thermal expansion of STO ($9.4\times10^{-6}\,K^{-1}$) is also close to that of YBCO ($12\times10^{-6}\,K^{-1}$). The shortcomings of STO — its high dielectric constant and high microwave losses — limit its use in microwave technique. For such purposes sapphire and silicon are more suitable substrate materials, and they are considerably cheaper as well. When these materials are used, however, it is necessary to employ guard sublayers to prevent the diffusion of atoms of the substrate into the growing HTSC film. One of the most often used materials for a guard sublayer in the deposition of YBCO films on sapphire substrates is cerium oxide CeO_2, which has a cubic crystal lattice (of the fluorite type) with a lattice parameter $a=0.541$ nm, differing by less than 1% from a translation along the [110] direction of YBCO. It has been shown (see, e.g., Refs. 1–4) that by using a $(1\bar{1}02)Al_2O_3$ (r plane) substrate with a thin (30–50 nm) epitaxial sublayer of CeO_2 one can grow epitaxial films of (001)YBCO with good structural and electrophysical parameters at temperatures of 700–770 °C. However, increasing the deposition temperature above 800 °C to permit the growth of the highest-quality films on STO substrates causes the properties of the YBCO film to be degraded on account of the chemical interaction between the HTSC film and the CeO_2 guard sublayer.[3] To prevent this interaction it has been proposed[5,6] to use an additional buffer layer of STO. In the present study we have obtained YBCO films on sapphire with an additional buffer layer of STO and have investigated their superconducting characteristics. We have found that buffering the sapphire by an STO film can raise the critical temperature of YBCO films by two degrees and can increase the critical current density severalfold.

The YBCO, CeO_2, and STO films were deposited using a KrF excimer laser (output wavelength 248 nm) with an energy at the target of up to 3 J/cm^2. The pressure in the chamber was maintained constant in the interval 0.03–1 mbar, depending on the material being deposited. The substrate lay at a distance of 50 mm from the target on a heated susceptor, the temperature of which was held constant during the deposition to a precision of 1 °C in the range 750–900 °C. To improve the thermal contact with the heater the substrate was fastened to the susceptor with silver paste. At the end of the deposition the chamber was filled with oxygen to a pressure of 800 mbar and the substrate was cooled to room temperature at a rate of 15 °C/min. The thickness of the deposited films was 20–60 nm for the buffer layers and 120–200 nm for the YBCO film.

The structure of the grown films was investigated by x-ray diffractometry ($\theta/2\theta$ scan). The superconducting parameters of the YBCO films (the critical temperature T_c and the superconducting transition width ΔT_c) were determined from measurements of the magnetic susceptibility of the films and of the temperature dependence of the resistance and critical current of bridges 4–8 μm wide, obtained by ion-beam etching of the YBCO films through a photoresist mask.

Figure 1a shows the diffractograms obtained in a $\theta/2\theta$ scan of a CeO_2/STO buffer layer with a thickness of 430 nm (30+400) on an r-oriented sapphire substrate. The CeO_2 had the (001) orientation; no other orientations were observed at the accuracy of the measurements. The upper STO layer, however, grows in a mixed orientation of (110) and (111). Although the growth of STO films with a predominant (001) orientation on a CeO_2/Al_2O_3 heterostructure was reported in Ref. 7, the authors of that paper did not manage to eliminate the growth of extraneous (110) and (111) orientations of STO. It may be that the disruption of epitaxial

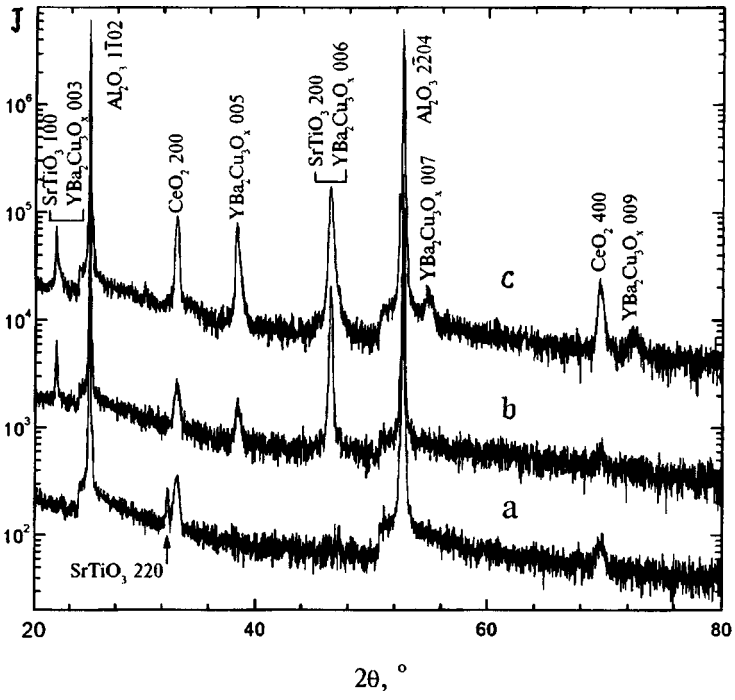

FIG. 1. X-ray diffractograms obtained in a $\theta/2\theta$ scan of the following heterostructures: a — STO-400/CeO_2-30/Al_2O_3; b — STO-200/YBCO-50/CeO_2-30/Al_2O_3; c — YBCO-150/STO-60/YBCO-20/CeO_2-30/Al_2O_3 (the number after the name of the compound is the layer thickness in nm).

growth of STO on CeO_2/Al_2O_3 is caused by the chemical interaction of STO with CeO_2 (Ref. 5). In several studies[5,6] additional buffer layers have been used to ensure growth of the (001) orientation of STO. Here we have used for this purpose a thin (30 nm) layer of YBCO.

Figure 1b shows the diffractograms obtained in a $\theta/2\theta$ scan of a STO/YBCO/CeO_2/Al_2O_3 heterostructure with a thick upper layer of STO. In addition to the (00n) peaks of CeO_2 one observes a pronounced system of (00m) peaks of STO, the (002) peak of which is merged with the (006) peak of YBCO. The main contribution to the intensity of that reflection is from the STO, since the thickness of the STO film is substantially greater. A three-layer buffer of this type with a 50 nm thickness of the STO layer was used for the deposition of YBCO films 100–200 nm thick on sapphire. An x-ray diffractogram of the entire heterostructure with an upper layer of YBCO film is shown in Fig. 1c. The lattice constants and half-widths of the most interesting reflections for all the layers of the heterostructure are given in Table I.

The critical temperatures T_c of the superconducting transition of nine of the ten YBCO films deposited on an STO buffer layer lay in the interval 89–90 K, while, as a rule, the

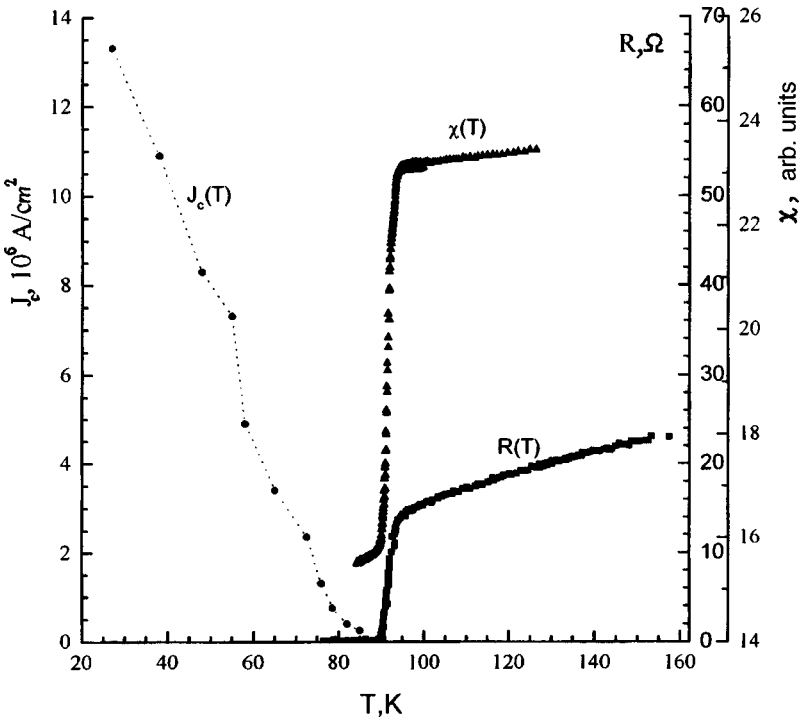

FIG. 2. Temperature dependence of the magnetic susceptibility of a YBCO film on an STO/YBCO/CeO_2/Al_2O_3 heterostructure and of the resistance and critical current of a bridge 7 μm wide made from the same film.

TABLE I. Crystallographic parameters of the films, determined from the x-ray diffractograms obtained in a $\theta/2\theta$ scan.

Film material	Film thickness, nm	Index of reflection	Lattice parameter, nm	Half-width of reflection, deg
CeO_2	30	(002)	0.504	0.37
YBCO*	50	(005)	1.171	0.47
STO*	200	(002)	0.391	0.23
YBCO	150	(005)	1.173	0.28

*The parameters of the YBCO and STO buffer layers were determined in a separate experiment.

critical temperature for films deposited on CeO_2 have not exceeded 88 K.[2,3] Figure 2 shows the dependence of the magnetic susceptibility of YBCO films 120 nm thick and the superconducting parameters (resistance and critical current) of a bridge 7 μm wide made from the same film by ion-beam etching through a photoresist mask. It is seen that the critical temperature of the entire film, as determined from the magnetic measurements ($T_{cm}=88.0$ K), is somewhat lower than the value ($T_{c0}=89.6$ K) determined from the condition of zero resistance of a bridge 7 μm wide. The difference of these temperatures, $T_{cm}-T_{c0}=1.6$ K, together with the width of the resistive superconducting transition $\Delta T_c=2.8$ K, defined as the temperature interval between the 0.9 and 0.1 levels of the resistance of the bridge for $T>T_c$, can serve as a measure of the nonuniformity of the superconducting parameters of the film over the area of the substrate. The superconducting critical current density j_c has a value of 2×10^6 A/cm^2 at liquid-nitrogen temperature and increases almost linearly with decreasing temperature, reaching a value of 1.4×10^7 A/cm^2 at liquid-helium temperature (Fig. 2). We note that in the case of a single-layer CeO_2 buffer on sapphire, j_c was equal to 10^6 A/cm^2 at $T=77$ K.

Thus we have shown experimentally that the use of a complex buffer with an upper layer of strontium titanate makes it possible to grow epitaxial films of the HTSC YBCO of higher quality than can be grown on a single buffer layer of cerium oxide. The proposed method can be used in the growth of HTSC films of YBCO for passive microwave electronics (filters, resonators, switches, etc.). By varying the thicknesses and deposition conditions of the buffer layers — in particular, by depleting the STO of oxygen to lower its dielectric constant[8] — one can regulate the parameters of microwave devices on sapphire.

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