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YBCO/manganite layered structures on $NdGaO_3$ substrates

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Abstract. Results of deposition of $YBa_2Cu_3O_{7-x}/CeO_2/$($La_{0.7}Ca_{0.3}MnO_3$ or $La_{0.7}Sr_{0.3}MnO_3$) structures on the standard oriented and tilted (= 8°) $NdGaO_3$ substrates and results of investigation of electrical parameters of $YBa_2Cu_3O_{7-x}$ (YBCO) films in such structures are presented. The YBCO component of the structure exhibits lower value of the critical parameters in comparison with those of single YBCO films. The contribution of the magnetic layer to the microwave losses of the YBCO film in the layered structure is evaluated.

1. Introduction

High temperature superconducting (HTS) $YBa_2Cu_3O_{7-x}$ (YBCO) and magnetic $La_{0.7}Ca_{0.3}MnO_3$ (LCMO) $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) are oxide materials, which are characterized by compatible crystalline structures and original physical properties [1,2]. Multilayers of HTS YBCO and magnetic manganese LCMO and LSMO oxides have recently attracted much attention because of their specific physical characteristics originating from the individual layers and the interlayer interaction. Fabrication and investigation of multilayer structures is a complex procedure and the experiments were made mainly for the cases of standard substrates and low frequency region [3,4].

In this paper we report results of deposition of YBCO/CeO_2/(LCMO or LSMO) structures on standard oriented and tilted $NdGaO_3$ substrates and investigation of main electrical characteristics of the YBCO film in these structures.

2. Experimental

Bottom $La_{0.7}Ca_{0.3}MnO_3$ (or $La_{0.7}Sr_{0.3}MnO_3$) films with a thickness ~240 nm were deposited on $NdGaO_3$ substrates (5-mm x 5-mm x 0.5 mm) using RF magnetron sputtering technique in off-axis geometry. The substrate surface was tilted (around the [001] axis) from the (110) plane of $NdGaO_3$ crystal and one of the substrate edges was perpendicular to the tilt axis. A ~100 nm thick CeO_2 buffer layer was deposited on the top of the LCMO (or LSMO) film and an YBCO film with the thickness of ~560 nm was grown on this buffer layer by laser ablation technique. Sample 1 consisted of

$YBCO/CeO_2/LCMO$ structure grown on standard $NdGaO_3$ substrate and samples 2, 3 consisted of $YBCO/CeO_2/LSMO$ and $YBCO/CeO_2/LCMO$ structures grown on tilted (= 8°, is the tilt angle) $NdGaO_3$ substrates, respectively. A single layer YBCO film (sample 4) was grown on a standard $NdGaO_3$ substrate as well. The edge areas of the top superconducting films were removed before the measurements, so the dimensions of YBCO film component were 4-mm x 4-mm in all samples.

The YBCO film resistance for directions, parallel and perpendicular to the step edges of the tilted substrates (*L*- and *T*- directions, respectively), was measured at 295 K by four - probe method. Critical temperature T_C and critical current density J_C were determined from investigation of AC screening properties of the samples placed between small drive and receive coils. Magnetic moment of the samples films was measured in magnetic field applied perpendicularly to the film surface. Effective surface resistance R_S was determined at ~8 GHz from measurements of the quality factor of a test microstrip resonator, containing a copper ground plane, a $LaAlO_3$ dielectric spacer and the test film, which served as a microstrip electrode. The films were measured twice when the microwave current direction were parallel to the *L*- and *T*- directions of the sample [5], and effective values R_{SL}, R_{ST} of the surface resistance were determined for these two directions. Measurements were performed at 77 K.

3. Results and Discussion

Temperature dependences of receive coil signal, which reflects AC screening ability of the layered structures, are shown in figure 1. It should be noted, that a contribution of LCMO (or LSMO) films to the screening ability of the structure is small (because of small thickness of the magnetic films and because of the fact that their magnetic moments are oriented parallel to the film surface). Therefore the dependences presented in figure 1 describe the screening properties of YBCO films in the structure. The critical temperatures T_C of these films are close to those of the standard YBCO films, although a small second step of the superconductive transition is observed at lower temperatures.

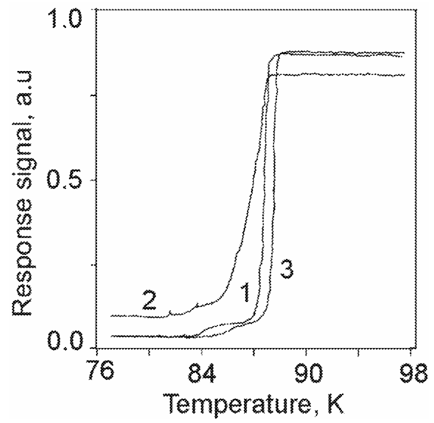

Figure 1. Temperature dependences of AC responses of layered structures 1-3 (curves 1-3, respectively) measured at 77 K.

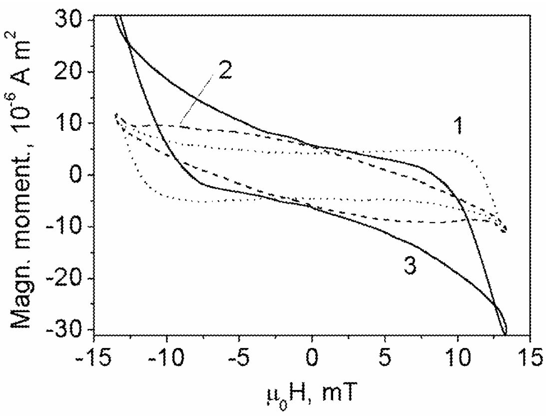

Figure 2. Hysteresis loops of samples 1-3 (curves 1-3, respectively) measured in perpendicular magnetic field at 77 K.

Dependences of the magnetic moments of the samples on the external magnetic field *H* (or hysteresis loops) measured at 77 K in a perpendicular geometry, are presented in figures 2 and 3. The magnetic moment is due to the screening current flowing in the YBCO film. According to the estimations, the perpendicular component of the magnetic moment of LCMO and LSMO films at $\mu_0 H$< 15 mT is small (<10^{-7} A m^2) and does not affect noticeably the behaviour of the hysteresis loops. Critical current densities calculated from the magnetic moments were J_C~ 10^5 A/cm^2 at H=0 for samples 1-3 and

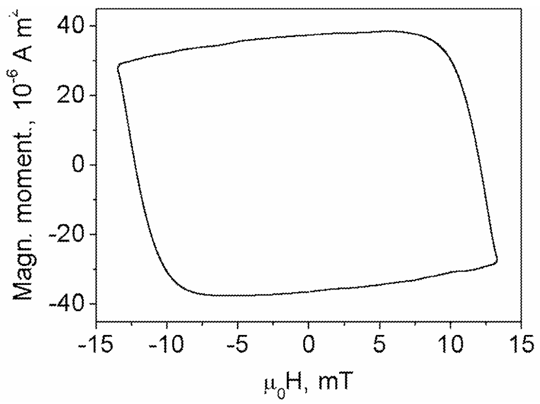

Figure 3. Hysteresis loop of a single YBCO layer (sample 4) deposited on a standard $NdGaO_3$ substrate, $T = 77$ K.

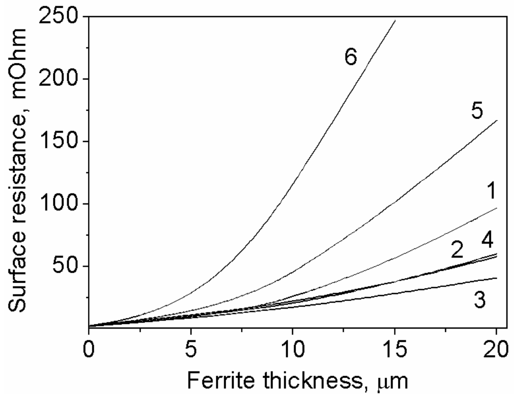

Figure 4. Dependence of the surface resistance of a layered structure on the magnetic layer thickness, calculated from formula (1).

J_C~ 7 10^5 A/cm^2 for the single YBCO film (Fig.3). There was some difference between the values of J_C obtained from the screening data: J_C was higher for sample 3 (YBCO/CeO_2/LCMO) and lower for sample 2 (YBCO/CeO_2/LSMO) prepared on tilted substrates. In fact, such a difference between the electrical characteristics of the samples can be seen in Fig.1 as well, and the sample 3, which is characterized with higher T_C, can be considered as the best one.

Normal state resistances $R_{L,T}$ of YBCO films measured at 295 K were smaller for L- direction: R_L = 6.9 •, R_T =7.9 • (sample 2) and R_L =4.1 •, R_T= 4.9 • (sample 3). No anisotropy of R was observed in sample 1 (R=3.9 •) grown on a standard substrate. It can be assumed that the anisotropy of the top YBCO layers was induced by the tilted substrate. Normal resistance of YBCO film is higher in sample 2 (YBCO/CeO2/LSMO) than in sample 3. This can not be explained by the magnetic layer effect (there was not a direct electrical contact between the HTS and manganite layers in the structures) but by the quality of the surfaces of the buffer CeO_2 layers. It is well known, that the resistivity of YBCO films significantly depends on the substrate parameters [6]. Therefore, it can be assumed, that in our experiments the quality of CeO_2 buffer deposited on LCMO was better than that of CeO_2 deposited on LSMO.

The layered structures were characterized with relatively high values of the surface resistance at 8 GHz and at T=77 K: R_S=0.05 • (sample 1); R_{SL}, R_{ST}> 0.15 • (sample 2); R_{SL}=0.061 •, R_{ST}=0.069 • (sample 3). The typical values of the R_S were several m• for the single YBCO films grown on $NdGaO_3$ substrates. The surface resistance characterizes the total microwave losses of the layered structures and includes the losses of magnetic nature and the losses caused by the microwave currents in the magnetic and superconducting layers.

In order to estimate the contribution of a magnetic layer to the total microwave losses, the surface impedance of our layered structure was modeled using the impedance transformation rule. For this purpose the n-th layer was considered as a transmission line with the characteristic impedance Z_n loaded to the effective surface impedance Z_{en-1} of n-1 th layer. The effective surface impedance Z_{en} of the n-th layer is equal to the input impedance of this transmission line and can be determined using the following formula:

$$Z_{en} = Z_n \frac{Z_{en-1} + Z_n th(jk_n d_n)}{Z_n + Z_{en-1} th(jk_n d_n)} \qquad (1)$$

where $j^2 = -1$; $Z_n = Z_0(\mu_{rn} / \varepsilon_{rn})^{1/2}$; $k_n = k_0(\mu_{rn}\varepsilon_{rn})^{1/2}$; $Z_0 = (\mu_0 / \varepsilon_0)^{1/2}$; $k_0 = \omega(\varepsilon_0\mu_0)^{1/2}$; μ_0 and $_0$ are the vacuum permeability and dielectric constant; is the angular frequency; $\varepsilon_{rn} = \varepsilon_{rn}$, $\varepsilon_{rn} = -j\sigma_n / (\varepsilon_0\omega)$, $\varepsilon_{rn} = -j\sigma_n / (\varepsilon_0\omega) - 1/(\omega^2\lambda^2\varepsilon_0\mu_0)$ are the relative dielectric constants for the cases of dielectric, metal and superconductor media, respectively, the relative permeability of these media is $\mu_r = 1$; $\mu_{rn} = \mu - (\mu_a^2 / \mu)$ [7] and $\varepsilon_{rn} = -j\sigma_n / (\varepsilon_0 \omega)$ in the case of a conducting magnetic layer if the external magnetic field H is applied parallel to the layer and perpendicularly to the microwave magnetic field; $\mu = 1 + \omega_H \omega_M (\omega_H^2 - \omega^2)^{-1}$; $\mu_a = \omega\omega_M / (\omega_H^2 - \omega^2)$; $\omega_H = 2\pi\gamma H + j\alpha\omega$; $\omega_M = 2\pi\gamma M$; M,   and   are the magnetization vector, the gyromagnetic ratio and a coefficient for the damping term in the magnetic layer, respectively; $_n$ is the normal conductivity of the medium;   is the London penetration depth; d_n is the thickness of n-th layer.

Some results of calculation of the surface resistance of layered structures using above formulas are presented in figure 4 for the single-domain state of the magnetic layer (magnetic field H is applied parallel to the film surface). Parameters of calculations were the following: /2 =8 GHz, =0.3 µm, R_s=2.18 m , d=0.56 µm for the superconducting layer; =10, d=0.1 µm for the dielectric buffer layer; =0.01, =2 10^5 (cm)$^{-1}$, $\mu_0 M$=25 mT (figure 4, curves 1-3) or $\mu_0 M$=30 mT (figure 4, curves 4-6) for the ferromagnetic layer; $\mu_0 H$ =5 mT (figure 4, curves 1, 4), $\mu_0 H$=25 mT (figure 4, curves 3, 5) and $\mu_0 H$=50 mT (figure 4, curves 2, 6). It can be seen that a thin manganite film (d<1 µm) does not affect significantly the surface resistance of the structures because of a low normal conductivity of this material. Therefore it can be assumed that the microwave losses in above experimental structures are not caused by the magnetic layer and could be reduced by further optimization of the technology of growing of layered structures.

4. Conclusion

Layered YBCO/CeO_2/LCMO and YBCO/CeO_2/LSMO structures were grown on the standard oriented and tilted (= 8°) $NdGaO_3$ substrates and electrical parameters of YBCO films in these structures were investigated. The YBCO component of the structures prepared on the tilted substrates exhibited anisotropy of the normal resistance and the microwave surface resistance. The critical parameters of YBCO films in the layered structures were lower in comparison with those of single YBCO films. The contribution of the magnetic layer to the microwave losses of the layered structures was evaluated.

Acknowledgments

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