SURFACE ACOUSTIC WAVE PROPAGATION IN MANGANESE OXIDE FILMS

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ABSTRACT

We present the investigations of the attenuation of surface acoustic waves (SAW) in a monolithic layered structure, composed of piezodielectric $LiNbO_3$ substrate and manganese oxide $La_{0.67}Ca_{0.33}MnO_3$ film. We measured the SAW attenuation at 30 MHz, and at higher harmonics of this frequency in a wide temperature range. The attenuation reaches a maximum at the temperature corresponding to the peak of the film resistivity, and increases with increasing SAW frequency. The applied magnetic field reduces the attenuation. The observed behavior at high temperatures, above the metal-insulator transition, can be explained by the standard theory of SAW attenuation in a conducting film. No such good theoretical fit is obtained at low temperatures, indicating that additional mechanisms of dissipation arise below the metal-insulator transition.

INTRODUCTION

The mixed-valence perovskite manganese oxides (or manganites) $R_{1-x}A_xMnO_3$, where R = La, Nd, Pr, and A = Ca, Sr, Ba, Pb, have been the subject of intense experimental and theoretical studies over the past years. These compounds attract much attention not only because they exhibit a rich variety of strongly interrelated magnetic, structural, and electronic properties, but also because of possible technical applications. These studies have shown that the properties of manganites are determined not only by double-exchange mechanism [1] but also by strong electron-phonon interaction [2] of the Jahn-Teller type. Due to the strong electron-phonon interaction, acoustical and acoustoelectrical techniques are of special interest and perspective in the studies of manganites. Such measurements yield information about relaxation processes in electronic, magnetic and lattice subsystems in the manganites, and their interrelation. Recently we have reported on the anomalous acoustoelectric effect in manganite $La_{0.67}Ca_{0.33}MnO_3$ (LCMO) films [3]. In this paper, we present the investigation of the acoustical properties of LCMO thin films. We have employed a monolithic layered structure composed of piezodielectric $LiNbO_3$ (LNO) monocrystalline substrate onto which was deposited the LCMO thin film. In our structure, charge carriers in the film were affected both by a deformation wave and a piezoelectric field, which accompany the propagating SAW. The field induces dissipative currents in the film, and results in the SAW attenuation.

EXPERIMENTAL RESULTS

The investigated LCMO films, 100 to 200 nm thick, were grown on +y -cut of LNO substrates by laser ablation technique without post-annealing. X-ray diffraction shows that the films are single phase, epitaxial and (211) oriented with the pseudocubic lattice parameter a = 0.3853 nm. Chemical composition of the films was checked by electron probe microanalysis.

Additional characterization of the films was performed by ac susceptibility and thermoelectric power measurements.

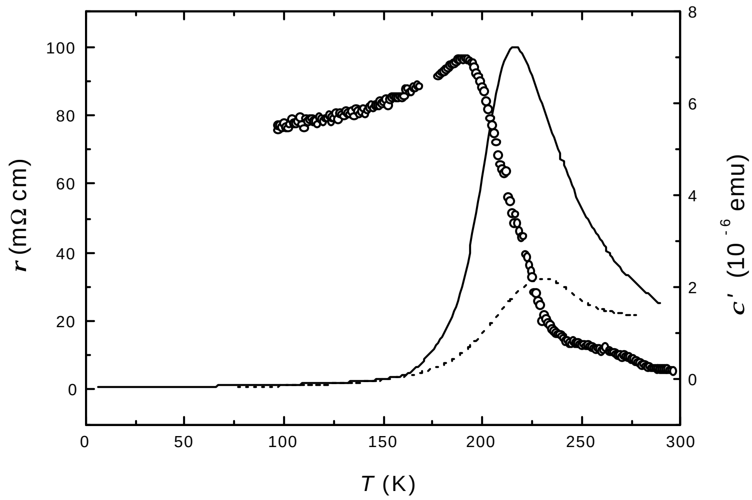

Fig. 1. Temperature dependence of the sample resistivity at H = 0 (solid line) and H = 25.5 kOe (dashed line), and ac susceptibility measured using in-plane ac magnetic field of 5 Oe at 625 kHz (open circles).

In the experiments, the SAW of the Rayleigh type was launched along the surface of LNO substrate. The SAW pulse was generated and detected by two interdigital transducers (IDT), positioned at the edges of the substrate with the LCMO film deposited centrally between them. The pulse duration was varied from 1 to 7 μs and the pulse repetition rate was kept constant at 50 Hz. The SAW attenuation has been measured at the IDT resonant frequency of 30 MHz and its higher harmonics in the linear in the SAW intensity regime.

The resistivity ρ(T) of the investigated LCMO films attains a maximum at 220 K in the vicinity of the ferromagnetic phase transition (Fig.1). An applied magnetic field H shifts the ρ(T) peak towards higher temperatures and reduces the film resistivity, resulting in the magnetoresistance effect: MR = [ρ (H)-ρ(0)]/ρ(0) ~ -80 % at 25.5 kOe.

The temperature dependence of the SAW attenuation Γ in the LCMO films, measured at H = 0 and at various frequencies, is shown in Fig.2, where symbols mark the experimental data obtained for different frequencies. At all frequencies Γ(T) demonstrates the following behavior: it is small at high and low temperatures and approaches its maximum value when the resistivity peaks. The attenuation increases with increasing SAW frequency. We analyze the observed temperature behavior in frame of the standard theory of the SAW attenuation in a layered structure composed of piezoelectric substrate and conducting film [4]. In this case, the attenuation can be described by the following equation:

$$G = \frac{2p}{l} K^2 \frac{s_0 / s_m}{1 + (s_0 / s_m)^2}, \qquad (1)$$

where K^2 is the electromechanical coupling coefficient, λ is the SAW wavelength, s_0 is the LCMO film sheet conductivity and s_m is a material constant. Assuming a frequency dependent conductivity, we calculated the attenuation from Eq.(1) and found a good agreement between the theory and our experimental data at high temperatures, above the metal-insulator transition. Our analysis indicates an approximately linear frequency dependent contribution to the conductivity in the paramagnetic region. The sheet conductivity of the LCMO film increases with increasing frequency from $2.2{\cdot}10^{-4}\ \Omega^{-1}$ at 30 MHz to $4.3{\cdot}10^{-4}\ \Omega^{-1}$ at 203 MHz, as shown in the inset in Fig.2. Such a non Drude behavior of the conductivity, as well as the temperature dependence of the

SAW attenuation, may be explained by the formation of small polarons due to the strong electron-phonon coupling.

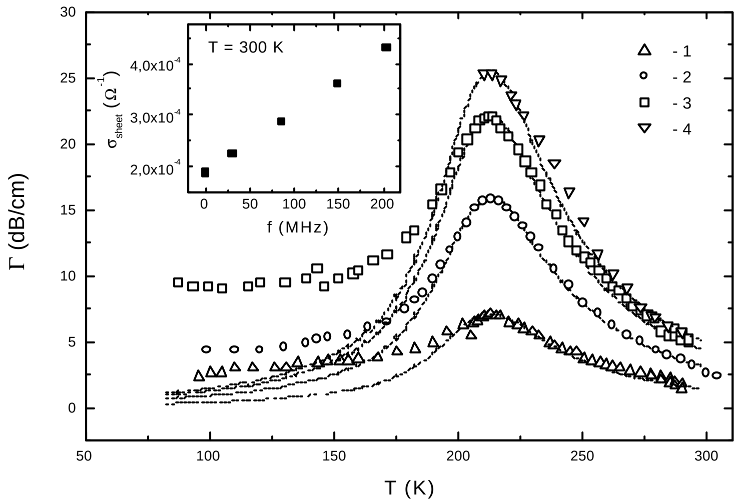

Fig. 2. SAW attenuation Γ versus temperature in the LCMO-LNO layered structure at H=0 for different frequencies: 1 - 30 MHz; 2 - 87 MHz; 3 - 150 MHz; 4 - 203 MHz. Dashed lines - the attenuation calculated from from Eq.(1). Inset: fequency dependence of the LCMO film sheet conductivity at T = 300 K.

No such good fit is obtained at low temperatures, indicating that additional mechanisms of dissipation arise below the metal-insulator transition. The deformation potential interaction, the electronic phase separation observed in manganites in the ferromagnetic phase and the Joule losses in oscillating magnetic domains are likely candidates for such mechanisms.

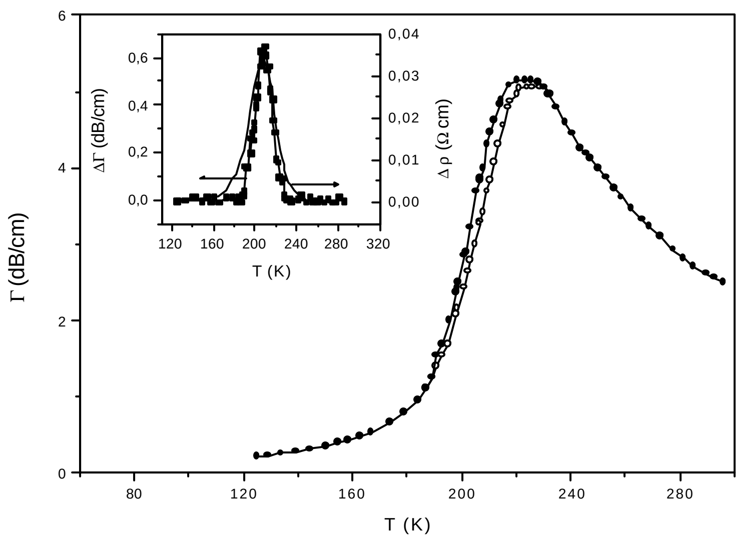

Fig. 3. SAW attenuation Γ versus temperature in the LCMO-LNO layered structure at H = 0 (solid circles) and H = 3 kOe (open circles) measured at frequency 87 MHz. Inset: the magnetoresistance effect in the LCMO film (solid line); the change of attenuation in the magnetic field (solid squares).

We also investigated the influence of the magnetic field H = 3 kOe on the SAW attenuation, and found a decrease of about 17% when H was parallel to the surface of the LCMO film (Fig.3). The decrease of the attenuation is observed only near the metal-insulator transition and correlates with the magnetoresistance effect, while at high and low temperatures the attenuation is left essentially unchanged (inset in Fig.3). This can be tentatively explained by the fact that in accordance with Eq.(1), the SAW attenuation changes inversely proportionally to the film conductivity when $s_0 >> s_m$ (this relation is valid for the investigated LCMO films), and thus, an increase of the conductivity in the magnetic field results in a decrease of the SAW attenuation.

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BIBLIOGRAPHICAL REFERENCES

[1] C. Zener, Phys. Rev. 82, 403 (1951).
[2] A.J. Millis, P.B. Littlewood, and B.I. Schraiman, Phys.Rev.Lett. 75, 5144 (1995).
[3] Y. Ilisavskii, A. Goltsev, K. Dyakonov et al., Phys.Rev.Lett. 87, 146602 (2001).
[4] K.A. Ingebrigtsen, J.Appl.Phys. 41, 454 (1970).