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Relaxation of Magnetoresistance of Single-Crystalline $(La_{0.5}Eu_{0.5})_{0.7}Pb_{0.3}MnO_3$ in a Pulsed Magnetic Field

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Abstract—The magnetoresistance (MR) of substituted lanthanum manganite $(La_{0.5}Eu_{0.5})_{0.7}Pb_{0.3}MnO_3$ has been measured in a pulsed magnetic field with amplitude $H = 250$ kOe at various temperatures. It is established that temperature dependence of the MR relaxation parameter $\tau(T)$ is correlated with temperature dependence of the electric resistance $R(T)$. A mechanism of relaxation is proposed that is related to the relaxation of conducting and dielectric phases in the volume of a sample under the conditions of phase separation. It is shown that the behavior of τ is related to the number of phase boundaries in the volume.

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Substituted lanthanum manganites are of considerable basic and applied interest, which is due to the phenomenon of colossal magnetoresistance (CMR) observed in these compounds. It is an interesting task in the physics of manganites to investigate the relaxation of their magnetoresistance (MR) and magnetization [1], since this knowledge can elucidate the nature of mechanisms responsible for the macroscopic properties of these materials. The MR relaxation observed in substituted lanthanum manganites can be classified into two types—slow and fast—depending on the characteristic relaxation time being on the order of 10^3 [2] or 10^{-3} s [1, 3, 4].

In granular manganites, there are two well-known principal mechanisms responsible for the MR and relaxation processes, which are operative in various intervals of fields. The first mechanism is related to the spin-dependent tunneling of carriers via dielectric interlayers between grains, the latter being capable of possessing a certain magnetic order [5]. This order usually determines the MR in weak fields (up to 1–10 kOe), in which the ferromagnetic grains do not reach a saturation magnetization. In cases where dielectric boundaries possess an antiferromagnetic order, the MR and the related hysteresis and relaxation are observed in fields up to 10^5 Oe. The second mechanism represents the classical negative MR, which is related to a nanophase separation inherent in substituted lanthanum manganites (see, e.g., [6]). Evidently, this MR mechanism can be experimentally observed in pure form in high-quality single-crystalline films and volume single crystals.

We have studied a single crystal of $(La_{0.5}Eu_{0.5})_{0.7}Pb_{0.3}MnO_3$ compound that was grown by spontaneous crystallization. A thorough characterization of these crystals has been reported elsewhere [7]. Measurements in strong pulsed magnetic fields have been performed on a special setup at the Kirensky Institute of Physics (Krasnoyarsk).

Previously, we have studied [7] the temperature dependence of the resistance of an identical $(La_{0.5}Eu_{0.5})_{0.7}Pb_{0.3}MnO_3$ single crystal in magnetic fields up to 250 kOe, at which complete saturation of the MR was observed. The variation of MR was traced in a temperature interval of $T = 2$–300 K. Metal–dielectric phase transition in the sample at $H = 0$ was observed at $T_{max} = 185$ K. Figure 1 shows the temporal variation of the magnetic field H and resistance R of the sample. These data show that the magnetic field switch-on is accompanied by the phenomenon of negative MR. When the field decays, the resistance tends to return to the initial value. The moment of field switch-off is clearly manifested by a sharp outburst at 15 ms that corresponds to the thyristor closing in a coil–capacitor oscillatory circuit of the pulsed setup. As can also be seen, the field switch-off leaves a certain level of resistance, which exhibits subsequent relaxation (within about 15 ms) to the initial value.

Some researchers who had previously observed [3, 8] the MR relaxation with characteristic times on the order of several milliseconds for polycrystalline films in high magnetic fields suggested that this relaxation was related to a spin-dependent tunneling transport of carriers through antiferromagnetic boundaries between manganite grains. However, the relaxation with characteristic times on the same level observed in our experiments on a single crystal excludes this hypothetical mechanism, since grain boundaries are absent. It is possible that such transport in a single crystal can take place on the twinning boundaries and defects. However, it can also be suggested that relaxation is related to changes of the ratio between con-

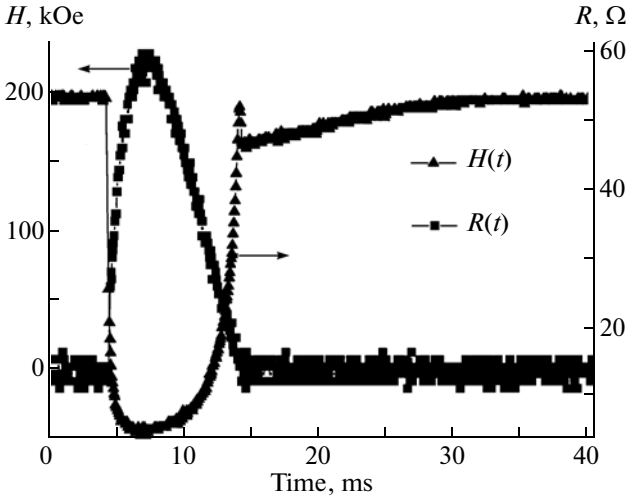

Fig. 1. Temporal variation of field $H(t)$ and sample resistance $R(t)$. It can be seen that, after switching off the field, the resistance remains at a certain level and relaxes with the time.

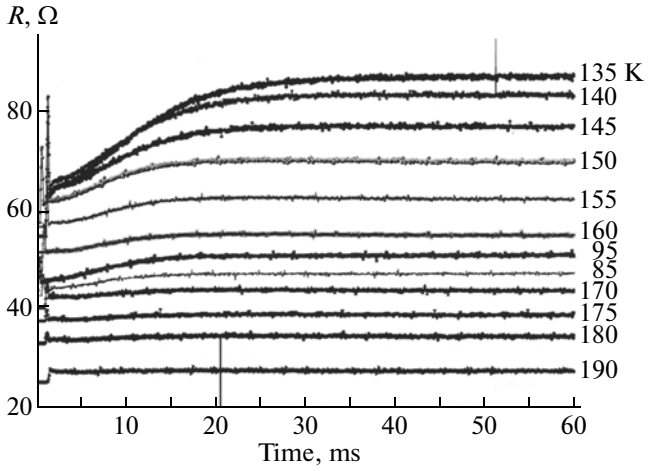

Fig. 2. Plots of $R(t)$ measured at various temperatures (indicated at the curves) in a field of $H = 250$ kOe at the relaxation stage (upon magnetic field switch-off).

ducting and dielectric phases in the bulk under the action of the applied magnetic field.

Figure 2 shows the temporal variation of resistance R in the crystal studied at various temperatures. The initial moment corresponds to switching off a field pulse with amplitude $H = 250$ kOe, for which the MR is maximum and reaches saturation [7]. The observed $R(t)$ curves can readily be approximated by the following function:

$$R(t) = R_0 \exp(-(t - t_0)/\tau), \quad (1)$$

where R_0 and t_0 are fitting parameters that ensure coincidence of the initial points and τ is a parameter that characterizes the damping coefficient. The parameters of approximation were chosen by minimizing the variance between experimental data and function (1). After processing of the MR relaxation curves measured at all the temperatures indicated in Fig. 2, we obtained the dependence of parameter τ on temperature T. This $\tau(T)$ curve is presented in Fig. 3.

As can be seen from Fig. 3, the $\tau(T)$ curve qualitatively coincides with the temperature dependence of resistance R in the same sample. This behavior can be explained by taking into account the energy of boundaries of the ferromagnetic regions (also called clusters or droplets [6]) that appear on cooling in the manganite sample. The saturation of MR observed at $H \sim 250$ kOe implies that the entire crystal volume is occupied by the ferromagnetic phase, so that no phase separation is observed. After switching off the magnetic field, a reverse process of phase separation takes place and the ratio of conducting and dielectric regions in the crystal depends in the temperature. At a temperature of the metal–dielectric transition, an infinite conducting cluster begins to form in the sample and the number of conducting and dielectric regions (and, hence, of their interfaces) in the crystal is at maximum. The maximum relaxation of MR is also observed in this temperature region. On passing away to both higher and lower temperatures from the metal–dielectric transition point, the degree of phase separation decreases, which also favors a decrease in the value of τ.

Thus, we have observed the MR relaxation with a characteristic time of 10^{-3} s in a single crystal of substituted lanthanum manganite $(La_{0.5}Eu_{0.5})_{0.7}Pb_{0.3}MnO_3$ in a broad temperature range. It is established that

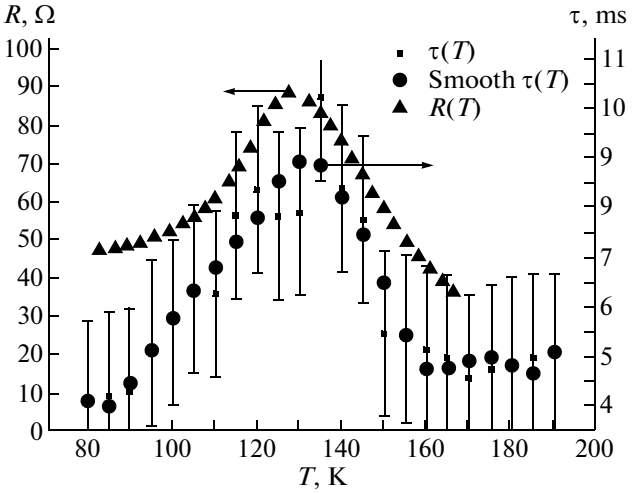

Fig. 3. Plots of MR relaxation parameter τ vs. temperature T: (squares) experimental τ values (vertical bars show rms deviation); (black circles) smoothened $\tau(T)$ curve; (triangles) experimental values of resistance R for the same sample. The $\tau(T)$ curve exhibits correlation with variation of resistance.

temperature dependence of the MR relaxation parameter $\tau(T)$ is correlated with temperature dependence of the electric resistance $R(T)$. It is shown that the behavior of τ is related to the number of phase boundaries in the crystal volume.

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