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THERMAL RESPONSE OF GRAINED $\mathbf{La_{0.67}Ca_{0.33}MnO_3}$ FILMS TO MICROWAVE RADIATION

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Response to a microwave radiation was studied for grained $La_{0.67}Ca_{0.33}MnO_3$ films (d = 0.15 and 1.30 μm) grown by pulsed laser deposition on MgO (100) substrates. Thermal nature of the response has been certified for the films at T = 78 K. A mechanism of the response has been proposed that takes into account different role of grains and intergrain boundaries on dc and high frequency currents flowing in the films. Assuming a nonzero intergrain boundary capacitance, we point out that the microwave radiation heats mainly the low resistance grains rather than the intergrain boundaries. Meanwhile, dc current flowing in the films is determined by temperature-dependent resistance of the intergrain media.

Keywords: manganite thin films, microwave radiation

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1. Introduction

During recent years, increasing attention was paid to perovskite manganites referred to by a general formula $R_{1-x}M_xMnO_3$ (here R = La, Nd, Pr; M = Ca, Sr, Ba, and Pb). Most of these compounds with x = 0.2–0.4 demonstrate phase transition from high resistance paramagnetic (PM) to a metallic ferromagnetic (FM) phase at Curie temperature T_c (100–350 K) and the so-called colossal magnetoresistance effect (CMR) observed just below T_c. The compounds are believed to be very promising for fabrication of novel magnetoelectronic devices such as magnetic field sensors, magnetic recording and reading heads, elements of magnetic memory, etc. Lattice parameters of these compounds are close to a number of other perovskite oxides including ferroelectrics and high-temperature superconductors. Therefore, manganite heterostructures with other metal oxides [1–5] offer additional application possibilities.

Electrical properties of both single crystals of the manganites [6, 7] and their thin films [8–11] were studied recently either by applying dc or microwave current, by using short laser pulses, as well as by employing various resonant techniques [12–14].

Various properties of the manganite thin films such as resistance of their grains, magnetic impedance [6, 9–11], ferromagnetic resonance [6, 9], absorption of microwaves in the absence and presence of external magnetic field [15–20] have been explored by employing the resonant techniques. Resonant response measured for the manganite films under applied microwave electrical field together with low-frequency ac electrical field [21] or internal dc electrical field induced in the film by pulsed laser radiation [13] have been reported. In recent paper [17], the authors pointed out coincidence of the absorbed microwave power P_{ab} measured in the film by the resonant technique with that obtained by employing a conventional method, i. e. by measuring separately the incident (P_i), reflected (P_r), and transmitted (P_t) microwave power.

The main goals of this work were: (i) to determine the nature of the response of $La_{0.67}Ca_{0.33}MnO_3$ thin films to a microwave radiation (f = 10 GHz), and (ii) to reveal the mechanism of the response.

2. Film response to microwave radiation

Let's analyze first a thermal conductivity equation for a rectangular manganite sample of length l, width b, and thickness d with direct current (density j_0) and microwave current (density j_m; $j_m \gg j_0$) flowing along the sample. Assuming that one surface of the film is

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thermally isolated (temperature $T(0)$) and the other one kept at a constant temperature $T(d)$, the temperature difference between two film surfaces can be expressed as

$$T(0) - T(d) = \frac{\sigma}{4\kappa} E^2 d^2 \,. \qquad (1)$$

Here κ is the intrinsic thermal conductivity of the film, σ is the intrinsic electrical conductivity, $E = E_0 + \tilde{E}$ is the total electric field strength, E_0 and $\tilde{E}$ represent strengths of dc electrical field and ac microwave field, respectively. From Eq. (1) one can conclude that thermal response should demonstrate the following properties:

(i) Below the characteristic temperature T_m ($\cong T_\mathrm{c}$) (corresponding to the maximum resistance in the $R(T)$ plots), resistance of the manganite films increases with temperature, and thus the microwave response for the films at $T < T_\mathrm{m}$ might be determined by microwave radiation-induced film heating and the resultant resistance increase.

(ii) In the case of $T(d) = \mathrm{const}$, temperature difference between two film surfaces and the corresponding thermal response should depend linearly on the square of the amplitude of microwave electrical field $\tilde{E}$, i. e. on the radiation power.

(iii) For a fixed radiation power, the thermal response should increase with film thickness.

The experiment was carried out for two $La_{0.67}Ca_{0.33}MnO_3$ films of different thicknesses (0.15 and 1.30 μm) grown by pulsed laser deposition on crystalline MgO (100) substrates using disk-shaped ceramic target of the same chemical composition. The width of the samples was 3 mm, and the distance between low resistance ohmic contacts was about 10 mm.

The microwave response measurements were performed at liquid nitrogen temperature ($T = 78$ K) and radiation frequency $f = 10$ GHz. A simplified scheme of the measurement is shown in Fig. 1. The corresponding set-up consists of a $23{\times}5$ mm^2 waveguide head *B* with the sample *M* located in the central part of the wavequide, i. e. at a place of electrical field maximum. The dc circuit consisted of the voltage supply U_0, the sample resistance R_p, and the load resistance R ($R \ll R_p$) connected in series.

A decrease of dc current caused by radiation-induced film resistance increase has been indicated for the samples at $T = 78$ K. The measured power–voltage characteristics for two $La_{0.67}Ca_{0.33}MnO_3$ films with different thicknesses are presented in Fig. 2 (curves *1* and *2* for thick and thin films, respectively). It can be seen from the figure that the measured voltage (the microwave response) for both of the samples increases linearly with microwave power at $P > 0.3$ W. Extrapolation of the observed linear V–P dependences to lower power values gives the characteristic intersects in the P axis at points P_1 and P_2 ($P_1 < P_2$) marked by arrows for thick and thin films, respectively. In a case of thin film, a small amount of heat generated by low radiation power can be drained to the substrate, meanwhile a similar heat removal is less efficient for thicker film, because nonequilibrium phonons generated by the microwave radiation in this case must pass a longer way.

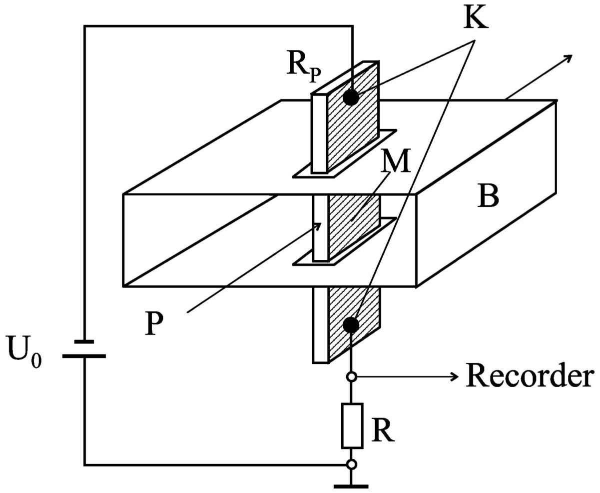

Fig. 1. The scheme of microwave measurement set-up: *B* is the waveguide head, R_p is the sample, *M* is the film under study, *R* is the ohmic resistance, *K* are the contacts, U_0 is the dc voltage supply, and *P* is the microwave radiation.

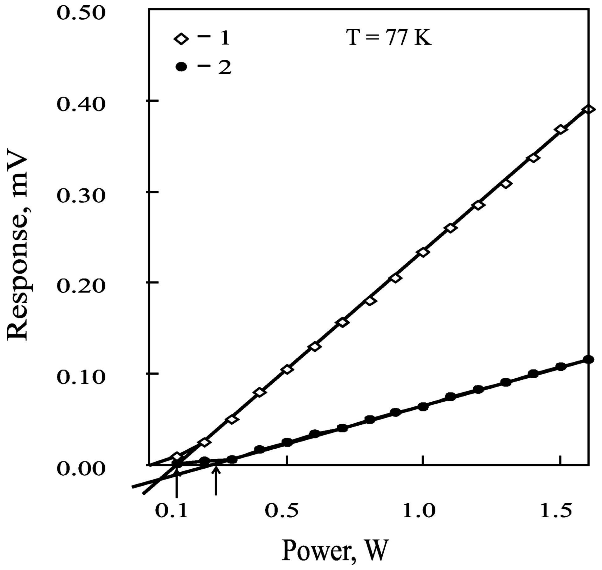

Fig. 2. Power–voltage characteristics of the thick (*1*) and thin (*2*) film.

Thus, we see that major properties of thermal response are certified by the experiment. Therefore we conclude that the response observed for the $La_{0.67}Ca_{0.33}MnO_3$ films at liquid nitrogen temperature is of thermal nature. According to the obtained experimental data, we propose the following model of the film response to a microwave radiation. In a case of high frequency current, the relatively large electrical capacitance of the intergrain boundaries bypasses their ohmic resistance, therefore microwave radiation heats only the grains, which in their turn heat up the intergrain boundaries and so change their ohmic resistance. Since the main contribution to the film resistance is determined by the intergrain resistance, its variation in effect changes the dc current flowing in the sample and the resultant voltage drop in the load resistance connected in series to the sample, thus generating the sample response to the microwave radiation.

3. Conclusions

1. It has been found that the response of $La_{0.67}Ca_{0.33}MnO_3$ film to a microwave radiation at $T = 78$ K is of thermal nature.
2. A mechanism of the response has been proposed that takes into account different role of grains and intergrain boundaries on dc and high frequency currents flowing in the films. The microwave radiation heats mainly the low resistance grains rather than the intergrain boundaries shunted by a capacitance. The grains, while being heated, heat up the intergrain boundaries and so change their ohmic resistance and, consequently, the magnitude of dc current flowing along the sample.

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ŠILUMINIS GRANULIUOTŲ $La_{0,67}Ca_{0,33}MnO_3$ SLUOKSNIŲ ATSAKAS Į MIKROBANGĘ SPINDULIUOTĘ

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Santrauka

Aptiktas tiriamųjų sluoksnių atsakas mikrobangei spinduliuotei ir nustatyta, kad jis yra šiluminės prigimties. Pateiktas atsako mechanizmo paaiškinimas, rodantis, jog elektrinei talpai šuntuojant tarpgranulinių jungčių omines varžas, mikrobangė spinduliuotė labiausiai kaitina granules, kurios, šildydamos tarpgranulines jungtis, pakeičia jų ominę varžą, o kartu ir sluoksnyje tekančios nuolatinės srovės stiprį.