FAST PROTECTOR AGAINST EMP USING ELECTRICAL FIELD INDUCED RESISTANCE CHANGE IN $La_{0.67}Ca_{0.33}MnO_3$ THIN FILMS

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Abstract

$La_{0.67}$ $Ca_{0.33}$ MnO_3 thin films were investigated using nanosecond duration electrical pulses. It was found that strong (up to 30 kV/cm) electric fields significantly reduces the resistance of the film and shifts the peak in resistance vs. temperature dependence to higher temperatures. The results are discussed using a model based on fast spin and charge system response to electric field action on the magnetic material. It was concluded that electric field induced changes in the $La_{0.67}$ $Ca_{0.33}$ MnO_3 thin film's resistance can be used to protect fast 50 Ohm impedance high frequency transmission lines against short rise time fault current pulses.

I. INTRODUCTION

The rapid development of pulsed power technologies enabled the design of powerful microwave sources capable of generating nanosecond duration pulses with peak power ranging from hundreds of MW [1] to several GWs [2]. Such sources can be an effective tool for electromagnetic attack against high-speed electronics. Especially sensitive to short electromagnetic pulses (EMPs) action are the input circuits of ultra-high frequency wireless communication systems. The protection of these circuits against EMP can be realised by inserting a fast fault current limiter having low intrinsic loss between the antenna and the receiving system. It was demonstrated that switches based on amorphous semiconductor [3], superconducting limiters [4], and high-pressure gas arresters [5] can be used for this purpose. However, semiconductor switches only have a limited number of operations when protecting circuits against high voltage transients, superconducting limiters require low temperature cooling, gas arresters have complicated design and relatively large size. For this reason, the search for new materials and phenomenon that can be used in fast protector development is still important.

In this work we demonstrate that current induced resistance changes in magnetic materials such as La-Ca-MnO can be used to develop fast, low threshold voltage fault current limiters.

II. EXPERIMENT

Thin films of $La_{0.67}Ca_{0.33}MnO_3$ used in the investigation were prepared by using the pulsed laser deposition technique. The samples, having thicknesses ranging from 0.05 to 0.15 μm, were deposited on MgO substrates under oxygen pressures of 20-25. During the deposition, the substrate temperature was kept at 750 C. After the deposition the oxygen pressure was increased to 1 atmosphere. This operation was realised by keeping the temperature of the substrate constant (750 C). The last stage of sample preparation was a 3 hour process to slowly reduce the temperature of the substrate from 750 C to room temperature. This enabled the fabrication of films with phase transition temperatures (T_m) ranging from 125K to135 K. It was found that the specific resistance

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14. ABSTRACT
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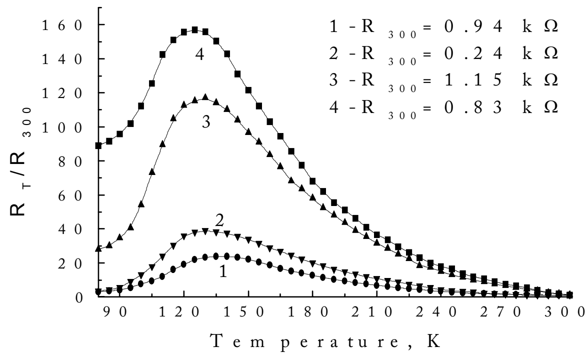

Figure 1. Resistance–vs-temperature dependence for samples having different thickness. 1 - 50 nm; 2 – 80 nm; 3 – 100 nm; 4 – 120 nm.

and T_m of the film depends on its thickness. Fig.1 demonstrates a typical resistance vs. temperature dependence for films having various thicknesses. This phenomenon is due to a 9% mismatch between the lattice constants of pseudocubic $La_{0.67}Ca_{0.33}MnO_3$ and MgO substrate [6]. X-ray diffraction measurements demonstrated that the prepared films were single-phased and had a pseudocubic perovskite structure. The electric field induced resistance change study was performed on co-planar shaped samples having 0.75 mm wide Ag electrodes. The gap between these electrodes varied from 15 to 30 μm**.**

The electric field influence on film resistance was investigated by using square shaped pulses having a pulse length of 5 to 500 ns, a rise time of 0.5-1 ns, and repetition rate of 150-500 Hz. The sample was mounted in parallel with a Z = 50 Ohm impedance transmission line. A high-speed sampling oscilloscope was used to record the incident and transmitted pulses. In the cases where the sample's resistance was much higher than Z, the transmitted pulse was additionally amplified 20 times.

III. RESULTS AND DISCUSSION

Fig. 2 and Fig. 3 demonstrate the influence of the electric field on the resistance vs. temperature [R = f(T)] dependence for two thin film samples having different thicknesses. As can be seen, an increase in the electric field strength decreases the resistance of the film and shifts the peak of the R = f(T) curve to higher temperatures. This shift is about 3 K per 1kV/cm for films with 50 nm thickness and 2 K per 1kV/cm for 120 nm thick films. The dynamic response of the resistance to the action of the electric field is that the decrease in the resistance of the film appears simultaneously with the increase in the electric field. This means that resistance change ($\Delta R = R_0 - R_E$) response time is less than 1 ns. The value of ΔR changes with temperature and has a maximum near $T_m(E = 0)$. The highest value of

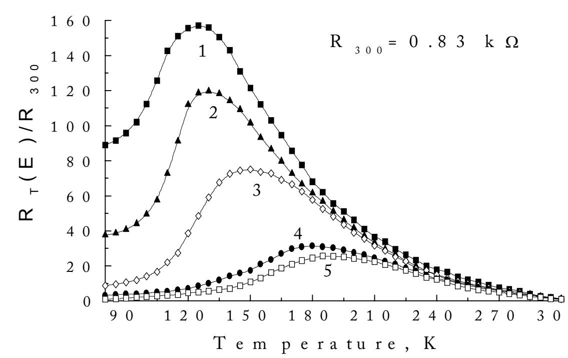

Figure 2. Resistance-vs-temperature dependence for film with thickness 120 nm at different electric field strengths: 1 – E = 0, 2 - 1 kV/cm, 3 - 3.5 kV/cm, 4 - 10 kV/cm, 5 - 22 kV/cm

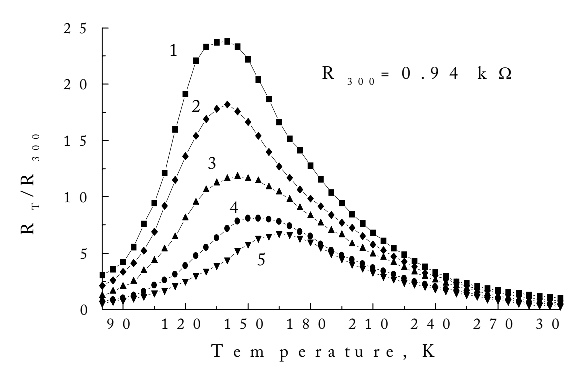

Figure 3. Resistance–vs-temperature dependence for film with thickness 50 nm at different electric field strengths: 1 – E = 0, 2 - 1 kV/cm, 3 - 4.5 kV/cm, 4 - 18 kV/cm, 5 - 23 kV/cm

the R_0 / R_E ratio was about 70 and 10 for 50 nm and 120 nm thick films, respectively.

The experimental results demonstrate that strong electric fields significantly changes the resistance of the manganite films. This phenomenon cannot be the result of the strain induced by the electric field on the manganite film, because the electrical forces, acting on the film, are not large enough to create high mechanical tensions. Moreover, Fig.1 demonstrates that the strain mainly changes the resistance of the film, while the position of the pike of R = f(T) curve is shifted much less than in the case of electric field action. Most probably, the electric field affects the energy of the electric charge carriers, thus increasing the probability that they can penetrate though the potential barrier between Mn ions. The strong electric field is able to change the orbital momentum of the electrons and makes possible, after phonon emission, changes in the electron‘s spin orientation. This increases the possibility of the “hopping process” and decreases the resistance of the film.

IV. LIMITER

In order to demonstrate how electric fields induced resistance changes could be used for protection of HF input circuits from EMP, a fault current limiter having a co-planar two-gap microstrip transmission line (Fig. 4) was fabricated. It consists of MgO substrate covered by 0.1 μm thick $La_{0.67}Ca_{0.33}MnO_3$ film with T_m = 135 K and thin film tape-shaped 1.2 cm long Ag conductors deposited onto this film. The distance (d) between the central and ground conductors

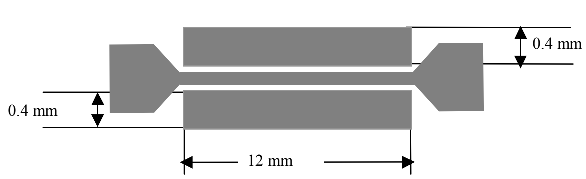

Figure 4. Scematic diagram of the limiter.

was 50 μm. Such a device was connected in series to a 50-Ohm transmission line, cooled below 160 K, and subjected to square shaped electrical pulses having pulse duration of 10 ns and a rise time of 0.5 ns. The amplitude (V) of the pulses was varied from 1 to 350 volts.

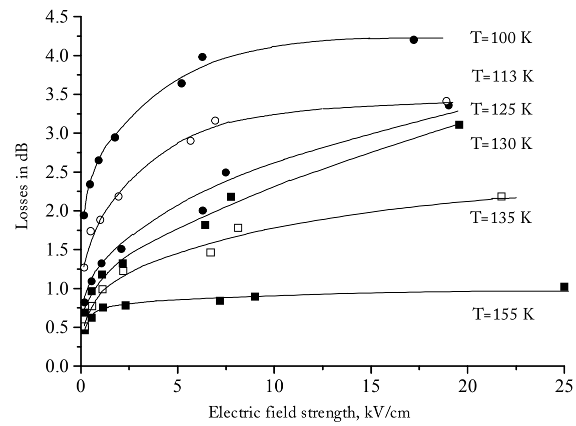

Figure 5. Losses *vs* electric field strength of limiter made from $La_{0.67}Ca_{0.33}MnO_3$ film with T_m=135 K.

Fig. 5 demonstrates the losses in dB appearing in the 50-Ohm transmission line *vs.* the input electric field (E = V/d) at various ambient temperatures. As can be seen, the limiter is most effective when it operates in the temperature range between 125 and 130 K. In this case, the initial losses are less than 0.75 dB, however at electric field strengths close to 20 kV/cm these losses increase to 3 dB. Estimates show that changing the geometry of the limiter, T_m, and the resistivity of the film makes it possible to design fast, room temperature limiters having low (less **than** 1 dB) initial losses and high (more than 15 dB) losses in its operating regime.

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