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FAST BOLOMETRIC RESPONSE OF BULK $La_{0.7}Sr_{0.3}MnO_3$ ELECTROCERAMIC STRUCTURES

YU.M. NIKOLAENKO[a], I.S. MAKSIMOV[a], YU.V. MEDVEDEV[a], A.N. ULYANOV[a] AND A.M. GRISHIN[b]

[a]Donetsk Physico-Technical Institute of the National
Academy of Sciences of the Ukraine
72 R. Luxemburg, Donetsk, 340114, Ukraine
[b]Dept. of Condensed Matter Physics, Royal Institute of Technology
100 44, Stockholm, Sweden

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We report on the performance of a microwave electroceramic bolometer of hybrid $La_{0.7}Sr_{0.3}MnO_3/Al_2O_3$ ($0.2 \times 2 \times 4$ mm^3) structure. The estimated thermal resistance of the bulk ceramic manganite film-single crystal sapphire interface is about 500 K/W at room temperature. This resistance is the main thermal barrier in the heat sink system and has been found to be slightly dependent on temperature. When compared with the high-T_c superconducting bolometers, the $La_{0.7}Sr_{0.3}MnO_3$ microwave electroceramic bolometer works in a more wide temperature range, from 77 K to 330 K, excluding the narrow temperature interval at the metal–insulator phase transition ($T = 230$ K). The microwave electroceramic bolometer sensitivity and the time constant at room temperature have been found to be 0.1 V/W and 100 ms, respectively. To improve the bolometer performance the point contact has been fabricated by a break junction technique. The optimization of a microwave electroceramic bolometer design brought to a considerable improvement of basic bolometer characteristics. The microwave sensitivity was about 0.3 V/W and the time constant was less than 100 ns.

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The recent progress of film technology in the creation of bolometers and microbolometers using the multi-component materials was achieved at the developing of devices on the base of high temperature superconductors (HTSC). The increasing interest in this field is related to the high superconducting phase transition. The film technology of HTSC assumes the relatively simple production of bolometers and allows to vary the frequency, sensitivity, and speed of response in a wide range due to applications of sublayers, heat barriers, and optimization of construction and shape of sensitive elements [1–3]. Nevertheless, the need of nitrogen temperature restricts the applications of HTSC in the sensor technique. In reality, the HTSC bolometers have a competitive ability in a far infrared spectrum ($\lambda > 20$ μm) only, where the pyroelectric detectors are used as sensible elements and have a relatively low sensitivity (10^{-10} W/(Hz)$^{1/2}$ [3]).

To create a bolometer operating at room temperature and above, it is necessary to have new cheap materials like electroceramics. It explains a rise in interest to the systems on the base of manganite of rare-earth elements. These materials are specified by a high value of temperature coefficient of resistance (TCR) at the metal–insulator phase transition [4]. The changing of composition of solid solution $R_{1-x}A_xMnO_3$ (R — trivalent ions of La, Pr, Nd, etc., A — divalent ions of Ca, Sr, Ba, Pb [5, 6] varies the transition temperature, T_c, in wide limits. These compounds have a high rate of absorption in a wide range of wavelengths and they are chemically stable in the air. The paper [4] describes the optimization of important attributes for $La_{0.7}Sr_{0.3}MnO_3$ and for $Nd_{0.7}Sr_{0.3}MnO_3$. The highest value of the temperature coefficient of resistivity ($TCR \approx 20\%$) was obtained for $Nd_{0.7}Sr_{0.3}MnO_3$ and the temperature T_c (≈ 380 K) was obtained for $La_{0.7}Sr_{0.3}MnO_3$ compounds. The rise in T_c related to the reduction of TCR was found. Thus the coefficient TCR of $La_{0.7}Sr_{0.3}MnO_3$ is only 3–4% and the temperature T_c of $Nd_{0.7}Sr_{0.3}MnO_3$ is only 200 K.

A bolometric response on the manganite film structures has been investigated recently [7, 8]. An experience of the optimization of heat and electrical characteristics of film HTSC bolometers [2] has not been still realized in La–Mn structures. In particular, the characteristic time of the bolometer response is about 10^{-3} c [7] and cannot be reduced without optimization of heat parameters of film structure [9]. Methods of creation of "weak-banded places", electric contacts, heat threshold sublayers, etc. for this class of materials have not been developed.

In this work we have demonstrated a possibility of radical decreasing of the time constant of the $La_{0.7}Sr_{0.3}MnO_3/Al_2O_3$ bolometer by mean of creation of the point contact of manganite ceramics with a help of a break-junction technique. The work region of this bolometer includes a narrow connection between two massive pieces of electroceramics. In this case the ceramics volume is a good thermostat and the time constant of such bolometer is determined by the size of thermal overheating region [10].

Manganite electroceramics was produced by the nitrate method from oxides La_2O_3, MnO_2, and carbonates $SrCO_3$. The solution of the initial compounds were evaporated and powders were pressed into pellets. The pellets were annealed at 950°C for 78 h with intermediate grinding and pressing. Finally, the samples were sintered at 1150°C for 20 h.

To provide a thermal barrier on the interface of bulk manganite film and substrate, we have used a 40 μm thick sublayer of polymer film. The thermal resistance of this barrier is about 500 K/W and has been found to be slightly dependent on temperature. Other thermal resistances at the heat sink system at room temperature were estimated by the values of $R_s = 0.5$ K/W and $R_{st} = 68$ K/W, where

R_s and R_{st} are the thermal resistances of substrate and substrate–thermostat interface.

A temperature dependence of electrical resistivity was measured by a four-point technique in the regime of heating of the structure in vacuum. The value of bias current was equal to 1 mA. As it is seen from Fig. 1 the maximum of the pick-like temperature dependence of electrical resistivity $R(T)$ is achieved at $T_c = 230$ K. It is the so-called metal–insulator transition temperature.

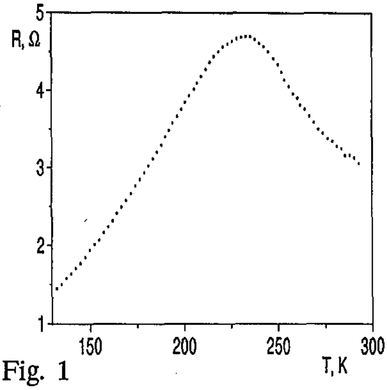

Fig. 1

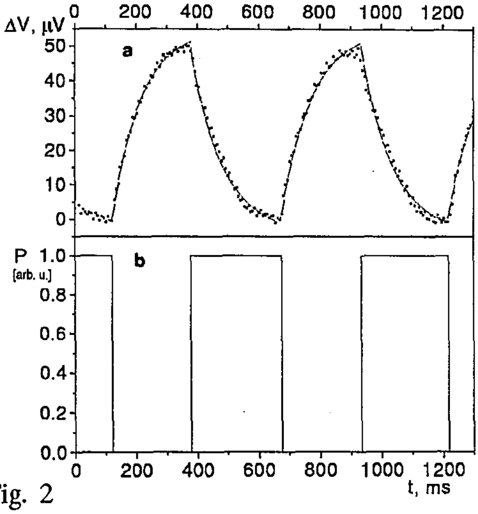

Fig. 2

Fig. 1. Temperature dependence of resistivity of the $La_{0.7}Sr_{0.3}MnO_3$ bulk film.

Fig. 2. Time dependence of the bolometric response of the hybrid $La_{0.7}Sr_{0.3}MnO_3/Al_2O_3$ structure (a), the shape and position of the time pulses of a microwave power (arbitrary units) (b).

Time characteristics of a film bolometric response to 8 mm band waves power pulses (the dotted line in Fig. 2a) were measured with a help of direct recording of the voltage values in computer memory. The data of Fig. 2 were obtained at the thermostat temperature $T_0 = 287$ K and bias current $I_b = 5$ mA. The shape of the periodical pulses of microwave power is showed in Fig. 2b. The lines in Fig. 2a show the result of approximation of the experimental data by the fragments of the exponential time dependences

$$R(T_0,t) - R(T_0,t_{1n}) = (\mathrm{d}R/\mathrm{d}T)\Delta T_1\{1 - \exp[(t_{1n} - t)/\tau_1]\} \qquad (1)$$

for the film heating, and

$$R(T_0,t_{2n}) - R(T_0,t) = (\mathrm{d}R/\mathrm{d}T)\Delta T_1\{1 - \exp[(t_{2n} - t)/\tau_1] \qquad (2)$$

for the film cooling, where t_{1n} and t_{2n} are the times of input and output of power pulse, ΔT_1 is the temperature amplitudes on the film–substrate interface, $\tau_1 = d_f c_f \rho_f/\lambda_{fs}$, ($d_f$, c_f, ρ_f, and λ_{fs} are thickness, heat capacity, density, and the thermal conductivity of film–substrate interface, respectively). Good agreement of these dependences is a consequence of the main thermal barrier existence in the film–substrate boundary. Other thermal dynamics process gives a small addition. For the Joule power of the film heating being equal to 1 mW, the temperature amplitudes of the heat sink system of the microwave electroceramic bolometer (MECB) are as follows [9]: $\Delta T_1 = 0.5$ K, $\Delta T_2 = 0.5$ mK, $\Delta T_3 = 68$ mK. We estimated the time constant of the sapphire substrate as

$$\tau_2/\pi^2 = d_s^2 c_s \rho_s / \lambda_s \pi^2 = 3 \text{ ms}, \tag{3}$$

where d_s, c_s, ρ_s, and λ_s are thickness, heat capacity, density, and thermal conductivity of sapphire, respectively.

Therefore, the substrate is heated by each power pulse but the influence of this process is small because the corresponding amplitude relation is $\Delta T_2/\Delta T_1 = 10^{-3}$. The time constant of heat relaxation on the substrate–thermostat interface is estimated by the value of $\tau_3 = R_{st}(c_f + c_s) = 4 \text{ s} \gg \tau_1$. In this case for the duration of the microwave power pulses $t_0 \ll \tau_3$, the effect of the non-zero value of R_{st} results in shifting the average temperature of substrate by the value of $\Delta T_3/2$ only [9].

The temperature dependence of time constant of MECB and amplitude of the bolometric response are performed in Fig. 3. The sensitivity of MECB at room temperature is 0.1 V/W. It is enough for application of MECB. One of the ways to decrease the time constant of MECB consists in decreasing the bulk film thickness. We note that the sensitivity of the bolometer may be increased directly by means of an increase in *TCR* from 2% to 14% [4]. We have demonstrated the significant improvement of MECB parameters in the example of the break junction bolometer (BJB) which is produced by the mechanical loading of the bulk film of MECB. The sensitivity of BJB at room temperature is about 0.3 V/W and the

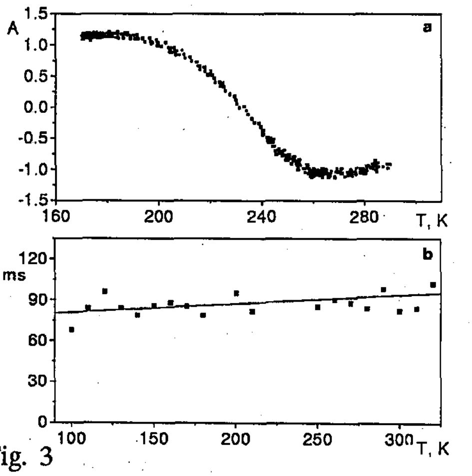

Fig. 3

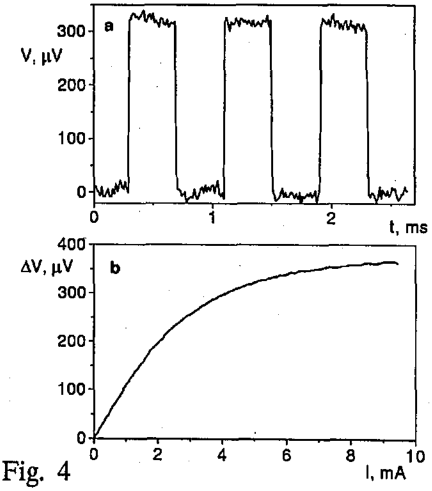

Fig. 4

Fig. 3. Temperature dependence of amplitude ($A = V/|V_{290\text{ K}}|$) (a) and time constant (b) of bolometric response of MECB.

Fig. 4. Time (a) and amplitude (b) dependences of the voltage bolometric response of BJB at $T = 292$ K and $I_b = 4$ mA.

time constant was estimated by the value less than 100 ns. The time dependence of BJB voltage response is performed in Fig. 4a. The value of electrical resistivity of BJB was 52 Ω. Figure 4b demonstrates the dependence of BJB amplitude from the bias current value. The saturation tend of this dependence is explained by the strong heating of the BJB point contact by bias current.

We have investigated the time characteristics of another point contact bolometer (PCB) which is produced in the base of electrical contact between still needle and surface of the manganite bulk film. The amplitude and time constant of bolometric response of PCB are strongly dependent on the type of realization of point contact and, as a rule, two kinds of response are included with strong different time constants.

The maximal sensitivity of PCB was about 20 V/W. We have noted that the manganite ceramics material allow us to make the non-tunnel point contact with linear $I-V$ characteristics easily. It opens a possibility to design microbolometers in the base of one or two grains of electroceramics only.

Two possibilities of radical decreasing of time constant of manganite bolometers were demonstrated. The first method concerns the optimization of film structure by mean of major heat barrier on the film–substrate interface. A choice of optimal value of heat resistance, the film–substrate boundary and film thickness provides with the required speed of bolometer response without reduction in volt–watt sensitivity.

The second way shows a possibility of creation of fast-response bolometers on the basis of point contact of manganite ceramic. The advantage of such bolometers is a small size of the device. Actually it is feasible to make bolometers with help just of one or two granules. We have noted the good protection of manganite bolometers from a short overheating in contrast to analogue semiconductor devices.

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