Proceedings

Optical and Electrical Characterizations of Uncooled Bolometers Based on LSMO Thin Films †

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Abstract: In this paper the optical and electrical characterization of a 75 × 75 μm² uncooled bolometers based on free-standing $La_{0.7}Sr_{0.3}MnO_3$ /$CaTiO_3$ (LSMO/CTO) thin films fabricated by micromachining of the silicon substrates is presented. R(T) curves have been compared to electro thermal simulations. Its thermal conductance was measured to be 9×10^{-6} $W \cdot K^{-1}$ around 300 K. The optical characterization was performed by modulating the power of a 635 nm laser diode and was carried out at different bias currents and temperatures. Finally, the frequency dependence of the bolometer presented at different temperatures and at optimal current shows that both sensitive and fast uncooled bolometers can be fabricated using suspended LSMO thin films.

Keywords: bolometer; thermal conductance; frequency response

1. Introduction

A bolometer is a thermal radiation detector whose electrical resistance varies with the temperature rise due to the absorption of the incoming electromagnetic radiation [1]. An important feature of a bolometer is that its optical sensitivity depends on the absorbed wavelength only through absorption, which can be very interesting to measure infrared radiation. It is required to develop uncooled thermal detectors having high sensitivity and high frequency response for targeted applications such as imaging cameras, thermal sensors, gas sensors, etc.

$La_{0.7}Sr_{0.3}MnO_3$ (LSMO) is a very interesting material for the fabrication of infrared bolometers because of the large variation of its electrical resistance R with temperature T close to room temperature [2–5]. It has a large temperature coefficient of resistance, named TCR = 1/R × dR/dT, of about 0.02 K^{-1} in the 300–340 K range and it also shows a low noise level compared with other resistive materials such as semiconductors and other oxide materials [6–8].

The bolometer operation is presented in Section 2. Experimental details, such as sample preparation and measurement conditions, are given in Section 3. Experimental results and simulations are presented in Section 4. Finally, conclusions are given.

2. Bolometer Operation

From the equation of conservation of the received (both electrical and optical) and evacuated power, one can write the expression of the optical responsivity $\Re_V$ (expressed in $V \cdot W^{-1}$) of a bolometer of electrical resistance R. It is defined as the output voltage ΔV(f) per incoming radiation power ΔP(f), where f is the modulation frequency of the incoming radiation power, and it can be written as in the case of a constant current biased bolometer:

$$\Re_V(f) = \frac{\Delta V(f)}{\Delta P(f)} = \frac{\eta \times I}{G_{eff}\sqrt{1+(2\pi f \tau)^2}} \times \frac{dR}{dT}, \quad (1)$$

where η is the absorption coefficient (dimensionless), I is the bias current (in A), G_{eff} is the effective thermal conductance of the device (in W·K^{-1}), $\tau = C/G_{eff}$ is the effective thermal time constant (in s), C is the thermal capacitance (in J·K^{-1}).

The exchange of heat between the active area of the sensor and the environment is given by the effective thermal conductance G_{eff}, which is defined by taking into account the self-heating effects and the geometrical thermal conductance as:

$$G_{eff} = G - I^2 \times \frac{dR}{dT}, \quad (2)$$

In order to fabricate sensitive bolometers, the thermal conductance has to be as small as possible. The absorption, the derivative of R with T and the bias current have to be as high as possible. In the meanwhile, in order to keep thermal time constant low, small thermal capacitance is required. Suspended thin films are then a good solution for achieving both high sensitivity and low thermal response time (i.e., high cut-off frequency), by reducing simultaneously both G and C.

3. Experimental Details

The studied bolometer has a detection area of 75 × 75 μm^2, made of 13 suspended LSMO/CTO lines of width 4 μm separated by about 2 μm. The 50 nm thick LSMO layer has been epitaxially deposited by reactive molecular beam epitaxy [9,10] onto $CaTiO_3$ buffered silicon substrates. The suspended lines were fabricated by using the isotropic nature of the reactive ion etching of the silicon in SF_6 gas as described in [8]. A reference suspended bridge have been also fabricated (width = 4 μm, length = 100 μm, thickness = 10 nm).

Electrical characteristics have been performed using a sample holder placed in a vacuum chamber (at a pressure of about 0.5 × 10^{-3} mbar). Liquid nitrogen was used to cool the sample and a temperature controller using a platinum sensor and a simple Proportional-Integral-Derivative (PID) loop set the sample temperature during measurements in the 240–350 K range [11,12,13].

For the optical characterization set-up, a laser diode emitting at wavelength of 635 nm and nominal power of 5 mW was used as the modulated radiation source. The radiation beam exiting the laser diode passed through a beam splitter cube, which separated the beam into two paths, one on the sample and one on the photodiode. The laser beam that arrives on the sample was focused and highly attenuated. The power received by the LSMO bolometer was evaluated by knowing the transmission coefficients of the optical elements and by reading the output signal of the photodiode.

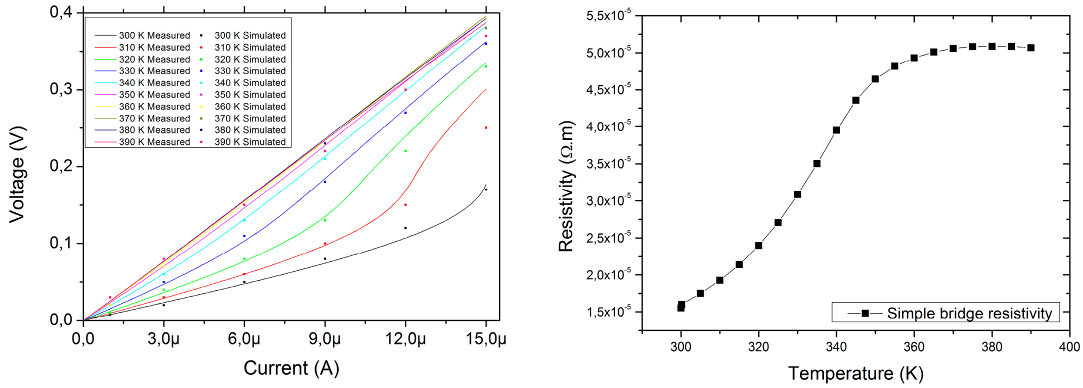
4. Results and Discussion

The electrical characteristic of the simple bridge was measured in the 300–390 K range (Figure 1a). R(T) curve was fitted using a polynomial of degree 9 and was implemented into the COMSOL simulation software. Electro-thermal analysis has been performed assuming only heat transfer conduction mechanisms.

At low bias current the electrical resistance has an ohmic behaviour. At high current, I-V curves are non-linear due to self-heating in the non-linear behaviour sensor in R(T), see Figure 1b.

The electrical resistance R of the 75 × 75 μm^2 suspended bolometer was measured as a function of temperature T between 240 and 340 K. The maximum value of dR/dT was found to be 72 Ω·K^{-1} at 320 K and the maximum TCR was of 1.9 × 10^{-2} K^{-1}, similar to literature [6].

The thermal conductance was measured from current versus voltage and R(T) characteristics. Values around 9 × 10^{-6} W·K^{-1} were found in the 270–330 K range. Compared to thermal conductance measured on non-suspended LSMO films [14], we thus observe a reduction by 3 orders of magnitude, thus letting expecting an increase of the sensitivity by 3 orders of magnitude.

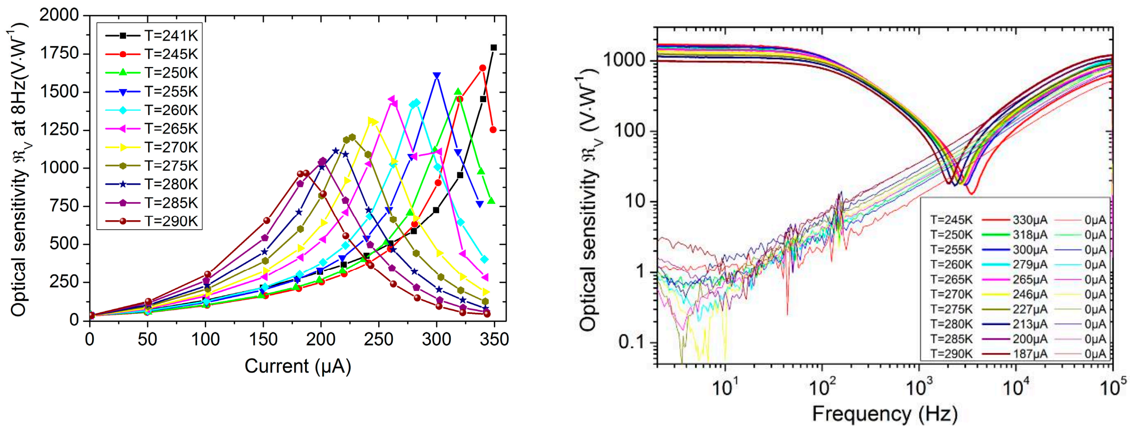


(**a**) (**b**)

Figure 1. (**a**) Electrical resistivity versus temperature in the 300–390 K range at I = 0 A; (**b**) Measured and simulated simple bolometer voltage versus current for temperatures in the 300–390 K range.

Optical characterization using low incident power (up to 20 μW) have been performed. The optical sensitivity at 8 Hz (in the bandwidth) versus bias current at different fixed temperatures is shown in Fig. 2. Higher optical sensitivities can be reached by lowering the sample temperature and increasing the bias current, so that the maximum of dR/dT can be reached thanks to Joule effects. At room temperature, measurements presented in Figure 2a show that the maximum of sensitivity about 1000 $V{\cdot}W^{-1}$ is reached at a bias current of 187 μA compatible with the LSMO absorption (η = 0.8) [4].

Finally Figure 2b shows the measured optical sensitivity versus frequency in the 1 Hz–100 kHz range at different temperatures and at the optimal bias current where the sensitivity was found to be maximum. The measured curves are typical of low pass filters, as expected from Equation (1). At 290 K (resp. 245 K), the optical sensitivity is 944 $V{\cdot}W^{-1}$ (resp. 1666 $V{\cdot}W^{-1}$) and the cut-off frequency is 145 Hz (resp. 95 Hz). Above few kHz, we observed a non-bolometric behaviour of the optical response, which actually exists at a bias current of 0 μA. This behaviour may be due to photovoltaic effects in the LSMO/CTO/Si structure. Further studies are in progress in order to fully characterize this interesting non-bolometric response.



(**a**) (**b**)

Figure 2. Optical characterization (**a**) Optical sensitivity as a function of the bias current for temperatures in the 240–290 K range; (**b**) Frequency response of the LSMO suspended bolometer measured at the optimal current for temperatures in the 245–290 K range.

5. Conclusions

The optical characterization of suspended LSMO bolometers was presented. The maximum TCR was found to be 1.9×10^{-2} K^{-1}, which corresponds to expected values for LSMO. The thermal conductance was measured in the 8–10 × 10^{-6} $W{\cdot}K^{-1}$ range, which is reduced by 3 orders of magnitude compared to non suspended LSMO bolometers. Optical sensitivity of about 1000 $V{\cdot}W^{-1}$ could be measured at room temperature with response time around 1 ms. The simulations results are presented and close to the experimental IxV curves for different currents. Our results thus demonstrate that both sensitive and fast uncooled bolometers can be fabricated using suspended LSMO thin films. Future studies are being conducted in order to improve the performance of the LSMO bolometers, varying the size and number of suspended lines, the geometry and the LSMO film thickness.

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Conflicts of Interest: The authors declare no conflict of interest.

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