Study of Dynamic Thermal Phenomena during Readout of Uncooled Titanium-based Microbolometer

Piotr Zajac[1], Michal Szermer[1], Cezary Maj[1], Wojciech Zabierowski[1], Mykhaylo Melnyk[2], Oleh Matviykiv[2], Andrzej Napieralski[1], Mykhaylo Lobur[2]

1. Dept. of Microelectronics and Computer Science, Technical University of Lodz, Wolczanska street 221/223, 90-924 Lodz, POLAND, e-mail: pzajac@dmcs.pl

2. CAD Dept., Lviv Polytechnic National University, UKRAINE, Lviv, S. Bandery street 12, e-mail: mlobur@polynet.lviv.ua

Abstract – **Thanks to modern simulation tools, a designer can study the properties of MEMS devices before they are actually fabricated. In this paper, we perform a study of dynamic thermal phenomena occurring in Ti-based microbolometer using Finite Element Method (FEM) simulation in Ansys Workbench® environment. We show that even in the case of pulse-based device readout, the Joule heat generated by the current flowing through the microbolometer can significantly increase transient microbolometer temperature.**

Keywords – **MEMS, microbolometer, finite element method, dynamic thermal simulation.**

I. Introduction

Bolometers are used to measure electromagnetic radiation, basing on the quite simple principle: when the radiation heats up a layer of material, it changes its resistance which can be then measured and quantified. Thus, the original radiation intensity can be calculated. Microbolometers use the same principle but in the micro scale: they have usually the size of several micrometers and are most commonly used to measure infrared radiation in thermal cameras. Several hundred microbolometers organized in a rectangular array form together a complete radiation sensor. Note that each microbolometer in the array represents one pixel.

A typical simplified cross-section of a microbolometer is presented in Fig. 1. The IR-absorbing layer is hung over the substrate because it has to be thermally isolated as much as possible from the substrate. The absorbing material has to have a high thermal coefficient of resistance (TCR), therefore the materials which are most often used in microbolomter fabrocation are titanium [1], [3], amorphous germanium-silicon [5], vanadium oxide [6] or even CMOS n-well layer [4]. An additional mirror is usually put under the IR-absorbing layer to reflect back any radiation which may have passed through and improve detectivity.

However, the structure presented in Fig. 1 is very simplified. In reality, such devices are much more complex. This section briefly summarizes the desired properties of a microbolometer. First, the surface of the radiation-absorbing layer has to be of course as large as possible. Second, it has to be as thin as possible but obviously rigid enough to prevent the collapse. Third, it should be made from conducting material but have relatively high resistance. Since these requirements are sometimes contradictory, a special design is needed. Fig. 2a shows the microbolometer from above. Note that the absorbing material has a spiral shape. Thus, its length (and therefore resistance) is maximized and the surface is still quite large. To further maximize the absorbing surface, the active layer is put inside two other layers, which are made of isolator, usually silicon nitride (see Fig. 2b).

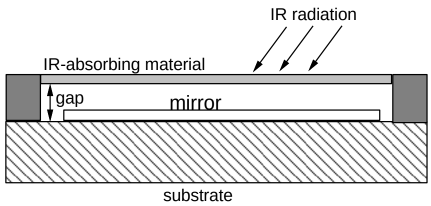

Fig.1 Simplified cross-section of a microbolometer.

The resistance of the absorbing material is often measured using Wheatstone bridge [2]. Other readout circuits are also possible but most of them are based on reading the voltage on the microbolometer. However, it also means that it is necessary to apply bias current to the IR-absorbing layer. It was discovered [6] that the increase of the bias current improves the device detectivity and responsivity. On the other hand however, it also has a negative effect because it increases unwanted heat generation in the microbolometer. More precisely, with bias current applied, the active layer is not only heated up by the energy of the absorbed radiation but also by Joule heating caused by the bias current. This in turn can have a twofold impact on the operation of the device: first, when calculating the radiation based on the resistance change, an error will be produced because of the resistance change caused by the Joule heat and second, excessive temperature can have a negative impact on the micro-bolometer parameters: it was estimated in [1] that the detectivity significantly drops if the temperature of the active material exceeds a given temperature. In our previous work [7], we performed electro-thermal simulations of the microbolometer and estimated the maximal bias current I_{MAX} for a given radiation, at the condition that the maximal temperature T_{MAX} is not exceeded. We also showed that in some cases, the heat generated by the bias current cannot be neglected. However, in our previous approach, we assumed that the bias current is constantly flowing through the microbolometer. In this paper, we analyze a more complex case, in which the bias current is applied as a pulse, only during readout. This of course should reduce the Joule heat, but can still have a negative effect on the micro-bolometer performance.

II. MICROBOLOMETER DESIGN

Our simulated microbolometer structure is similar to the one presented in [1]. It is described in detail in our precious paper. In short, the pixel size is 50x50 μm^2. The structure hangs 2 μm above the substrate. The absorbing material is made from titanium and is 0.07 μm thick. The titanium layer is "sandwiched" between two membranes made of silicon nitride, 0.6 μm and 0.35 μm thick. However, several changes have been made to the structure in comparison with our previous version. The supporting legs are made from chromium and are about 2 μm high. The structure, with and without the isolation membrane, is shown in Fig. 2.

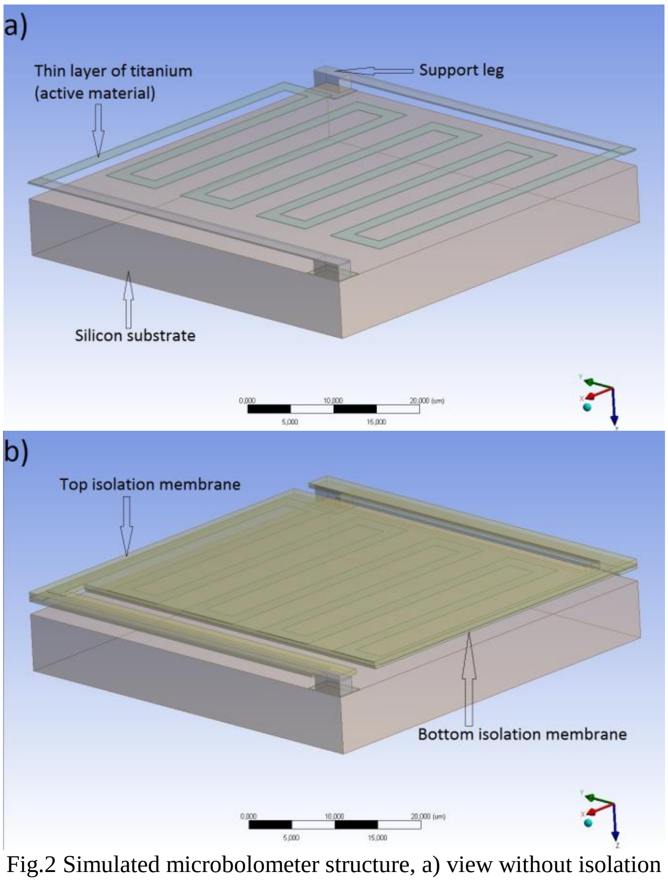

Fig.2 Simulated microbolometer structure, a) view without isolation membranes, b) view with isolation membranes.

Simulations were performed using FEM simulator Ansys WorkBench®. All necessary material parameters were defined and included in the simulator. They are listed in Table I. The resistivity of titanium is normally one order of magnitude lower. However, in our work we consider a thin film of titanium, which has different properties than bulk Ti.

TABLE 1

MATERIAL DATA

	Resistivity [Ωm]	Thermal conductivity [Wm^{-1}C^{-1}]	Specific heat [Jkg^{-1}C^{-1}]
Titanium (thin film)	1.6e-6	22	540
Silicon nitride	1.0e14	30	700
Silicon	1.0e-3	124	702
Chromium	1.3e-7	93.9	460

The simulation process graph is presented in Fig. 3. The problem here is that Ansys Workbench® does not support transient electric simulation which is necessary in our research. Therefore, a workaround was needed. First, we performed steady-state electric and thermal simulations. Second, by comparing the output temperature, we discovered the value of internal heat which produces the same temperature as a given current. Finally, we ran a transient thermal simulation, where the internal heat has a form of a pulse with amplitude equal to the previously calculated steady-state value. Thus, it can be concluded that the effect of the internal heat pulse is equivalent the effect of the current pulse during the readout of the microbolometer.

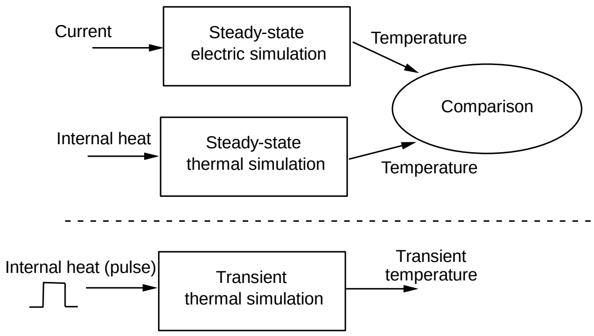

Fig.3 Simulation process graph.

III. SIMULATION RESULTS

Figures 4 and 5 present the obtained transient thermal simulation results. It can be seen that the current pulse causes the temperature to rise almost linearly with time. Of course, the longer the pulse and the higher its amplitude, the higher maximum temperature will be reached. For example, as shown in Fig. 4, a current pulse of 0.25 mA and the duration of 200 μA, is capable of rising the temperature to 32.2 ºC, i.e., by 10.2 ºC with respect to the ambient temperature, which is quite significant. Therefore, on one hand, the amplitude of the pulse should be as small as possible to reduce this effect. However, on the other hand, to increase the detectivity of the device the applied bias current should be as high as possible. Thus, two contradicting constraints appear during the design of the microbolometer and the readout circuit. Our model can serve as a useful tool for the designer to find a tradeoff between these constraints. Fig. 5 shows the results of simulations performed for various current pulse amplitudes and durations. Thanks to these data, a designer can roughly estimate the best value for bias current, taking into account the acceptable temperature rise due to Joule heating and the requirements of the readout circuit (bias current pulse duration).

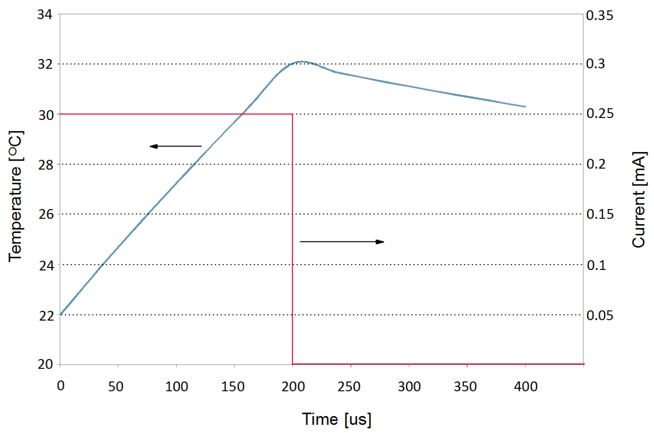

Fig.4 Temperature rise due to the application of bias current impulse.

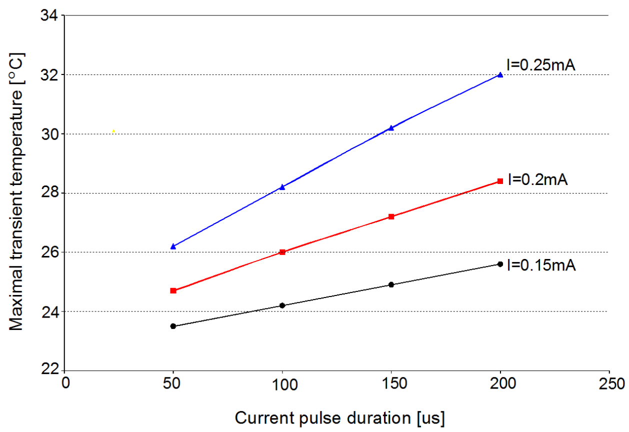

Fig.5 Maximal transient temperature as a function of current pulse duration

IV. Conclusions

A transient thermal simulation of a Titanium-based microbolometer model was performed in Ansys Workbench®. Thanks to the simulation results it was possible to estimate the temperature rise in the device due to bias current pulse for various values of pulse amplitude and duration. Our model may serve as a useful tool during the process of designing microbolometers and may significantly reduce the time used for the design. In the future, authors are planning the creation of an analytical model of the device, in the electric, thermal and mechanical domain. Also, other device designs with other materials will be studied.

Acknowledgements

Results presented in the paper are supported by Marie Curie International Research Staff Exchange Scheme Fellowship within the 7th European Community Framework Programme - - EduMEMS - Developing Multidomain MEMS Models for Educational Purposes, no. 269295.

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