Electrothermal FEM Simulation of Uncooled Titanium-based Microbolometer

Piotr Zajac[1], Cezary Maj[1], Michal Szermer[1], Wojciech Zabierowski[1], 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.p.lodz.pl

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

Abstract – **Current MEMS design tools allow accurate device simulation and predicting MEMS properties before their actual fabrication. In this paper, we study the Ti-based microbolometer using FEM simulation in Ansys Workbench environment. We show that our model is accurate by comparing it to the published experimental data. It is also demonstrated for which conditions the temperature increase of the device depends mostly on bias current and when it is mostly caused by radiation. We also estimate the maximal polarization current, which ensures that the device stays cooler than 80°C for various radiation power densities.**

Keywords – **MEMS, microbolometer, electrothermal simulation, finite element method.**

I. Introduction

Bolometers are, in general, devices which allow measuring electromagnetic radiation. They are based on the principle that the radiation heats the material, which changes its resistance. By measuring this resistance change it is possible to calculate the amount of radiation that the material was exposed to. Microbolometers use the same principle but are mostly used for thermal cameras. Usually, a complete IR radiation-measuring device is composed of several hundred microbolometers organized in a square array where each microbolometer represents one pixel.

Fig. 1 presents a simplified structure of a typical microbolometer. It has a bridge-like structure, to enable thermal isolation of IR-absorbing material from the rest of the structure. The absorbing material is located between two membranes made from isolator and is usually made from a material with high TCR coefficient, for example titanium [1],[3], amorphous germanium-silicon [5], vanadium oxide [6] or even CMOS n-well layer [4]. A reflecting layer is added to reflect back any radiation, which passes through the active material.

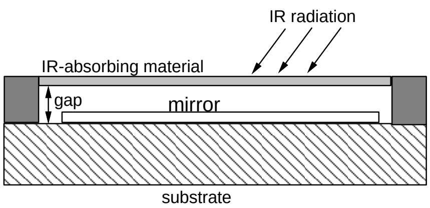

Fig.1 Simplified cross-section of a microbolometer.

The resistance of the absorbing material is often measured using Wheatstone bridge [2], as presented in Fig. 2. The advantages of this approach are that the measurement is independent of the used voltage, no calibration is necessary and, most importantly, it allows measuring even very small changes of resistance. Note that in this circuit the polarization current (bias current) flows through the microbolometer.

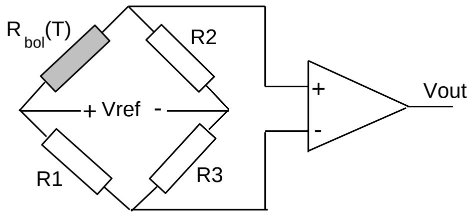

Fig. 2 Measuring circuit based on Wheatstone bridge.

On one hand, it is well known [6] that increasing the bias current improves the detectivity and responsivity of the microbolometer. On the other hand, it also has a negative effect because it increases power dissipation in the microbolometer. As a result, the microbolometer is not only heated by the absorbed radiation power (which is useful), but also by Joule heating caused by the bias current. Too high temperature can have a detrimental impact on the microbolometer parameters: it was estimated in [1] that the detectivity significantly drops if the temperature of the active material exceeds 370°C. Therefore, we decided to perform electro-thermal simulations of the microbolometer, which should answer the following question: for a given radiation power being absorbed, what is the maximal bias current I_{MAX} such that the maximal temperature T_{MAX} is not exceeded? Additionally, we ran the same simulations but without taking into account the bias current to quantify how much of the heat is generated by the radiation and how much by the polarization current.

II. Simulated Microbolometer Structure

Our simulated microbolometer structure is largely based on the similar structure presented in [1]. The pixel size is 50x50 μm^2 in size. The structure is hanging 2 μm above the substrate, supported by two legs. The absorbing material is a layer of titanium which is 0.07 μm thick. Its serpentine shape allows the increase of the detectivity. The titanium layer lies between two membranes made of silicon nitride. The top membrane is 0.6 μm thick while the bottom one has 0.35 μm thickness. The structure is depicted in Fig.3.

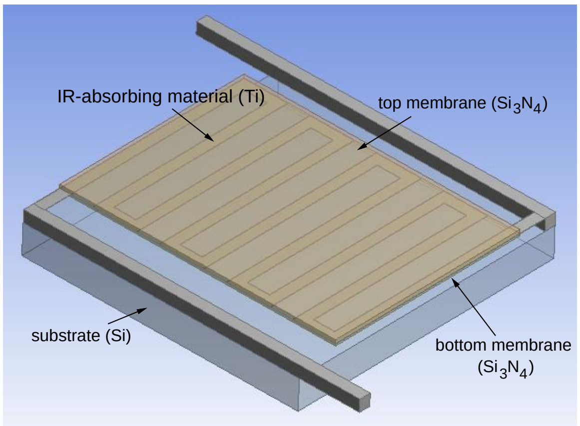

Fig.3 Simulated microbolometer structure.

Simulations were performed using finite element method simulator Ansys WorkBench®. All necessary material parameters were defined and included in the simulator. They are listed in Table I.

TABLE 1

MATERIAL DATA

	Resistivity [Ωm]	Thermal conductivity [$Wm^{-1}C^{-1}$]
Titanium (thin film)	1.6e-6	22
Silicon Nitride	1.0e14	30
Silicon	1.0e-3	124

Note that the resistivity of titanium is normally one order of magnitude lower. However, here we consider a thin film of titanium, which has different properties than bulk Ti.

The simulation process graph is presented in Fig.4. Electric simulations were performed first. Their results, namely the Joule heat generated in the structure, serves as an input load of the second, thermal simulation. Of course, in the thermal simulation, we also take into consideration the radiation absorbed by the microbolometer. For both simulations, the parameters specified above are fed into the simulator.

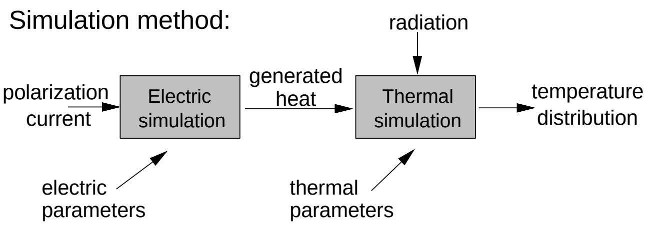

Fig.4 Simulation process graph.

During electric simulation, to one end of the active material zero voltage was applied and into the opposite end we injected a current, which represents polarization current of the Wheatstone bridge. During thermal simulation, a constant heat flow is applied perpendicularly to the top surface of the microbolometer, which represents the radiation.

III. SIMULATION RESULTS

It is worth emphasizing that the simulation results proved to be quite accurate when compared with experimental results given in [1]. The thermal conductance of the bolometer in [1] was estimated at 1.68 μW/K, whereas our simulations show the value of 1.52 μW/K, which may be considered very close. Additionally, in [1] authors reported that the device temperature of 370°C was measured for the bias current of 450 μA. In our simulations the same bias current heated up the microbolometer to 337°C, which again shows a good correlation between the simulations and real-life measurements. It may be then assumed that our microbolometer model designed in Ansys may be used for a rough prediction of the operation of real fabricated devices. Therefore, it can be of great help to designers, who need to tune up device parameters before sending the design for manufacturing. Our simulations were performed for three values of radiation power density, derived from the well-known Stefan-Boltzmann Law (Eq.1):

$$j = \varepsilon\, \sigma\, T^4 \qquad (1)$$

where j is the radiated power per unit surface, T is the temperature in Kelvins, ε is the emissivity and σ is the Stefan-Boltzmann constant equal to $5.67 \cdot 10^{-8}$ $Wm^{-2}K^{-4}$. We assumed the emissivity ε=0.6 and calculated the radiation power density for three cases:

A. 100°C,
B. 200°C,
C. 400°C,

which are, respectively, 0.066 Wcm^{-2}, 0.17 Wcm^{-2} and 0.7 Wcm^{-2}. These power densities were then used in our thermal simulations, representing radiation absorbed by the microbolometer.

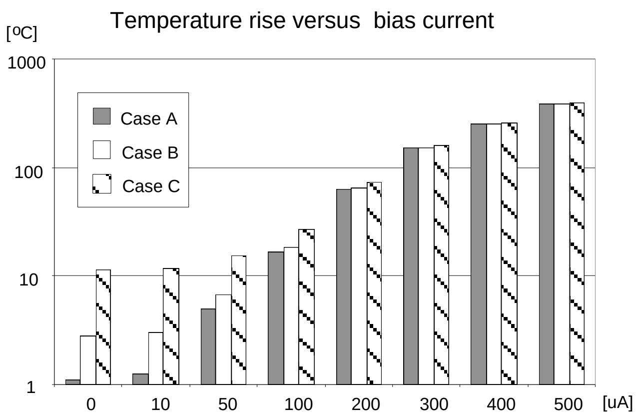

Fig.5 Increase in temperature of the device as a function of bias current for various radiation power densities (cases A, B and C).

Fig. 5 presents the maximal steady-state temperature of the microbolometer as a function of polarization current for various levels of radiation power absorbed by the device. We can see that for the case A and no polarization current, the change in the device temperature is very small, equal to only 1.1°C. It will then have an insignificant impact on the overall device temperature rise. The impact of Joule heating due to bias current is also quite small for low current values, but then increases rapidly and reaches even hundreds of degrees.

In case B, the impact of radiation-based heating is still small, as the microbolometer only increases its temperature by 2.8°C without the bias current. It has then an very small impact on the total temperature increase if bias current is above 50 μA. The impact of Joule heating is very similar to the previous case. In case C it is visible that the radiation-based heating can no longer be completely neglected, because without polarization current flowing, it increased the microbolometer temperature by 11.4°C. However, Joule heating still dominates for currents higher than 100 μA.

As mentioned previously, we used our simulation results to estimate the maximal value of bias current that can be applied to the device without exceeding a chosen maximal temperature T_{MAX}. Let us assume quite low T_{MAX} =80°C. Fig. 6 depicts the calculated I_{MAX} as a function of radiation power density, which is applied to the microbolometer.

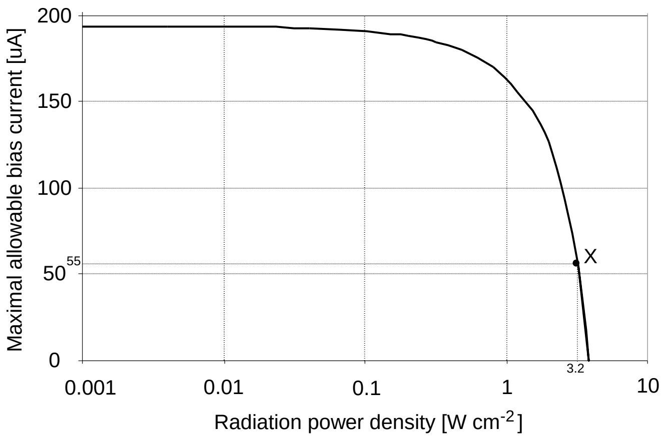

Fig.6 Maximal allowable bias current for T_{MAX} =80°C as a function of radiation power density.

Naturally, for low values of radiation power density, the maximal current I_{MAX} is almost constant and only when power density exceeds 0.02 Wcm^{-2} it starts visibly decreasing. Let us analyze a data point for clarity. For example point X in Fig. 6 shows that if the source of radiation has a radiation power density of 3.2 Wcm^{-2}, and if we want to ensure that the device temperature does not exceed 80°C, we are only allowed to apply the bias current of 55 μA. Such calculations can be very useful during the design stage: we are quickly able to improve the design without the time needed for fabrication and measurements.

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IV. CONCLUSIONS

A new microbolometer model was designed in Ansys Workbench®. Simulations results proved to be close to the published experimental data. Thanks to the model it was possible to estimate the temperature rise in the device due to bias current and due to radiation. Other simulations allowed for estimating the maximal allowable bias current for a given radiation power density. The model may serve as a useful tool during the process of designing microbolometers and may significantly reduce the time needed for the design. In the future, authors are planning dynamic thermal simulations of microbolometers. Dynamic thermal simulation may be more accurate when bias current is not constant and is only applied during readout and thus has a form of periodic pulses. Other alternative device architectures will be also studied.

V. ACKNOWLEDGEMENTS

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