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# Analytical Thermo-electric Model of Uncooled Microbolometer

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## Abstract

Modelling of Microelectromechanical systems (MEMS) is a field of active research. An analytical model of a MEMS device allows significantly reducing the design time because simulating such a model is much faster than Finite Element Method (FEM) simulation. The main idea presented in this paper is the analytical thermo-electric model of uncooled microbolometer. It is shown that the model gives accurate results for a wide range of geometric parameters and material properties.

**Keywords:** MEMS, microbolometer, FEM simulation, modelling.

## 1. Introduction

The detailed simulation of Microelectromechanical systems (MEMS) using Finite Element Method (FEM) is usually quite time-consuming during the early design phase, especially when transient simulation is concerned. Repeatedly computing the results for hundreds of time points for every change in the device dimensions or material properties can significantly slow down the design process. Therefore, in this paper, we propose the thermo-electric analytical model of uncooled microbolometer and demonstrate its accuracy by comparing it to FEM simulation.

## 2. Microbolometer structure

A microbolometer operates in both electrical and thermal domain. Its main operating principle is based on measuring the resistance change of a material due to absorbed infrared radiation generated by a body whose temperature we want to estimate. Therefore, two conclusions follow: first, the active material should be thermally isolated from the readout circuit. Consequently, the microbolometer is typically designed as a bridge suspended several micrometers above the substrate. Second, a conductor with high Temperature Coefficient of Resistance (TCR) should be used. Currently, the most commonly used materials are: vanadium oxide [Chen et al., 2001], amorphous silicon [Moreno et al., 2012], titanium [Saxena et al., 2008] etc. However, even materials with relatively high TCR exhibit quite small resistance change when used to measure the temperature of radiating objects. Consequently, an additional feature of microbolometers which increase their responsivity is the spiral shape of the active material (see Fig 1). Also, the layer of active material should be very thin, typically in the range of dozens to hundreds of Angstroms. These features produce however additional problems. First, due to the shape of the active material, its surface is quite small while it should be as large as possible to absorb as much radiation as possible. Second, a very thin layer of serpentine-shaped material would be unlikely not to collapse to the substrate.

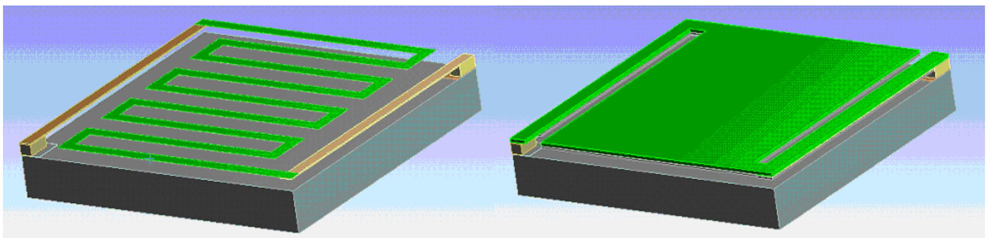

Fig. 1 Microbolometer structure without isolating membrane (left) and with isolating membrane (right)

The solution to these problems is to use another material, an isolator, on the bottom and on the top of the conducting material (see Fig 1). The isolator has no effect on the electrical behaviour of the microbolometer and it significantly improves its properties: it increases the absorbing surface and strengthens the structure hanging above the substrate. The only slight disadvantage (which may be considered as acceptable) is that it increases the heat capacity of the microbolometer.

## 3. Operation of a microbolometer

Let us now investigate step by step the functioning of the microbolometer and identify the most important elements which will be included in our model.

- The radiation falls on the upper surface of the microbolometer. Since the bridge is only connected to the substrate through relatively narrow legs, the radiation practically heats up the bridge only

- The temperature of every point in the top membrane is the same (the temperature distribution is uniform), because the thermal resistance of supporting legs is much higher that the thermal resistance within the top membrane
- Similarly, we may neglect the vertical temperature changes within the membrane
- Thus, from the previous points we may discover the first important parameter of our model: the thermal resistance of supporting legs $R_{TH,legs}$. Other thermal resistances are not necessary for the model to work as long as they are much lower than $R_{TH,legs}$
- Since the radiation is not necessarily constant, if we want to model the transient behavior of the microbolometer, heat capacity has to be included. Since only the bridge is heated up, only the heat capacity of the bridge $C_{TH,bridge}$ should be taken into consideration
- Let us assume that we now want to read the resistance change of the microbolometer. In a typical solution, a constant current is flown through the active material and the voltage at the end legs of the microbolometer is read. However, such a method induces other source of heat into the circuit which in practice cannot be neglected: the Joule heat. To calculate the voltage and the Joule heat, we have to know the electrical resistance of the active material $R_{active}$
- There are also several inputs that have to be taken into account: the bias current $I_{bias}$, the radiation power $P_R$ and the Joule power $P_J$

## 4. Model parameters

The identified parameters depend on the sizes of the particular elements and the respective material properties. In the following analysis we specify all these parameters and explain how we calculate them.

- Resistance of the active material $R_{active}=R$.

This parameter is easily calculated using the simple formula:

$$R = \rho \frac{l_a}{w_a h_a} \tag{1}$$

where $\rho$ is the resistivity of the material and $l_a$, $w_a$, $h_a$ are its length, width and thickness, respectively. Together with $I_{bias}$, the resistance can be used to calculate the Joule power using the well-known equation $P=I^2R$.

- Heat capacity $C_{TH,bridge}=C_{TH}$

Heat capacity of an object depends on its size, its density and its specific heat. Therefore, we identify the following parameters: $l_b$, $w_b$. $h_b$ which are length, width and thickness of the bridge, respectively and $\rho_D$ which is density of the isolating material and $c$ which is its specific heat. Note that we ignored here the influence of the thin layer of the active material on the total value of the heat capacity because typically this layer is much thinner than the top and bottom isolating membranes. Thus, heat capacity is calculated as follows:

$$C_{TH} = \rho_D c l_b w_b h_b \tag{2}$$

- Thermal resistance of the supporting legs $R_{TH,legs}=R_{TH}$

Similarly to its electrical counterpart, thermal resistance can be calculated using the formula:

$$R_{TH} = \frac{1}{\kappa}\frac{l_{leg}}{w_{leg}h_{leg}} \tag{3}$$

where $\kappa$ denotes the thermal conductivity of a material, and $l_{leg}$, $w_{leg}$, $h_{leg}$ are its length, width and thickness, respectively. However, our first experiments with the model have shown that in this case, the thermal resistance of the active layer located in-between the top and bottom membrane cannot be neglected. Consequently, we have to calculate the effective thermal resistance of a block composed from two materials. It can be shown that in such a case, the effective thermal resistance can be calculated as a parallel connection of the thermal resistances of both materials. Therefore, in our model, the final thermal resistance of the supporting leg is given by the following formula:

$$R_{TH} = \frac{R_{TH1}R_{TH2}}{R_{TH1}+R_{TH2}} \tag{4}$$

where $R_{TH1}$ and $R_{TH2}$ can be calculated in the same way using the equation (3) for their respective sizes/material. With all inputs ready, we can calculate the transient temperature of the bridge as a function of the parameters $P_R$, $P_J$, $R_{TH}$ and $C_{TH}$ at any time point using the following equivalent electrical model:

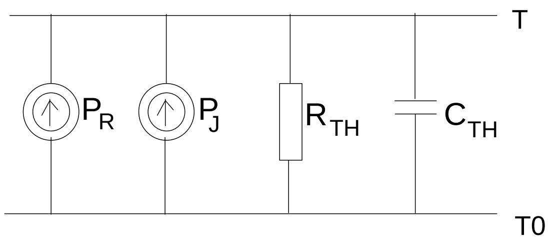


Fig. 2 Equivalent electrical model

## 5. Model verification

To verify our model against FEM simulation (performed using Ansys Workbench), we designed a titanium-based 50x50 $\mu m^2$ microbolometer with silicon nitride $Si_3N_4$ as isolating material (see Fig. 1). All the material data used in Ansys was copied to our model, as well as all the necessary element sizes. The detailed description of the simulation methodology is presented in [Zając et al., 2013]. In short, we use electric steady-state simulation to calculate the Joule heat dissipated inside the active material and then we use it as an input to transient thermal simulation. Of course thermal simulation also includes radiation (represented as a heat flow). The results obtained from Ansys were used as a reference and compared with the results obtained using our analytical model. The model was verified for a wide range of input parameters, i.e., for various geometrical dimensions of the microbolometer and for various material parameters. In this paper, we show the results obtained for three cases.

- Case A: 50x50 $\mu m^2$ microbolometer with titanium as active material and silicon nitride as isolator.
- Case B: 25x25 $\mu m^2$ microbolometer (the same structure as in case A, scaled by 50%)
- Case C: The same structure as in case B, but with all material properties changed

For all cases, we analyzed two types of input parameters. In the first one, the microbolometer is irradiated by a constant heat flow and biased by a costant electrical current. In the second, it is assumed that there is no radiation and the microbolometer is biased by a current pulse. The output of our simulations is the transient temperature of the bridge. The obtained results are shown in Figures 3, 4 and 5. The presented results prove that our model stays valid for various microbolometer dimensions and various material properties. In all analyzed cases the error was lower than 1°C.

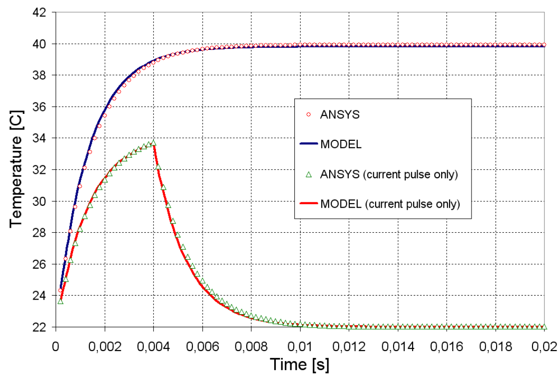


Fig. 3 Model verification for case A

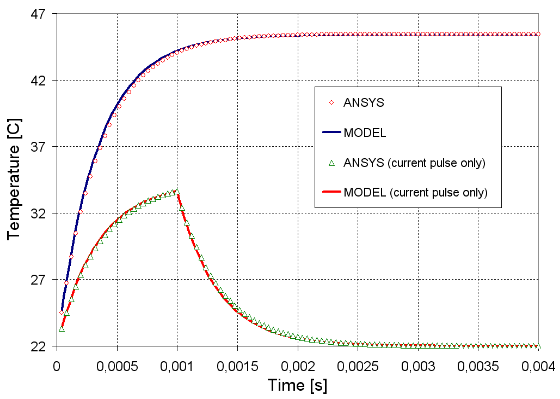


Fig. 4 Model verification for case B

## 6. Conclusions and perspectives

In this paper, a new analytical model of uncooled microbolometer was presented. Such a model allows for fast analysis of microbolometer properties during the early design phase, when FEM simulation may be too time-consuming. Therefore, it helps the designer to reduce the design time by preliminarily choosing the desired dimensions and materials before running the detailed simulation using FEM. While being much faster, the model produces results practically identical to those from FEM simulation. In the future, authors plan to improve the model by including in it mechanical and electrostatic phenomena.

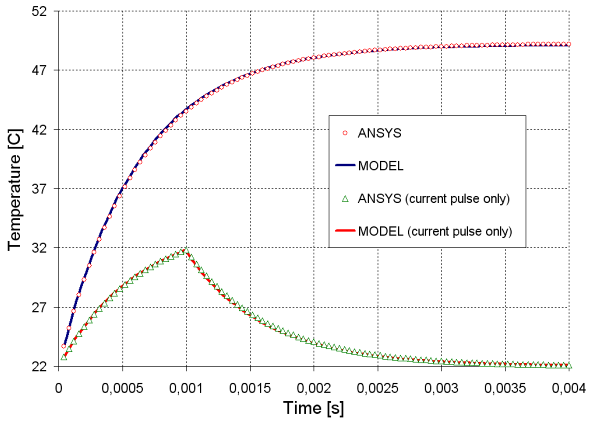


Fig. 5 Model verification for case C

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