THERMAL ANALYSIS OF MICROBOLOMETER

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1. Introduction

The microbolometer is micro electro system (this system belongs to Micro Electro Mechanical System – MEMS – branch) that acts as a sensor of electromagnetic signal within the range of thermal radiation or visible spectrum with the frequencies of electromagnetic waves about several THz.

The basis of microbolometer sensing capabilities consists in process of absorption the radiation energy of specified frequency and wavelength by matching antenna, conversion of the absorbed energy into the heat resulting in heating up the sensitive part of bolometer that finally changes the internal resistance of this sensitive material. This change of resistance is electrically measured and evaluated [1].

The proposed paper deals with design of microbolometer layered structure in terms of thermal Finite Element Method (FEM) analysis. The paper presents static thermal analyses with defined thermal power emitted by laser beam and absorbed by matching antenna into the sensitive part of device. Promising material for sensitive part of bolometer is $La_{0.7}Sr_{0.3}MnO_3$ also denoted as LSMO. This material has suitable temperature-to-resistivity characteristics, that means that modest change in temperature of this sensitive part results in measurable change of its resistivity, so the absorbed electromagnetic radiation of defined frequency can be directly changed into the electrically measurable signal.

2. Design of microbolometer

Fig. 1 shows top and cross-section views of FEM model of proposed microbolometer design with overall dimensions of about $4 \times 4 \times 15.10^{-3}$ mm (square base with small thickness). Because the thickness of microbolometer structure is very small, finite elements with very high aspect ratio had to be used (very thin elements used to describe material changes in layered structure). The bolometer is layered structure, where layers of different material are used for antenna (Au), LSMO sensitive disc, layers ensuring epitaxial growth or etching of bolometer layers – stop layers (BTO, CeO_2, YSZ), layers that mechanically support whole system (single crystalline Si, SiO_2) and bulk material (Si). Layers BTO, CeO_2 and YSZ were modelled as single layer with homogenized material properties because of their very small thickness. Schemes of these bolometer layers are shown in Fig. 2.

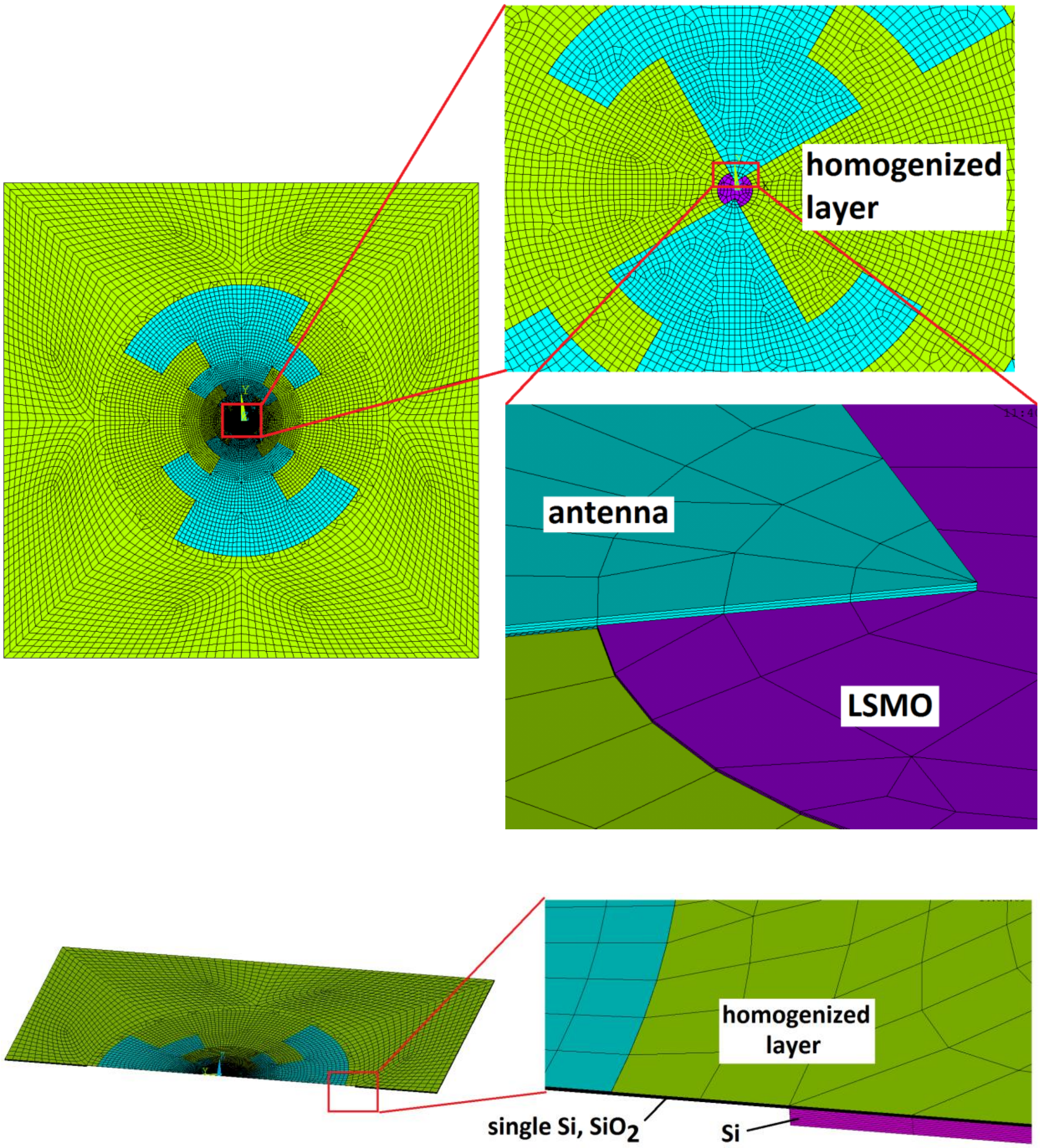

Fig.1: *Design and mesh of microbolometer (top - antenna with LSMO, bottom - thickness of individual layers)*

Two different thicknesses were used for single crystalline Si layer and SiO_2 layer:

- Model 1: model has 2 μm thick single crystalline layer and 1 μm thick SiO_2 layer
- Model 2: model has 0.5 μm thick single crystalline layer and 1 μm thick SiO_2 layer

The goal of thermal FEM analyses was to investigate the influence of thickness of single crystalline Si and SiO_2 layers to maximum value of temperature and temperature distribution in LSMO disc reached under conditions of specified constant heat power homogenously applied into LSMO sensitive disc.

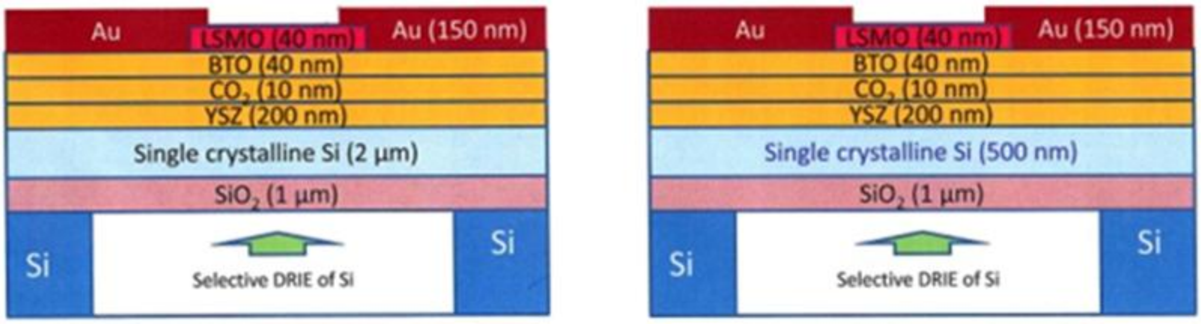

Fig.2: *Scheme of the layered structure of bolometer(left side - Model 1, right side - Model 2),thickness and length of layers are not in scale*

3. FEM model

All thermal steady-state analyses were performed in finite element code ANSYS [2], where 20 node solid elements SOLID 90 was used. Discretized FEM model of microbolometer is shown in Fig. 1, where details of LSMO disc, Au antenna, homogenized layers of BTO, CeO_2 and YSZ and bulk Si substrate and supporting layers (Si and SiO_2) are shown. Considered thermal material properties with constant values are shown in Tab. 1.

Tab. 1. *Thermal material properties of bolometer layers.*

	heat conductivity [W/mK]
Au	314
LSMO (sensor)	1.60
Si Single crystal.	156
SiO_2	1.38
Si (bulk material)	156
YSZ	1.55
BTO	2.61
CeO_2	6.00
YSZ	1.55
BTO+CeO_2+YSZ	1.90

Thermal boundary conditions and thermal power of the FEM model were considered as follows:

- bottom area of Si bulk layer: 20 °C (this temperature was considered as reference value)
- heat transfer to surroundings: 2 different conditions are considered:
  - system is placed into the ideal environment – vacuum, where maximum heat up (ideal heat up) is expected in the model
  - convection with parameters: film coefficient 100 W/m^2K, ambient temperature 20°C
- thermal power defined for volume of the LSMO disc: 1 mW
- no radiation was considered.

Obtained results - distribution of temperature in individual layers of both considered layer thickness compositions for system placed in vacuum are shown in Fig. 3 and Fig. 4. Maximum temperature in Model 1 is 23.2°C, i.e. rise of temperature due to thermal power 1 mW is 3.2°C. Maximum temperature in Model 2 is 29.4°C and temperature rise is 9.4°C.

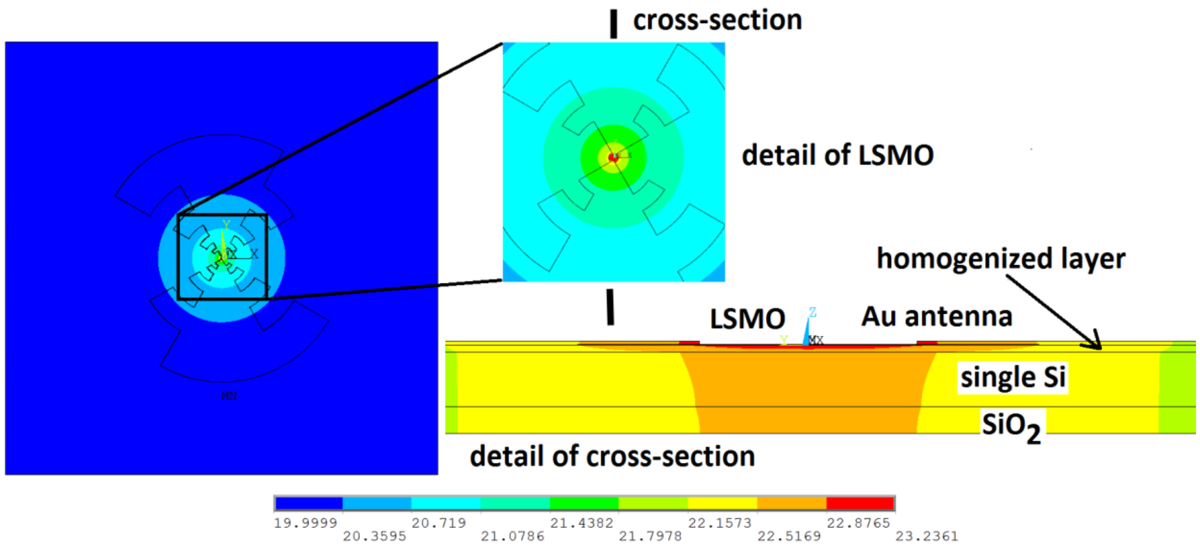

Fig.3: *Model 1 - temperature distribution of the steady-state simulation*

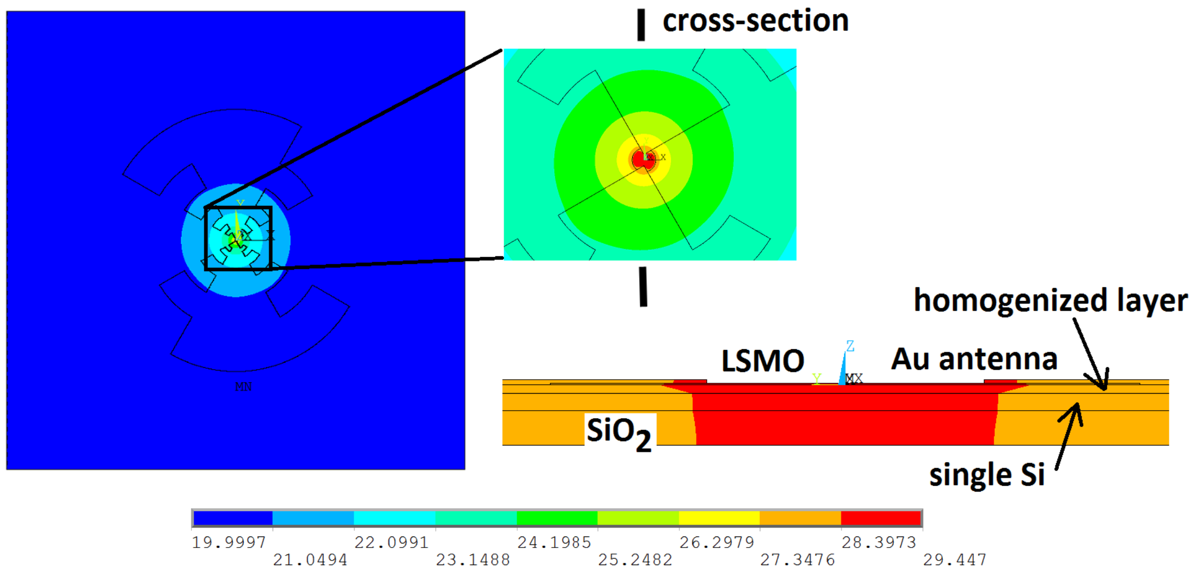

Fig.4: *Model 2 - temperature distribution of the steady-state simulation*

As it can be seen, thinner layers for mechanical support of the microbolometer active part (Model 2) ensure higher temperatures in LSMO disc itself under the same thermal power conditions received from antenna.

Comparison of temperature distribution in Model 2 for vacuum and convection heat transfer to surroundings are shown in Fig. 5. As it can be seen from this figure, there is only a little temperature difference between both analyzed systems. This temperature difference is 0.8°C. Similar small influence of convection for steady state thermal analysis can be also observed in Model 1.

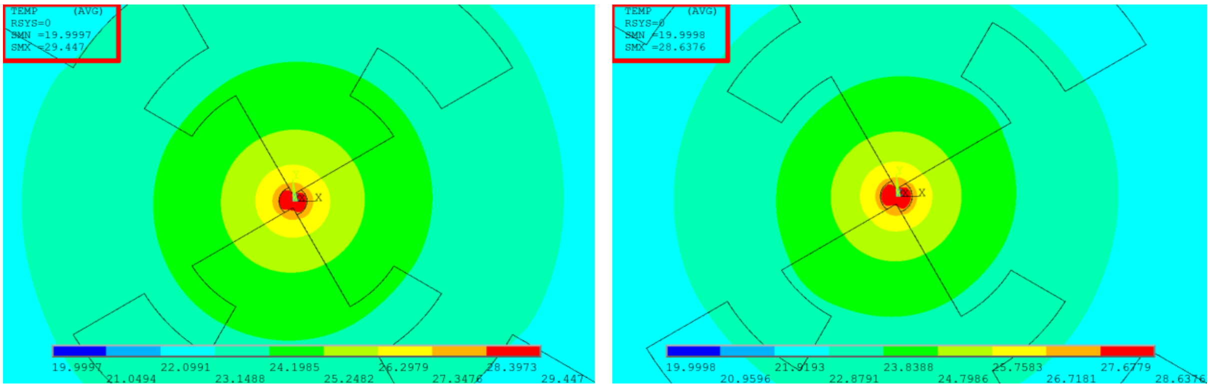

Fig.5: *Model 2 - temperature distribution of the steady-state simulation for vacuum and convection heat transfer to surroundings*

4. Conclusion

There were two different designs of the microbolometer layered structure presented in this paper. Defined thermal power with specified THz frequency received by antenna into the sensitive layer caused relatively small heat up of the system. This change in temperature can by transformed into electrical signal by change of resistivity of the LSMO sensing disc. This ensure direct measuring of the radiation signal. The model with thinner mechanical layers has better sensitivity but the mechanical load capacity has to be investigated further.

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References:

[1] T. Lalinský, et. al.: *Thermo-mechanical Analysis of Uncooled La0.67Sr0.33MnO3 Microbolometer Made on Circular SOI Membrane.* Procedia Engineering, 2016, Volume **168**, Pages 733-736. ISSN: 1877-7058.

[2] ANSYS 15, Theory manual