IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.
PP 47-52
www.iosrjournals.org

Designing of Sensing Element for Bolometer Working at Room Temperature

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Abstract: *Bolometer is a highly sensitive thermal detector used for detection of heat or electromagnetic radiation. It has vast applications extending their range to the field of military, medical, astronomy, particle physics and in day-to-day use thus devising it as a significant part of our society. The basic operation principle is that it measures the incident radiation power through absorption resulting a specific change in a measurable quantity. This present work aims at designing of a MEMS based bolometer analysing the variation of thermal conductivity in response to the temperature by using COMSOL Multiphysics®. Here the temperature change occurs due to the incident infrared radiation. The proposed bolometer design is efficient of operating at elevated temperatures (>273 K) and thus can be implemented in a Wheatstone bridge to make it a modifiable detector for better sensitivity.*

I. Introduction

Bolometer is light, rugged, reliable and low cost resistive thermal detectors generally used for low temperature operation. These are radiation power detectors constructed from a material having very small thermal capacity and large thermal coefficient so that the absorbed incident radiation produces a large change in resistance. It consists of an absorptive element connected to a thermal reservoir (or heat sink) and a thermopile attached to it for measurement of temperature as shown in Fig.1.

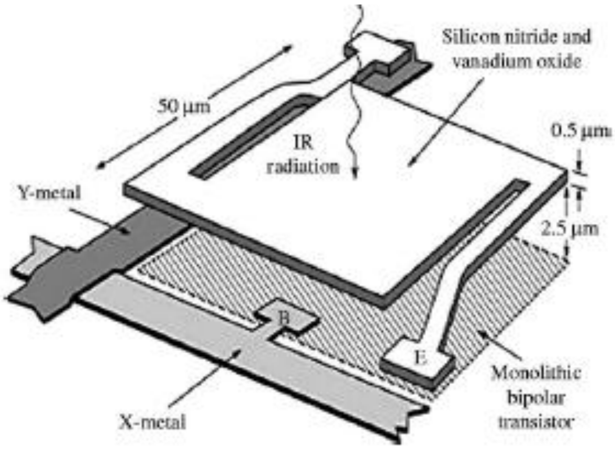


Fig.1. The typical bolometer structure

Instead of a thermopile a resistive element can also be used so that the change in temperature varies the resistance thus measuring the resulting current or voltage change which is proportional to the absorbed power. When an incident electromagnetic radiation impinges on the bolometer surface it heats up, thus, changing the temperature of the absorber surface. The heat is then transferred immediately to the substrate where the temperature change is measured. The substrate is made such that it takes some time to transfer the heat to the reservoir so that the measurement can be carried out during that period.

In this paper, the proposed model of bolometer measures the change in thermal conductivity with respect to the temperature change. The working model is so designed that it can be implemented using Wheatstone bridge. This implementation allows the device to act as an adjustable thermal detector, thus, providing improved sensitivity of the incoming radiation. This work aims for operating at elevated temperatures i.e., temperature raised above the room level (>273K). This model is designed using COMSOL Multiphysics.

This paper is organized as follows. First, a brief overview on COMSOL Multiphysics is being discussed followed by the model description, result analysis and future improvements. Finally, the last section concludes the paper.

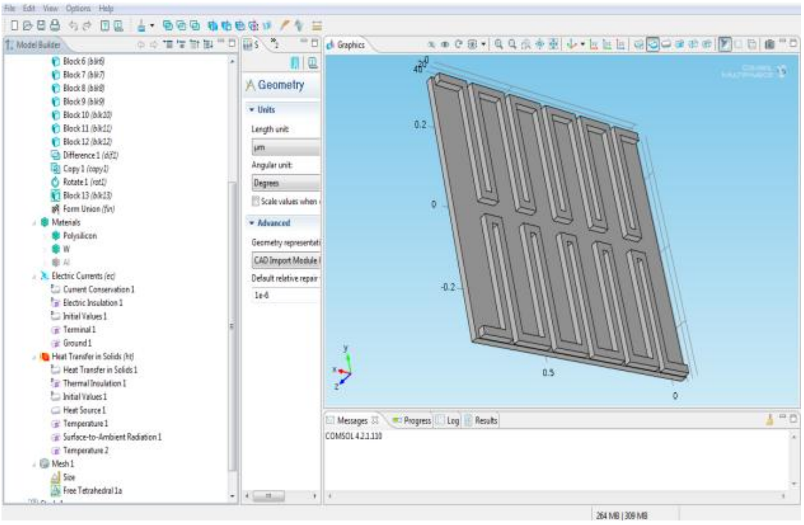
II. Overview Of Comsol Multiphysics

The software tool used in this work is COMSOL Multiphysics. This software is a powerful finite element (FEM), partial differential equation (PDE) solution engine. It is an analysis, solver and simulation software/ FEA software package for various physics and engineering applications, easily coupled phenomena, or multiphysics. The package is cross platform i.e., it can be used in various operating systems.

The basic software consists of eight add-on modules expanding its capabilities in the diversified application areas of AC/DC, Acoustics, Chemical Engineering, Earth Science, Heat Transfer, MEMS, RF, and Structural Mechanics. It also has other supporting softwares such as CAD Import module and Material Library.

This software is a very efficient and powerful interactive environment for device modelling. It supports modelling of device in 1D, 2D and 3D coordinate systems. It consists of three sources of materials properties data: the COMSOL Material Library, MatWeb, and the PKS-MPD. COMSOL Material Library contains data on approximately 2500 materials, including elements, minerals, soil, metal alloys, oxides, steels, thermal insulators, semiconductors, and optical materials. MatWeb as the name suggests is an online source for searching data on materials properties. It has 69,000 data sheets for materials, including plastics, metals, ceramics, semiconductors, fibers, and various other commercially available materials. PKS-MPD (Pryor Knowledge Systems-Materials Properties Database) is a new searchable database for materials properties including elements, minerals, soil, metal alloys, oxides, steels, thermal insulators, semiconductors, optical materials, and biomaterials (tissue).

Modelling of any device using COMSOL software consists of four fundamental steps: (1) specifying the geometry (2) required physical interfaces addition (3) suitable material selection for the structure (4) meshing and simulation of the model by providing inputs. Initially, the geometry for the proposed model is defined and after completion of the structure suitable materials are assigned to it from the Materials Library. Then based on the analysis which is going to be carried out on the model its required physical parameters are selected. Finally, the simulation of model and result verification/observation is carried out with different inputs provided.



Length unit: µm

Angular unit: Degrees

1e-6

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COMSOL 4.2.1.110
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Fig.2 COMSOL interface

III. Designing Procedure Of Bolometer Model

The structure consists of two resistors and one photosensitive absorber surface. The absorber surface acts as the upper layer on which the incoming incident infrared radiation impinges. A measurable amount of current is passed through the resistors separately. The heat is then transferred from the absorber to the resistors. With the increase in temperature the thermal conductivity of the resistors changes which is being plotted in both 1D and 3D plots.

3.1. Geometry

Firstly, a resistor is constructed with the following specifications as shown in Table1.

Table1: Geometry of resistor

PARAMETERS	VALUES
Width of the resistor	0.78 mm
Height of the resistor	0.02 mm
Depth of the resistor	0.3 mm

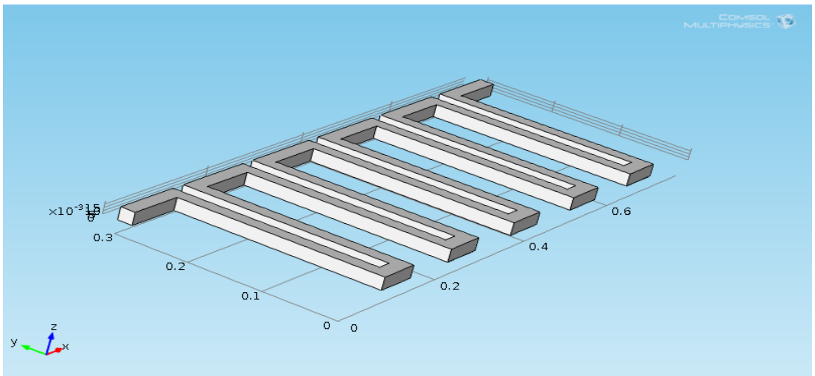

Fig.3 Resistor

Then by using the same specifications another resistor is constructed oppositely faced to the first one.

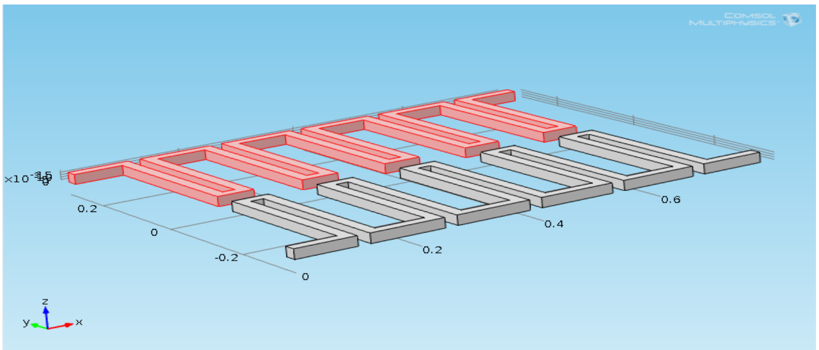

Fig.4 Construction of resistors

The structure is completed by constructing an absorber layer on the upper surface of the resistors with the following specifications as shown in Table 2.

Table 2: Geometry of absorber

PARAMETERS	VALUES
Width of the absorber	0.8 mm
Height of the absorber	0.02 mm
Depth of the absorber	0.64 mm

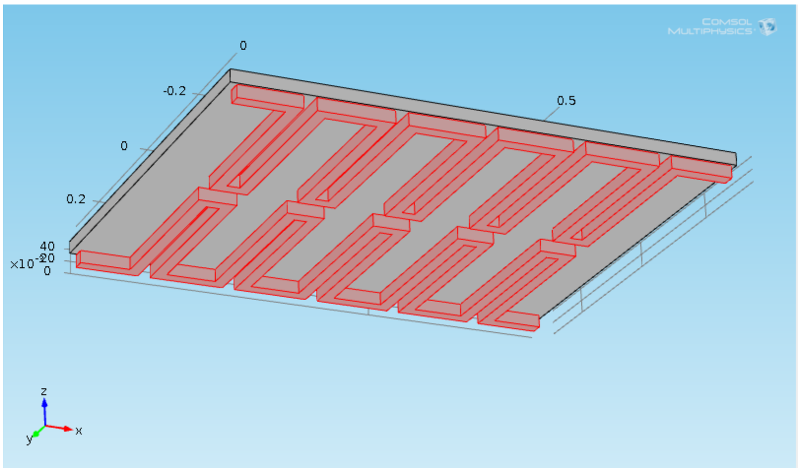

Fig.5 Construction of the absorber layer

3.2. Addition of Materials

After the construction, materials are added to the structure. The upper layer (i.e., the absorber) is assigned with Tungsten. One of the resistors is assigned with Tungsten and another with Polysilicon. Tungsten is used as the absorber layer because of its high sensitivity effects as a photosensitive element, high strength at elevated temperatures, high melting point, low coefficient of thermal expansion and high thermal and electrical conductivity.

All these materials are being added to the structure to carry out the final simulation. Various properties of Tungsten and Polysilicon are listed in the following tables.

Table 3: Properties of Polysilicon

PROPERTY	VALUE
Heat capacity at constant pressure	678 J/(kg*k)
Relative permittivity	4.5
Density	2320 kg/m^3

Table 4: Properties of Tungsten

PROPERTY	VALUE
Heat capacity at constant pressure	132 J/(kg*k)
Relative permittivity	0
Density	19350 kg/m^3

3.3. Adding Physics Interface

This model is primarily based on the heat transfer in solids. An additional physics of electric currents is also added to this model as a measurable amount of electric current is passed through both the resistors. The change of temperature in the model relates to the change in the thermal conductivity of the resistors. This change is being plotted to analyse the result and find the relationship between thermal conductivity and temperature.

3.4. Meshing

Meshing enables the discretization of the geometry model into small units of simple shapes which are in technical terms referred to as the mesh elements. In this module, an extremely fine FREE TETRAHEDRAL meshing is applied and then distributed to the total module through the distribution technique. The total meshed structure is as shown in the figure.

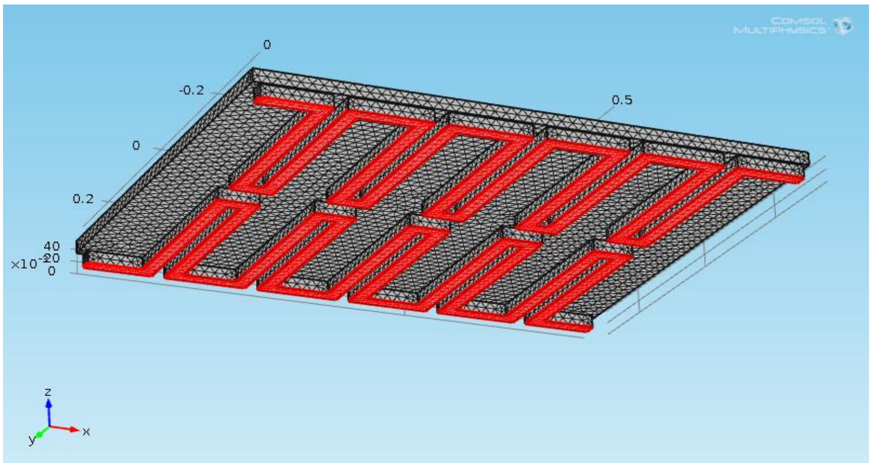

Fig 6. Mesh

After the completion of design process, the proposed bolometer has been simulated to study the thermal conductivity across the resistors. The model is simulated by providing the inputs from Table 5.

Table 5: Input Parameters for Simulation of Model

INPUT PARAMETERS	VALUES
Initial potential	0 V
Terminal current	0.00337 A
Initial temperature	293 K
Heat source	Electromagnetic power loss density (ec/cucn1)
Surface emissivity	0.4
Ambient temperature	340 K

The 3D and 1D output plots showing the change in thermal conductivity with respect to the temperature can be seen in Fig 7 and Fig 8 respectively.

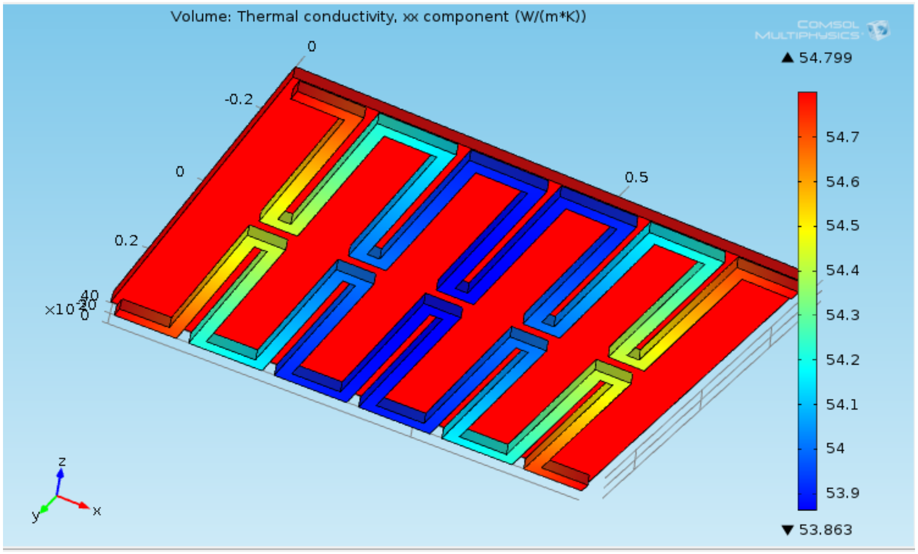

Fig 7. Output plot in 3D showing variation of thermal conductivity with respect to temperature

Here we have taken initially the room temperature, because as discussed the design is based on detection of IR at room temperature. To achieve this, we are using a current source to determine the thermal conductivity of the materials. We have been simulating the model starting from the temperature of 293K upto the range of 340K and we have observed that the thermal conductivity varies linearly with respect to temperature. In other words, thermal conductivity is inversely proportional to temperature, that is, it decreases with the rise in temperature. The thermal conductivity variation plot is as shown in Fig.8.

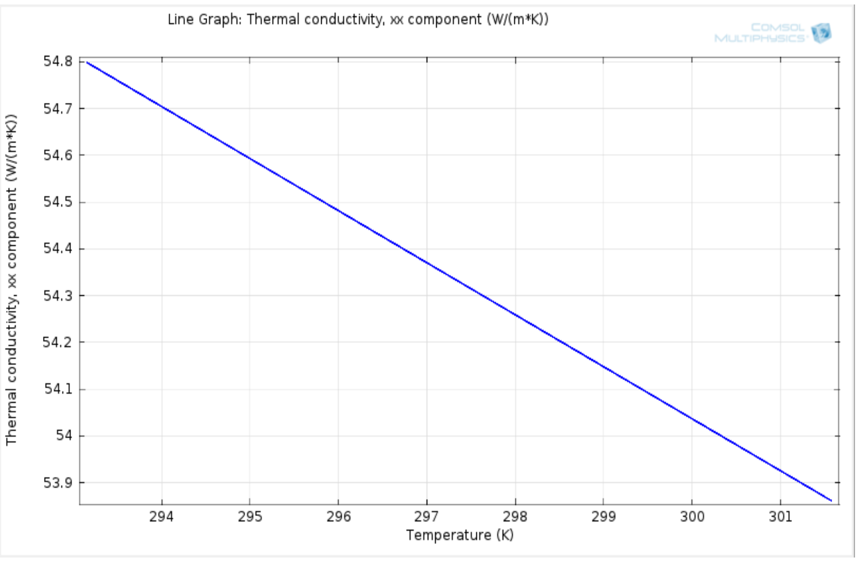

Fig 8. Thermal conductivity versus temperature plot

IV. Conclusion

Resistive Bolometer has been designed using COMSOL Multiphysics. Specifically, the variation of thermal conductivity with respect to the variation in temperature is studied by simulating the model under necessary conditions. From the simulation results we can find that the thermal conductivity of the materials varies linearly with temperature. The output plots shows that thermal conductivity decreases with the increase in temperature, that is, temperature is inversely proportional to the thermal conductivity.

This work can be extended to calibrate for sensing IR of different frequencies along with the interfacing circuit. This can also be physically fabricated for semi-commercial and commercial use.

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