Modeling of MEMS Based Bolometer for Measuring Radiations from Nuclear Power Plant

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ABSTRACT: There has been growing demand for high performance micro sensors capable of detecting nuclear radiations being released from various industries. Nuclear reactors produce large quantities of ionizing radiation. During normal operations of nuclear power plant, penetrating radiation (like gamma and X-rays) emitted from the radioactive materials in the reactor and in the systems and buildings of the plant may be able to expose someone outside the boundary of the plant where ionizing radiation is invisible and not directly detectable by human senses. Nuclear radiation accounts for about 0.16% of total ionizing. Thus it is highly essential to work on design of bolometers with absorptive elements having different geometries providing optimum sensitivity.

The present work is aimed at design of MEMS based bolometer for detecting the nuclear radiation to provide high security and also an attempt has been made to improve the performance of the bolometer by changing materials. Specifically, the present work concentrated on resistive bolometer detectors as their responsivity is much higher than that of thermopile detectors and fabrication process also much easier than pyroelectric detectors through advanced micro machining technology. Thermal detection mechanism of the selected bolometer is to measure the change in electrical resistance of a material as that caused by change in temperature of that material due to absorption of electromagnetic radiation or pressure distribution across the plate.

The energy of the incident radiation heats the thermally sensitive micro metal plates (held together and placed on both sides of a copper link connected to the substrate) that make them to deflect. This deflection contacts the copper links and the changes the voltage across it. Now, by measuring the voltage, the frequency of incident radiation can be determined. The micro plate and micro thermal links are designed and simulated using the physical interfaces viz., Heat transfer and Structural Mechanics in COMSOL Multiphysics.

Keywords: Coefficient of thermal expansion (CTE), MEMS, Nuclear radiations

1. Introduction

The word ‘bole’ means ray. Bolometer is a thermal infrared sensor that measures the power of incident radiation. It absorbs electromagnetic radiation and temperature is increased. This temperature increase results in the deformation of absorptive element [1]. Absorptive element is a thin layer of metal, connected to the thermal reservoir through a link.

The principal risks associated with nuclear power arise from ill-effects of radiation. Nuclear power technology produces materials that are active in emitting radiation called "radioactive". These materials can come into contact with people principally through small releases during routine plant operation, accidents in nuclear power plants, accidents in transporting radioactive materials, and escape of radioactive wastes from confinement systems [2]. This radiation consists of subatomic particles traveling at or near the velocity of light-186,000 miles per second. They can penetrate deep inside the human body where they can damage biological cells and thereby initiate cancer, radiation sickness and death. Various techniques are used to detect them [3] Compared to more conventional particle detectors bolometers are extremely efficient in resolution and sensitivity [4].

In this paper we mainly focused to develop a MEMS based bolometer for detecting the nuclear radiation to provide high security around nuclear power plants and also to improve the performance of the bolometer by updating geometry and by studying different metal pairs.

1.1 Working principle of bolometer:

Bolometer works on the principle of thermal expansion of metals. Thermal expansion is the tendency of matter to change in volume in response to a change in temperature. When a substance is heated, its particles begin moving more and thus usually maintain a greater average separation. The degree of expansion divided by the change in temperature is called the material's coefficient of thermal expansion and generally varies with temperature. The coefficient of thermal expansion describes how the size of an object changes with a change in temperature

A bolometer consists of an absorptive element, such as a thin layer of metal, connected to a thermal reservoir through a thermal link. The result is that any radiation impinging on the absorptive element raises its temperature above that of the reservoir. The greater the absorbed power, the higher the temperature. The intrinsic thermal constant which sets the speed of the detector, is equal to the ratio of the heat capacity of the absorptive element to the thermal conductance between the absorptive element and the reservoir

2. Design of Micro Bolometer

2.1 Usage of COMSOL Software Tool

The software package selected to model and simulate the micro Bolometer is COMSOL MultiPhysics Version 4.3 a. It is a powerful interactive environment for modeling of various devices because there was previous experience and expertise regarding its use as well as confidence with its multiple physical interfaces. This software is also capable of facilitates for structural analyses which is highly essential for making present design.

For any device to be constructed by using COMSOL software it is required to follow four fundamental steps like (1) defining geometry (2) adding physical interfaces (3) adding material to the solid structure and finally (4) meshing, simulation of model with inputs provided.

Micro Bolometer was designed and analyzed by following above steps using COMSOL.

Initially, geometry is defined for the proposed model, after forming the complete structure, suitable material from the available built in Materials Library is added to the proposed structure. Then depending up on the analysis to be carried out required physical parameters are selected (discussed below). Finally the model is simulated; results are verified/observed with different materials and inputs.

2.2 Geometry

The device consists of two micro plates on either side of the support. The two micro plates are made of materials of different coefficient of thermal expansion (CTE). One of the micro plates is made of material with high CTE and the other is made of material of low CTE. Another such plate is designed and placed on either side of silicon support. Copper links are provided on either side of the substrate for contacts. Table 1 gives the dimensions of the device.

Parameters	Values (μm)
Width of the substrate	100
Depth of the substrate	100
Height of the substrate	11
Width of the metal plate	45
Depth of the metal plate	20
Height of the metal plate	1
Width of the copper link	10
Depth of the copper link	20
Height of the copper link	13
Width of the central support	20
Depth of the central support	20
Height of the central support	20

Table 1: Design parameters

With the above mentioned parameters model is constructed in COMSOL. Initially base of width 100μm, height 11μm and depth 100μm is built. Central support of width 20μm, depth 20μm, and height 20μm is built at the centre of the base. Two links of width 10μm, depth 20μm and height 13μm is built on the edges of the base. Two metal plates of width 45μm, depth 25μm and height 1 μm are built on either sides of the central support. Finally the union of 8 blocks is formed, and the model appears as follows.

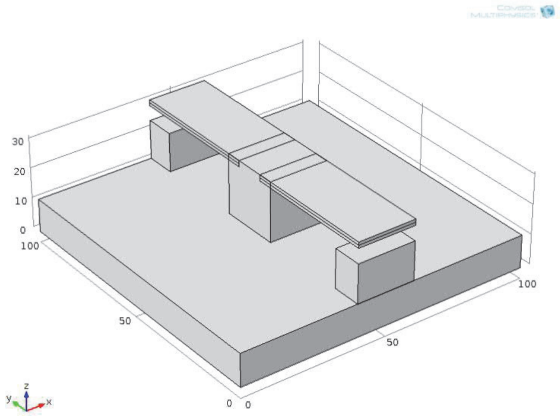

Figure 2: designed model of bolometer

2.3 Addition of Materials

After the construction, materials are added to the model. Silicon is added to base and central support. Copper is added to the two links and aluminum, tungsten are added to the plates. Schematic diagram of the model is illustrated in the figure given below.

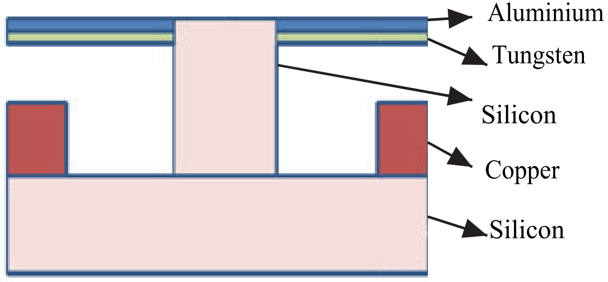

Figure 1: structural details of bolometer

All these materials are added to carry out the final simulation. Aluminium has high thermal conductivity and tungsten has high heat capacity. Various thermal properties of aluminium and tungsten are presented in table 2 and table 3.

Property	Value
Thermal conductivity	160[W/mK]
Heat capacity	900[J/kg×K]
Coefficient of thermal expansion	23M[1/K]
Heat Density	2700[Kg/m^3]

Table 2: Thermal properties of aluminium

Property	Value
Thermal conductivity	173[W/mK]
Heat capacity	1340[J/kg×K]
Coefficient of thermal expansion	4.5M[1/K]
Heat Density	17800[Kg/m^3]

Table 3: Thermal properties of tungsten

3. Physical interfaces

This model is carried out based on joule heating and thermal expansion physical interfaces which automatically facilitates for coupling of thermal, electrical and structural analyses. The linear thermal expansion coefficient relates the change in a material's linear dimensions to a change in temperature. The high value of coefficient of thermal expansion allows us to make use of aluminium as absorptive micro metal on which radiation is impinging rather than other metal plates.

4. Results and Discussions

After the completion of design process, the proposed micro bolometer has been simulated to study the pressure distribution across the device. The model is simulated by providing the inputs temperature 300k and stress 10 N/m^2. The pressure distribution of the model after simulation is shown in the figure.

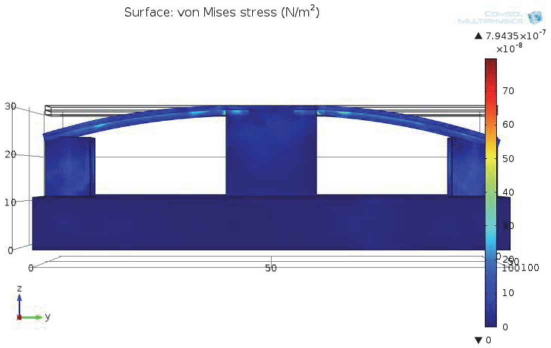

Figure 3: Pressure Distribution

From the figure, it is clear that with the applied stress, deformation of aluminium metal plate taking place and thus touches the copper link. The maximum stress applied is found to be 7.9435 x 10^{-7} N/m^2. This changes the resistance of the absorptive element. Simulation result also confirms the entire distribution of pressure across the absorptive micro aluminium metal plate. It should also be noted that with increase in pressure, the deformation of metal plate increases. Thus the deformation occurs in metal plate causes change in resistance due to change in temperature. By measuring the change in resistance of the metal one can determine the intensity of the incident radiation. Based on intensity of incident radiation, necessary precautionary things will be done. Thus, the study allows us to know the pressure distribution across the metal plate such that changes in resistance and intensity of incident radiation. These studies would be useful in making of bolometers that prevent the people from powerful radiations. The study can be extended to find the pressure distribution for various metallic materials in place of aluminium which has high thermal coefficient of expansion. Thus the beam which posses optimum sensitivity for small pressure may be used in developing real time bolometers.

5. Conclusion

Resistive micro bolometer has been designed by using COMSOL 4.3 a. Specifically the stress distribution across aluminium metal surface is studied by simulating the model under necessary conditions. The maximum stress is found to be 7.9435 x 10^{-7}. Metals having optimum sensitivity for small pressures can be used as absorptive element in bolometer.

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