

Multiphysics Modeling and Simulation of MEMS Based Bolometer for Detecting the Radiations in Nuclear Power Plants

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Abstract: High performance micro sensors are important for detecting nuclear radiations in different fields to save the globe. This paper is mainly focused on to develop a MEMS based device for detecting the nuclear radiation to provide high security around Nuclear power Plants.

Two Thermally sensitive micro metal plates of different coefficient of expansion are joined together and placed on both sides of a link connected to the substrate. The energy of the incident radiation heats the micro plates which make them to deflect. Copper links are provided on either side of the substrate. The deflection produces contact with the copper links and the changes the voltage across it.

Three different material pairs were studied and modeled. They are Aluminium-Tungsten, Silver-Tungsten and Lead-Tungsten. Among them Aluminium-Tungsten pair exhibited satisfied results over conventional detectors. It can be also used for detecting hazardous radiation from Base Transceiver Stations. The micro plate and micro thermal links are designed and simulated using the Heat transfer and Structural Mechanics physics in COMSOL Multiphysics.

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

1. INTRODUCTION:

1.1 Nuclear radiation hazards:

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. Ionizing radiation is invisible and not directly detectable by human senses. Nuclear radiation accounts for about 0.16% of total ionizing

radiation. Figure 1 shows the amount of radiation from various sources. They consist of particles (alpha, beta and neutron) as well as short wavelength waves (gamma). Their energy is high enough to ionize molecules and cause biological damage. Exposure to ionizing radiation causes damage to living tissue, and can result in mutation, radiation sickness, cancer and death. Various techniques are used to detect them [1, 2]. In this paper we have used the Bolometer to detect the presence of Nuclear Radiation.

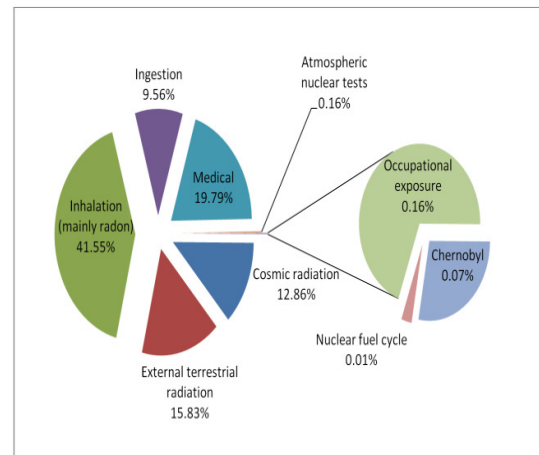


Figure 1: Radiation sources

A bolometer is a device for measuring the power of incident radiation. It consists of an absorptive element, such as a thin layer of metal, connected to the thermal reservoir through a link. Bolometer is directly sensitive to the energy left inside the absorber. Compared to more conventional particle detectors they are extremely efficient in energy resolution and in sensitivity.

This paper gives the design of the absorptive element of the Bolometer. The principle of this device is based on the thermal coefficient of expansion of metals.

1.2 Actuating metal plates

Thermal micro actuators form potential applications for large and linear displacements. 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). 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. Materials which contract with increasing temperature are rare; these effects are limited in size, and only occur within limited temperature ranges. 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. Specifically, it measures the fractional change in size per degree change in temperature at a constant pressure. In the general case of a gas, liquid, or solid, the volumetric coefficient of thermal expansion is given by

$$\alpha_V = \frac{1}{V} \left(\frac{\partial V}{\partial T} \right)_p$$

The subscript p indicates that the pressure is held constant during the expansion, and the subscript "V" stresses that it is the volumetric (not linear) expansion. Materials generally change their size when subjected to a temperature change while the pressure is held constant. In the special case of solid materials, the pressure does not appreciably affect the size of an object. The design has materials with different CTEs sandwiched together. When temperature excursions occur, because of changes in either ambient condition, these materials will expand differently, leading to the creation of stresses.

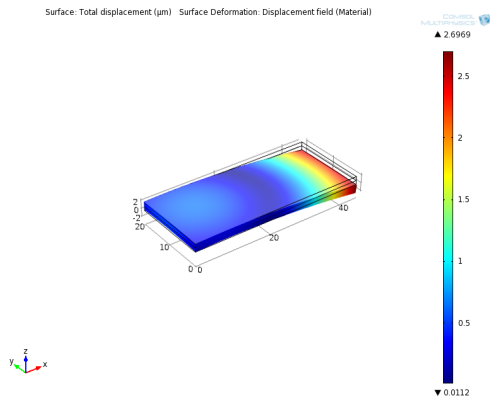


Figure2: Expansion of metals

Figure 2 shows the deflection of metals when heat is applied. In this paper different metal pairs are studied and their deflections due to application of heat are detected.

2. DESIGN:

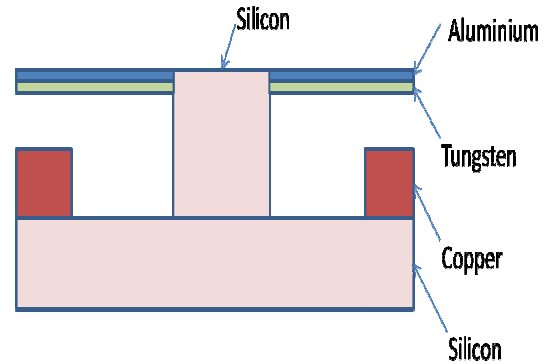


Figure3: Design

The schematic diagram of the designed model is illustrated in the figure 3. It consists of silicon substrate which has a support at the centre to hold the micro plates. 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.

Three pairs of such plates were designed and modelled separately and the results were compared. The three metal pairs were Aluminium-Tungsten, Silver-Tungsten and Lead-Tungsten. The difference between the coefficients of thermal expansion between the two micro metal plates determines the performance of the Bolometer. The properties of the materials used in the model are tabulated in the table 1, 2 and 3.

Mechanical properties:

PROPERTY	Al	W	Pb	Ag
Young's Modulus	70G Pa	411G Pa	16G Pa	83G Pa
Poisson's ratio	0.33	0.27	0.44	0.37

Table1: Mechanical properties

Thermal properties:

PROPERTY	ALUMINIUM	TUNGSTEN
Thermal conductivity	160[W/mK]	173[W/mK]
Heat capacity	900[J/kg*K]	1340[J/kg*K]
Coefficient of thermal expansion	23e-6[1/K]	4.5e-6[1/K]
Density	2700[Kg/m^3]	17800[Kg/m^3]

Table2: Thermal properties of Aluminium and Tungsten

PROPERTY	LEAD	SILVER
Thermal conductivity	35.3[W/mK]	429[W/mK]
Heat capacity	127[J/kg*K]	235[J/kg*K]
Coefficient of thermal expansion	28.9e-6[1/K]	18.9e-6[1/K]
Density	11340[Kg/m^3]	10500[Kg/m^3]

Table3: Thermal properties of Lead and Silver

Aluminium-Tungsten pair has the highest difference in their coefficient of thermal expansion.

3. USE OF COMSOL MULTIPHYSICS:

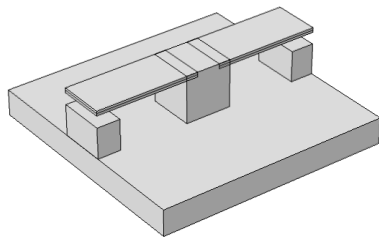


Figure4: Geometry model

Figure 4 shows the designed model for this application. The design is implemented and simulated using COMSOL Multiphysics software.

MEMS module is used to design this sensor. Thermal stress physics is applied in order to simulate the results with the input parameters. Three such designs were modelled using different combinations of micro plates. Their corresponding results were compared. Table 4 gives the dimensions of the design. Substrate is of dimension 100x100x11µm. Micro plates are of dimensions 45x20x1µm.

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

Table4: Design parameters

4. Results:

The incident radiation produces heat on the metal plates uniformly. Owing to the change in coefficient of thermal expansion, the plates deflect accordingly. This makes a contact with the copper links at the end of the substrate. A readout circuit can be used to detect the changes in deflection. The deflection of the plates for different pairs of materials was observed.

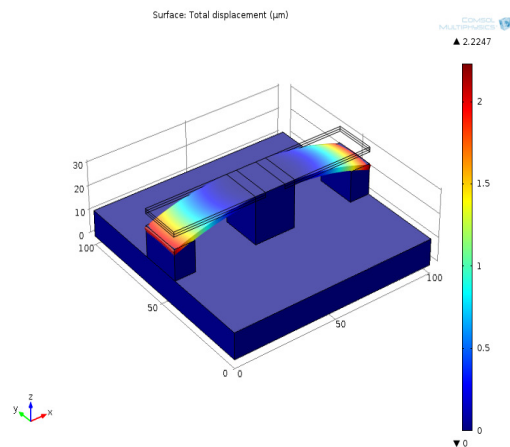


Figure5: Displacement by Aluminium-Tungsten plate.

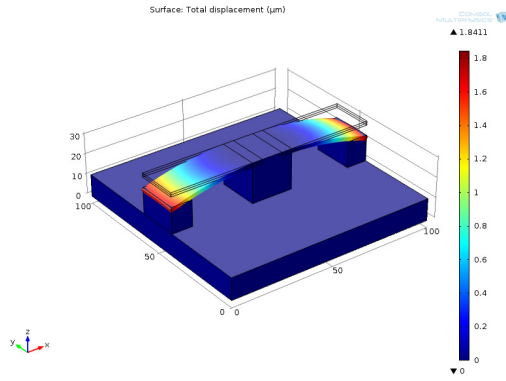


Figure6: Displacement by Silver-Tungsten plate

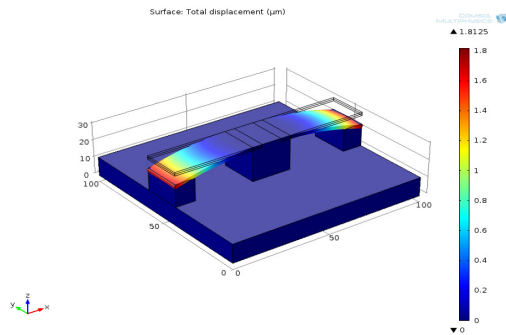


Figure7: Displacement by Lead-Tungsten plate

Figures 5, 6 and 7 show the deflection of Aluminium-Tungsten, Silver-Tungsten and Lead-Tungsten plates for a temperature of 500K. The maximum displacement was observed in Aluminium-Tungsten pair. This was due to the large difference in their coefficient of thermal expansion of Aluminium and Tungsten. The displacements for various metal pairs at different temperatures are given in table 5.

Temperature (K)	Displacement(μm)		
	Al-W	Pb-W	Ag-W
300	0.0567	0.035	0.0486
320	0.193	0.1176	0.1654
340	0.5045	0.411	0.4178
360	0.827	0.5862	0.5957
380	0.9345	0.7614	0.7736
400	1.1473	0.9352	0.9496
420	1.3646	1.1118	1.1294
440	1.5796	1.287	1.3073
460	1.7947	1.4622	1.4853
480	2.0097	1.6373	1.6632
500	2.2247	1.8125	1.8411
520	2.4398	1.9877	2.019
540	2.6548	2.1629	2.1969
560	2.8698	2.3881	2.3748
580	3.0849	2.5133	2.5528
600	3.2999	2.6885	2.7307

Table5: Displacement for various pairs of metals.

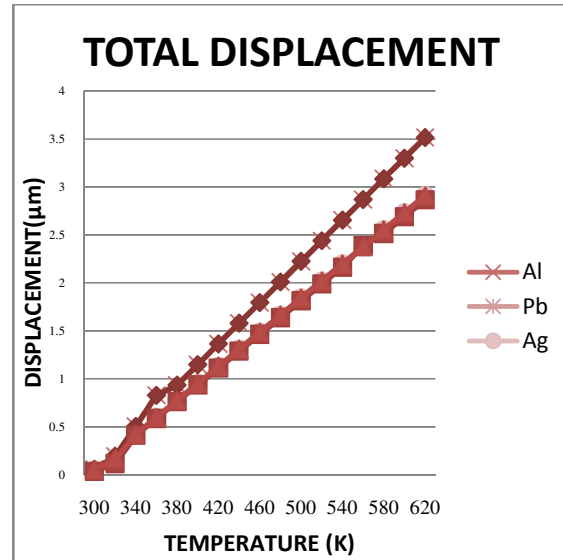


Figure8: Temperature versus Displacement Graph

Figure 8 shows the displacement of the three pairs of metals for different temperatures.

5. CONCLUSION:

The absorption plate of the Bolometer was designed and modeled using COMSOL Multiphysics Software. The micro plates exhibit deflection for various temperature ranges. The deflection gives contact with copper links. The changes due to temperature and displacement are studied and plotted. Deformation is observed on both sides. A read-out circuit can be used to detect the change in deflection. Three such models were designed using different materials. The metal pairs used were Aluminium-Tungsten, Lead-Tungsten and Silver-Tungsten. Among them, the model with Aluminium-Tungsten pair exhibited faster response than the other pairs.

5. References:

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