Design of A MEMS Bolometer Biosensor with Absorptive Element as Piezo-protein

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Abstract: Bolometer is a thermal infrared sensor used for measuring the intensity of radiation via the heating of a material due to the radiations. A bolometer consists of an absorptive element, a thin layered material, connected to a thermal reservoir. The result is that any radiation received on the absorptive element raises its temperature above that of the reservoir: the greater the absorbed radiation, the higher the temperature. The element is thus deformed proportional to the temperature of radiation and thus the temperature is measured. This paper presents a design of the said bolometer with absorptive element as a biologically sensitive material namely a Piezo-Protein which can be employed for biosensing applications.

Keywords: MEMS, Piezo-protein, Bolometer**,** Biosensor

1. Introduction

Bolometer stands for ray-meter. Bolometer is a thermal sensor used to determine the intensity of nuclear radiation. A bolometer contains an absorptive element joined with another metal plate which acts as a heat sink. The absorbed radiation increases the temperature of absorptive element causing deflection due to asymmetrical expansion of both the plates. Higher the intensity of radiation, higher the deflection [1]. This paper proposes a bolometer biosensor using a piezo-protein as the absorptive element.

Bolometer is used mainly for radiation sensing. Radioactive elements are produced by nuclear power plants which emit radiation. Exposure to them occurs mainly through accidents while transportation, escape of waste or leaks in power plants. The radiation though invisible is harmful for biological cells and can cause cancer and even death in human beings [2]. Therefore it is important to detect them and as bolometers are the most efficient in terms of resolution and sensitivity [3].

Piezo proteins are large proteins found in membranes which act as ion channels by facilitating mechanosensory transduction in mammalian cells. Mechano-transduction is the process of conversion of mechanical forces to biological signals. They are hence proteins required for generating currents, activated mechanically in a mammalian cell. The piezoelectric property is exhibited in them as the mechanical force, create an electric potential to induce currents. There are two kinds of piezo-proteins, Piezo1 and Piezo2 which are a part of diverse species like protozoa, plants and invertebrates [4].

Bio sensing has various applications by implementing different types of biosensors. The basic requirements are finding a suitable bio-sensitive material and a detection system that is used on a target element [5]. Some examples of bio-sensing are in environmental and medical fields like detection of pesticides and water contaminants, glucose monitoring in diabetes patients, determination of toxic levels of substances etc.
Our model, thus also can be used as a biosensor. Bio sensing involves analysis of different properties of a material using a bio sensitive component and a detector. Here, the Piezo protein is the bio sensitive material which on heating shows a temperature change that is transduced into a mechanical deformation of the protein by its piezoelectric property.

In this paper we mainly focus to develop a MEMS based bolometer for detecting the radiation by using a biosensor i.e. a piezo protein as the absorptive element.

The remainder of the paper is organized as follows. Section 2 presents the proposed design of the bolometer model. Section 3 covers the use of Comsol Multiphysics. In section 4, results and discussions is given. Section 5 compiles the results and concludes this paper.

2. Proposed Structure

The schematic design of the proposed model illustrated in the figure 1. It consists of substrate which has a support at the center to hold the micro plates [6]. One of the micro plates is made of material with high Coefficient of Thermal Expansion and the other is made up of piezo-protein. Copper links are provided on either side of the substrate for contacts. The dimensions of the components of the structure is mentioned in the table given below.

Table 1: Dimensions of the structure

Parameters	**Values(μm)**
Width of substrate	750
Depth of substrate	200
Height of substrate	100
Width of copper link	100
Depth of copper link	200
Height of copper link	90
Width of central support	150
Depth of central support	200
Height of central support	200
Width of arm plate	750
Depth of arm plate	200
Height of arm plate	10

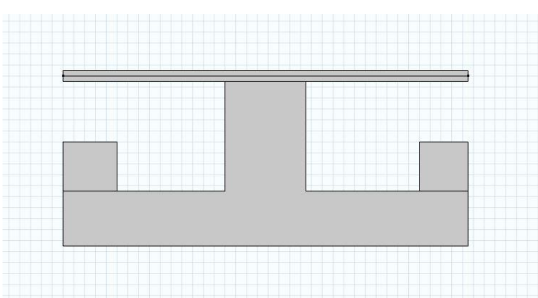

Figure 1. 2-D view of the structure.

3. Use of COMSOL Multiphysics® Software

MEMS module is used to design this sensor. The Bolometer structure was simulated in COMSOL Multiphysics. It is a powerful interactive environment for modeling of various devices and structural analyses. It involves mainly three coupled physics solid mechanics, heat transfer and piezoelectric devices. Material properties are in accordance with the requisite objective. The incident radiation increases the temperature of the surface which causes the deflection of the structure. The finite element method analysis of the structure is also carried out using COMSOL. Finite element method (FEM) analysis divides a continuous geometry into simpler units as shown in figure 2. A set of objects thus replace the original geometry, each with a finite number of degree of freedom (DOF). It defines equations for each individual unit and the results are combined to give a cumulative solution for the system instead of solving for the whole system in one operation.

The first step is defining the geometry of the complete model after which suitable materials are added from default Materials Library. Different parameters are selected for carrying out the analyses. The model is then simulated to give results for various combinations of inputs which are verified.

3.1 Materials used

After the construction, materials are added to the model. For the base and central support, Silicon is used. Copper is added for the two links on the sides of the central support. Metal plate is made of Aluminum. Piezo-protein is used with properties given in table 3. Schematic diagram of the model is shown in figure 3.

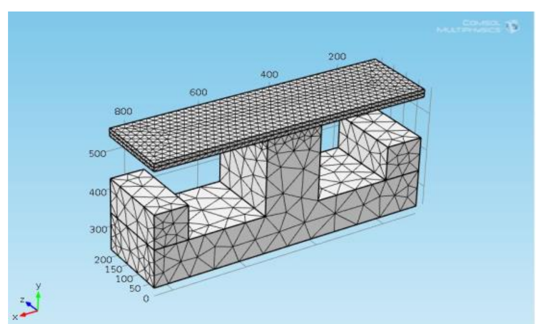

Figure 2. Finite element analysis

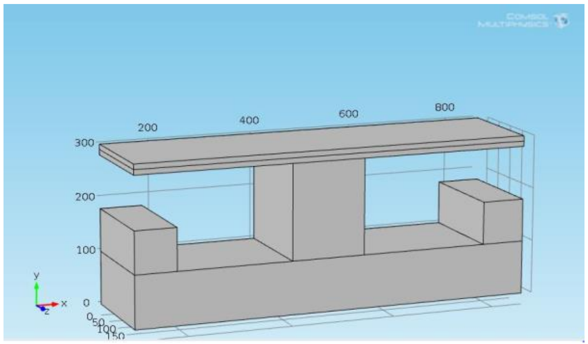

Figure 3. Schematic diagram of the proposed model.

The various material properties of Aluminum and Piezo-protein are given below.

Table2: Mechanical properties of Aluminum

Property	Value
Young's Modulus	70e9(Pa)
Poisson's Ratio	0.33
Heat capacity	900(J/kgK)
Density	2700(kg/m$^{3)}$
Coefficient of thermal expansion	23e-6(1/K)
Thermal conductivity	238(W/mK)

Table3: Mechanical properties of piezo protein

Property	Value
Young's Modulus	3.6e11(Pa)
Poisson's Ratio	0.27
Piezoelectric coefficient(d_{11})	2.3e-12(m/volt)
Density	2651(kg/m$^{3)}$
Coefficient of thermal expansion	4.5e-6(1/K)

3.2 Equation used:

The deflection of the plates is based on the concept of conversion of thermal energy into mechanical energy. The heat generated causes asymmetric expansion of the structure resulting in deflection. The differential expansion is due to the difference in coefficient of thermal expansion of both the materials. This expansion is directly proportional to the heat generated in the material governed by thermal expansion law given by:

$$\Delta l = \alpha l(T - T_{ref})$$

Where,

T_{ref} = Reference Temperature

Δl=Change in length

α = Coefficient of thermal expansion

4. Results and Discussion:

The proposed bolometer gives a direct voltage output which requires no external read out circuitry to measure the external radiation. The obtained potential distribution of one of the arms is shown in figure 6. Earlier proposed bolometers required an external measuring circuitry to measure the amount of deflection due the heat of nuclear radiation. The piezo-proteins used gives a direct voltage output due to its piezoelectric property eliminating the need for such external circuit. Such sensors can be used in nuclear power plants and nuclear energy reserves where there is a necessity to monitor the amount of nuclear radiation regularly. Also this structure can be used for bio-sensing applications. The protein used has good absorptive properties, making it suitable for selective absorption of specific bio-ions. By using different piezo-proteins, the structure can be used in various bio-sensing applications. Bio sensing can be used in various medical and chemical applications where there is a need to measure the amount of ions present.

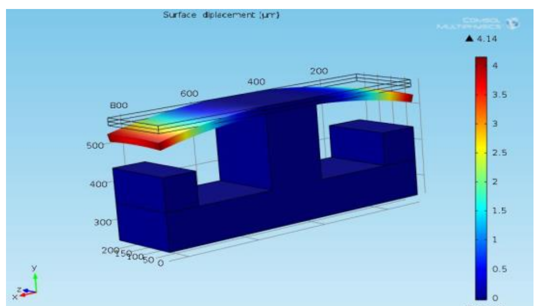

Figure 4. Displacement of the structure.

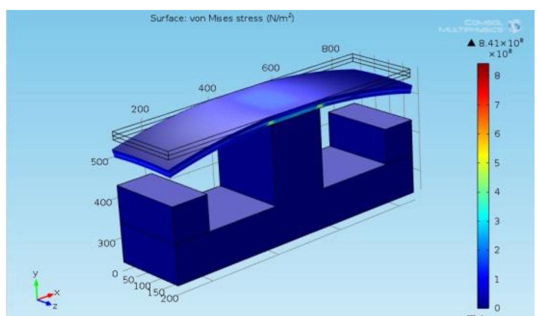

Figure 5. Stress analysis of the structure.

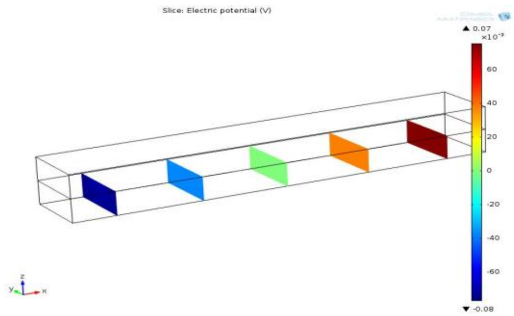

Figure 6. Potential distribution.

5. Conclusions

The simulation result obtained favours the direct transduction technique introduced. The application of such a biosensor is immense. It can be integrated to be used in harsh radiation environments. Also it can be incorporated in certain medical application related to radiation detection as well as in applications related to estimation of certain ions. An advance radiation detection mechanism can be developed by using these in array structures for increased efficiency and performance.

9. References

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