Design of Micro Resistor Beam through COMSOL Simulation Software

K.Sunil Babu[1], Dr.K.Uma kantham[2], V.Prasanthi [3]

[1,2] Department of Physics, Pydah Kaushik college of Engineering, Vizag, A.P., INDIA

ABSTRACT: *This paper explains about the design and analysis of micro resistor beam using COMSOL Multi Physics software V 4.1. The current passing through the beam dissipates heat power due to its resistivity that displaces the entire micro beam to preferred distance through thermal expansion phenomenon. The proposed model analyses mainly the various displacements produced for the beam due to passage of currents and rise in temperature. It also reports the displacements produced in the beam, made of different metallic equipment and for different input potentials.*

I. Introduction

With the materialization of micro electro mechanical systems (MEMS), major attention has been focused on the expansion of new fabrication processes, new semi conducting devices [1] to be used in various optoelectronic devices and new micro scale resistors. The micromachining technology that emerged in the late 1980's has replaced the established bulky actuators [2] and sensors [3] with micro scale equivalent devices with more efficiency. Electromechanical coupling has been widely used to actuate and control micromechanical structures and to produce nano structured materials from micron and submicron particles.

Micro resistor beams are mostly used for accurate measurement of residual stress, like stress produced in integrated circuit chips that are included into electronic package. The micro resistor beams are also used as actuators for controlling purpose, thermally-actuated sensors [4], gyroscopes, and micro engines, resonators, for micro welding purposes and in wide range of industrial applications. When current is passed all the way through a material, heat energy is degenerated due to material`s electrical resistance property [5]; this degenerated energy heats up the material and induces thermal stress. The induced stress loads the material and deforms the structure through which current is passed. The thermal expansion depends upon the amount of current passed through it and dissipated temperature. The application of micro resistor beam is to move the entire beam to desired distance by conducting suitable magnitude of current through conductive layers and generate a temperature increase that leads to displacement through thermal expansion. The goal of this model is to estimate the amount of current and increase in temperature required to cause displacement in proposed micro beam using COMSOL software.

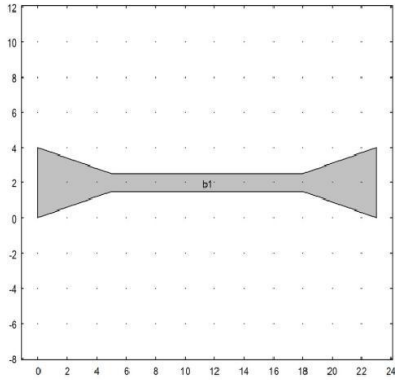Designing of Micro Resistor Beam COMSOL Software Tool

The software package selected to model and simulate the micro resistor beam made of different metals at different potentials is COMSOL MultiPhysics Version 4.1. 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 providing facilitates for the coupling of thermal, electrical, and structural analyses which is highly essential for 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 (4) Meshing, simulation of model with inputs provided.
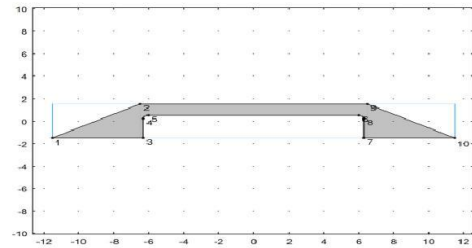
Copper micro resistor beam was designed and analyzed by following above steps using COMSOL. Initially, geometry is defined for the proposed model, after forming the complete structure, suitable material from the available built in Materials Library is added to the proposed structure. Then depending up on the analysis to be carried out required physical parameters are discussed below. Finally the model is stimulated; results are verified or observed with different resources and inputs.

II. Geometry Details

Micro resistor beam of length of 13 μm, height and width of 1 μm is considered to carry out to investigate the deformation produced. COMSOL Multiphysics provides a number of features for creating geometric primitives from the available geometry structures in COMSOL Multiphysics, Bezier polygon is preferred for construction of the beam. Bezier polygon structure is generally a chain of connected line segments, quadratic or cubic curves (simulation can also be carried out for other structures). By choosing suitable control points a closed curve forming a polygon structure is built in work plane as shown in figure 1. The formed 2D structure is transferred in to 3D in work plane by projecting beam along its z-axis of 3μmfrom origin as show in figure 2 and which form as an extrude 1.

Bezier polygon 1 (2D): Figure 1

Bezier polygon 1 (3D): Figure 2

Now another work plane is selected and here control points are chosen in order to form a fillet and placed at a distance of 4 µ m from work plane which form as an extrude 2,by intersecting these two extruded objects geometry of beam is created as shown in figure 3.

Fillet: Figure 3

Next step is addition of material to the proposed geometry. Browsing all the available databases a specific material is chosen and properties are assigned to the chosen material. In the present work, copper is chosen from the material browser. Copper is being used as functional material in the field of MEMS due to its important physical and electrical properties. The main reason for selecting copper for the present model is its property of showing linear relationship between resistivity and temperature. It can exhibit linear relation over a wide range of temperatures when compared to other metals. Properties of copper are listed as below. These two structures are pooled together by selecting Boolean operation in geometry settings and then in intersection, Form union is selected to form a complete micro resistor beam as shown in figure 5. In order to find the best displacement of the proposed micro resistor beam, other metals like silver and aluminum are also considered for simulation. Deformation produced in the beam varies accordingly with each material depending on their properties.
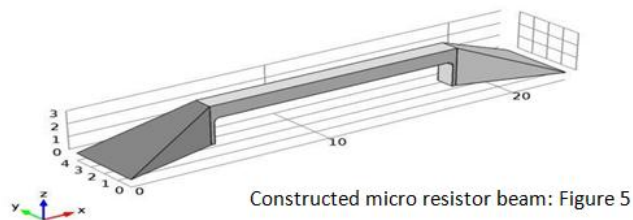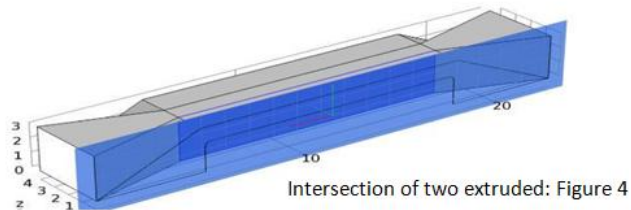

Intersection of two extruded: Figure 4

Constructed micro resistor beam: Figure 5

Table 1: Physical Properties of Copper.

S.No	PROPERTY	VALUE	
1	Relative permittivity	1	
2	Reference resistivity (Ω- m)	1.72e-8	
3	Resistivity temperature coefficient	0.0039	

	(1/K)		
4	Reference temperature (K)	293	

Physical interfaces

This model is carried out in joule heating and thermal expansion multiphysics which automatically facilitates for coupling of thermal, electrical, and structural analysis. The linear thermal expansion coefficient relates the change in a material's linear dimensions to a change in temperature. It is the fractional change in length per degree of temperature change. In order to carry out simulation it is necessary to set suitable boundary conditions for the heat transfer and the conduction of electric current. This model is assumed to be carried out in open air so the convection air cooling is set by using heat flux boundary condition given by equation (1)

$$q_0 = h(T_{ext} - T) \quad (1)$$

Where h is heat transfer co-efficient. Insulating boundary condition for heat transfer interfaces and conduction current is set by thermal insulation given by equation (2) and electrical insulation equation (3)

$$-n.(-k.\nabla T) = 0 \quad (2)$$

$$-n.J = 0 \quad (3)$$

The joule heating and thermal expansion multi physics interface includes three physics equations mentioned above along with necessary couplings. The equations describe the current and heat conduction and structural mechanics problems.

Simulation

The simulation process is conceded out in two steps, initially copper micro resistor beam is constructed and its deformation is carried out for two different input potentials. In second step deformations are carried out for aluminum and silver metallic beams replacing copper material for similar input potentials.

Feet of the copper beam at both ends are rigidly bond to a substrate and electric potential is applied at both ends. The applied electric potential induces an electric current in the micro resistor beam; current passing through the structure causes some retardation to flow of electrons by which energy is dissipated in the form of heat. This generated heat induces thermal stress on beam and displaces the beam. The following three graphs in figures 6, 7, 8 show the amount of deformation produced in the beam when a potential of 0.1V is applied between the feet.

Figure: 6
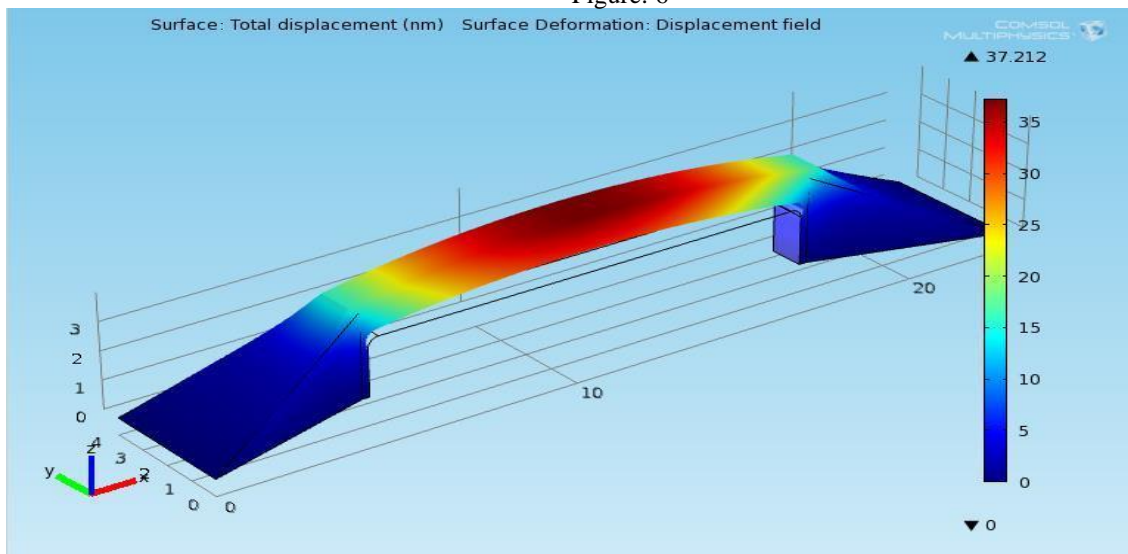
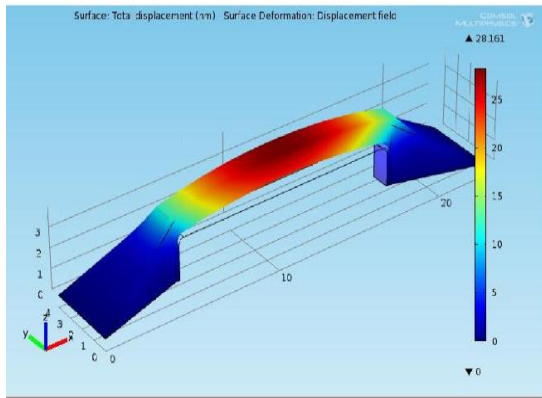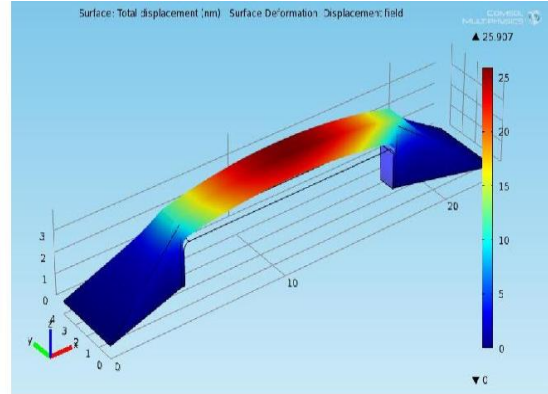Figure: 7   Figure: 8

The similarity of deformations produced for three metallic resistor beams with same input potential 0.2 V are shown in Figures, 9, 10 & 11. From this, it was observed that aluminum metallic beam exhibits more buckle than others for identical geometry and same applied potentials.
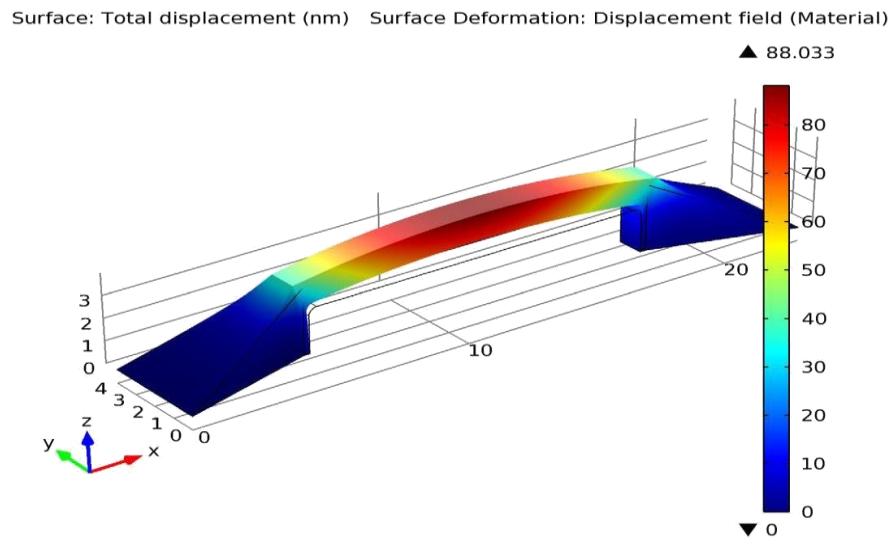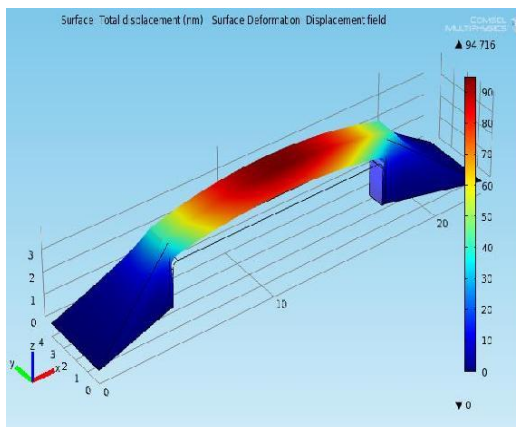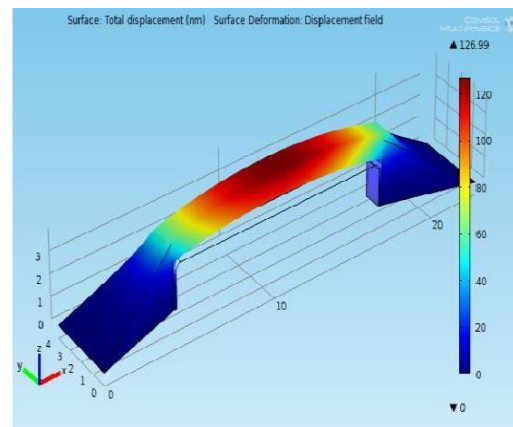
Figure: 9

Figure: 10   Figure: 11

III.   Results and analysis

Analysis was carried out on various materials like copper, silver and aluminum by varying input Potentials applied to each material. Mainly observation was done on amount of buckle produced by passing current through the beam. Following table shows amount of buckle and temperature produced in metals at two different input potentials. Silver produces reasonable amount of deformation compared to aluminum because of its lower value of thermal coefficient of expansion. It has the highest electrical conductivity than that of any element and the highest thermal conductivity of any metal even higher than copper, but its greater cost has restricted it from being used instead of copper for electrical appliances.

Table 2: Results observed at 0.1v potential

S.No	Name of the metal	Deformation (nm)	Maximum Temperature (K)
1	Copper	26	504
2	Silver	28	492
3	Aluminum	37	510

The analyses of these results allowed us to terminate that the aluminum metallic micro resistor beam gives significant amount of deformation (Table 3) for given proposed geometry due to its high value of coefficient of thermal expansion. Thus, the projected geometry will be useful in making devices for producing desired displacements of entire micro scale beam structures through the simple phenomenon of thermal expansion that associated with the current passed through the beam.

Table 3: Results observed at 0.2V potential

Name of the Metal	Deformation (nm)	Maximum Temperature (K)
Copper	88	1074
Silver	95	1000
Aluminum	127	1071

IV.   Conclusion

Micro resistor beam is designed using COMSOL MultiPhysics software v 4.1. It reports the movement Produced in the beam by conducting a current through it to generate temperature that lead to a displacement through thermal expansion. Coupling of thermal, electrical, and structural analyses makes it possible to estimate the current and temperature increase needed to displace the beam. The quantity of deformations produced for three different metallic micro beams of same design have been carried out with different input potentials. The analyses of results have indicated that the aluminum metallic micro resistor beam gives significant amount of deformation for given proposed geometry rather than other metallic beams.

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