# MODELLING AND THERMAL ANALYSIS OF MICRO BEAM USING COMSOL MULTIPHYSICS

by

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*In this study, the design and analysis of the micro beam is carried out using COMSOL multiphysics. The current passing through the beam distributes the heat energy due to its resistance that pushes the entire micro beam to the desired distance through thermal expansion. This expansion varies depending on the amount of current passing through the beam and the emitted temperature. The purpose of the model created is to estimate the amount of current and temperature increase required to cause displacement in the proposed micro beam using analysis software. In addition, displacements and temperature data produced in micro beams for different metallic materials (Al, Cu, Ni, and Pt) and different input potentials (0.3 V, 0.6 V, and 0.9 V) are reported. These materials are used as functional materials in the field of micro-electro-mechanical-system because of their important physical and electrical properties. As a result of the simulation studies, increasing the voltage increased the displacement in the materials and the resulting temperature. While there is a serious difference between the displacement data of the materials, the temperatures are close to each other. When 0.9 V voltage is applied, the highest displacement values for Al, Cu, Ni, and Pt are; 7.88 μm, 5.36 μm, 3.62 μm, and 2.72 μm, respectively. As a result, it has been observed that aluminum used in micro beam design gives a significant amount of displacement for the proposed geometry when compared to other metallic beams.*

Key words*: micro beam, electrical potentia, thermal expansion, displacement, COMSOL multiphysics*

## Introduction

Micro-electro-mechanical-system (MEMS) is a process technology used to create small integrated devices or systems that combine mechanical and electrical components [1, 2]. Integrated circuits (IC) are produced using batch processing techniques and can vary in size from a few micrometers to millimeters. These devices or systems are capable of sensing, controlling, activating and generating macro-scale effects [3, 4]. The MEMS technology consists of mechanical micro-structures, micro-sensors, micro-conductors, and micro-electronics integrated into silicon chip devices. The components of MEMS devices are generally microscopic. Lifts, gears, pistons, engines and steam engines are manufactured by MEMS [5-7]. However, this technology is not just about miniaturizing mechanical components or making something out of silicone. It is a fabrication technology developed to design and build integrated electronics using mass production techniques as well as complex mechanical devices, and systems [8].

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The MEMS is the latest technology in mechanical, electrical, electronic and chemical engineering. The MEMS consist of mechanical, electrical systems with a size in microns. It is a technology used to minimize systems. Electrical components such as inductors and capacitors can be significantly improved compared to their integrated counterparts when manufactured using MEMS and nanotechnology [9, 10].

With the use of MEMS technology, great attention was paid to expanding new production processes, semiconductor devices and micro-scale resistors to be used in various opto-electronic devices. The micro-processing technology that emerged in the late 1980's replaced the existing large actuators more efficiently with micro-scale equivalent devices [11]. Electromechanical coupling is widely used to move and control micro mechanical structures, and to produce nanostructured materials from micron and submicron particles.

Micro beams are generally used for accurate measurement of the residual voltage, such as the voltage produced in IC chips included in the electronics package. In addition, micro beams are used as actuators to control thermally operated sensors, gyroscopes, micro-motors, resonators and to micro-weld a wide range of industrial applications [12-14]. When the electric current passes completely through a material, heat energy is generated due to the electrical resistance property of the material. This heat energy heats the material and induces thermal voltage.

There are three main sources of stresses in thin films and multilayered plates: structural, thermal, and mechanical. Structural and thermal stresses are generally called residual stresses. When the film and coating material (or layers in a multilayer layer) have different thermal expansion coefficients, stresses occur due to temperature changes. These stress values can be very large (a few GPa) for some systems and often provide actuating power for mechanical failure. When the temperature differs from the accumulation temperature, the remaining voltages include both structural, and thermal additives [15].

The induced stress loads the material and deforms the structure through which the current passes. Thermal expansion depends on the amount of current flowing through it and the emitted temperature. The micro beam application transfers the appropriate size of current through the conductive layers and moves the entire beam to the desired distance and creates a temperature increase that causes displacement through thermal expansion. The purpose of this model is to estimate the amount of current and temperature increase required to cause displacement in the proposed micro beam using COMSOL Multiphysics software. This software has been selected to model and simulate micro beam made of different metal materials of different potentials. This software makes it easy to combine thermal, electrical and structural analysis, which is essential for the current design.

The difference of this article from other studies [16, 17], displacement and temperature analysis using different materials. With this analysis, the effect of material diversity on displacement was performed for the first time with this study. Current studies have generally explored the displacement characteristics of aluminum and copper materials.

In this paper, the design and analysis of the micro beam was carried out using COMSOL software. As a result of the electrical potentials applied to the proposed model, displacements and temperature data were analyzed. Micro beam displacements and temperature values were investigated for different potentials (0.3, 0.6, and 0.9 V) and metallic materials (Al, Cu, Ni, and Pt).

## Materials and methods

### *The COMSOL multiphysics software package*

The COMSOL multiphysics software package was used to model and simulate micro beam made of different metals. This software has a powerful interactive physical interfaces for

modelling various devices. It can also facilitate the merging of thermal, electrical, and structural analyzes, which are essential for the current design. For a micro device to be made using this software, it is necessary to follow four basic steps such as:
– geometry definition,
– adding physical interface,
– adding materials to solid structure, and
– meshing, model simulation with the inputs.

Initially, geometry was defined for the proposed model. After the entire structure was created, suitable material was added to the proposed structure in the existing material library. Depending on the analysis to be performed later, the necessary physical parameters were selected. Finally, model simulation was carried out; results are validated/observed with different materials and inputs.

### *Design conditions*

The micro beam designed using Al, Cu, Ni, and Pt metals, is 260 μm in length and 20 μm in height and width. Temperature and displacement analyzes of the materials were carried out with this design. Support points on both ends of the micro beam are firmly connected to a substrate. An electric potential of 0.3 V, 0.6 V, and 0.9V voltage applied through the pads between the support points creates an electric current. Due to the resistivity of the materials, the resulting current heats the model. Since the micro beam operates in the open area, the heat generated is dissipated into the air. The thermally induced tension loads the material and deforms the beam. As a first approach, we can assume that the electrical conductivity is constant. However, the resistance of a conductor increases with temperature. The relationship between resistance and temperature is approximately linear over a wide temperature range.

The geometric structure of the micro beam designed as 3-D using COMSOL is shown in fig. 1. Metallic material was added to the proposed geometric structure. When browsing all available databases, a specific material is selected and properties are assigned to the selected material. For this study, Al, Cu, Ni, and Pt were selected from the material scanner. These materials are used as functional materials in the field of MEMS due to their important physical and electrical properties. The physical properties of the materials used in the analysis phase are given in tab. 1.

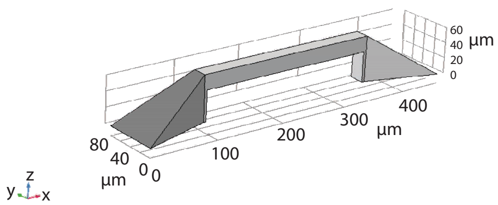

**Figure 1. The designed micro beam**

**Table 1. Physical properties of the materials**

| Parameters | Value | | | |
|---|---|---|---|---|
| | Al | Cu | Ni | Pt |
| Reference resistivity [Ωm] | $2.65 \cdot 10^{-8}$ | $1.72 \cdot 10^{-8}$ | $6.48 \cdot 10^{-8}$ | $1.06 \cdot 10^{-8}$ |
| Resistivity temperature [$K^{-1}$] | 0.00429 | 0.0039 | 0.00641 | 0.003927 |
| Reference `temperature [K] | 293 | 293 | 293 | 293 |
| Density [$kgm^{-3}$] | 2700 | 8960 | 8900 | 21450 |
| Young's module [Pa] | $70 \cdot 10^9$ | $120 \cdot 10^9$ | $219 \cdot 10^9$ | $168 \cdot 10^9$ |
| Poisson ratio [Dimensionless] | 0.35 | 0.34 | 0.31 | 0.38 |

This study demonstrates the ability to combine thermal, electrical and structural analysis into a single model. With the application, movement is provided by-passing current through a micro beam. Heat is produced by current, and the rise in temperature leads to displacement through thermal expansion. The model estimates how much current and temperature increase is required to displace the micro beam.

### *Thermal flux analysis*

This model is implemented in Joule heating and thermal expansion multiphysics that automatically facilitate the merging of thermal, electrical and structural analysis. The linear thermal expansion coefficient relates the change in linear dimensions of a material to a change in temperature. It is the fractional change in length per degree of temperature change. With the formation of the structure of the beam and the addition of the physical interfaces of the material, the design phase of the micro beam is completed. To perform the simulation, it is necessary to set suitable boundary conditions for heat transfer and transmission of electric current. Assuming that this model is made outdoors, convection air cooling is adjusted using the heat flux boundary condition:

$$q_0 = h\left(T_{\text{ext}} - T\right) \tag{1}$$

where $h$ is the heat transfer coefficient. The insulation boundary condition for heat transfer interfaces and transmission current is determined by the thermal insulation:

$$-n\left(-k\nabla T\right) = 0 \tag{2}$$

and electrical isolation:

$$-nJ = 0 \tag{3}$$

The Joule heating and thermal expansion multiphysics interface automatically includes the three physics equations aforementioned along with the necessary connections. Physics equations describe current, heat conduction and structural mechanical problems. The interface also provides appropriate assumptions for the solvent.

## Results and discussion

### *Simulation results*

The simulation process was carried out in two-stages, initially the Al micro beam was designed and its displacement was carried out for three different input potentials. In the second stage, displacements were performed for Cu, Ni, and Pt beams instead of Al material for similar input potentials. The support points of the micro beams at both ends are fixed on a substrate and electrical potential is applied through the pads. The applied electric potential induces an electric current in the micro beam. The current passing through the structure causes some slowdown in the flow of electrons where energy is emitted in the form of heat. This generated heat induces thermal stress on the beam and causes the beam to move. The displacement amount and temperature distribution in the beam when the electrical potential of 0.3 V, 0.6 V, and 0.9 V are applied between the support points of the micro beam made of aluminum material, respectively, are shown in figs. 2-4.

The displacement amount and temperature distribution in the beam when the electrical potential of 0.3 V, 0.6 V, and 0.9 V are applied between the support points of the micro beam made of Cu material, respectively, are shown in figs. 5-7.

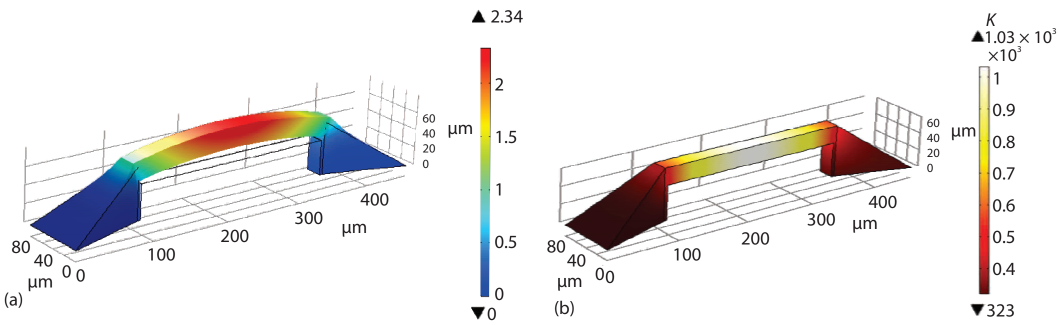


**Figure 2. Displacement and temperature data in Al when 0.3 V voltage is applied; (a) total displacement and (b) total temperature distribution**

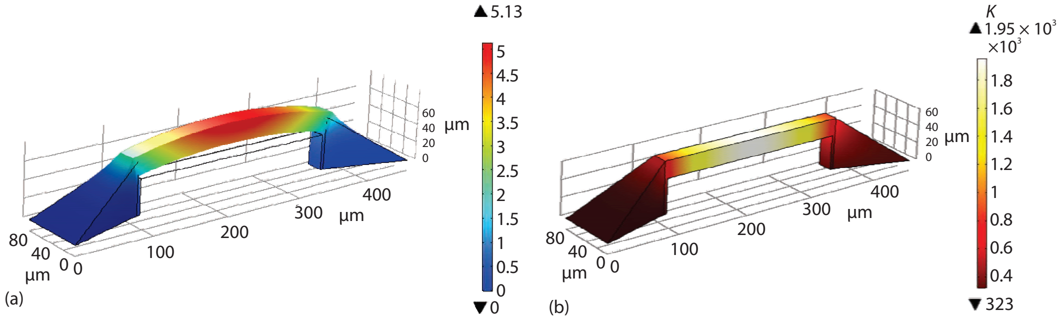


**Figure 3. Displacement and temperature data in Al when 0.6 V voltage is applied; (a) total displacement and (b) total temperature distribution**

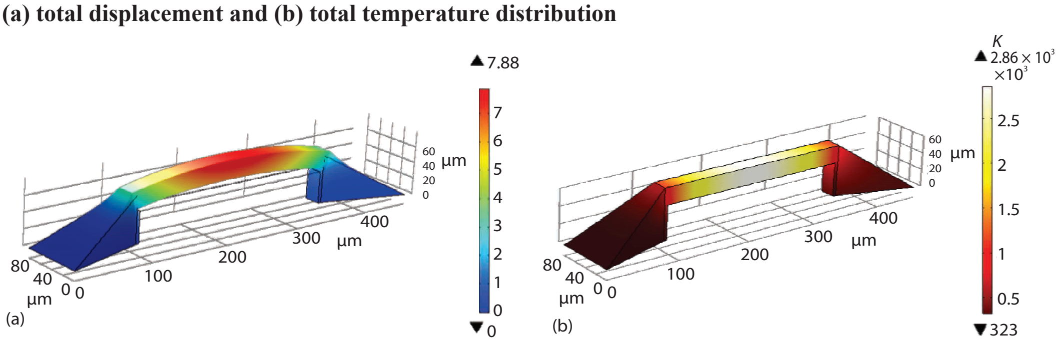


**Figure 4. Displacement and temperature data in Al when 0.9 V voltage is applied; (a) total displacement and (b) total temperature distribution**

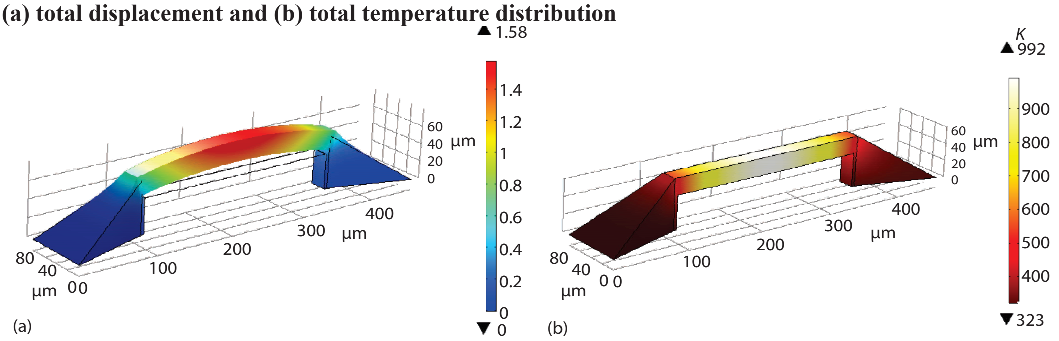


**Figure 5. Displacement and temperature data in Cu when 0.3 V voltage is applied; (a) total displacement and (b) total temperature distribution**

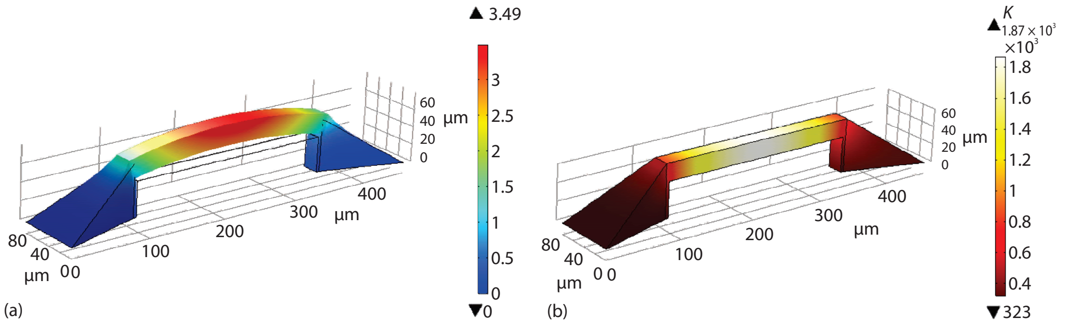


**Figure 6. Displacement and temperature data in Cu when 0.6V voltage is applied; (a) total displacement and (b) total temperature distribution**

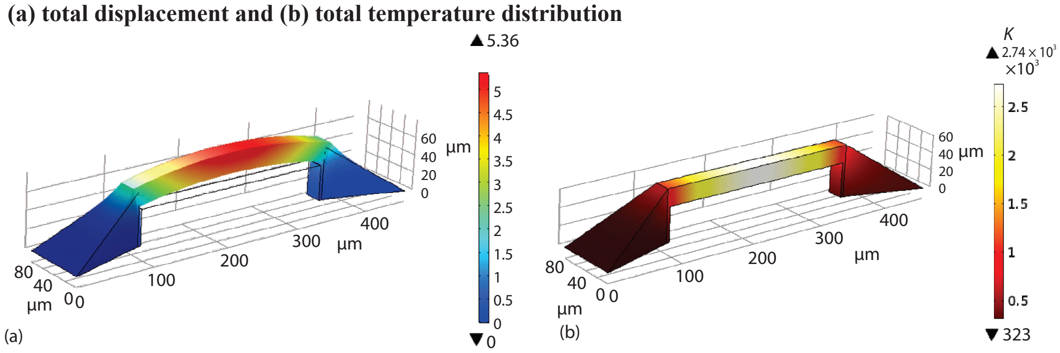


**Figure 7. Displacement and temperature data in Cu when 0.9 V voltage is applied; (a) total displacement and (b) total temperature distribution**

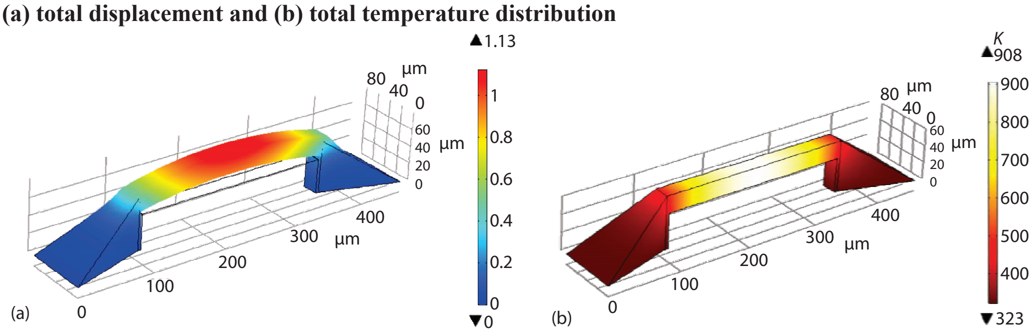


**Figure 8. Displacement and temperature data in Ni when 0.3 V voltage is applied; (a) total displacement and (b) total temperature distribution**

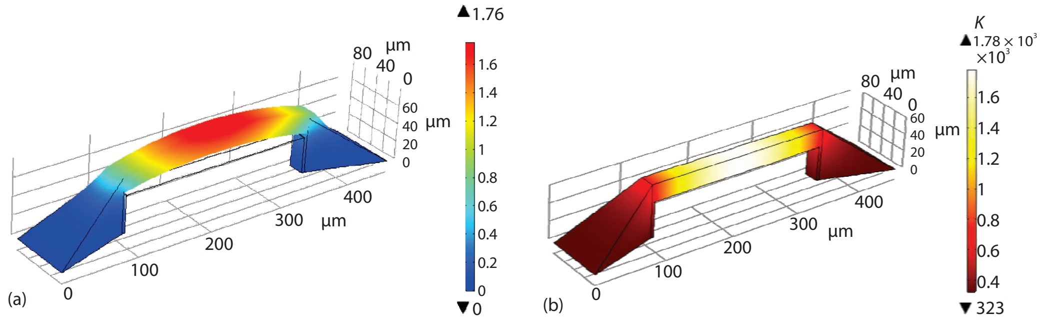


**Figure 9. Displacement and temperature data in Ni when 0.6 V voltage is applied; (a) total displacement and (b) total temperature distribution**

The displacement amount and temperature distribution in the beam when the electrical potential of 0.3 V, 0.6 V, and 0.9 V are applied between the support points of the micro beam made of Ni material, respectively, are shown in figs. 8-10.

The displacement amount and temperature distribution in the beam when the electrical potential of 0.3 V, 0.6 V, and 0.9 V are applied between the support points of the micro beam made of Pt material, respectively, are shown in figs. 11-13.

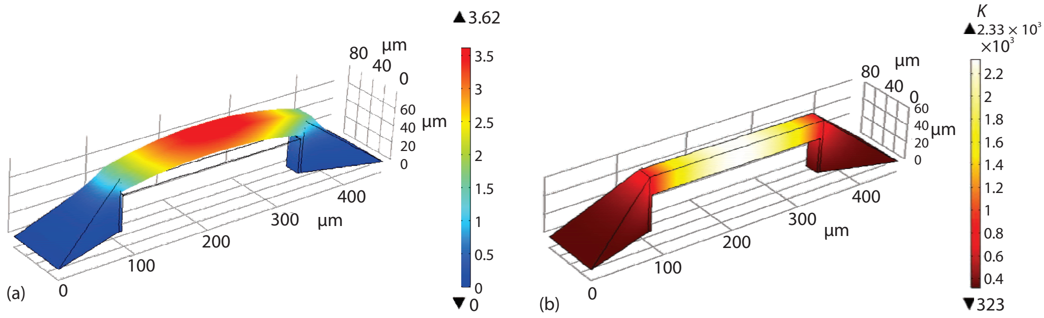


**Figure 10. Displacement and temperature data in Ni when 0.9 V voltage is applied; (a) total displacement and (b) total temperature distribution**

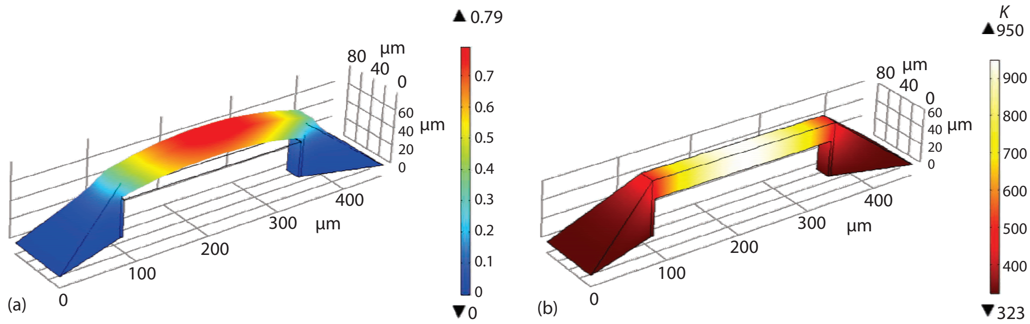


**Figure 11. Displacement and temperature data in Pt when 0.3 V voltage is applied; (a) total displacement and (b) total temperature distribution**

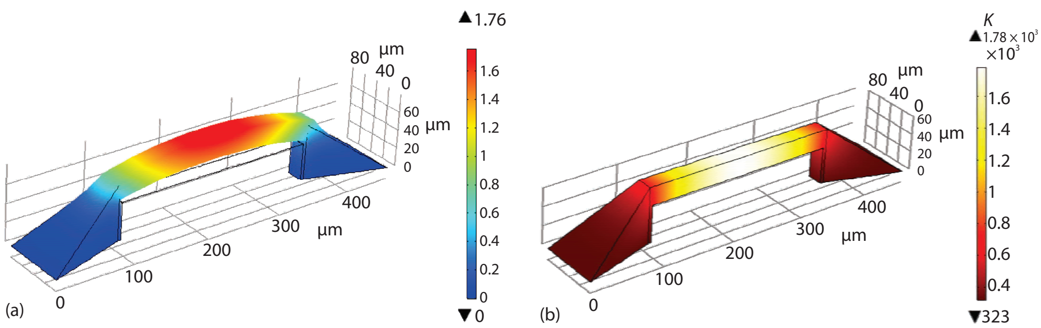


**Figure 12. Displacement and temperature data in Pt when 0.6 V voltage is applied; (a) total displacement and (b) total temperature distribution**

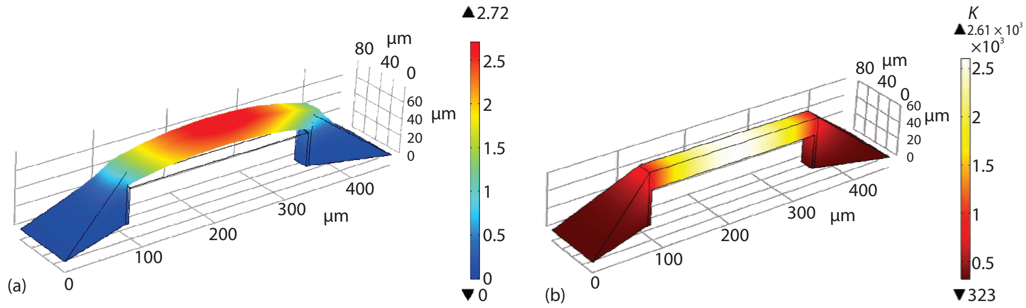

**Figure 13. Displacement and temperature data in Pt when 0.9 V voltage is applied; (a) total displacement and (b) total temperature distribution**

*Discussion*

The model was analyzed by applying Al, Cu, Ni, and Pt materials to the micro beam. Analysis operations were carried out with variable electrical potentials (0.3 V, 0.6 V, and 0. 9 V) applied to each material. Firstly, observation was made on the amount of displacement that occurs by-passing current through the beam. The following table show the amount of displacement and temperature data that occur in metal materials at three different input potentials. The Cu material showed low displacement compared to aluminum due to its low expansion coefficient.

Analysis of these results showed that aluminum materials give a significant amount of displacement for the proposed geometry due to the high value of the thermal expansion coefficient of the metallic micro beam, tab. 2. The Al material has attracted attention due to its low density and ability to withstand corrosion. The proposed geometry will be useful in the production of MEMS devices to produce the desired displacements of all micro scale beam structures through the simple phenomenon of thermal expansion associated with the current through the beam.

**Table 2. Data from the application of 0.3 V, 0.6 V, and 0.9 V voltage**

| Material | 0.3 V | | 0.6 V | | 0.9 V | |
|---|---|---|---|---|---|---|
| | Displacment [μm] | Temperature [K] | Displacement [μm] | Temperature [K] | Displacement [μm] | Temperature [K] |
| Al | 2.34 | 1030 | 5.13 | 1950 | 7.88 | 2860 |
| Cu | 1.58 | 992 | 3.49 | 1870 | 5.36 | 2740 |
| Ni | 1.13 | 908 | 2.4 | 1630 | 3.62 | 2330 |
| Pt | 0.79 | 950 | 1.76 | 1780 | 2.72 | 2610 |

## Conclusions

In this study, MEMS based micro beam is designed using COMSOL multiphysics software. The current flowing through the beam caused displacement and thermal production through thermal expansion. Combining thermal, electrical and structural analysis made it possible to estimate the current and temperature rise required to deform the micro beam.

The displacement amounts produced for the micro beam designed from four different materials were realized with different input potentials (0.3 V, 0.6 V, and 0.9 V). According to the results, the micro beam designed with Al material showed significant displacement for the proposed geometry compared to other materials. The highest displacement was obtained as 7.88 by applying 0.9 V voltage to the Al material. The lowest displacement was obtained as 0.79 by applying 0.3 V voltage to Pt material. The resulting temperature data was close for each material. This model will be able to find dominant displacements for all micro-scale devices containing potential applications in the biomedical field.

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