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European Journal of Applied Engineering and Scientific Research, 2012, 1 (1):30-36
(http://scholarsresearchlibrary.com/archive.html)

ISSN: 2278 – 0041

Design and modeling of a Micro robot Leg by COMSOL Multiphysics

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ABSTRACT

This example describes the modeling of one of the legs of a silicon microrobot. The microrobot uses a technique based on polyimide V-groove joints to get each of the legs to move. The polyimide has a relatively high coefficient of thermal expansion α, which causes the leg to bend slightly when the polyimide is heated. Putting several V-grooves on each leg provides sufficient deflection.

Keywords: Sensors, Actuators, Robot leg, COMSOL Multiphysics, MEMS.

INTRODUCTION

Micro Electromechanical systems or MEMS, represent an extraordinary technology that promises to transform whole industries and drive the next technological revolution. These devices can replace bulky actuators and sensors with micron-scale equivalent that can be produced in large quantities by fabrication processes used in integrated circuits photolithography [1,2]. This reduces cost, bulk, weight and power consumption while increasing performance, production volume, and functionality by orders of magnitude. For example, one well known MEMS device is the accelerometer (its now being manufactured using mems low cost, small size, more reliability). Furthermore, it is clear that current MEMS products are simply precursors to greater and more pervasive applications to come, including genetic and disease testing, guidance and navigation systems, power generation, RF devices(especially for cell phone technology), weapon systems, biological and chemical agent detection, and data storage [3,4.5]. Micro mirror based optical switches have already proven their value; several start-up companies specializing in their development have already been sold to large network companies for hundreds of millions of dollars [6]. The promise of MEMS is increasingly capturing the attention of new and old industries alike, as more and more of their challenges are solved with MEMS.

In this paper, we have reported the design and modeling of micro robot leg by COMSOL Multiphysics version 3.5a.

MATERIALS AND METHODS

2. Modeling of micro robot leg in COMSOL Multiphysics

The original 2D model consists of thin layers, and it is essential to remove these layers in order to reduce the mesh size in the 3D model. Instead, apply the following boundary conditions [7]:

For the thermal part, a highly conductive boundary condition replaces the highly conductive layer of aluminum (see Figure 1):

$$-n.(-k\nabla T) = -d\rho C \partial T \partial t - \nabla.(-dk\nabla T) \qquad \text{----------} \qquad (1)$$

Represent the resistive layer (see Figure 1) with the stiff spring condition

$$-n.(-k\nabla T2) = k\ layer/d.(T1-T2) \qquad \text{-----------} \qquad (2)$$

where klayer is the thermal conductivity of the material, *d* the thickness of the layer, and *T*1 and *T*2 are the temperatures on the each side of the boundary.

The structural part includes a shell element with thermal expansion to model the two thin layers. The software handles the coupling between the shell and the solid elements automatically.

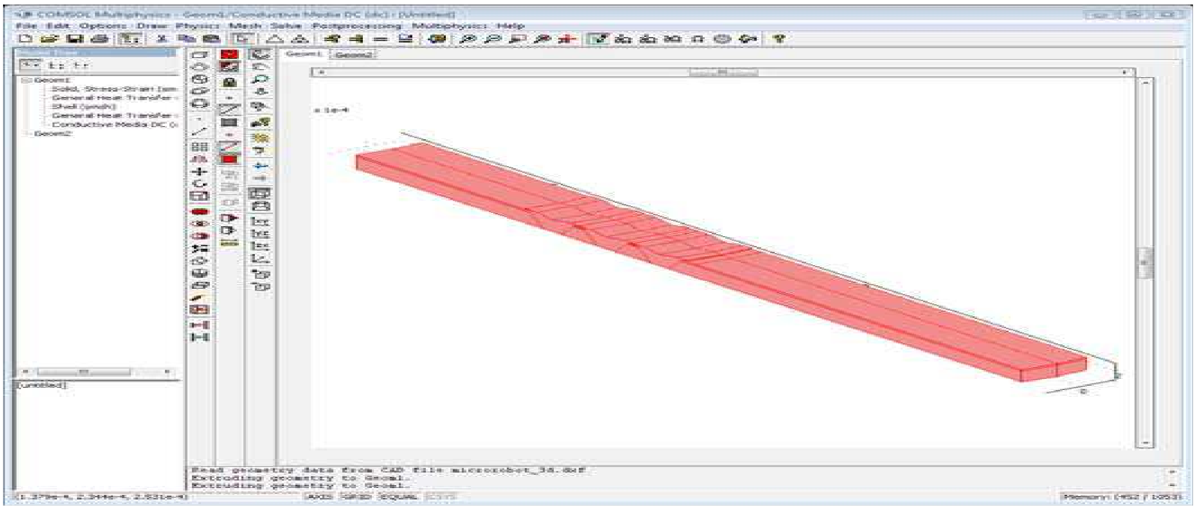
Because the time scale of the structural mechanics part is much smaller compared with the heat transfer part, you can neglect the mass effects in the structural analysis. Instead use a parametric analysis to solve the structural mechanics part. This problem only couples the solid analysis to the heat transfer analysis, and not the other way around, so you can use sequential solution procedure: First solve the heat transfer and conductive media DC equations, and then, after storing the solution in a file and setting the linearization point to the stored solution, solve the structural part using the parametric analysis with the time variable *t* as the parameter.

Model Definition

The model is a transient heat transfer analysis combined with a quasi-static thermal deformation analysis [**7**]. The materials used in the microrobot leg are: Si, SiN, Al, P, SiO, and pSi. They are assembled as shown below:

Figure 1: Cross-section cut of the microrobot leg.

The geometry of the model comes from an initial 2D geometry using mesh extrusion.



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Read geometry data from CAD file microrobot_34.dxf
Extruding geometry to Geom1.
Extruding geometry to Geom1.
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Figure 2: 3D extruded mesh of the microbot leg.

The heat is generated by resistive heating. An electric potential of 30 mV is applied in each of two heating resistors during the first 10 ms of the 20 ms of the simulation. The resulting heat source generated is about 2·1013 W/m3, corresponding to 100 mW (see Figure 3).

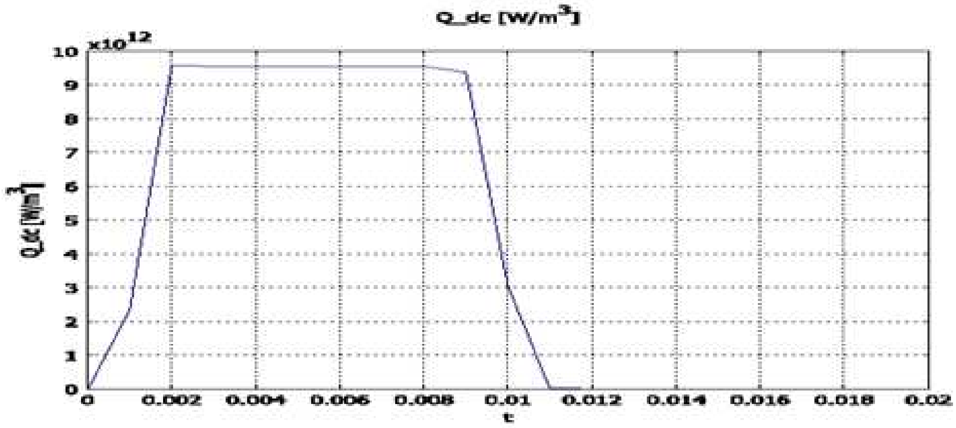


Figure 3: Heat source vs. time in the heating resistors.

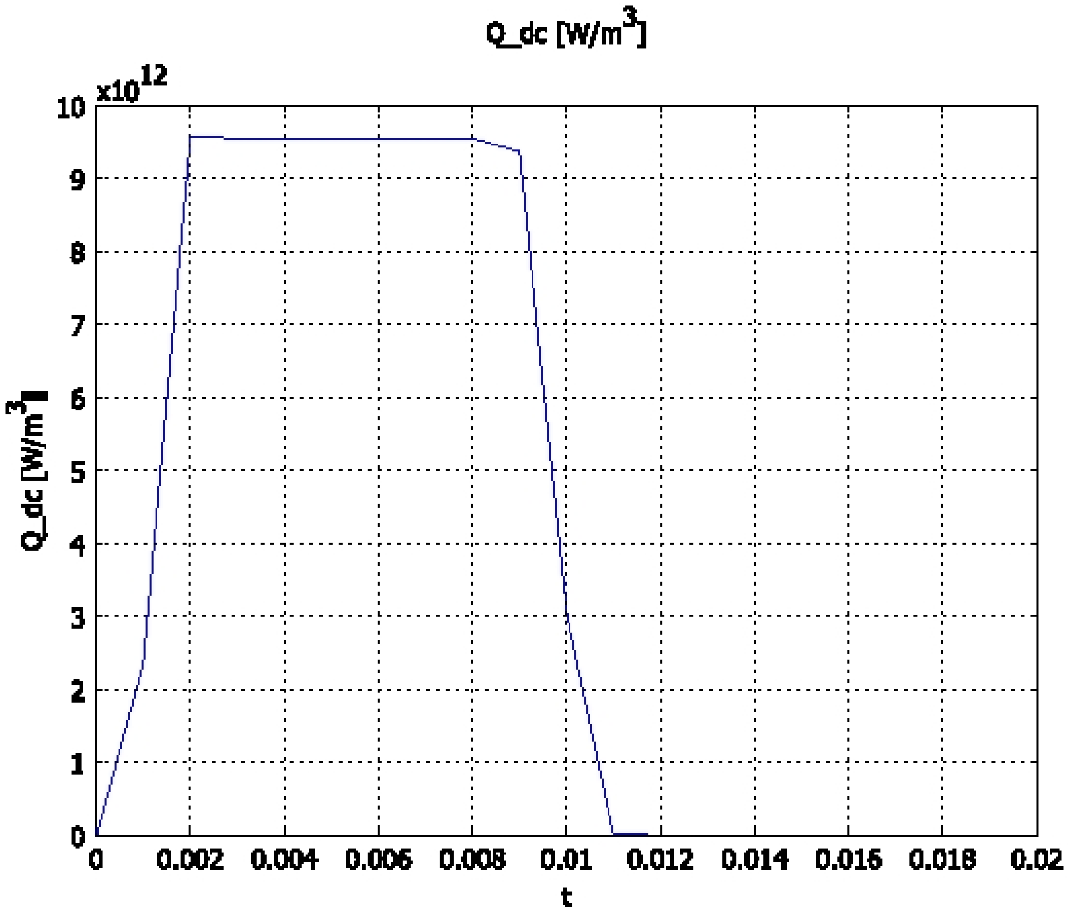
An important part of the simulation is the modeling of the cooling effects at the boundaries. Experimentally, it has been verified that most of the heat is dissipated in the silicon structure, that is, the “body” of the robot. Also, a minor cooling effect at the tip of the leg has been observed. Motivated by this, the model uses a heat transfer coefficient of 1·106 W/(m2·K) on the part of the leg connected to the rest of the robot, and a coefficient of 1·105 W/(m2·K) on the tip of the leg. These values have been chosen somewhat arbitrarily, but the results have been calibrated with experimental data.

The boundary conditions for the structural mechanics part are simply constrained displacement at the left end of the robot leg and zero force on the rest of the structure.

The 3D model does not include the thin layer of Al and SiO. On the resulting boundary, a structural shell application mode and two specific thermal boundary conditions model the highly conductive and poorly conductive layer. The heat propagates by conduction through the leg, and thermal expansion and different thermal expansion coefficients of the several materials induce a bending action.

RESULTS AND DISCUSSION

Figure 4 below shows the bending action at t = 0.2 ms. The plot also includes the temperature at the boundary.



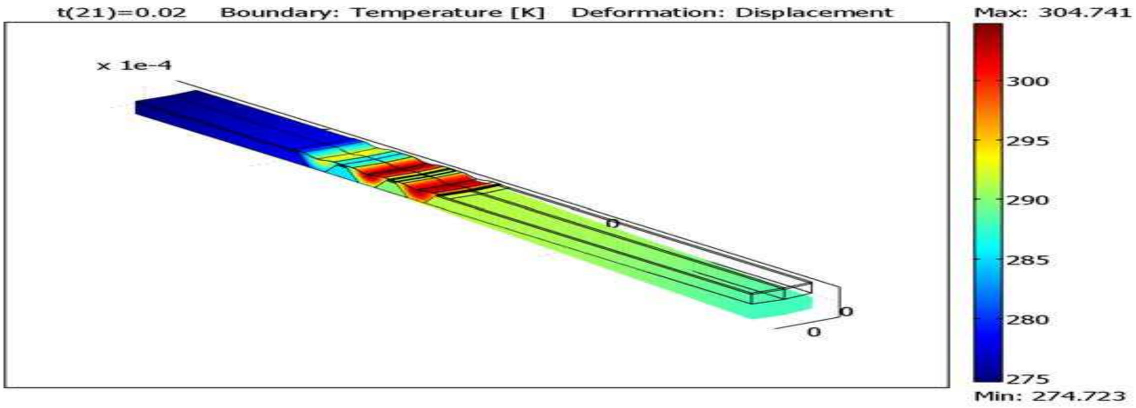


Figure 4: Temperature distribution in the microrobot at 20 ms.

The plots shows that the leg bends as expected with the increase of temperature and moves toward its original position when the heat source is turned off.

Figure 5 below shows the total displacement as a function of time at the tip of the leg.

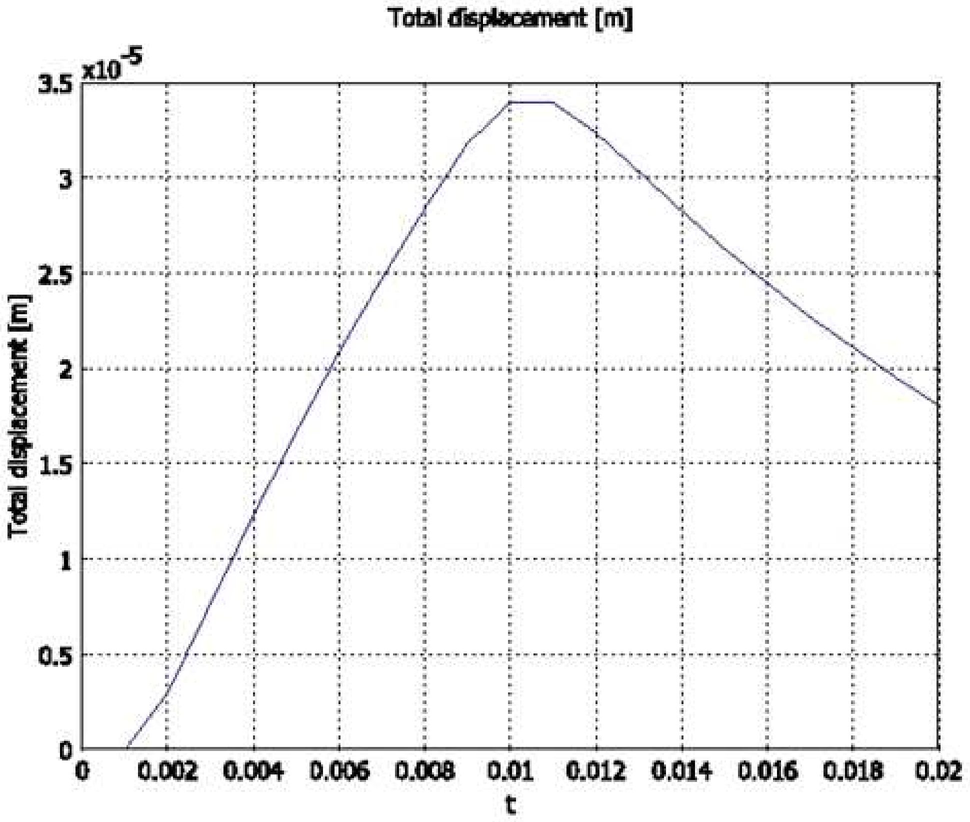


Figure 5: Total displacement at the tip of the leg.

To verify the validity of the highly conductive and resistive layer, a cross-section plot of the temperature focuses on the middle of the V-groove joints (see Figure 6).

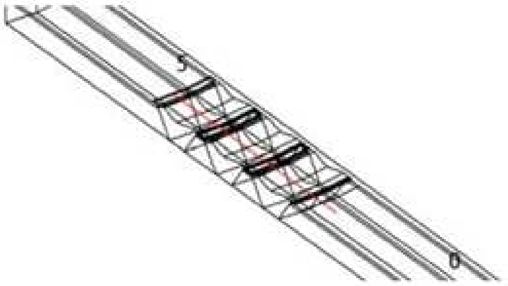


Figure 6: Position of the cross-section plot.

Observe the effect of the thin layer at the positions z = −1.1·10−4, −0.6·10−4, −0.2·10−4, 0.2·10−4, 0.6·10−4, and 1.1·10−4 m in a cross-section plot of the temperature inside the microrobot leg (see Figure 7).

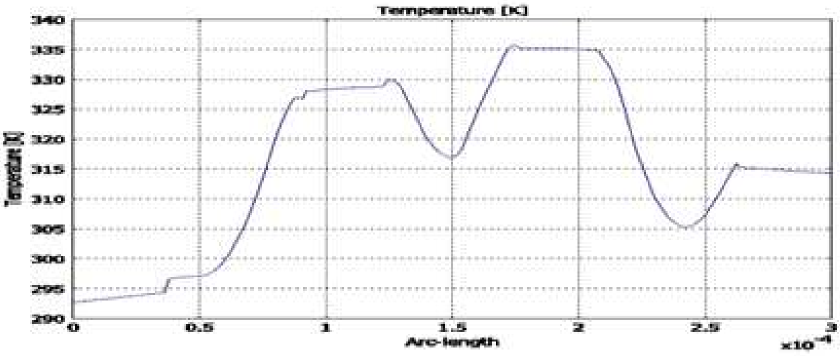


Figure 7: A cross-sectional plot of the temperature distribution inside the microbot leg.

The small dips at z = −0.2·10−4 m and 1.1·10−4 m correspond well with a 2D model where the thin composite layers are modeled using solids instead of the highly and resistive conductive layers and structural shell elements.

CONCLUSION

MEMS technology has the potential to change our daily lives as much as the computer has. However, the material needs of the MEMS field are at a preliminary stage. A thorough understanding of the properties of existing MEMS materials is just as important as the development of new MEMS materials.

The model is a transient heat transfer analysis combined with a quasi-static thermal deformation analysis. The materials used in the microrobot leg are: Si, SiN, Al, P, SiO, and pSi. This example describes the modeling of one of the legs of a silicon microrobot. The microrobot uses a technique based on polyimide V-groove joints to get each of the legs to move.

Future MEMS products will demand higher levels of electrical-mechanical integration and more intimate interaction with the physical world. The high up-front investment costs for large-volume commercialization of MEMS will likely limit the initial involvement to larger companies in the IC industry. Advancing from their success as sensors, MEMS products will be embedded in larger non-MEMS systems, such as printers, automobiles, and biomedical diagnostic equipment, and will enable new and improved systems.

Acknowledgements

The author Dr.K.Srinivasa Rao would like to thank IISc, Bangalore, for providing research facilities under NPMASS Scheme. The author also would like to thank the director and The Management of Lakireddy Bali Reddy College of engineering for constant encouragement for the development of MEMS Technology.

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