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# Paper Based Piezoresistive Sensor Using MEMS

**Prof G Mallikarjuna Rao[1], Pavani Kollamudi[2]**

Professor, EIE, LBRCE, Mylavaram, India[1]

Assistant Professor, EIE, LBRCE, Mylavaram, India [2]

**Abstract**: This paper describes the development of MEMS force sensors constructed using paper as the structural material. The working principle on which these paper-based sensors are based is the piezo-resistive effect generated by conductive materials patterned on a paper substrate. The device is inexpensive (∼\$0.04 per device for materials), simple to fabricate, lightweight, and disposable. Paper can be readily folded into three-dimensional structures to increase the stiffness of the sensor while keeping it light in weight. The entire fabrication process can be completed within one hour without expensive clean room facilities using simple tools (*e.g.*, a paper cutter and a painting knife). In this project demonstrated that the paper-based sensor can measure forces with moderate performance. In this project applied this sensor to characterizing the mechanical properties of a soft material. The design of MEMS based piezo-resistive cantilever was made using COMSOL multi physics software version 5.0, in which the free end of the beam gets displaced when input pressure is applied. Five piezo-resistive materials are used. Copper, Silver, Graphite, Al2O3, Aluminium are analysed by varying input load. The work is concentrated mainly on the maximum amount of displacement observed for the applied pressure as a result of piezo resistive effect. Among the two materials considered, the material resulted in greater displacement for proposed geometry is Al2O3. When compared with other materials Al2O3 has low value of Young's modulus and considerably high value of Poisson ratio.

**Keywords**: Piezo resistive sensor, MEMS

## I. INTRODUCTION

Micro-electromechanical systems (MEMS) are a process technology used to create tiny integrated devices or systems that combine mechanical and electrical components. They are fabricated using integrated circuit (IC) batch processing techniques and can range in size from a few micrometers to millimetres. These devices (or systems) have the ability to sense, control and actuate on the micro scale, and generate effects on the macro scale. MEMS, an acronym that originated in the United States, is also referred to as Microsystems Technology (MST) in Europe and Micro machines in Japan. Regardless of terminology, the uniting factor of a MEMS device is in the way it is made. While the device electronics are fabricated using 'computer chip' IC technology, the micromechanical components are fabricated by sophisticated manipulations of silicon and other substrates using micromachining processes. Processes such as bulk and surface micromachining, as well as high-aspect-ratio micromachining (HARM) selectively remove parts of the silicon or add additional structural layers to form the mechanical and electromechanical components. While integrated circuits are designed to exploit the electrical properties of silicon, MEMS takes advantage of either silicon's mechanical properties or both its electrical and mechanical properties. In the most general form, MEMS consist of mechanical microstructures, micro sensors,micro actuators and microelectronics, all integrated onto the same silicon chip. This is shown schematically in Figure 1.

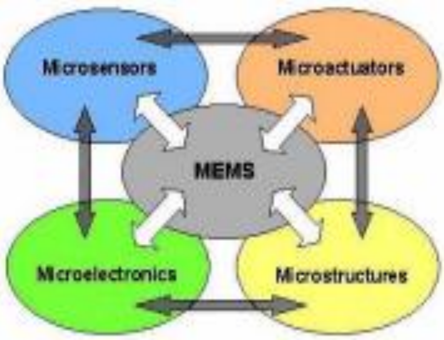


FIGURE 1: SCHEMATIC ILLUSTRATION OF MEMS COMPONENTS.

The past three decades have witnessed the extensive development of MEMS devices and systems, which have found important applications in industrial and medical fields. Silicon-based materials (e.g., single crystal silicon, polycrystalline silicon, silicon dioxide, and silicon nitride) are used as the primary materials for constructing MEMS

Device. Despite recent efforts on utilizing other materials (e.g., polymer, diamond, and ceramics) for MEMS construction, the material cost is still relatively high. In addition, the micro-fabrication process used for MEMS (especially for prototyping) is time-consuming (days for a single batch) and requires clean room equipment. Both materials and the use of clean room are expensive; and although the performance of silicon-based MEMS can be excellent, their relatively high cost has limited the applications and markets they can address. We are interested in the development of new MEMS technologies, where the emphasis is on minimizing cost, and the ratio of performance to cost is maximized by minimizing cost rather than maximizing performance. As the materials serve as the basis for this exploratory progress, we have chosen paper. A conceptually selected effort to reduce the cost of diagnostic systems by developing paper-based diagnostic systems has opened a new venue of technologies [5-7]. Paper is readily available, lightweight, and easy-to-manufacture; it can be safely disposed of by incineration. As our first investigation of using paper for MEMS construction, we developed a paper-based piezo-resistive force sensor and applied it to mechanical characterization of soft materials. Leveraging the same concept, we also demonstrated a paper-based weighting balance.

The piezo resistive effect is a change in the electrical resistivity of a semiconductor or metal when mechanical strain is applied. In contrast to the piezo electric effect, the piezo resistive effect causes a change only in electrical resistance, not in electric potential. The working principle of the paper-based force sensor is based on the piezo-resistive inducing strain/stress. Based on the piezo-resistive effect, the strain/stress can be converted into a resistance change by the sensing component, which is easily detected by the electrical instrument. In order to realize a flexible system, a paper substrate is used instead. The paper cantilever beam is made to let the force apply on it. The graphite located on the cantilever beam functions as the sensing component. When force is applied on the cantilever beam, the stress of the beam will change sensitively.

## II DEVICE STRUCTURE

The schematic structure of the paper-based force sensor is shown in Figure 1. In this structure, a graphite resistor is located at the root of the cantilever beam. When a force is applied to the beam structure, the graphite resistor will experience a mechanical strain/stress, which then induces a change in the resistance of the resistor. Measuring the change in resistance can reflect the magnitude of the applied force.

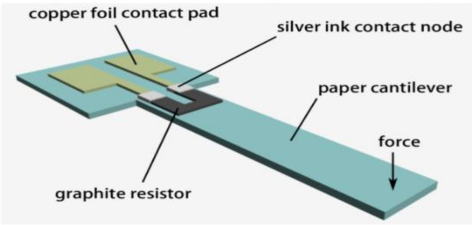


Figure 2. Schematic structure of a paper-based force sensor. Graphite is used as the sensing component.

## III DESIGN

**Geometry**

Cantilever made of a block. Block having length, depth, height of 10mm, 3mm, 0.2mm respectively. Steps to be followed to get desired structure:

**For Block:**

In the model builder window>under component 1>right click geometry > choose block> give dimensions as mentioned and define layers as Aluminium and copper of thickness 0.2mm each.

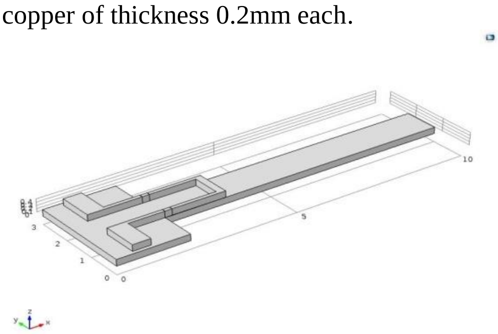

Figure 3 : Geometry

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**Materials**

Geometry is followed by addition of material; among different physics available structural mechanics is used. In this physics it is possible to add piezoresistive materials to the model. Only layer 1 is varied with the 2 chosen piezo resistive material. And the entire remaining part of cantilever is assigned Copper, Silver, and Graphite material.

Steps to be followed while assigning the materials:

In the model builder window>under component 1>right click materials >choose add material>Built in>Copper> select domain to be applied.

In the model builder window>under component 1>right click materials >choose add material>piezoresistive materials>choose 1 out of 2 materials mentioned> select domain to be applied.

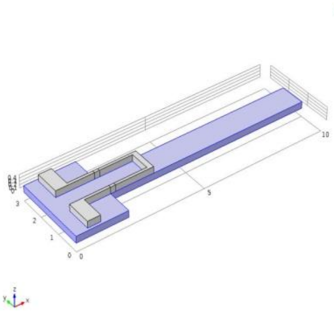

Figure 4: Add Al2O3 Material

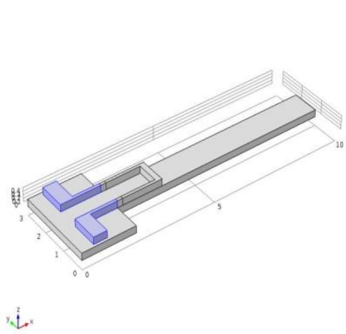

Figure 5:Add Copper Material

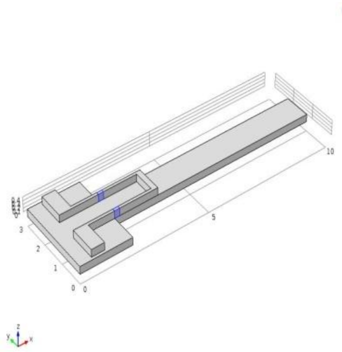

Figure 6: Add Silver material

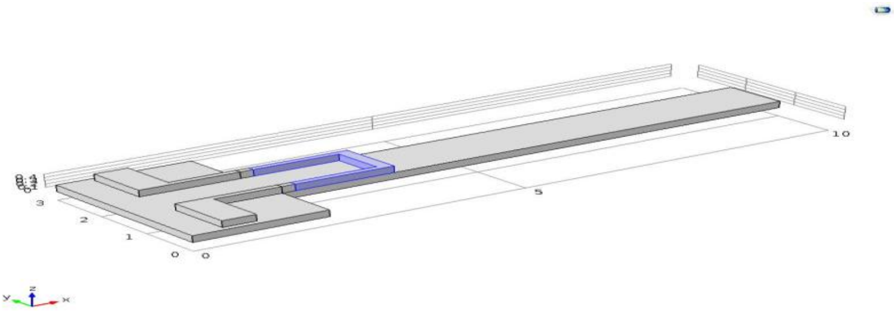

Figure 7 : Add Graphite Material

**IV Simulation Results**

With the aim to obtain the better output from the proposed design, cantilever beam is analysed for each piezoresistive material by applying pressure as boundary load on the free end of the structure. Displacement observed is noticed for the applied pressure ranging from $10N/m^2$ to $20N/m^2$.Displacement is decreasing by increasing pressure. It is observed that Al2O3 generates high displacement (for millimetre displacement) than others for same geometry and same applied pressure. The following figures indicate simulation images for each piezo resistive material selected:

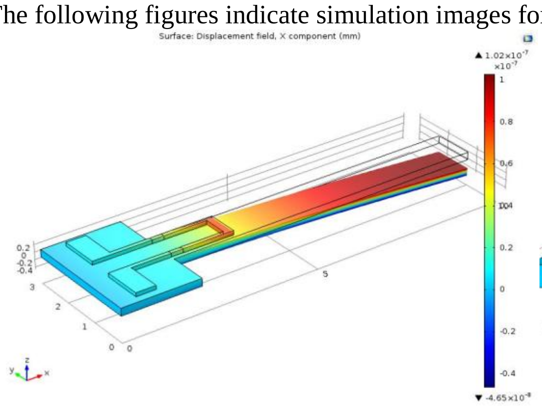


Figure 8: Displacement shown by cantilever when Aluminium is used with 0.2

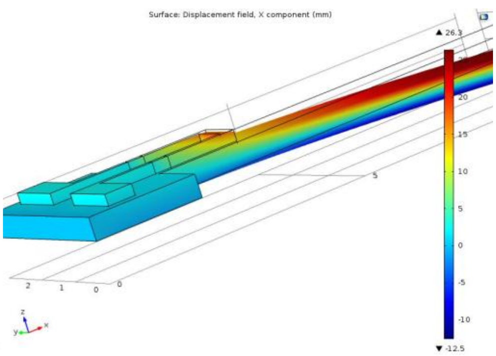


Figure 9: Displacement shown by cantilever when Al2O3 is with 0.4

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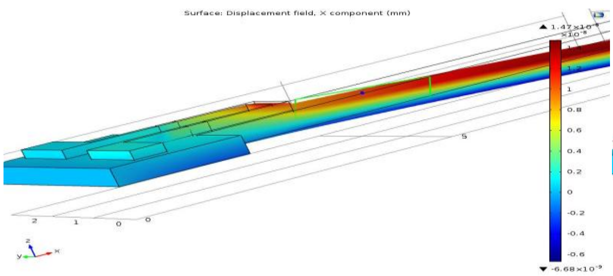


Figure 10: Displacement shown by cantilever when is Aluminium is used with 0.4

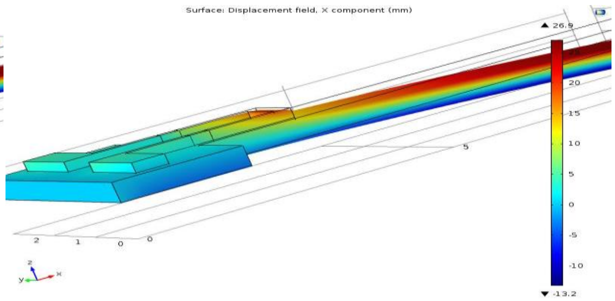


Figure 11: Displacement shown by cantilever when Al2O3 used with 0.4

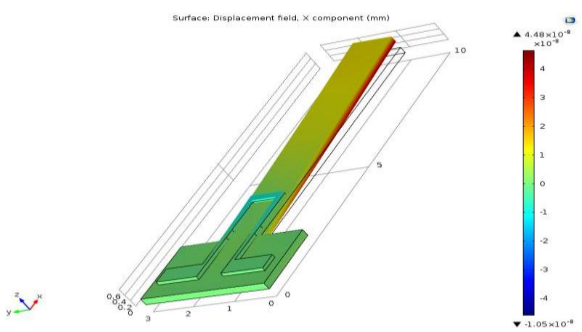


Figure 12: Displacement shown by cantilever when Aluminium is used with 0.2

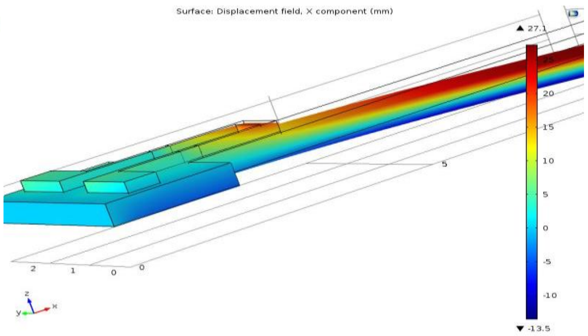


Figure 13: Displacement shown by cantilever when Al2O3 is used with 0.4

Table 1: Response of each piezoresistive material for applied pressure

| SNo. | Piezoresistive material | Pressure applied($N/m^2$) | Displacement (mm) | Thickness(mm) |
|---|---|---|---|---|
| **1** | Al2O3 | 2<br>15<br>20 | 6370*10^(3)<br>4.21*10^(4)<br>5.58*10^(4) | 0.2 |
| **2** | Al2O3 | 2<br>15<br>2 | 26.3<br>26.9<br>27.1 | 0.4 |
| **3** | Aluminum | 2<br>15<br>20 | 1.02*10^(-7)<br>1.06*10^(-7)<br>4.62*10^(-8) | 0.2 |
| **4** | Aluminum | 2<br>15<br>20 | 1.47*10^(-8)<br>1.08*10^(-7)<br>1.41*10^(-7) | 0.4 |

Table 2 : Comparison of piezoresistive materials

| Piezoresistive Materials | Résistance (ohm-m) | Young's Modulus (GPa) | Poisson's Ratio |
|---|---|---|---|
| Copper | 5.3062*10^(-4) | 117 | 0.33 |
| Silver | 4.6835*10^(-4) | 10.5 | 0.37 |
| Graphite | 0.95550 | 27.6 | 0.23 |
| Al2O3 | 3.1850*10^(18) | 413 | 0.33 |
| Aluminium | 8.3813*10^(-4) | 415 | 0.35 |

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## V CONCLUSION

The design of MEMS based piezoresistive cantilever was made using COMSOL multi-physics software version 5.0, in which the free end of the beam gets displaced when input pressure is applied.

Five piezoresistive materials are used. Copper, Silver, Graphite, Al2O3, Aluminium are analysed by varying input load. The work is concentrated mainly on the maximum amount of displacement observed for the applied pressure as a result of piezoresistive effect.Among the Two materials considered, the material resulted in greater displacement for proposed geometry is Al2O3. When compared with other materials Al2O3has low value of Young's modulus and considerably high value of Poisson ratio. The comparative study by simulations can be used to provide the guidelines for a design and optimization of performance of the different piezoresistive micro-cantilever pressure sensors.

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