# Design and Analysis of Temperature Sensor Array by Using Comsol Multiphysics 4.3

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**Abstract:** ***This paper propose a new design and analysis of MEMS sensor array based on thermal stress and electric current properties. The COMSOL Multiphysics 4.3 software is used to design the sensor array of the sensing layer. The material selection is done based on the thermal analysis of the sensor array. The polysilicon yield a maximum displacement of 0.00143µm and also it is suitable for human skin. So polysilicon can be proposed for sensor array and then analysis the performance of sensor array.***

**Keywords:** Tactile sensor, sensor array, Comsol Multiphysics, Semiconductor material, Minimal access surgery

## 1. Introduction

The term tactile sensor usually refers to a transducer that is sensitive to touch, force, pressure. Tactile sensors are employed wherever interactions between a contact surface and the environment are to be measured and registered. Tactile sensors are useful in a wide variety of applications, robotics, computer hardware, medical field[10].The main transducer technologies used are piezoelectric [11], piezoresistive[12],capacitive [13],optical [14], and mechanical Some transducers are based on elastomer or silicon micromachining technology [15].The electronics layer comprises the hardware necessary for signal conditioning. In this layer may be found multiplexors, bridges, amplifiers and other functional circuitry [15, 16]. One major design trend is to integrate this layer with the sensing layer in the same chip as might be realised using integrated circuit (IC) compatible technology such as micromachining .A thin layer of elastic material for protection, both of the sensor and, in MAS, the patient, covers the sensor. This layer also provides the important functionality of grasping. The presence of this layer may, however, complicate the analysis of the sensor output .The support layer might be rigid or flexible. The method of attaching this layer to the gripper greatly affects the performance of the overall sensor system. The most common tactile sensors available today are static and passive[10]. They can be used to provide only a static perception of object shape. Less common are dynamic and active sensors. These can be used in conjunction with relative motion between sensor and contact body to provide a dynamic perception of high frequency quantities such as surface texture, sharp of edges etc. Although these latter, dynamic, sensors are less far advanced than the simpler static type, they will be essential in providing a base for intelligent dexterous manipulation by robot. The piezoelectric properties of organic ferroelectrics for use in medical tactile sensor applications, especially for intravascular surgery, by means of both experimental analyses and mathematical simulations. First, we measured the piezoelectric properties of the organic ferroelectrics. Second, we investigated the palpation in vivo by the tactile sensor composed of organic ferroelectrics using a computer-based surgical simulator to simulate a catheter and a guide wire in blood vessels for treatment of the brain which we have previously developed. MEMS based capacitive tactile sensor intended to be incorporated into a tactile array as the core element of a bio mimetic finger pad. The use of standard micro fabrication technologies in realizing the device allowed a cost efficient fabrication involving only a few process steps. A low noise readout electronics system was developed for measuring the sensor response. The performance of both bare and packaged sensors was evaluated by direct probing of individual capacitive sensor units and characterizing their response to load–unload indentation cycles [7].A micro electro mechanical systems (MEMS) temperature sensor based on a cascade three-stage “bent-beam” structure. A suspended structure mechanically deforms in response to the change in ambient temperature, and then, a displacement is obtained; the structure is composed of three cascaded systems in order to enhance sensor sensitivity. The final conversion is made to an electrical signal that is obtained by using an interdigitated capacitor having one electrode fixed to the substrate and one electrode embedded into the moving tip of the MEMS sensor [8]. The design of a RFID-enabled temperature sensor is described in this paper. In this sensor, a change in temperature causes structural beams to bend, which results in a proportional displacement of the plates of the capacitor. Plates' displacement results, in turn, in changing the value of its capacitance. The capacitor of the sensor is coupled to the LC resonant network of a passive RFID tag. This makes the tag's resonance frequency dependent on the value of the sensor's capacitance. Hence by measuring the shift in the resonance frequency, one can measure the change in temperature[3].In MAS the working environment is a closed system containing soft tissue, living organs and body fluids as well as other instruments deployed by the surgeon. Since a tactile sensor for MAS is used inside the body, it must be reliable, biocompatible and water proof and packaged in an appropriate useful manner. It must also be miniature and might need to be disposable. Some of these specifications can be met by the use of elastomer-based tactile sensors, but there remain some inherent limitations. Silicon-based tactile sensors have the potential to meet all of the specifications [10].In the new version presented here, the tactile sensing chips have been fabricated using CMOS technology. Both, the individual taxels and the array are designed to match spatio-temporal performance of the human fingertips. To detect contact parameters such as contact force, the taxels utilize the contact induced change in the polarization level of piezoelectric polymer The performance of POSFET device has been evaluated in the dynamic contact forces range of 0.01–3 N. The response of POSFET is linear in the tested range, with the sensitivity (without amplification) of 102.4 mV/N – which is more than twice the response of POSFETs presented earlier[1].This paper presents a novel design of a fingerprint sensor composed of a 2D array of piezoresistive micro beams has been presented. When the user presses the sensor array with a finger, the ridges and valleys that compose the fingerprint induce corresponding deflections in the micro beams. These deflections can be detected by means of a resistivity change, which when used with appropriate signal processing circuits, convert the deflections into an equivalent voltage signal. The design also includes post processing circuits comprising of A/D converter, needed to digitalize the amplified signal. The digitalized outputs from individual micro beams represent the pixels of the final fingerprint image. A sample data resulting from a sensor array of (224 x 256) micro beams, each of dimensions 50µm x 50µm, has been successfully used to reconstruct an image of the fingerprint using MATLAB.COMSOL was used to simulate the micro beams [4].In this paper presents a fabrication of a piezoelectric tactile sensor based on piezoelectric PVDF-TrFE film integrated with a low temperature polysilicon thin film transistor (LTPS TFT) in an extended gate configuration. The piezoelectric PVDF-TrFE properties have been enhanced with a poling procedure, reaching a piezoelectric coefficient of about 25 pC/N. The device has been measured in a source-follower floating gate arrangement, showing an output signal of 0.5mV/N to a normal sinusoidal stimulus at 1Hz [5].This paper presents a new approach to the construction of tactile array sensors based on barometric pressure sensor chips and standard printed circuit boards. The chips include tightly integrated instrumentation amplifiers, analog-to-digital converters, pressure and temperature sensors, and control circuitry that provides excellent signal quality over standard digital bus interfaces. The resulting array electronics can be easily encapsulated with soft polymers to provide robust and compliant grasping surfaces for specific hand designs. The use of standard commercial-off-the-shelf technologies means that only basic electrical and mechanical skills are required to build effective tactile sensors for new applications. Performance evaluation of prototype arrays demonstrate excellent linearity (<1% typical) and low noise (<0.01 N). External addressing circuitry allows multiple sensors to communicate on the same bus at over 100 Hz per sensor element. Sensors can be mounted as close as 3x5 mm spacing, and spatial impulse response tests show that solid-mechanics based signal processing is feasible. This approach promises to make sensitive, robust, and inexpensive tactile sensing available for a wide range of robotics and human-interface applications[6].In this paper analyse a Simulation of Thermal Sensor for Satellite Thermal Control Using Comsol. It focuses on the development of a Micro electro mechanical systems (MEMS) mechanism which involves a bimetallic micro beam, a piezoelectric crystal and Field effect transistor (FET) to detect the rise in temperature and actuate the temperature control system. The relation between their individual response to parameters like temperature rise, stress and voltage is used to detect the temperature rise. The interaction between the three components is modeled by the application modes in comsol and the voltage output across the FET which will actuate the thermal control system is obtained[9].PiezoresistiveNiCr tactile sensors have been developed on surface micromachined aluminum oxide membranes, embedded between two polyimidelayers, i.e., one serving as a substrate, another as a superstrate. A novel method to bond a flexible superstrate polyimide layer onto a microelectro mechanical system tactile sensor array is presented. The piezoresistors were connected in a half-Wheatstone bridge configuration to minimize the effects of thermal drift. Three different types of sensor designs were fabricated and characterized to obtain the nichrome thin-film gauge factor. The experimental results were compared with those simulated for the same conditions of membrane deflection. The gauge factors range between 2.2 and 7.9 for sensors with a superstrate and between 1.5 and 3.2 without a superstrate. [2].In the micro gyroscope or other sensors having a U-shape sensor array for acceleration or positioning of the system, here we propose a triangle shape array.

## 2. Mathematical Modelling

### 2.1 Joule heating

The Joule Heating Model node in COMSOL uses the following version of the heat equation as the mathematical model for heat transfer in solids

$$\rho C_P \frac{\partial T}{\partial t} - \Delta.(k.\Delta T) = Q \quad (1) \longrightarrow$$

With the following material properties:

- **ρ** is the **density.**
- **Cp** is the **heat capacity.**
- **k** is the **thermal conductivity**

(a scalar or a tensor if the thermal conductivity is anisotropic).

- **Q** is the **heat source (or sink).**

In Joule heating, the temperature increases due to the resistive heating from the electric current. The electric potential V is the solution variable in the Conductive Media DC application mode. The generated resistive heat Q is proportional to the square of the magnitude of the electric current density J. Current density which in turn, is proportional to the electric field, which equals the negative of the gradient of the potential V, so we have

$$Q \alpha |J2| \quad (2) \longrightarrow$$

### 2.2 Sensors based on thermal expansion

Nearly all materials undergo a change in volume or dimensions as their temperature changes. For solids such as semiconductors, metals and dielectric materials, their volume increases as the temperature increases, as follows: The **Volumetric thermal expansion coefficient (TCE),**commonly denoted as **α,**is the ratio between relative change of volume to the degree of temperature variation,

**Volumetric thermal expansion coefficient (TCE)**

$$\alpha = \frac{\Delta V/V}{\Delta T} \quad (3) \longrightarrow$$

The **Linear thermal expansion coefficient** is the change of only one dimension of an object due to temperature variation.

$$\beta = \frac{\Delta L/L}{\Delta T} \quad (4)$$

The volumetric and linear expansion coefficients are related by

$$\alpha = 3\beta \quad (5)$$

Thermal expansion coefficients of thin film materials are different from their bulk versions and have to be characterized separately. Thermal expansion in liquids is higher than solid. Thermal expansion of gases are calculated by ideal gas law

$$PV = nRT = NkT \quad (6)$$

Where P-absolute pressure, V-Volume, T- absolution temperature, N-number of molecules,R-Universal gas constant.

## 3. Sensor Design Using COMSOL Multiphysics 4.3

Figure 1 given below shows the geometrical model of the sensor array obtained using COMSOL.

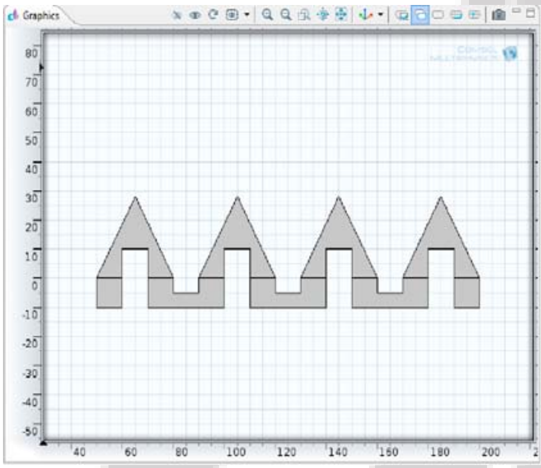

**Figure1:** Geometric model of sensor

The thermal stress and electric current module in COMSOL was used to show the displacement, temperature variant of the device and electric potential flow of the device. We design the above structure by using the model wizard window and geometry section (Rectangle and square).Then we applied the polysilicon material ,This material is chosen from thermal analysis of the material section.

## 4. Selection of Material

The selection of material depends on the performance graph between the temperature value and materials. It has a four temperature variant table and corresponding performance graph for metal, semiconductor, insulator, polymers respectively.

### 4.1Thermal analysis of Metal

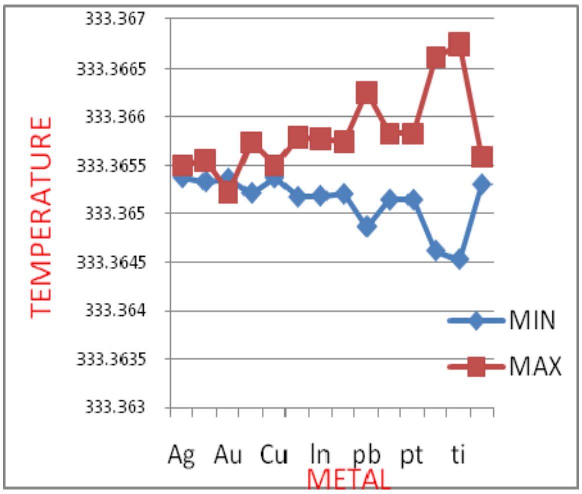


**Figure 2**: Metal performance graph

### 4.2 Thermal analysis of Semiconductor

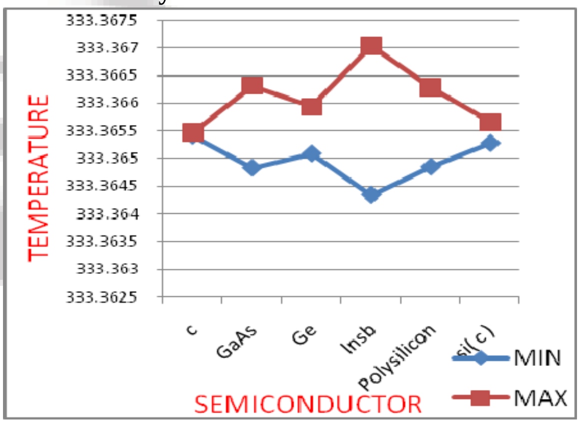


**Figure 3:** Semiconductor performance graph

### 4.3 Thermal analysis of insulator

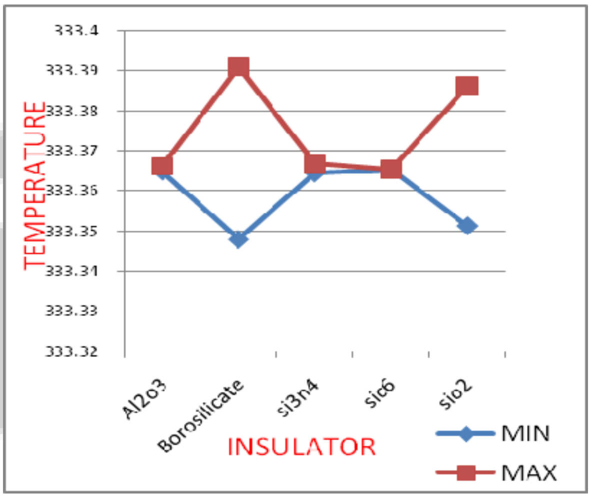


**Figure 4:** Insulator performance graph

### 4.4 Thermal analysis of Polymers

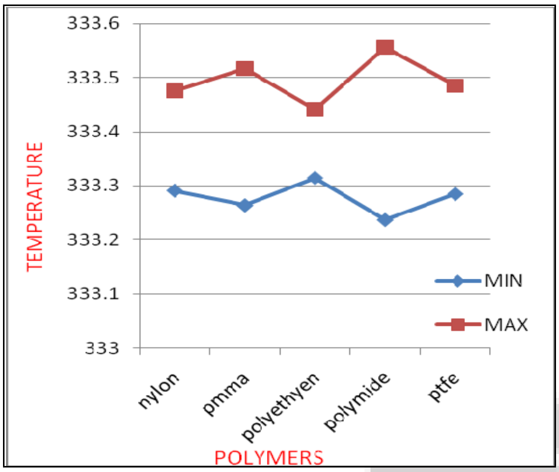


**Figure 5:** Polymers Performance Graph

### 4.5 Comparison of Materials

**Table 1:** Comparison table for materials

| *Material* | *Minimum Temperature(K)* | *Maximum Temperature(K)* |
|---|---|---|
| Metal (Titanium) | 333.36453 | 333.36675 |
| Semiconductor (Polysilicon) | 333.36485 | 333.36628 |
| Insulator (Borosilicate) | 333.34806 | 333.39103 |
| Polymers (polymide) | 333.23655 | 333.55648 |

By using the above four graph and comparison table, the polymers has a high sensing temperature, however the semiconductor materials gives a more accurate output compare than other materials. We select the semiconductor material such as polysilicon because this material is suitable for human skin. The thermal balance consists of a balance of flux at steady state. The heat flux is given by conduction only. The heat source is a constant heat source of 1·108 W/m3. The air cooling at the boundaries is expressed using a constant heat transfer coefficient of 10 W/m2 and an ambient temperature of 298K.

The stress and strains are well within the elastic region for the material. The expression for thermal expansion requires a strain reference temperature for the polysilicon, which in this case is 293K..All other thermal and mechanical properties are obtained from the Material Library. These properties are given in the table 2.

**Table 2:** Properties of the polysilicon material

| *Property* | *Value* |
|---|---|
| Coefficient of thermal expansion | 2.6e-6[1/k] |
| Heat capacity at constant pressure | 678[J/(kg*k)] |
| Density | 2320 [kg/m$^3$] |
| Thermal conductivity | 34 [W/(m*k)] |
| Young's modulus | 160e9[pa] |
| Poisson's ratio | 0.22 |
| Relative permittivity | 4.5 |

## 5. Results and Discussion

### 5.1 Analysis of Temperature Distribution

The following figure shows the temperature distribution in the device. The heat source increases the temperature to 333 K from an ambient temperature of 298 K.The edges of the original geometry are shown in black.

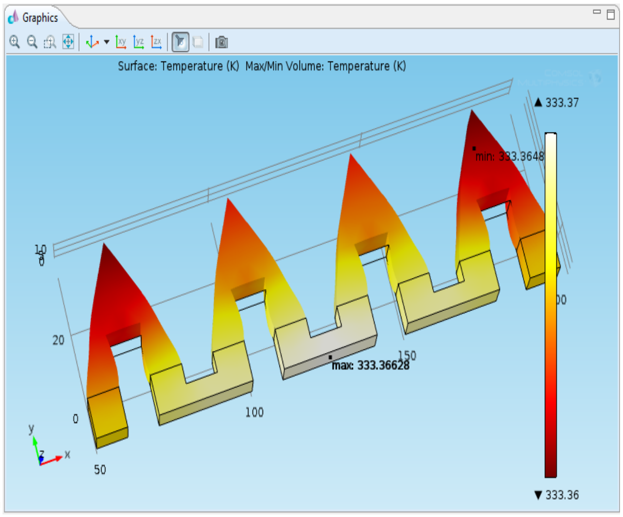


**Figure 6:** Temperature distribution of the device

### 5.2 Analysis of Potential Flow

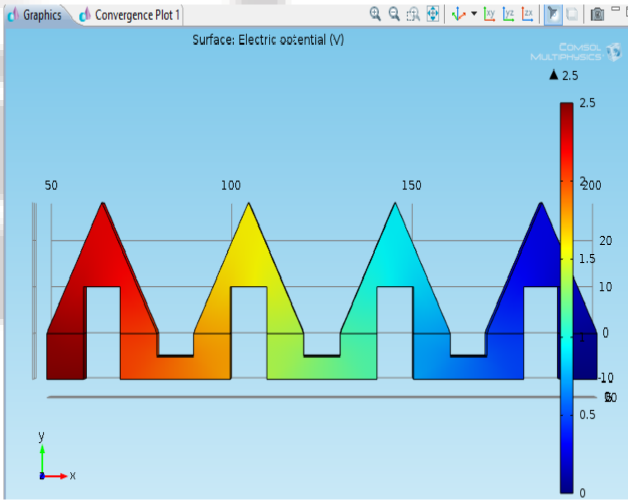


**Figure 7:** Electric Potential flow of the device

In the electric current section, we select the boundary conditions, such as ground and electric potential. In the selection list, we select the boundary 2 for ground and boundary 65 for electric potential and then we set the initial potential value is a 2.5V in the electric potential section. The above 3D plot graph shows the potential flow in the device with initial value.

### 5.3 Analysis of Displacement

The thermal expansion was occurred due to the heat transfer, so after the thermal stress applied, the polysilicon temperature sensor expands with some distance from the original position. This distance is measured in µmrange; it is called as a displacement of the device. Here the displacement value is 0.00143µm. It shows the displacement of a curve that follows the top inner edges of the device from left to right.In the displacement graph the x-axis represented as a position along the edge,and the y-axis represented as a displacement in the range of µm.

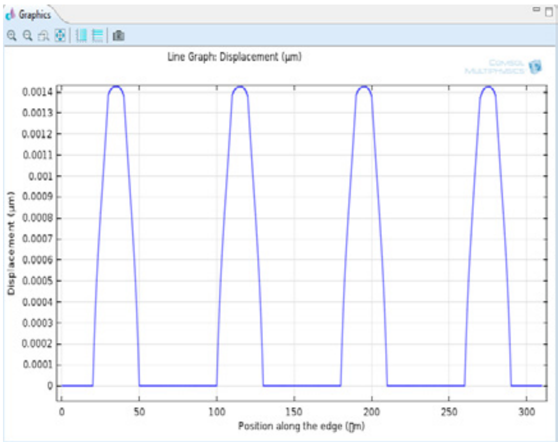


**Figure 7:** Displacement along the edge

### 5.4 Analysis of Temperature Variants

Here the temperature values are measured along the position of the top inner edge.The heat source increases the temperature to 333 K from an ambient temperature of 298K.In the below graph the temperature values are changed along the top inner edges of the model,so it has various temperature value in each position.This temperature graph varies in the range of minimum temperature value of 333.36485K to maximum temperature value of 333.36628K.

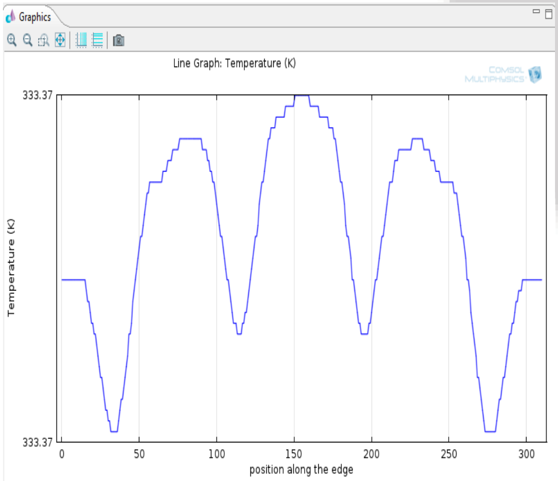


**Figure 8:** Temperature Variant Along The Edge

## 6. Conclusion

The sensor array based on thermal sense is designed and the semiconductor material, such as polysilicon is implemented to the sensor array design by using COMSOL Multiphysics 4.3 software. The thermal stress properties are fixed to the design and the ambient temperature is set to 298k in the heat flux field. This temperature is increased to the 333k after the computation of the complete sensor design. Analysis the displacement of the sensor due to the heat transfer, the sensor is displaced to the value of 0.00143µm from the original position in the workplane. The change in temperature for the top inner edge of the design is completely analysed and the corresponding graph is plotted. In future this design can be fabricated and made into an MEMS IC and this sensor is used in various applications such as medical application, industries purpose and robotics applications.

## 7. Future Work

In future, we design the remaining layers of the thermal sensor for fabrication technology.

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