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Multi-Domain Analysis of Silicon Structures for MEMS based-sensors

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Abstract: Investigation in this paper aims at performing Mechanical Stress-Strain analysis, Thermal, Piezoresistive and Piezoelectric analysis of Silicon based structures using COMSOL. Such structures forms the main component of MEMS based sensors used for various applications, since it is this part which actually senses the stimulus. Therefore realization of how these structures manipulate the external stimulus into measurable parameter has been successfully done using COMSOL. The simulation results have been cross checked by mathematical calculation.

Keywords: Stress-Strain, Thermal, Piezo-resistive, Piezoelectric

1. Introduction

Micro Electro Mechanical Systems are miniature multifunctional microsystems consisting of sensors actuators and electronics. Its application covers diverse fields including Ultra High- Density data Storage systems, Micro mirrors, on chip optical systems, lab on chips, wireless communication Transceivers Inertial sensors etc[5,6]. Micromachining technology along with standard silicon IC fabrication technology has made it possible to realize such microstructures efficiently in terms of functionality and cost. The preliminary step involved is the multi domain simulation and analysis to make sure that the final structure works the way one anticipates[6]. To make sure that the computed simulation results are correct they are compared with the governing theoretical and mathematical concepts.

Simulations in the paper covers Mechanical Stress-Strain analysis, Thermal, Piezoresistive and Piezoelectric types for silicon structures that serve as the main sensing component of a sensing system. The software used to run finite element simulation for these structures was COMSOL 3.5a [2].

2. Mechanical Stress-Strain Analysis

Two types of diaphragm are chosen for the analysis. One is square shaped diaphragm and another is circular in shape. Such structure would act as a pressure sensor. Analysis for Von Mises stress (i.e. effective stress) distribution, longitudinal stress, shear stress and maximum displacement has been observed[2].

2.1 Square Diaphragm

Finite element simulation for a pressure sensor fabricated using (100) silicon wafer has been accomplished. The side length of the structure is (*l*=200 um) and the thickness (*h*=2um). Figure 1. Shows the von Mises stress distribution when pressure of 1Pa is applied. It is seen that the maximum stress points are located at the center of edges. Figure 2 shows that compressive stress is on the bottom of the diaphragm. The nature stress at the top would be tensile in nature.

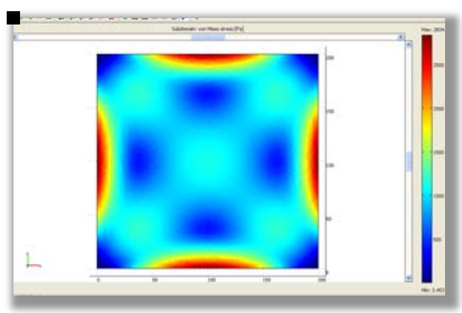

Figure 1. Von Mises Stress

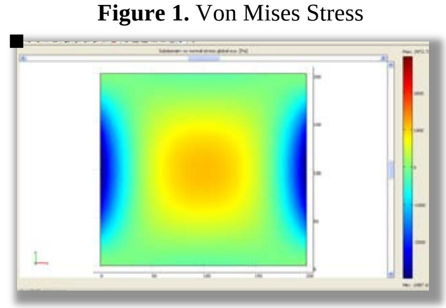

Figure 2. Compressive stress distribution

Figure 3 and Figure 4 shows the shear stress and maximum displacement of the diaphragm. The stress and displacement on the square diaphragm are verified by the following equation[1]. Once we know the stress the displacement can be calculated using normalized deflection vs. normalized distance curves from the center of the diaphragm.

$$\sigma = C\frac{Pl^2}{h^2} \qquad (1)$$

In the above equation σ is stress C constant P is pressure with l and h as dimensions of the diaphragm.

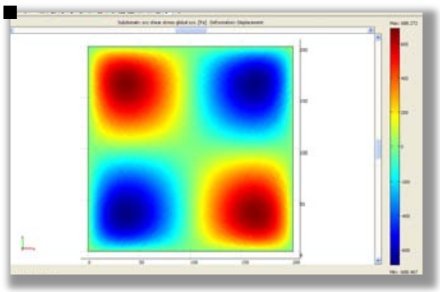

Figure 3. Shear stress distribution

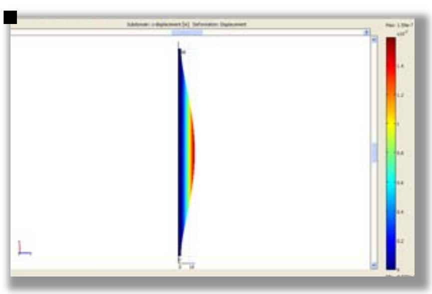

Figure 4. Displacement Plot.

2.2 Circular Diaphragm

The stress on a Circular Diaphragm made up of polysilicon is shown on Figure 5.

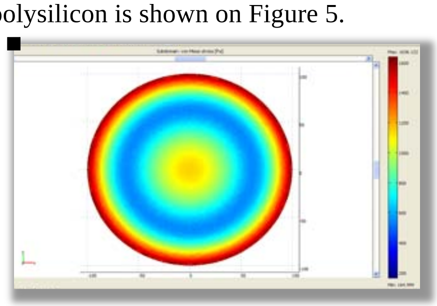

Figure 5. von Mises stress distribution

In the figure above it is seen that the maximum stress is located that the edges. This type of analysis is essential in designing piezoresistive type where the piezoresistors at placed at maximum stress points for higher sensitivity[1]. Figures 6 shows the displacement for the circular diaphragm.

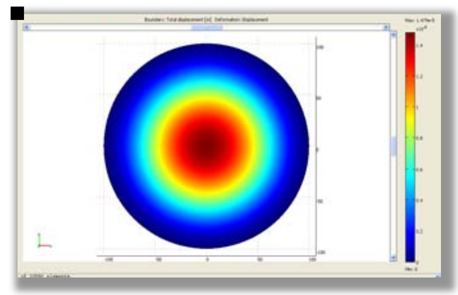

Figure 6. Displacement Plot.

3. Thermal Analysis

Heat is an important form of energy that can be used for both sensing and actuation applications. Thermal transducers have found a wide range of applications. The most important parameter to consider in thermal systems is temperature. Most transducers operate on the principle of transfer of heart from a hot region of a medium to the cold region. Therefor the thermal characteristics and properties of the medium are of great importance [3,4]. In the micro domain we have the ability to control these thermal characteristics very accurately and reliably.

Figure 7 given below shows the temperature distribution in the bent beam when a voltage of 0.2 V is applied to one of the ends of the beam

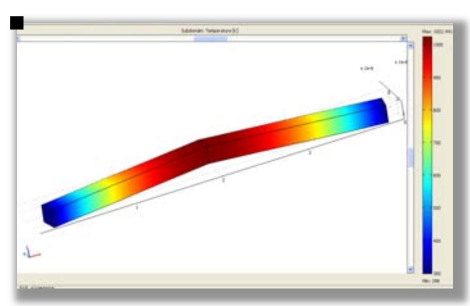

Figure 7. Temperature distribution in a bent beam

The analysis is moreover Electro-Thermo-Mechanical analysis. The bent beam actuator is made up of Copper with angle 10 degree Celsius. One of the sides is grounded and other is dc-biased with 0.2V. The surroundings and the silicon substrate, which acts as a heat sink, are both at room temperature 25 degrees Celsius. The applied voltage changes the temperature of the beam which interns makes the beam move. Figure 8 shows the displacement in the bending beam due the above-explained phenomena.

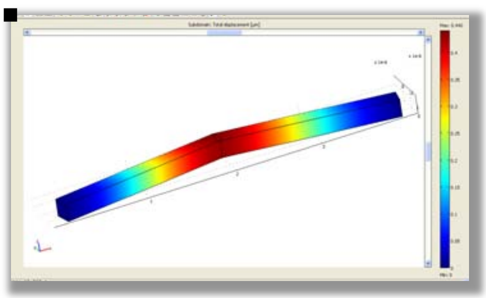

Figure 8. Displacement of a bent beam due to Electro-Thermo-Mechanical Stress

4. Piezoresistive Analysis

Piezoresistive transducer analysis for a cantilever beam is shown in figures 9 to 11. This beam is made up of single crystal silicon where (100) p-type wafer is used and where the length axis (i.e., x-axis) of the beam is aligned with [100] direction of the silicon wafer [5]. The length of the beam is 100um with the embedded piezoresistor being 10um. Load of 1mN is applied the one end where as the opposite end is fixed

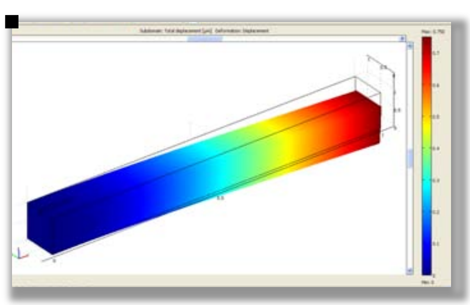

Figure 9. Displacement in a silicon beam

The above figure 9 shows the displacement in the beam which is governed by equation (2), where F is the force on the beam, L is the length of the beam and E is the modulus of elasticity of p-type silicon and I being the moment of Inertia.

$$D= [FL^3 \{L -(1/3)\}] /2EI \qquad (2)$$

Future maximum stress, which is located at the fixed end, was calculated to be 600 MPa using equation (3). These results matched the simulations in COMSOL. In equation (3) w is the width of the beam with h as height.

$$6FL/(wh^2) \qquad (3)$$

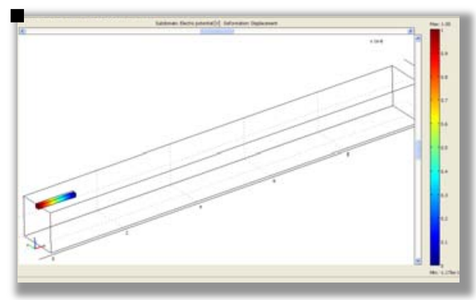

Figure 10. Voltage Distribution in Piezoresistor

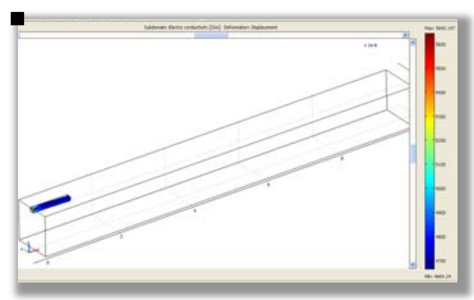

Figure 11. Change in Conductivity of Piezoresistor

The above to figures 10-11 clearly indicate that the there is a change in the resistivity of the piezoresistor since change in conductivity is can observed supported with the voltage distribution in the piezoresistor.

5. Piezoelectric Analysis

Piezoelectric effect refers to conversion of electrical energy to mechanical energy and vice versa through the use of a piezoelectric material [5]. Along with Longitudinal motion slight bending is observed when a potential drop of 10V is created on the two sides of the beam (x-axis). This phenomenon is shown in figures 12 and 13. Figure 12 shows that the longitudinal motion along y-axis, where as figure 13 depict a slight bending along z-axis. The size of beam in figures 12 to 14 is 40um in length 10um in width and 2um in height.

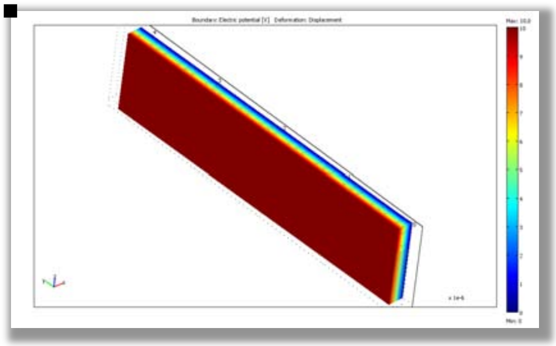

Figure 12. Longitudinal Motion of a beam

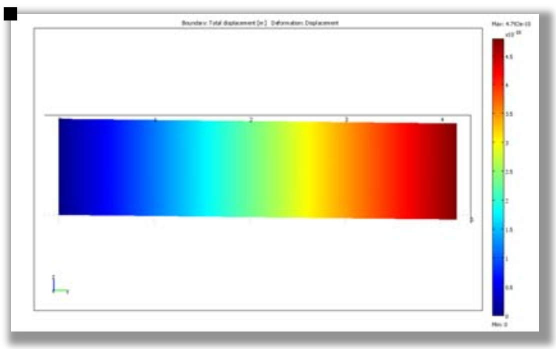

Figure 13. Z-axis motion in the beam

It is also observed that when 2 faces along one axis is kept at higher potential and 2 sides of another axis is kept at lower potential, there is a considerable amount of stress created along the 3rd axis. This is shown on figure 14.

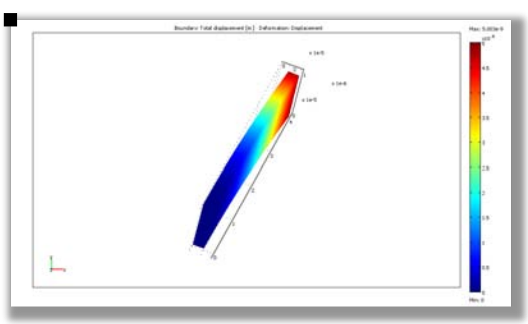

Figure 14. Bending in beam

7. Conclusions

Simulations for Mechanical Stress-Strain analysis, Electro-Thermo-Mechanical analysis, Piezoresistive and Piezoelectric analysis were done successfully in COMSOL 3.5a. This gives an insight of how Silicon based structures actually sense the stimulus. The next step after simulations match our specifications is to fabricate the structure using the standard processes available in MEMS / IC foundries. Therefore such simulations are necessary to cross check our theoretical assumptions and calculation.

8. References

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