Design and Simulation of MEMS based Micro Pressure Sensor

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ABSTRACT: The world is getting digitalized, demands for new and emerging technologies have reached its peak, and customer demands have taken a U-turn. To cope with such unique requirements many systems and system devices are into the market and one of such enhancing technology is MEMS. MEMS are systems of small size, light weight, enhanced performance and reliability finding widest of applications in sectors of Automotive and instrumentation. A typical MEMS Sensor is at least one order of magnitude smaller than the traditional sensors used to measure instantaneous flow quantities like Pressure and Velocity. In this we focus on the outlook of measurement of Pressures like fluctuating wall pressure and wall shear stress and provide general background Design Criteria. These micro pressure sensors can also resolve all relevant scales even in high Reynolds number turbulent flows and arrays of micro pressure sensors make it feasible. MEMS sensor measure the pressure in term of deflection of sensing plate. In this paper we have designed and simulated the air pressure sensor using MEMS tool COMSOL multi physics 4.2a[1] The analysis is carried out for different parameters and results are verified.

KEYWORDS: MEMS, PRESSURE SENSOR, COMSOL Multiphysics

1. INTRODUCTION

Micro Electro Mechanical Systems (MEMS) are the integration of mechanical elements, sensors, actuators and electronics on a common substrate using integrated circuit process sequences.

Nowadays it has become common for scientist and engineers working in micro-electro mechanical system (MEMS) area to simulate the structures using mems simulation software like COMSOL before actual fabrication. The software helps to build the structure, mesh it and then simulate. The main intension in using this software is to optimize the structure dimensions to get the required output which saves time and money during fabrication. Before simulation the beginners should have an idea of required dimensions of the device, materials, material properties and tentative fabrication process. With COMSOL one can do the modal, harmonic, contact, hysteresis, temperature sensitivity and piezoelectric analysis. This is done by computing parameters like stress, strain, reaction forces, contact forces, contact heating etc on MEMS structures. The most important point is parameters dependence on dimensions and material properties of structure.

This paper emphasizes on the design and simulation of a micro air/fluid pressure sensor which can be attached to any pipe which carries the fluid/air. The system uses the property of deformation of model for the applied pressure. The model is to operate efficiently in greater range of pressure and provides highest deformation

Basic principle of aluminium material is that it has greater tensile strength and can be operated in almost every environment in the presence of air pressure and air flow.

2. .LITERATURE SURVEY

The literature is carried out to find the existing models of pressure sensors. The survey showed that the major applications in pressure measurements involved the use of Manometers and High end pressure gauges.

1) Manometer:

Almost all practical [2] pressure measurements of industry involve the usage of Manometers. They use the head of the flow to measure the pressure of the flowing fluid. They measure the Static Pressure ranging from 5 to 100bar.The high end of the same measurements involve the use of Mercury based

Manometer. The Manometers are the so called most feasible, portable and takes account of losses in them. This adds on to the advantage of using Manometers in pressure measurements ranging from low sensing to the High end pressure measurement.

2) Pressure Gauges:

The pressure gauges use the methodology of conversion of displacement into the corresponding Pressure. The amount of displacement gives the indirect method of measurement of Pressure.

But the Pressure gauges are restricted for Low end pressure measurements, because space constrains while conversion of linear motion of the object to its corresponding pressure.

3. PROBLEM STATEMENT

There are many conventional methods for measuring pressure. The important methods are measurement of the pressure by manometer, pressure gauges etc. These methods are quiet easy but measuring range is too small.

To overcome the drawbacks of conventional methods, and to reduce the size of the sensors we switched to MEMS structures. A MEMS pressure sensor the material used for the design of MEMS structure should be very tensile and should not have hysteresis. When pressure is applied to the design corresponding to applied pressure the material get deformed.

The material which is suitable for our application is aluminum (Al) as it is abundantly available. This metal has a better tensile strength and less hysteresis and can be placed in air or fluid carrying pipes.

4. MATHEMATICAL MODELLING

The design consists of mechanical structure fixed at two ends and the uniform load or pressure is applied at the center of the structure, then there will be deformation of the structure, deformation is maximum at the center. As the applied pressure increases the mechanical deformation also increases.

The maximum displacement possible (∂max) for the model is given by the formula [3]

$\partial max = 5\omega\ell^4/(384\, EI)$ ……..(1)

Here it proves that the displacement is directly proportional to diameter (ℓ) and uniform pressure applied (ω),but inversely depends on young's modulus of the used material(E) and second moment of area (moment of inertia) of the structures used (I).

For the proposed model parameters are:
Diameter (ℓ) = $2*10^{-3}$ m
Uniform pressure applied = P/(∏*r*) pa/m^2
Young's modulus of Al (E) = $69*10^{-9}$ pa
Moment of inertia = $(\prod *l^4)/64$

The matlab proof for the same is below:

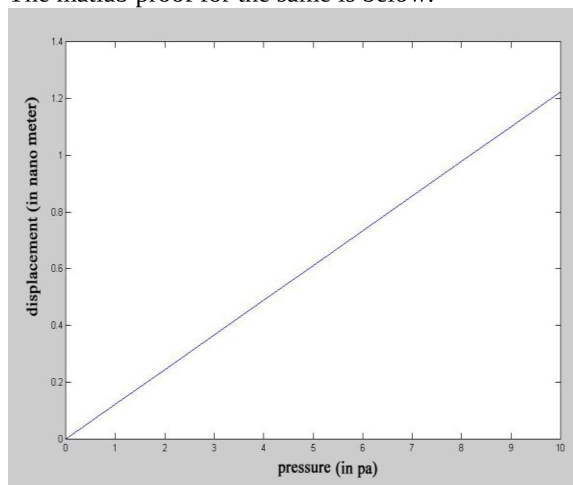

Figure 1: Graph of pressure Vs displacement

So the model should give a maximum displacement of $12*10^{-10}$m according Matlab1 simulation.

The displacement (y) at any point (x) at a particular pressure is given by the formula (2)

$Y=\omega x(l^3-2lx^2+x^3)/(24EI)$ ………(2)

The same can be calculated in matlab simulation.

The figure below shows the displacement at particular value of (x):

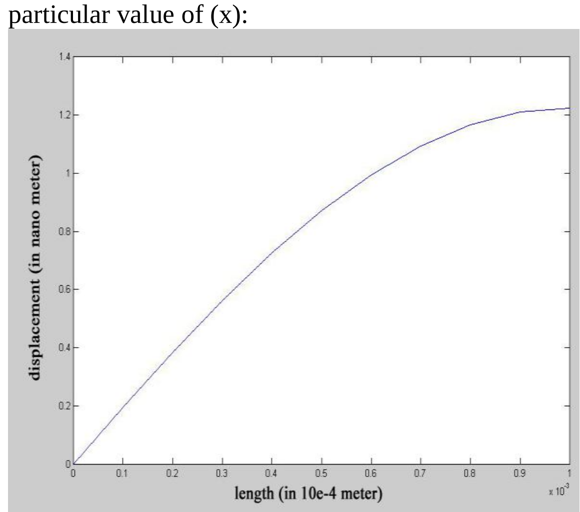

Figure 2: Graph of length Vs displacement

The above graphs show that the displacement is more at the center and it is less in the edges of the model.

5. SIMULATION AND ANALYSIS OF PRESSURE SENSOR

As stated above the model was built in the COMSOL tool. The 2-d and 3-d models were built in the same tool on 1:1 scale. The tool has the provision for the selection of the material till the stimulation of the same [1]. This will make the tool more usable and adaptable. Therefore COMSOL multi physics version 4.2a was adopted for the stimulation. The pressure application was done on the chosen material and the plots of

Deformation against Applied pressure are plotted on 2-axis graph to analyses the results.

Process Editor:

In process editor we define the various steps that make up the required design as shown in Fig.3. And the preliminary 2-d model is shown in Fig 4

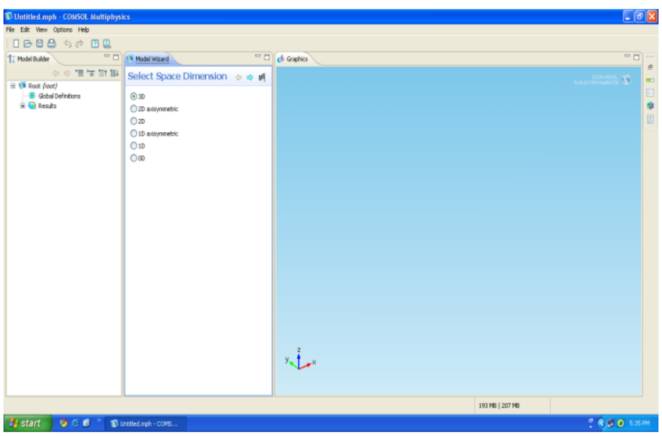

Figure 3: COMSOL Layout

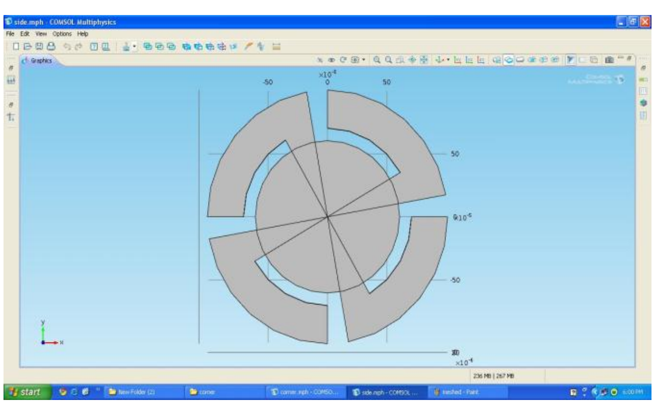

Figure 4: Designing of 2D layout

3D designing and Meshing:

The aim of the simulation analysis is to simulate the resonance frequency since the resonance frequency provides has the maximum displacement of vibration and therefore maximum output will be produced. A mechanical finite element simulation was conducted using COMSOL. The model must now be meshed so the geometry of the Structure can be reduced to a group of simpler finite element bricks and presented to the solver for finite element analysis. Manhattan Bricks is used for meshing because the structure has as shown in fig.5.

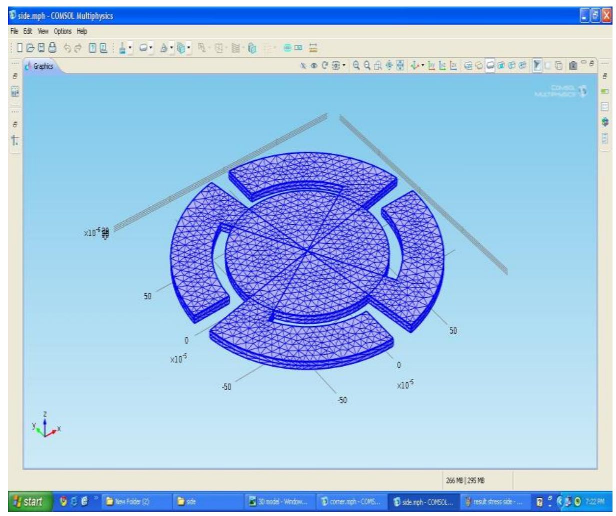

Figure 5: Meshed model

Modal analysis

Based on the 3-d simulations done in the COMSOL tool, the graphs were obtained from the tool directly. This graph gave the plots of displacements against the test pressure being applied. At different points the system response of the pressure sensor will be tracked. The Fig 6 gives the result mode of simulation after the application of pressure load. The graphs in the Fig 7. and Fig 8. give the pressure variations along the disc at the cut and uncut ends.

Here with the help of COMSOL, the sensor is designed and the above Fig shows the result obtained after simulation in the real time. Then the 2-D layout is drawn. Then with the layout editor, the 3-D layout is drawn. Then the meshing of the structure is done.

After meshing required modal and critical pressure analysis are done. The results from the fig can be inferred that at different pressure loads which are subjected to fluid pressure varies linearly. The center portion of the material is displaced to the maximum extent as seen by the Red color in the Fig 6.

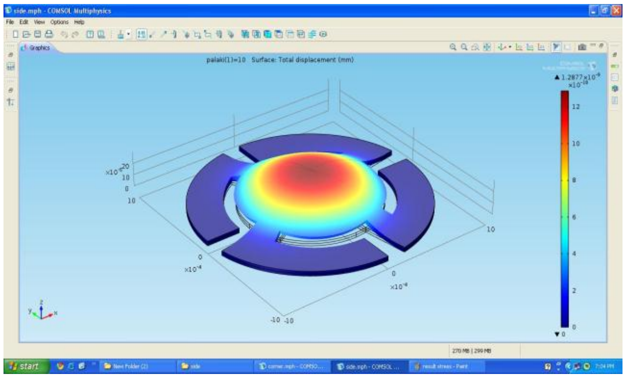

Figure 6: Result of mode stimulation

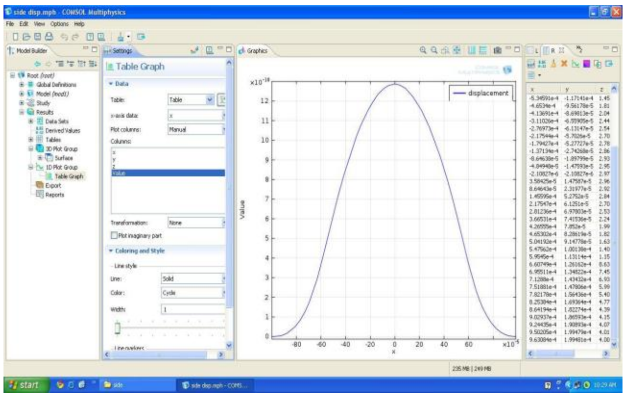

Figure 7: Graph of displacement Vs Pressure

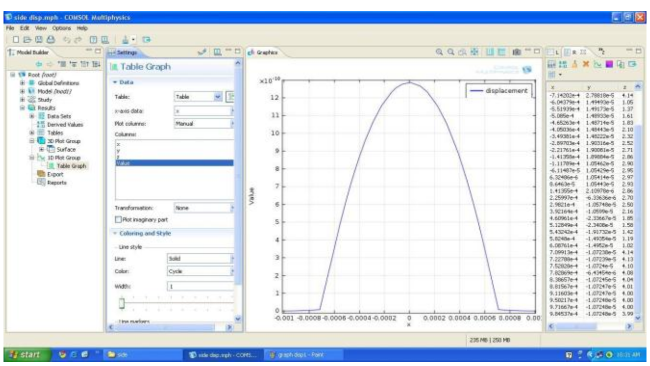

Figure 8: Results of Displacement

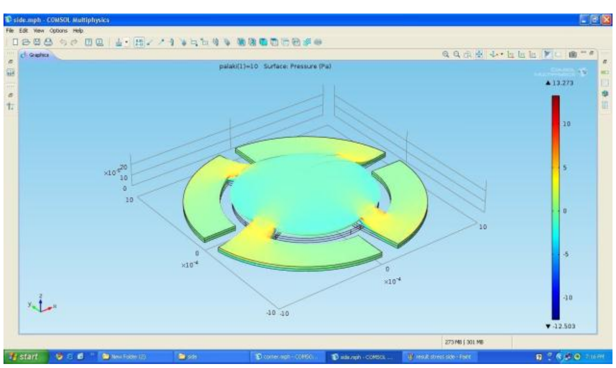

Figure 9: Results obtained from tool

6. RESULT AND DISCUSSION

As we away from the core the pressure intensification goes on reducing as seen from the Yellow, Blue and Green lines to the right of the Fig 9.There by we get the minimum and maximum tolerable pressure ranges of the system. This valuable information is indeed a greater help in Industrial application and material testing.

7.CONCLUSION AND FUTURE SCOPE

The pressure sensor is designed and developed in COMSOL and it is simulated for different values of applied pressure. The simulated results i.e. Pressure Vs displacement obtained from COMSOL Simulator is 1.1 nm. for an applied pressure of 10pa. The result obtained in MatLab for proposed design is 1.2 nm which is near to the Simulated result (COMSOL).

In the future work the optimization of the proposed model can be done to achieve better results.

ACKNOWLEDGMENT

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