COMPARISIONOF MEMS PIEZOELECTRIC MATERIAL FOR DESIGN OF PRESSURE SENSOR

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Abstract

MEMS is identified as one of the most encouraging and rising technology. It is the combination of mechanical and electrical component. This technology plays a major role in creating a tiny devices or systems. It consists of machine like fine structures, microsensors, micro-actuators and microelectronics. Microsensors adopt the changes in the nature by determining mechanical, thermal, electromagnetic information. The author conveys characterization of MEMS Piezoelectric Pressure Sensors. In the proposed context three piezoelectric materials with desired dimensions are placed on the silicon diaphragm and analysis on each piezoelectric material is done separately, in terms of stress, displacement and electric potential. The simulation is performed using COMSOL multi-physics. Micro Electro Mechanical Systems (MEMS) is an applied science, exalted perception part acuteness and firmness have been wangled. The outcome of the proposed idea gives initial data on choosing best piezoelectric material on different parameters considered.

Keywords: Piezoelectric materials,COMSOL Multiphysics, MEMS.

I. INTRODUCTION

MEMS is an advancement defined as miniaturized mechanical and electromechanical sections that are expertized using micro fabrication. This amelioration has been newly used in micro sensors, like vibration sensors, DNA detection biochips and so on. This reduced system has improved reproducibility, redundancy, enhanced biasing and reactivity, wider dynamic range, upgrade mastery and reliability. Making plenty of things on one single wafer and thus reduces the cost per individual things. For smaller gadgets the energy required will be less. Major benefits of using MEMS in squeeze detectors are tiny segment, worth the money, and high performance. Capacitive pressure sensors provide, very high-pressure responsiveness, quite creak and minimum temperature reaction. High sensor sensitivity is achieved by MEMS**.** This mechanization involves two faces. The contact faces are substrate (electrode) and diaphragm (polysilicon). This will be very useful to monitor the pressure continuously. In the family of crystals, certain materials are called as piezoelectric because of their property to cause electrical phenomenon (voltage) for suitable practical load, vice versa is also possible that is when the voltage is applied, the crystal starts vibrating. The designing of piezoelectric pressure sensor is carried out using COMSOL Multiphysics software. Several modules are available in COMSOL, which are classified in proportion to the application areas, namely Electrical, Mechanical, Fluid, Chemical, Multipurpose, and Interfacing. AC/DC Module is used for simulating electric, magnetic, and electromagnetic fields in static and low frequency applications. This helps to solve essentially all models that works under this module. MEMS module provides elevation in user interfaces, for a diversity of coupled physics, including electromagnetic-structure, thermal-structure, or fluid-structures that are conditional to static or dynamic loads, it can be used for a far reach of analysis types, including stationary, Eigen frequency, parametric, quasi-static, frequency-response, bucking, and pre-stressed.

II. LITERATURE SURVEY

Here, the search for relevant piezoelectric material which has comparatively good sensitivity together with the tensile strength is done. Parameters on which working of the sensors depends, is noted. Also, the various designing methods of sensors and the parameters required are analyzed **[1]**. Piezoelectric patch of materials PVDF, $BaTiO_3$ and GaAs are positioned at areas where residual stress is high. The substrate per-case silicon or steel where deformation happens **[2]**. Compression on the substrate results in different values of displacement and electric potential on piezoelectric material and it has come into sight that the voltage generated was linearly proportional to the applied pressure. Meshing **[3]** is performed to verify that whole structure is included in computation of the studies. The analysis is done using two methods: Mathematical modeling **[5]** and Finite Element Method model. Less temperature sensitivity was brought to light from the results.

III. METHODOLOGY

A square Diaphragm designed by Silicon material of side length 100µm and thickness 2µm is constructed. Indication in Fig 1 Shows the Model geometry and TABLE I explain the model dimensions. The dimensions of each specification have been epitomized in each case. Each of such conditions in relation to geometry are discussed briefly as follows

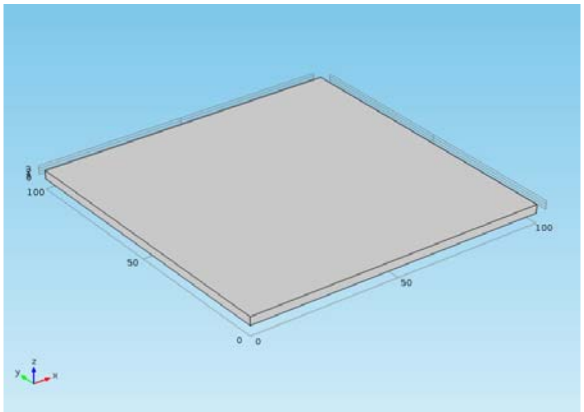

Fig. 1. Model Geometry(µm)

Fig 2. gives an analogy of maximum stress region. This region appears in the middle of the arc length. Hence piezoelectric patches are placed in those regions.

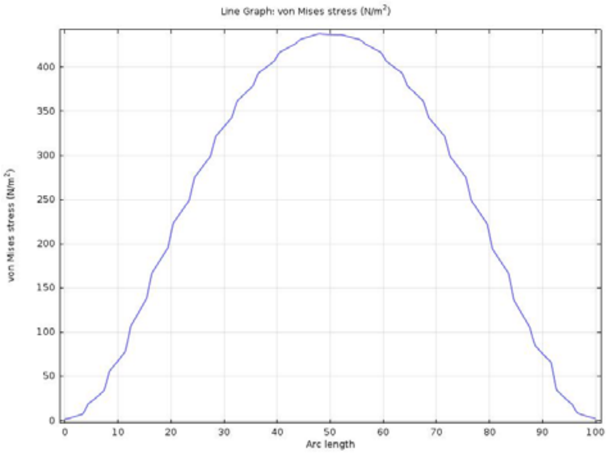

Fig. 2. Stress v/s Arc length

Considering this graph, piezoelectric patches of dimensions 50*10 are placed at the four sides of the diaphragm. Therefore, response of the sensor is increased. A rectangle shaped patch is created of length 10µm*50µm and of thickness 1µm is located at the edges of the diaphragm. This arrangement is viewed in the Fig. 3.

TABLE I. MODEL DIMENSIONS

Material	Side Length (µm)	Thickness (µm)
Silicon Diaphragm	100	2
Piezoelectric Patch	10*50	1

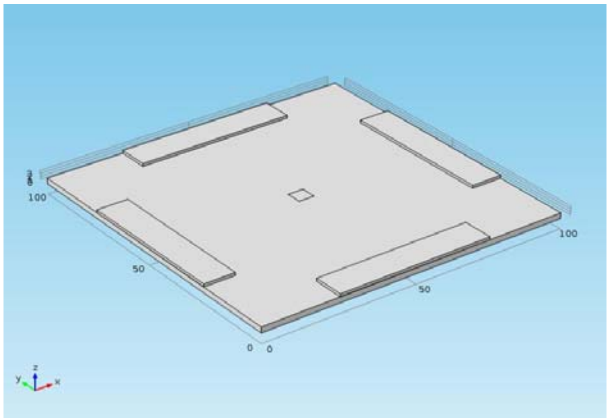

Fig. 3. Patch arrangement (µm)

IV. MODEL SETTINGS

The model uses four materials: Silicon, Barium Titanate($BaTiO_3$), Polyvinylidene fluoridene(PVDF) and Gallium Arsenide(GaAs)(Table I).The finite element method (FEM) demonstrated in Fig 4 is used to generate the mesh model. The boundary conditions(Stationary): A constant pressure of 1 Pa is applied. Here the values of stress, displacement and Electric potential of the model is obtained and also the Eigen frequency (Resonant frequency) of the model is determined . Displacement versus frequency (Frequency domain) plot is obtained from 1 to 10 at an increment of 1 MHz.

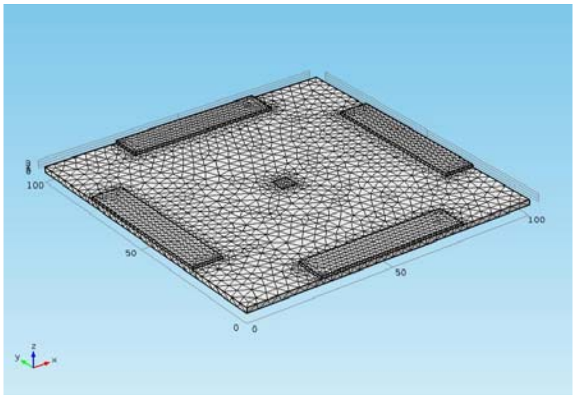

Fig. 4. Model Finite Element Discretization (Mesh)

TABLE II. MODEL PROPERTIES

	Young's Modulus (GPa)	Poisson's Ratio	Density (Kg/m^3)	Permittivity
Silicon	150	0.17	2329	2859
BaTiO$_3$	266.81	0.23	6020	2000
PVDF	8.3	0.18	1780	12
GaAs	85	0.31	5.316	12.5

V. MATHEMATICAL MODELING

The physics used to carry out this design is structural mechanics, in this the two subsections utilized are Solid mechanics and Piezoelectric Devices (PZD). Solid mechanics model incorporates the initial stress and strain features, which is the stress-strain state in the structure before pertinent to any constraint or load. Maximum stress of a square and rectangle at the edge is obtained by equation (1).

$$\sigma = 0.378\, p\, \frac{a^2}{h^2} \qquad (1)$$

Where,
p= Pressure applied (Pa)
a= Side length (μm)
h= Thickness of the geometry (μm)

Using equation (1) the theoretical values are calculated

For a square diaphragm with a side length 'a' and displacement for a pressure 'P' is given by equation (2). Where 'R' is the flexure rigidity and is calculated using equation (3).

$$W = \frac{1}{47} p \frac{a^4}{16R} \qquad (2)$$

$$R = \frac{Eh^3}{12(1-\gamma^2)} \qquad (3)$$

Where,
w= Displacement
R= Flexure rigidity of the diaphragm
p=Pressure applied in Pascal
γ= Poisson's ratio
E= Young's modulus
a= Side length
h= Thickness

Using equation (1), (3) and (4) for applied pressure 'P=1Pa', The charge density 'D' is calculated using equation (4).

$$D = \sigma * d_{33} \qquad (4)$$

Where,
D = Charge density
σ = Mechanical stress
d_{33} = Piezoelectric strain co-efficient

Substituting the values in equation 4 we get
$D = 0.91476 * 10^{-6}$ C/m^2

Charge 'Q' is given as Q= CV, The Electric Potential V is calculated using equation (5). To obtain the value of capacitance between the patch and the diaphragm is calculated using equation (6).

$$V = \frac{Q}{C} = \frac{D.A}{C} \qquad (5)$$

$$C = \frac{\varepsilon_o \varepsilon_r A}{d} \qquad (6)$$

Where,
V= Electric Potential (Voltage)
Q= Charge accumulated
ε_0 = Permittivity of free space ($8.854*10^{-12}$)
ε_r= Relative permittivity
A= Area of piezoelectric material at the center and
d= Thickness ofPiezoelectric patch

The theoretical values of Stress, Electrical Potential and Displacement of Barium Titanate($BaTiO_3$), Polyvinylidene fluoride (PVDF) and Gallium Arsenide(GaAs) are calculated using equations (1), (2) and (5).

VI. SIMULATION AND RESULTS

First the diaphragm displayed in Fig. 1, is constructed and silicon material is added to it. With Solid Mechanics, boundary load of 1 Pa is applied by fixing the four edges.

In the Stationary study, the peak stressed region is identified as observed in Fig. 5.

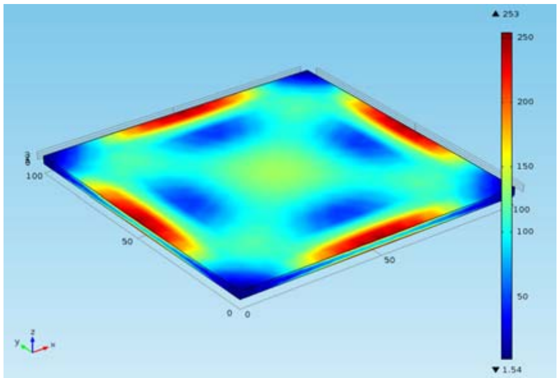

Fig. 5. Maximum stress region in Silicon diaphragm.

Three Piezoelectric materials $BaTiO_3$, PVDF, GaAs are laid at the most stressed region represented in a way shown in Fig. 6 and are analyzed separately.

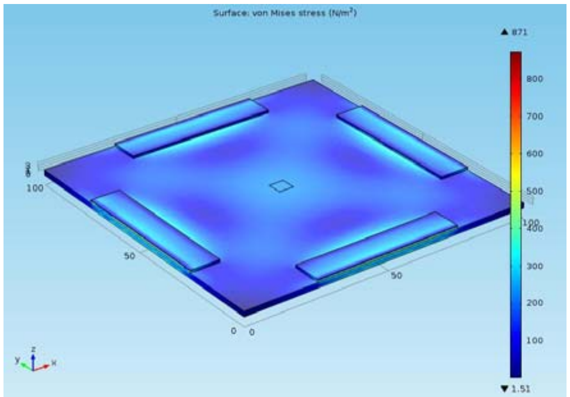

Fig. 6. Stress plot of $BaTiO_3$, PVDF, GaAs

On applying the different boundary conditions on the silicon substrate, linear alteration of the stress are analyzed.

The change in the displacement is understood in fig.7.Also, the displacement varies linearly with respect to the applied pressure. Fig. 8. Shows the variations of the electric potential for different values of pressure.

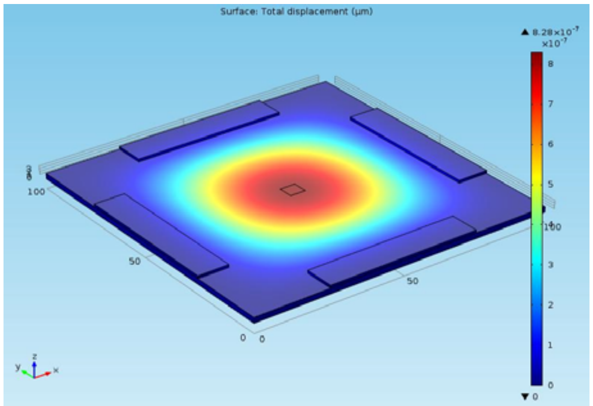

Fig. 7. Displacement plot of $BaTiO_3$, PVDF, GaAs

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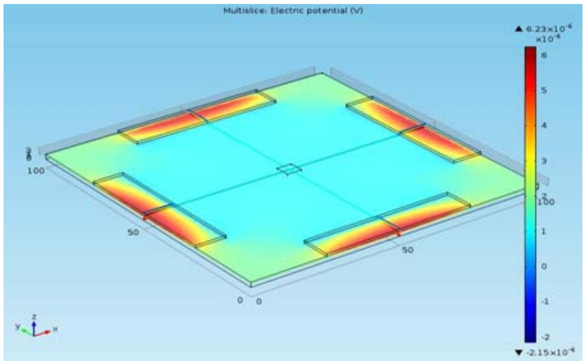

Fig. 8. Electric potential plot of $BaTiO_3$, PVDF, GaAs

TABLE III.The comparison of practical and theoretical values of Stress, and Electric Potential of $BaTiO_3$ for a pressure of 1 Pa.

Study	Theoretical	Simulation
Stress	9.45E2	871
Electric Potential (V)	1.013945E-5	6.23E-6
Displacement	7.4074E-13	8.28E-7

TABLE IV.The comparison of practical and theoretical values of Stress, Displacement and Electric Potential of PVDF for a pressure of 1 Pa.

Study	Theoretical	Simulation
Stress	945	88600
Electric Potential	2.07	4.9E-5
Displacement	40265E-12	9.08E-7

TABLE V**.**The comparison of practical and theoretical values of Stress, Displacement and Electric Potential of GaAs for a pressure of 1 Pa.

Study	Theoretical	Simulation
Stress	945	655
Electric Potential	1.88E-5	1.16E-6
Displacement	6.092672E-11	9.08E-7

A. *Pressure versus Electric potential.*

Pressure versus Electric potential plot of GaAs is as shown in the Fig. 9. The x-axis is pressure, varies at 10 Pa per unit and correspondingly the voltage in the y-axis varies linearly. Similarly, Fig. 10, 11 and 12 shows the variation of Pressure versus Electric potential for GaAs,BaTiO3 and PVDF.

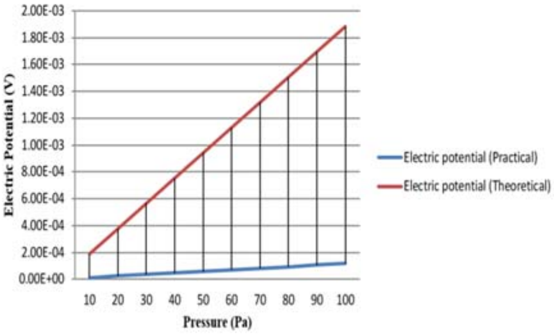

Fig. 9. Plot GaAs

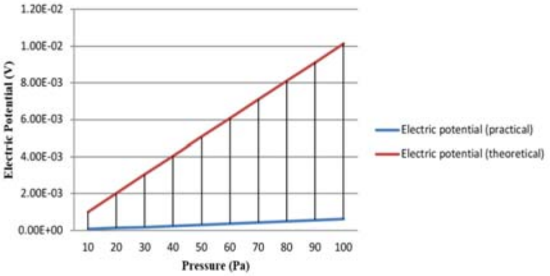

Fig. 10. Plot of BaTiO3

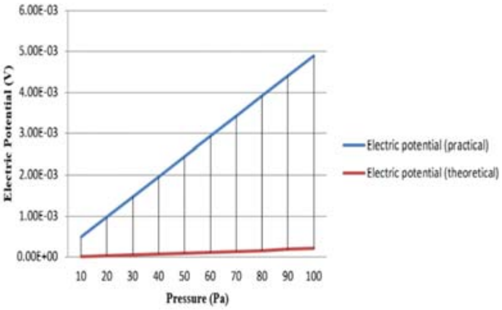

Fig. 11. Plot of PVDF

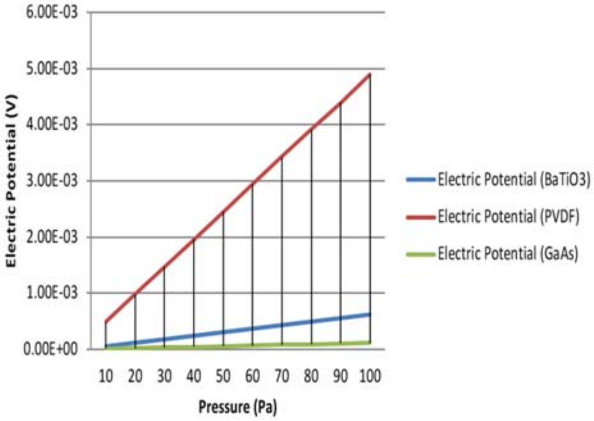

Fig. 12.Electricpotential variations with linearly upwards pressure.(Comparison of all the three piezoelectric materials)

Fig. 12 shows that PVDF has the positive response with linearly increasing pressure. This is because Young's modulus of the PVDF is very less compare to the other three materials.

B. *Frequency Domain.*

The plot of Eigen Frequency for PVDF,BaTiO$_3$ and GaAs is shown in Fig. 13.

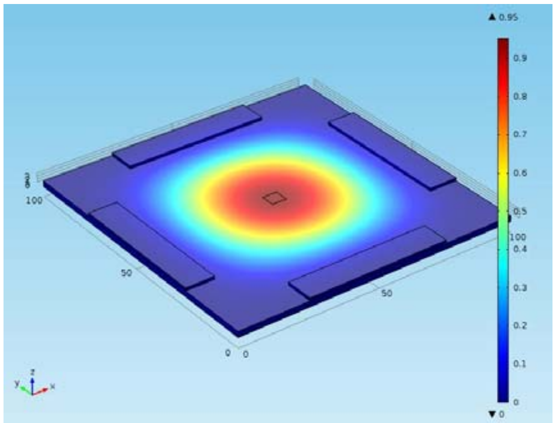

Fig. 13. Eigen Frequency plot of BaTiO$_3$, PVDF, GaAs

The Displacement versus Frequency plot is shown in the Fig. 14. The frequency of PVDF, BaTiO$_3$, and GaAs are approximately 3MHz. Eigen frequency is the natural frequency, in which the material starts to vibrate. Eigen Frequency correlates to the variations in the pressure but the impact on the change in the parameters which will not affect the frequency values.

The Plot indicates the change adapted with respect to the pressure and the voltage can be varied by subjecting to the constant Eigen frequency values.

Interior noise is caused due to the variation of the structure. And hence accurate modeling of Eigen frequency analysis is required. Analysis is done by considering the boundary condition on 3D model as shown in fig. 13.

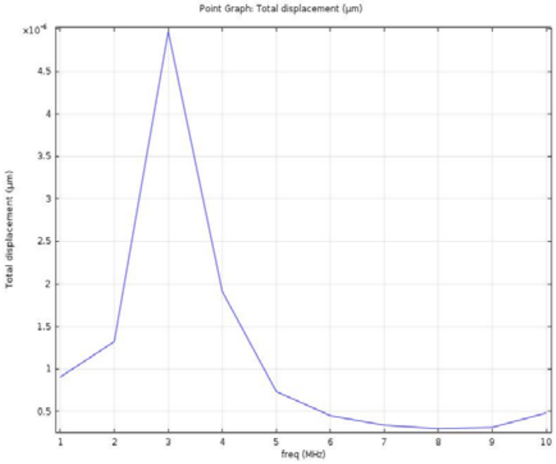

Fig. 14. 1D Plot of Frequency vs Displacement

The maximum displacement as a function of applied pressure is obtained with analytical, experimental and computational results.

VII. CONCLUSION

Among several synthetic piezoelectric materials, analysis is been done for PVDF, $BaTiO_3$ and GaAs.The structural design is carried out through COMSOL simulation tool. The estimation based on Stress, Displacement, Electric potential and Eigen frequency has been done. Upon examining, it is noticed that PVDF exhibits greater piezoelectricity, which means that PVDF produces considerably high voltage to small magnitude of pressure and hence Fig 12. describes that PVDF has higher sensitivity and can be considered for specific applications. Also, for all the piezoelectric materials the disparity of pressure applied has no effect on its Eigen frequency. From frequency versus displacement plot (fig.14.) PVDF, $BaTiO_3$, and GaAs shows the vibration in 3MHz frequency, and can be used for the applications such as Military and Space application. The variation of the stress and the displacement is also increasing linearly to the applied pressure.

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