Design And Comparison of Piezoelectric High Pressure Sensor by using COMSOL Multiphysics

Pooja A N
Student, Dept. of ECE
VVIET, Mysuru

Dr. Bindu A Thomas
HOD, Dept. of ECE
VVIET, Mysuru

***Abstract*— The innovation upsets of miniaturized scale electromechanical frameworks (MEMS) over most recent two decades have pulled in a few scientists to contribute in the developments especially in smaller scale sensors and actuators. MEMS pressure sensors are one of the fundamental sensors among them. These pressure sensors are primarily grouped into three sorts like capacitive, piezoresistive and piezoelectric pressure sensor. Piezoelectric pressure sensor has a few preferences over other kind of pressure sensors, for example, self driving, quick response for very powerful load, moderately basic readout circuit. The primary point of this paper is to plan a piezoelectric high pressure sensor with various materials and simulate it to explore the energy generation capability as well as sensitivity of the sensor using COMSOL Multiphysics tool and compare the results of designed models. Model 1 utilizes material stainless steel as diaphragm and model 2 utilizes silicon as a diaphragm. In this paper PZT is utilized as a piezoelectric material in view of its high affectability and great piezoelectric property. The analysis demonstrates that the deflection of the diaphragm is in a linear relationship with pressure connected to the piezoelectric high pressure sensor which causes change in the electrical potential. Additionally the thickness variation of the diaphragm and also the piezoelectric layer will be done to think about its impact on the performance of MEMS piezoelectric pressure sensor. In this paper piezoelectric high pressure sensor will be intended to withstand pressure extending from 1 Pascal to 100 kilo Pascal.**

Keywords*— *MEMS, Piezoelectric pressure sensor, Stainless steel, Silicon, PZT, COMSOL Multiphysics.

I. INTRODUCTION

Pressure detecting innovation is comprehensively used as a piece of step by step human's life. Greatness and change of pressure is essential and important in numerous frameworks for instance, water pipeline, oil tank, engine start chamber, learn about worn on vehicle, blood and breath system for human body, et cetera. Pressure Sensors are one among the by and large used scaled down scale sensors, generally to identify pressure from gas stream, liquid stream, stickiness et cetera. Pressure sensor is a contraption which distinguishes pressure and changes over it into a straightforward electric flag whose degree depends on the pressure applies. Since they change over pressure into an electrical flag, they are furthermore named as pressure transducers. Pressure sensors are comprehensively used as a piece of various applications like touch screen devices, auto industry, bio-restorative instrumentation, current uses, flight and marine industry, et cetera.Ease of Use.

Piezoelectric pressure sensor produces recognizable charge motion without anyone else's input in reacting to connected pressure. This sensor has a couple of purposes of intrigue like self fueling, brisk reaction of incredibly powerful load and for the most part basic readout circuit. Piezoelectric pressure sensor has diaphragm structure, which is the best blueprint for pressure detecting and it is ideal for assessing fluctuating info pressure flag. High pressure sensors are utilized as a part of numerous applications like Variable Air Volume(VAV) frameworks, jug and gear spill discovery, air sharp edges, modern stream observing, gas recognition, compacted pneumatic force checking, channel weight observing, mine security instrumentation, pipe wind stream, and so forth.

II. LITERATURE SURVEY

Vinay shettar, Sneha B. kotin, Kirankumar B. B. also, B. G. Sheeparamatti [1] separated between various MEMS weight sensors in view of their detecting instruments, for example, MEMS capacitive, piezoelectric and piezoresistive pressure sensors, additionally these sensors are demonstrated and reproduced utilizing COMSOL Multiphysics. Capacitive pressure sensor utilizes a diaphragm cavity structure to identify the adjustment noticeable all around hole caused by connected pressure; piezoresistive pressure sensor recognizes strain because of pressure stacking that outcomes change in protection lastly piezoelectric pressure sensor produces distinguishable charge motion without anyone else in reacting to connected pressure. On correlation, they reason that piezoelectric pressure sensor is more invaluable contrast with other two sorts of pressure sensors as it demonstrates the most extreme relocation and has high affectability. The manufacture of capacitive pressure sensor is straightforward and has the ease with most noteworthy exactness when contrasted with piezoelectric and piezoresistive pressure sensor.

Uday jyoti Gogoi, T. Shanmuganantham [2] examined about square formed piezoelectric self fueled sensor. The examination of this sensor gives the connection between pressure dislodging, voltage-weight and also the weight charge thickness. It demonstrates that, created voltage is reliant on the thickness of both the stomach and piezoelectric layer at similar conditions. By watching the outcome they infer that lower thickness of stomach and piezoelectric layer is desirable over accomplish bigger voltage and better affectability. Square formed stomach gives more worry for the connected weight and it has greater affectability as contrast with roundabout molded stomach. With change in the materials and measurements of the sensor, it can be utilized for advance improvement.

Nader Ahmadzadeh khosroshahi, Javad Karamdel [3] examined about piezoelectric weight sensor that was displayed in the shape roundabout stomach with some settled region. The material utilized for stomach is silicon with thickness of 100µm and weight shifting from 1pa to 10kpa. The outline and reenactment have been done in view of Finite Element Method utilizing COMSOL Multiphysics 5.2. By watching the outcome they presume that when weight is connected to the piezoelectric pressure sensor that will cause to change the electrical potential. There is direct connection between connected pressure and created electric charge

Ashish kumar, C. Periasamy and B.D. Pant [4] talked about MEMS Cantilever piezoelectric weight sensor utilizing three piezoelectric material utilizing PZT, ZnS and BaTiO3. According to the reproduction comes about the presume that PZT gives best execution contrast with other two materials. They likewise learned around two terminal metals in the sensor to be specific platinum and aluminum, correlation demonstrates that aluminum performs better then platinum for every one of the three materials (PZT, ZnS, BaTiO3) because of its low estimations of Poisson proportion and Young modulus. The blend of aluminum and PZT delivered electric potential in the scope of 1-10 mV while different mixes were not ready to accomplish over the 8 mV.

Amira Mahmoud Olayan, Amal Zaki, Hazem Hassan [5] talked about outline and execution of thin shot piezoelectric weight sensor. In this work the MEMS acoustic sensor is demonstrated utilizing FEM procedure by COMSOL with a specific end goal to acquire the greatest redirection happened at the tip of the thin plate structure layers, and the conveyed voltage through the sensor because of the dispersed weight in the surface zone of the thin plate layers. The deliberate capacitance estimation of 115-120pF on the focal locale is done utilizing the C-V Plotter Instrument. The acoustic sensor demonstrated a level recurrence reaction from 31.5Hz to 8 KHz. The deliberate normal affectability is 50mVrms/Pa and a sensibly straight yield more than 110-160dB of SPL.

III. DESIGN METHEDOLOGY

The Piezoelectric high pressure sensor is composed such that, the sensor that can produces electric potential for pressure extending from 1 Pascal to 100 kilo Pascal. COMSOL Multiphysics is utilized to plan a piezoelectric high pressure sensor. It is extremely useful in real time applications.

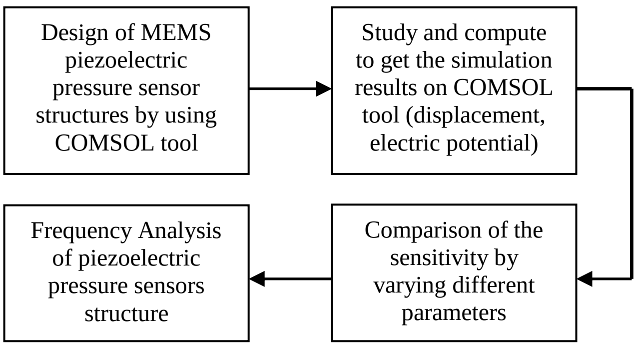


Fig. 1. Architecture for designing piezoelectric high pressure sensor

The Fig.1 shows architecture of designing apiezoelectric high pressure sensor. MEMS piezoelectric high pressure sensors were designed by using COMSOL Multiphysics with different combinations, one of the combinations was diaphragm as stainless steel, piezoelectric material as PZT and another combination was diaphragm as silicon and piezoelectric material as PZT. Compute designed structures to get results like electric potential, stress, and displacement on COMSOL Multiphysics. Finally frequency analysis were done for all designed models and compare result of all models like displacement, electric potential.

A. *Model 1 of Piezoelectric High Pressure Sensor With Stainless Steel As Diaphragm*

Keeping in mind the end goal to outline piezoelectric high weight sensor, first select the material science as piezoelectric gadgets at that point select with length as micrometer at that point select work plane which gives adaptability of giving length, width and thickness for the coveted model. As the plan criteria appears in TABLE 1 select materials and measurements to outline piezoelectric high pressure sensor utilizing the materials like stainless steel and PZT.

TABLE I. MATERIALS AND THEIR DIMENSIONS FOR MODEL 1

Parameter	Material	Dimension (um)	Thickness (um)
Diaphragm	Stainless Steel	1100*1100	10
Insulator	Silicon Oxide	200*400	1
Bottom Electrode	Aluminum	200*400	1
Piezoelectric Patch	PZT	200*400	2
Top Electrode	Aluminum	200*400	1

Model 1 of piezoelectric high pressure sensor was designed by using COMSOL Multiphysics. First stainless steel was placed as a diaphragm of the sensor, upon that diaphragm silicon oxide was placed as insulator. Aluminum is used as top and bottom electrodes and placed on the top layer of insulator; finally piezoelectric material was placed between top and bottom electrodes, PZT material is used as piezoelectric patches. Geometrical representation of model 1 with stainless steel as diaphragm is as shown in Fig.2.

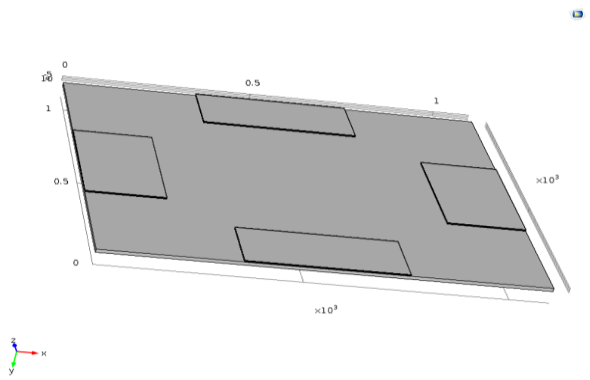
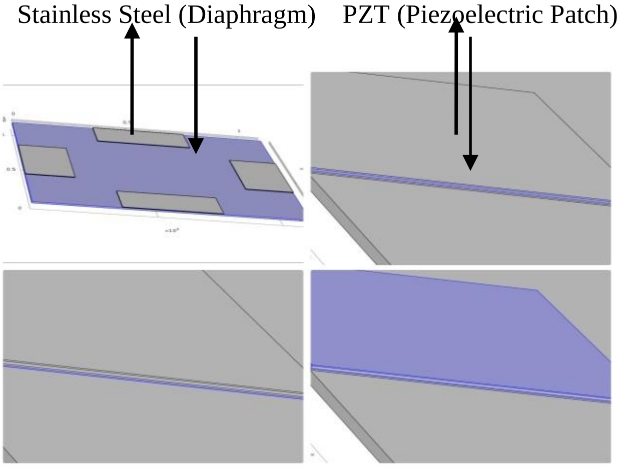


Fig. 2. 3D Geometrical representation of model 1

Fig.3 shows insights about material used to outline piezoelectric high weight sensor. Stainless steel is utilized as stomach with thickness of 10 um, upon this stomach oxide layer is utilized as insulator with thickness of 1 um, aluminum is utilized as base terminal and best anode with thickness of 1 um and is put over the encasing at last PZT is set between top cathode and base cathode as piezoelectric fix with thickness of 2 um.

Stainless Steel (Diaphragm) PZT (Piezoelectric Patch)



Silicon Oxide (Insulator) Aluminum (Electrodes)

Fig. 3. Adding materials to the model 1

Once finished with including material, subsequent stage is to apply pressure of 1 Pascal on top surface of the diaphragm by fixing every one of the four edges which gives the outcome as stress, strain and displacement. In this paper tetrahedral type of meshing is used because of its high accuracy and resolution.

A. *Model 2 of Piezoelectric High Pressure Sensor With Silicon As Diaphragm*

Remembering the true objective to layout piezoelectric high pressure sensor, first select the material science as piezoelectric devices by then select with length as micrometer by then select work plane which gives versatility of giving length, width and thickness for the desired model. As the arrangement criteria shows up in TABLE 2 select materials and estimations to layout piezoelectric high pressure sensor using the materials like silicon and PZT.

TABLE II. MATERIALS AND THEIR DIMENSIONS FOR MODEL 2

Parameter	Material	Dimension (um)	Thickness (um)
Diaphragm	Silicon	1100*1100	10
Insulator	Silicon Oxide	100*400	1
Bottom Electrode	Aluminum	100*400	1
Piezoelectric Patch	PZT	100*400	2
Top Electrode	Aluminum	100*400	1

Model 2 of piezoelectric high pressure sensor was composed by utilizing COMSOL Multiphysics. In the first place silicon was put as a stomach of the sensor; upon that stomach silicon oxide was set as insulator. Aluminum is utilized as best and base cathodes and set on the best layer of insulator, at last piezoelectric material was put amongst best and base anodes, PZT material is utilized as piezoelectric patches. Geometrical portrayal of model 2 with silicon as diaphragm is as appeared in Fig.4.

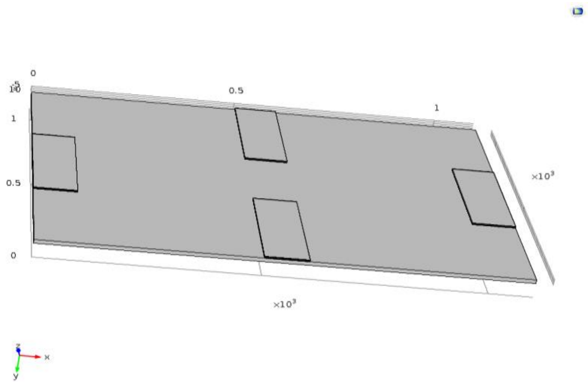
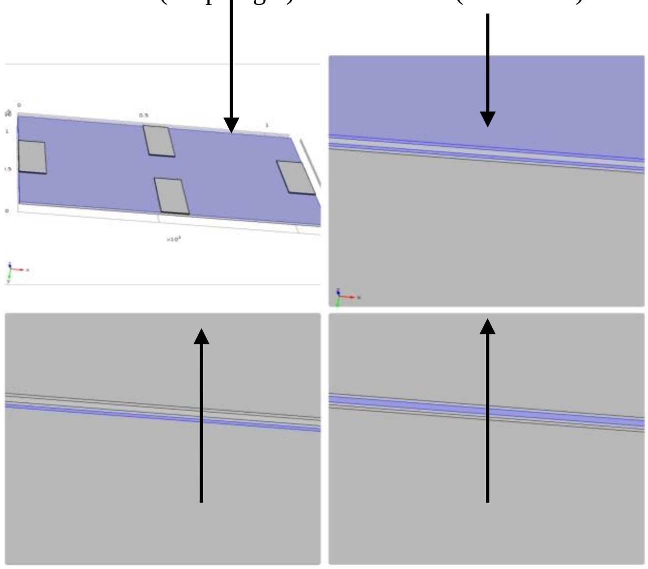


Fig. 4. 3D Geometrical representation of model 2

Fig.5 demonstrates experiences about material used to outline piezoelectric high pressure sensor. Silicon is used as diaphragm with thickness of 10 um, upon this diaphragm oxide layer is used as insulator with thickness of 1 um, aluminum is used as base terminal and best anode with thickness of 1 um and is put over the encasing finally PZT is set between top cathode and base cathode as piezoelectric fix with thickness of 2 um.

Silicon (Diaphragm) Aluminum (Electrodes)



Silicon Oxide (Insulator) PZT(Piezoelectric Patch)

Fig. 5. Adding materials to the model 2

Once completed with including material, ensuing stage is to apply weight of 1 Pascal on top surface of the stomach by settling each one of the four edges which gives the result as pressure, strain and uprooting. In this paper tetrahedral sort of cross section is utilized in view of its high precision and determination.

IV. DESIGN CALCULATIONS

In planned investigation, Eigen frequency, displacement and electric potential for both the materials that is silicon and stainless steel are figured utilizing a few conditions, they are as per the following

Eigen frequency for a piezoelectric high pressure sensor

$$f_r = 2\Pi(0.1015/d_d)^2 \sqrt{\frac{E_y t_d^2}{12e(1-N_u^2)}} \quad \text{——— Equation 1}$$

Where, f_r is Eigen frequency, d_d is dimension of diaphragm, E_y is young's modulus of diaphragm, t_d is thickness of diaphragm, e is density of diaphragm and N_u is poisson's ratio of diaphragm.

Displacement for the diaphragm

$$Y_{max} = \frac{0.0151 * PL^4(1-N_u^2)}{E_y H^3} \quad \text{——— Equation 2}$$

Where, Y_{max} is deflection of the diaphragm, P is pressure applied on the diaphragm, L is length of the diaphragm, N_u is poisson's ratio of diaphragm, E_y is young's modulus of diaphragm and H is thickness of diaphragm.

Electric potential for a piezoelectric high pressure sensor

$$V = \frac{d_{33} * f * t}{E_{33} * L * W} \quad \text{——— Equation 3}$$

Where, V is electric potential, d_{33} is piezoelectric charge constant per unit stress applied in direction 3, E_{33} is di-electric constant applied in direction 3, f is Eigen frequency, t is thickness of piezoelectric patch, L is length of piezoelectric patch, W is width of piezoelectric patch.

V. SIMULATION RESULTS

Model 1 and Model 2 of piezoelectric high pressure sensor was planned by utilizing COMSOL Multiphysics. It gives the outcomes as stress, displacement and electric potential and they are portrayed as takes after,

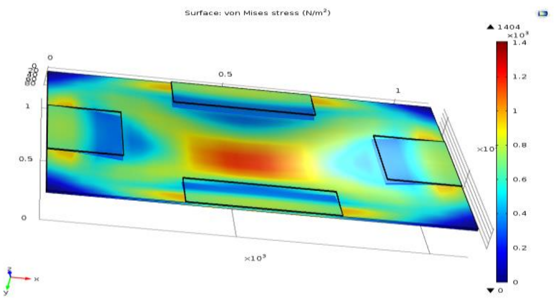


Fig. 6. Stress of piezoelectric high pressure sensor

Fig.6 shows signify stress on the piezoelectric high pressure sensor. Exactly when 4 edges of the diaphragm were settled and pressure was associated on top surface of the diaphragm, which comes to fruition more worry at settled terminations and slightest worry at free end. Model 1 gives total stress as 1404*103 N/m2 and model 2 gives 1355*103 N/m2.

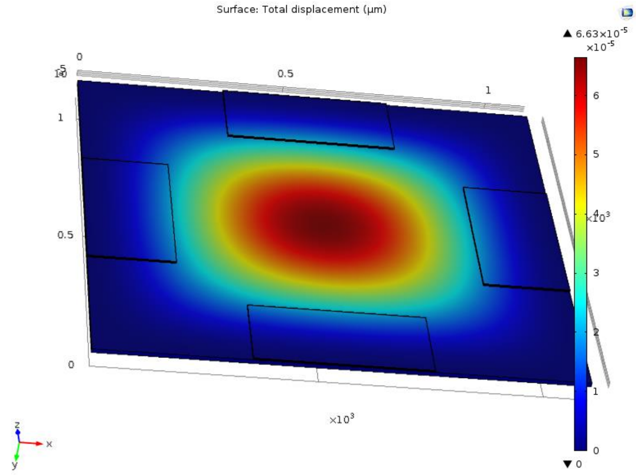


Fig. 7. Displacement of piezoelectric high pressure sensor

Fig.7 shows representation of displacement of the piezoelectric high pressure sensor. Diversion will be more at the point of convergence of the diaphragm and slightest at settled terminations when pressure is associated on the diaphragm with settled edges. Model 1 gives total displacement as 6.63*10-5 um anf model 2 gives total displacement as 7.46*10-5 μm.

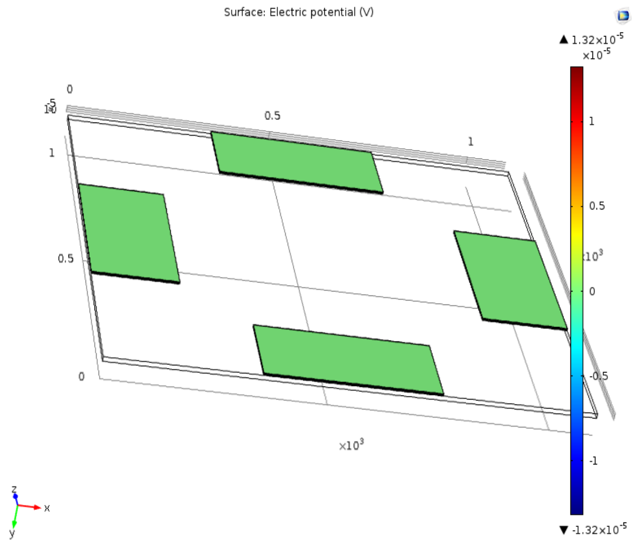


Fig. 8. Electric potential of piezoelectric high pressure sensor

Fig.8 shows made electric ability of the piezoelectric high pressure sensor. In this paper sensor produces electric potential for associated pressure. Exactly when the pressure is associated on the best surface of diaphragm, electric potential was made in the anodes. Model 1 gives electric potetial as $1.32*10^{-5}$ Volts anf model 2 gives electric potential as $1.45*10^{-5}$ Volts for 1 Pascal of associated pressure.

TABLE III. RESULT ANALYSIS OF MODEL 1 AND MODEL 2 OF PIEZOELECTRIC HIGH PRESSURE SENSOR

Parameter	**Theoretical**	**Model 1 (Practical)**	**Model 2 (Practical)**
Eigen Frequency (kHz)	82 (Stainless steel)	82	131
	137 (Silicon)		
Displacement (um)	$10.2777*10^{-5}$ (Stainless steel)	$6.63*10^{-5}$	$8.59*10^{-5}$
	$11.9850*10^{-5}$ (Silicon)		
Electric Potential (Volts)	$2.0773*10^{-5}$	$1.32*10^{-5}$	$2.00*10^{-5}$

TABLE 3 shows theoretical and practical examination of model 1 and model 2 of piezoelectric high pressure sensor for different parameters. In this examination, the speculative estimation of Eigen frequency, displacement and electric potential were composed to practical regard.

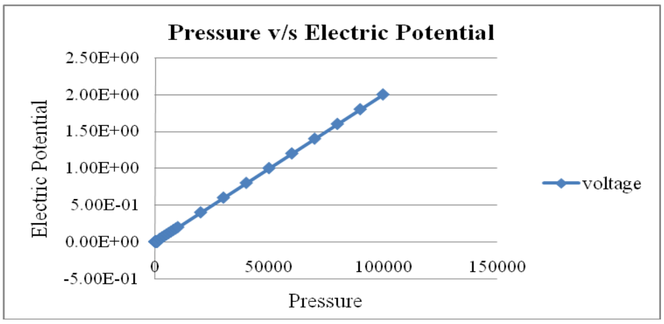


Fig. 9. Pressure versus Electric Potential

Fig.9 demonstrates a plot of connected pressure versus electric potential. For this situation produces electric potential was expanded with the expansion of connected pressure. This task was fit for creating electric potential for the connected weight running from 1Pa to 100kPa. Fig.9 shows created electric potential was in direct association with applied pressure.

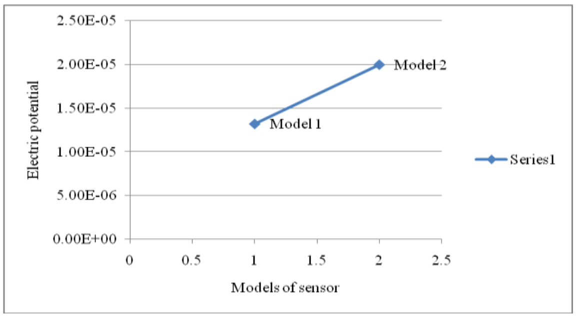


Fig. 10. Piezoelectric models v/s electric potential

Fig.10 shows comparison of model 1 and model 2. Electric potential which was generated is more in model 2 than model 1 Model 1 gives electric potential as 1.32*10-5 volts and model 2 gives electric potential as 1.45*10-5 volts.

VI. CONCLUSION

A piezoelectric high pressure sensor was planned utilizing COMSOL Multiphysics by differing material of the diaphragm. Among the two models, model 1 generates 1.32*10-5 volts of electric potential and model 2 generates 2*10-5 volts of electric potential for the applied pressure of 1 Pascal. By observing the result model 2 gives more voltage as compare to model 1. In this paper a piezoelectric high pressure sensor was intended to withstand pressure ranging from 1 Pascal to 100 kilo Pascal. Future work of this paper is to create layout structure for designed model by using CoventorWare tool and MEMS+ tools. The results can be further improved by changing the piezoelectric material and diaphragm material of the piezoelectric high pressure sensor.

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