PIEZORESISTIVE PRESSURE SENSOR DESIGN, SIMULATION AND MODIFICATION USING COVENTORWARE SOFTWARE

By

MUHAMMAD SYAQIQ BIN MAT SIHAT

FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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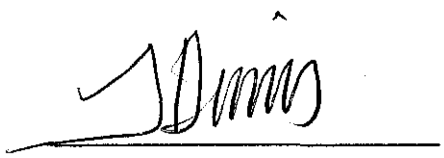
Approved:



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ABSTRACT

This research is undertaken for Piezoresistive (PZR) Pressure Sensor Design, Simulation and Modification using Coventorware Software. The main objective of the project is to design the sensor using the Coventorware. The pressure sensor is one of the micro-electromechanical systems (MEMS) devices. It uses the piezoresistive effect as the detection mechanism. The circuit used to arrange the implanted piezoresistor is the Wheatstone bridge that usually measures the small resistance change. The methodology of the project is the theory and the parameter study of the pressure sensor. The author used the Coventorware to design and simulate the sensor. After the design and modeling of the sensor, the simulation and result were obtained. Modification to improve the pressure sensor's output was then made to the design. The modification is to add an additional resistor with one resistor in parallel. The modification resulted in overall resistors implanted is eight from four. The results of both typical and modified versions of the sensor were obtained by simulations using architect in Coventorware. The results showed that modified and typical sensor give similar pattern of output voltage. The dynamic range for the modified sensor is higher but has low sensitivity.

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

PZR	Piezoresistive
FEM	Finite Element Method
MEMS	Micro Electro-mechanical Systems

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Micro Electro Mechanical Systems or MEMS is generally the micro systems consisting of micro mechanical sensors. The piezoresistive (PZR) pressure sensor is one of the MEMS devices. The piezoresistive effect is the change in resistivity of piezoresistive material due to the mechanical deformation. Pressure sensors are used for many purposes. For examples, to measure the bladder pressure in humans, to measure pressure in heating application, measurement of blood pressure, and measurement of manifold pressure in cars [1].

The performance of the PZR sensor, such as the sensitivity, temperature dependency and size of the output signal, depend largely on the position and shape of the implanted piezoresistor. Therefore, the optimization of the resistor arrangements in the sensor is the key part of the design. By using the Coventorware software as the medium, the optimization can be achieved [1]. The project also includes study of the membrane thickness which is very important to determine the relation between membrane displacement and the pressure applied.

1.2 Problem Statement

Pressure measurement is the key part of many commercial industrial systems. Silicon has been proven to be an excellent material to build the micro pressure sensor [2]. Today, pressure sensor constitutes the largest market segment of MEMS device. There are three main types of pressure sensor which are the metal strain gauge, piezoresistive pressure sensor and capacitor pressure sensor. Metal strain gauge was discovered long before the piezoresistive effect in semiconductor [2].

The most common technique for measuring pressure involves applying pressure to one side of the diaphragm, a reference pressure in the other side, and determines how much the diaphragm will deform. The design project will base on the piezoresistivity property of the silicon. The design is to get the output of the pressure sensor. There are two sensors designed in this project, typical sensor and the modified sensor. The difference between the sensors will be explained in methodology part.

1.3 Objectives and scope of study

1.3.1 Objectives

The objective of this project is simulation and designing of the piezoresistive (PZR) pressure sensor using the Coventorware by performing following task:

- To design and modify the PZR pressure sensor to get better result
- To simulate the micro scale PZR pressure sensor to analyze the output of the modified and typical sensor for comparison.

1.3.2 Scope of study

The scope of work of this project is to study the piezoresistive effect in silicon and the micro-electromechanical systems (MEMS) pressure device. The scope of study also includes the learning of Coventorware software. The software is a powerful tool of designing PZR pressure sensor. The piezoresistors will be arranged using Wheatstone bridge's arrangement which used to measure the small resistance change in resistors. In this project, the main interest is in the sensing part of the pressure sensor.

CHAPTER 2
LITERATURE REVIEW

2.1 Pressure sensor

A pressure sensor is used to measure pressure in gas or liquids. Pressure is an expression of force per unit area. Pressure sensor usually acts as a transducer, generates a signal as a function of the pressure imposed. It also can be alternatively called pressure transducer, pressure transmitter and pressure indicator [3].

There are several types of mechanism used in pressure sensor. There are two mains mechanism which are Piezoresistive strain gauge and capacitive type.

2.1.1 Piezoresistive strain gauge

Use the piezoresistive effect of bonded or formed strain gages to detect strain due to applied pressure. Common technology types are silicon (mono-crystalline), poly-silicon thin film, bonded metal foil, thick film, and sputtered thin film. Generally, the strain gages are connected to form a Wheatstone bridge circuit to maximize the output of the sensor. This is the most commonly employed sensing technology for general purpose pressure measurement. Generally, these technologies are suited to measure absolute, gauge, vacuum, and differential pressures [4].

2.1.2 Capacitive

Capacitive pressure sensor uses a diaphragm and pressure cavity to create variable capacitor to detect strain due to applied pressure. Common technologies use metal, ceramic, and silicon diaphragms. Generally, these technologies are most applied to low pressures (Absolute, Differential and Gauge) [4].

2.2 Piezoresistive effect

S.C Smith discovered in 1954 that the change in resistance of a strained germanium or silicon filament is larger than the metal strain gauge. The resistance changes because the change of the material dimension for the metal strain gauge. For germanium and silicon the resistivity changes not only because of the material dimension, but as the change of the material resistivity. The effect is called Piezoresistive effect [5].

The sensitivity of Piezoresistive devices is characterized by the gauge factor [6]

$$K = \left(\frac{dR}{R}\right) / \epsilon_L \qquad (1)$$

Equation (1) shows the gauge factor, K where dR is the change in resistance due to deformation, R is the initial resistance and ϵ_L is the strain [6].

2.3 Piezoresistivity for silicon

Silicon is an anisotropic material. The gauge factor for silicon device is dominated by the contribution of piezoresistive effect. The anisotropy causes more complicated mathematical description. The piezoresistive effect of semiconductor materials can be several orders of magnitudes larger than the geometrical piezoresistive effect in metals and is present in materials like germanium, polycrystalline silicon, amorphous silicon, silicon carbide, and single crystal silicon [7].

The simple result can be obtained for the case of plane stress and where the current in the resistor is in the direction or perpendicular to the stress. The change in resistivity can be describes by three piezo coefficients:

i. π l describing the effect of longitudinal stress, σ_l, - stress in the direction of the current.

ii. π t describing the effect of transversal stress, σ_t - stress perpendicular to the direction of the current.

iii. π s describing the effect of shear stress, σ_s.

Table 1 shows the value of piezo coefficient with subject to the direction on silicon<100>. <100> is the stress coordinate system as the reference to the direction on the silicon wafer. The coefficients determine the resistance change when stress is applied. Figure 1 shows the direction of longitudinal stress, σ_l transversal stress, σ_t and shear stress, σ_s. The longitudinal stress is perpendicular to the direction of current.

Table 1 Longitudinal, transversal and shear piezoresistive coefficient resistor oriented along <110> on 001 silicon wafer (300K)[7]

	n-type	p-type
$\pi_l (10^{-11} Pa^{-1})$	−31.2	71.8
$\pi_t (10^{-11} Pa^{-1})$	-17.6	-66.3
$\pi_s (10^{-11} Pa^{-1})$	0	0

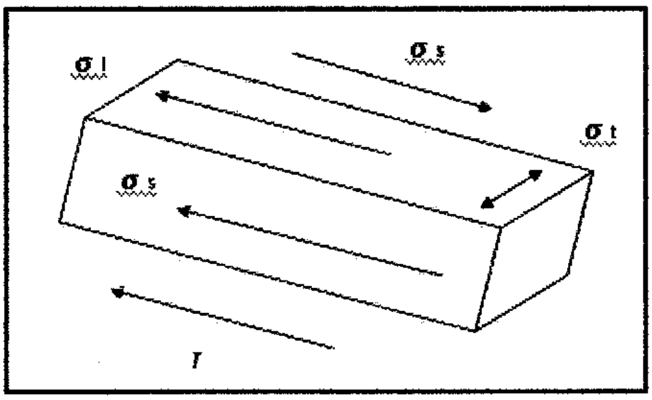

Figure 1 A piezo resistor subjected to plane stress. The current, I, is oriented along the direction of σl.

The resistivity change can be expressed

$$\frac{\Delta\rho}{\rho} = \frac{\Delta R}{R_0} = \pi l \sigma l + \pi t \sigma t + \pi s \sigma s \qquad (2)$$

Equation (2) shows the change of the resistivity of a piezoresistive material where πl and πt are the effective longitudinal and transversal piezo coefficients respectively, and πs is the effective shear stress piezo coefficient. These piezo coefficients depend on the orientation of the resistor, the substrate orientation, the temperature and doping level and dopant type[7].

2.4 Temperature and doping dependence

The longitudinal and transversal piezo coefficients depend on both temperature, T, and doping level, N. This can be describe by introducing a scaling factor P (N,T) that corrects the room temperature piezo coefficients

$$\pi l(N, T) = P(N, T)\pi l(300K)$$

$$\pi t(N, T) = P(N,T)\pi t(300K)$$

Piezoresistive effect decreases with increasing doping level and for increasing temperature. The temperature dependence is smaller at higher doping level. This is important for device design; by increasing the doping level the temperature dependence is decreased, however at the cost of lower sensitivity[7].

Figure 2 and Figure 3 show that Piezoresistive effect in silicon decrease with increasing temperature. When the doping concentrations increase, it also reduces the Piezoresistive effect in silicon.

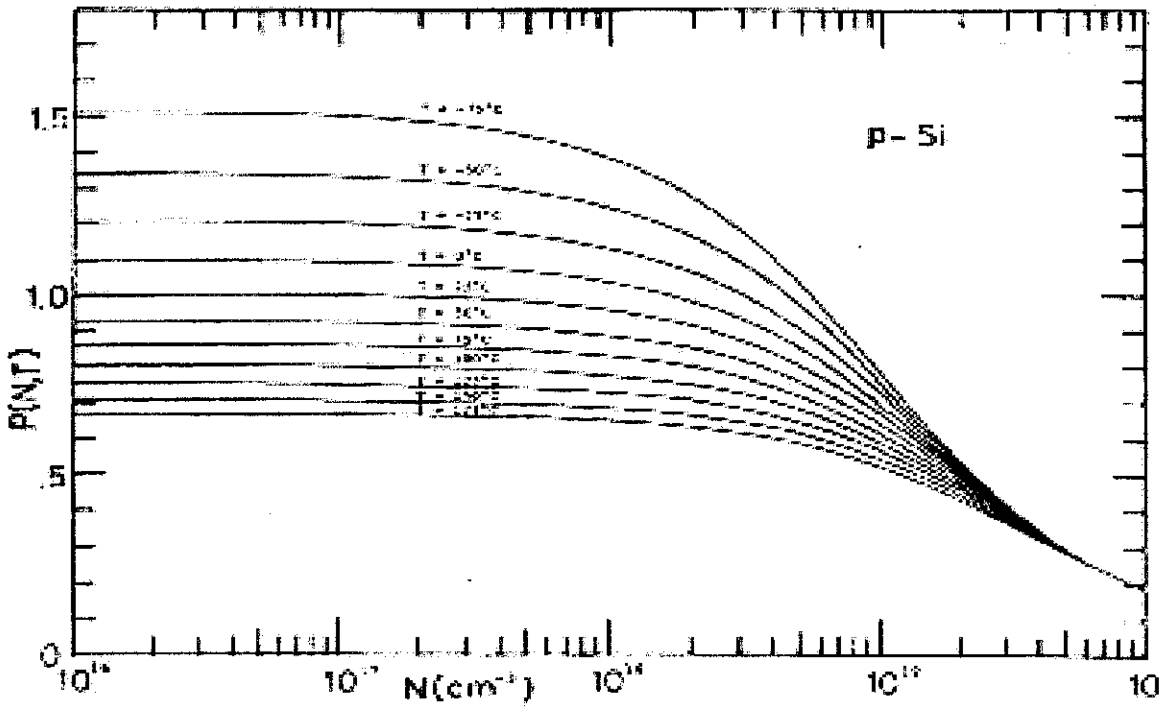

Figure 2 Piezo resistance correction factor P(N, T) as function of doping level and temperature for p-type silicon[7]

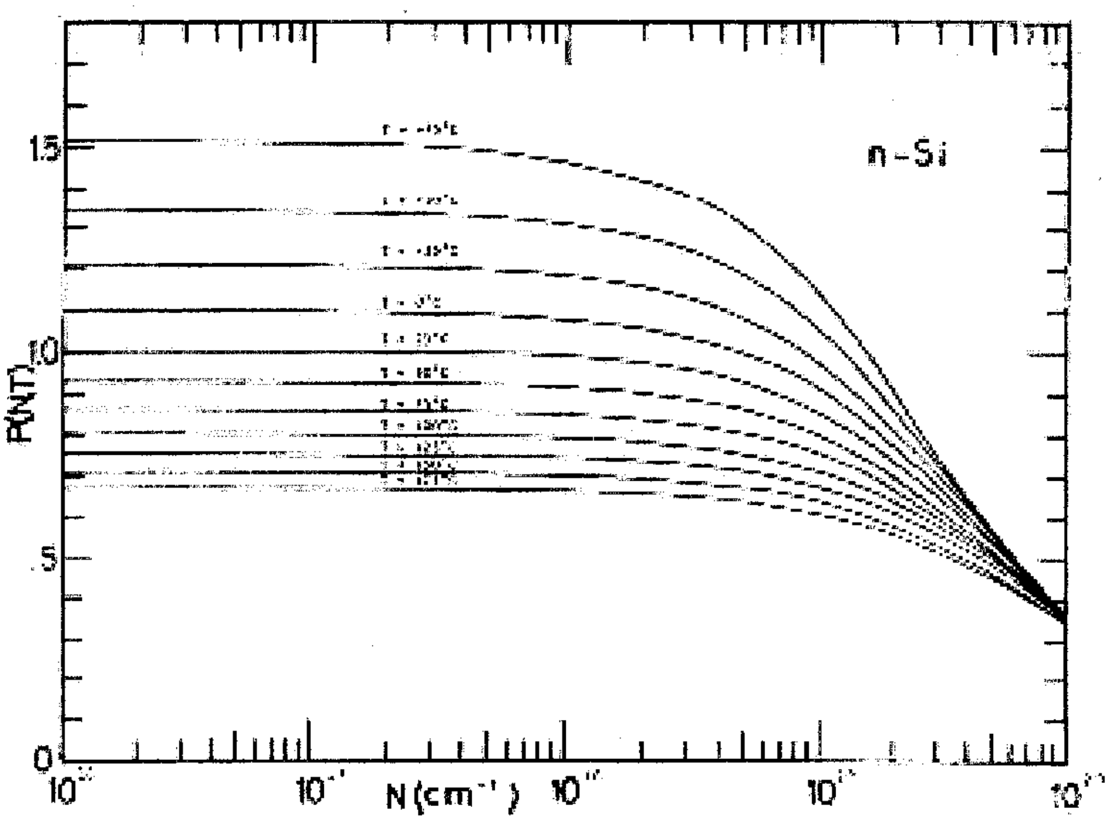

Figure 3 Piezo resistance correction factor P(N, T) as function of doping level and temperature for n-type silicon[7]

2.5 Wheatestone Bridge

The Wheatstone bridge is an electrical circuit for the precise comparison of resistances. Sir Charles Wheatstone is most famous for this device but never claimed to have invented it. However, he did more than anyone else to invent uses for it, when he 'found' the description of the device in 1843. The first description of the bridge was by Samuel Hunter Christie (1784-1865) in 1833 [8].

The Wheatstone bridge is an electrical bridge circuit used to measure resistance. It consists of a common source of electrical current (such as a battery) and a galvanometer that connects two parallel branches, containing four resistors, three of which are known [8]. One parallel branch contains one known resistance and an unknown (R4 in the above example); the other parallel branch contains resistors of known resistances. In order to determine the resistance of the unknown resistor, the resistances of the other three are adjusted and balanced until the current passing through the galvanometer decreases to zero.

The Wheatstone bridge is well suited also for the measurement of small changes of a resistance and, therefore, is also suitable to measure the resistance change in a strain gauge. It is commonly known that the strain gauge transforms strain applied to it into a proportional change of resistance. It is widely used across industry even today.

Figure 4 shows a typical Wheatstone bridge. It consists of four resistors and a DC voltage source. The initial output voltage is zero since all resistors have same value of resistance. When resistance changes, the output voltage, Vs will have value. This configuration will be implanted on the membrane as the resistance of the resistors will change when the membrane bends.

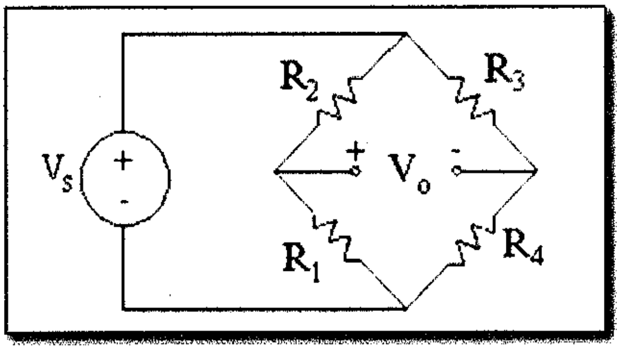

Figure 4 Wheatstone bridge

The output voltage of the bridge

$$V_o = \left(\frac{R_2R_4 - R_1R_3}{(R_3R_4)(R_1R_2)}\right) \cdot V_s \tag{3}$$

Equation 3 shows the connections between output voltage and the source voltage in the bridge. Normally all resistors are chosen equal to each other, resulting in zero output voltage. For sensor applications at least of the resistor has to be dependent on the measurement. When $R_1=R_2=R_3=R$ and $R_4=R+\Delta R$, the output can be expressed [5]

$$V_o = \left(\frac{\Delta R/_R}{4+2\cdot\Delta R/_R}\right) \cdot V_s \tag{4}$$

2.6 Diaphragm membrane stress analysis

$$\left(\frac{L}{H}\right)^2 < \frac{\sigma_{safe}}{0.294}\frac{1}{P} \tag{5}$$

Equation 5 represents the limitation of L/H ratio with respect to the pressure range for the sensor. The membrane side length, L and the thickness, H must be chosen carefully to satisfy for all P without breaking the membrane. The ratio will determined the range of pressure of interest. Based on [5] the yield stress (fracture strength) of silicon is 7 GPa and the σ_{safe} is about 500 MPa. This will impose absolute design limitations on dimensions of pressure sensor.

CHAPTER 3
METHODOLOGY

3.1 Procedure identification

The first part of the project is the study about the piezoresistive effect and the pressure sensor itself. The piezoresistors implanted onto silicon diaphragm using the Wheatstone bridge arrangement. The arrangement used to calculate small resistance changes.

The second part of the project is designing the pressure sensor using Coventorware. Study about the software is essential in the design stage. After the design stage, the parametric study and analysis can be done to improve the output of the sensor. The result then will be presented in the final report. The parametric study includes the membrane displacement for the given pressure applied, the output voltage for the typical and modified sensor and also the output voltage when the y offset and x offset are varied.

Figure 5 shows the flowchart of project work from the early stage until the final report documentation. The designs basically use the Coventorware software. Coventorware consists of three main powerful tools which are Architect, Designer and Analyzer. The Architect is used to design the schematic of the Wheatstone bridge that will be implanted on the silicon membrane. It also used to modify the sensor. Designer is used to build the 3D design of the diaphragm and the meshed design. Analyzer is used to analyze the membrane deflection with given pressure. Comparisons are done between the typical four piezoresistors sensor and eight piezoresistors sensor.

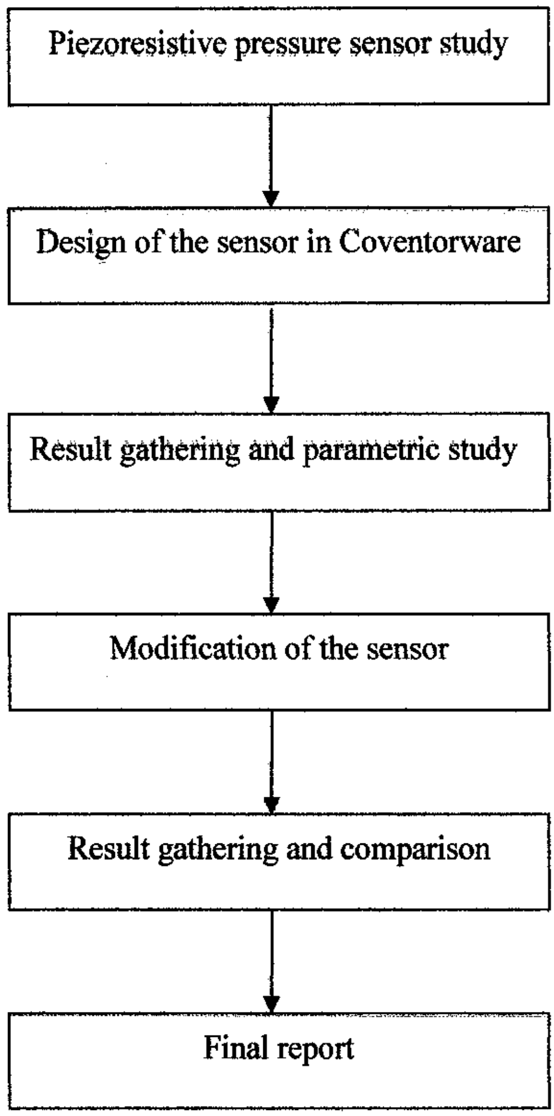

Figure 5 Flowchart of project works

3.2 Piezoresistive pressure sensor design steps in Coventorware

Figure 6 shows the design steps of piezoresistive pressure sensor from the diaphragm modeling until the sensor parametric study for output voltage of the sensor.

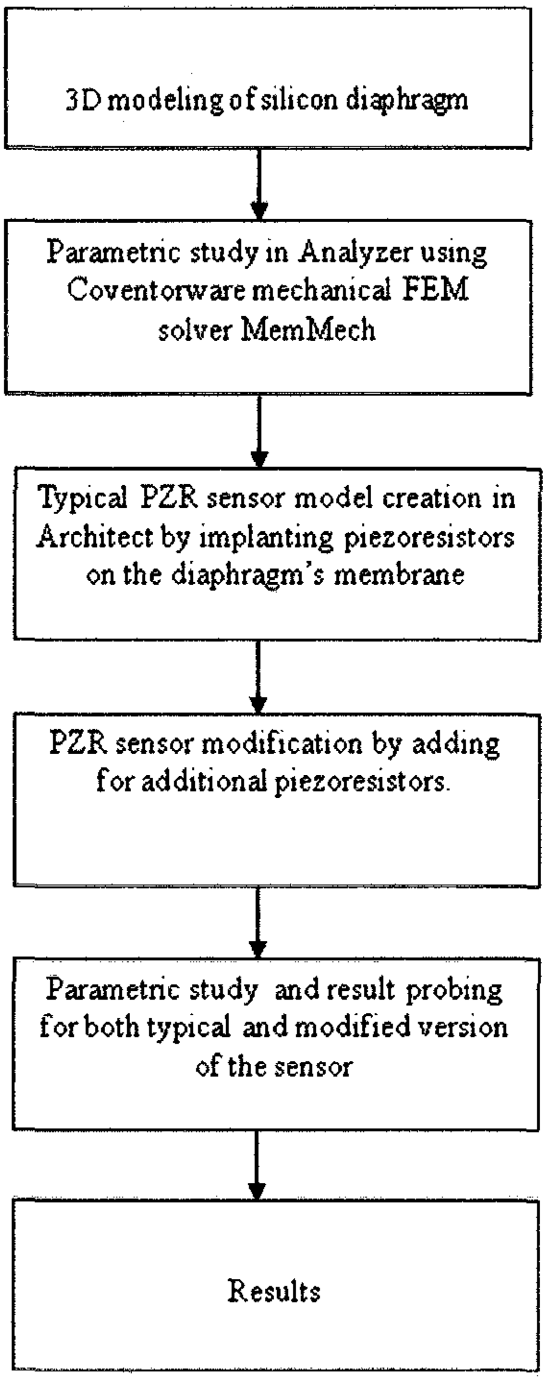

Figure 6 Coventorware design steps

3.2.1 Model creation of 3D silicon diaphragm

The initialization of the diaphragm process is in the process editor icon. The steps involve are setting the substrate layer and wet etch-backside of the substrate to create a membrane. The properties of the processes is shown on the Table 2,

Table 2 Properties of substrate layer and the etching process

Substrate layer	Wet etch-backside step
Mask = gnd Thickness = 400 um Material = SILICON_100	Depth = 390 um Mask = membrane Photoresist = - Sidewall angle = -35.3

Figure 7 shows the steps in creating the silicon diaphragm and the properties of the process. After that, using Designer the 2D diaphragm will be created. The diaphragm will have 1600 um x 1600 um dimension. The membrane layer will have 1053 um x 1053 um dimension. The thickness of the membrane is 10 um. After the dimension has been defined, the Preprocessor will build a 3D diaphragm. There are only two steps involved; the substrate step and the anisotropic backside wet etch. The substrate layer material is using the Silicon_100. The wet etch properties are 390um depth and -35.3 degree angle.

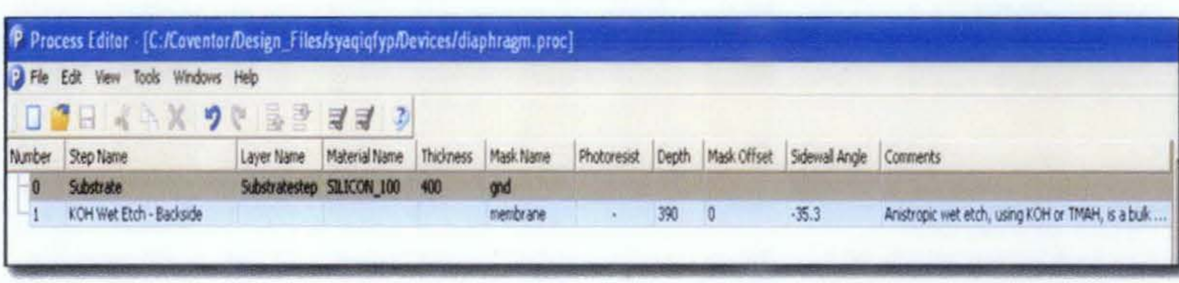

Figure 7 Steps in process editor

Then, a solid model of the diaphragm is constructed. The Preprocessor will generate the solid diaphragm based on the setting in process editor above. Figure 8 shows the solid model that created using Preprocessor

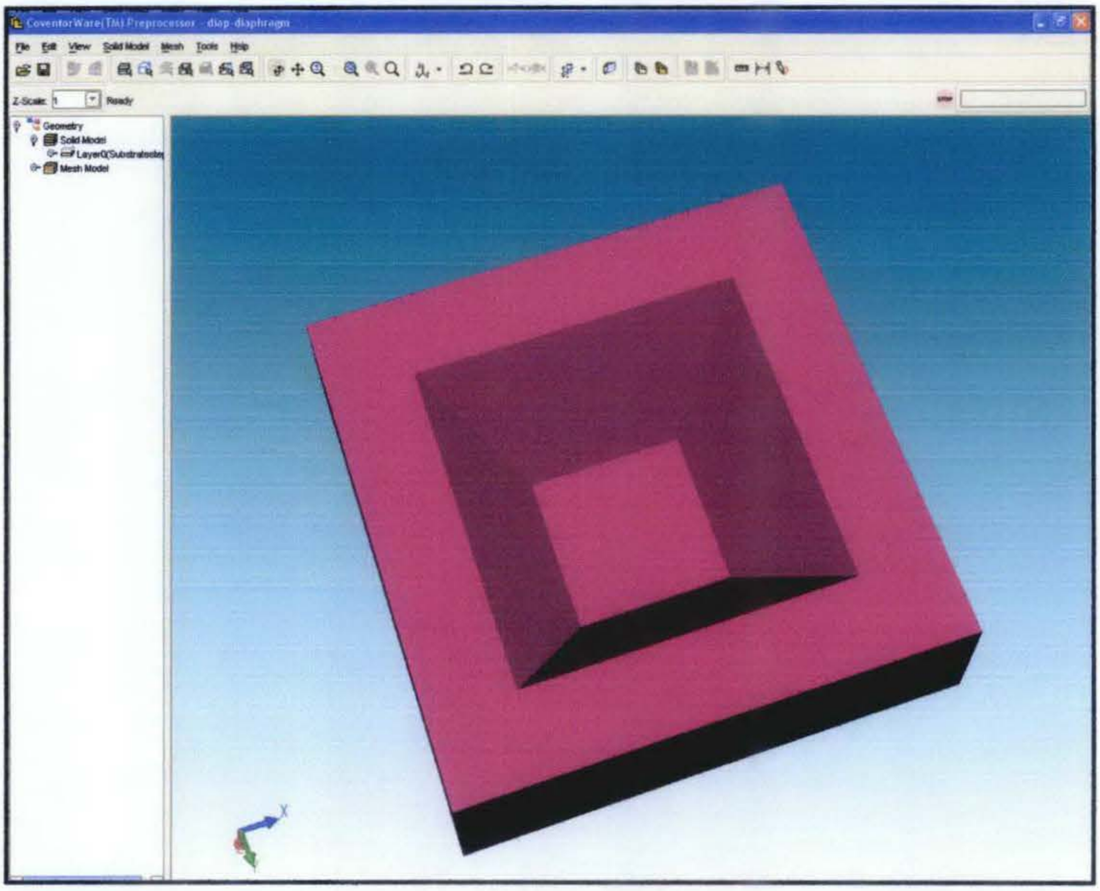

Figure 8 Solid model of diaphragm

Next process is meshing the solid model. Meshing process is essential to allow Analyzer to do the pressure boundary condition analysis on the model. The analysis is important for the parametric study in Architect since the study is related to the pressure applied on the diaphragm.

The first step is to do partition between the membrane and the diaphragm. A block is placed at the membrane layer. Then, select *block1* and *layer0.* At the solid model menu, select partition. The model now has two layers, which is the diaphragm frame and the diaphragm. Figure 9 shows the two layers. Magenta colour is the diaphragm frame and the diaphragm is represented by grey colour.

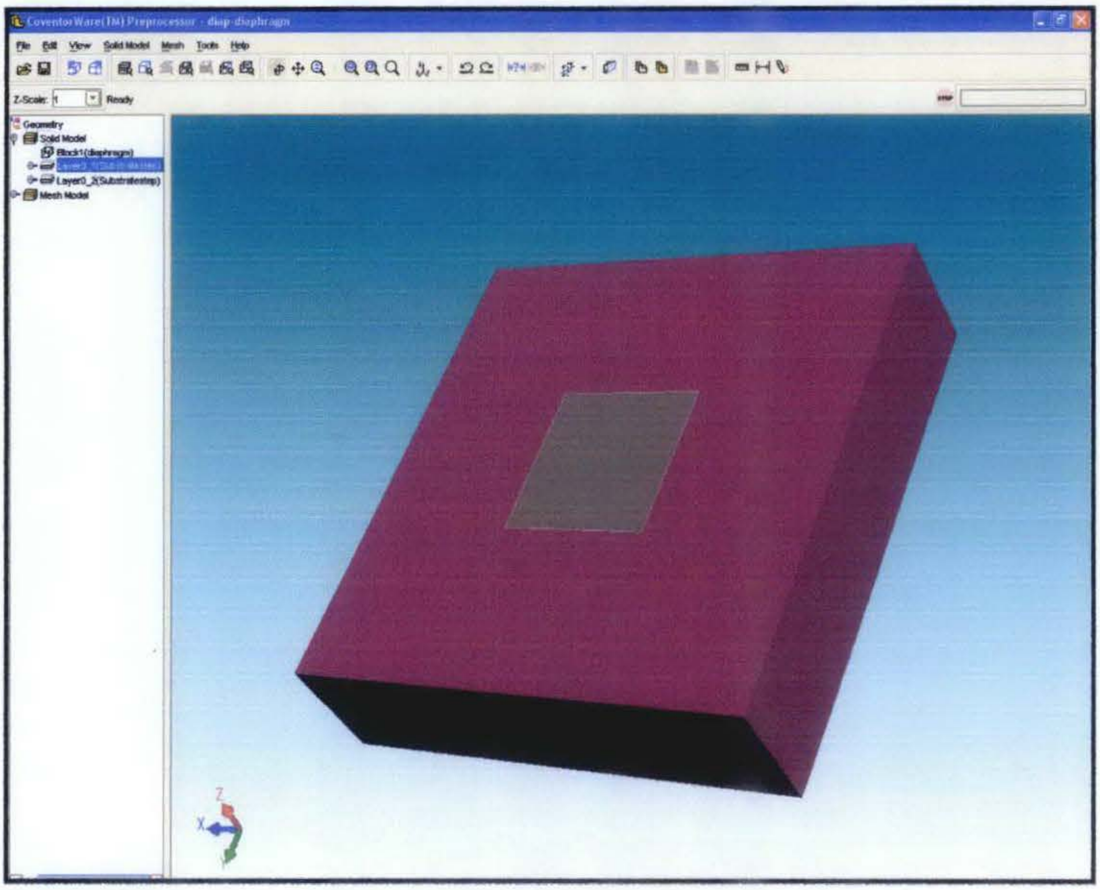

Figure 9 Diaphragm and diaphragm frame

Then, a horizontal plane and two vertical planes are placed on the solid model. The purpose of the planes is to make eight partition of the solid model. Figure 10 shows the planes as they partition the solid model into six-sided volumes.

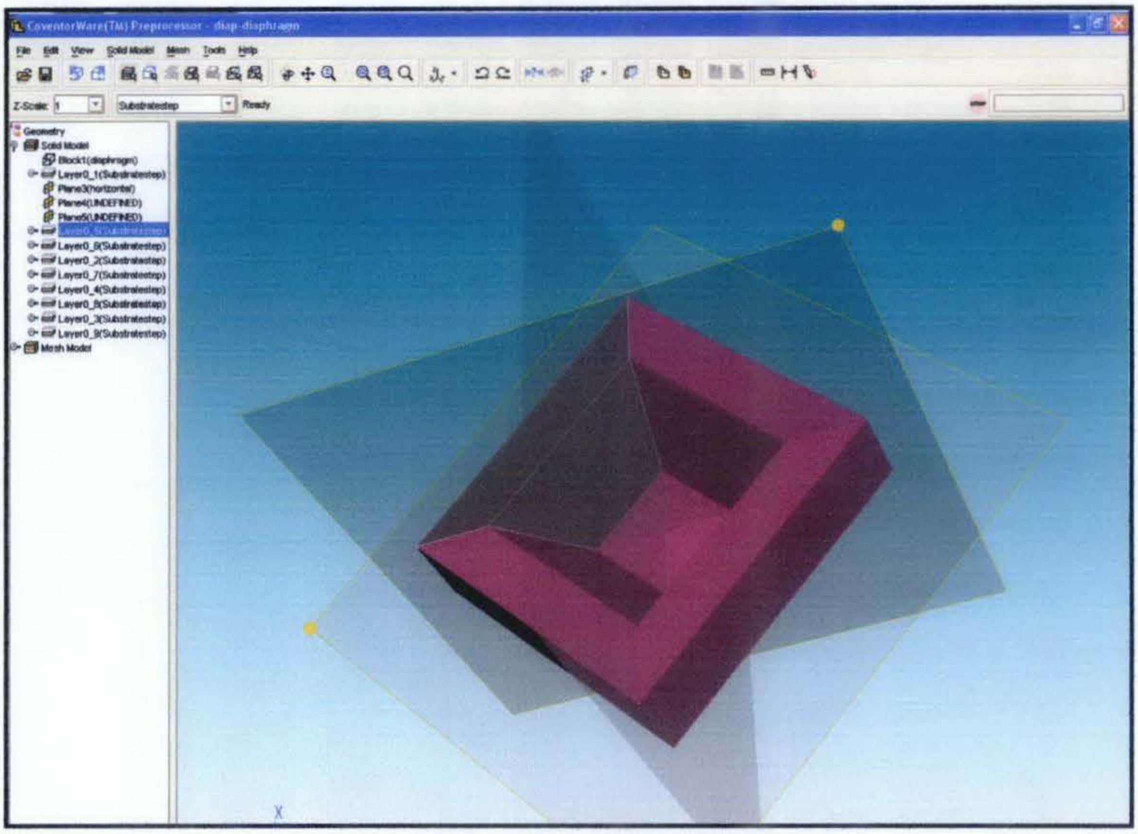

Figure 10   Inserted partition planes

After the partition steps, the diaphragm frame will have eight layers and one membrane layer. Add all the layers in Mesh Model folder. Then mesh the region with the Mapped bricks, Linear Element order and element size of 50. Figure 11 below shows the Mesher settings.

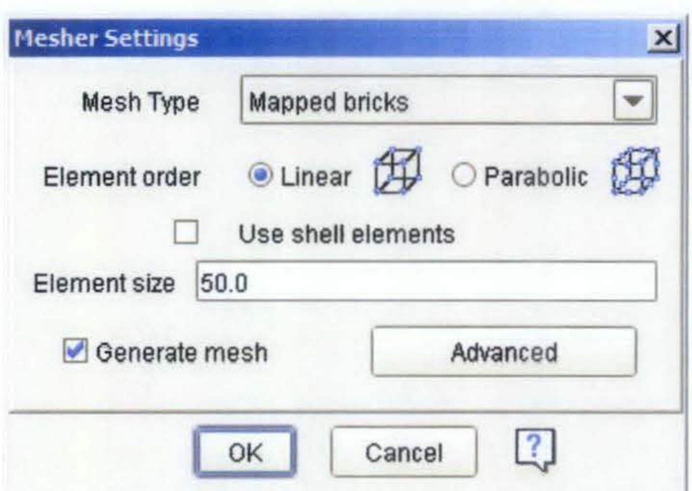

Figure 11   Mesher settings

3.2.2 Membrane stress analysis in Analyzer

The analysis is done using Coventorware's mechanical FEM solver MemMech. The analysis will simulate the diaphragm deformation under a series of different pressure. The result is used in Architect schematic when the simulation of the sensor was run. The analysis allows the simulation in Architect to have data for the diaphragm deformation and the pressure applied. Then, the simulation will have the relationship between pressure and the output voltage. In Analyzer, the result will be shown in Visualizer.

Figure 12 below shows the surface boundary condition setting in Analyzer. The two surface boundary conditions are, fixed and pressure. The name face *pressure* will be applied by the pressure.

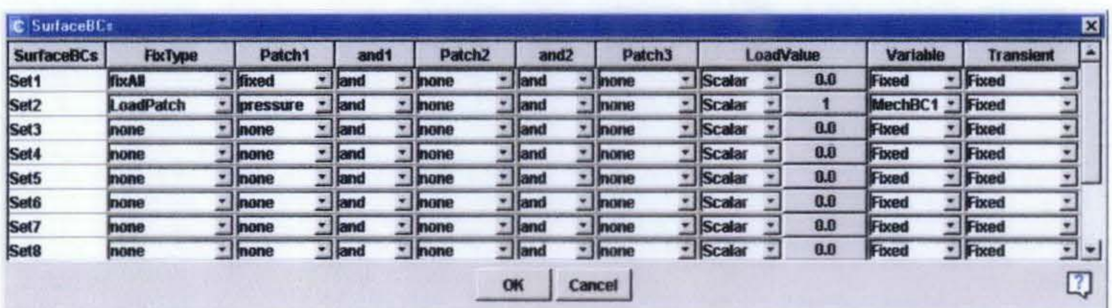

Figure 12 Surface boundary condition setting for the diaphragm

In Parametric study, the pressure trajectory is set from 0.0 to 0.2 MPa with delta of 0.05. Figure 13 shows the pressure trajectory setting for the analysis.

Figure 13 Pressure trajectory setting

3.2.3 PZR sensor model creation in Architect

Before the creation in Architect, the ion implantation step is defined at the Function Manager. Figure 14 shows the additional step of ion implantation surface. This step allows piezoresistor to be implanted on the diaphragm using Architect.

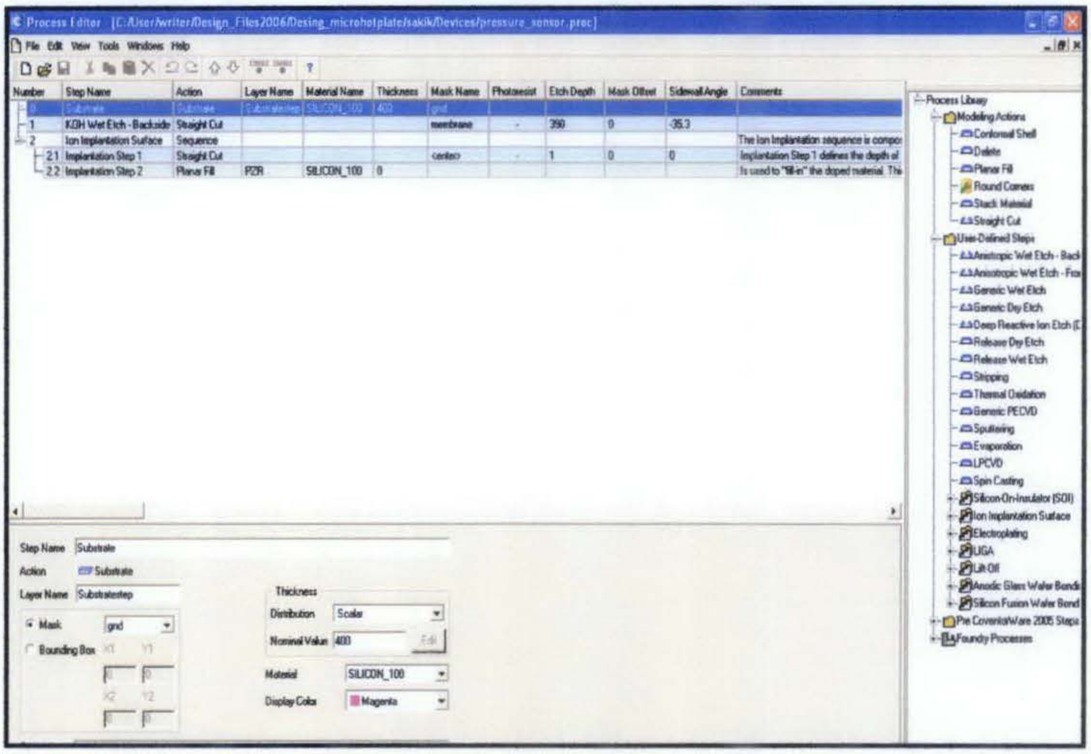

Figure 14 Piezoresistors implantation step

After the implantation step is defined, the construction of the schematic circuit is done in Architect. Figure 15 shows model creation includes the schematic design of the piezoresistors that follows the Wheatstone bridge arrangement. This model is defined as the typical sensor in the project. The op-amp used to amplify the voltage output of the circuit.

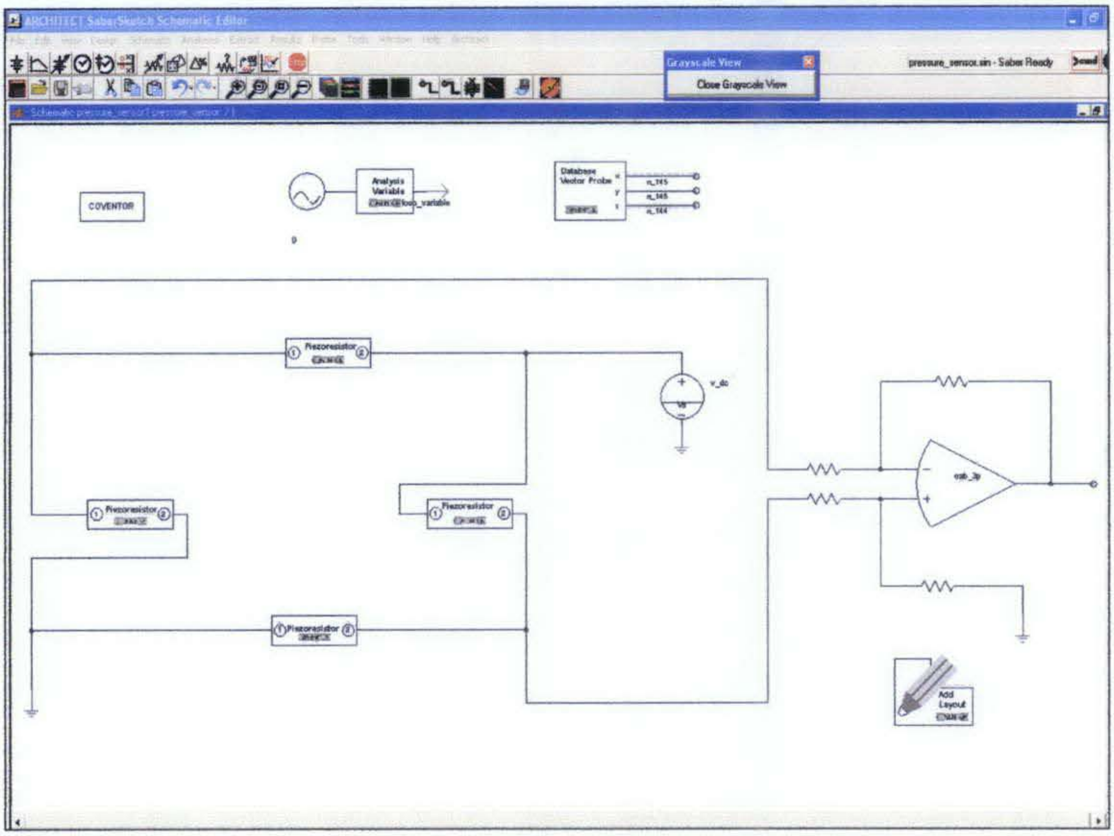

Figure 15 Pressure sensor schematic on Architect

The properties of the each piezoresistors are the same. The same properties will give the same value of resistance. Table 3 shows the properties of the pizoresistor.

Table 3 Properties of piezoresistors

Name	Value
pzr_width	normal(8u,8u-0.25u,8u+0.25)
pzr_height	normal(1u,0.1)
membrane_size	500u
pzr_length	normal(80u,80u-0.25u,80u+0.25u)
Vs	5
edge_offset_x	0
edge_offset_y	0
mask_angle	normal(0,-1,1)
mask_offset_x	normal(0,-1u,1u)
mask_offset_y	normal(0,-1u,1u)
pressure	0.2

After constructing the schematic circuit, the placement of the piezoresistors on the membrane is done. The placement of them is using the coordinate system. The center of the diaphragm will have (0, 0) coordinate or the origin. Table 4 shows the coordinate properties of the piezoresistors.

Table 4 Piezoresistors coordinate on the diaphragm

Left	Upper center	Lower Center	Right
PZR1	PZR2	PZR3	PZR4
x= -membrane_size/2 +pzr_length/2 +edge_offset_x y = 0 position = center	x = 0 y = membrane_size/2- pzr_width/2- edge_offset_y position = center	x = 0 y = - membrane_size/2 +pzr_width/2 +edge_offset_y position = center	x= membrane_size/2- pzr_length/2- edge_offset_x y = 0 position = center

Figure 16 shows the placement of the piezoresistors on the diaphragm. Four green rectangles on the diaphragm represent the piezoresistors.

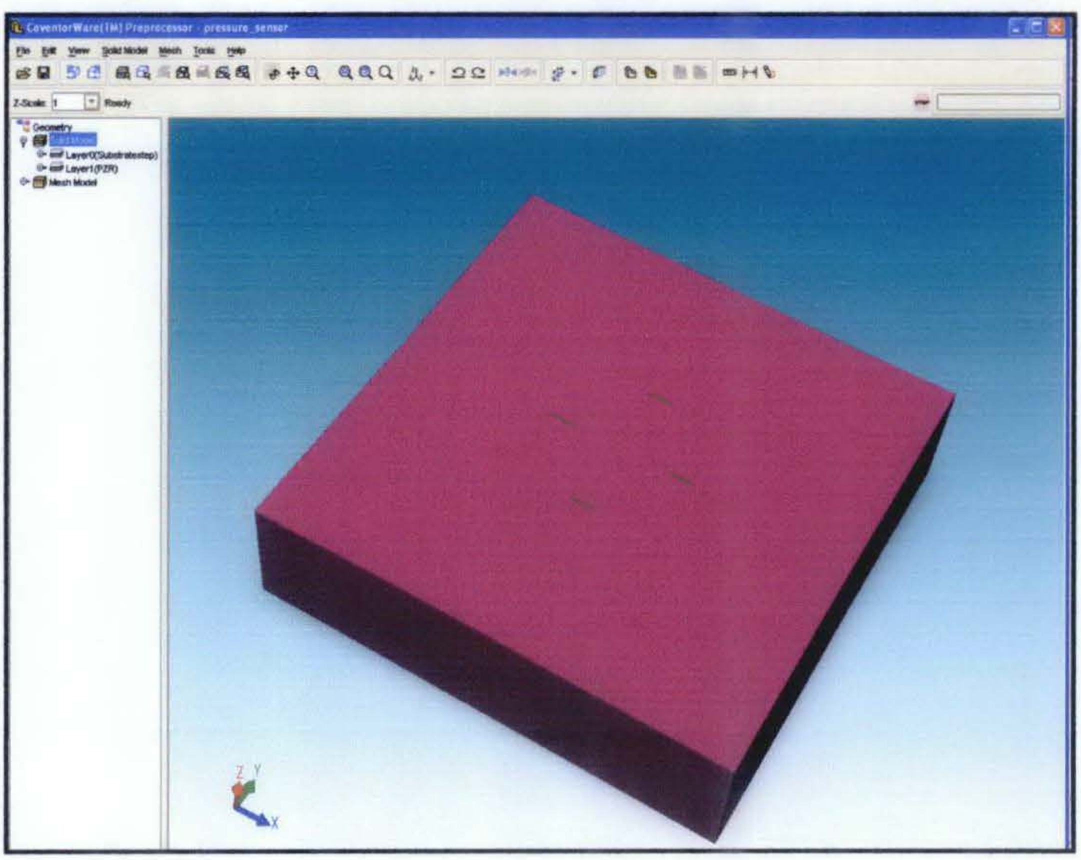

Figure 16 Piezoresistors placement on the diaphragm

The modification on the schematic is also done in Architect. The modification is by adding the same properties of pizoresistor in parallel with the existing four piezoresisitors. The new schematic of modified sensor is shown in Figure 17

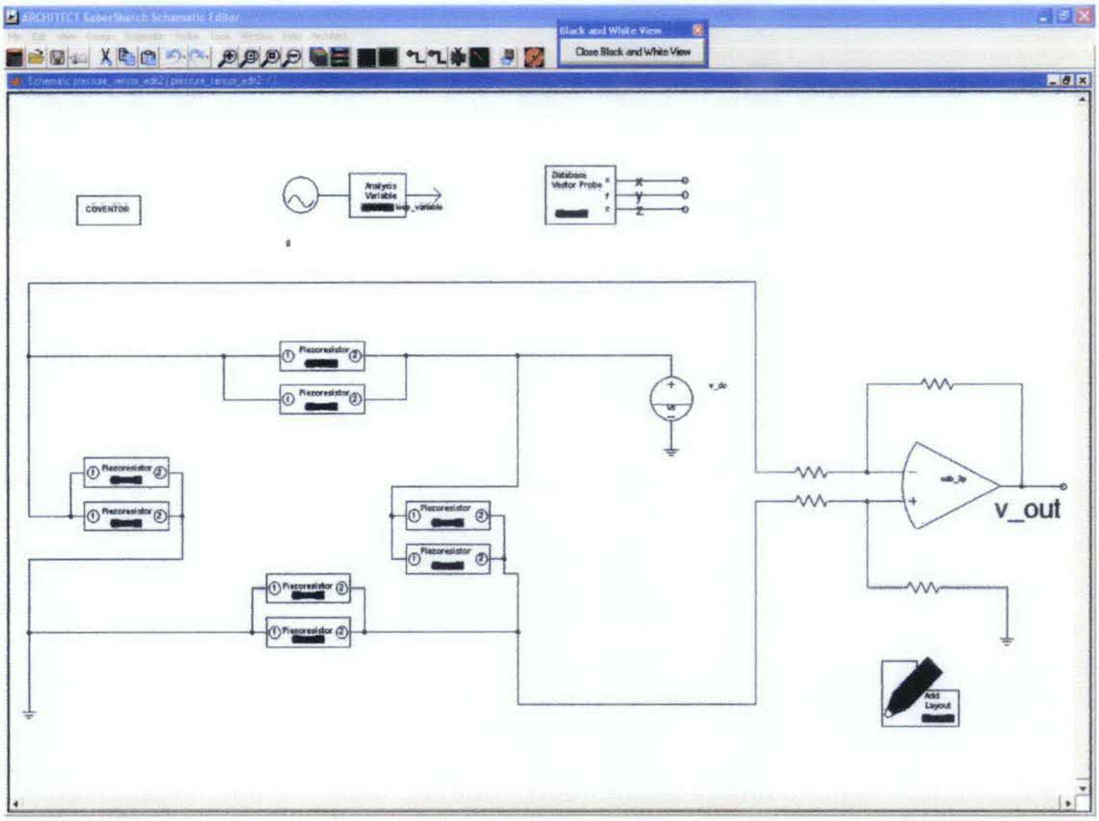

Figure 17 Modified sensor schematic in Architect

The additional piezoresistors also placed on the diaphragm using the coordinate system as the earlier piezoresistors. Table 5 shows the four additional piezoresistors coordinate properties.

Table 5 Coordinaate properties of additional piezoresistors

Left	Upper center	Lower Center	Right
PZR5	PZR6	PZR7	PZR8
x= -membrane_size/3 +pzr_length/2 +edge_offset_x y = 0 position = center	x = 0 y = membrane_size/2.5- pzr_width/2- edge_offset_y position = center	x = 0 y = - membrane_size/2.5 +pzr_width/2 +edge_offset_y position = center	x= membrane_size/3- pzr_length/2- edge_offset_x y = 0 position = center

3.2.4 *Parametric Study*

The parametric study that is conducted in this project is gathering the output voltage of the sensor based on the typical and modified sensor. The parameters that are taken into consideration are the y edge offset and x edge offset of the piezoresistors placement on the membrane. The analysis involved is vary analysis. The analysis is done for both of typical and modified sensor. Figure 18 show the vary analysis setting for loop that pushes PZR1 and PZR3 over the edge of the membrane and PZR2 and PZR4 towards the center of the diaphragm.

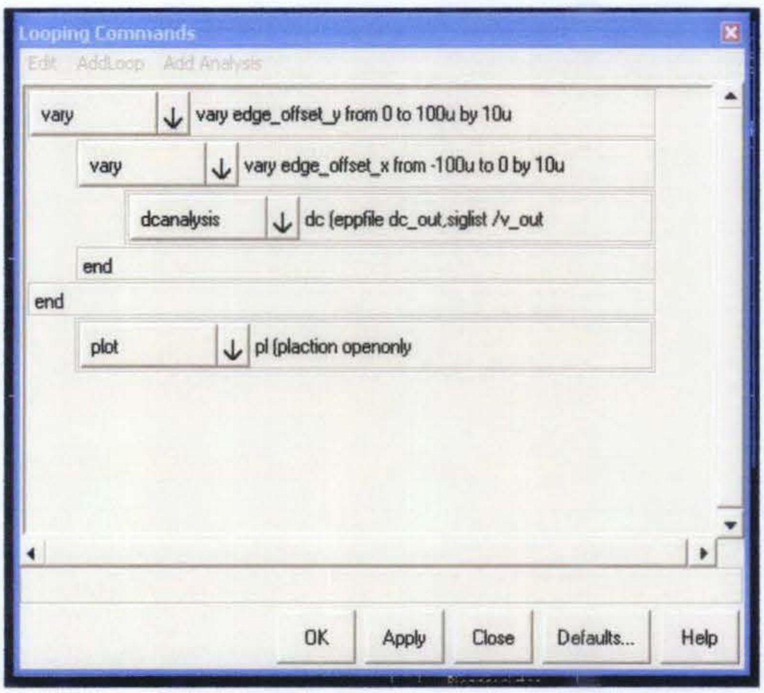

Figure 18 Settings for vary analysis

. Second analysis is the DC transfer analysis. This analysis is observing the output voltage when the different pressure load is given. The setting for the analysis is shown in Figure 19.

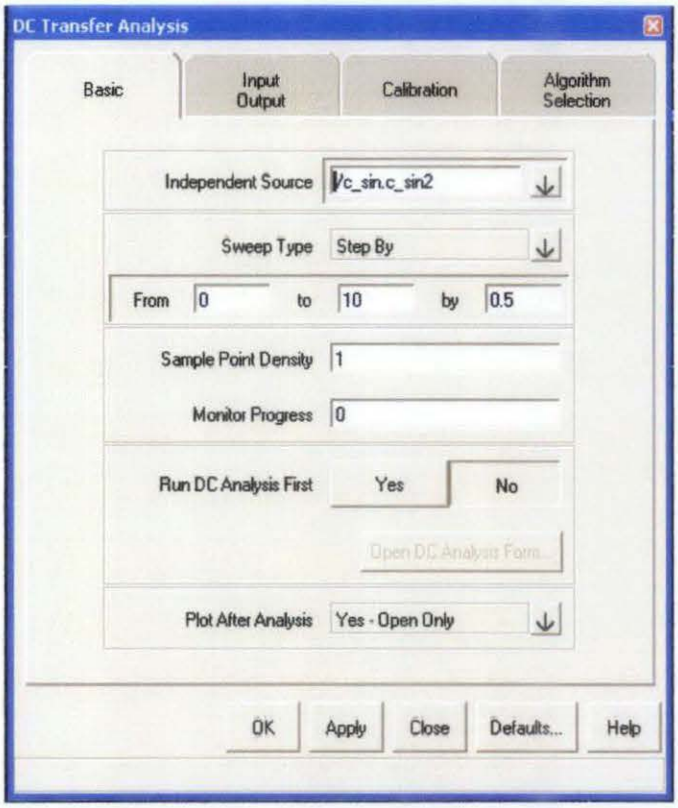

Figure 19 Setting for DC transfer analysis

3.3 Tools and equipment required

Coventorware software is the main tool that required in this project. The software usually used in model and simulate MEMS devices. Using this software, the design, simulation and the modification of pressure sensor can be done.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

4.1.1 3D model of silicon diaphragm

. Figure 20 shows the diaphragm with mapped bricks mesh. The mesh is important to east the diaphragm analysis and study.

Figure 20 3-D diaphragm with mapped mesh

4.1.2 Diaphragm membrane stress analysis

The membrane is designed with width of 500 um and thickness of 10 um. This is the typical dimension of membrane for pressure sensor. The range of pressure applied is between 0 to 0.2 MPa. The highest displacement of the membrane is located at the center of the membrane which is about 1.3 um displacement. The resulting membrane displacement is shown in the figure 21.

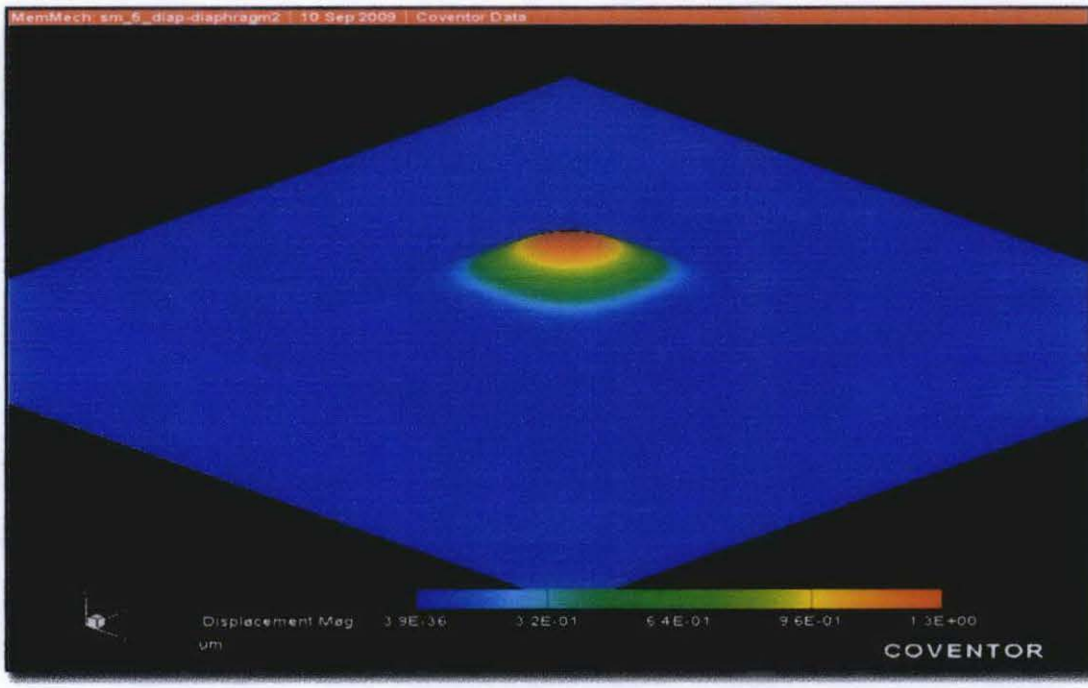

Figure 21 Membrane displacement with respect to maximum pressure applied

Using Analyzer in Coventorware, the simulation determines the relationship between the pressure applied and the resulting displacement of the membrane. The graph is shown in figure 22. The graph shows a linear dependence on displacement of the membrane in a function of the pressure applied.

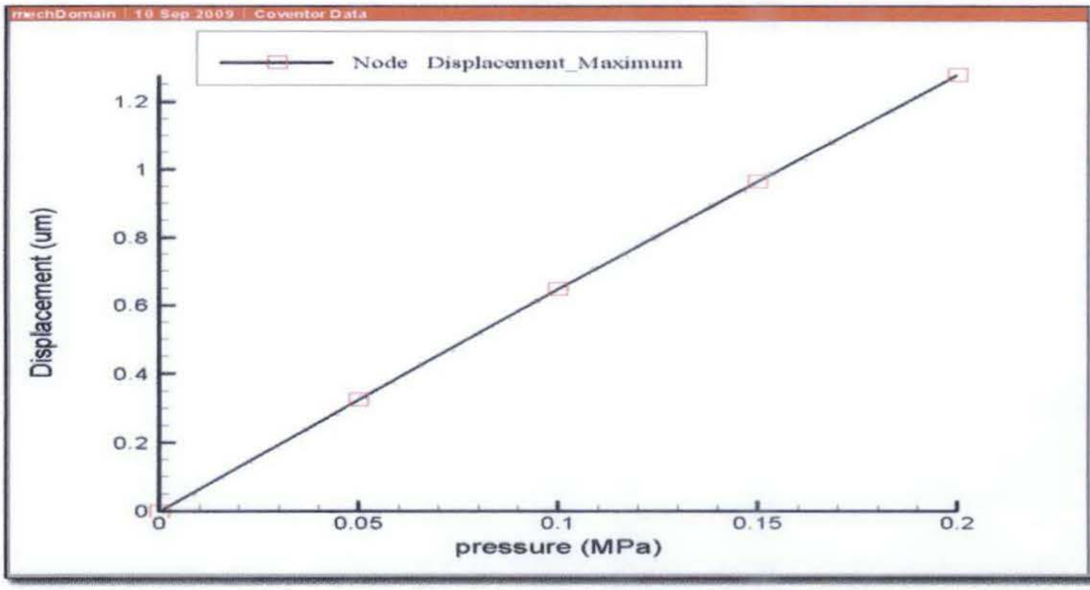

Figure 22 Displacement versus pressure graph for membrane thickness of 10 um

The other diaphragm is design similar to the diaphragm above but it has different membrane's thickness, 5 um and same width, 500 um. Figure 23 below shows the membrane displacement versus the pressure applied to the diaphragm. The pressure is from 0 to 0.2 MPa. In this case, the dependence of displacement on pressure is not linear. The maximum displacement for the 5 um membrane with respect to maximum pressure, 0.2 MPa is 5.6 um.

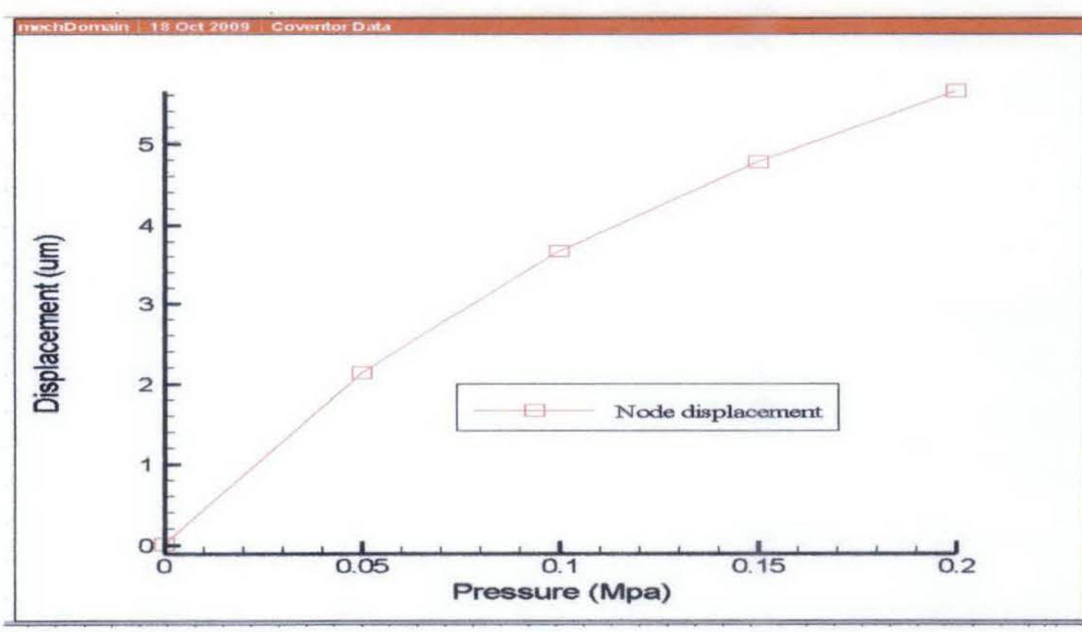

Figure 23 Displacement versus pressure graph for membrane thickness of 5 um

4.1.3 PZR sensor with modification

The modification done to the sensor is to add four additional piezoresistors parallel with each existing piezoresistors. The modification gives the pieoresistors more area to cover within the membrane. Figure 24 shows the placement of all the piezoresistors on the membrane. The figure is from top view of the membrane. Blue rectangle line is the diaphragm's membrane. Pink rectangular lines are the eight piezoresistors that implanted on the membrane. The small circle is at the middle of the membrane and also origin of the coordinate system in the design.

Figure 24 Piezoresistors placement within the diaphragm membrane

4.1.4 Output voltage for varied x edge offset and y edge offset

Figure 25 shows the piezoresistors' y and x edge offset. The vary analysis done vary the x edge offset range from 100 um to 0 by 20 um and y edge range from 100 um to 0 by 20 um. The analysis will push piezoresistors 1 and 3 towards the center of the diaphragm and push away piezoresistors 2 and 4 to the edge of the membrane.

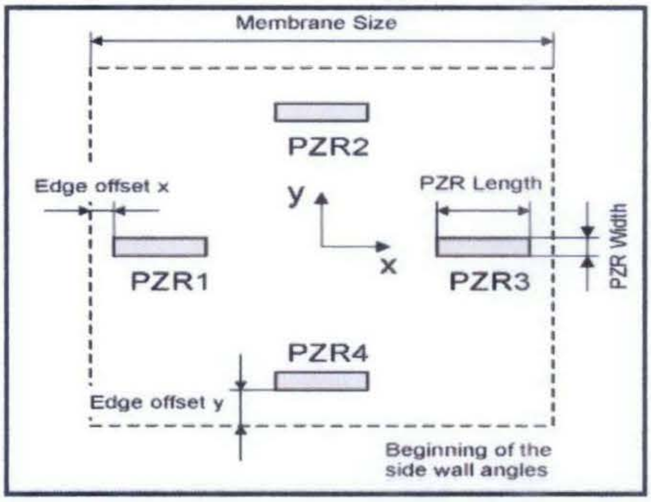

Figure 25 Piesoresistors offset edge x and offset edge y in the membrane

The analysis is done to both of the typical and the modified version of the sensor. Figure 26 below shows the output voltage for the typical sensor. The maximum voltage output is when the x edge is -20 um and y edge is 20 um. The highest output voltage obtained is 0.185 V. The lowest line in the graph is the value of the output voltage when y edge is 100 um. The highest line is when the y edge is 20 um.

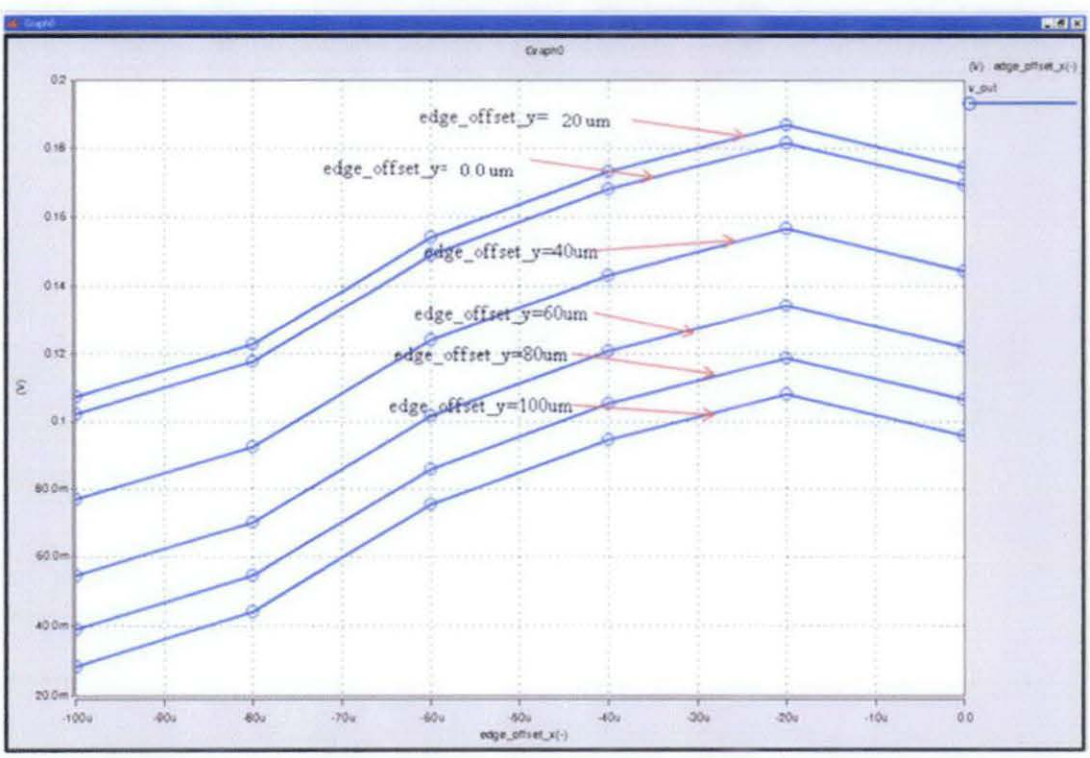

Figure 26 Output voltage versus y and x edge offset graph for typical sensor device with four piezoresistors.

For the modified sensor, the graph obtained from the analysis is similar. The maximum output when x edge offset between -40 um and -20 um, and the y edge offset is 20 um. The highest output voltage is 96 mV. Figure 27 below shows the graph of output voltage versus x edge offset and y edge offset for the modified sensor.

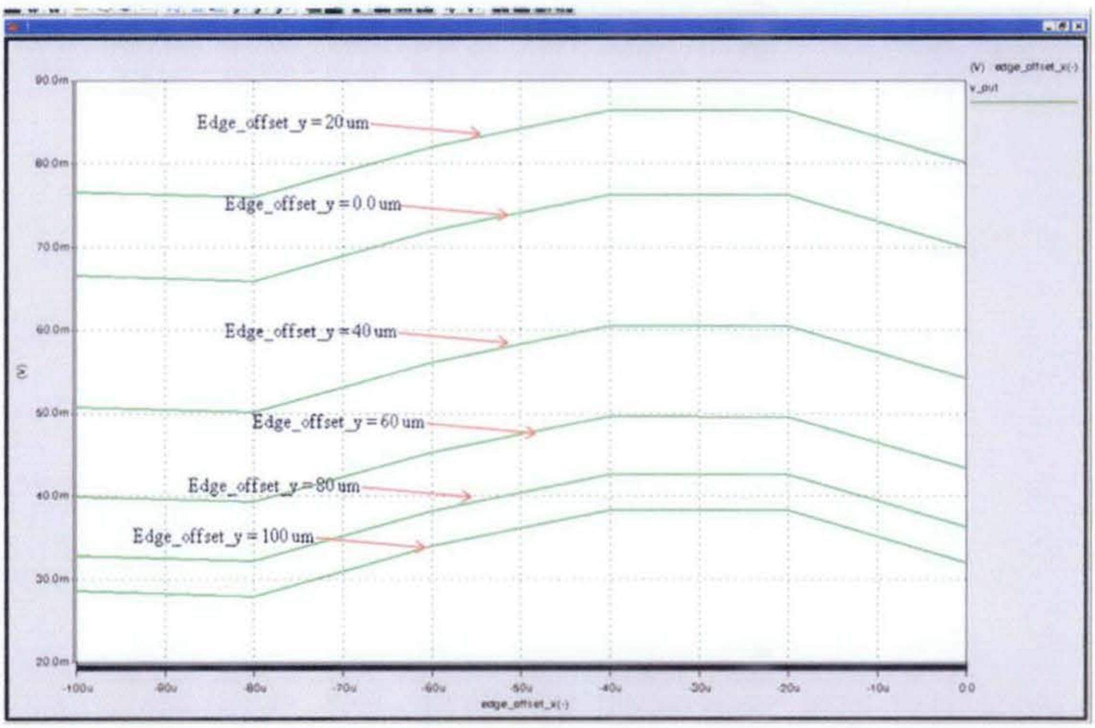

Figure 27 Output voltage versus x edge offset and y edge offset for the modified sensor device with eight piezoresistors

4.1.5 Output voltage for maximum pressure applied

Figure 28 below shows the output voltage for typical sensor when the range of 0 to 10 Mpa pressure is applied. The maximum voltage is 5.0 V at pressure of 5.0 MPa.

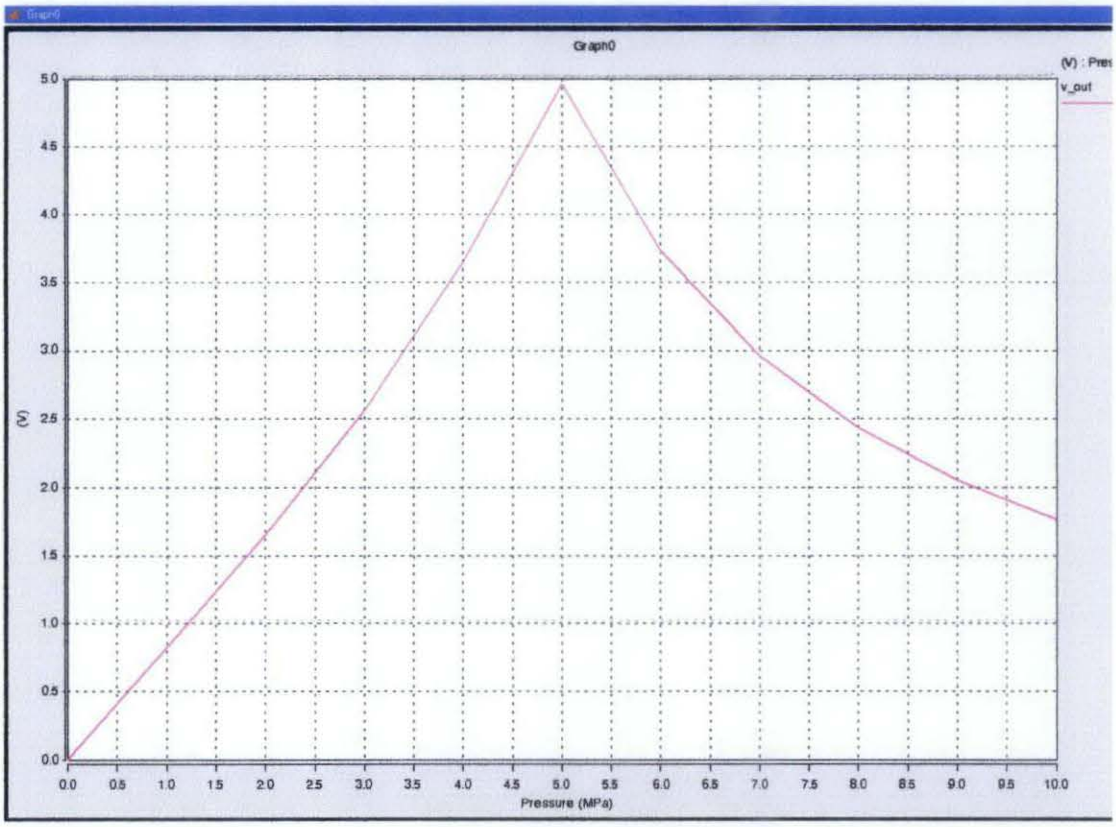

Figure 28   Output voltage versus pressure graph for typical sensor

Figure 29 shows the output voltage for modified pressure sensor when the range of 0 to 10 MPa pressure is applied. The maximum voltage is 5.0 V at pressure of 9.5 MPa

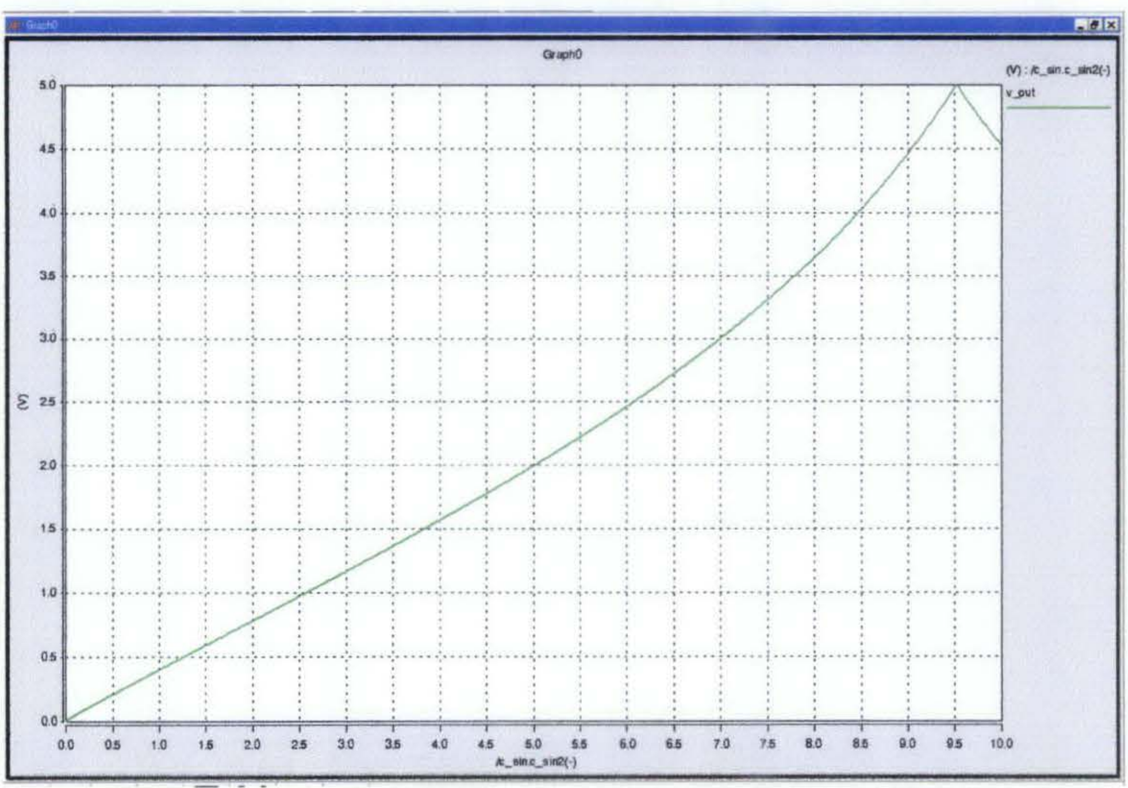

Figure 29   Output voltage versus pressure applied for modified sensor

4.2 Discussions

4.2.1 Membrane stress analysis

There are two different thickness for the membrane which are 5 um and 10 um. The displacement of the 5 um thickness membrane is higher than 10 um membrane. Range of pressure is 0.0 to 0.2 MPa. The 5 um membrane has displacement range from 0.0 to 5.6 um. The 10 um membrane has displacement range from 0.0 to 1.3 um. This show that when the thickness of the membrane increases, the membrane's displacement will lower. Lower membrane displacement means lower sensitivity to the pressure. But the higher membrane thickness will give linear relationship between the pressure and the displacement as we can see from the graphs.

4.2.2 Output voltage for typical and modified pressure sensor device

For x edge offset and y edge offset output voltage for typical and modified device, the highest voltage obtained by both devices is when y edge offset at 20 um and x edge offset is -20 um. Table 6 shows the maximum output voltage reach by both devices.

Table 6 Maximum output voltage of typical and modified sensor for x and y edge offset simulation

Pressure sensor	Maximum V_o (V)
Typical sensor	0.185
Modified sensor	96m

Table 7 shows the comparison on the output voltage when the pressure from 0 to maximum 10 MPa is applied.

Table 7 Output voltage comparison between typical and modified pressure sensor when 0 to 10 MPa pressure is applied

Pressure (MPa)	$V_{o\ typical}$	$V_{o\ modified}$
0	0.0	0.0
2	1.6	0.8
4	3.6	1.6
6	3.7	2.5
8	2.4	3.7
10	1.7	4.5

Table 8 shows the highest pressure that can be achieved for the maximum 5V output voltage. From the relationship, we can find the sensitivity for both typical and modified sensor.

Table 8 Maximum pressure for maximum 5V output voltage

Sensor	**Maximum voltage (V)**	**Maximum pressure (MPa)**	**Sensitivity (V/V.MPa)**
Typical	5.0	5.0	0.2
Modified	5.0	9.5	0.105

$$S = \frac{V_{out}}{PV_s} \tag{6}$$

Equation (6) is the general equation for pressure sensor sensitivity. V_{out} is the output voltage, V_s is the voltage source and P is the pressure with respect to output voltage.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The design of PZR pressure sensor using the Coventorware software was successfully undertake. The technical details of the design are also collected and documented. The modification of the existing PZR pressure sensor was successfully designed and simulated.

The modified and typical sensors give the similar output voltage pattern when the y and x offset edge are varied but the modified sensor gives lower maximum output voltage, 96 mV compare to the typical sensor output voltage of 0.185 V.

The modified sensor has larger pressure dynamic range compare to the typical sensor. The range is from 0 to 9.5 Mpa for the modified sensor and 0 to 5.0 Mpa for the typical pressure sensor. Typical pressure sensor has higher sensitivity but the modified sensor can be used to measure higher pressure than the typical sensor in when the piezoresistors properties is same between the two sensors.

5.2 Recommendation

The linearity between output voltage and the pressure applied is very important in designing a good pressure sensor. The modified sensor has nonlinear output which is not a very good output characteristic. It can be used to measure pressure but it must be coming with the electronic nonlinear compensation circuit to result a linear output voltage versus the pressure.

REFERENCES

[1] Coventor, Inc. 2006, *MEMS Designs and Analysis Tutorials, Volume 2.*

[2] Minhang Bao 2006, *Analysis and Design Principles of MEMS Devices.*

[3] <http://en.wikipedia.org/wiki/Pressure_sensor> retrieved date: 2rd April 2009

[4] <http://www.answers.com/topic/pressure-sensor> retrieved date: 3rd April 2009

[5] M. Elwenspoek and R. Wiegerink 2001, *Mechanical Microsensors*

[6] <http://www.answers.com/topic/piezoresistive-effect> retrieved date: 3rd April 2009

[7] Erik V Thomsen and Jacob Ritcher 2005, *Piezoresistive MEMS Devices: Theory and Applications*

[8] <http://www.zmd.de/wheatstone_bridge> retrieved date: 2rd March 2009

[9] Erik V Thomsen and Jacob Ritcher 2005, *Piezoresistive MEMS Devices: Theory and Applications.*

[10] Tsung-Lin Chou, Chen-Hung Chu, Kuo-Ning Chiang 2009, *Sensitivity analysis of packaging effect of silicon-based Piezoresistive pressure sensor.*

APPENDICES

APPENDIX A

KEY MILESTONE FOR FIRST SEMESTER

No.	Detail/ Week	1	2	3	4	5	6	7	8	9		10	11	12	13	14
1	Selection of Project Topic	■	■													
2	Preliminary Research Work		■	■	■											
3	Submission of Preliminary Report				●											
4	Seminar 1 (optional)					■	■	■	■	■						
5	Project Work					■	■	■	■	■	Mid-semester Break					
6	Submission of Progress Report								●							
7	Seminar 2 (compulsory)											■	■	■		
8	Project work continues											■	■	■		
9	Submission of Interim Report Final Draft														●	
10	Oral Presentation															●

● Suggested milestone

■ Process

APPENDIX B

KEY MILESTONE FOR SECEND SEMESTER

No.	Detail/ Week	1	2	3	4	5	6	7	8	9		10	11	12	13	14
1	Selection of Project Topic	■	■								Mid-semester Break					
2	Preliminary Research Work		■	■	■											
3	Submission of Preliminary Report				●											
4	Seminar 1 (optional)					■	■	■	■	■						
5	Project Work					■	■	■	■	■						
6	Submission of Progress Report								●							
7	Seminar 2 (compulsory)											■	■	■		
8	Project work continues											■	■	■		
9	Submission of Interim Report Final Draft														●	
10	Oral Presentation															●

● Suggested milestone

■ Process