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Comparative Study on Capacitive Pressure Sensor for Structural Health Monitoring Applications with Coventorware

Shivaleela.G[1], Dr. Praveen.J[2], Mahendra.HN[3], Nithya G[4]

[1]M.Tech Student, Dept. of Electronics and Communication Engineering, Alva's Institute of Engg. & Technology, Mijar, Moodbidri, Karnataka, India
[2]Dean Academic, Dept. of Electronics and communication Engineering, Alva's Institute of Engg. & Technology, Mijar, Moodbidri, Karnataka, India
[3]Assistant professor, Dept. of Electronics and Communication Engineering, Alva's Institute of Engg. & Technology, Mijar, Moodbidri, Karnataka, India
[4]JRF, Center for Nanomaterials & MEMS Center, Nitte Meenakshi Institute of Technology, yelahanka, Bangalore, Karnataka, India

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Abstract - *This paper is mainly focuses on the design and simulation of capacitive pressure sensor device for structural health monitoring applications using COVENTOWARE to obtain high sensitivity. MEMS based sensor has gained more attention in many fields such as automotive, industrial and biomedical applications. The capacitive pressure sensor has its advantage over MEMS based piezoresistive pressure sensors such as low power consumption, high sensitivity, IC compatibility, free from a temperature effects, etc. In this proposed work, the MEMS based capacitive pressure sensor using 1-spring, 4-springs and 9-springs has been designed having a square diaphragm of length 10,000µm × 10,000µm and thickness of 525µm using Finite Element Method (FEM) and the models are implemented using POLYMUMPs process flow. The design is analyzed for applied pressure of 1Pa on the square diaphragm. The simulation analysis of the capacitive pressure sensor is done using COVENTORWARE TURBO 2010.*

Key Words: **MEMS, Sensitivity, Capacitive pressure sensor, POLYMUMPs, COVENTORWARE**

1. INTRODUCTION

Micro-Electro Mechanical Systems (MEMS) is a technology that shows evident exponential growth from last two decades in terms of device miniaturization as its feature size varies in micrometer range. A MEMS device has a many applications in the field of automobiles, Bio-medicals, microphones, communication, smart systems, underground oil explorations etc. [1]. Due to the recent development in the micro-scale fabrication technology, MEMS based pressure sensors are being fictitious for the pressure levels ranges from ultra-low to extraordinarily high. There are different kinds of MEMS pressure sensor devices such as capacitive sensor, piezoelectric sensor, piezoresistive sensor etc. The piezoresistive type of sensors is considered as the first micro-machined sensor that yields to be mass created. The piezoresistive pressure sensors are extremely temperature sensitive and high power consumption; hence they are not used for higher temperature applications [3]. The capacitive pressure sensor is mainly gained attention for measuring of each absolute and differential pressure. They also have the advantage of high pressure sensitivity, low power consumption, less elementary noise floor and low temperature sensitivity. Additionally to those, it has high frequency permeability, compactness, low cost, ease to fabricate, smaller volume and high resolution [1].

In general, MEMS capacitive pressure sensors are constructed using two parallel plates during which the upper plate consists of a thin flexible membrane called as diaphragm and therefore the lower plate is fixed or vice versa. These two parallel plates are separated by a dielectric material such as vacuum or air. Once the external pressure is applied on the diaphragm membrane, it displaces the diaphragm thereby change in the gap between the two plates takes place, thus the capacitance is also changes [2]. The sensitivity of the capacitive sensors are directly depends upon the materials and structures used.

1.1 Literature Review

In [3], the author have been designed the Square diaphragm pressure sensor with length 1500µm ×1500µm and separation gap between the top and bottom diaphragm was 196µm was demonstrated. The thickness of the diaphragm was 4µm with a center boss structure of diameter 150µm and thickness of 1µm. The uniform pressure ranges from 10 kPa to 120 kPa had been applied on the diaphragm. The deflection sensitivities observed for the given range for normal diaphragm and bossed diaphragm was 2.02µm/kPa and 2.94µm/kPa. The design analysis is done using Comsol Multiphysics tool, that involves simulation results and performance analysis of MEMS based capacitive pressure sensor using springs with square diaphragm. In [6], the authors have designed and analyzed the perforated MEMS capacitive pressure sensor of length 50µm and gap between the plates is 3µm. The simulation is carried out using both COMSOL and Coventorware tools. The sensitivity of the model is increased with respect to increase in the applied pressure.

In the next section of the paper clearly gives the idea about a design and implementation of the capacitive pressure sensor for different structures followed by a simulation results and discussions in third section. The fourth section finally concludes the overall design of the capacitive pressure sensor.

2. DESIGN AND IMPLEMENTATION

There are many methods are used in order to predict the capacitive pressure sensor performance and to meet the desired specifications. The different structures of capacitive pressure sensors were designed, analyzed and simulated using COVENTORWARE TURBO tool. Here the sensitivity of the models is analyzed and compared the results to have better sensitivity among them.

2.1 Capacitive pressure sensor with 1-spring

The first structure is a capacitive pressure sensor with 1-spring attached which is designed and simulated in COVENTORWARE to obtain 3-D result. Before obtaining 3-D design, the layout has to be drawn which is shown in Fig – 1. The substrate of the structure is attached with a one-spring at each corner of the square diaphragm. The spring is used to overcome the contact problem faced between the two parallel plates when the large amount of pressure is applied on it. The structure is implemented using POLYMUMPs process flow. The design specifications required to construct the structure is listed in the table-1.

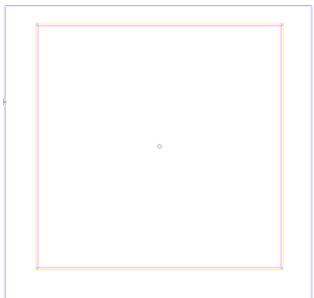

Fig-1: Layout of capacitive pressure sensor with 1-spring

Table -1: Design specifications for capacitive pressure sensor

Sl.NO	Layers	Materials	Size [µm]	Thickness [µm]
1	Top and Bottom plate	Silicon	10000×10000	525
2	Top and Bottom Electrode	Platinum	9500×9500	2
3	Air block (Gap b/w two plates)	Air	9500×9500	180
4	Spring blocks	Platinum	80	20

The model has top plate and bottom plate with the length of 10000×10000µm with thickness of 525µm. Similarly the top and bottom electrode plates with the length of 9500×9500µm and thickness of 2µm followed by air block with the length of 9500×9500µm and thickness of 180µm. The springs with length of 80µm and thickness of 20µm is integrated in between top and bottom plates. Once the 3-D model is designed, the next step is to generate a mesh for the obtained 3-D model. The meshed model divides the structure into finite number of element and finds the solution to the each element. The meshed model of the capacitive pressure sensor having 1-spring at each corner is shown in the Fig-2. Here the model can set names for different faces, hide layers, and define conductors. The structure is verified at applied pressure of 1pa.

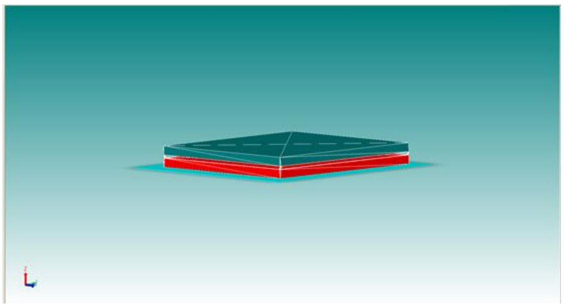

Fig-2: Meshed model of capacitive pressure sensor with 1-spring

2.2 Capacitive pressure sensor with 4-springs

The second structure is a capacitive pressure sensor with 4-springs attached at all the four edges of the square diaphragm. In order to improve the sensitivity of the sensor, the capacitive pressure sensor with 1-spring is slightly modified into capacitive sensor with 4-springs attached at all four edges as shown in the Fig-3. The sensor is designed with a specifications listed in table-1.

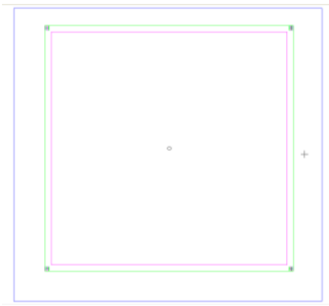

Fig-3: Layout of capacitive pressure sensor with 4-springs

The designed layout is further build in order to get the 3-D structure of the sensor and finally mesh is generated which is shown in the Fig-4.

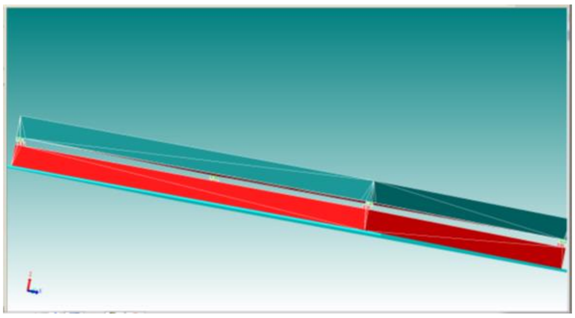

Fig-4: Meshed model of capacitive pressure sensor with 4-springs

The uniform pressure of 1pa is applied on the top plate whereas the bottom plate is fixed. The sensitivity of the devices can depends upon the materials used and the number of springs.

2.3 Capacitive pressure sensor with 9-springs

The capacitive pressure sensor with 4-springs model is further modified into 9-springs structure. Here each corner of the square diaphragm is attached by 9-spring elements. Hence there are total 36-spring elements are integrated. The layout design of capacitive pressure sensor is shown in Fig-5.

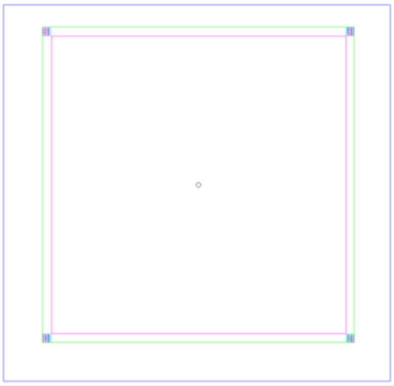

Fig-5: Layout of capacitive pressure sensor with 4-springs

The layout of the sensor is build to obtaine a 3-D structure. Once the 3-D model is designed with POLYMUMPs process, the next work is to generate a mesh for the structure. The meshed model of the capacitive pressure sensor with 9-springs is shown in Fig-6.

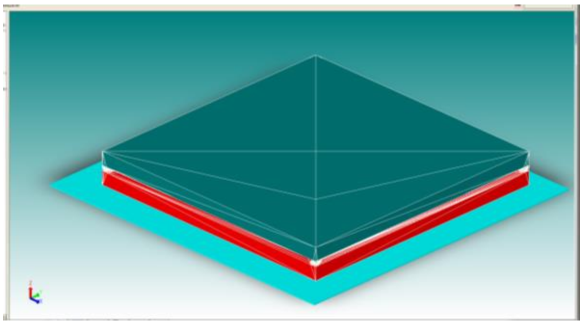

Fig-6: Meshed model of capacitive pressure sensor with 9-springs

The POLYMUMPs process flow can be constructed with sequence of stack materials foloowed by etching steps which is shown in Fig-7.

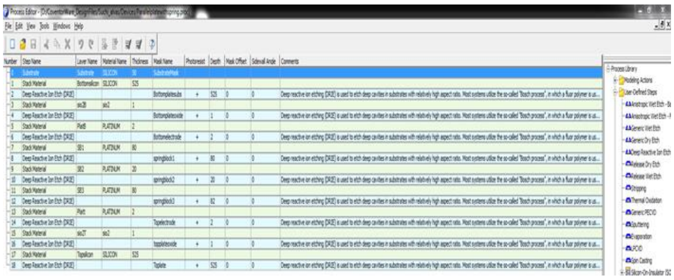

Fig-7: POLYMYMPs process flow

3. SIMULATION RESULTS AND DISCUSSIONS

The different structures of capacitive pressure sensor are designed and simulated using COVENTORWARE tool.

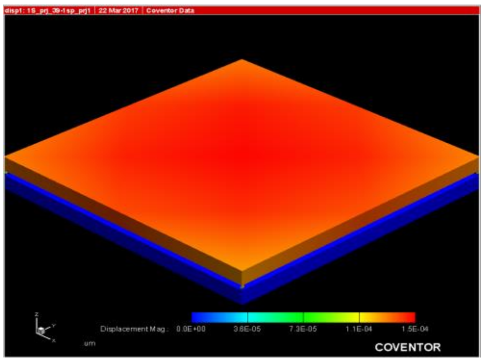

Fig-8: Simulation result of MEMMECH (Displacement) for capacitive pressure sensor with 1-spring

The Fig-8 shows the simulation result of displacement for capacitive pressure sensor with 1-spring attached. The maximum displacement of 1.456e-4µm is obtained for applied pressure of 1pa.

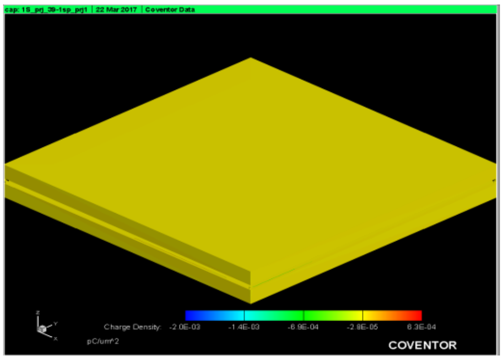

Fig-9: Simulation result of MEMELECTRO (capacitance) for capacitive pressure sensor with 1-spring

The Fig-9 shows the simulation result of capacitance for capacitive pressure sensor with 1-spring attached. The capacitance of 3.23e01pF is obtained for bias voltage of 5v.

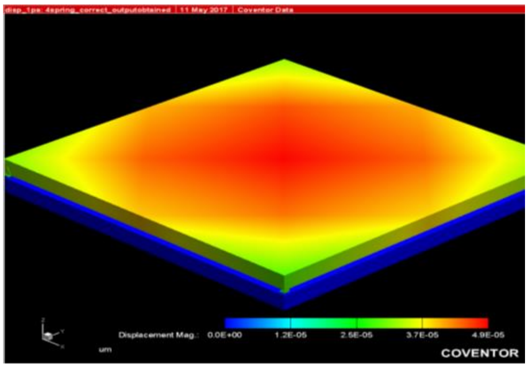

Fig-10: Simulation result of MEMMECH (Displacement) for capacitive pressure sensor with 4-springs

The Fig-10 shows the simulation result of displacement for capacitive pressure sensor with 4-springs attached. The maximum displacement of 4.909e-5µm is obtained for applied pressure of 1pa.

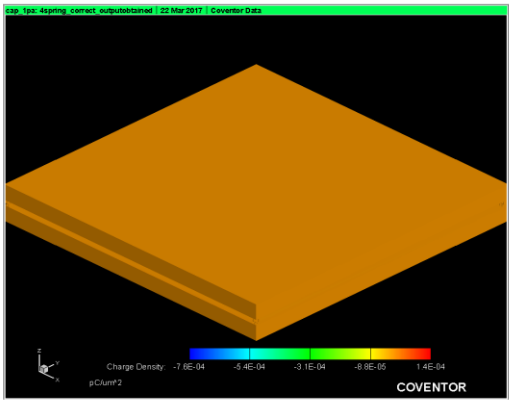

Fig-11: Simulation result of MEMELECTRO (capacitance) for capacitive pressure sensor with 4-springs

The Fig-11 shows the simulation result of capacitance for capacitive pressure sensor with 4-springs attached. The capacitance of 7.879e0pF is obtained for bias voltage of 5v. The sensitivity of the capacitive sensor with 4-springs can be increased by 4.649pF as compared to capacitive sensor with 1-spring.

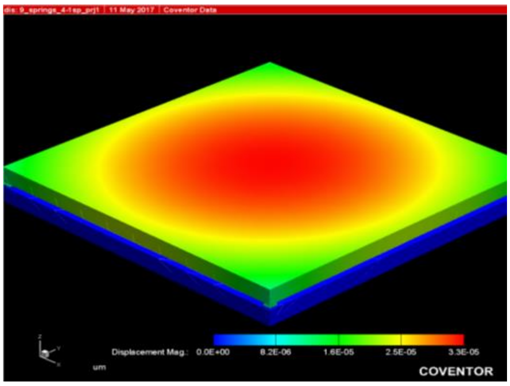

Fig-12: Simulation result of MEMMECH (Displacement) for capacitive pressure sensor with 9-springs

The Fig-12 shows the simulation result of displacement for capacitive pressure sensor with 9-springs attached. The maximum displacement of 3.288e-5µm is obtained for applied pressure of 1pa. The MEMELECTRO or capacitance of 1.013e0pF is obtained for bias voltage of 5v.
The capacitance in a parallel plate capacitor is given by,

$$C = \varepsilon_o A / d \quad \text{...... (1)}$$

Where ε_o = permittivity of the medium.
A= Area of the two plates.
d = gap between the two plates.

From equation (1) we can conclude that, as the distance between the two plates decreases the capacitance increases. That means, when the displacement of the structure is less, the distance between the two plates is more and capacitance is less. The sensitivity of the device can be defined as the rate of change of capacitance with respect to the change in applied pressure. The table-2 gives the comparison of displacement, capacitance and sensitivity of all the proposed structures of capacitive pressure sensor at applied pressure of 1pa.

Table -2: Comparison of different parameters for proposed structures of capacitive pressure sensor

Structure	Displacement (µm)	Capacitance (pF)	Sensitivity (pF)
Capacitive pressure sensor with 1-spring	1.456e-4	3.23e01	3.23e01
Capacitive pressure sensor with 4-springs	4.909e-5	7.879e0	7.879e0
Capacitive pressure sensor with 9-springs	3.288e-5	1.013e0	1.013e0

By comparing the above results, it can be clearly seen that the capacitance pressure sensor with 9-springs has best sensitivity of 1.013e0pF at applied pressure of 1Pa as compared to other two structures.

4. CONCLUSIONS

In this proposed paper, MEMS based capacitive pressure sensor is designed, simulated and analysed for 1-spring, 4-spring and 9-springs capacitive pressure sensor using COVENTORWARE TURBO tool. By observing the above simulation results and discussions we noticed that the 9-springs capacitive pressure sensor model achieves a good and high sensitivity of 1.010e0pF/pa with displacement of 3.288e-5 µm at applied pressure of 1pa as compared to 1-spring and 4-spring capacitive pressure sensors. Thus 9-springs capacitive sensors are much preferred for high sensitivity applications. The sensitivity of the sensor device can be improved by decreasing the gap between two plates of the diaphragm and one can also look at the feasibility of fabricating the device. The capacitance sensitivity of the design increases as the number of springs increases. Hence the proposed capacitive pressure sensors can be used in many health monitoring applications in the field of artificial intelligence systems and in wearable health care devices like blood pressure sensors, Electro cardiogram sensor etc.in which the sensor can achieve very high sensitivity.

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