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DESIGN AND STUDY ON COMB BASED CAPACITIVE PRESSURE SENSOR USING COMSOL MULTIPHYSICS

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ABSTRACT

This Project is mainly direct toward the design of comb based capacitive pressure sensor and the measuring of the external environmental pressure using COMSOL Multi-physics 5.5. It includes the design and development possibilities to enlarge the sensor sensitivity by enhancing the device dimension and including different types of materials in the design. The parameters such as displacement, electrical potential, and capacitance with variation in temperature and pressure are analyzed and studied. Comb-based capacitive pressure sensors compute pressure by detecting variation in electrical capacitance given by the movement of a diaphragm. The simulation is executed using COMSOL Multi-physics 5.5 software. The capacitive pressure sensor is created on a CMOS chip. The suggested device contains a square-shaped sensing capacitor, a reference capacitor, and a readout circuit, to detect capacitance in different environmental pressures.

Keywords: COMSOL Multi-physics 5.5, CMOS chips Sensing capacitor, readout circuit.

1. INTRODUCTION

Sensors are universal, and it's being implanted in human bodies, aircraft, mobile phones, automobiles, broadcasting, and other infinite operations similar as safety affiliated areas, public, and health security systems, smart systems, monitoring operations, and biomedical systems, submarines, etc. Sensors are devices that give respond to external environmental phenomena such as light, sound, pressure, electromagnetic flux, electric fields, moisture, magnetic field, etc. Among the sensors, capacitive pressure sensors are highly sensitive when compared with other sensors like piezo-resistive and piezoelectric sensors. Capacitive pressure sensor gives rapid response to change in pressure with low noise as it can withstand a lot of vibrations [1]. COMSOL Multi-physics is a multiplatform for finite element analysis, solver, and Multi-physics simulation software. We can simulate electromagnetics, structural mechanics, acoustics, fluid flow, and heat transfer phenomena in a single software environment. For designing a capacitive pressure sensor, two parallel conducting plates specifically a silicon layer is used which are separated by a gap [2]. Here air acts as the dielectric one of the conducting plates is fixed and another one is movable. When pressure is applied the movable layer gets displaced. This changes the distance between the conducting layers. This results in the change of capacitance. we can similarly detect the exerted pressure by the environment and gives a capacitance change. This can be simulated using COMSOL Multi-physics software. For adding physics setting to the model, these include the pressure forces acting on the sensor the applied voltages, and other appropriate domain and boundary conditions. A linear elastic material node is added to the electro-mechanics physics interface. From the physics ribbon, primarily domains are selected, electro-mechanics: linear elastic material is selected as per the selections created earlier. The assigned linear elastic selection in linear elastic encompasses all domains except for the vacuum cavity. Afterward, the symmetry boundary condition is applied from the physics ribbon, we select the boundary condition and the structural condition, and appropriate symmetry choices are determined earlier.

2. METHODOLOGY

COMSOL Multi-physics is a user-friendly program that lets you expand physics-primarily based fashions and simulates them. Scientists and engineers use the program to simulate diverse designs and techniques in all disciplines of engineering, manufacturing, and medical areas. It is straightforward to analyze, anticipate, and optimize real-global designs with the COMSOL Multi-physics software program. COMSOL Multi-physics lets in to simulate any engineering or Multi-physics tool or process. The structural mesh is built up from the mesh tool, and to edit the default physics the edit is induced in mesh sequence. The tetrahedral is chosen rather than the default, the selected geometry is used to call for mapped swept mesh. The diaphragm is firmly attached to the moving silicon plate of the sensor. The sensitivity of the sensor can be increased by reducing the thickness of the silicon plate so that minute variations can respond to the capacitive pressure sensor. The thickness of the diaphragm and thickness of the periphery in a comb plate is taken as 1µm. The diaphragm is designed in different shapes such as squares and circular to study the performance. In the COMSOL Multi-physics software, the meshing utilizes four different geometry element types hexahedra (bricks), tetrahedral (tets), triangular prisms (prisms), and pyramids. The appropriate mesh is chosen for the key elements for obtaining the accurate result for a Finite Element Analysis (FEA). The meshing is a dimensionless quantity between 0 and 1, where 1 goes for a perfectly regular element, and 0 represents the degenerated element. In one software program environment, COMSOL Multi-physics can simulate electromagnetics, structural mechanics, acoustics, fluid flow, warmness transport, and chemical response phenomena.

2.1 Course of action

It is possible to simulate a capacitive pressure sensor both with and without temperature stresses induced by the packaging[4]. The geometrical design of the sensor is similar to the two combs that are placed in such a way that the tooth of the combs are faces each other. The sensor comprises a thin chamber sealed in a high vacuum, acting as the dielectric in a capacitor. It is separated from the environmental air by a thin membrane, which is electrically isolated from the grounded membrane of the sensor[5].

2.2 Design and model

For convenience, the geometry is imported from an external file. To do this from the home tab, select impound rt, and choose the desired file. To design and optimize the capacitive pressure sensor with high resolution, both sensor designs were simulated using COMSOL Multi-physics ver. 4.3 software. A narrow diaphragm is kept at a constant 1.0 Volt voltage. 3C-SiC, silicon nitride (SiN), and Si layers make up the MEMS capacitive pressure sensor [6]. The structure was started with a diaphragm of 3C-SiC, an insulator of SiN, and a substrate of Si. A Si substrate forms a hollow with a thickness of 2.2 m in the 3C-SiC diaphragm. The displacement inside the cavity is inversely proportional to the external pressure suspended over a vacuum reference cavity. To prevent conductor losses from the metal connection between the diaphragm and the substrate, an insulating layer of SiN is applied. The diaphragm deflects under a variation in the external environmental pressure contacting its substrate. The distance between the diaphragm and fixed silicon plate exhibits an increase in the device capacitance value[4]. At a certain extreme pressure, the diaphragm starts to touch the fixed plate. Due to the change of contacting area, the capacitance increases with increasing pressures. Any variation in parameters a d the properties of the device such as diaphragm thickness, insulator, and a sealed cavity has a significant impact on the resulting deflection performance that can be directed by simulating the capacitive pressure sensors to perform accurate and reliable output. The sensor is designed in such a way that two comb fringes faced each other. The lower portion of the plate is fixed and the upper plate is movable. The area of contact gets increased in this design and by decreasing the thickness of the diaphragm applied pressure can be measured.

3. MODELING AND ANALYSIS

This is a unique capacitive pressure sensor structure that resembles t comb having fingers like extensions that measure the capacitance accurately and precisely. The effort is given during the design of the diaphragm by selecting the thickness and shape of the diaphragm. The thickness of the diaphragm is made thinner to calculate the sensitivity correctly. In this design, the diaphragm is isolated from the moving plate by a small cylindrical coupling to increase the pressure sensitivity. Comb based capacitive pressure sensor can be extensively used for research. They consume low power and easy fabrication of the sensor design [1]. The 2-D design of the comb-based capacitive pressure sensor is given in figure 3.1 (a). Each fringe pair acts as a capacitor and thereby exhibits capacitance according to the displacement change. And the 3-D design of the capacitive pressure sensor design is given in figure 3.1 (b). The sensor dimensions are given in figure 3.2.

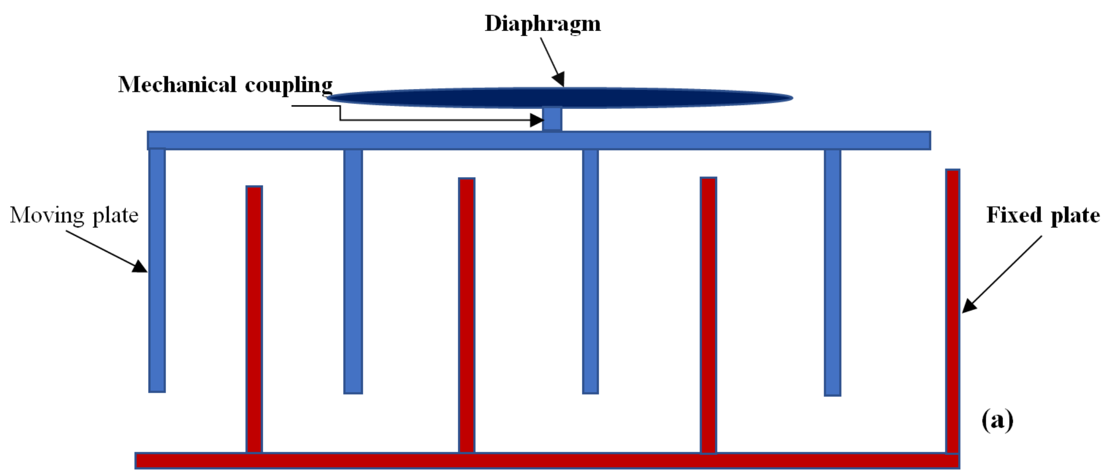

Figure 1: 2-D Cross-section view of comb based capcitive pressure sensor

To simplify the configuration of the physical interface, and to aid with post-processing of the results. It is convenient to now define some coupling components and some geometry selections. Two coupling components have been added; an average operator, which operates on the boundary, corresponding to the underside of the silicon membrane. Here, we have the silicon membrane, the cavity, and the silicon die[6]. The underside of the silicon membrane and an integration operator, which integrates one point, this point is where we expect the maximum deflection is right in the center of the underneath, underside

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of the membrane. A collection of boundaries that make up the YZ symmetry plane and the collection of boundaries that make up the XY symmetry plane, will be used when specifying the symmetry boundary conditions in the physics interface. Explicit selection has been used to select the cavity between the silicon membrane and the grounded body of the sensor. A second explicit selection has been used to select all domains and then a different operator has been used to remove the cavity domain, leaving a selection that is everything except for the cavity[8]. This will be useful when assigning the linear elastic materials properties later. The selection is taken in places where the deflection responses are about to analyze the environmental pressure fluctuations. The fringes in a comb-like designed sensor increase the sensitivity by increasing the capacitance responses thereby the pressure is detected even if minute pressure variation is reported.

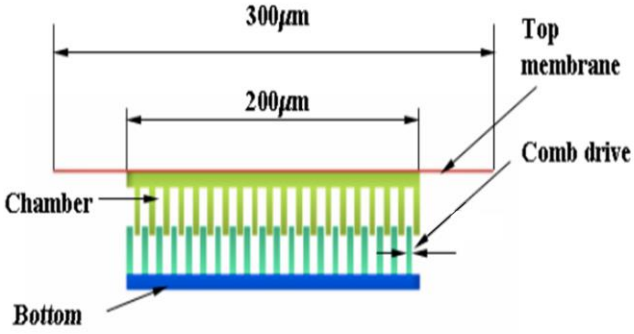

Figure 2: Dimensions

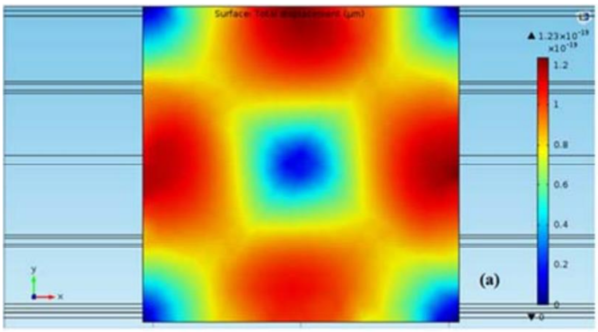

Figure 3: Displacement profile in square membrane

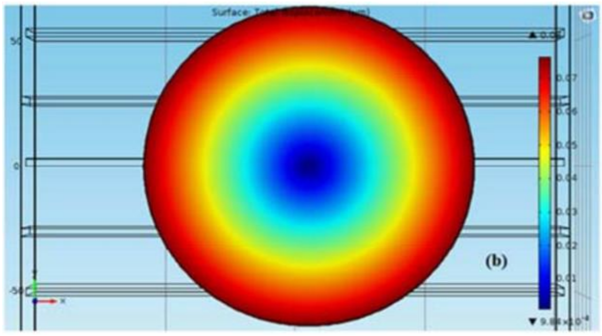

Figure 4: Displacement profile in a circular membrane

The simulation is observed and the diagram has maximum variation in the center of the diaphragm[11]. And the edges of the diaphragm. In the circular diaphragm, the highest deviation occurs on the radius point of the diaphragm. The figure 3 represents the displacement profile in square membrane. And displacement profile in a circular membrane is represented in figure 4.

To add a prescribed displacement to a point on the model, the points are chosen from the physics ribbon, and electro-mechanics: prescribed displacement. This displacement is applied to the center point of the silicon membrane, where maximum deflections occur. In this geometry, the point comes in the corner of the structure. The reason to apply the boundary condition is to constrain the position of the geometry on the Z-axis and this will prevent COMSOL Multi-physics from searching the solution in which the whole geometry is translated arbitrarily up or down the Z-axis. So, to do that prescribe in the Z direction is selected and a default 0 has opted. Thus, the structure is pinned in the Z coordinates, and although it deflects. Further a boundary load condition is used to apply the pressure to the device. The capacitance changes are more susceptible. Because of the thickness and design of the sensor, the impurity added to the silicon enhances the capacitance of the capacitive-based pressure sensor. Instead of pure silicon impurities are added, so that the free electrons are created. And the conductivity of the semiconductor is improved. The small change in the external environmental pressure will affect the capacitance of the silicon capacitor. The resolution of the system is increased by adding impurities to the silicon and decreasing the thickness of the diaphragm and the fringes.

Based on the three-dimensional design of the comb-based capacitive pressure sensor simulations done in the COMSOL tool and the graphs were obtained from the tool directly. The sensor is made more sensitive to the environmental pressure by reducing the gap between the membranes. The height of the fringes is increased so that the capacitance of the sensor design seems to be enhanced. Membrane thickness is also reduced to make it more sensitive.

4. RESULTS AND DISCUSSION

The capacitive pressure sensor is designed using **COMSOL Multi-physics** and thereby measures the environmental pressure by the change in capacitance of the comb-based model of the capacitive pressure sensor. As the displacement increases the capacitance of the sensor decreases. The comb-based model of the capacitive pressure sensor is designed as a highly sensitive response to the external environmental pressure of the sensor. The capacitance of the silicon is made more effective by reducing the thickness. The length of the sensor diaphragm is also enlarged to increase the sensitivity and resolution of the sensor.

The variation in the sensitivity of the device for different diaphragm thicknesses is also simulated thoroughly. After the simulation, it is observed that found that with a decrease in the thickness of the diaphragm, the sensitivity of the sensor increases. Similarly, with an increase in the area of the cross-section, the sensitivity also increases.

The displacement of the diaphragm with the applied external pressure:

Table 1: Final simulated parameters

Applied Pressure (MPa)	Displacement (μm)	Capacitance (F)
0	0	2.8333×10^{-13}
10	1.4357	2.8335×10^{-13}
20	2.8459	2.8339×10^{-13}
30	4.2293	2.8345×10^{-13}
40	5.5713	2.8352×10^{-13}
50	6.8647	2.8362×10^{-13}
60	8.105	2.8372×10^{-13}
70	9.2904	2.8384×10^{-13}
80	10.421	2.8397×10^{-13}
90	11.498	2.841×10^{-13}
100	12.325	2.8425×10^{-13}

The ultimate objective is to increase the efficiency of the capacitive pressure sensor. The rate of change of the diaphragm response is more as compared to the normal capacitive pressure sensor. The comb-based model design enhances the sensitivity of the susceptibility to external ambient pressure.

5. CONCLUSION

Sensors are used widely in all applications for sensing environmental variations while operating several performances. In all the sensors capacitive pressure sensor performs more efficiently. By designing comb based model of capacitive pressure sensor its efficiency is enhanced. The change in pressure can be measured more effectively. The resolution of the capacitive pressure sensor is increased and the minimum variation in the external environmental pressure can be measured using this highly sensitive design of the comb-based capacitive pressure sensor.

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