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Comparative Study on Mechanical Throughput of MEMS Based Capacitive Pressure Sensor

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ABSTRACT: The world is becoming more digital, there is a peak in the demand for new and developing technologies. Many systems and their devices are available on the market to meet the specific criteria, and one such advancing technology to create devices is the micro electromechanical system (MEMS). Miniature mechanical and electro-mechanical elements combined on the same chip utilizing microfabrication processes constitute the most basic definition of MEMS technology. It has several advantages, including inexpensive cost, lightweight, accurate measurement in confined spaces, and low power consumption.

Micro-Electro-Mechanical Systems, or MEMS for short, are a rapidly expanding branch of technology that integrates mechanical and electrical components on a single chip. The primary goal is to model a capacitive pressure sensor using finite elements. The performance characteristics of the sensor, such as stress, deflection, displacement, capacitance, and sensitivity, have been studied. Utilizing COMSOL, the pressure sensor design, simulation, and performance analysis are completed. It is projected that the MEMS pressure sensor will work more effectively in many applications and cost effective.

KEYWORDS: MEMS, Capacitive Pressure Sensor, Stiffness, Displacement.

I. INTRODUCTION

Micro Electro Mechanical Systems, or MEMS for short, are tiny systems with combined mechanical and electrical components. Prior to the development of micromachining technology, every sensor was big. With the development of Micro Electro Mechanical Systems (MEMS) technology in the late 1960s and early 1970s, the shrinking of sensors began. MEMS can be as big as several millimetres or as little as one micrometre in size. Pressure sensors made by Micro Electro Mechanical Systems (MEMS) are essential in both the industrial and commercial sectors. Mechanical components, sensors, actuators, and electronics are all combined to form MEMS.

Day by day the pressure sensor application in medical, aerospace, automobile, industrial and commercial application has drastically increased. Nowadays it has become common for scientist and engineers working in MEMS area to simulate the structure using MEMS simulation software like COMSOL before actual fabrication. The main intension of the software is to optimize the structure dimensions to get required output which saves time and money during fabrication. Before simulation, the beginners should have an idea about required dimensions. One can perform the modal with COMSOL by computing parameters on MEMS structures, such as stress, strain, reaction forces, etc. The most crucial element is how parameters rely on the structure's dimensions.

The Capacitive element is straightforward and durable. Capacitive sensors can function in a wide variety of temperatures and are particularly tolerant of temporary overpressure situations. From vacuum (2.5 mbar or 250 Pa) to high pressure up to about 70 MPa, they can be used to measure a wide range of pressure. They are low power by nature because no DC current travels through the capacitor. Low hysteresis and excellent measurement reproducibility are characteristics of capacitive sensors. They are also less sensitive to temperature. In the case of MEMS devices, the response time is on the order of milliseconds and even quicker.

Two parallel plates make up a capacitive pressure sensor, and a change in capacitance was obtained by adjusting the distance between the plates due to the deformation of the film electrode under pressure. A thin membrane or diaphragm is used as a capacitance and pressure sensing component. Most of the sculpture was constructed using diaphragm constructions that are square, rectangular, or round. The centre of the diaphragm exhibits the greatest deflection for built-in edges.

In many different places, such as automobile tyres, human body parts, and jet engines, capacitive pressure sensors are frequently employed to monitor the pressure of gases or liquids. Measurements of absolute, gauge, relative, or differential pressure can be made using capacitive sensors. Compared to other types of pressure sensors, capacitive pressure sensors have several benefits.

II. CAPACITIVE PRESSURE SENSOR

A. PARALLEL PLATE CAPACITOR

Parallel plate capacitive transduction is used by capacitive pressure sensors. Between two plates, the pressure being applied causes a change in capacitance. Regarding a fixed electrode, the diaphragm is used as one moveable electrode. A potential difference created by the charge can be maintained with external voltage. A capacitive pressure sensor detects changes in electrostatic capacitance to determine pressure. The diaphragm's deflection causes a change in capacitance.

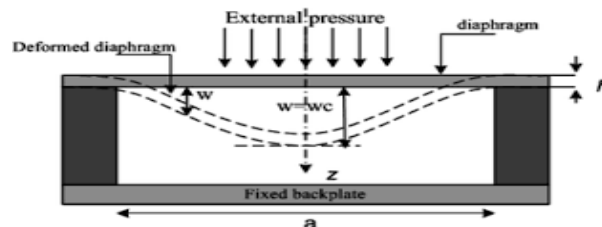


Fig. 2.1 Basic operating principle of Capacitive pressure sensor.

B. COMB DRIVE

Despite being the most popular electrostatic actuator and sensor in the MEMS sector, the comb drive has a number of design flaws [1]. The amount of force that can be applied to the comb fingers and its sensitivity to capacitance changes are both restricted by positioning the comb fingers with a significant gap. Actuators with comb drives move laterally and vertically. Applications requiring compact device size, low drive voltage, and large vertical displacement benefit most from vertical comb drive actuation [2]. Comb drives are the most prevalent capacitance-based sensors and actuators [3].

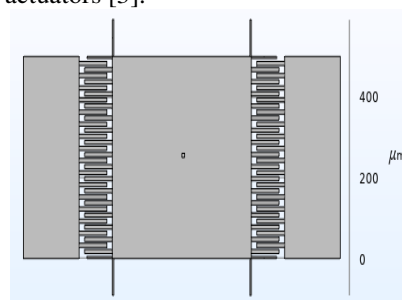


Fig 2.2 Comb Drive



III. MATHEMATICAL MODELLING

1. Parallel Plate Capacitance

The Capacitance of fixed parallel plate capacitor is given in equation 1.

$$C = \frac{\epsilon A}{d} \dots\dots\dots (1)$$

Where ϵ = permittivity of the material between the parallel plates (free plate permittivity 8.85×10^{-12} F/m)

A = Plate area

d = Distance between top and bottom

2. Stiffness

The Stiffness of the spring is given by equation 2.

$$K = \frac{Eb^3d}{l^3} \dots\dots\dots (2)$$

where E = Young's Modulus

b = Width of Spring

d = Depth of Spring

l = Length of Spring

3. Stiffness of Springs in Series and Parallel

Stiffness of springs connected in series in given by equation 3.

$$\frac{1}{K_{series}} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + \frac{1}{k_4} + \dots\dots\dots (3)$$

Stiffness of springs connected in parallel in given by equation 4.

$$K_{parallel} = K_1 + K_2 + K_3 + \dots\dots\dots (4)$$

4. Displacement

Displacement of the spring is given by equation 5.

$$d = \frac{F}{K} \dots\dots\dots (5)$$

Value of Stiffness, K = 26785.7142

Displacement, d = 37.33µm

IV. DESIGN PARAMETER OF PARALLEL PLATE AND COMB DRIVE CAPACITIVE PRESSURE SENSOR

A device's design is influenced by several factors, including its shape, material, and structure. To achieve the desired device specification, all parameters must be optimised. The choice of the substrate material and its characteristics formed the basis of the design.

Table 4.1: Dimensional Details of Parallel Plate Capacitive Pressure Sensor

DESCRIPTION	VALUE
Diaphragm Length	1000 μm
Diaphragm Width	1000 μm
Diaphragm Depth	10 μm
Suspension Area	70 μm x 5 μm

Table 4.2: Dimensional Details of Comb Drive Parallel Plate Capacitive Pressure Sensor

DESCRIPTION	VALUE
Proof Mass Area	500 μm x 500 μm
Device Thickness	10 μm
Comb Length	100 μm
Comb Width	10 μm
Distance between Comb Fingers	15 μm
Fixed Comb Anchor Area	200 μm x 500 μm
Suspension Length	91 μm
Suspension Width	5 μm

V. SIMULATION AND RESULT

The Single Spring, Double Spring, and Quadruple Spring Parallel Plate Capacitive Pressure Sensor are used in this instance. The single spring parallel plate capacitive pressure sensor shown below has a centre part of material that has been maximally displaced, as indicated by the red colour. As shown, the displacement is greatest in the middle.

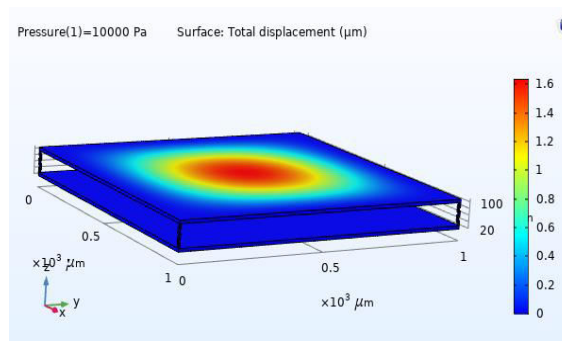


Fig. 5.1 Total displacement of a single spring parallel plate capacitive pressure sensor

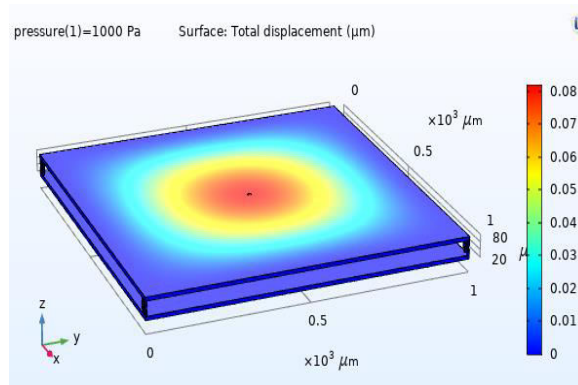


Fig. 5.2 Total displacement of a double spring parallel plate capacitive pressure sensor

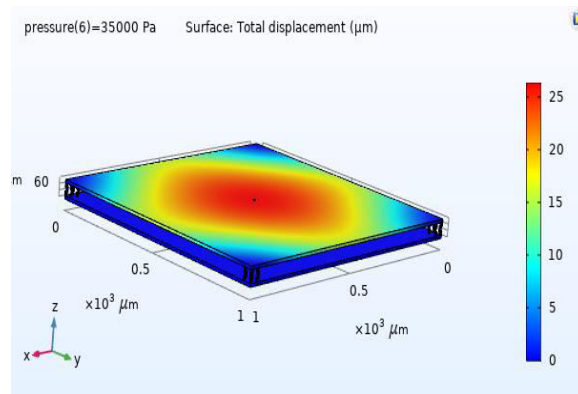


Fig. 5.3 Total displacement of Quadruple spring capacitive pressure sensor

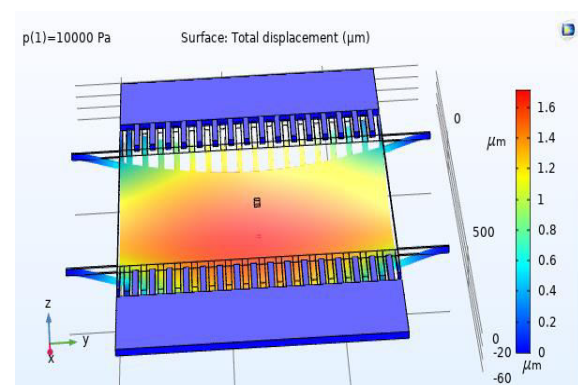


Fig. 5.4 Total displacement of comb drive parallel plate capacitive pressure sensor

The linear relationship between pressure and displacement is depicted in figure 5. It is clear from figure 5 that displacement varies with pressure.

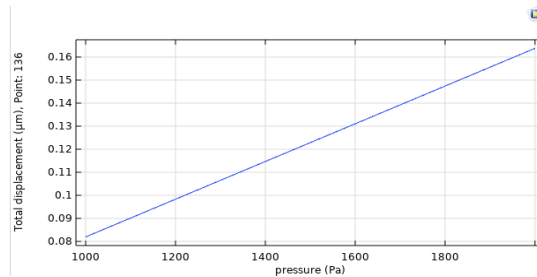


Fig. 5.5 Graph of Displacement (μm) vs Pressure (Pa)

VI. CONCLUSION

In this paper the author has designed and simulated MEMS Capacitive Pressure Sensor for single spring, double spring, quadruple spring, and comb drive. The paper gives the details of the mathematical analysis of the stiffness and displacement. Based on the simulation result, it has been observed that there is a linear increase in the displacement of the parallel plate capacitor as pressure increases.

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