# Simulation of High Sensitivity MEMS Capacitive Pressure Sensor with Small Size and Clamped Square Diaphragm

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**ABSTRACT:**
In this paper a novel MEMS capacitive pressure sensor with small size and high sensitivity is presented. This sensor has the separated clamped square diaphragm and movable plate. The diaphragm material is polysilicon. The movable and fixed plates are gold and the substrate is pyrex glass. The mechanical coupling is $Si_3N_4$. In capacitive sensor the sensitivity is proportional to deflection and capacitance changes with pressure for this reason with this design is improved the sensitivity with small size. The size of this sensor is 350×350 ($\mu m^2$) and the thickness of diaphragm is 2µm with $1\mu$ air gap. This structure is designed by intellisuite software. In this simulation are shown the compare of polysilicon and polyimide diaphragms. Because in many previous works polysilicon and polyimide are used. In this MEMS capacitive pressure sensor the sensor sensitivity, diaphragm mechanical sensitivity for polysilicon(stress=100Mpa) diaphragm are 0.0074 (Pf/mmHg), 0.0042 ($\mu m$/mmHg), respectively and for polysilicon(stress=20Mpa) diaphragm are 0.0469(Pf/mmHg), 0.011 $\mu m$/mmHg, respectively and polyimide diaphragm are 0.0226(pF/mmHg), 0.0091 ($\mu m$/mmHg), respectively. According to the simulating results for low pressure, the structure with polysilicon diaphragm has more change of the displacement and capacitance, this lead to high sensitivity than other diaphragms.

**KEYWORDS:** MEMS capacitive pressure sensor, small size, high sensitivity, mechanical coupling, polyimide, polysilicon, movable plate, linearity response, clamped diaphragm, intellieuite, low pressure.

## 1. INTRODUCTION

In the past years MEMS capacitive pressure sensors have received increasing attention due to several advantages such as: low temperature sensitivity, good DC response and stability, low power consumption. The capacitive pressure sensor is used for advanced industrial, military and automotive and medical applications, control systems and process control.

During these years many different designs have been proposed for increasing sensitivity based on the reduction of diaphragm stiffness with different structures and different materials. But in general, the capacitive pressure sensors contains a thin flexible plate (diaphragm) for pressure sensing element and capacitive sensing element as one of the electrodes and the electrode is fixed plate that separated each other by a small air gap [1-3].

In MEMS capacitive pressure sensor when the external pressure is applied on diaphragm, the diaphragm is deflected and changed the air gap between two plates, this lead to change capacitance that with the appropriate microelectronic circuit is used to convert the capacitance change of capacitance to a useful voltage signal [4].

Generally the pressure sensitivity of capacitive pressure sensor is increased by reducing diaphragm thickness and air gap, increasing diaphragm size. But some of these elements are limited in different devices under different conditions. This paper offers a new design for increasing sensitivity and reduces sensor size.

## 2. SENSOR STRUCTURE

In pressure sensors is determined by the deflection of the diaphragm due to applied pressure. Fig.1 shows a new design for MEMS capacitive pressure sensor that consist of the three plates, a diaphragm and a movable plate that decoupled to diaphragm with mechanical coupling and a fixed plate.

In this design the diaphragm, sensing pressure, fixed and movable plate are for sensing capacitance. The size of this sensor is $350\times350\mu m^2$, the thickness of diaphragm is $2\mu m$ and the height of air gap is about

$1\mu m$. Also the size of mechanical coupling is small enough to ignoring the effect on the diaphragm deflection. In this design the clamped square diaphragm is used, also the edges of movable plate are free.

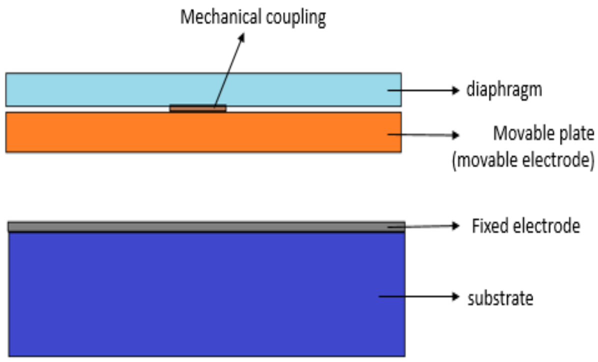



**Fig. 2** cross section view of pressure sensor

This structure consist of gold movable and fixed plate, $Si_3N_4$ mechanical coupling and pyrex glass substrate. The use of $Si_3N_4$ for mechanical coupling leads to diaphragm and movable plate mechanically are decoupled but electrically are isolated.

In many previous works polysilicon and polyimide were used for diaphragm materials. Polyimide properties are electrical isolation thermal stability, high flexibility and stability for low pressure measurement. The polysilicon properties are the polyimide and polysilicon compared each other with this paper simulation. Polysilicon and polyimide properties listed in table 1 have been used for simulation. [5-8].

**Table1.** The properties of diaphragm materials

| | Young modulus | Poisson's ratio | stress |
|---|---|---|---|
| polysilicon | 169(Gpa) | 0.3 | 100(Mpa) |
| polysilicon | 169(Gpa) | 0.3 | 20(Mpa) |
| polyimide | 2.7(Gpa) | 0.34 | 60(Mpa) |

The polysilicon is used for diaphragm under the high temperature annealing of a low pressure chemical vapor deposition (LPCVD) of polysilicon thin film that is ion implanted with phosphorous reduced the polysilicon residual stress equal to 20Mpa[9], [10].

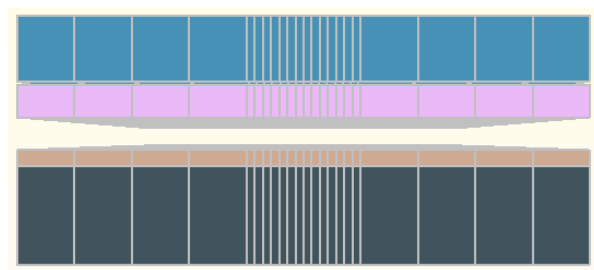
Like the other clamped square diaphragm, when pressure is applied, the maximum deflection is in the center of diaphragm, but in this design, the attachment of movable plate at the center of diaphragm with mechanical coupling and the oter hand the edges of the movable plate are not fixed thhan not seen any stress at the edge of movable plate and the clamped edges stress just exist at the edges of diaphragm.

These reasons influence on the displacement of the movable plate. The movable plate displaced equal to the diaphragm center deflection, like a flat plate without any deflection. With this displacement, this capacitive pressure sensor have more effective surface for making capacitive and obtain higher capacitance and linear response. Also the use of polysicon with residual stress equal to 20Mpa, help to reduction diaphragm stiffness and made a MEMS capacitive pressure with high mechanical sensitivity.

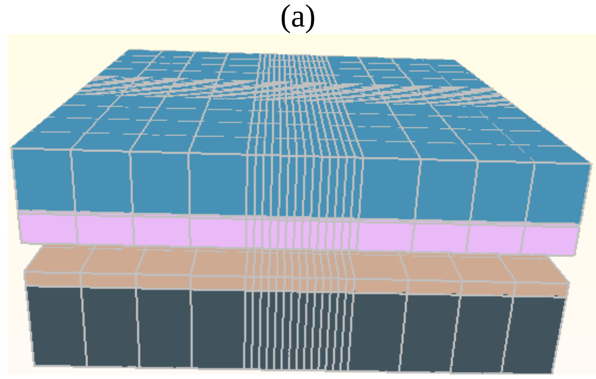
### 2.1. MEMS capacitive pressure sensor simulation

Intellisute software is used for simulating MEMS capacitive pressure sensor to improve performance and reduce the time of fabricating process of the device. The analysis type is thermoelectromechanical relaxation, iteration accuracy is 0.001. Figure 2 shows the simulated sensor with this setup. This sensor consists of a diaphragm with fixed edges and mechanical coupling in the center of movable plate, fixed plate and substrate.

By applying pressure on diaphragm, it causes the movable plate linearly is getting close to fixed plate. The sample of MEMS pressure sensor with polyimide diaphragm, under 50mmHg pressure is shown in Fig.3. As seen in this figure, by applying pressure, diaphragm is deflected but movable plate is displaced like a flat plate and diaphragm deflection just causes the movable plate to become close to fixed plate.



(a)



(b)

**Fig.2.** Simulation setup for the MEMS capacitive pressure sensor (a) side view (b) top view

## 3. RESULT AND DISCUSSION

The displacements of diaphragms with polysilicon and polyimide materials are shown in Fig.4. According to the Fig. 4 when the applied pressure is increased on diaphragms, the diaphragm deflection is increased, too and polysilicon (stress=20Mpa) diaphragm displaced higher than the other diaphragms under same pressure.
Fig. 5 shows the changing of the capacitance versus pressure. The capacitance between two electrodes is increased by increasing the applying pressure and reducing the air gap. It can be seen from Fig.5 the change of capacitance for polysilicon (stress=20Mpa) is more than polyimide and polysilicon (stress=100Mpa).

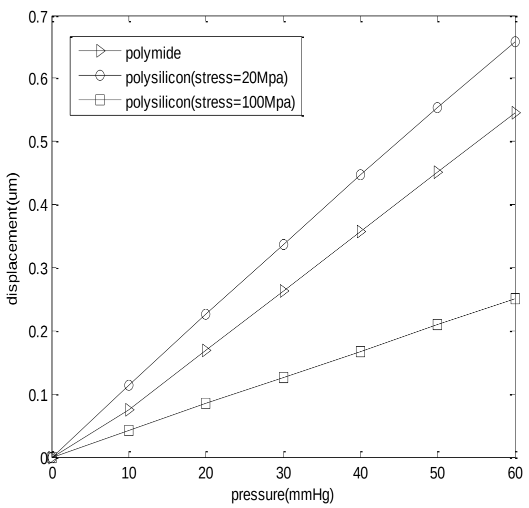
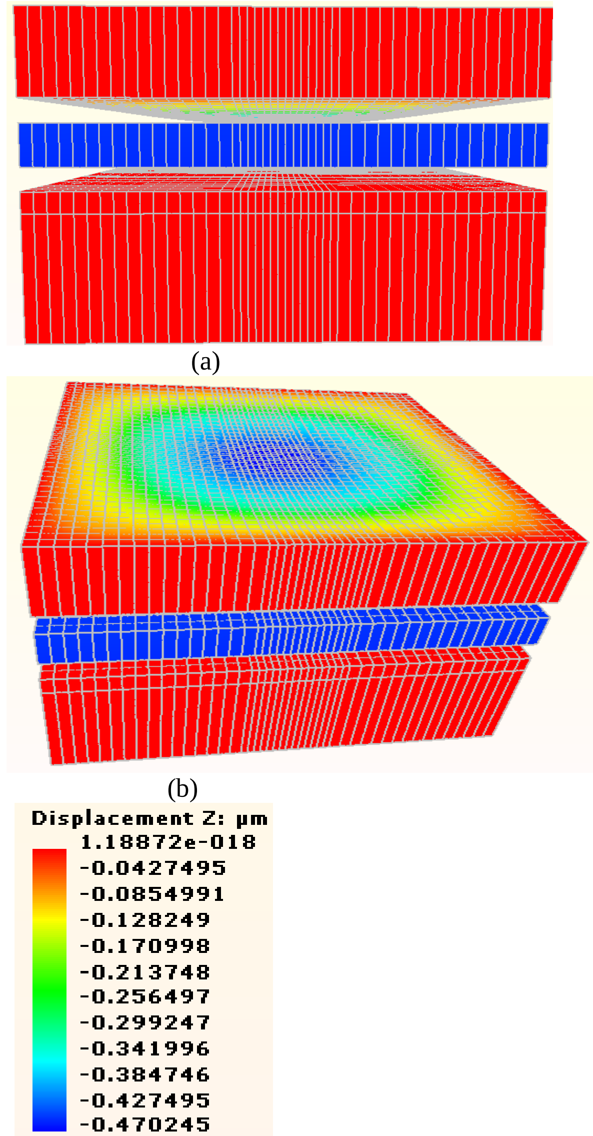



**Fig.4.** Displacement vs. pressure

Diaphragm mechanical sensitivity, $S_m$, defined as follows

$$S_m = \frac{dW}{dP} \qquad (1)$$

Where W is the maximum deflection of the movable plate and P is the applying pressure to diaphragm. From the slope of the Fig. 4 shows the mechanical sensitivity for this sensor with polysilicon (stress=100Mpa) diaphragm, polysilicon (stress=20Mpa) diaphragm and polyimide diaphragm are 0.0042 ($\mu m$/mmHg), 0.011 ($\mu m$/mmHg) and 0.0091($\mu m$/mmHg), respectively.



(a)

(b)



**Fig. 3.** MEMS capacitive pressure sensor under 50mmHg pressure with polyimide diaphragm (a) side view (b) top view

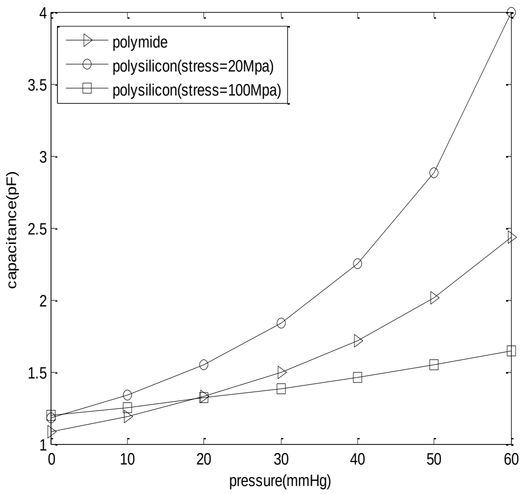



**Fig.5.** Capacitance versus pressure

The sensitivity of capacitive pressure sensor, $S_c$, is given by:

$$S_c=dc/dp \quad (2)$$

Where C is capacitance, P is applied pressure. In this design the sensor sensitivity for this sensor with polysilicon(stress=100Mpa) diaphragm, polysilicon(stress=20Mpa) diaphragm and polyimide diaphragm are 0.00742 (Pf/mmHg), 0.0469 (Pf/mmHg), 0.0226 (Pf/mmHg ) respectively.

## 4. CONCLUSION

In this paper, MEMS capacitive pressure sensor with high sensitivity, small size and linear displacement has been presented. The separated diaphragm and movable plate that are decoupled to each other with mechanical coupling, in the center of diaphragm, and polysilicon material for diaphragm are the cause of these improvements. Fixed and movable plates are gold and substrate is pyrex glass. The dimension of this sensor is $350\times 350\mu m^2$, diaphragm size and air gap are $1\mu m$. According to the simulation results with intellisuite software sensor sensitivity and mechanical sensitivity for this MEMS capacitive pressure sensor the sensor sensitivity, diaphragm mechanical sensitivity for polysilicon( stress=100Mpa) diaphragm are 0.0074 (Pf/mmHg), 0.0042 ($\mu m$/mmHg), respectively and for polysilicon( stress=20Mpa) diaphragm are 0.0469(Pf/mmHg), 0.011 ($\mu m$/mmHg), respectively and polyimide diaphragm are (0.0226pF/mmHg), 0.0091 ($\mu m$/mmHg), respectively.

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