MODELING AND ANALYSIC OF MEMS CAPACITIVE PRESSURE SENSOR USING GRAPHENE MEMBRANE

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Abstract: Micro electromechanical systems (MEMS) based capacitive pressure sensor for ultral-low pressure using graphene has been proposed. The characteristics of sensor such as membrane displacement, capacitance and sensitivity of sensor with external pressure effect are simulated and analyzed using Comsol Multiphysics software. The obtained results show that the MEMS capacitive pressure sensor using 3, 5, 7-layer graphene exhibits the sensitivity of 230.8 aF/Pa, 174.4 aF/Pa and 144.4 aF/Pa, respectively.

1. INTRODUCTION

Nowadays, micro electromechanical system (MEMS) devices are commercially available in many applications, such as acceleration and pressure sensors, etc. Among the potential MEMS devices, pressure sensor has been studied extensively for both industrial and medical applications due to its small size (from µm to mm), high performance, high reliability and low cost. There are some types of pressure sensors including piezoelectric, piezoresistive and capacitive sensors [3, 5, 8]. Compared to piezoelectric and piezoresistive, capacitive sensor has more attracted attention for practical applications because of its high sensitivity, low power and compatible with IC [3]. In particular, most of studies of MEMS capacitive pressure sensors focused on improving the sensitivity of the pressure sensor using variation of material and optimization of shape and size of sensors [1, 4]. Among these approaches, graphene has been extensively studied as the most potential material to improve the sensitivity of sensor.

In this paper, we report the design and simulation of MEMS capacitive pressure sensor using graphene membrance which is based on Comsol Multiphysics simulation. The dimensions of graphene membrane are 10 µm x 10 µm with different thicknesses of the membrane. Furthermore, the size of the air chamber has been optimized to increase the sensitivity of sensor. The obtained results show that using 3, 5, 7-layer graphene membrane, the sensor exhibits the sensitivity of 230.8 aF/Pa, 174.4 aF/Pa and 144.4 aF/Pa, respectively.

2. CAPACITIVE PRESSURE SENSOR

a. Device design

A capacitive pressure sensor has two parallel plates acting as electrodes of capacitor which separates by air gap. The bottom plate is silicon substrate and the top plate is the thin film of graphene. The thickness of graphene membrane is varied, which is 1.05 nm (~3 layer), 1.75 nm (~ 5 layer) and 2.45 nm (~ 7 layer). The symmetric device geometry with one quadrant of pressure sensor as shown in fig. 1.

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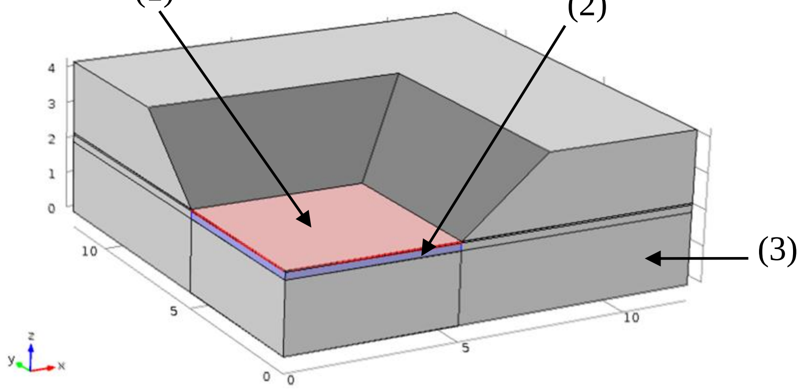

Fig. 1: *The symmetric device geometry with one quadrant of pressure sensor, where: (1) graphene membrane, (2) air chamber, (3) silicon substrate.*

Fig. 2 shows the cross-sectional view of the MEMS capacitive pressure sensor. A thin membrane is held at a fixed potential of 1 V. The distance of the two electrodes were surveyed and selection is 0.05 µm to achieve the high sensitivity.

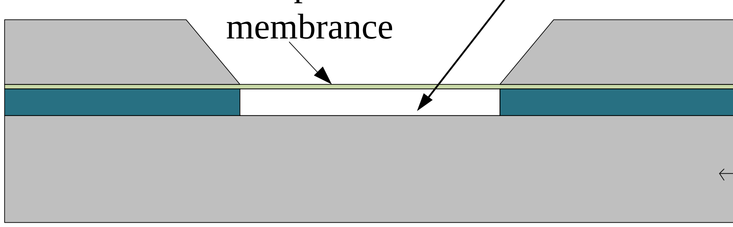

Fig. 2: *The cross-sectional view of the MEMS capacitive pressure sensor*

The technical properties of materials which are used for fabrication of the sensor as shown in table 1.

Properties	**Graphene**	**Silicon**
Young's modul [TPa]	1	0.17
Poisson's ratio	0.17	0.06
Relative permittivity	2.14	11.7
Density [kgm^{-3}]	2,000	2,320

Table 1: *Properties of graphene and silicon*

b. Operating principle

The underlying operating principle of capacitive pressure sensor is based on of changing the capacitance value of the sensor when applied an external pressure.

Normally, capacitance value between two electrodes is expressed as,

$$C = \frac{\varepsilon_o \varepsilon_r A}{d} \tag{1}$$

where, ε_o is permittivity of free space, ε_r is relative dielectric constant of material between plates, A is effective electrode area and d is separation between plates which is the height of air chamber gap.

When an external pressure is applied to membrane, the membrane surface will be deformed non-uniformly. Thus, the equation (1) is not sufficient to calculate the capacitance value. With square shaped membrane of MEMS capacitive pressure sensor, centre deformation of membrane is given by [2],

$$w_{max} = 0.01512\,(1 - \mu^2)\frac{PL^4}{Eh^3} \tag{2}$$

where, L, h, E, μ, P and w_{max} are length of diaphragm, thickness of diaphragm, Young's Modulus (GPa), Poisson's ratio, applied external pressure and maximum diaphragm deflection, respectively.

Then, the capacitance value due to deformation is presented by [2],

$$C = \iint \frac{\varepsilon_o}{d - w(x,y)}\,dxdy \tag{3}$$

where w(x, y) is deformation of membrane.

3. SIMULATION RESULTS AND DISCUSSION

In order to evaluate the sensitivity of the sensor using graphene material, the displacement and capacitance of sensor are simulated and analyzed. Fig. 3 shows the deflection of 3 layer graphene membrane due to external ultral-low pressure of 10 Pa. As shown in Fig. 3, the displacement is non-uniform on entire surface of membrane. The displacement value decreases gradually from the centre to the edge of the membrane. The strongest displacement at the centre of membrane is 0.0135 μm.

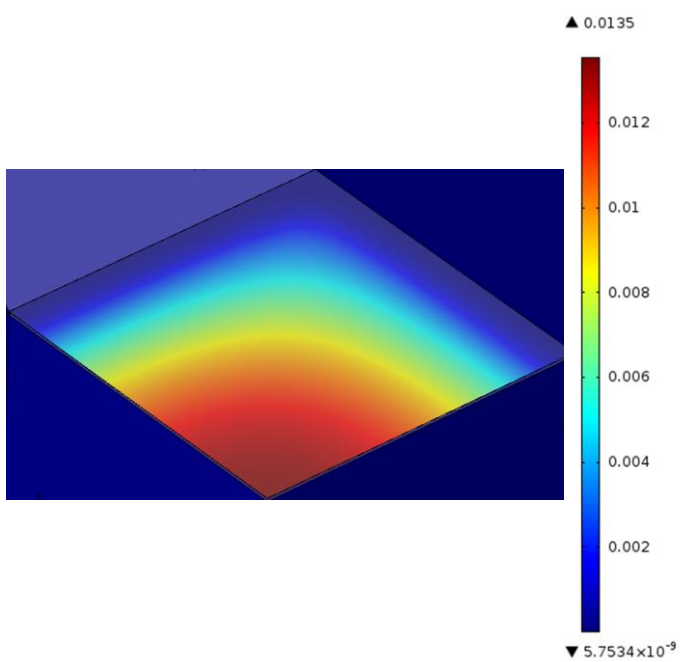

Fig. 3: *Structure surface deflection of 3 layer graphene membrane when applied pressure of 10 Pa*

Fig. 4 shows the displacements of membrane with different thicknesses when a pressure of 10 Pa is applied to it. The obtained results show that when the ultral-low pressure applied on membrane surface is between 0 Pa and 10 Pa, the membrane displacement of the sensor with different thicknesses of 1.05 nm (~3 layer), 1.75 nm (~ 5 layer), and 2.45 nm (~ 7 layer) is 0.0135 µm, 0.0111 µm and 0.0097µm, respectively. It indicates that displacements of membrane can be increased by decreasing the thicknesses of membrane.

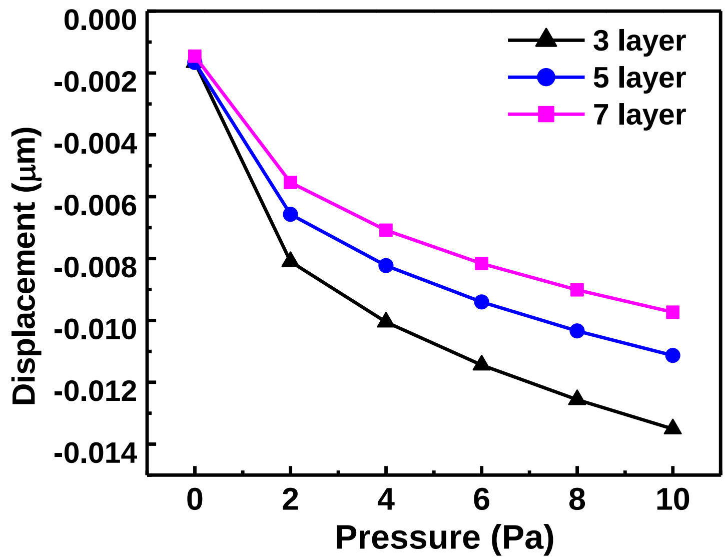

Fig. 4: *Displacement of sensor with different thicknesses of membrane*

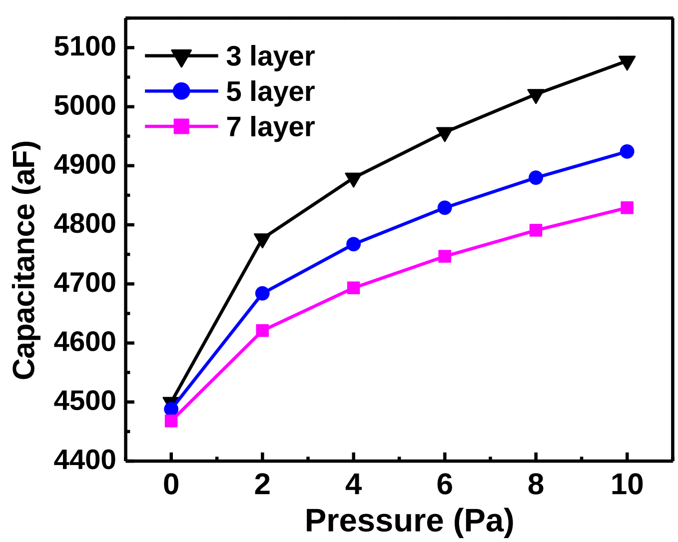

Fig. 5: *Capacitance of the sensor when apply pressure*

Furthermore, the effect of pressure on the capacitance of the sensor is also investigated. Fig. 5 shows the capacitance values of the sensor based on a few layers graphene when applied ultral-low pressure 0 to 10 Pa. As shown in Fig. 5, with increasing pressure from 0 to 10 Pa, the capacitance value of the sensor with different membrane thicknesses of 1.05 nm (~3 layer), 1.75 nm (~ 5 layer), and 2.45 nm (~ 7 layer) increases non-linearly and the maximum capacitance value of sensors are 5077.5 aF, 4923.9 aF and 4828.8 aF, respectively. Therefore, sensitivity of sensor is 57.7 aF/Pa, 43.6 aF/Pa, 36.1 aF/Pa (one quadrant of sensor) and 230.8 aF/Pa, 174.4 aF/Pa and 144.4 aF/Pa (on whole sensor), respectively. It notes that the sensitivity of our proposed sensor structure is improve rather than that reported in references [6, 7].

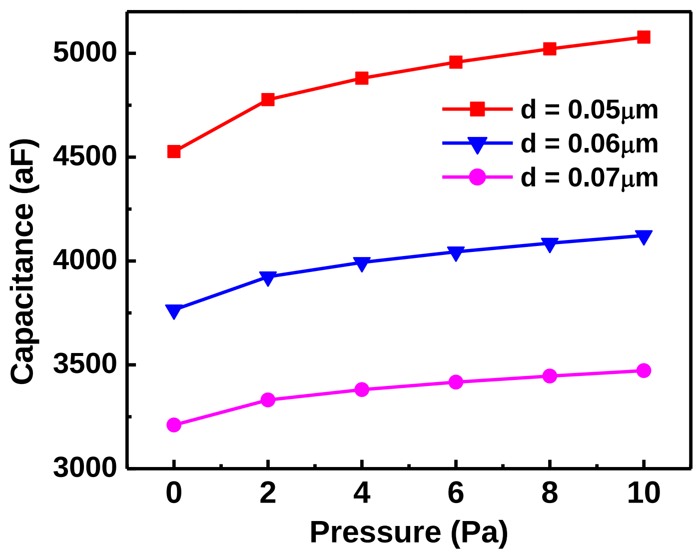

Fig. 6: *Capacitance of pressure sensor with different thickness of air chamber*

With the size of the sensor membrane has been proposed, the thickness of the air chamber is surveyed and selected to achieve the high sensitivity. Figure 6 shows the relationship between pressure and capacitance with different thickness of the air chamber gap. As shown in Fig. 6, the thickness of the air chamber is strongly affected to the capacitance of the sensor. With increasing the air chamber from 0.05 µm to 0.07 µm, the capacitance value of the sensor decreaces at the same pressure. It indicates that the sensitive of the sensor can be increased by decreasing the air chamber gap.

4. CONCLUSION

Micro electromechanical systems (MEMS) based capacitive pressure sensor using graphene has been designed and simulated using COMSOL Multiphysics software. The membrane displacement, capacitance and sensitivity of the sensor with external pressure effect are evaluated. The MEMS capacitive pressure sensors using 3, 5, 7 - layer graphene exhibits the sensitivity of 230.8 aF/Pa, 174.4 aF/Pa and 144.4 aF/Pa, respectively. The obtained results indicate that the proposed sensor using graphene is a promising candidate for MEMS capacitive pressure sensor.

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TÓM TẮT

MÔ PHỎNG VÀ PHÂN TÍCH CẢM BIẾN ÁP SUẤT ĐIỆN DUNG MEMS DÙNG MÀNG VẬT LIỆU GRAPHENE

Cảm biến áp suất điện dung chế tạo dựa trên công nghệ vi cơ điện tử dùng cho áp suất cực thấp sử dụng lớp màng vật liệu graphene đã được đề xuất nghiên cứu. Các đặc tính của cảm biến như độ dịch chuyển của lớp màng, giá trị điện dung và độ nhạy của cảm biến khi có tác động của áp suất bên ngoài đã được mô phỏng và phân tích bằng phần mềm Comsol Multiphysis. Các kết quả đạt được cho thấy cảm biến áp suất điện dung MEMS dùng 3, 5, 7 lớp graphene có độ nhạy tương ứng lên đến 230,8 aF/Pa, 174,4 aF/Pa, 114,4 aF/Pa.