Simulation Analysis of Capacitive Pressure Sensor for MEMS Using Graphene

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Abstract— Recently Microelectromechanical system (MEMS) capacitive pressure sensor gains more advantage over micromachined piezoresistive pressure sensor due to high sensitivity, low power consumption, free from temperature effects, IC compatibility, etc. This paper reports an ultra-thin graphene MEMS capacitive pressure sensor with high pressure sensitivity of 120 pF/Pa, and small die size of 3.0mm × 3.0mm × 1mm. The capacitive pressure sensor is simulated by graphene material. With an applied pressure of 10 kPa the diaphragm displacement in the center is 0.3 μm and the average displacement of the diaphragm is 0.1 μm. The sensor model is simulated by COMSOL Multiphysics software.

IndexTerms—Graphene, Capacitive pressure sensor, MEMS, COMSOL, Pressure sensibility.

I. INTRODUCTION

Capacitive pressure sensors have been designed for a variety range of applications in measuring both absolute and differential pressures because of their high pressure sensitivity, low temperature sensitivity and good dc response [1-5]. Today MEMS devices are used for actuators, Sensor, microfluidics, piezoelectric devices and switches [6]. Typically a capacitive pressure sensor contains a thin diaphragm and this same diaphragm is used as the pressure sensing element and the capacitive sensing element as well.

At present days, silicon and polymer material are used for traditional metal diaphragm pressure sensor. Most researchers used Silicon, because the properties of silicon material were well established and the facilities of existing silicon foundry can be used for fabrication in batch production. So, there is a need for a new material which can provide the better performance for MEMS devices. Graphene is an exciting material [7]. Graphene, emerging as a true 2-dimensional material, has received increasing attention due to its unique electrical and mechanical properties. V. Kaajakari et al.[8] shows a capacitive pressure sensor with silicon material but in this paper authors presented a capacitive pressure sensor with graphene material.

With the simulation of graphene capacitive pressure sensor, this paper presented a review of the performance of quadrant deflection, Electric potential in the air chamber, displacement of the membrane and sensing capacitance. Since this graphene capacitive pressure sensor for MEMS provides a better performance, it can be deployed in industrial, consumer, military and automotive applications.

II. SIMULATION METHODOLOGY

The simulation model of capacitive pressure sensor is implemented by COMSOL Multiphysics 4.4 software. The model consists of graphene, Steel AISI 4340 and air. The basic geometry of the model is imported from built in COMSOL file. The pressure sensor is part of a graphene die that has been bonded to a metal plate at 70°C. Since the geometry is symmetric, only a single quadrant of the geometry model is taken for analyzing and the symmetry boundary condition can be employed. The operating temperature of the model is 20°C and die bonding temperature is 70°C. The property of graphene material by which graphene is defined into the model is shown in TABLE 1.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value with Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s modulus</td>
<td>1.0 TPa</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.17</td>
</tr>
<tr>
<td>Density</td>
<td>2000 kg/m^3</td>
</tr>
<tr>
<td>Relative permittivity</td>
<td>2.14</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>5000 W/m °K</td>
</tr>
<tr>
<td>Coefficient of thermal expansion</td>
<td>8x10^-11 °K^-1</td>
</tr>
<tr>
<td>Specific surface area</td>
<td>2630 m^2/g</td>
</tr>
</tbody>
</table>

TABLE I. PROPERTIES OF GRAPHENE [9-12]

The functional part of the device consists of a thin membrane biased with 1V potential, a ground plane chamber sealed under high vacuum. The ground part and the membrane are separated by anisulator. When the pressure outside of the sealed chamber changed, the pressure difference causes the membrane to deflect. Initially the sensor is analyzed in the case where there are no packaging stresses. Then the effect of the packaging stress is considered. The device response at fixed temperature is evaluated with the additional packaging stress. Finally the temperature dependence of the device response at a fixed applied pressure is assessed.
Fig. 1. (a) Shows the quarter of the sensor and (b) shows the total sensor geometry.

The basic figure of the simulation model is shown in Fig.1.

III. RESULT AND DISCUSSION

Fig.2 shows the deformation surface of the membrane when a pressure of 25 kPa is applied to it, in the absence of packaging stresses. The maximum deflection is $3.64 \times 10^{-8}$m and the minimum deflection is $2.58 \times 10^{-8}$m.

Fig.3 shows the surface potential on a plane located between the plates. The potential is almost uniform and the value is near to 0.3V.

Fig.4 shows the mean and maximum displacements of the membrane as a function of applied pressure. At an applied pressure of 10 kPa the diaphragm displacement in the center is 0.15 μm. The average displacement of the diaphragm is 0.5 μm. These results indicate the mean diaphragm and the maximum diaphragm results are very close which increases the stability of the sensor.

Fig.5 shows that the capacitance of the device increases non-linearly with applied pressure. The gradient of the curve plotted is a measure of the sensitivity of the sensor. At zero applied pressure the sensitivity of the model (quarter of the whole sensor) is $7.4 \times 10^{-6}$ pF/Pa. The device sensitivity is therefore $7.4 \times 10^{-6}$ pF/Pa.
The capacitance without package stress is less than the analytic capacitance but the capacitance with package stress is greater than the analytic capacitance. Fig. 6 shows the displacement surface of the structure when applied pressure of 25 kPa. At zero applied pressure the sensitivity of the capacitance has increased from $8 \times 10^{-6}$ pF/Pa to $12 \times 10^{-6}$ pF/Pa (48 $\times 10^{-6}$ pF/Pa for the entire device). The effect is even more pronounced at a pressure of 20 kPa, then thermal stresses show a pressure sensitivity of $30 \times 10^{-6}$ pF/Pa ($120 \times 10^{-6}$ pF/Pa for the entire device). Since the thermal stresses are temperature dependent, the response of the device is also now temperature dependent. Fig. 7 shows the temperature dependence of the capacitance of the packaged device. The capacitance is decreases linearly with the increasing of the temperature.

These analyses clearly demonstrate that the pressure sensitivity can be scaled independently with this graphene material capacitive pressure sensor.

IV. CONCLUSION

A review on graphene capacitive pressure sensor for MEMS reveals the advantage over piezoresistive pressure sensor. The simulation results was very promising results. It shows high sensitivity, small size, free from the effects of temperature. So, it’s may use for various MEMS application.

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