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Investigation on Influence of Geometry on Performance of a Cavity-less Pressure Sensor

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Abstract. In recent years the automobile comfort and safety greatly improved by incorporation of specialized sensors. These sensors monitor the satisfactory working of different parts of an automobile by providing timely information to the driver. Tyre inflation pressure sensor is one of the important devices whose satisfactory working will improve tyre life as well fuel economy. The present work is focussed on modeling of a Cavity-Less pressure sensor for sensing inflation tyre pressure. Dielectric soft material for the sensor is taken as Silicone rubber. The sensor is modeled using finite element technique. The influence of width to thickness ratio of dielectric material for square geometry is studied. It is observed that change in capacitance increases with the applied pressure. The highest sensitivity of 4.79 fF/kPa is obtained for a sensor with width to thickness ratio of 100.

1. Introduction

Tyres of an automobile play a vital role in providing better comfort and control while driving. Under inflation of tyre pressure may lead to increased rolling resistance, reduced fuel economy and reduce tyre life [1, 2]. Tyre Pressure Monitoring System (TPMS) is a system that monitors tyre air inflation pressure at any instant of time [3]. Direct TPMS makes use of pressure sensor to measure air inflation pressure whereas Indirect TPMS is based on wheel speed measurements [4]. It provides the information about individual tyre pressure more accurately compared to Indirect TPMS [5]. The Direct TPMS consists of Micro-Electro Mechanical System (MEMS) pressure sensor that made up of a thin elastic diaphragm placed above a cavity that is filled with vacuum [6]. The deflection of diaphragm is transducted to measure of tyre inflation pressure.

The repeated deflections of the thin elastic diaphragm, leads breaking the cavity and therefore, shortens the sensor life [7]. One of the alternative to this problem could be a Cavity-Less Pressure Sensor (CLPS), which is not fully explored is discussed in the subsequent section.

The performance of MEMS pressure sensors is generally studied by modeling using Computer Aided Design tools based on Finite Element Analysis (FEA) such as ANSYS, Intellisuite, COMSOL, etc. [8-11]. These software packages are widely used due to the availability of multiphysics modules for analysis of sensor materials. Limited literature is available on performance analysis CLPS using FEA. Thus the following study is an attempt on such modeling and analysis of a CLPS pressure sensor.

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In the present work, a CLPS is modeled using finite element modeling technique using COMSOL Multiphysics software. Silicone rubber material is used as a thin soft dielectric material for the sensor. The influence of Width to Thickness ratio (W/T) of sensor material on sensitivity CLPS is analyzed.

2. Methodology

Working of CLPS is similar to a parallel plate capacitor, where the bottom electrode is fixed and the top electrode is subjected to the pressure with a soft dielectric material placed in between. The intermediate soft material undergoes compression under the application of pressure. This intern increases the capacitance due to reduced gap between the electrodes. This change in capacitance is a measure of the applied pressure [12].

An attempt is made to determine the sensitivity of the CLPS in terms of geometry parameter. The sensitivity is defined as the smallest change in the output capacitance for a given change of the applied pressure. Sensitivity of CLPS depends upon dielectric constant of material, area of the electrode and thickness of the material. In present study influence of geometry on the sensitivity of the sensor is studied.

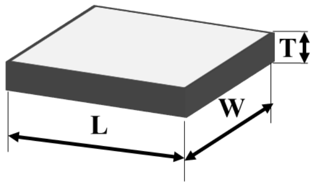

Figure 1. Dimensions of the Sensor.

2.1. Modeling

Modeling of CLPS is done on COMSOL Multiphysics 5.2. It's a commercial finite element modeling and analysis software for analysing domains involving multidiscipline. Three dimensional model of CLPS with square geometry having L x W dimensions as 10 mm x 10 mm (figure 1) is developed as shown in Figure 2 with material properties as shown in table 1. The top and bottom volumes are specified as electrodes. The geometry is converted to finite element model with hexahedral elements as shown in figure 3. The bottom volume is defined with fixed boundary condition whereas top volume is applied with a pressure varying from 0 to 300 kPa in steps of 25 kPa. The bottom volume is grounded and top volume is applied with a voltage of 1 V.

Table 1. Material properties of sensor

Parameters	Values
Young's Modulus	1 MPa
Poisson's ratio	0.47
Dielectric constant	2.9
Density	1100 Kg/m^3

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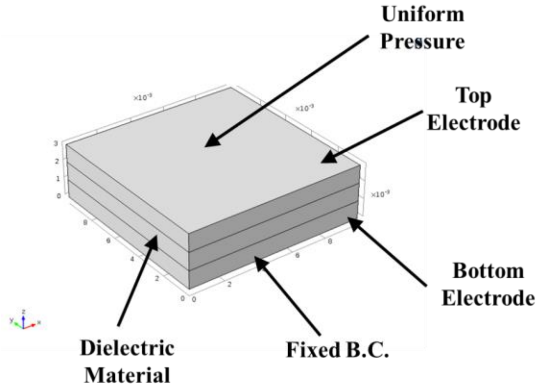

Figure 2. Geometry of CLPS for W/T=5

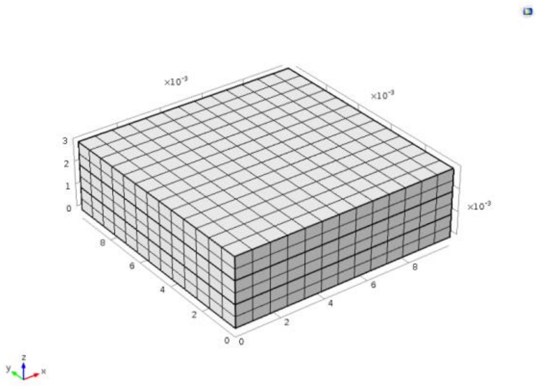

Figure 3. Finite element model of CLPS for W/T=5.

The sensor performance is analysed by coupling three physics in COMSOL Multiphysics software namely, solid mechanics, moving mesh and electrostatics. The moving mesh and electrostatics modules defined in a frame to allow the mesh to move. Initially, solid mechanics module solves for the deflection of dielectric material for the applied pressure. The recalculation of the mesh is done using moving mesh module using the dependent variables of solid mechanics module. Later for solving the electric field, the electrostatics module is used. The electrostatics module uses deformed mesh to calculate the capacitance of the sensor. Change in capacitance is evaluated by taking the difference between the capacitance before and after application of pressure.

3. Results and discussion

The performance of CLPS is analysed by varying W/T ratio as 1, 5, 10, 50 and 100. The plot of deflection and capacitance obtained from COMSOL software for the sensor material is as shown in figure 4 and 5.

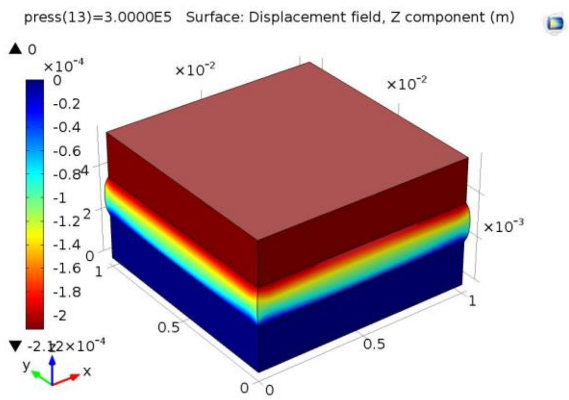

Figure 4. Deflection plot for the pressure of 300 kPa for W/T =5

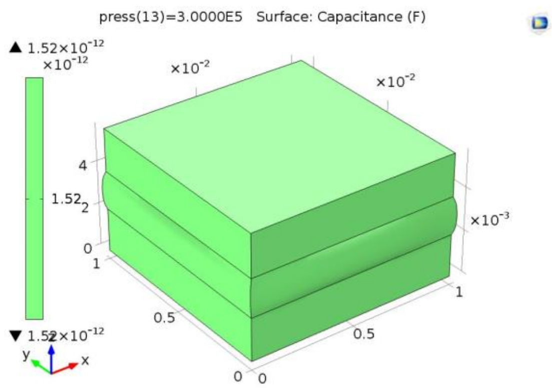

Figure 5. Capacitance plot for W/T=5

The variation of change in deflection of dielectric material with respect to pressure is shown in figure 6. When pressure is applied to the sensor, the dielectric material undergoes deflection. It is observed that deflection gradually increases with the increase in the applied pressure. It is noted that deflection is lesser for higher W/T ratio of the dielectric material. This could be due to the fact that, as dielectric material becomes thinner, it becomes more resistant to deformation.

Figure 7 shows the plot of the change in capacitance with the applied pressure for different W/T ratios. It is observed that the change in capacitance gradually increases with increase in the applied pressure. It is also noted that the W/T ratio of 100 gives the highest change in capacitance. The slope of the graph is less for lower W/T ratio. Therefore, it is observed that the CLPS with higher W/T ratio of the dielectric material is more sensitive. This could be mainly due to the fact that the capacitance is inversely proportional to the thickness of the dielectric material. Highest sensitivity 4.79 fF/kPa is obtained for a sensor with W/T ratio of 100.

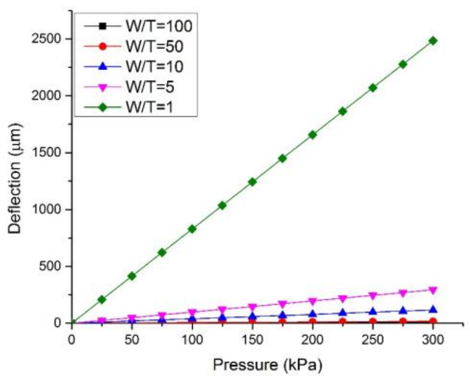

Figure 6. Variation of deflection with pressure

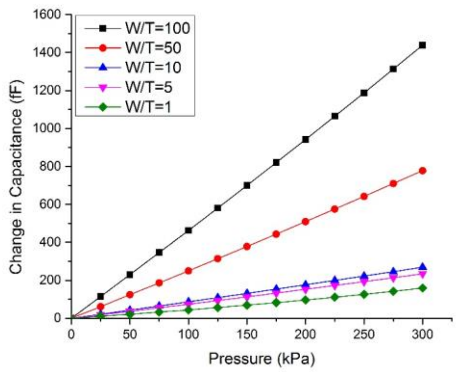

Figure 7. Variation of change in capacitance with pressure

From figures 6 and 7, it is observed that as sensor material becomes thin, the change in capacitance increases whereas deflection decreases. The variation of deflection and change of capacitance are plotted for different W/T ratios for a pressure of 300 kPa as shown in figure 8. It is observed that, both the graphs cross each other for a value W/T ratio ranging from 5 to 10. This implies that, there exists a value of W/T ratio for which change in deflection and change in capacitance are maximum. In the present case for a sensor with W/T ratio of nearly 6.5 exhibits optimum performance.

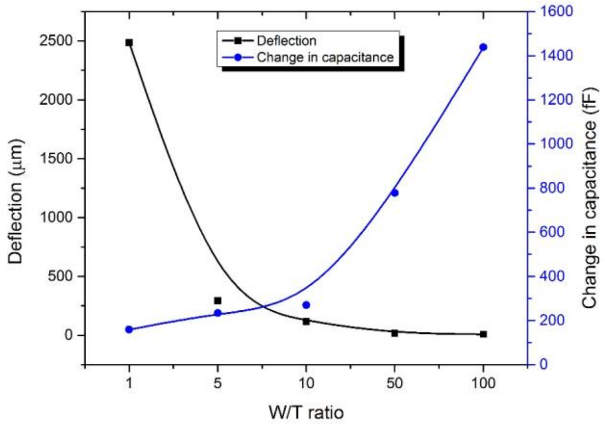

Figure 8. Variation of Deflection and Change in capacitance for different W/T ratio for the pressure of 300 kPa

4. Conclusion

The CLPS successfully modeled and analyzed using COMSOL Multiphysics software. From the above study, it can be concluded that for lower values of W/T ratio the deflection of the sensor material is higher. For higher values of W/T ratio change in capacitance of the sensor is higher that intern increases the sensitivity of the sensor. Highest sensitivity of 4.79 fF/kPa is obtained for a sensor with dielectric material W/T ratio of 100 which is higher than the sensitivity of TPMS sensor cited in [13]. Hence proposed sensor could be a possible alternative for the diaphragm type of pressure sensor used in TPMS. Also, it is observed that as sensor material becomes thinner, the deflection and change in capacitance exhibit trade-off the relationship. The CLPS performance is found to be optimum for W/T ratio of nearly 6.5.

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