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# Design of a Novel Capacitive Pressure Sensor

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**Abstract:** A novel capacitive pressure sensor based on surface micromachining technology is proposed and simulated. The sense element is considered as a parallel plate capacitor with one electrode fixed to the substrate, and the other suspended on a polysilicon diaphragm. In the presence of an oil pressure, the silicon diaphragm is deflected downward, which also displaces the suspended electrode downward. The sensor structure is in such away that due to the suspended electrode displacement, the effective area between two plates is changed, and therefore the capacitance is changed. It must be mentioned that the effective area as well as the gap between the capacitor plates vary with the applied pressure. However, the nonlinearity due to gap variation is about 9.46%. The dimensions of the sense element are 1.5mm×1.5mm, which consists of 25 cells: in a 5 columns and 5 rows manner. The capacitance varies between the 11.455-24.72pF, when the pressure varies in the range of 4-60psi. The minimum sensitivity of this sensor is about 0.135pF/psi. *Copyright © 2007 IFSA.*

**Keywords**: MEMS, Micromachining, Sensors, Pressure and FEA

## 1. Introduction

Pressure sensing is one of the most established and well-developed areas of sensor technology. One reason for its popularity is that it can be used to measure various real-word phenomena like flow, fluid level and acoustic intensities, in addition to pressure. Modern pressure sensors are fabricated using the process of silicon micromachining [1]. Various sense techniques are available such as piezoresistive, piezoelectric, capacitive, optical and resonance. This paper includes the design of a novel capacitive pressure sensor based on surface micromachining technology. Surface micromachining is selected due to its more compatibility with standard IC processing steps in comparison to the bulk micromachining

[1, 2]. This technique reduces the chip size and thus the cost of final product [3, 4]. Surface micromachining simply permits the fabrication of sensors with complex structure by stacking and patterning layers or building blocks of thin films, while multilayered bulk devices are difficult to construct. Lower power requirements and less temperature dependence (small temperature coefficient) [2, 5] are two important reasons to choose the capacitive sensor in comparison to piezoresistive type. One of the most important parameter in pressure sensors is linearity. Here, a new structure of capacitive sensor with high linearity is presented. This device relies on the variation of overlapping plate area between the two electrodes of a parallel plate capacitor.

## 2. Device Design

The schematic structure of different parts of pressure sensor is shown in Fig.1. The cross section of the sensor structure is shown in Fig.2. The substrate is considered as a <100> oriented single-crystal silicon. The inter-digital capacitor plates can be formed using two layers of highly doped polysilicon. The suspended part and the sensor diaphragm is considered as a low level doped polysilicon. The electrical insulation of the sensing element with the substrate can be obtained using a thermal oxide layer. The movable part of this structure can easily be released using the sacrificial layer technique.

To obtain a maximum area for the capacitor plates a spiral square form is chosen. The middle layer serves as a movable electrode, which is free to move due to an applied pressure. In the absence of any external pressure, this electrode is in its initial position with the sensor capacitance minimum. When the pressure is applied, the diaphragm is deflected downward. Note that the maximum displacement is in the center of the diaphragm and is displaced exactly at the same amount. The important feature of the structure is that the displacements of the all points on the movable electrode are the same. Another point is the perfectly sealed structure, which is essential for the liquid pressure sensors.

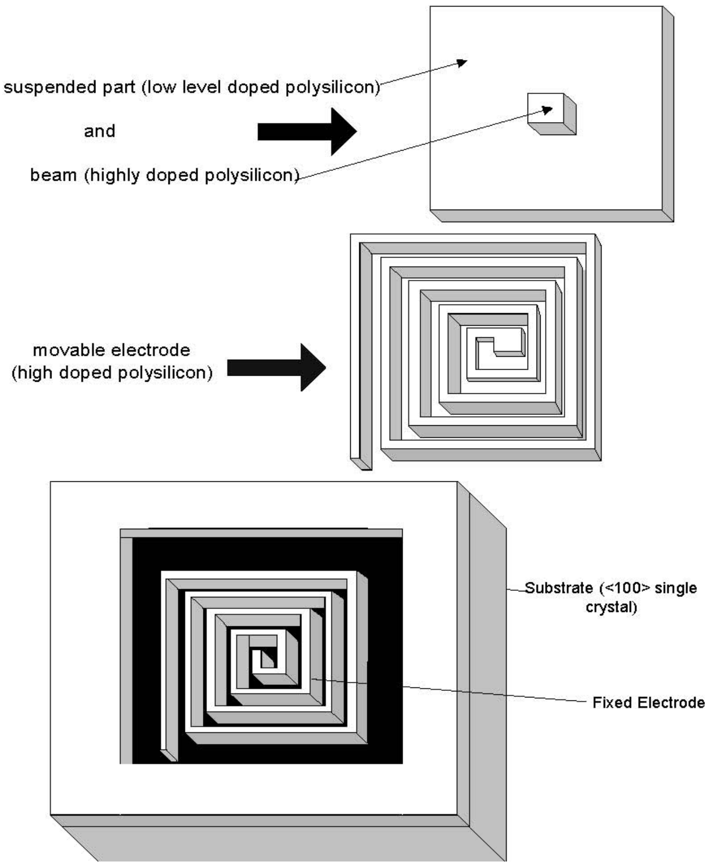



**Fig.1.** Schematic structure of the pressure sensor.

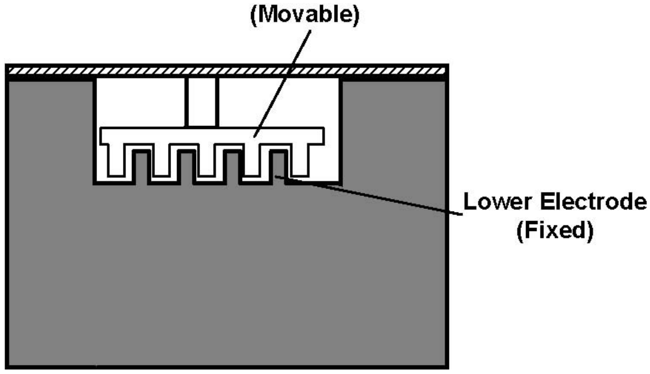


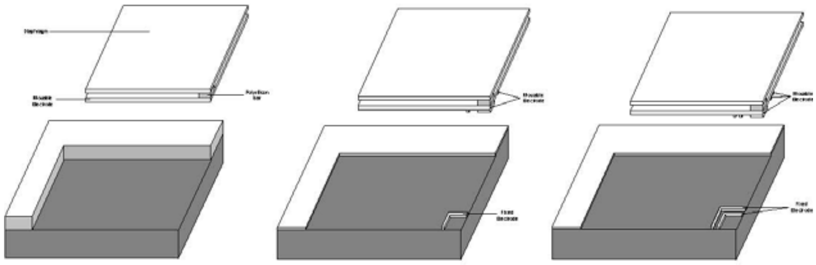

**Fig.2.** Cross section of the sensor structure.

## 3. Finite Element Analysis

To determine the thickness of the layers (especially the diaphragm undoped polysilicon thickness), and the dimensions of the different parts of the structure, the mechanical structural analysis is used. We simulated the sensor structure by using the ANSYS finite element package. The simulation is done in three steps: in the first step, only a planar plate is defined as the movable electrode (Fig.3). At the second analysis, a single spiral square upper electrode is considered and the procedure is repeated for this structure (Fig.3b). At the final step, two spiral squares are taken into the consideration and analysis is done using this structure. In all steps, the symmetry property of the shape is used and ¼ of structure is analyzed instead of total structure so that the specific boundary conditions parallel to axis of symmetry are applied. The considered pressure at the simulation is in the range of 4psi-60psi. Two important features to choose the diaphragm thickness are: (a) under the maximum applied pressure, the stress of any point of diaphragm should not exceed the critical shear stress for silicon; (b) the diaphragm displacement must be as large as possible. After the sequential analysis and examination of the results by try and error method, the best suitable diaphragm thickness was obtained. Fig.4 shows the finite element model (FEM) of this structure. Fig.5 shows the simulated results by ANSYS software for the displacement of the center of the diaphragm. It is clear from Fig.5 that the displacement of the diaphragm center and therefore, the capacitance of the inter-digital capacitor is linearly related to the applied pressure. According to the simulated results, capacitance linearly varies from 0.453 pF to 0.971 pF for the pressure range of 4psi-60psi with the maximum non-linearity of about 9.46% at full scale.

The results of the simulation for three different spiral structures indicate that the diaphragm displacement under different pressures for all cases result in the identical curves. Also, in all cases displacement of the different points of the movable electrode is perfectly uniform. Therefore, the obtained results, which are similar for all three cases, are considered to be true for the complete structure with 12 spiral squares.

These capacitances are very small and the detection of these values will be very difficult. Therefore, the above structure is considered as a unit cell and a number of these cells are considered to be connected in parallel on the final die. In this case, under a certain pressure, all cells are displaced identically. Therefore, the effective area is increased and in turn the capacitance is increased with the total capacitance multiplied by the number of cells. In an optimum case, a 1.5mm×1.5mm die size is considered, which consists of 25 cells: in a 5 columns and 5 rows manner. Therefore, the effective area and capacitance value are 25 times larger than the unit cell. The total sensor capacitance changes from 11.324 pF to 24.282 pF, for the pressure variation of 4psi-60psi.



(a) (b) (c)

**Fig. 3.** The ¼ of sensor structure with (a) a planar plate (b) a single spiral square (c) two turns of spiral; as movable electrode.

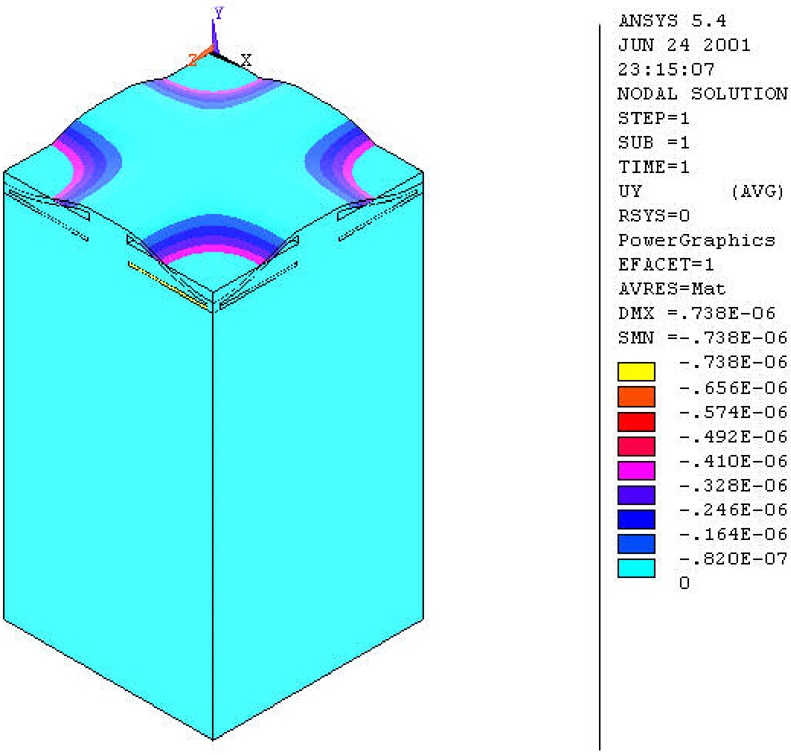



**Fig.4.** Displacement value and deformation shape of the four cells under the 60psi pressure.

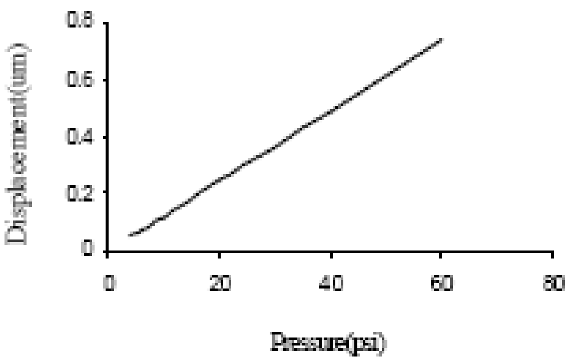



**Fig.5.** Displacement of the center of diaphragm versus applied pressure.

## 4. Conclusions

A novel capacitive pressure sensor structure is proposed using surface micromachining technology. The most important characteristic of this sensor is the high linearity between the applied pressures and capacitance. Additional features of the device are small size, low temperature dependency, symmetrical form. The dimensions of the sense element are 1.5mm×1.5mm, which consists of 25 cells: in a 5 columns and 5 rows manner. The capacitance varies between the 11.455-24.72pF, when the pressure changes in the range of 4-60psi. The minimum sensitivity of this sensor is about 0.135pF/psi.

## Acknowledgement

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# Guide for Contributors

## Aims and Scope

*Sensors & Transducers Journal (ISSN 1726- 5479)* provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

## Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

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