International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622
National Conference on Advances in Engineering and Technology
(AET- 29th March 2014)

RESEARCH ARTICLE OPEN ACCESS

Design and Analysis of Flexible Micromachined Touch Mode Capacitive Sensor for Pressure Measurement

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ABSTRACT
Now a days, capacitive touch sensors are widely used in consumer products like MP3 players, mobile phones and other portable devices. More and more, this technology is utilized in further application fields such as household appliances as well as automotive and industrial applications. The robustness, usability and cost efficiency are driving forces for the rapid development of capacitive touch sensors. In this paper, a simulation environment is created for fabricating capacitive sensors with different materials and then a performance analysis is carried out. \
Keywords - Capacitive Sensing, Virtual Fabrication, Touch Sensors.

I. INTRODUCTION

Capacitive pressure sensors [6][7] work by detecting the change in capacitance between a fixed plate and the flexible plate [1][8]. The major difficulty to the designer is the dimensions and properties used in the simulation of the Micro-Electro-Mechanical-Systems (MEMS) devices cannot be exactly followed during fabrication. In order to overcome this problem, we must test the device in simulation for bound of parameters involved in it. This will be done by using Intellisuite software modules like Intellifab, Thermoelectromechanical analysis module, Synple etc.

II. CAPACITIVE SENSING

Capacitance describes how the space between two conductors affects an electric field between them. If two metal plates are placed with a gap between them and a voltage is applied to one of the plates, an electric field will exist between the plates. This electric field is the result of the difference between electric charges that are stored on the surfaces of the plates [5]. E-Fields are generated from the greatest potential to the least potential. Figure 1 shows E-Field lines from the capacitive sensor to ground. The measurement of the capacitance at this point gives the parasitic capacitance.

The conductive object allows an increased number of E-Field lines to travel between the sensor and ground. The greater concentration of E-Field lines results in a greater capacitance measured at the sensor as shown in Figure 2. In human interface devices, the conductive object is typically a human finger, hand, foot, etc.

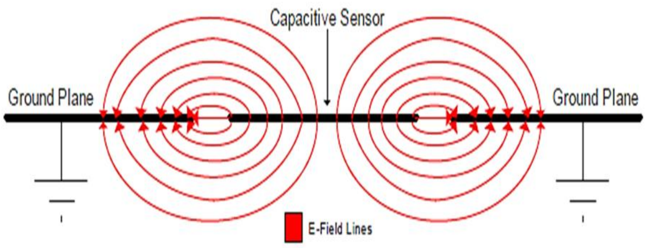

Figure 1: E-fields and parasitic capacitance

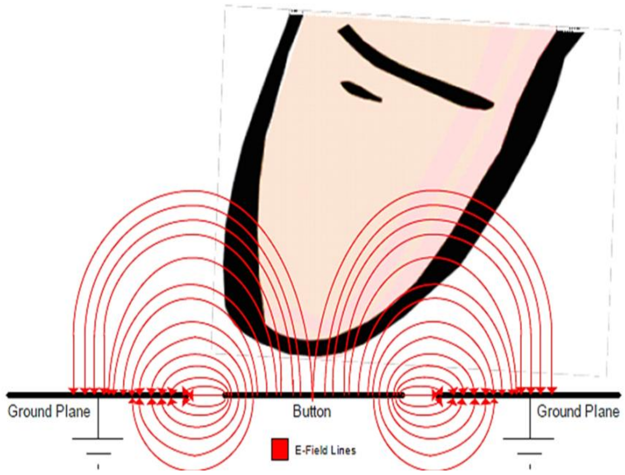

Figure 2: E-fields with a finger present

MEMS based pressure sensors and microphones use an elastic plate as a membrane or a diaphragm as the active mechanical element. As the plate deflects due to the applied pressure, the middle surface remains unstressed. The pressure introduces bi-axial stresses in the plate. Stresses at points are proportional to the distance from the middle surface and the maximum stresses occur at the outer surfaces of the plate. The simplest form of a capacitor consists of two conductors [3], e.g. two metal plates, separated by an insulator. The following formula shows the parameters which influence capacitance:

C= (Area×Dielectric)/Gap …….(1)

In ordinary capacitive sensing the size of the sensor, and the dielectric material (air) remain constant. The only variable is the gap size. Based on this assumption, driver electronics assume that all changes in capacitance are a result of a change in gap size. The electronics are calibrated to output specific voltage changes for corresponding changes in capacitance. These voltages are scaled to represent specific changes in gap size. The amount of voltage change for a given amount of gap change is called the sensitivity [3][4].

In this paper, all the designing or fabrication and different types of analysis or simulation is performed at virtual level using Intellisuite Tools.

III. INTELLIMASK

It is a Mask layout design tool for MEMS devices. IntelliMask is specially used for constructing and editing MEMS device level masks.

In this work, we have created three circular masks of different radius which are 45 micron, 50 micron and last mask is of 55 micron. The last mask has a different shape where four rectangles are create on the outer surface of circle at equal distances to allow the electric field lines path on the upper section of the sensor as shown in Figure 3. These masks are used at the time of virtual fabrication of the device.

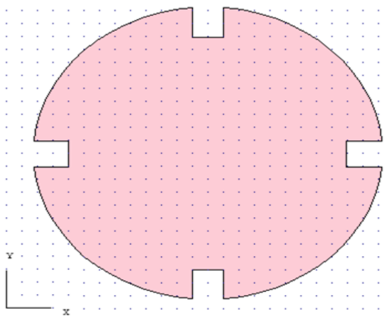

Figure 3: Mask 3 layout in Intellimask

IV. INTELLIFAB

Intellifab allows us to construct 3D models directly from the process steps and then export them to the analysis modules. Here, we analyze the methods for determining material properties from fabrication and operating parameters. So it is a fabrication based computer aided designing using virtual fabrication techniques.

By this tool, we create or fabricate capacitor sensor device using the two methods and different materials is used for both the devices. First capacitor sensor diaphragm is made by polysilicon material and silicon substrate is doped through the P ions whereas second capacitor sensor diaphragm is made by silicon.

Table 1: Fabrication Process Steps

S.NO.	DEVICE 1	DEVICE 2
1	Definition Si czochralski 100	Definition Si czochralski 100
2	Deposition SiO_2 thermal wet	Deposition SiO_2 thermal wet
3	Definition X-Ray standard	Definition UV contact
4	Etch SiO_2 RIE	Etch SiO_2 wet BOE
5	Deposition P implant P-ion	Deposition B implant B-ion
6	Etch SiO_2 RIE	Etch SiO_2 wet BOE
7	Deposition PSG LPCVD generic	Deposition PSG LPCVD generic
8	Definition UV contact	Definition UV contact
9	Etch PSG wet sacrifice	Etch PSG wet sacrifice
10	Deposition Polysilicon LPCVD SiH_4	Deposition Si_3N_4 LPCVD SiH_4
11	Definition X-Ray standard	Definition UV contact
12	Etch Polysilicon dry SF_6 plasma	Etch Si_3N_4 RIE
13	Etch PSG wet sacrifice	Etch PSG wet sacrifice
14	Etch Si wet KOH	Etch Si wet sacrifice

Nitride and substrate is doped with the B ions. The process steps used in the fabrication of our devices are shown in Table 1.

V. ELECTROMECHANICAL ANALYSIS

It is a fully coupled thermal, electrostatic, mechanical, packing, contact & post-contact analysis and system model extraction tool. Here, the device level simulation performed can be categorized into frequency analysis, static analysis, dynamic analysis and system model extraction.

For analysis, the fabricated device is initially imported from intellifab to thermoelectromechanical tool and the sensor looks like as shown in Figure 4.

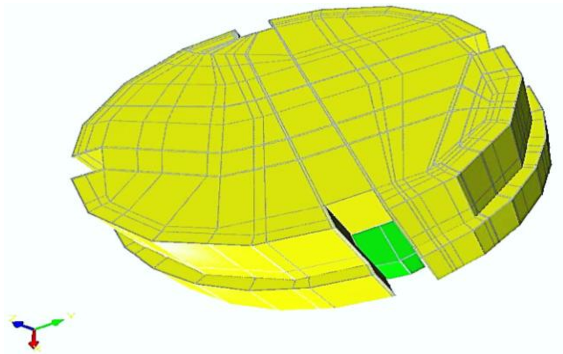

Figure 4: Capacitor sensor in TEM tool

5.1 Boundary Conditions

In all mechanical analysis, each separate part of the structure (entity) must be assigned at least one fixed boundary to make the problem solvable. Hence, we can set the boundary conditions by selecting the appropriate degree of freedom of a particular entity and clicking on the appropriate boundaries.

5.2 Natural Frequency Analysis

The natural frequencies of a structure are those frequencies at which the structure naturally tends to vibrate if it is subjected to a disturbance. The deformed shape of the structure at a specific natural frequency of vibration is termed as its normal mode of vibration. Hence this simulation computes the natural frequencies and associated mode shapes of a structure including any natural frequency shift due to external forces and/or in-plane stresses [2]. Natural frequencies and mode shapes are functions of the structural properties and boundary conditions. If the structural properties change, the natural frequencies change but the mode shapes may not necessarily change. For example, if the elastic modulus of the cantilever beam is changed then the natural frequencies change but mode shapes remain the same. If the boundary conditions change then the natural frequencies and mode shapes both change. Table 2 depicts the natural frequencies of both devices.

Table 2: Natural Frequencies of Devices at Respected Mode

Mode No.	Natural Frequency (MHz)	
	Device 1	**Device 2**
Mode 1	2.45373	2.86888
Mode 2	5.18315	6.05978
Mode 3	5.31804	6.21969
Mode 4	8.62529	10.08640
Mode 5	8.83642	10.32930
Mode 6	10.11390	11.82680

5.3 Pressure versus Capacitance Analysis

For pressure versus the capacitance, thermoelectro mechanical relaxation is the method used in Intellisuite to solve coupled Mechanical Electrostatic analysis. The method implemented uses a boundary element solver to calculate capacitance and charge information and a finite element solver to determine mechanical deformations. Each domain solver is called iteratively, updating the values of its associated variables. This sequence is repeated until convergence is achieved.

By this analysis, we get capacitance in femto farad between the diaphragm and bottom doped substrate also we get the distance between these two due to applied different pressure values as shown in the Figures 5 and Figure 6.

As on examining, Figure 5 and Figure 6 we fobsereved that capacitance of device 2 is less as compared to device 1 which has polysicion diaphragm also the deflection in silicon nitride diaphragm of device 2 is less because stress and stiffness of silicon nitride diaphragm is larger than polysilicon diaphragm.

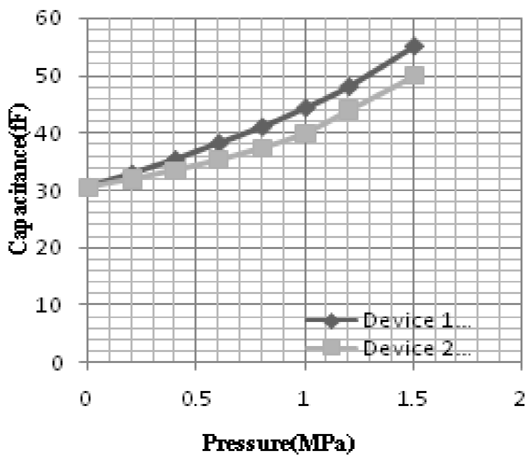

Figure 5: Pressure vs Capacitance

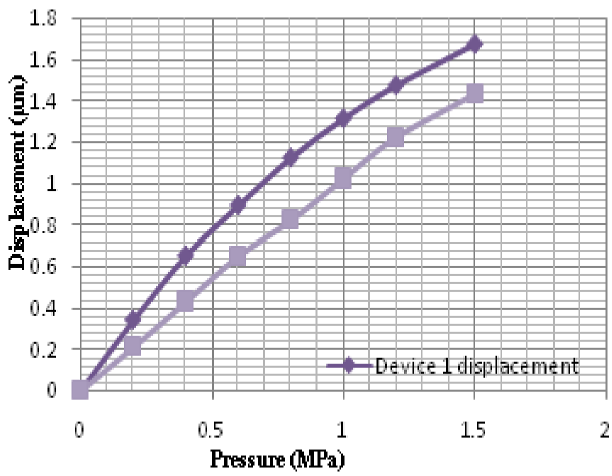

Figure 6: Pressure vs Displacement

5.4 Voltage versus Capacitance

In this analysis, we check the behavior of capacitance as we increase voltage at lower levels on regular intervals. After getting the results as shown in Figure 7, we found that there is no change in the capacitance of device when we increase the voltage to device.

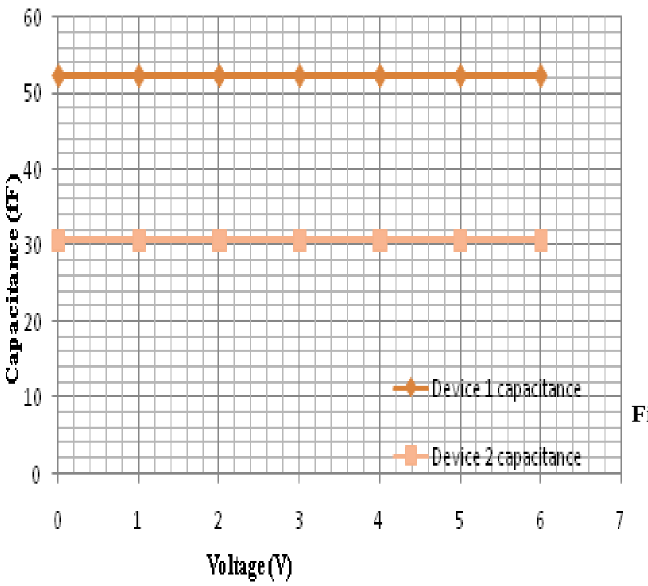

Figure 7: Voltage vs Capacitance

5.5 Pull-in Analysis

In this analysis, we apply the high Voltage to the device and check the behavioral displacement of diaphragm to substrate. When we apply the voltage of about 0 V and increase it step by step of 100 V to 1000 V then the diaphragm starts falling into downward direction and after reaching its maximum limit of stressing the diaphragm going to damage itself when we increase the voltage level after this threshold point. As shown in the Figure 8 and Figure 9, the threshold voltage point of polysilicon diaphragm is less in comparison to the silicon nitride diaphragm.

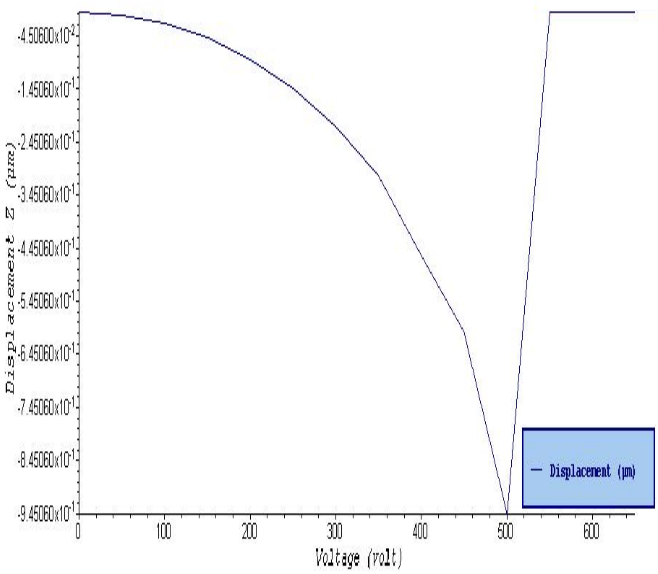

Figure 8: Device 1 Z-displacement Vs Voltage during pull-in analysis

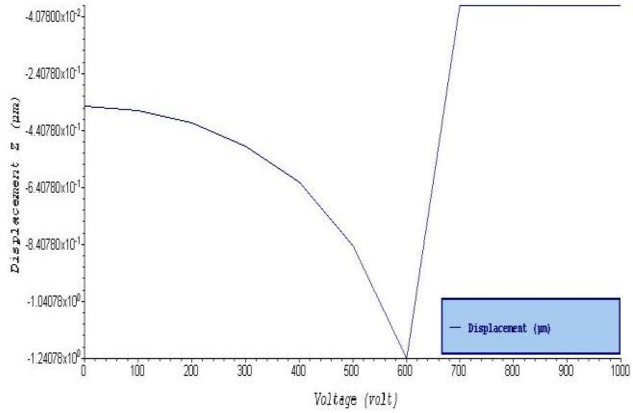

Fig. 9 Device 2 Z-displacement Vs Voltage during pull-in analysis

VI. CONCLUSION

This capacitor shall be easy to construct as well as sensitive to human touch, so it acts as an alternative to mechanical buttons and switches.

The various issues in fabrication, designing and system modeling of integrated pressure sensor devices are analyzed and it has been observed that the device made of silicon nitride diaphragm has more stiffness and able to tolerate the higher voltage shock upto 600 V rather than 500 V in comparison to the polysilicon diaphragm device. But the polysilicon diaphragm device is more sensitive to pressure because this gives more capacitance in comparison to the silicon nitrite diaphragm device. This capacitance is easy to calibrate by using driver electronics. Where all changes in corresponding capacitance will calibrate to output specific voltage changes. These voltages are scaled to represent specific changes in gap size due to pressure.

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