© August 2022| IJIRT | Volume 9 Issue 3 | ISSN: 2349-6002

Design, Modeling and Simulation of Nems Based Capacitive Sensor for Medical Pressure Sensing Applications

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***Abstract* - For a quality of life, health plays an important role for our healthy lifestyle. In hospitals to keep eye on patients of diseases like variation in Blood Pressure, changes in Respiration Rate and Asthma and many more, requires continues monitoring of their health activities. Pressure is a important parameter in human being, which can reveal health conditions. Therefore, it is very important to monitor patient’s pressure levels. There are lot of pressure sensors designed in past to monitor the pressure levels in humans. The work presented here, is a design on NEMS based Capacitive Pressure Sensor with high sensitivity and accuracy. The sensor is made up of two plates, a flexible Silicon and a fixed Steel and a dielectric Silicon dioxide (SiO2) .The designed senor is able to perform excellently over pressure ranges of up to 0 to 40KPa.**

***Index Terms* - NEMS, Capacitive Sensors, Pressure Sensors, Medical Applications.**

I.INTRODUCTION

The process technology that creates an integrated system or tool to combine the components such as electrical and mechanical at Nano scales is NEMS. The technique that uses to fabricate the components is by using an integrated circuit batch processing method. The properties of materials can be measured in Nano scale. The NEMS technology that fabricate both the electrical and as well as the mechanical components or parts on a single isolated chip using an accurate manufacturing technology that function according to embedded system principle [1]. The NEMS technology is trending and growing rapidly in market day by day due its absolute features and properties. The different types of the parts like diodes, insulators, transistors etc. can be used as electronic components. The capacitors, resistors, inductors, conductors can be used as electric components. The cantilever, diaphragm, spring, gear, bearing can be used as mechanical components. The main building blocks of NEMS are sensors, actuators and microcontroller [2]. These sensors and actuators acts as the transducers which transform one form of energy into other form. The speedy growth of NEMS pressure sensors has been very rapid over last decades due to its amazing characteristics that the technology possesses. The recent study reveals that the MEMS & NEMS pressure sensors global market awaits to marks great heights [3]. Appreciable growth has been reached in the evolution of MEMS/NEMS pressure sensors over last decades. The market for MEMS/NEMS is growing not only in automotive, industrial, utility and aviation but also in medical fields [3]. Piezoelecttric, capacitive, piezoresistive and resonance-based NEMS pressure sensors using signal transduction mechanism are being universally used in medical applications. Piezoelectric pressure sensor is widely used pressure sensor, but it suits high pressure measurements. Capacitive pressure sensors are well suited ofr low pressure sensing applications and hence are in use in medical fields. Capacitive pressure sensor is the type of pressure sensor in which the changes in capacitance of a sensor can be detected by the variation or movement of diaphragm when the pressure is applied on it [4]. They can be used in medial field, home appliances, wearable electronics equipment’s and automotive electronics etc. The NEMS capacitive pressure sensor acts as a parallel electrode capacitor [4], and the capacitance can be expressed as (for a linear range only),

$$C= (\varepsilon 0.\ \varepsilon r.\ A)/d \qquad (1)$$

Where,

ε0 is represented as absolute permittivity of dielectric substance. εr is represented as relative permittivity of free dielectric path. 'A' represents the area of surface. 'd' represents the gap between the electrodes [4]. Pressure sensors can be classified as absolute and relative. Fig 1. Presents a simple capacitive relative pressure sensor, where a pressure is sensed with respect to a reference pressure.

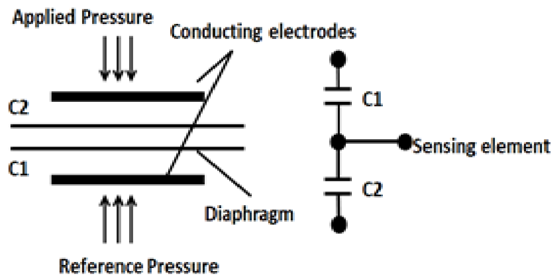

Fig. 1 Parallel Plate capacitor theory

The fabrication of device is made as it is done for ICs batch processing method, which makes the device mass productive with low cost. Manufacturing of device requires only few materials which operates or performs on less power supply. The device is made up of minute electrical and mechanical parts on an isolated chip which make the device compact. NEMS devices deliver the best and effective performance at minimal size [5]. In the paper, design and simulation of NEMS based capacitive pressure sensor is presented. Which provide high sensitivity and is well suited for medical pressure monitoring.

II. RELATED WORKS

The work presented in [6], represents the development of MEMS based capacitive pressure for Respiration Rate (RR) measurement of a human being. The sensor is designed and fabricated using two parallel plate capacitor schemes. The two plates (diaphragm) in which top one is movable and bottom one is fixed and dielectric is placed in between these plates. The deflection in the diaphragm when pressure is applied on a sensor causes change in capacitance. This scheme is developed for continues monitoring of a human respiration rate. The sensor is placed below the right and left nostril of human. The input to the sensor is the person's breath which cause changes in the diaphragm thus can measures the respiration rate changes continuously. The sensor is capable for identifying the normal respiration rate (18.5 + 1.5 bpm) of a human. Paper [7] represents the design and fabrication with a new scheme of TMCPS (Touch Mode Capacitive Pressure Sensor) which can be used in medical application. The design, fabrication and simulation of TMCPS is based on the surface micromachining fabrication method. It is made up of two electrodes (plates), the top electrode is made up of aluminum films or Polysilicon and the dielectric material can be air/SiO2 or air/undoped poly. The bottom electrode is fixed. The material capped with think polyimide films with 1.5um thickness. The touch point increases if the applied pressure increases. The capacitance of device will effect from touching area with high sensitivity of the device and touch point pressure. This type of TMCPS can also be used in biomedical applications. Paper [8] represents the process technology that creates an integrated system or tool to combine the components such as electrical and mechanical at micro or nano scales is a MEMS. Better simulation of the device depends on the type of software used; this paper presents the different types of software from their initial history to their features, applications, design, analysis, simulation process and major modules used for simulation process. The MEMS simulation software's are such as ANSYS, INTELLISUITE, COMSOL Multiphysics, Coventor, MEMS Pro, MEMS Solver and SUGAR. Preprocessing MEMS simulation software's are Math CAD, Layout Editor Mentor work and Auto CAD. Post processing MEMS software's are Verilog, MEMS+, Matlab, Simulink, SPICE, Mathematics and Matlab and much more. Paper [9] represents, for a quality-of-life health plays an important role, for continues monitoring the patient health care situations. The continuous monitoring devices like sensors need to be incorporated in the hospitals which monitor the different activities of patient's health. This paper presents, the design of continues monitoring of Respiratory condition of patients using MEMS capacitive pressure sensor. This type of sensor is able to detect the continues change in the respiratory condition of patients. The design of sensor is of cylindrical channel with an inlet and outlet and a cantilever has been isolated inside the cylindrical channel. Paper [10] represents the detection of the beat-to-beat blood pressure monitoring using capacitive pressure sensor. The sensor is made up of highly wrinkled Au (wAu) fine films to incorporate the flexible and stretchable electrodes on a elastomeric substance. Dielectric will be the air between these parallel plates combination sensor. The integration of polymer with wrinkled films creates a robust combination. The parallel plated comes closer together when the radial artery of human enhanced the pressure on the sensor. This sensor allows continues monitoring for arterial pulses with high sensitivity. The sensitivity with applied pressure increases up to 0.148kPa-1 with input pressure range of 10kPa. This type of soft wearable pressure sensor using the fine wrinkled gold films will be best suited for the continues beat to beat blood pressure monitoring of patients in hospitals. The sensor is able to work good throughout the pressure measurement. Paper [11], presents complete simulation study of different types of capacitive pressure sensors and provide a critical review on the performance of the same. Paper [12], presents a NEMS based Nano capacitive pressure sensor for medical applications. Papers [13-15], provide a lot of information on design and development of NEMS/MEMS based capacitive pressure sensors. These works mentioned here provide base for the sensor designed and presented in the paper.

III. DESIGN OF NANO CAPACITIVE PRESSURE SENSOR

There are various papers on design and development of nano-capacitive pressure sensors, which are used for medical applications. In this work, using theory of thin plates a NEMS based capacitive sensor is designed and simulated with the sensitivity of 2.5X10^-6pF/kPa with the applied pressure range of 0 to 40kPa. The sensor is designed using a parallel electrodes (plates) capacitor theory using three different types of materials which acts as electrodes. The top electrode is made up of Silicon (Si), the bottom electrode is made up of Steel Base AISI 4303 and the dielectric in-between these two plates is Silicon Dioxide (SiO_2). The designed sensor is simulated using COMSOL Multiphysics. Designed sensor dimensions for three capacitor plates are listed in the TABLE I. The complete designed model of the sensor is shown in Fig. 2.

TABLE I DIMENSIONS OF DESIGNED SENSOR

Parameters	Size
Length	300nm
Width	300nm
Height	5nm
Gap between two Plates	5nm

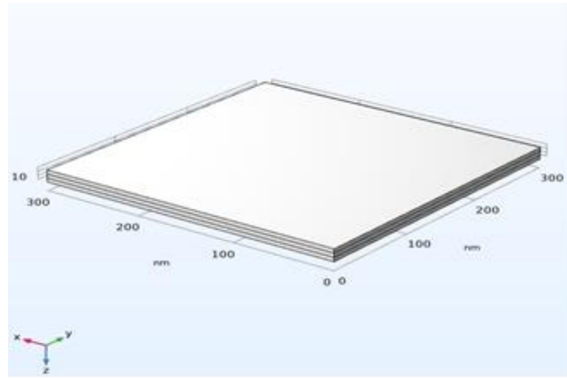

Fig. 2 Capacitive Pressure Sensor Model

Choosing of materials with their enhanced properties suited for medical application plays an important role for development of a sensor with high sensitivity. The model in Fig. 2 is simulated using electromechanics physics in COMSOL Multiphysics simulation software. For simulation, a square diaphragm is taken since it has better distribution of strain and stress. The size of the model and the materials properties used for simulation are mentioned in TablesI & II respectively. The sensor is meshed for the FEM analysis using free tetrahedral meshing and the same is shown in Fig. 3. In the simulated sensor, top plate boundary conditions: a known variable pressure is applied and a temperature of 25 °C is maintained, while 0 to 40kPa of pressure is applied. The sensor is biased using 1V of external voltage. Each plate is of 300nm Width, 300nm Length, 5nm Height and gap between two plates is 5nm.

TABLE II MATERIAL PROPERTIES

Materials	Density	Young's Modulus	Poisson's Ratio	Relative Permittivity
Silicon	2329[kg/m^3]	170e9[Pa]	0.28	11.7
Steel base	7850[kg/m^3]	205e[Pa]	0.28	1
Silicon dioxide	2200[kg/m^3]	70e9[Pa]	0.17	4.2

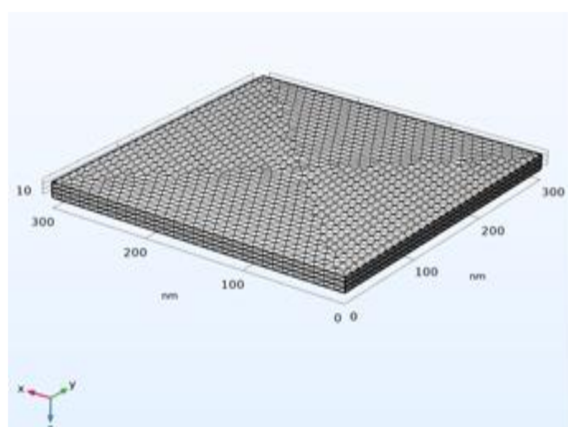

Fig. 3 Capacitive sensor mesh model

IV. RESULTS AND DISCUSION

The designed NEMS capacitive pressure is simulated for its performance parameters like displacement and capacitance. The model is simulated for pressure ranging form 0 o 40KPa, which suits medical applications. A known pressure on 0 to 40KPa is applied on top diaphragm of the sensor and the sensor provides relative displacement of the diaphragms leading to change in capacitance. Simulated Capacitive Pressure Sensor model is verified for both simulated and theoretical values using mathematical calculations for displacement and capacitance. TABLE III shows the simulated values of displacement with applied pressure ranges from 0 to 40kPa. TABLE IV shows the simulated and theoretical values of capacitance values.

TABLE III DISPLACEMENT RESULTS

Pressure[kPa]	Simulated values
0	2.74X10^-12
5	1.01X10^-11
10	2X10^-11
15	3X10^-11
20	3.99X10^-11
25	4.98X10^-11
30	5.97X10^-6
35	6.96X10^-6
40	7.95X10^-6

TABLE III CAPACITANCE RESULTS

Pressure[kPa]	Simulated value	Theoretical values
0	3.3469X10^-12	0
5	3.3469X10^-12	1.1458X10^-13
10	3.3469X10^-12	5.732X10^-12
15	3.3469X10^-12	3.824X10^-12
20	3.3469X10^-12	2.865X10^-12
25	6.6938X10^-12	2.291X10^-12
30	6.6938X10^-12	1.910X10^-12
35	6.6938X10^-12	1.637X10^-12
40	6.6938X10^-12	1.432X10^-12

Fig. 4 shows the side view of designed capacitive sensor model. Fig. 5, shows the complete NEMS based capacitive pressure sensor portraying the displacement. The change in displacement also makes changes in capacitance of the sensor. The sensor's displacement exhibits linear behavior with the applied input pressure on it. The capacitance, however, fluctuates nonlinearly. The results are further addressed in the next subsection. Fig. 6 depicts the displacement v/s applied pressure graph. In the graph, it is possible noticed that the displacement changes linearly with the applied pressure. The sensor's largest displacement at 40 kPa has a value of 0.007nm. Fig. 7 shows the capacitance v/s applied pressure graph. This illustration demonstrates that the capacitance changes nonlinearly as input pressure is 40kPa applied, at this heights pressure, capacitance is around 6.6938pF.

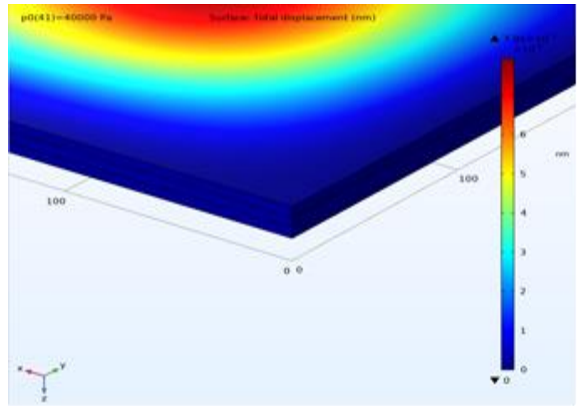

Fig. 4 Side view of capacitive pressure sensor model

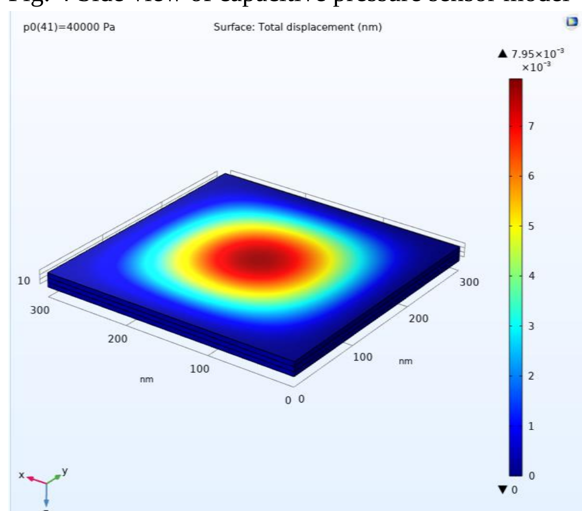

Fig. 5 Capacitive pressure sensor displacement model

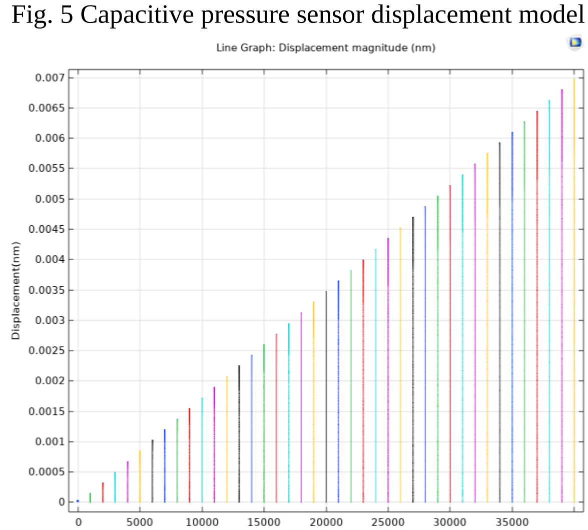

Fig.6 Simulated displacement graph

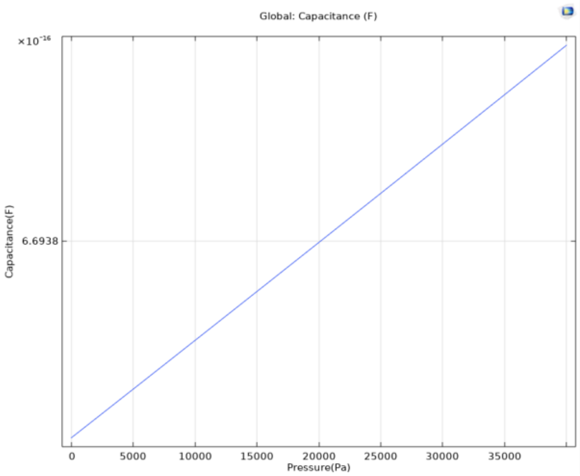

Fig.7 Simulated capacitance graph

V. CONCLUSION

In this paper, an approach of developing NEMS based nano Capacitive Pressure Sensor design, analysis and simulation using a COMSOL Multiphysics for medical pressure sensing is presented. The sensor designed is fully scaled down at Nano scale. The sensor is made of materials like Silicon (top electrode), Steel AISI 4340 (bottom electrode) and Silicon dioxid (SiO2) as dielectric. The sensor is evaluated using different values of input pressure ranges which best suits for healthcare applications to achieve higher sensitivity. With input pressure being applied ranging from 0 to 40kPa, the sensor displacement and capacitance are evaluated. The sensor is able to produce sensitivity up to 2.5X10^-6 pF/kPa. This type of sensors model can be used in healthcare devices, wearable monitor devices, and wearable touch devices.

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