ISSN: 2321-8169
95 - 98

Design and Simulation of MEMS Cantilever based Capacitive Sensor

T. Sarath[1]
School of Electronics Engineering
Vellore Institute of Technology University
Chennai, India
turaga.sarath7@gmail.com

D. Chakradhar Rao[1]
School of Electronics Engineering
Vellore Institute of Technology University
Chennai, India
rao199325@gmail.com

Y. G. S. S Sai Charan[1]
School of Electronics Engineering
Vellore Institute of Technology University
Chennai, India
charanyashwanth@gmail.com

Dr. S. Annaiah Durai[2]
School of Electronics Engineering
Vellore Institute of Technology University
Chennai, India
annaiahdurai.s@vit.ac.in

Abstract- As the technology has grabbed a lot of attention, the micro-electro-mechanical-system(MEMS) cantilever based capacitive sensors are promising devices with good performance. These are also capable of observing the temporal effects of the environment and to calibrate the values in order to provide information regarding the physical parameters by studying the deflection of the cantilever structure. In this work, a MEMS based capacitive sensor is designed, which while bending provides a movement of the cantileverwhen it is subjected to applied pressure by means of external factors. Toestimate the cantilever performance and to obtain an application specific design of the parameters, finite element analysis simulations were performed using COMSOL Multiphysics.

Keywords— *MEMS, Cantilever, Capacitive sensor, Comsol, Displacement*

*****

I. Introduction

Micro-electromechanical sensors are widely used in industry, civil, defence applications, and can present serious medical, environmental and explosion dangers [1-3]. They are capable of converting any kind of change into electrical responses and can precisely detect, amplify and measure the response [2]. One of the methods used is, the cantilever beam as a sensing element. Cantilevers are the most favourable devices that bend when a pressure is applied and results in to
an oscillation similar to a spring as shown Fig.1. Thereby it is used for the detection of different parameterswith relatively good sensitivity [4-6]. In our work we have designed a MEMS cantilever based capacitive pressure sensor with fixed dimensions using COMSOL Multiphysics. The behaviour of the sensor at different pressure and the charge, displacement related to it were determined. The capacitive sensors are designed to operate by generating an electrostatic field and detecting changes in this field caused when an object approaches the sensing area [7-10]. Designing a capacitance sensing system requires first choosing the type of sensingmaterial[12]. We have chosen gold as the sensing element on the top of the cantilever.

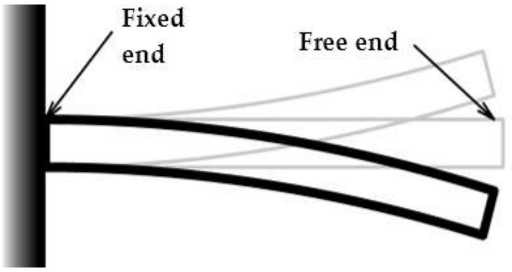

Fig.1. Simple cantilever

II. Finite Element Analysis Using COMSOL Multiphysics

COMSOL is a finite element analysis CAD tool package for various physics and engineering applications. This program is taken as the simulation tool in this study as it provides predefined user interfaces with associated modelling tools. In the simulation one end of the cantilever has been made as a fixed constraint and the other as a free. The top portion of the cantilever can be coated with different materials. In adetection process, the sensing element over the top of the cantilever beam reacts either due to the antigen or any other chemical interactions and in turn induces a surface stress over the beam thereby resultingin a tip deflection. The sensitivity can be measured by change in the capacitance value. To analyse different factors like sensitivity, stress, and deformation etc., a cantilever beam with dimensions of800, 10 um as the length and thickness respectively were declared as in Fig2.

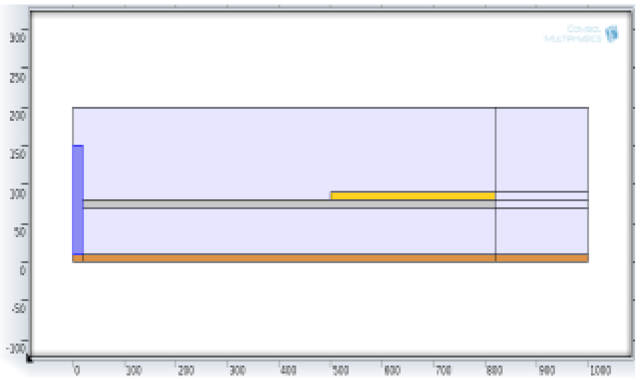

Fig.2. Two dimensional structure of Cantilever based capacitive sensor using COMSOL Multiphysics

ISSN: 2321-8169
95 - 98

III. THEORETICALAND STRUCTURAL MODELLING

A cantilever beamhas one of its endsfixed at one side. The beam bears the applied pressure to the support where it is kept out by moment and stress. When any event occurs on the top of the cantilever, a differential surface stress will be experienced by the lever which in turn causes a movement of the beam. Therefore tip displacement $\mathcal{Z}$ can be written as,

$$\mathcal{Z} = \frac{3(1-\vartheta)L^2}{T^2E}\,\delta s \qquad \text{- [1]}$$

Where **L** is the cantilever beam length, **T** is the cantilever thickness which was taken as 100um, $\boldsymbol{\vartheta}$is the Poisson's ratio, $\boldsymbol{\delta s}$is the differential surface stresswhich is nothing but the applied pressure, and **E**is the Young's modulus of elasticity which is a material property.

Electrostatic moment of bending that was induced in the beam with respect to the electrostatic force $\mathbf{F_E}$is expressed as,

$$-\mathbf{EI}\,\frac{d^2\,y(x)}{dy^2} = -\mathbf{F_E}(\mathbf{L}-\mathbf{x}) \qquad \text{- [2]}$$

Where **E** represents young's modulus, **I** being the moment of inertia and L is the total beam length. The solution of above equation is obtained by solving the second order ordinary differential equations that leads to the maximum displacement of the cantilever, which is given by,

$$\mathbf{y(L)} = \frac{F_E\,L^3}{3EI} = \frac{4\,L^3\,F_E}{Ewh^3} \qquad \text{- [3]}$$

The variation in the capacitance is given by,

$$\mathbf{C} = \frac{\varepsilon_0\varepsilon_r\,A}{d} \qquad \text{- [4]}$$

Where,$\boldsymbol{\varepsilon_r}$is the relative permittivity of the dielectric medium that was used in the sensor and in this work air will be acting as medium with $\boldsymbol{\varepsilon_r}$=1throughout the design, $\boldsymbol{\varepsilon_0}$is the free space permittivity, **A**being the cross-sectional area of the cantilever beam where the pressure interactions were being applied and **d**is the distance between the ground plane and the cantilever beam.

We have carried out computation and simulation on cantilever based capacitive sensor by assuming some fixedparameters. Here, we have considered the length of the cantilever beam as 800um with 10um as height and was realized using aluminium (Al) material. The sensing element is chosen to be gold (Au) with 500um length and 10um height and was placed over the beam. The support is supposed to be of insulating material and silicon dioxide (SiO_2) has served this purpose with having the fixed end of cantilever beam.

The entire sensor is enclosed and realized as a 2-D box with the dimensions of 1000um X 200um and was filled with air as a dielectric medium. On the other hand to bring out a complete structure of parallel plate capacitor, the ground plane is of copper (cu) material with 1000um X 10um as dimensions.

Finally a cantilever based parallel plate capacitive sensor was built with extra fined tetrahedral as mesh consisting of Al and Cu planes acting as two parallel plates and air as a dielectric medium.

IV. RESULTS & DISCUSSIONS

The movement of the cantilever is effected by its length, height, and various properties and parameters of the material used to make the structure of the sensor. In the simulation the stress on the cantilever surface is defined as the input. These process carterswith the pressure applied on the surface that corresponds to the surface stress appearing on the real cantilever during any detection process.

The sensitive detection of the targeted elements is attained by evaluating the deflection. The tip displacement values of the cantilever in reference with the applied pressure that are varied between 1kpa to 15kpa with an applied voltage of 40V to the cantilever beam as in fig.3, 4 ,5 and fig.6.

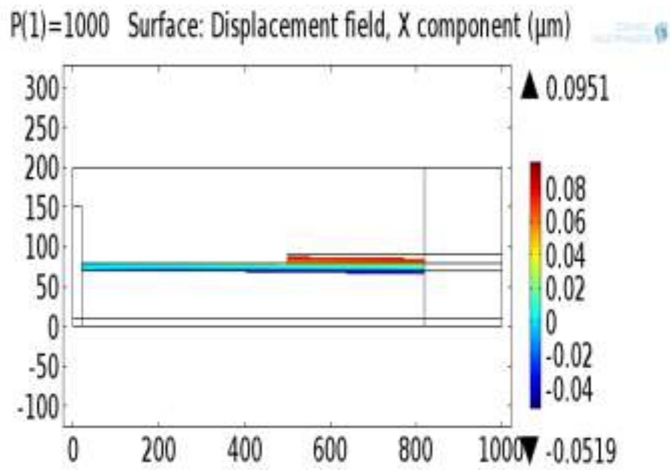

Fig.3.Displacement of the cantilever beam for the applied pressure of 1000 Pa

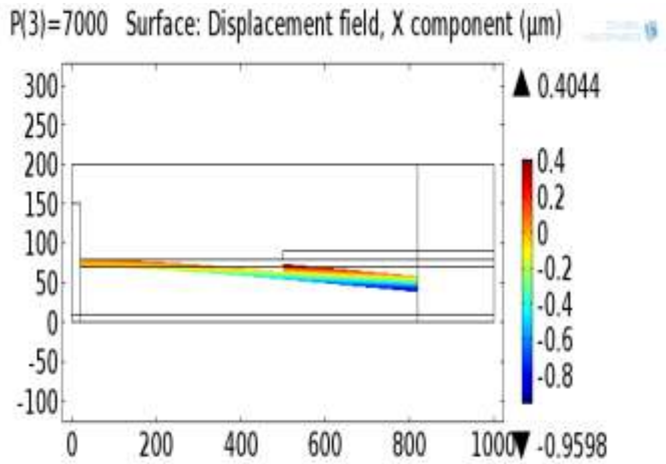

Fig.4.Displacement of the cantilever beam for the applied pressure of 7000 Pa

Here in the above case we can clearly observe the deflection of cantilever when the stationary analysis is performed at the bottom tip of the cantilever beam.

ISSN: 2321-8169
95 - 98

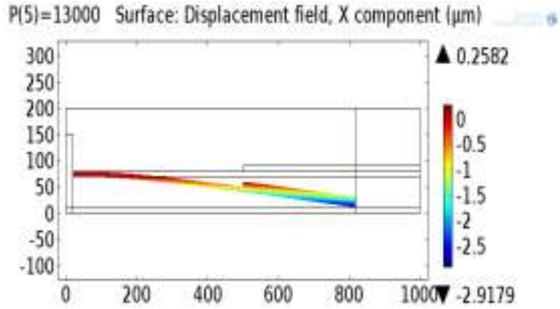

Fig.5.Displacement of the cantilever beam for the applied pressure of 13000 Pa

Here we can observe the maximum displacement of the beam. On further increase of pressure the displacement of the beam increases. A cutoff point for the increment in the pressure is obtained, where the beam gets further deflected and touches the ground plane and gets short circuited.

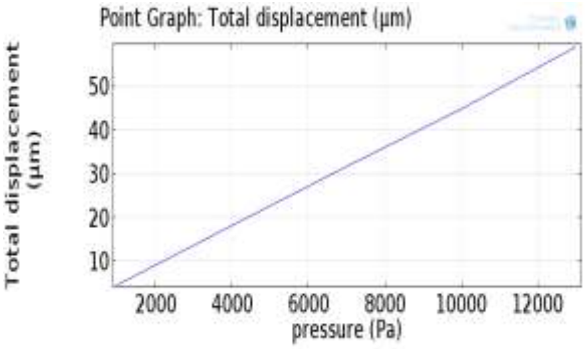

Fig.6. Applied Pressure vs Displacement of the cantilever beam

The above point graph demonstrates the linear increment of applied pressure and displacement and where the distance between the parallel planes has being reduced and this results in the change in capacitance.

A typical capacitor is composed of two conductive objects with a dielectric. A voltage difference applied between these objects results in an electric field between them. This electric field exists not just directly between the conductive objects, but elongates some distance away; these is known as a fringing fields. The electric field or the potential distribution throughout the device at different pressures are reported in fig. 7, 8 & 9.

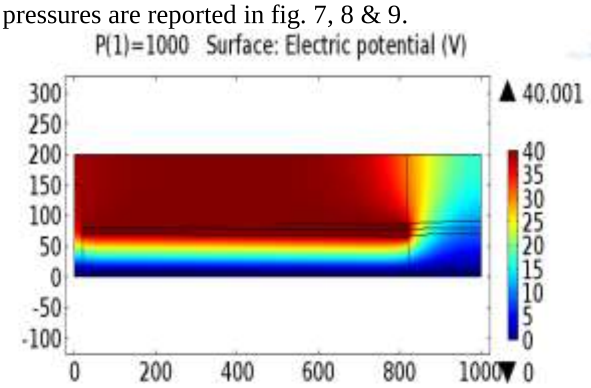

Fig.7.Electric field distribution in the sensor for the applied pressure of 1000 Pa

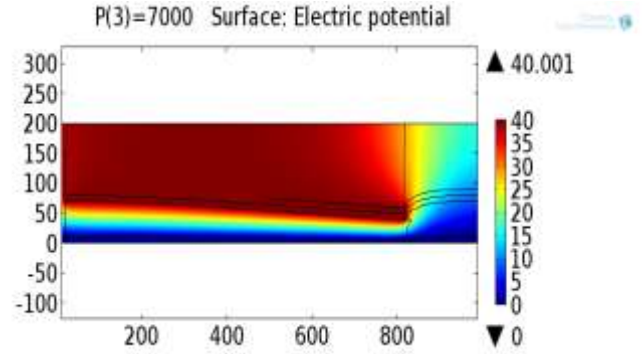

Fig.8.Electric field distribution in the sensor for the applied pressure of 7000 Pa

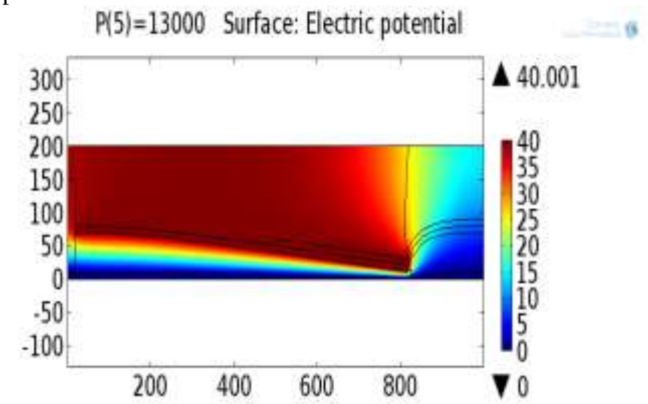

Fig.9.Electric field distribution in the sensor for the applied pressure of 13000 Pa

The cantilever beam is developed with the sensing element on top of it. The parameters like pressure and voltage are applied on it. The sensing element senses with the targeted elements which incorporates gases, chemicals and other biological components like antibodies i.e., antigen interactions.

These would provoke a surface stress on the top beam, which produces a deflection of the beam and in turn produces a change in the capacitance. The sensitive detection of the targeted elements is attained by evaluating the deflection. Figs. 10 & 11show the simulated sensor characteristics in terms of change in capacitance (C) and terminal charge (Q) vs. applied pressure (P).

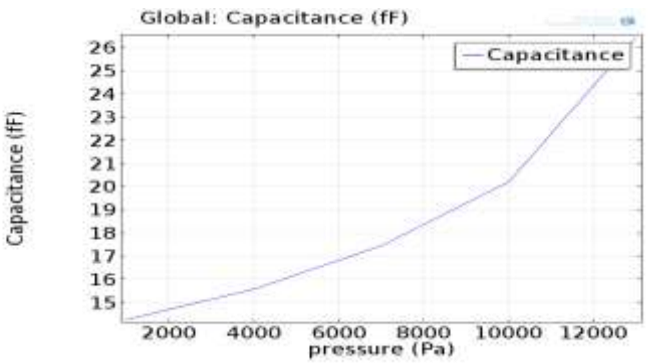

Fig.10. Capacitance produced for the applied pressure range 1000Pa to 13000 Pa.

The capacitive sensing range of the cantilever sensor for the applied pressure varying from 1 to 13 kPawas found to be 10 to 26 fFand were increasing proportionally.

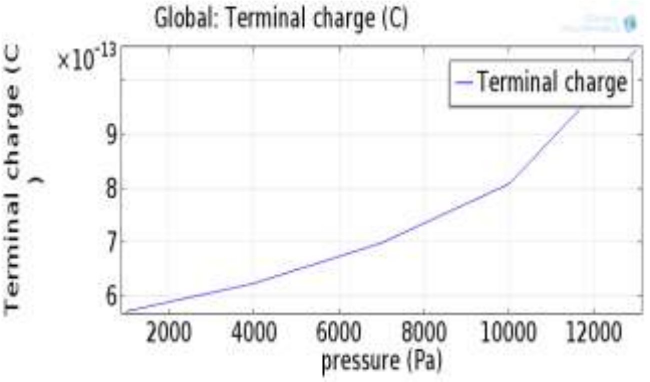

Fig.11. Increase in charge with an increase in pressure

A similar characteristic can be obtained for the terminal charge on the parallel plate for the increase in applied pressure as the capacitance is linearly proportional to the charge for a constant applied voltage of 40V and was found to be 4X 10^{-13}C to 11 X 10^{-13}C.Thus the applied pressure equivalently produces a deflection and sequentially the capacitance will be set up resulting in charge accumulation.

V. Conclusion

In summary we have provided a structural model and analysis of the cantilever with the specified dimensions was designed with aluminium as the beam material and a gold layer over it. Thecantilever based capacitive pressure sensor is simulated and the performance is characterized for a range of pressure loads by using stationary analysis.The model is used to compute capacitance by using different materials.Further works onvariation of the beam dimensions, the sensitivity of the sensor and the Eigen frequencies might show a better picture for effective sensing and optimizing the device performance.

VI. References

[1] Wei Zhoua, Abdul Khaliq, Yanjun Tang, Haifeng Ji, Rastko R. Selmic, "Simulation and design of piezoelectric micro-cantilever chemical sensors", *Sensors and Actuators A 125* (2005) 69–75, 2005 Elsevier.

[2] Shuaipeng Wang, Jingjing Wang, Yinfang Zhu, Jinling Yang, Fuhua Yang," A new device for liver cancer biomarker detection with high accuracy", 2004 Elsevier.

[3] AnjaBoisen, Thomas Thundat, "Design and fabrication of cantilever array biosensors", *Material today*Volume 12, Issue 9, September 2009

[4] www.comsol.co.in/videos

[5] Muhammad Shoaib, Nor Hisham, Noohul Basheer, Mohammad Tariq, "Frequency and displacement analysis of electrostatic cantilever based MEMS sensor", *Analog Integrated Circuits and Signal Processing*, Springer 2016.

[6] AnaniahDurai Sundararajan and S. M. RezaulHasan,"Elliptic Diaphragm Capacitive Pressure Sensor andSignal Conditioning Circuit Fabricated inSiGe CMOS Integrated MEMS",*IEEE SENSORS JOURNAL, VOL. 15, NO. 3*, MARCH 2015.

[7] A.Preethi,L.Chitra,"Comparative Analysis of Materials For the Designof a highly Sensitive Capacitive Type of MEMSPressure Sensor",2014 *IEEE transactions.*

[8] Suryansh Arora, Sumati, Arti Arora, P.J.George, Design of MEMS bases microcantilever using comsol Multiphysics, *International Journal of Applied Engineering Research*, ISSN 0973-4562 Vol.7 No.11 (2012).

[9] S. R. Munnangi, G. Haobijam, M. Kothamasu, R. Paily* and R. S. Kshetrimayum, CMOS Capacitive Pressure Sensor Design andIntegration with RFID Tag for BiomedicalApplications, 2008 Elsevier.

[10] Monika Chaudhary and Amita Gupta, Microcantilever-based Sensors, *Defence Science Journal, Vol. 59, No. 6,* November 2009, pp. 634-641, 2009, DESIDOC.

[11] Joan Bausells, Piezoresistive cantilevers for nanomechanical sensing, 2015 Elsevier.

[12] SriguruJaydevKrushnadasKar, BijayakumarSahoo ,SakuntalaMahapatraTanmay Kumar Das, DETECTION OF ANTIGEN BY CANTILEVER SENSOR,*ISSS National Conference on MEMS, Smart Materials, Structures and Systems* September 06-07, 2013.

[13] M. Zimmermanna,T.Volden,K.-U.Kirstein,S. Hafizovic,J.Lichtenberg,OliverBrand,A. Hierlemann,A CMOS-based integrated-system architecture for a static cantilever array,Sensors and Actuators B 131 (2008) 254–264, 2007 Elsevier.

[14] A.A. Vasiliev,A.V. Pisliakov, A.V. Sokolov, N.N. Samotaev, S.A. Soloviev, K. Oblov,V. Guarnieri, L. Lorenzelli, J. Brunelli, A. Maglione, A.S. Lipilin, A. Mozalev,A.V. Legin,Non-silicon MEMS platforms for gas sensors, Sensors and Actuators B 224 (2016) 700–713, 2015 Elsevier.