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DESIGN OF MEMS PRESURE SENSOR FOR ENVIRONMENTAL APPLICATIONS

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Abstract—**In this paper, the design and analysis of diaphragm based Micro-Electro-Mechanical Systems (MEMS) sensor for environmental applications is presented. Performance parameters like the maximum induced stress, deflection and sensitivity of the diaphragms have been compared using the INTELLISUITE software. In order to increase the sensitivity of pressure sensor, the membrane needs to be either thin or large to achieve good results. But there is tradeoff between stability, linearity and sensitivity. If membrane is thinner, the sensor structure is more unstable. With change in dimension and sensing material, better sensitivity can be observed.**

Keywords-- **MEMS, Micro Sensor, Diaphragm, Piezoresistor Displacement.**

I. INTRODUCTION

Pressure sensors are key part of many commercial and industrial systems. Pressure sensors can be fabricated either by bulk micromachining, surface micromachining or combination of both [1]. The pressure sensor works on the principle that deflection occurs due to an applied pressure on the diaphragm. The aim of this work is to model, compare and analyze the different performance parameters like deflection, voltage output and sensitivity. In first design, Silicon is the substrate material, Silicon Nitride is used as Diaphragm material and Zinc Oxide as sensing material [2]. The second set of design consists of Gold as sensing material with silicon oxide as dielectric layer [3]. The pressure sensor is found to maintain an appreciable output and sensitivity for all temperatures under consideration. In this study INTELLISUITE is used for simulating various structures in pressure sensor [4],[5].

II. SENSOR DESIGN

The substrate layer material used here is silicon .The area of both design is 150×100 μm^2 with thickness of the membrane as 5µm.The deflection is simulated and compared for the two diaphragms for an applied pressure range of 95-105 KPa. The design parameters of the pressure sensor include membrane size shape. The maximum deflection of the diaphragm is given by the equation,

$$W_{\max} = 0.01512 \times (1 - v^2) \times \left[\frac{P_a \times L^4}{E \times h^3} \right] \ldots (1)$$

Where, **W** max is maximum deflection, **V** is Poisson's ratio, **P** is applied pressure, **L** is the length of the diaphragm, **E** is young's modulus and **h** is diaphragm thickness. The maximum stress that a silicon diaphragm can withstand is 7GPa, which is equal to its fracture stress. Under normal operating conditions stress should never exceed the fracture stress of silicon. The deflection of a flat diaphragm under uniform pressure load can be found by solving the forth-order differential equation

$$\frac{\partial^4 \xi}{\partial x^4} + \frac{\partial^4 \xi}{\partial x^2 \partial y^2} + \frac{\partial^4 \xi}{\partial y^4} = \frac{p}{D} \ldots .(2)$$

where $\xi = f(x, y)$ denotes the displacement of the natural plane from its original position, **p** is the pressure loading force in the direction of ξ, and **D** denotes flexural rigidity of the diaphragm, which depends upon the modulus of elasticity **E** and Poisson's ratio **v** of the diaphragm material, and the thickness of the diaphragm **h** i.e.,

$$D = \frac{Eh^3}{12\left(1 - v^2\right)} \ldots\ldots (3)$$

A simplified solution for the maximum stress and deflection of the rectangular diaphragms with all edges fixed is

$$(w)_{\max} = -\alpha \times \frac{p.b^4}{E.h^3} \;\ldots. (4)$$

$$(\sigma_{yy})_{\max} = \beta \times \frac{p.b^2}{h^2} \ldots . (5)$$

Coefficients of maximum stress and deflection in a rectangular diaphragm are expressed as:

a/b	1	1.2	1.4	1.6	1.8	2.0	∞
α	0.0138	0.0188	0.0226	0.0251	0.0267	0.0277	0.0284
β	0.3078	0.3834	0.4356	0.4680	0.4872	0.4974	0.5000

If the conductor is subjected to a normal stress along the axis of the strain gauge, the cross sectional area and the length will change, resulting in a change of the total

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electrical resistance, **Re.** The total change in **Re** is due to several effects, as illustrated by

$$\frac{dR_e}{R_e}=\frac{dL}{L}+\frac{d\rho_e}{\rho_e}-\frac{dA}{A} \quad \ldots\ldots (6)$$

Which can be expressed in terms of Poisson's ratio v_x and v_y in the x direction and y direction respectively as

$$\frac{dR_e}{R_e}=\frac{dL}{L}\times(1+v_x+v_y)+\frac{d\rho_e}{\rho_e} \quad \ldots.\,..\ (7)$$

The gauge factor of a material is defined as the fractional change in resistance R_e of a material per unit strain **ε** i.e.

$$GF=\frac{dR_e/R_e}{dL/L}=\frac{dR_e/R_e}{\varepsilon} \quad \ldots\ldots (8)$$

III. MODELLING OF PRESSURE SENSOR

The Pressure sensor model was drawn using the 3D Builder module of the IntelliSuite. In this paper we discussed two different structures of pressure sensors with

1. Piezoresistive as sensing layer.
2. Gold electrode as sensing layer.

In first case, the level 0 represent the substrate, The diaphragm is suspended over the substrate by a gap of 5 µm supported by beams which forms the level 1.The diaphragm is at level 2 while the sensing layer is above this layer. The designed sensor was imported to Thermo Electro-Mechanical analysis tool for further static and dynamic analysis.

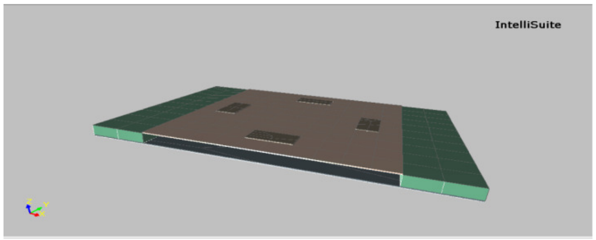


Figure.1 Pressure Sensor Model-1

In second case the sensor is composed of Silicon Nitride as diaphragm that deflects because of applied pressure. Over the diaphragm, Gold is deposited to form electrode and a fixed gold electrode is deposited over the silicon dioxide layer which acts as an insulating layer between electrode and substrate. The diaphragm and the substrate are separated by air gap and a thin layer of SiO2.

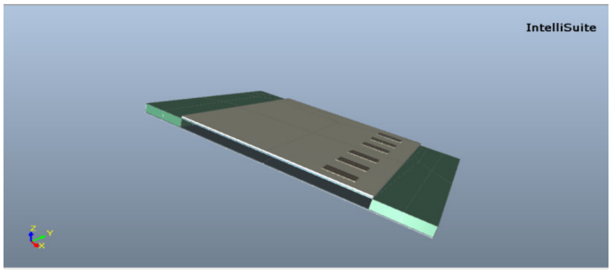


Figure.2 Pressure Sensor Model-2

IV. RESULTS AND DISCUSSION

TABLE-1
Dimension & Material Property of Model-1

LAYERS	DIMENSION (µm)	MATERIAL	YOUNG MODULUS (GPa)	POISSON RATIO	DENSITY (gm/cc)
Substrate	150×100×5	silicon	170	0.26	2.32
Diaphragm	100×100×5	Silicon Nitride	296	0.27	3.1
Sensing Layer	10×10×1	Zinc Oxide	123	0.68	5.606

TABLE-2
Dimension & Material Property of Model-2

LAYERS	DIMENSION (µm)	MATERIAL	YOUNG MODULUS (GPa)	POISSON RATIO	DENSITY (gm/cc)
Substrate	150×100×5	silicon	170	0.26	2.32
Diaphragm	100×100×5	Silicon Nitride	296	0.27	3.1
Sensing Layer	10×10×1	Gold	74.48	0.42	19.32
Dielectric Layer	100×100×0.1	Silicon Oxide	73	0.17	2.2

TABLE-3
Sensitivity Analysis of Pressure Sensor

Input Pressure (Kpa)	Existing Model		Proposed Model	
	Displacement (µm)	Sensitivity (m/pa)	Displacement (µm)	Sensitivity (m/pa)
95	0.00109338	0.01151 e -12	2.23619	0.02312 e-9
97	0.00111634	0.01151 e -12	2.28326	0.02331 e-9
99	0.00113993	0.01152 e -12	2.33034	0.02351 e-9
101	0.00116226	0.01153 e -12	2.37742	0.02353 e-9
103	0.00118522	0.01153 e -12	2.42454	0.02353 e-9
105	0.00120818	0.01154 e -12	2.47157	0.02356 e-9

SIMULATION RESULTS

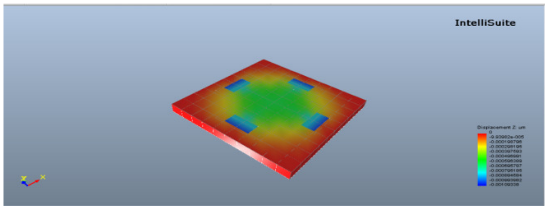


Fig.3 Model-1 (95ºC)

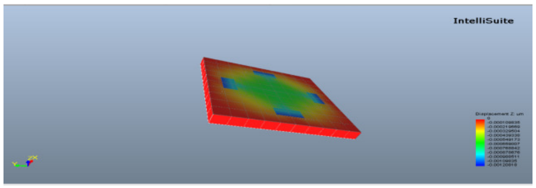


Fig.4 Model-1 (105 ºC)

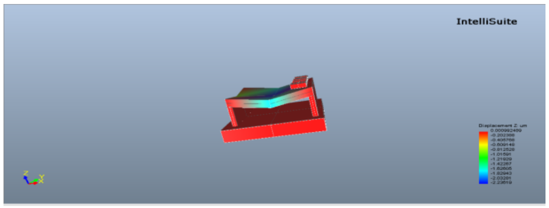


Fig.5 Model-2 (95ºC)

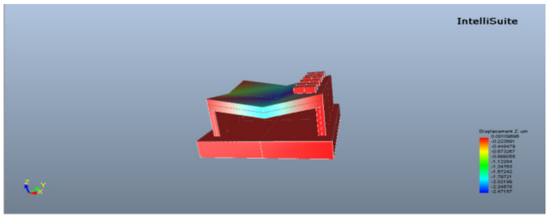
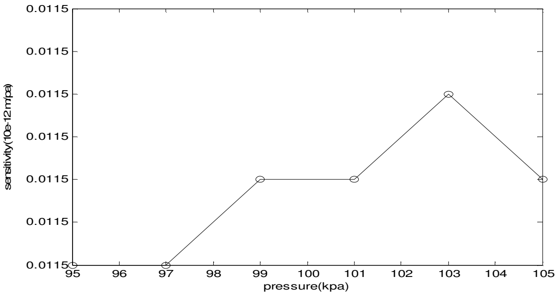
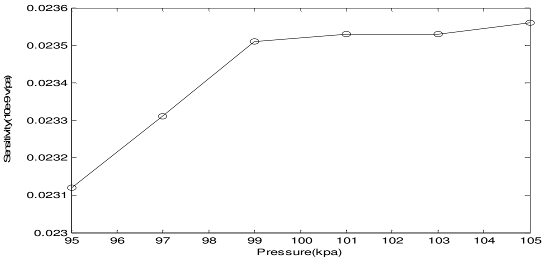


Fig.6 Model-2 (105ºC)

Sensitivity Analysis of Model 1



Sensitivity Analysis of Model 2



V. CONCLUSION

The effect of diaphragm geometry, materials and dimensions on the sensitivity of a pressure sensor has been analyzed using INTELLISUITE as finite element based tool. The sensitivity analysis for different pressure ranges presents an idea to utilize a Silicon wafer area in an optimum manner, when designing diaphragm type pressure sensors for different pressure ranges. From the analysis it is observed that Gold metal electrode shows better sensitivity than zinc oxide as sensing layer.

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