International Journal Of Computer Science And Applications Vol. 1, No. 3, December 2008
ISSN 0974-1003

A Comparative Performance Analysis Of Capacitive And Piezoresistive MEMS For Pressure Measurement

M.Z. Shaikh
Research scholar
JNTU Hyderabad
A.P, India
+91 9866666658
mzhaikh2003@yahoo.co.in

Dr. S.F. Kodad
Professor EEE Department
Aurora's Engineering College, Bhongir
+91 9866666660
kodadsf@rediff.mail.com

Dr. B.C. Jinaga
Rector JNTU, Hyderabad
A.P, INDIA
91+ 9848046931
jinagabc@gmail.com

ABSTRACT

The Paper describes the design and simulation of capacitive and piezoresistive MEMS for pressure measurement. Performance measurement parameters ie. Sensitivity and deflection of both the sensors are compared through simulated results. The comparison helps the user to know the suitability of sensors for various applications. It will also help manufactures to know the change in behavior and performance of a sensor due to change in geometrical parameters of the sensors such L/h ratio, thickness etc.

Keywords

Capacitive MEMS, Biomedical, Pressure

1 INTRODUCTION

1.1 MEMS Today and Tomorrow

MEMS devices are now making the world of the future a reality. Scientists have created "smart dust" where millions of miniscule MEMS sensors are spread over a military site and communicate information to humans or computers ready to interpret possible troop movements. "Smart roads" would have MEMS devices embedded in them, conveying information about the roadway, traffic and accidents to automobile mounted global positioning systems, allowing drivers to avoid problems and alerting highway workers to areas that are potential trouble spots. Today, MEMS are most commonly found as sensors in automobile airbags, but the devices are making extensive inroads into medical, aviation, defence, wireless and optical communications systems.

1.2 MEMS In Bio Medical

The foremost application for MEMS pressure sensors is the measurement of blood pressure. Catheters offer a significant opportunity for miniaturized invasive pressure sensors used, for example in angioplasty treatments to widen passageways.

Kidney dialysis machines, ventilation monitors and treatment of respiratory conditions are other applications for pressure sensors The ubiquitous biomedical applications of MEMS include the sensing of pressure and acceleration. Typically, the sensing element consists of a micro machined beam or diaphragm, which deflects in proportion to the measured. The extent of the microstructure deformation is then converted to an electronic signal that is then sent to Microprocessor circuitry for further processing or display. In implementation of an external blood pressure monitoring system, the pressure sensor is an integral part of an instrument that consists of a saline solution bag and tubing, to which the sensor is attached. The components are then connected to the patient to provide signals to a monitor. Fluid passes through the tubing into the patient and when the heart beats, a pressure wave moves up the fluid path and is detected by the sensor. In other implementations, especially when blood pressure must be measured internally, the sensing element is coated with an inert, compliant gel that transmits the pressure signal, but avoids direct contact between the MEMS device and body fluids and tissues.[4]

1.3 Difference Between Piezoresistive And Capacitive Principles

SENSING PRINCIPLES	
Piezo Resistive	Capacitive
Measure mechanical stress in doped resistor	Measure deflection (distance to other capacitor plate)
Diaphragm pressure sensor or	Diaphragm pressure sensor or
Bending beam due to volume forces(e.g acceleration - End forces (e.g Protein attached)	Bending bean due to - volume forces (acceleration) - End forces (e.g Protein attached)

1.4 Capacitive Sensor Principle

Capacitive sensors have at least one electrode moving under the input variable, which typically would be pressure, acceleration, or rate. While the simplest configuration is two flat electrode capacitors, the interdigitated silicon fingers. gained wide acceptance as an inertial sensor, as it allows for larger sensing capacitance.

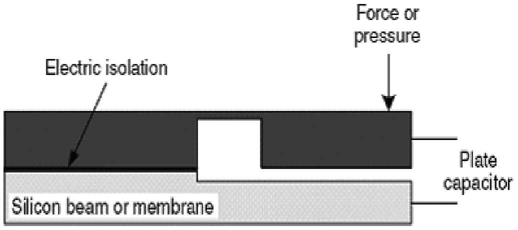


Figure1. Schematic of capacitive sensor

Capacitive pressure sensors use a thin diaphragm, usually metal or metal-coated quartz, as one plate of a capacitor. The diaphragm is exposed to the process pressure on one side and to a reference pressure on the other. Changes in pressure cause it to deflect and change the capacitance. The change may or may not be linear with pressure and is typically a few percent of the total capacitance. Using it to control the frequency of an oscillator or to vary the coupling of an AC signal can monitor the capacitance. It is good practice to keep the signal-conditioning electronics close to the sensor in order to mitigate the adverse effects of stray capacitance. Developments in silicon-based micro-machined technology have lead to several significant improvements in the performance and usability of capacitive pressure sensors. [2]

1.5 Diaphragm Pressure Sensors

Diaphragm based pressure sensors are a well-established technique for MEMS pressure sensors. The principle of the design is that pressure deflects the diaphragm until the elastic reaction force of the diaphragm balances it. The most common method of diaphragm fabrication is anisotropic wet silicon etching which allows a high degree of control of the diaphragm dimensions. Wet potassium hydroxide etching produces sidewalls in parallel to the<111> planes, i.e. 54.7° with a <100> wafer orientation. The diaphragm thickness is controlled by the etch time. An advantage of using silicon is its durability - it does not become plastically deformed and returns to its original dimensions and tension. Also, silicon diaphragms usually only fail due to rupturing. As a result pressure sensors are often designed to have a maximum range of one and a half times the pressure expected in a system. This is achieved by increasing the diaphragm thickness, but increasing thickness results in a loss of sensitivity by a factor of four for every doubling of diaphragm thickness. Devices are, therefore, regularly shielded in a stainless steel enclosure as a protective measure against rupturing. Bossed diaphragms (Figure 1) are also used extensively to increase the device sensitivity by increasing the rigidity of the diaphragm, therefore, inducing higher stresses than a non-bossed diaphragm for an equal deflection. Bossed diaphragms also enable improved linearity in the sensor.

1.6 Capacitive Pressure Sensors

Capacitive sensing mechanisms can readily be employed to realize pressure sensors, despite the fact that this mechanism is inherently non-linear (because capacitance is Inversely proportional to gap width). Since the membranes employed are typically clamped at all edges, the capacitance of Such membrane structures is not given simply by the parallel-plate capacitor equation, but it can be used as a crude starting point,

$C = \in x A/D$

This gives a ΔC in terms of change in gap width, δd, of,

$\Delta C = \in x A x \delta d / d$

An interesting example of a micro machined capacitive pressure sensor is an acutely Implantable blood pressure sensor developed at the University of Michigan [3]. They Fabricated pressure transducer membranes using boron-selective EDP etching of Structures that were anodically bonded to a glass substrate pre-etched to form cavities for lead attachment and metallized to form the lower capacitor plate and interconnections to Capacitive MEMS pressure sensors were first developed in the 1970's [3]. Capacitive sensors have high sensitivity, low power consumption and low temperature sensitivity. A cross section through a typical capacitive pressure sensor is shown in Figure 2

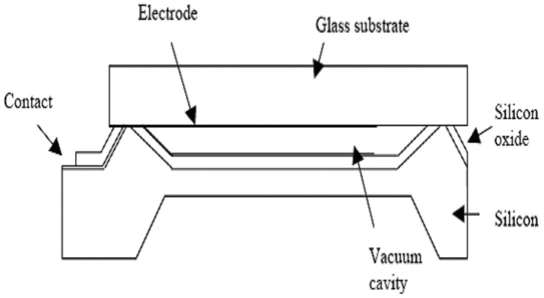


Figure 2. A cross section through a typical capacitive pressure sensor

2 CASE STUDY: COMPARATIVE STUDY OF PIEZORESISTIVE AND CAPACITIVE PRESSURE SENSORS

The study is based on the sensitivity and deflection of the pressure sensors, these two pressure sensors are having same square type diaphragm structures, these sensors are compared by keeping the pressure ranges equal and they are having same type of diaphragm structures. Various parameters responses have been observed in this comparative study.

2.1 2.1 Pressure Vs Sensitivity

2.1.1 PIEZORESISTIVE PRESSURE SENSOR:

(i) Pressure Vs Resistance

The sensitivity of piezoresistive sensor is given by [4]

$$S = \frac{\Delta V}{\Delta P} \cdot \frac{1}{V_{bias}} = \frac{\Delta R}{\Delta P} - \frac{1}{R} \quad \ldots\ldots\ldots \qquad (1)$$

Where

R = Zero Stress resistance

V_{bias} = Bridge Supply Voltage

ΔP = Differential Pressure change

ΔR = Change in Resistance

As per the relationship given in equation 1 the programs were written in MATLAB the pressure range is defined up to 0 to 1000 mmHg.The simulated results of which are shown in fig 3.

2.1.2 CAPACITIVE PRESSURE SENSOR:

The relative Pressure sensitivity of capacitive sensor is given by [2]

$$S_R(C)=\frac{1}{2(V_p-V_d)}\frac{dVout}{d_p}=\frac{2C_o+2C_p}{(C_o+C_x+2C_p)^2}\frac{dc_x}{dp} \quad \text{-- (2)}$$

Where

$S_R(C)$ = Relative Pressure Sensitivity

$\frac{dV_{out}}{d_P}$ = Voltage sensitivity

C= Pressure Sensitive capacitor and
C_0 = Reference Capacitor

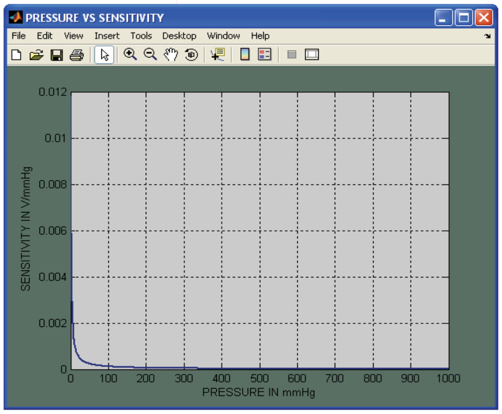
C_p= Parasitic capacitor

C_x= Capacitance formed by the Electrodes

The equation 2 is simulated using MATLAB and the results are shown in fig 3.

$$\frac{dc_x}{d_p}=\frac{Cx}{P}+\frac{1}{2}\frac{C_{xo}\frac{L}{W_o}}{P}\frac{\frac{L}{W_o}-\gamma 2+1}{(\frac{L}{W_o}-1+2\gamma 2-\gamma 4)(\frac{L}{W_0}-1)} \quad \text{----(3)}$$

2.1.3 RESULTS AND DISCUSSION PIEZORESISTIVE



CAPACITIVE

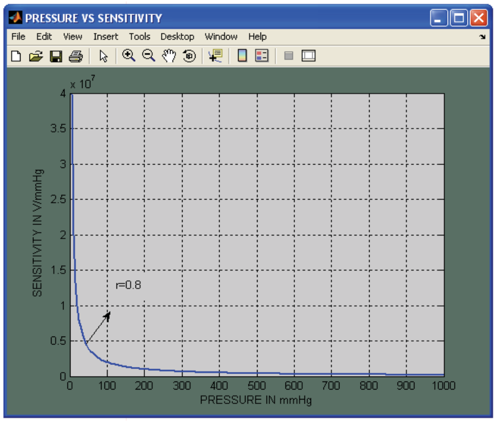


Figure3.Simulated Results of Pressure v/s Sensitivity

From the above graphs it can be observed that the sensitivity curve of piezoresistive is steeper than that of capacitive pressure sensor piezoresistive pressure sensor sensitivity changes up to 180 mmHg where as capacitive pressure sensor sensitivity changes up to 335mmHg. From this discussion it can be concluded that the sensitivity of capacitive pressure sensor is more than that of piezoresistive pressure sensor.

(ii) Pressure Vs Deflection

2.1.4 PIEZORESISTIVE PRESSURE SENSOR

The max deflection is given by [4]

$$\frac{\omega_{\max}}{h}=0.015121(1-v^2)\frac{P}{E}(\frac{L}{H})\text{\textasciicircum}4 \ \ldots\ldots \quad (4)$$

Where

$\frac{L}{h}$ = Ratio of diaphgram length to thickness

P= Pressure

E= Young's modulus

V= Poistion Ration

$\omega_{\max}$ = Maximum delfection

Fig shows how the ratio of diaphragm length to diaphragm thickness affects the maximum diaphragm deflection. The Larger L/h has larger deflection at the same applied Pressure. That is, Larger L/h has larger Pressure sensitivity. Where Pressure range is taken on X-axis and Wmax/h on Y-axis

2.1.5 CAPACITIVE PRESSURE SENSOR

The Deflection of the diaphragm is given by

ω_0=(PR^4)/49.6D ---------- (5)

Where ω_0= Maximum deflection is the flexural rigidity is given by

D = EyH³/12(1-υ²) --------- (6)

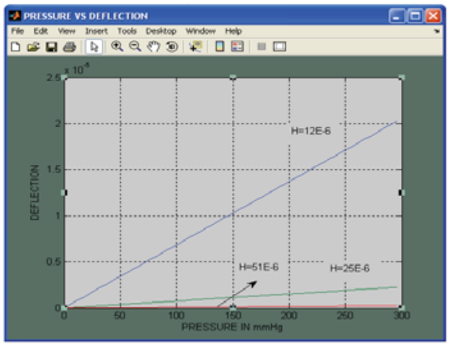
Where *Ey* = Young's modulus (1 *3 8* X 10" dyn/cm2 for ', 100) silicon)

W = Poison's ratio *(0.3* for silicon).

The equations 4,5,and 6 are simulated using MATLAB and results are shown in figure.4

3 RESULTS AND DISCUSSION

CAPACITIVE



Piezoresistive

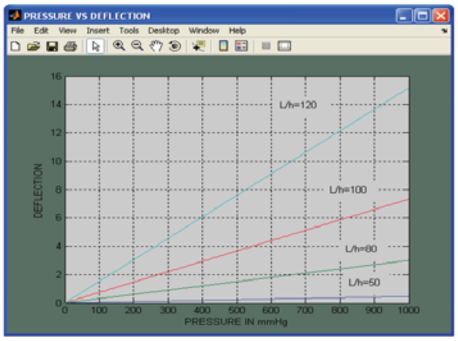


Figure: 4 Simulated results of pressure v/s deflection

From the above graph we can conclude that the smaller value of thickness has more deflection. Capacitive pressure sensor has larger pressure dependency due to which there is fast response in the deflection for minimum thickness than the piezo resistance sensor

4 CONCLUSION

In This paper the design and simulation details of a capacitive and piezoresistive MEMS are described against of certain performance analysis such as pressure v/s sensitivity and pressure v/s deflection. It is found from the results that capacitive MEMS are more sensitive than Peizoresistive. Capacitive MEMS are even more suitable for Bio medical applications such as blood pressure measurement.

5 REFERENCES

[1] Jithendra N Palasagaram and Ramesh Ramadoss,Mems capacitive pressure sensor array fabricated using printed circuit processing techniques

[2] Wen h. ko, fellow, ieee, min-hang bao, and yeun-ding hong ,A high-sensitivity integrated-circuit capacitive pressure transducer”

[3] Samuel k.clark and kensall d.wise member ieee, Pressure sensitivity in anisotropically etched thin-diaphragm pressur.e- sensors”

[4] 1Ranjit Singh, 1Low Lee Ngo, 1Ho Soon Seng, 2Frederick Neo Chwee Mok,

[5] A silicon piezoresistive pressure sensor”

[6] j aebersold1, k walsh2, m crain2, m voor3, m martin2, w hnat1, j lin2, d jackson2 and j naber2 ,Design, Modleing, Fabrication and Testing of a mems capacitive bending strain sensor”

[7] Lung-Jieh Yang1*, Chen-Chun Lai3, Ching-Liang Dai2, Pei-Zen Chang3,A piezoresistive micro pressure sensor fabricated by commercial dpdm cmos process.