PERFORMANCE ANALYSIS OF PIEZORESISTIVE MEMS FOR PRESSURE MEASUREMENT

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ABSTRACT

The paper describes the performance analysis and of design piezoresistive pressure sensorusing simulation technique. The piequ resistors are arranged in the wheat stone bridge configuration to achieve higher voltage sensitivity and low temp sensitivity The MFMS has been designed and simulated using MATLAB.This paper also discuses the simulations and the response from the MEMS.

Keywords: *MEMS, Matlab, pressure sensorusing, Simulation*

1.MEMS IN BIO MEDICAL

The MEMS technology to biomedical applications offers the potential to realize small and compact devices with sophisticated functionality. Biomedical application areas include diagnostic tools, surgical Instrumentation, artificial organs and drug delivery devices. Two 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. The foremost medical application for MEMS pressure sensors is the measurement of blood pressure. In one 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. [1]

2. PIEZORESISTIVE PRINCIPLE

If a strip of elastic material is subjected to tension (force), its longitudinal dimension will increase while there will be a reduction in a lateral dimensions. So when a gauge is subjected to a positive strain, its length increases while its area of cross section decreases. Since the resistance of a conductor is proportional to its length and inversely proportional to its area of cross section, the resistance of gauge increases with positive strain. The change in the resistance value of a conductor due to applied strain is called piezoresistive effect, [2]

2.1Guage Factor

Gauge factor is defined as the ratio of per unit change in resistance to per unit change in the length

$$\text{Gauge factor K} = \frac{\Lambda R / R}{\Lambda 1 / 1}$$

The resistivity of the material, this change can be an increase or decrease according to the orientation of the resistors. Typically, four piezoresistors are connected into a Wheatstone bridge configuration to reduce temperature errors.[3]

2.2 Piezoresistive Pressure Sensor

Piezoresistive pressure sensors use diffused or implanted resistors that measure the strain on a silicon diaphragm. This type of piezoresistive pressure sensor is widely available and is commonly used for applications in Biomedical field. A layout with the resistors placed on the edge of the diaphragm, orientated in the same direction and in a bridge configuration around a boss results in each resistor experiencing an equal and opposite force, improving linearity and minimizing temperature cross-sensitivity, because manufacturing tolerances on the resistors are relatively large, piezoresistive based devices often require the use of a temperature sensor and require calibrating or the use of a dummy bridge.

One commonly used method for improving device performance is the use of meandering resistor patterns. Improving the strain sensitivity. Silicon on insulator (SOI) wafers offer a number of benefits to MEMS pressure sensors, primarily because the buried insulator can act as an etch stop allowing precise control of the diaphragm thickness. SOI has also been used for high temperature sensor applications as an electrical insulator on a pressure sensor that has been demonstrated up to 600 ºC.

Diaphragms can be made from a range of materials using surface micro machining techniques. For the fabrication of a polysilicon diaphragm a wet etch is used to remove a sacrificial silicon dioxide layer, while the lateral dimensions are defined by the oxide layering. This process allows vacuum sealing during fabrication, resulting in a device that can be used as an absolute pressure sensor. Silicon nitride diaphragms have been fabricated with a polysilicon sacrificial layer by Sugiyama (1986). A side view of this device is shown in Figure 1.

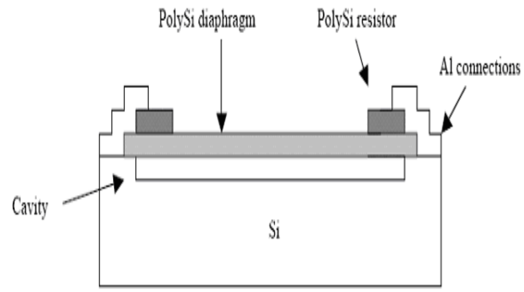

Fig 1: Cross section through a polysilicon diaphragm sensor

Piezoresistive Pressure Sensor was the earliest and most successful commercial product in the field of MEMS technology. The sensors combine the excellent mechanical properties and piezoresistive effect of single crystal silicon and related process technologies of integrated circuits. In order to enhance the piezoresistive effect and also the sensitivity of the sensors, a thin diaphragm is formed by silicon micro machining technology so that the stress resulting from applied pressure is concentrated on the piezoresistors located on the diaphragm. Piezoresistive pressure sensors are used in a wide variety of applications including tire pressure meters, pressure gauges, pressure switches, blood pressure monitoring, process control, and automobile parts, etc.

Silicon pressure sensors with integrated piezoresistors have been fabricated for many years and are perhaps the most mature MEMS product in the market. Pressure sensors are used for many purposes for example for measuring the bladder pressure in humans, to measure the water pressure in heating applications, for measurement of blood pressure, measurement of the manifold pressure in cars and in common rail diesel engines for measuring the fuel line pressure.

A typical silicon pressure sensor is shown in fig2. It is made on a (001) silicon wafer and a membrane has been formed by anisotropic etching in KOH - an etch stops on (111) planes. Due to the nature of this etch; the sides of the membrane are oriented along <110> directions. The basic idea behind this device is that a pressure difference across the membrane will lead to a deflection of the membrane that in turn leads to a stress distribution in the membrane proportional to the pressure. This stress can be measured by placing piezoresistors, often connected in a Wheatstone

bridge, on the membrane and the actual value of the pressure can be calculated from the output voltage of the bridge.
To derive the relation between the output voltage and the pressure, this is done by first considering the stress state in the membrane as function of applied pressure and then calculating the resistance change in the piezoresistors due to the induced stress. It is assumed that the membrane is subjected to plane stress and that the piezo resistors are located at the surface of the membrane.

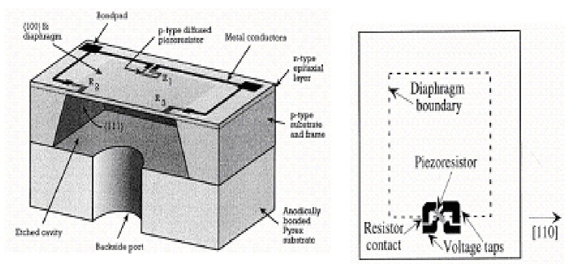

Fig2. Piezoresistive pressure sensor

2.3 Advantages

Low cost sensor fabrication.
Advanced processing technology.
Different pressure levels can be achieved according to the application.
Also, various sensitivities can be obtained.

2.4 Future Goals

Different pressure sensors with different sensitivities. Capability of performing advanced pressure, temperature, and vibration test for better characterization of the final product improvement in the packaging of the sensor.

3. CASE STUDY: PIEZORESISTIVE PRESSURE SENSOR

The sensitivity of piezoresistive pressure sensor can be calculated by using the given relationship and we can also determine the relationship between the change in resistance and change in pressure.[4]

3.1 Pressure Vs Resistance

$$S = \frac{\Delta V}{\Delta p} \frac{1}{V_{Bias}} = \frac{\Delta R}{\Delta P} X \frac{1}{R} \qquad (1)$$

S = Sensitivity
ΔV = Change in voltage
ΔP = Change in pressure
ΔR = Change in resistance
V_{bias} = Bias Voltage.

According to the above given relationship, the programs are written in MATLAB, the pressure range is defined up to 0 to 1000 mmHg
And simulated results are shown in the fig.3,.

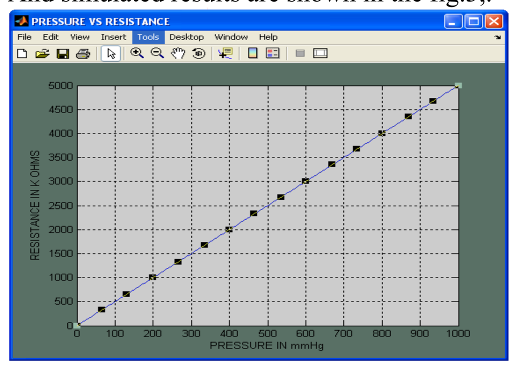

Fig3.simulated results of pressure vs resistance

3.1.1 Result and Discussion

The graph shows the linear relation ship between pressure and change in resistance. From the graph it can be concluded that resistance linearly changes with the pressure for the pressure of 0-1000 the resistance changes from 0-5 K Ohms

3.2 Pressure vs Sensitivity

$$S = \frac{\Delta V}{\Delta P} X \frac{1}{V_{bias}} = \frac{\Delta R}{\Delta P} \qquad (2)$$

S = Sensitivity
ΔP = Change in pressure
ΔR = Change in resistance
ΔV = Change in voltage
Vbias = Bias voltage

According to the above given relationship, the programs were written in MATLAB, the pressure range is defined up to 0 to 1000 mmHg, and simulated results are shown in the fig.4

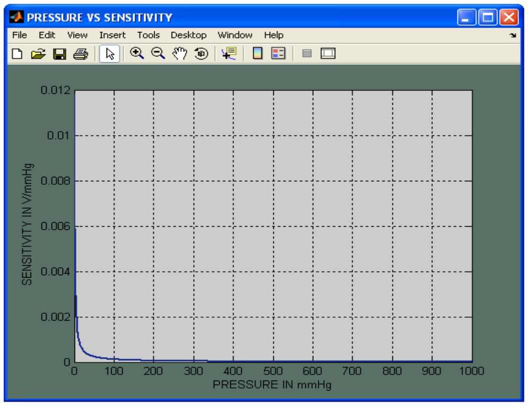

Fig 4. The simulated results of pressure vs sensitivity

3.2.1 Result and Disscussion

The sensitivity of the piezoresistive pressure sensor changes up to the pressure range 180mmHg after that the sensitivity of the sensor is constant. The pressure range is taken up to 1000. From the above study we can conclude that the pressure dependency of this device is up to 180mmHg beyond that pressure range the sensitivity does not change i.e. zero.

3.3 Pressure vs Maximum Deflection

The maximum deflection of the diaphragm is at the center of the diaphragm. In practice, the diaphragm thickness is about some ten micrometers, and the deflection is less than half of the diaphragm thickness. The length of the diaphragm is from some hundreds of micrometers to two thousand micrometers. The thin plate can be adopted in the design of pressure micro pressure sensors; the maximum diaphragm deflection is divided by deflection diaphragm thickness. Here is the given relation [4]

$$\frac{\omega_{\max}}{h} = 0.01512(1-\nu^2)\frac{P}{E}(\frac{L}{H})^4 \quad (3)$$

Where

L/h= Ratio of diaphragm length to thickness

P = Pressure

E= Young's modulus

ν = Positions ratio

$\omega_{\max}$ = Maximum deflection

The relation between pressure and deflection is simulated using MATLAB and shown in fig.5

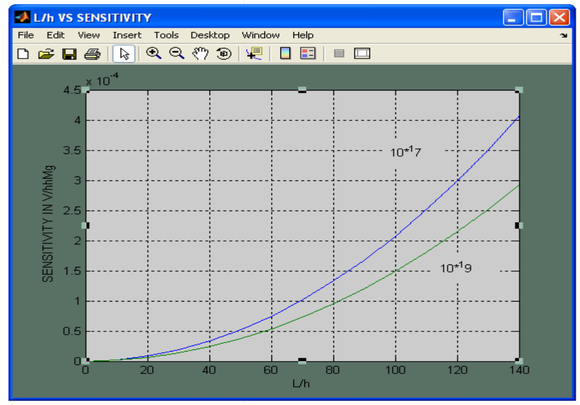

Fig5.simulated results of pressure vs. deflection

3.3.1 Results and Disscussion

That result shows the sensitivity increases as the diaphragm length to diaphragm thickness ratio increases. From the graph we can conclude that the higher ratio of L/h exhibits higher sensitivity. Besides, the lower impurity concentration has higher value of Π4, so it means that lower concentration will have higher sensitivity

4. CONCLUSION

The performance analysis, design and simulation of piezoresistive MEMS is described. The simulation result shows that. There exists a linear relationship between change in presume and change in resistance, another result shows that. The sensor is sensitive up to 180 mmHg after that device sensitivity is constant, where as for blood presume measurement the device sensitivity needed up to 300 mmHg hence the said sensor is net suitable for blood pressure measurement another parameter which was considered for analysis was diaphragm length to thickness ratio the result shows that as the this ratio (L/h) increases the sensitivity also increases.

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