A CASE STUDY ON MEMS BASED PIEZORESISTIVE PRESSURE SENSOR

Santhosh Bankar[1] Varsha Tadas[2] Vinayak Badger[3] Shruti Patil[4] Vinay Shettar[5] Sneha Kotin[6] Ravi Bashetti[7]
[1,2,3,4]Students, Department of ECE. Biluru Gurubasava Mahaswamiji Institute of Technology, Mudhol. Karnataka
[5,6,7]Faculties, Department of ECE. Biluru Gurubasava Mahaswamiji Institute of Technology, Mudhol. Karnataka

Abstract
Amongst various transduction principles of pressure sensor, piezoresistive method provides high sensitivity and linear operation over a wide range of pressure. In this paper, piezorestive transduction mechanism is employed for design of a pressure sensor. The diaphragm of the proposed sensor is designed using n-type of Si with copper material used as a connecting arms for the p-type meander shaped piezoresistors placed on the surface of the diaphragm in a Wheatstone bridge configuration at the high strain region of the diaphragm. Meander shape piezoresistors of different length are simulated, in order to find out the best configuration for high sensitivity and linearity. The proposed design is analysed to study the deflection of the diaphragm and output voltage across the bridge. Results reveal that the 50 µm length of piezoresistors is found to have the best sensitivity.
Keywords: Piezoresistive pressure sensor, Wheatstone bridge Linearity; Sensitivity.

1.INTRODUCTION

Micro pressure sensors were the first MEMS based devices to be fabricated. So far about 18% of the MEMS based devices available in the world are pressure sensors .MEMS pressure sensors work on the principle of the mechanical deformation of a thin diaphragm due to the pressure exerted by the contact medium. The mechanical stress induced due to the applied pressure is converted into an electrical signal using piezoresistive, capacitive, optical and resonant sensing mechanisms. Among the various transduction mechanisms available for the sensor, piezoresistive type is the most widely used due to various advantages such as good linear input/output relationship, high reliability, small size, easy integration with electronics, simple compensation circuitry and a well matured f Piezoresistance is the phenomenon of change in resistivity of certain materials (like silicon, polysilicon, SiC etc.) on application of stress/strain . Piezoresistive pressure sensors employ this principle to measure the applied pressure. Piezoresistive sensors also have much higher sensitivity than the metal strain gauges which work on the basis of change in resistance due to geometrical deformation. Meander shape of piezoresistive pressure sensor configuration constitutes an important part to a pressure sensor market. These types of sensors are helpful in placing the entire length of the piezoresistors inside the long and narrow high stress regions and they are used mainly because of their high sensitivity and good linearity. Piezoresistive pressure sensors employing the use of silicon, poly silicon as piezoresistive materials, because of its high sensitivity and repeatability. Pressure sensors employing the use of other materials like SiC, and diamond for piezoresistors are not very popular for commercial usage because the fabrication technology is not mature for such materials . Also silicon based piezoresistors can be easily fabricated using ion implantation and the sheet resistance of the resistors can also be carefully controlled using ion implantation. In this work, we will discuss the design methodology and simulation of a meander shape piezoresistive pressure sensor based on piezoresistance in silicon. Fabricate.

1.1Basic Principle of pressure sensor

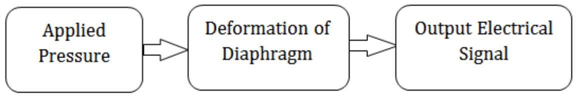

Figure1.1 Basic Principle of pressure sensor

Pressure is an important parameter in our real life applications. Pressure is represented as force per unit area; the mathematical expression of pressure, P is given by:
P = F/A

Where F is applied force and A is area where the force is applied.

Pressure sensors generally use a pressure sensitive element (such a diaphragm, piston, bourdon tube, or bellows). So when a pressure is applied to the sensor, pressure sensitive element is deformed, that produces electrical signal at output; this is a basic principle of any pressure sensor.

2. PIEZORESISTIVE PRESSURE SENSORS

A piezoresistive pressure sensor consists of a diaphragm with four piezoresistors on its surface connected in a Wheatstone bridge circuitry.which is used to measure the output voltage. In the absence of pressure, the bridge is balanced and the output voltage, V0 is zero. On the application of pressure to the diaphragm, the diaphragm gets deflected. This deflection results in a stress in the piezoresistors, which in turn results in a change in the resistance of the piezoresistors, there by changing its resistivity value, hence exhibiting the piezoresistive behaviour. The resistors are placed where maximum stresses are being experienced. For a square diaphragm the maximum stresses are found at the centre of each edge. Hence the four resistors are pledges of the diaphragms as shown in Fig. 2 The size, shape and thickness of the diaphragm and the shape and placement of piezoresistors are the important factors which affect the output of the pressure sensor. Sensitivity and linearity of pressure sensors are the two most important specifications of a pressure sensor aced at the ion process

This semiconductor material acts as piezoresistive sensing element in the pressure sensor. When pressure is applied then the diaphragm is stretched and deformed, the piezoresistive element will change its resistance. When a pressure is applied, the diaphragm is flexed as well as the piezoresistive material. Therefore, the piezoresistive material becomes slightly longer and thinner due to applied pressure as shown in **Fig. 3**. This deformation results in the change in resistance of the piezoresistive material.

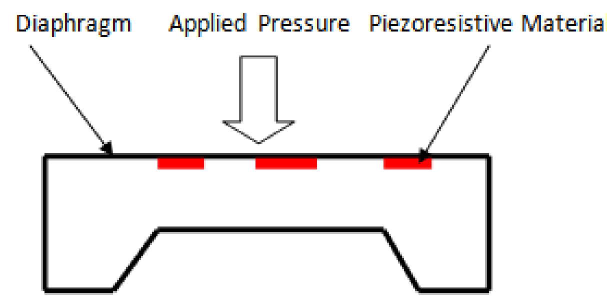

Figure 2 Piezoresistive pressure sensor

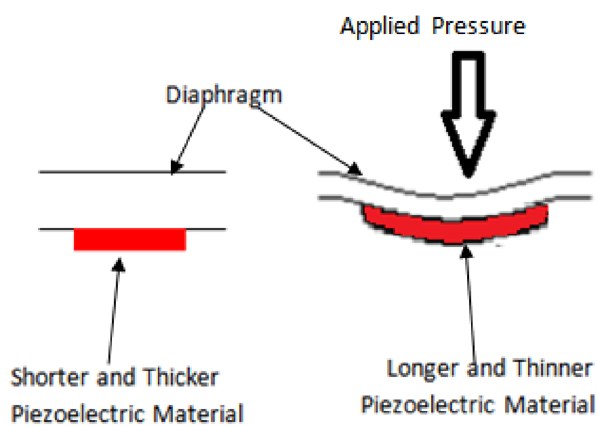

Figure 3 Deformation of piezoresistive material

The mathematical expression of the resistance, *R* is given by
R = ρL\A ……………………..(1)

Where, ρ is the resistivity of the material, L is the length of the piezoresistive material and A denotes the cross-sectional area of the piezoresistive material. Since cross-sectional area is equal to the width multiply with thickness; therefore,

R = ρL/Wt……………………..(2)

Where, w represents the width of the piezoresistive material and t represents the thickness of the piezoresistive material. Since the piezoresistive material becomes longer and thinner when it is subjected to a pressure, from equation-2, it can be said that the resistance of the piezoresistive material is increased. The piezoresistive pressure sensor is normally implemented together with Wheatstone bridge circuit is used to convert the resistance changes into the change in electrical potential. The Wheatstone bridge also provides some advantages to the pressure sensor for example provides more linear output, maximizes the sensitivity of the sensor and minimizes the error of the sensor.

From Fig. 4, the *ΔR* is the resistance change of the piezoresistive pressure sensor and the *R* is a re fixed resistance. Where, Vout is the output voltage of Wheatstone bridge and Vin the input voltage of Wheatstone bridge. Thus, by measuring the output voltage of Wheatstone bridge, the change in pressure can be determined.

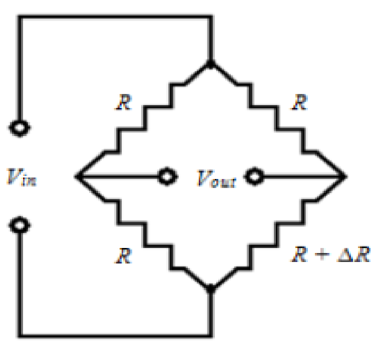

Figure 4 Piezoresistive pressure sensor in Wheatstone bridge

Where, Vout is the output voltage of Wheatstone bridge and Vin the input voltage of Wheatstone bridge. Thus, by measuring the output voltage of Wheatstone bridge, the change in pressure can be determined

3. FABRICATION

A solid-state piezoresistive chip is fabricated by using a <100>double-sided polished silicon wafer with an epitaxial layer made by a p-type substrate. The diaphragm is formed by back end bulk micromachining using anisotropic etchants like potassium hydroxide (KOH) or tetramethylammonium hydroxide (TMAH) with etch stops on <111> planes.The wafer is first pre-cleaned using piranha solution and a SiO_2 layer is grown on both ends using thermal oxidation. The back end is wax coated to prevent any etching while patterning the photoresist on the front side.

The front side is etched using KOH (40% at 75°C for ~7 min) and after piranha cleaning for the second time, oxide layer is grown on it. Using alignment masks, the back end is patterned and the back oxide is etched using KOH (30% at 75°Cfor ~120 min) and then followed by TMAH (25% in 5% DI water at 75°C for ~120 min) etching. This leads to formation of a thin membrane called diaphragm, which deflects under stress.

Piezoresistors patterns are imprinted on the front end of the wafer using photolithography after which the photoresist is stripped off and the wafer is cleaned using acetone and dried.n-type piezoresistors are formed by phosphorous diffusion (at 900°C)in the oxide-free regions. Contacts for the resistors are formed by thermally evaporating aluminum (Al) after which they are patterned and the wafers are annealed and calibrated.

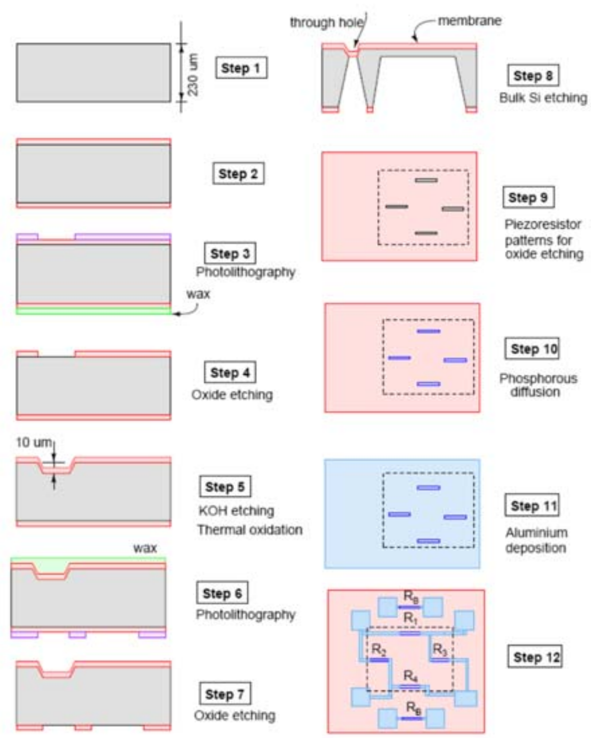

Figure 3. Fabrication steps for MEMS based piezoresistive pressure sensor

A low cost micromachined pressure sensor is fabricated using polysilicon piezoresistors and Si3N4 layer. Figure shows MEMS based piezoresistive pressure sensor commonl used in automobiles for control purposes.

4. LOCATION OF PIEZORESISTOR

The design specifications of the pressure sensor consist of location of piezoresistor, thickness of the membrane and its shape.

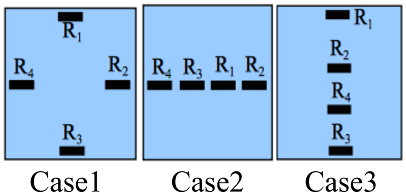

Figure 4. Location of piezoresistors [3].

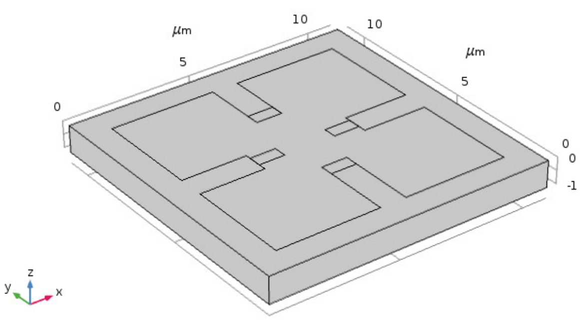

Figure 5 :case[1] Piezoresistive pressure sensor

The shape of the silicon membrane and the location of the piezoresistor affect the sensor output voltage. A high output voltage can increase sensor sensitivity and as a result causes increase in the sensor application range.

5. DESIGN OF MEMS PRESSURE SENSORS USING COMSOL MULTIPHYSICS

The Piezoresistive pressure sensor is designed with side length of 11μm piezoresistive pressure sensor is composed of n-Silicon (single-crystal, lightly doped) and p-silicon (single-crystal, lightly doped). COMSOL Multiphysics.

Piezoresistivity is the change of resistance of a material when it is submitted to stress. A piezoresistor pressure sensor measures the applied pressure on one side of the diaphragm. The stress change in the diaphragm causes the resistance to change. Shows in fig.5 Piezoresistive pressure sensors.

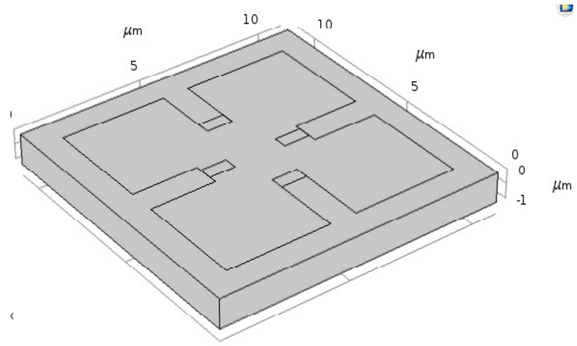

Figure 8 Piezoresistive pressure sensor

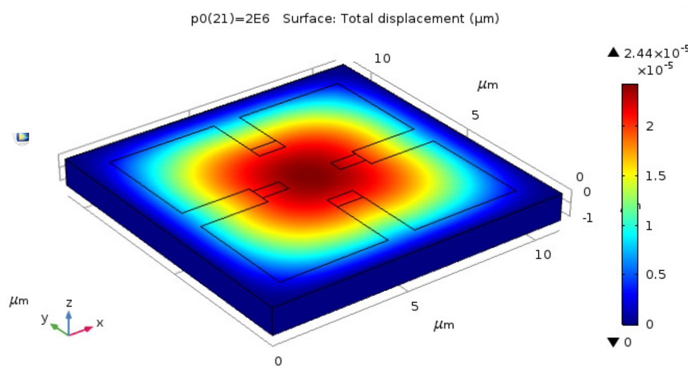

Figure 9 The model of piezoresistive pressure sensor

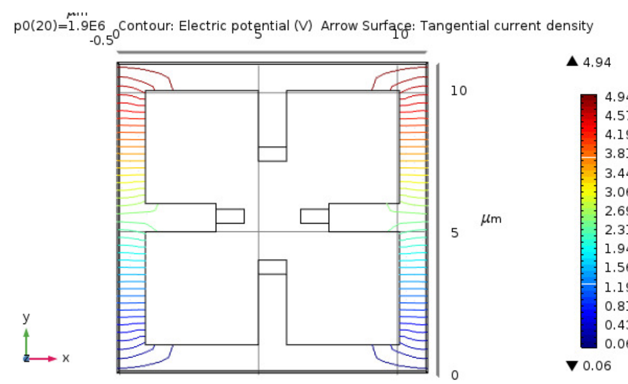

Figure 10: The distribution of voltage for applied pressure

6.CONCLUSION

Research activity in the areas related to the piezoresistive pressure sensor is very broad and it has made a phenomenal growth. The piezoresistive pressure sensor based on Wheatstone bridge circuit is widely used by many reported works. The exceptional properties, which allow piezoresistive pressure sensors to be used in sensors, have also been reviewed. MEMS pressure sensor based on piezoresistive transduction mechanism has lot of scope due to its high sensitivity, stability and high temperature. Results reveal that the 50 μm length of piezoresistors is found to have the best sensitivity.

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