Design and fabrication of sculptured diaphragm MEMS low range pressure sensor

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ABSTRACT

In this paper the MEMS pressure sensor with sculptured diaphragm is designed, fabricated and tested for measuring low pressure range (0 - 600mbar). The classical flat diaphragm sensors give rise to linearity error and offset drift problem when it is used for wide range of temperature. If the offset drift and linearity error is high then compensation of the sensor with external electronics also becomes very tedious process and impossible in some cases. So, in this paper initially simulation study is discussed to optimize the sculptured diaphragm structure dimensions, to measure low pressure like 600mbar for the wide temperature range from -40°C to 80°C. COMSOL simulator tool is used to estimate the stress values on the diaphragm, and use these values to analytically determine the sensor output for different temperatures. With this simulation approach, the effect of temperature on the zero offset drift and linearity is studied. Based on the simulated structure, the diaphragm and resistor dimensions are decided and the optimized structure is fabricated using SOI wafer technology in clean room and tested for the same specifications. Finally, the simulated and practically obtained results are discussed and compared.

1. Introduction

Today, most of the pressure sensors are fabricated by MEMS Technology using silicon as the substrate. This approach is particularly attractive due to its potential in reducing size and cost as a result of the batch processing and mass production capability of silicon technology. Flat diaphragm structure of sensor is well known and it works very well for measuring high pressure ranges [1]. For measuring low pressure, flat structure is not preferable because of their offset drift for different temperature ranges and also its non-linearity behaviour. In order to overcome this, we prefer single and double boss structures which give better linearity and offset drift for wide range of temperatures. And also compared to double boss the single boss structure gives better performance over its characteristics. Nowadays pressure sensors using MEMS technology have received great attention, because they find application in everyday life involving sensing, monitoring, and controlling of pressure. The invention of piezo resistivity in silicon and the recognition of excellent mechanical properties of silicon opened the doors of micromachined pressure sensors. They are widely used for aerospace [2], biomedical, automobile and defence application. A MEMS pressure sensor can be piezoelectric or capacitive or piezoresistive in nature [3]. Piezoelectric Pressure sensors use piezoelectric materials, which are not used in the conventional IC fabrication technology and also it cannot be used for static pressure sensing purposes due to charge leakage. The output of a capacitive pressure sensors is not linear with respect to applied pressure. However, they have high sensitivity and are not sensitive to temperature [4]. Piezoresistive pressure sensors make use of the change in the resistance of semiconductors due to the change in their physical dimensions when subjected to strain. When assembled on a membrane they give information about the strain experienced by the membrane. When the resistors are made of semiconductors, the change in the resistance is predominantly due to the change in the resistivity. The gauge factor of different strain gauges can be different. They are

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mainly determined by whether or not they have significant piezo resistance effect as in the case of single crystal silicon [5].

2. Simulation of Pressure Sensor with Sculptured or Bossed Diaphragm

As discussed in introduction the flat diaphragms suffer with linearity and offset drift error so bossed diaphragm will improve this error [6]. So here, single-boss structure is considered for simulation study. For fixed pressure of 600mbar the diaphragm dimensions are chosen. Here the diaphragm region is chosen as 2mm*2mm with diaphragm thickness 25µm (SOI-25µm) and boss region is 1200µm, which act as rigid silicon area. Fig.1 shows the diaphragm specifications. Fig.2 shows the cutline where stress is monitored.

The structure is simulated using COMSOL, taking solid mechanics physics and applying 600mbar at room temperature the maximum stress locations can be estimated. Fig.3 shows the maximum stress locations on the diaphragm.

To decide the resistor dimensions and its locations the stress plot is drawn along the cutline shown in Fig.2. The final stress plot is shown in fig.4. for the applied pressure 0,120,240,360,480 and 600mbar on top of the diaphragm at room temperature.

The stress plot in Fig.4 shows that maximum stress value at P=600mbar is 4.5*10^7 N/m^2 which is high enough to produce good sensitivity. And also, from this plot Wheatstone bridge resistor location can also be finalized as shown in Fig.5(a) and(b).

Based on this simulation the resistors are placed at maximum stress locations as shown in the Fig.5 (a). The region 1 and 2 are the place where the silicon region is etched from backside to form diaphragm region. Region 3 where the rigid silicon mass is present which gives concerted stress to the resistors. The resistors realised on the diaphragm are connected in Wheatstone bridge format as sown in the figure. When pressure is applied on top of the diaphragm all the four

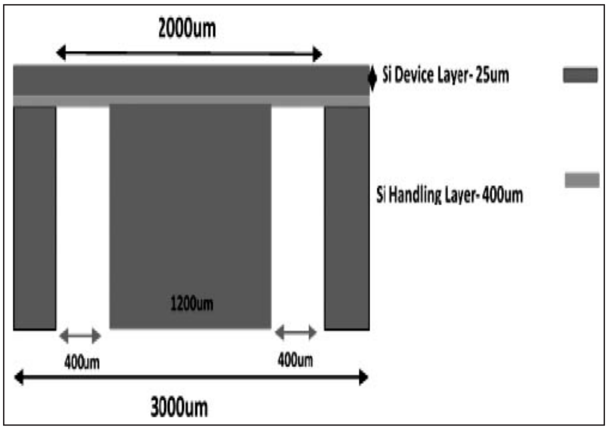

Fig. 1. Schematic view of single boss diaphragm.

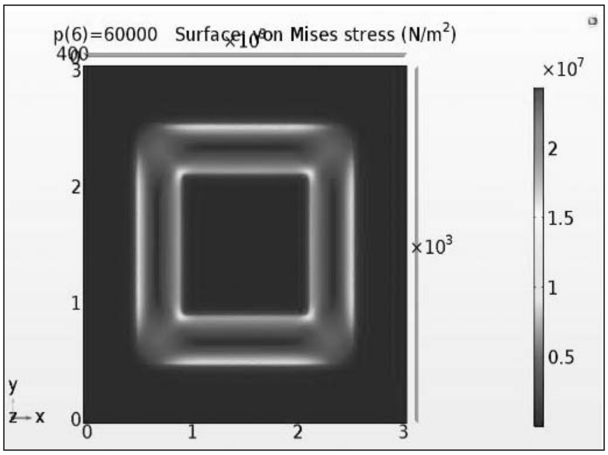

Fig. 3. Stress plot at 600 mbar.

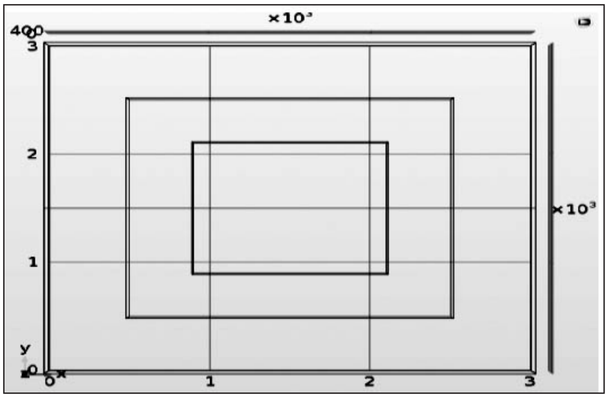

Fig. 2. Cutline where stress is measured.

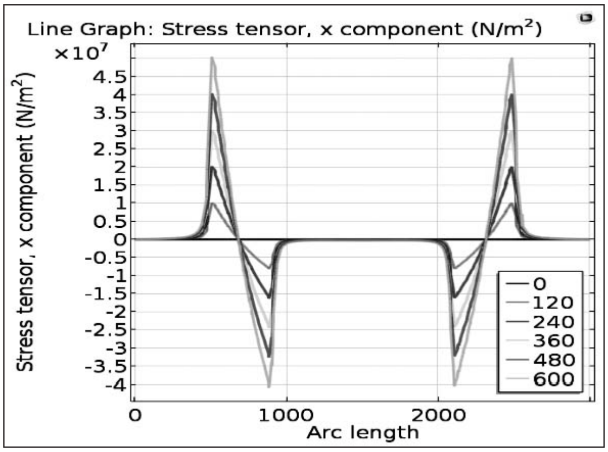

Fig. 4. Stress plot along the cutline for different pressure (0 to 600mbar) at 20 ˚C.

resistors will experience the transverse stress. The resistor R1 and R3 which are placed at the outer edges of region 1 and 2 experience the transverse tensile stress similarly the resistor R2 and R4 experience the transverse compressive stress. And these resistors kept opposite arm of the whetstone bridge as shown in the Fig.5(b). Temperature effect on the diaphragm is simulated for the range -40˚C and 80˚C. Fig.6. shows the how stress varies as temperature changes from -40˚C and 80˚C.

This stress plot shows that when temperature changes the stress on the sensor varies here both TCR and TCS effect be there. From this simulation results we can calculate the output voltage for different pressure and temperature using the equation 1.

$$Vo = Vin \times (\Delta R/R) \quad (1)$$

where $\frac{\Delta R}{R} = \frac{Stress \times gauge\ factor}{youngs\ modulus}$

The corresponding output voltage is calculated for input voltage Vin=5V, Youngs Modulus=170Gpa and taking gauge factor 100 at 20C for nominal doping and for -40°C is 125 and 80°C is 75. The output is calculated using the equation 1.

Simulated results show the good sensitivity along with better linearity and offset drift as sown in Fig.7 and characteristic Table 1. As temperature decrease span increases due to gauge factor effect similarly as temperature increases span decreases. The offset value due to temperature is also very less. This simulated structure is fabricated to its practical results the next section shows its fabrication and tested results.

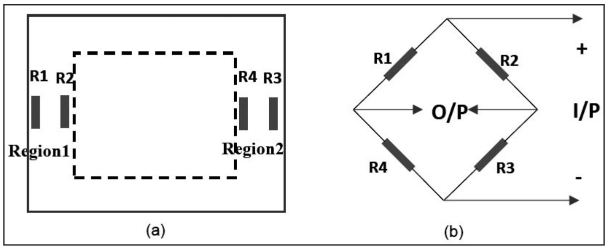

Fig. 5. Whetstone bridge
a) Resistor location b) Schematic diagram.

3. Fabrication and Testing of the Sensor

To fabricate the simulated structure SOI-25µm-4 inch wafer is used with n-type device layer. The fabrication steps are as follows

- Oxidation of SOI wafer, which act as masking layer for diffusion.
- P+ diffusion-Boron is heavily doped in specified region (Sheet resistance Rs=10 ohms/sqr) so that it is easy to form ohmic contact on the p+ region for the metal connection.
- Resistor diffusion- Boron in nominally doped (Rs=250 ohms/sqr) depending on the resistor

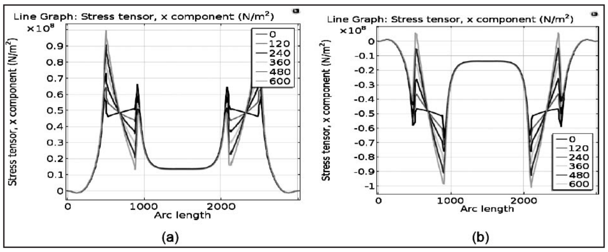

Fig. 6. Stress plot along the cutline for different pressure (0 to 600 mbar) at a) -40 ˚C b) 80 ˚C.

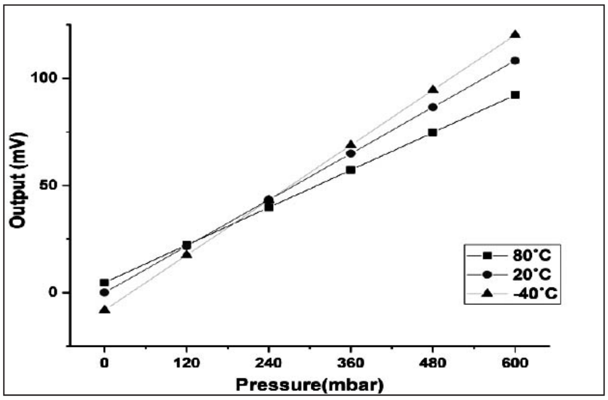

Fig. 7. Pressure Vs output plot at -40, 20 and 80˚C.

Table 1
Characteristic table of the sensor-simulated results.

Temp (˚C)	Offset (mV)	Full scale offset FSO (at 600 mbar)	Span (mV) (FSO - offset)	NL+Hys in % FSO	Change in Offset In % w.r.t span at 20˚C
-40	-8.19	120.16	128.35	0.002	7.57
20	0	108.15	108.15	0.014	0
80	4.73	92.16	87.43	0.009	4.37

Table 2
Characteristic table of the sensor- practical results.

Temp (˚C)	Temp (˚C) Offset (mV)	Full scale offset FSO (at 600 mbar)	Span (mV) (FSO - offset)	NL+Hys in % FSO	Change in Offset In % w.r.t span at 20˚C
-40	1.99	129.43	127.44	0.07	1.82
20	0	109.04	109.04	0.09	0
80	-1.1	97.05	98.15	0.08	1.00

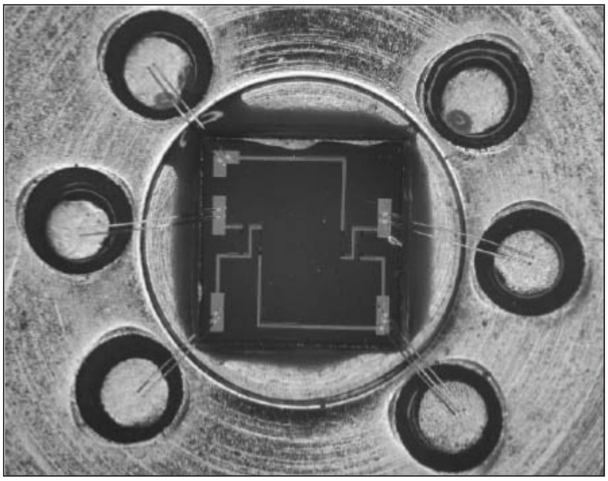

Fig. 8. Die mounting and wire bonded images of fabricated sensor.

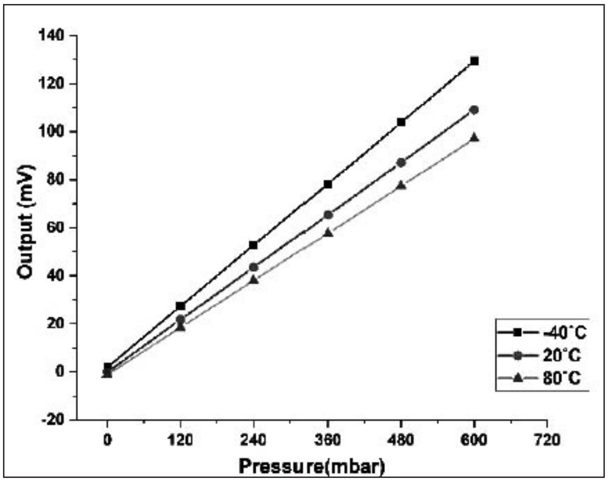

Fig. 9. Pressure Vs output plot at -40, 20 and 80˚C.

dimensions. The resistor length is 200um and width is 20um the ratio is 10. The total resistance is 10*250=2.5KOhms.

- Metal deposition- Al meatal is evaporated and patterned to connect resistors in Wheatstone bridge format and to form wire bonding pads.
- Passivation – The region except wire boning pads are deposited with insulted material sio2 which act as passivation layer for the diaphragm.
- Diaphragm formation- The front to back lithography is done to form diaphragm and using DRIE (Deep reactive ion etching) diaphragm is realized.

The fabricated sensor is then diced, die mounted and wire bonded for testing Fig.8 shows the sensor mounted on the header.

This packaged sensor is calibrated for 600mbar at different temperature to check its characteristics. The Fluke RUSKA 7250i pneumatic calibrator is used to calibrate the sensor with hot and cold chamber to create the extreme environment -40˚C to 80˚C. The obtained practical result Pressure Vs output is shown in Fig.9. The characteristic table 2 shows the complete sensor performance.

4. Results and Discussion

The simulated results show the better linearity and offset drift due temperature, the fabricated sensor characteristics also matches with simulation results. Fabrication of the sensor also easy compared to flat diaphragm in the case of resistor placement and diaphragm formation (DRIE). since all resistor experience transverse stress.

The fabricated sensor shows little high non-linearity due to fabrication and testing errors. Still the fabricated sensor non-linearity is less than 0.1% over wide range of temperature -40˚C to 80˚C and the offset drift is ±2mV.

5. Acknolowgement

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6. References

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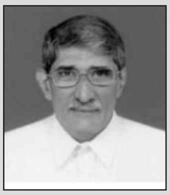

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