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Effects of Radiation on Silicon Pressure Sensor

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Abstract: The performance of MEMS based piezoresistive pressure sensors is affected by the radiations. This effect is of much importance for the sensors to be used in deep space environments. To reckon these effects in-house designed and developed piezoresistive sensor is exposed to the irradiation and the change in performance parameters is measured. And corrective measures have been suggested. *Copyright © 2009 IFSA.*

Keywords: Pressure sensor, Sensitivity, Linearity, Hysteresis, Irradiation

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1. Introduction

MEMS based pressure sensors are being widely used in automotive industry, process industry, oceanography, biomedical, space and military [1-2] applications. These sensors are mechanically similar to the traditional sensors with the exception that they are Si based and on micrometer scale. These sensors have number of advantages over the conventional sensors like batch fabrication, high gauge factor, small size, low cost, absence of adhesive bonding layer and easy integration with electronics on a single chip. These pressure sensors are available in wide operating pressure ranges covering from mbar to hundreds of bar. The low pressure regime is particularly important for many biomedical instruments such as those used for measuring blood pressure and intraocular eye pressure [3].

MEMS based pressure sensors can be either piezoresistive type or capacitive type. The vast majority use Piezoresistive sense element to detect stress in a thin silicon diaphragm in response to input pressure. A few designs use capacitive methods to sense the displacement of the thin diaphragm. However, the conventional MEMS piezoresistive sensors possess low sensitivity and suffer from

thermal drift and hysteresis. On the other hand, capacitive pressure sensors require complex electronics to detect small capacitance in case of low pressure applications. For high temperature applications ceramic based pressure sensors have also been reported [4]. Based upon fabrication technology, the sensors can be categorized as bulk micromachined and surface micromachined pressure sensors. Most of the piezoresistive pressure sensors are bulk micromachined whereas capacitive type is surface micromachined.

Literature [5, 6] reveals that the performance of Integrated circuits (IC) degrades when exposed to low dose of ionizing radiation. Although the mechanical part of the MEMS based sensors will be insensitive to the radiation but the piezoresistors, in particular, may degrade. Therefore, before MEMS can be used in radiation environment of space, it is important to test them for their sensitivity to ion-induced radiation damage. In this paper, the in-house designed and fabricated bulk micromachined piezoresistive pressure sensors are taken to study the effect of radiation exposure on the performance parameters like nominal output, sensitivity, linearity and hysteresis. The pressure sensor considered here is a low pressure sensor developed for meteorological applications. The typical specifications of the sensor are:

- Range: 0-1 bar (Absolute);
- Nominal output: 30±3 mV @ 3V dc;
- Linearity ≤ 0.4 % FSO;
- Hysteresis ≤ 0.2 % FSO.

2. Fabrication Process Flow

The fabrication process for the pressure sensor starts with a double side polished n-type silicon substrate with (100) surface orientation. The fabrication process will define boron piezoresistors implanted into an n-type silicon substrate and the membrane is formed using a timed etch technique. Fig. 1 shows the cross-sectional view of fabrication process steps. The initial thickness of the substrate is 675 μm with resistivity value of about 3-5 Ωcm. Standard CMOS technology and anisotropic etching technology are used to fabricate the device.

To start with, 0.25 μm oxide is grown by wet oxidation to create the initial alignment features, called *alignment targets*. The subsequent lithography step defines the region of the piezoresistors. The lithography alignment must be done precisely relative to the crystal orientation of the wafer such that the piezoresistors are along the <110> directions. After the resistor implantation in step 4, the same process is repeated for contact implant. The implant is then activated at 1000^0C for 5 min in O_2 which is followed by 20 min annealing in the inert (N_2) environment. The surface impurity concentration of $7x10^{18}cm^{-3}$ was calculated for piezoresistors and $4x10^{19}cm^{-3}$ for contacts with the target junction depth of 1 μm. All these parameters were optimized using TSUPREM software with an accuracy of ±0.2 μm. After implant drive-in, a layer of undoped oxide is deposited for providing isolation between metal and silicon. In preparation of making the metal contacts to the piezoresistors, resist openings are created which is followed by sputter deposition of aluminium over the entire surface. Next, the aluminium is patterned using metal mask. In step – 6, low tensile stress CVD nitride (<200MPa) is deposited on the back side. The purpose of this nitride was to act as hard mask for creating the opening during KOH etching. The mask alignment for this process is somewhat different from the standard lithographic processing and is very critical. The etch for membrane formation starts from the backside of the wafer, so the opening in the silicon nitride must be oriented properly relative to the piezoresistors already defined on the front side of the wafer. In step – 7, the membrane is formed using KOH anisotropic etching which is followed by the removal of oxide and nitride. The accuracy of ±1 μm is achieved for the diaphragm thickness.

Finally, the finished silicon wafer is anodically bonded to glass wafer. It has two purposes – to create the vacuum on one side of the diaphragm and to increase the strength of the silicon wafer which becomes quite fragile due to the formation of very thin diaphragm structures. After bonding, the standard dicing saw process separates the sensor elements for appropriate packaging (Fig. 2).

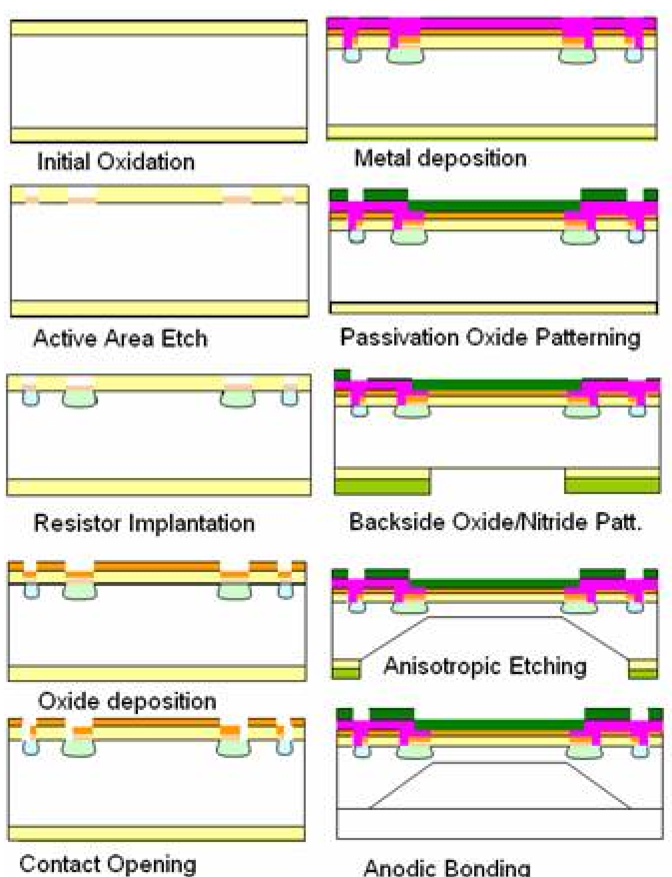

Fig. 1. Principle of Piezoresistive pressure sensor.

(a) (b)

Fig. 2. (a) Fabricated die (b) Packaged pressure sensor.

3. Experimental

The finally packaged pressure sensors were used for the radiation experimentation. Two sensors were initially pre-calibrated. Primary Pressure standard Model from Desgranges Et Huot, France was used to calibrate the Pressure sensor in five ascending and five descending pressure values of equal interval. Excitation to the bridge is kept constant at 3 Volts and Output in milli volts was recorded using a Keithley 6½ digit Digital multimeter. By method of least squares, Best fit straight line method the non linearity and hysteresis is calculated. Then, the same sensors were exposed to Co-60 irradiation in GAMA CHAMBER-5000. This is a compact, portable self-shielded type of Co-60 Gamma irradiator. The unit is designed to house 518TBq of Co-60 and it provides an irradiation volume of 5000cc with maximum dose rate capacity of 0.9 MRad/hr. The dose rate uniformity is +25% in radial direction and -25 % in transverse direction.

Fig. 3: Gamma Chamber test set-up.

The parameters selected for radiation test are:

Dose rate : 147 Rad/s
Max. Dose : 1 MRad.

4. Results and Discussions

To know the initial nominal output, sensitivity, linearity and hysteresis, the sensors were pre-calibrated in 0-1 bar pressure range. After the pre-calibration, the sensors were exposed to the Gamma radiations up to 1 MeV dose. A constant voltage supply of 3 V dc was applied to the sensors and the output was continuously monitored. Also the temperature variation inside the chamber during the radiation test was monitored. Fig. 4 shows the change in V_{out} and temperature as a function of total dose. An exponentially decreasing function was fit to the Vout and exponentially increasing function to the temperature. The purpose of curve fitting was to provide greater sensitivity in identifying small deviations from the general trend when the part is irradiated at high or low flux and with or without bias.

To elucidate the reasons for the voltage drop, the temperature voltage characteristic was observed by exposing the sensor to same temperature conditions as of radiation chamber. Fig. 5 shows the Temperature Voltage behavior both during radiation and no radiation. As can be seen from the figure that the output voltage (Vout) decreased due to temperature as well as radiation effect.

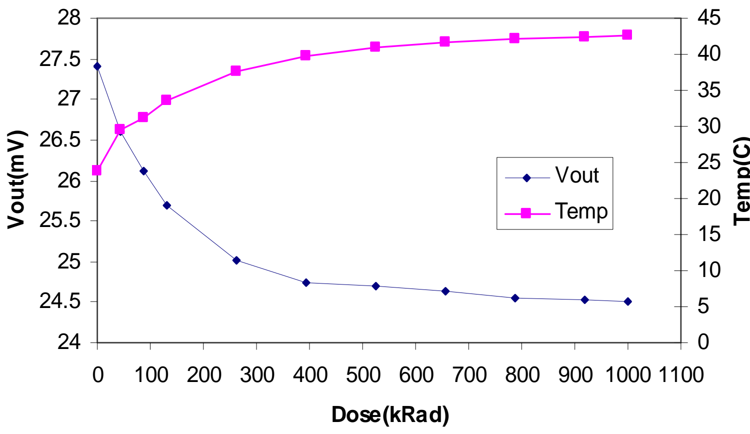

Fig. 4. Voltage and temperature variation with respect to dose rate.

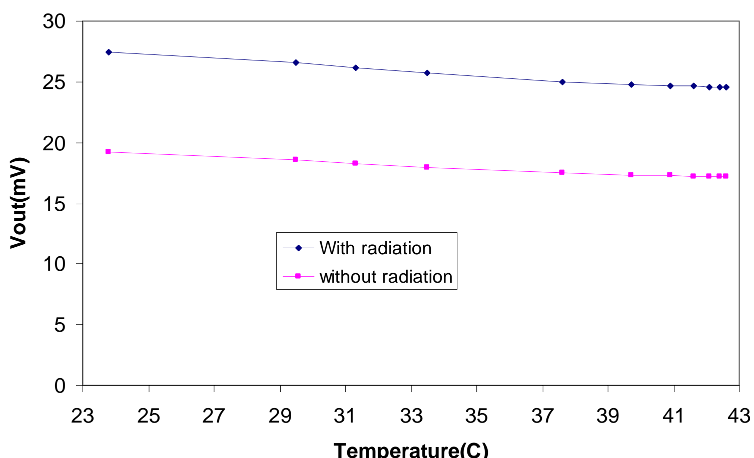

Fig. 5. Voltage temperature characteristic with and without radiation exposure.

Again, the sensors were post-calibrated to find the change in the performance parameters. Fig. 6 shows the pressure voltage curve before and after the irradiation. The drop in V_{out} could be due to charge trapping in the insulating layers after the radiation exposure along with the temperature.

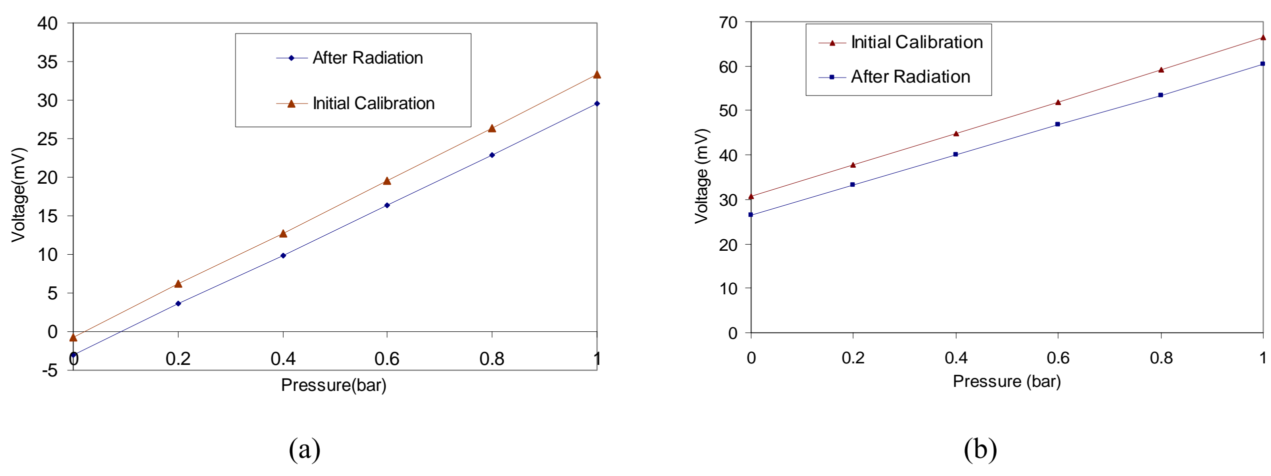

Fig. 6. Calibration curve for 0-1 bar: (a) absolute mode, (b) gauge mode.

The variation in performance parameters is shown in Table 1.

Table 1. Comparison of performance parameters before and after radiation test.

Parameter	Pre-Calibrated	Post Calibrated
Linearity (L+H) (%FSO)	0.611	1.070
Hysteresis (H) (%FSO)	0.32	0.18
Sensitivity (S) (mV/Vbar)	11.06	10.59
Nominal Output (mV)	33.19	31.76

To overcome the effects of the radiation, the devices were annealed at 100 degree C for 4 hours. The devices were again calibrated to monitor the regain of the shift. Very affirmative results have been observed (Fig. 7). The voltage drop of ~2.5 mV was seen after radiation exposure. It reduced to < 0.3 mV by annealing at 100 deg C for 4 hrs.

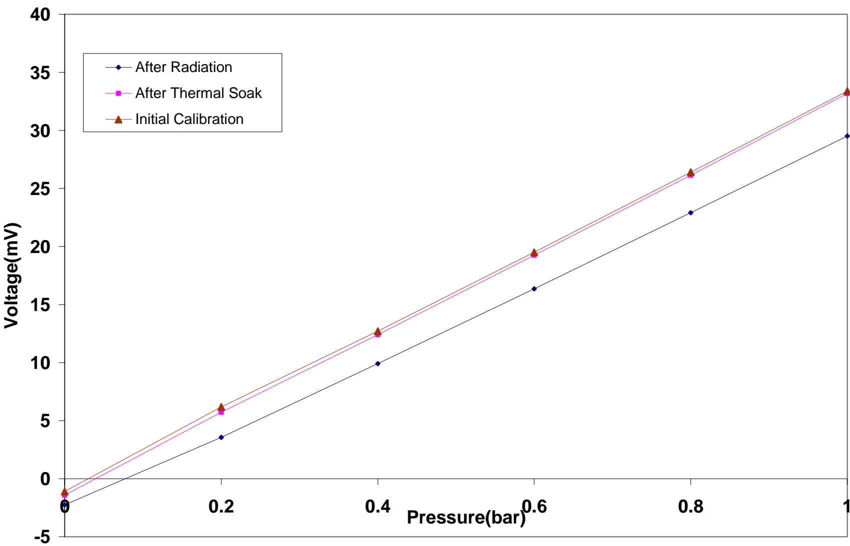

Fig. 7. Calibration curve for 0-1 bar – initial, after radiation and after thermal soak.

5. Conclusions

MEMS based piezoresistive pressure sensors were characterized for sensitivity to radiation. Performance degradation was observed when exposed to radiation. The MEMS based pressure sensors contain electronic components which are prone to radiation. Corrective mechanisms to counter the degradation have to be worked out when the pressure sensors are used in space applications where the devices are exposed to radiation. In this paper one approach of annealing of the sensors at elevated temperature is suggested which can be easily incorporated with the micro-heater.

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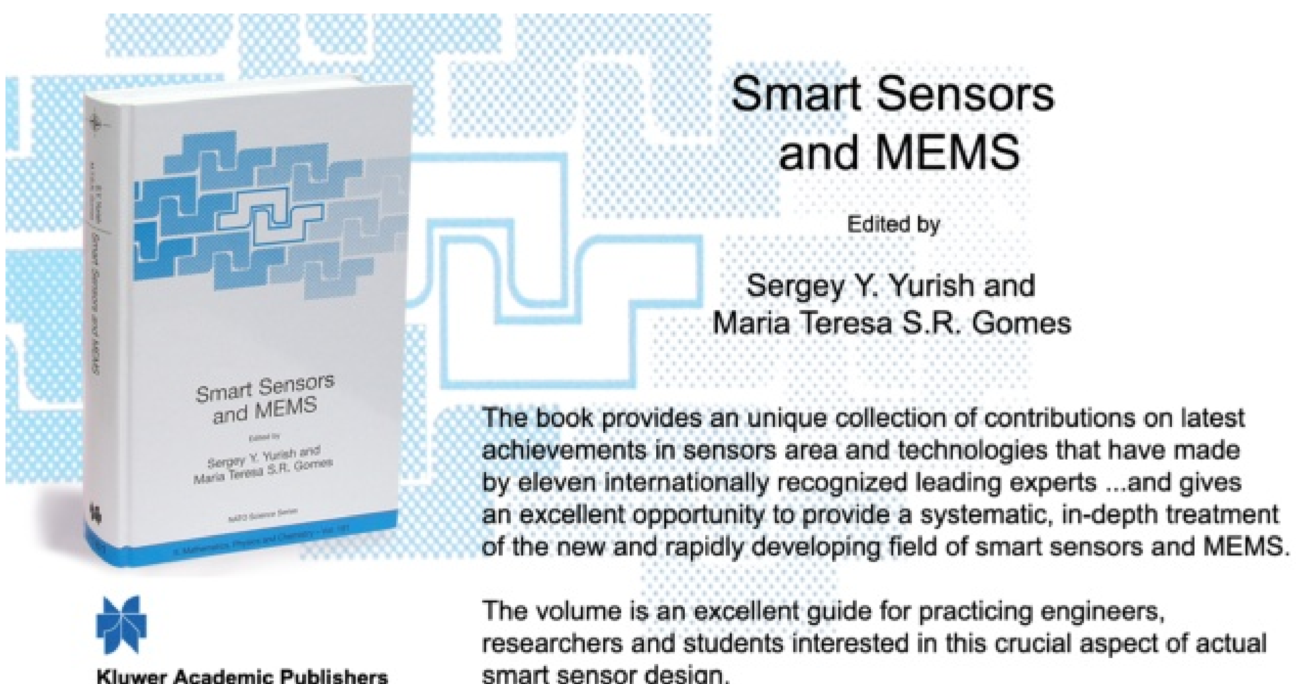

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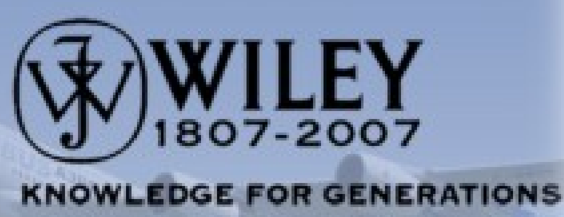

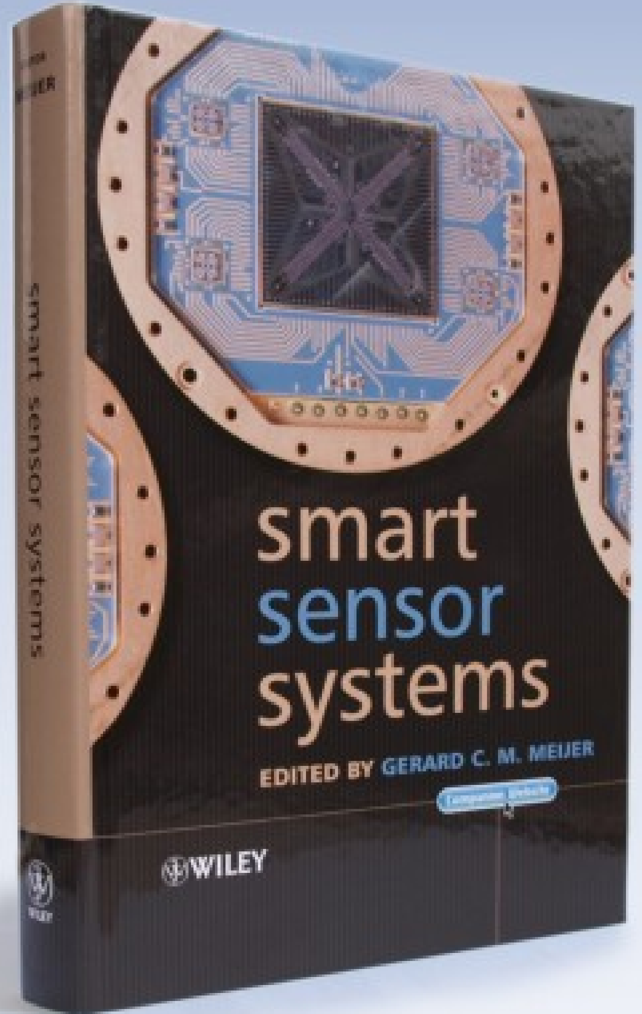

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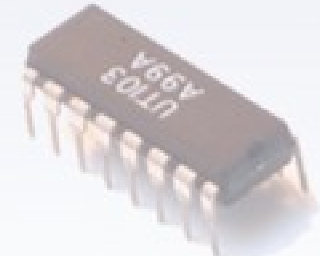

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