HIGH-PRECISION SILICON DIFFERENTIAL PRESSURE SENSOR MONOLITHICALLY INTEGRATED WITH TWIN DIAPHRAGMS AND MICRO OVER-RANGE PROTECTION STRUCTURES

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ABSTRACT

This paper describes a novel silicon differential pressure sensor that is fabricated using silicon surface micromachining, monolithically integrated with twin diaphragms, and has lateral openings for leading the substances the pressures of which are to be measured, and micro over-range protection structures. The two diaphragms that have piezo gauge resistors work complementarily to each other as a result of a difference in the respective pressures of fluids led through the lateral openings.

The sensor linearity and errors caused by changes in ambient temperature and static pressure have been improved to less than 0.2%, and high zero-point long-term stability of less than 0.01% has been obtained. Throughout this paper we will demonstrate the design for differential pressure sensors and show experimental results.

INTRODUCTION

Differential pressure transmitters are field instruments, which are widely used for measuring flow rates, pressures, liquid levels and so on. Pressure sensors using a single crystal silicon diaphragm have demonstrated excellent mechanical stability and have been produced by the same fabrication technology as that used for silicon integrated circuits, because of its suitability for mass production [1]. Also, a stable electrical signal is easily obtained by piezo gauge resistance [2,3]. For these reasons, sensors using a silicon diaphragm are used for measuring differential pressure.

Differential pressure sensors have two technical requirements. Both, high static pressure and high differential over-range pressure, which is caused by the misoperation of valves, must be applied to the sensors. Therefore, conventional silicon sensors for these applications must be mounted in a strong high-pressure vessel, and the output terminals need to be hermetically sealed. Also, a complex mechanical structure is required to protect each silicon diaphragm from high differential pressure [4]. These structural requirements will most likely lead to an increase in the cost of the sensor.

The first attempt to fabricate a sensor with a micro over-range protection structure was reported in Transducers '95 [5]. The following describes a sensor, which has two diaphragms with piezoresistors working complementarily to each other due to the respective pressures. This structure has improved sensor linearity, and reduced errors caused by changes in ambient temperature and static pressure.

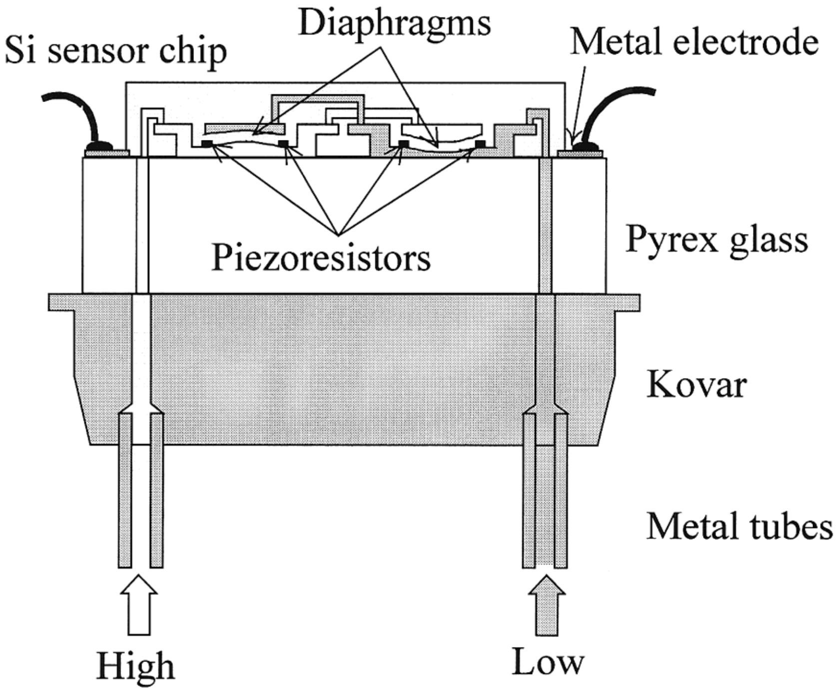

Figure 1: Cross sectional view of the sensor

SENSOR DESIGN

Figure 1 shows a cross sectional view of the sensor. The substance to be measured passes via two openings in the Pyrex glass base. The glass base and the silicon sensor chip are bonded using the anodic bonding method. The sensor has two diaphragms which work complementarily to each other by applying differential pressure. The substance is led through the gaps on both sides of the diaphragms via lateral openings that are formed inside the silicon sensor chip. Piezo gauge resistors are positioned on the side of each diaphragm.

Excess pressure causes the diaphragms to come into contact with the back planes, thus preventing the diaphragms from fracturing. The sensor is also a high-pressure vessel and the electrical feedthrough of the silicon surface and the pyrex glass is hermetically sealed with unique bonding structures. The ion-implanted layers are formed as piezoresistors and p-type leads on the silicon surface, and the p-type leads are connected to the electrodes that are formed on the glass surface. Ohmic contacts are gained by the anodic bonding and annealing process.

FABRICATION PROCESS

Figure 2 shows the fabrication process of the silicon sensor chip.

1) An SiO_2 film is etched and poly-silicon film is deposited on the SiO_2 film.
2) The surface of the poly-silicon film is flattened by grinding and then polished.
3) The film is then bonded to another n-type silicon film to form a wafer.
4) The original surface of the wafer is ground and polished until the desired thickness is obtained.
5) Gaps are created on the surface, by the LOCOS process. Piezoresistors and p-type leads (omitted from the figure) are implanted.
6) Openings to the buried SiO_2 film are etched by SF_6 RIE.
7) Buried SiO_2 film is etched with a HF solution.

After this process, the anodic bonding process is used to bond the silicon chip to the Pyrex glass base.

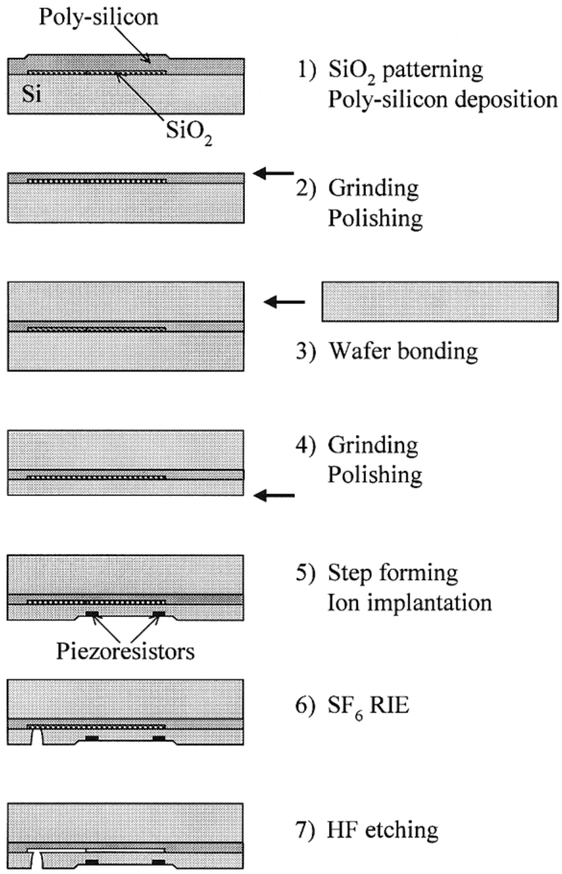

Figure 2: Fabrication process

THE SENSOR OPERATION

Figure 3 shows the sensor operation. The changes in the signals of the two gauges on the diaphragms complement each other as a result of differential pressure. While, the changes in static pressure and ambient temperature cause errors of the output signals of both gauges in the same direction. However, these errors can be offset since output signals from gauge 1 are subtracted by output signals from gauge 2. This results in high precision.

RESULTS OF EXPERIMENT

Figure 4 shows the output signal of a sensor covering ±100 kPa. The output signal saturation indicates that either diaphragm has come into contact with the back plane.

Linearity of sensor signal

Figure 5 shows the linearity of the signal for a sensor that was calibrated at 0 kPa and +100 kPa. The results show high linearity with an error rate of under 0.2% of full scale, and no hysteresis.

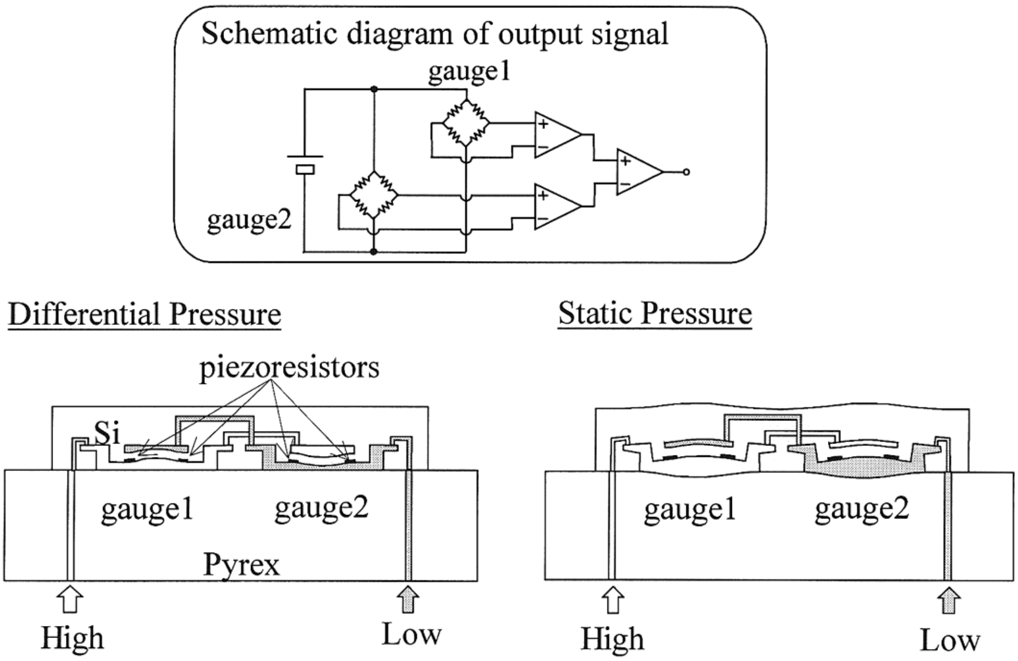

Figure 3: Sensor operation

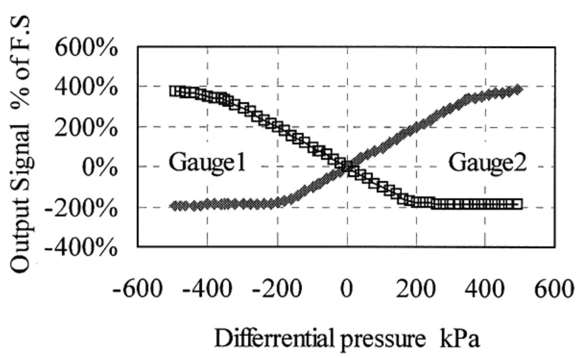

Figure 4: Output signal of the sensor

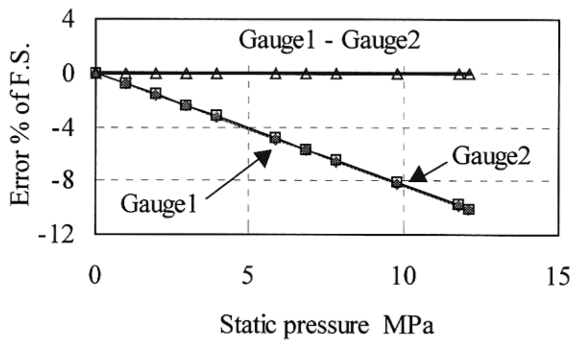

Figure 6: Static pressure effect

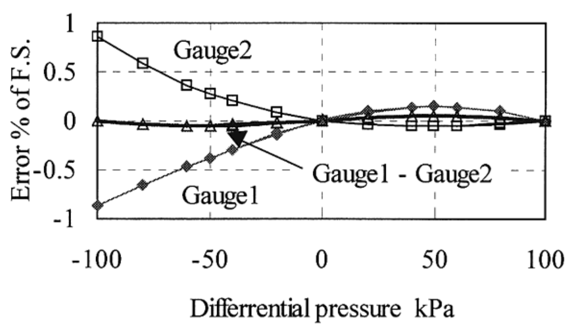

Figure 5: Linearity of the sensor

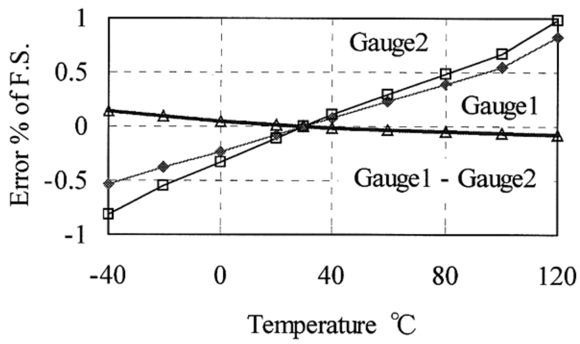

Figure 7: Temperature effect

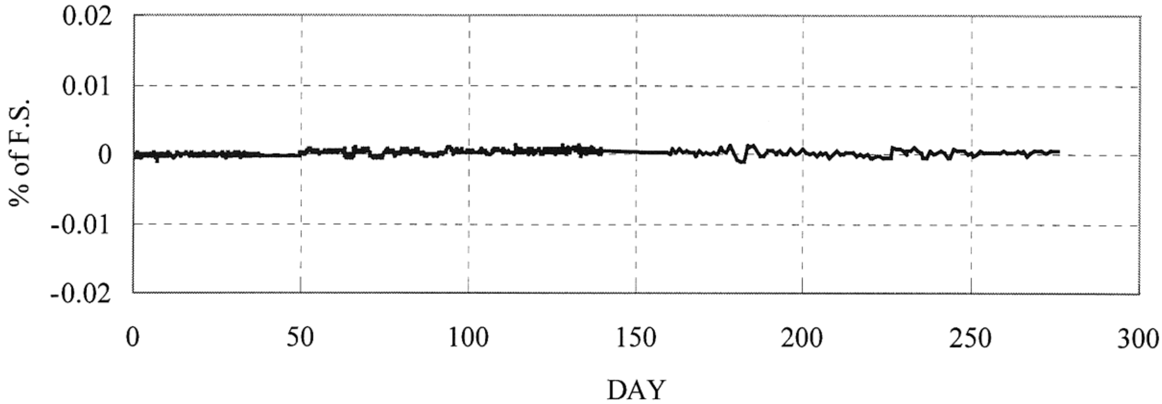

Figure 8: Zero-point Log-term stability

Effects of temperature and static pressure

Figure 6 shows the error caused by changes in static pressure, and Figure 7, the error by ambient temperature changes. The error of the sensor signal in both cases is under 0.2% of fullscale.

Long term stability

Figure 8 shows the result from testing long term stability. The zero drift after use for a long term was observed to be less than 0.01%.

CONCLUSION

The novel silicon differential pressure sensor we developed shows such superb linearity and greatly reduced effects from changes in ambient temperature and static pressure that it exhibits less than 0.2% of both temperature and static pressure effects, and high long-term stability of less than 0.01% of zero drift.

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