An Integrated Pressure Sensor with High Performance

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ABSTRACT

A bipolar integrated pressure sensor had been designed and simulated. The ion-implanted resistors with temperature coefficient of 1700pm/°C and 4700ppm/°C were used for calibration and temperature compensation. Ion-implanted resistors are simultaneously fabricated with base and piezoresistors. Simulation results of designed pressure sensor showed that maximum stress was 1590kPa and maximum deflection was $4.95\times10^{-4}\mu m$. The pressure sensitivity was 240μV/V·kPa. Simulation results of calibrated and temperature compensated circuits showed that the offset voltage was 0.4V at 10kPa and full scale span was 4.65V at 115kPa. The temperature coefficient of full scale span was 46 ppm/°C at the temperature range of −10 to 70°C.

Key Words : pressure sensor, calibration, temperature compensation, ion-implanted resistors

I. INTRODUCTION

Most silicon sensors need signal conditioners to make linear, compensate temperature, and set gains for their outputs[1]. Silicon pressure sensors have been made as discrete parts for many years. But the needed high volumes, especially, in automobile industry, have made manufactures integrating more functions onto the sensor chip itself. Temperature compensating resistors and operational amplifiers can now be found on the substrates of many silicon pressure sensors[2-6]. The conditioned signals are used to control devices or systems based on the measured signal. It makes sense to put as much signal conditioning as possible in the same package as the sensor in itself. Semiconductor manufacturers are making sensors that are compatible with bipolar[3-4], MOS[5] and CMOS [6] processing.

A bipolar integrated piezoresistive silicon pressure sensors for automotive applications[2-3] had been success in a few years ago and now widely used because of their low price and high reliability. Generally, piezoresistors are bridge connected on diaphragm edge through metal layer. The temperature compensation of output signal is generally made passively with thin or thick film resistors on ceramic substrate[2]. Recently, on-chip laser trimming using thin film resistors on silicon substrate was made[3-4]. Laser trimming is an accurate technique for fabricating precision thin film resistors on monolithic chips, but it is a relatively slow and costly step since each precision resistors must be aligned and trimmed individually.

In this paper, trimmable ion-implanted resistors with different temperature coefficient were used for calibration and temperature compensation of pressure sensor and its simulation results are discussed.

II. DESIGN

Sensor

Fig. 1 shows designed pressure sensor. The pressure sensor had diaphragm size of 1.5mm × 1.5mm and thickness of 20μm. A piezoresistor is made of three straight line along [110] direction and two connecting portions along [100]. The contact portions between the piezoresistor and metal pad are provided in a outside silicon diaphragm. Also, the conducting layers between the piezoresistor and the contact are formed along the crystal orientation with minimum piezoresistive coefficient and made of same layer that of piezoresistor. The sheet resistance of piezoresistors are 160Ω/□. The value of piezoresistors are determined by length of three straight line, corner resistance, conductive area and contact resistance. The perpendicular and parallel piezoresistors to diaphragm edge are designed to have same area. The pressure sensitivity was 240μV/V·kPa.

Signal Conditioning Circuitry

The specification for the integrated pressure sensor is shown in table 1. Operating pressure range is 10 to 115kPa. The offset voltage is 0.4V and full scale span is 4.65V at the temperature range of −10 to 70°C.

Fig. 2 shows the block diagram of signal conditioning circuitry. Signal conditioning circuits permits offset voltage, full scale span and temperature coefficient of offset voltage and full scale span to be calibrated from a trimming ion-implanted resistors. Ion-implanted resistors with different temperature coefficients of 1700ppm/°C and 4700ppm/°C were used to trim desired values. The sheet resistance of each ion-implanted resistors were 160Ω/□ and

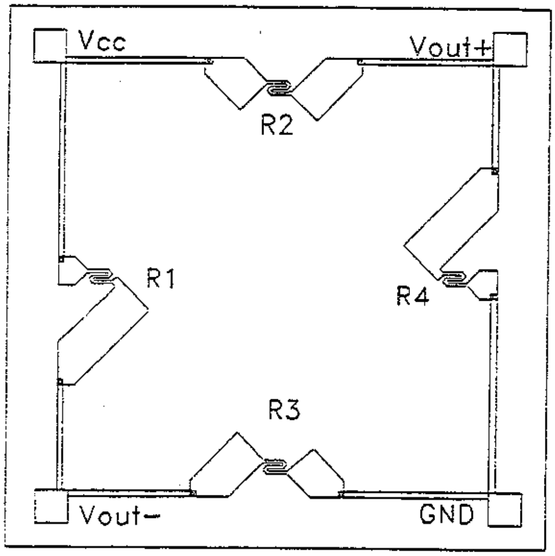


Figure 1. Layout of designed pressure sensor.

Table 1. Characteristics of pressure sensor

Pressure range	10 ~ 115 kPa
Offset voltage (-10 to 70°C)	0.4V±81mV
Full scale span (-10 to 70°C)	4.65V±81mV
Supply voltage	5V± 0.25V

$1k\Omega/\square$, respectively. The characteristics of designed signal conditioning circuitry are followings.

1. When the pressure sensor has offset voltage due to mismatches of piezoresistors or process-related variations, the output dc level is always constant value by dc level shift using trimming resistors Roff+ and Roff-.
2. The negative temperature coefficient of pressure sensitivity is compensated by the positive temperature coefficient of full scale span.
3. Roff+ and Roff- trimmings are unaffected to full scale span.
4. The offset voltage was calibrated to 0.4V at 10kPa and full scale output voltage was calibrated to 4.65V at 115kPa.
5. The full scale span and temperature coefficient of full scale span were sequentially adjusted through trimming of Rspan1 and Rspan2.

SIMULATION RESULTS

Mechanical simulation

The mechanical characteristics of pressure sensor was simulated using IntelliCAD. Diaphragm size and thickness are 1.5mm×1.5mm and 20μm, respectively. Three shapes of piezoresistors in Fig. 3 (a), (b), (c) were individually

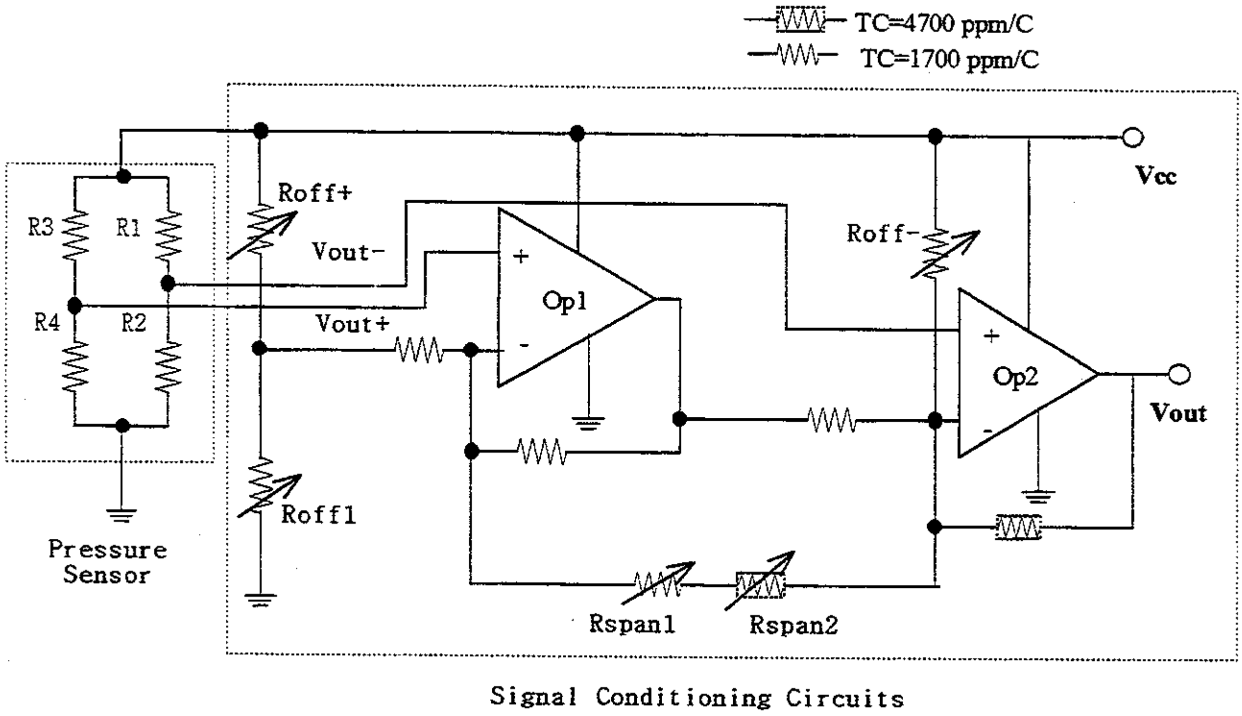


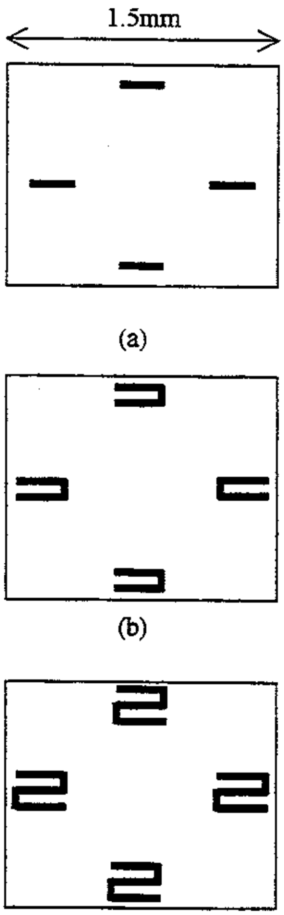
Figure 2. Block diagram of signal conditioning circuits.

simulated. A process flow for simulation are as following.

1. P-type (100) silicon wafer : 350μm thickness
2. N-type epitaxial layer : 20μm thickness
3. Piezoresistor implant : 4×10E+14 /cm^3 ion dose
4. PECVD Si_3N_4 Deposition : 5000 Å thickness
5. Double side align
6. Silicon Etching : 30wt%KOH, 80°C

As shown in Fig. 3(a), (b), (c), the length to width ratio of piezoresistors was 10, 5 and 5, respectively. The simulation results of stress distribution on diaphragm in Fig. 3(a), (b), (c) as a function of x, y, and z direction was shown in Fig. 4. In case of Fig. 3(a), the stress component of x and y direction, Sxx and Syy were larger than the stress component of z-direction , Szz. In case of Fig. 3(b), (c), the Szz was larger than Sxx and Syy.

Table 2 shows maximum displacement, Dis x, Dis y and Dis z in x-, y-, z-direction. In case of Fig. 3(a), Dis y was much larger than Dis x and Dis z. Whereas, in case of Fig. 3(b) and (c), Dis x and Dis y had similar value and Dis z was much smaller than Dis x and Dis y.



(a)

(b)

(c)

Figure 3. Three shapes of piezoresistors on diaphragm for simulation. (a) L=100μm, W=10μm. (b) and (c)L=50μm, W=10μm.

Table 2 Maximum displacement on diaphragm in case of Fig. 3(a), (b) and (c).

Unit:μm

	Fig. 3(a)	Fig. 3(b)	Fig.3(c)
Dis x	5.04E-05	1.57E-04	2.44E-04
Dis y	1.93E-04	5.93E-04	4.95E-04
Dis z	1.3E-05	5.16E-05	5.77E-05

SPICE Simulation

The signal conditioning circuitry as shown in Fig. 2 was simulated using SPICE. Table 3 shows simulation condition of integrated pressure sensor. The sequence of simulation was as following.

1. Variations of dc output voltage as a function of pressure at the condition of 25°C, zero offset voltage and zero span TC.
2. Variations of dc output voltage as a function of pressure and temperature at the condition of zero offset voltage and zerp span TC.
3. Variations of dc output voltage as a function of pressure, temperature and offset voltage at the condition of zero span TC.
4. Variations of dc output voltage as a function of pressure, temperature, offset voltage and span TC .

For the calibration and temperature compensation of pressure sensor , the trimming of ion-implanted resistors were achieved following sequence.

1. Calibration of dc output voltage at the applied pressure of 10kPa and 115kPa through trimming of Roff-, Roff+
2. Calibration of temperature coefficient and full scale span at the applied pressure of 10kPa and 115kPa through trimming of Rspan1, Rspan2 and Roff1.

Table 3. Simulation condition of signal conditioning Circuits.

Temperature range	-10 ~ 70°C
Compensation range of span TC	-1800 ~-2500ppm/°C
Maximum offset voltage	±45mV
Calibrated output voltage	0.4V at 10kPa 4.65V at 115kPa
Piezoresistance variation	1Ω/mV

When no offset voltage present , Roff+ and Roff- value set to maximum value. When positive or negative offset voltage is added to sensor output voltage, the dc output voltage can be level-shifted to determined value without variation of temperature coefficient of full scale span and offset voltage. If the positive offset voltage due to mismatches of piezoresistors process-related variations present the sensor in itself, Roff+ can be trimmed to from maximum value to lower value. If the negative offset voltage due to piezoresistor mismatch or process-related variations present the sensor in itself, Roff- can be trimmed to from maximum value to lower value.

At initial condition, the trimming resistor for span temperature coefficient , Rspan1 was set to minimum value and increased to larger value for accurate adjustment of span temperature compensation. As a variation of Rspan1, Rspan2 trimmed to desired value for full scale span adjustment.

Fig. 5 shows output voltage as a function of pressure after calibration and temperature compensation. Fig. 6 shows comparison of output voltage deviation before and after calibration and temperature compensation. After calibration, the output voltage was 0.4V and 4.65V at 10kPa and 115kPa, respectively. The temperature coefficient of span was 46ppm/°C. Before temperature compensation, output voltage deviation was 4.06% at -10°C and 2.89% at 70°C. After temperature compensation, output voltage deviation was reduced to 0.3% at -10°C and 0.19% at 70°C.

V. CONCLUSION

A piezoresistive pressure sensor with signal conditioning circuitry had been designed and simulated. Presented pressure sensor had no additional process except standard bipolar process and silicon etching process. Calibration and temperature compensation using trimmable ion-implanted resistors were very well comparable to conventional temperature compensated pressure sensor using thin or thick film resistors or thermistors. And offset voltage due to process-related variations can be compensated using offset voltage compensation.

To achieve a more accurate compensation, the temperature range of the compensation will be extended to larger value and trimming range of resistors will be accommodated to the sensor behavior.

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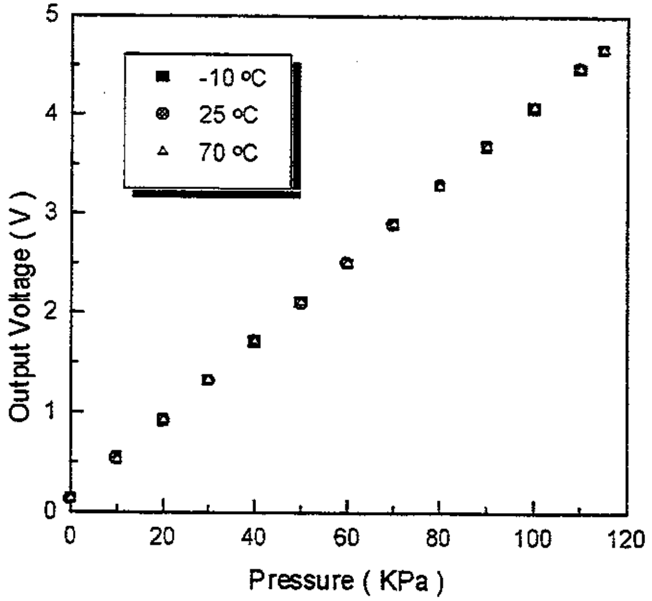

Figure 5. Output voltage as a function of pressure.

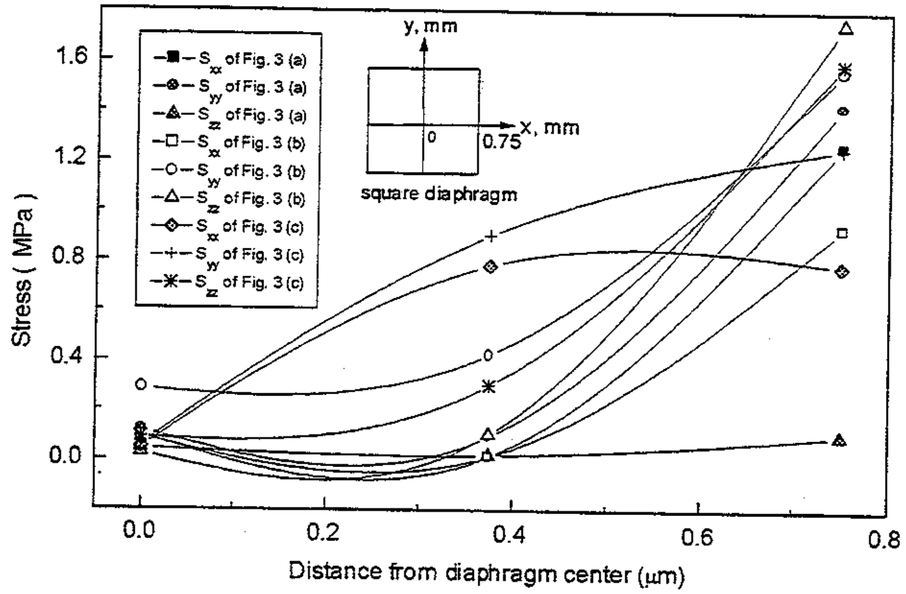

Figure 4. Stress distribution on diaphragm in case of Fig. 3(a),(b) and (c).

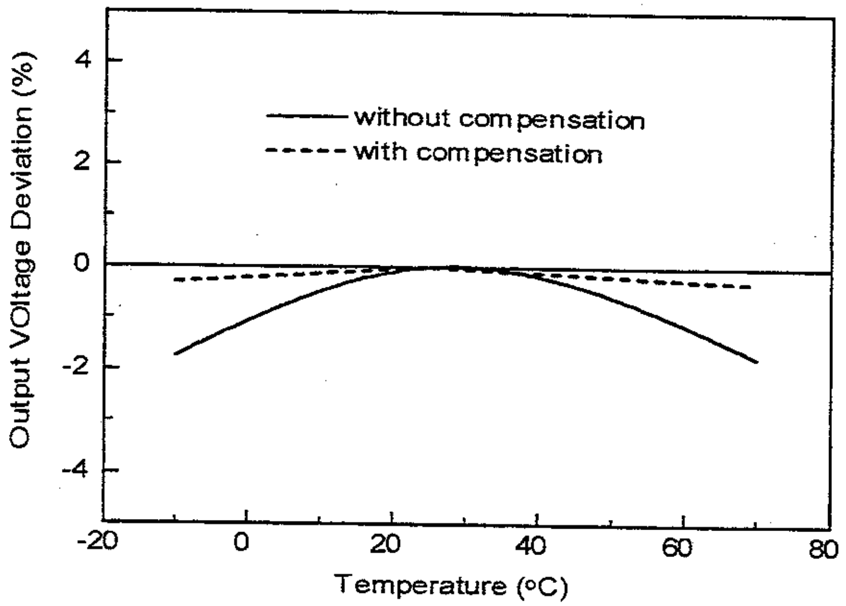

Figure 6 Comparison of output voltage deviation before and after temperature compensation.