

# FAMILY OF MICRO PRESSURE SENSOR $\mu$ SP

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*We have developed new pressure sensor  $\mu$ SP series of plastic molding package. It has four types of the pressure range; 1, 10, 100 kPa, and 1 Mpa gauge pressure. As the method of detecting pressure, the shearing type silicon piezo-resistive gauge is adopted. The driver circuit chip is mounted together with the pressure sensor chip in this package. This chip, correcting the temperature change of the sensor sensitivity, makes the steady operation possible from a low current of 0.5 mA to 1 mA over the range of -40 to +80°C. On the other hand, as the design of this mold package, a ditch is formed around the sensor chip not to transmit the stress of transformation of the package by impressed pressure and outside force.*

*Moreover, the mold type pressure sensor is achieved at a lower price than the conventional CAN type package. This sensor is suitable for measuring the air pressure in various applications such as air-conditioning equipments, FA equipments, and semiconductor manufacturing devices.*

*In this paper, the structure and characteristics of the sensor series are described.*

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## INTRODUCTION

The pressure sensor family, FP101 SERIES, using silicon micromachining technology with piezo-resistive gauge, suitable for various applications such as FA equipments, has been in market since 1988. In 1992, the differential pressure transmitter DPharp SERIES was developed by using single crystal silicon resonant sensor. The DPharp SERIES has used for the plant field instrumentation and the other wide applications, with high accuracy and high stability. On the other hand, a small size pressure sensor mounted on a printed wiring board, was developed in 1989. The sensor is 1 kgf/cm<sup>2</sup> (100kPa) pressure range sensor with a can package (TO-8). It has mainly used for electro-pneumatic converter. Small size pressure sensor has been used for various applications such as air conditioning equipments, electrical appliances, medical appliances, and semiconductor manufacturing devices.

Recently, we have developed new silicon pressure sensor series of plastic molding DIP-type package by means of developing new sensor chips. It consists of four types of the

pressure range; 1, 10, 100 kPa, and 1 MPa gauge pressure. The pressure sensor series, suitable for measuring the air pressure in various applications, has achieved lower price than the conventional sensors.

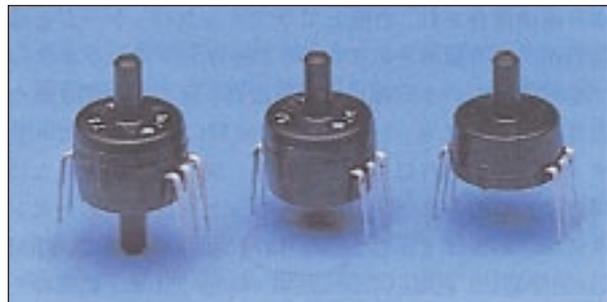


Figure 1 External View of the Pressure Sensor

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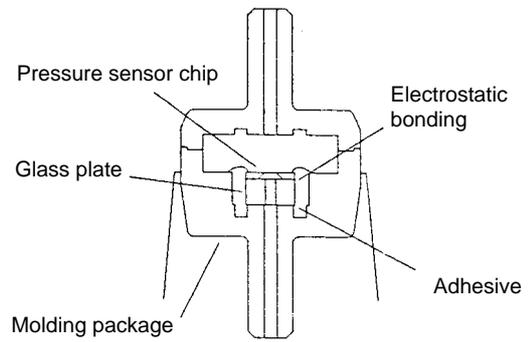
## STRUCTURE AND CIRCUIT CONFIGURATION

The only one rectangular diffused resistor, so called shearing type silicon piezo-resistive gauge, is adopted. This structure has more advantages than the other type of pressure sensor with two or four diffused resistors. For example, a zero-offset depended on a difference of the value of two or four resistors does not exist. There is no influence of uneven thermal distribution of the diaphragm.

The key points to characterize the accuracy of a piezo-resistive pressure sensor are as follows: 1) the first is repeatability (i.e. hysteresis) of output against pressure applied to the sensor, 2) and the next one is decrease of output drift depending on a temperature drift. The output drift depends on the temperature coefficient of diffused resistor and on the temperature effect of piezo-resistive coefficient. The pressure sensor in this paper takes advantage of material properties (e.g. elasticity) of single crystal silicon in adopting novel structure of molding package, and compensates the temperature drift by individual driver circuit.

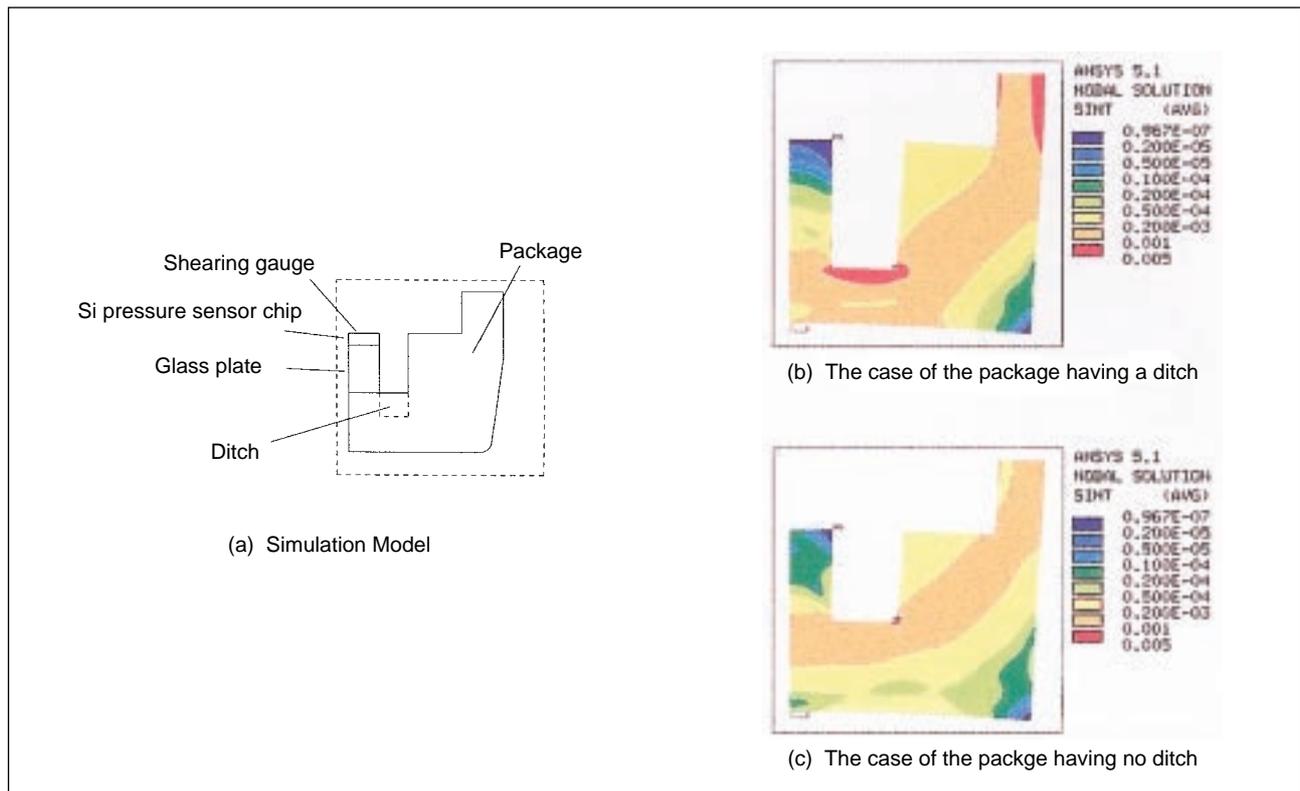
### 1. Structure of Pressure Sensor

Figure 1 shows the photograph of the pressure sensor. A diameter of outward form is about 14 mm. The length of pipe, with a diameter of 3.5 mm, is 8 mm. The DIP type package has 6 terminals of 15.24 mm (600 mil) width and 2.54 mm pitches. There are three types of package to apply for various applications.



**Figure 2** Construction of Pressure Sensor

Figure 2 shows a cross section of the pressure sensor. A glass base plate, with through-hole in the center, and the silicon pressure sensor chip are electrostatic bonded. The glass base plate and the plastic molding package are attached by adhesive. At the design of this mold package, a ditch is formed around the pressure sensor chip not to transmit the stress of transformation of the package by the applied pressure and the outside force. Figure 3 shows an example of result which is simulated by the finite element method (FEM). In the case of the package having a ditch



**Figure 3** Simulation (FEM)

or not (figure 3(a)), the stress was simulated by the transformation of the package with the applied pressure. The influence for the gauge on the surface of the sensor chip by its transformation was reduced to about 1/10.

In this package, the driver circuit chip is mounted together with the pressure sensor chip. This chip outputs precise voltage in proportion to temperature change by detecting the temperature change. Since the pressure sensor chip is driven by the output voltage, the sensor chip is compensated.

## 2. Process of diaphragm

There are several factors which characterize the sensitivity of the piezo-resistive pressure sensor. The factors are mainly as follows: 1) impurities density of the diffused gauge, 2) shape of the gauge, 3) position of the gauge on the diaphragm, 4) shape and thickness of diaphragm. In a manufacturing process of pressure sensor chip, it is possible to use a semiconductor wafer process which has exactly uniform photo lithography and impurities diffusion in a silicon wafer. Therefore, to the above items 1), 2), and 3), a stable manufacturing process is ensured. To the item 4), the shape of the diaphragm is formed accurately because of adopting an isotropic etching of single-crystal silicon in aqueous KOH, hydrazine. However, an etching rate depends on the distribution of temperature and or density of the etchant.

Furthermore, a silicon wafer itself has distribution of thickness. So it is difficult to control the thickness of the diaphragm. An electrochemical etch-stop, which has repeatability, has been developed. This thickness control method achieves high accuracy and small dispersion with less than 1 $\mu$ m.

## 3. Circuit configuration

The output voltage of the pressure sensor,  $V_{out}$ , is shown in the equation (1). In this equation, piezo-resistive coefficient ( $\pi$ ) has a temperature coefficient (about -2000 ppm/ $^{\circ}$ C). It is possible to cancel this temperature coefficient that  $V_s$  has positive one (about +2000 ppm/ $^{\circ}$ C).  $V_s$  is expressed in the equation (2). In this equation,  $n$  is a ratio of the current-density of two emitters, TR1 and TR2.  $R$  is a ratio of  $R_1$ ,  $R_2$ , and  $R_3$ .  $n$  and  $R$  result in the temperature coefficient of the  $V_s$ .

Figure 4 shows a circuit configuration of the pressure sensor.

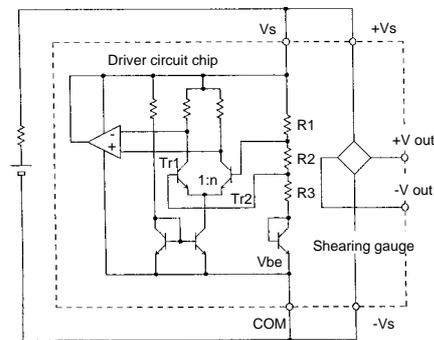


Figure 4 Circuit Configuration

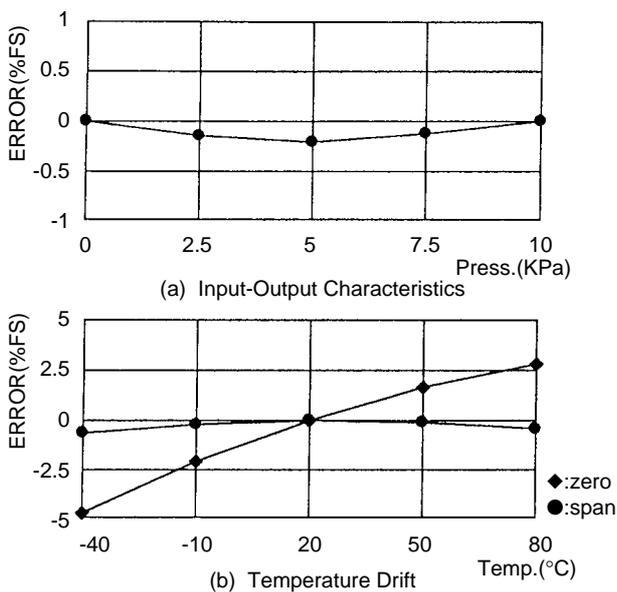


Figure 5 10kPa-range sensor

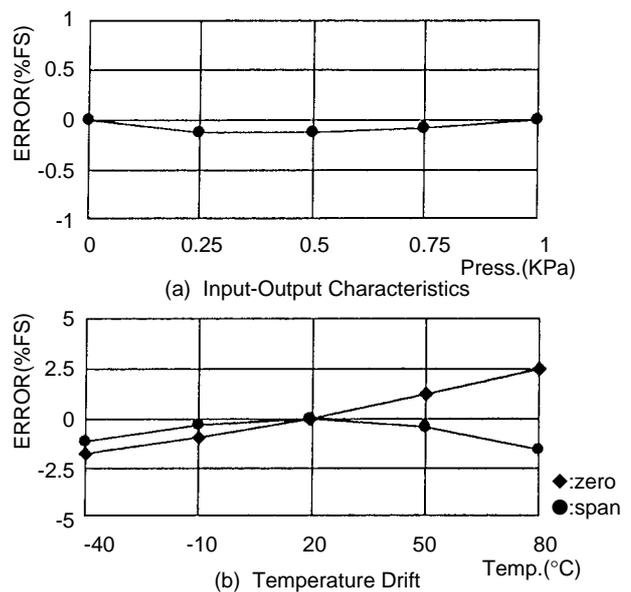


Figure 6 1MPa-range sensor

**Table 1** Electrical Characteristics (Typ.)

Item / Range	1kPa	10kPa	100kPa	1MPa	Unit
Pressure sensor					
Zero Offset	0±15				mV
Span Output	20±6	40±12			mV
Non-linearity	±0.5		±0.2	±0.5	%FS
Hysteresis	±0.2	±0.1			%FS
Temperature Effect on Offset	-1500±400	700±400	-400±400	0±700	ppm/°C
Temperature Effect on Span	0±800	0±400	0±200		ppm/°C
Driver Circuit					
Output Voltage	3.21±0.03				V
Temperature Coefficient	6.50±0.15				mV/°C

## CHARACTERISTICS

The driver circuit is located in a left side of this figure, and the pressure sensor chip is the other side.

$$V_{out} = K\pi\tau V_s \text{ ----- (1)}$$

$$V_s = R(kT/q)\ln(n) + V_{be} \text{ ----- (2)}$$

K : (constant)

$\pi$  : piezo-resistive coefficient

$\tau$  : stress (shearing stress)

$V_s$ : driving voltage on gauge

k : Boltzmann's constant

T : temperature

q : magnitude of electronic charge

n : ratio of current-density in two emitters

$$R = (R_1 + R_2 + R_3) / R_2$$

The driver circuit chip has two advantages other than the compensation of the temperature drift of the pressure sensor sensitivity. The first is that this chip eliminates an influence of fluctuation of supply current or voltage. The influence of the fluctuation on the pressure sensor output is less than 0.2%FS/mA. This sensor series differs from another pressure sensor which is directly influenced by fluctuation of supply current. The second one is that the chip is possible to use for temperature sensor. It is possible to monitor the temperature of pressure vehicle and to compensate the temperature drift adding external circuit. The operating conditions are from 5 to 30 volt of supply voltage and from 0.5 to 1 mA of supply current.

Figure 5 and Figure 6 show main characteristics in two ranges of 0 to 10 kPa, 0 to 1 MPa. Figure 5(a) and 6(a) show input-output characteristics. Figure 5(b) and 6(b) show zero and span shift when the ambient temperature is changed from -40°C to +80°C. This sensor family have the advantage that the temperature drift of span output (i.e. sensitivity) is compensated to zero using the driver circuit chip.

The characteristics of the sensor series list in the Table 1.

## CONCLUSION

We have developed the new silicon pressure sensor series, which has four types of the pressure range; 1, 10, 100 kPa, and 1 MPa gauge pressure, using the new silicon piezo-resistive pressure sensor chips and the new plastic molding DIP-type package. In addition, the electrochemical etch-stop method is developed. At the design of this package, the ditch is formed around the pressure sensor chip not to transmit the stress of transformation of the package by applied pressure and outside force. Therefore, this series has characterized the high accuracy and the high stability. It is suitable for measuring the air pressure in various applications such as air conditioning equipments, electrical appliances, medical appliances, and semiconductor manufacturing devices.

This series is expected to meet the wider variety of user requirements. ◆