6.5th-Generation Automotive Pressure Sensors

UZAWA, Ryohei* **NISHIKAWA, Mutsuo*** **TANAKA, Takahide***

ABSTRACT

There is increasing demand for reducing the environmental load of automobiles. Automotive pressure sensors, which are indispensable for control systems for high efficient engines and cleaner exhaust gas, are required to achieve high-temperature operation, corrosion resistance, electrification resistance, and miniaturization. In order to meet these demands, the 6.5th-generation automotive pressure sensors have been developed. They inherit from the 6th-generation series while providing several enhancements, such as improved electrification resistance and corrosion resistance to exhaust gas and vaporized fuel, as well as a smaller size and improved reliability of sensor accuracy. They optimize temperature characteristic to guarantee operation at 150 °C and add a clamp function to prevent erroneous detection by separating the diagnostic voltage range from the normal output voltage range.

1. Introduction

Currently, automobiles are strongly required to reduce their environmental impact as seen in the imposition of air pollutant and CO_2 emissions regulations, as well as to improve safety and comfort. To meet these regulations, development of control systems for electrically driven vehicles such as hybrid electric vehicles, electric vehicles and fuel cell vehicles is accelerating. Meanwhile, fuel efficiency of gasoline- and diesel-fueled vehicles have improved by precisely controlling the air-to-fuel ratio. Further, technologies to make exhaust gas cleaner by recirculating the gas after combustion so as to reduce air pollutants are becoming widespread at an increasing speed. Pressure sensors are used as one essential device in engine control and their uses include improving engine efficiency and purifying exhaust gas. They are becoming more important year by year.

Fuji Electric started mass producing automotive pressure sensors in 1984. Since then, we have been proposing high-reliability technology, circuit technology and sophisticated micro-electro-mechanical systems (MEMS) technology to meet the requirement of reliability to withstand a severe operating environment and improved detection accuracy. Our pressure sensors are adopted in automobiles in Japan and overseas. Starting in 2010, we have been mass-producing the 6th-generation automotive pressure sensors with digital trimming based on the complementary metal-oxide-semiconductor (CMOS) process.(1)

This paper presents the 6.5th-generation automotive pressure sensor. It is based on the conventional 6th-generation automotive pressure sensor while inheriting the basic "all-in-one chip" concept. It is provided with corrosion resistance and electrification resistance and is guaranteed to operate at 150 °C with a smaller sensor cell size.

2. Overview of Pressure Sensor

2.1 Examples of use of automotive pressure sensors

Figure 1 shows examples of use of automotive pressure sensors. To improve the fuel efficiency of vehicles, most fuel injection systems are now electronically controlled. These electronically-controlled fuel injection systems use a manifold absolute pressure (MAP) sensor for measuring the intake pressure or have a temperature manifold absolute pressure (TMAP) sensor equipped with a temperature sensing function. In addition, many pressure sensors are used to improve fuel efficiency and control engine systems so as to suppress the emission of air pollutants. Such sensors include atmospheric pressure sensors for highland correction intended for preventing any decrease in fuel efficiency when vehicles are travelling at high altitudes, pressure sensors for detecting any clogging of the air intake system air filter box, exhaust pressure sensors for exhaust gas recirculation (EGR) systems to reuse exhaust gas and boost pressure sensors mounted on turbo engines.

Another type of automotive pressure sensor to be mentioned is a pressure sensor for detecting any clogging of diesel particulate filters (DPFs). It is used to deal with stricter exhaust gas regulations represented by the 2016 tightening of emissions regulations of Japan and European Euro 6 in 2014.

Additionally, sensors for meeting safety regulations include fuel tank pressure sensors (FTPSs) for detecting tank leaks, and they are used in Europe and the U.S.

Demand for pressure sensors is also increasing for controlling air conditioner coolant pressure, the pres-

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* Electronic Devices Business Group, Fuji Electric Co., Ltd.

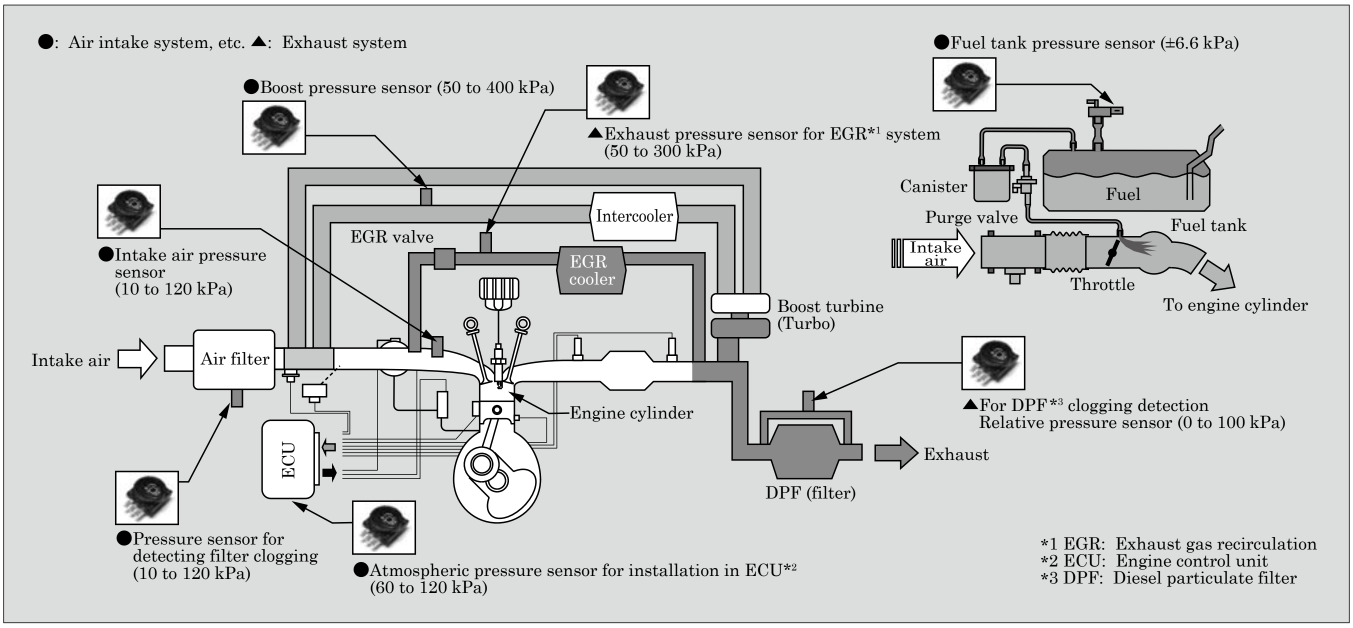


Fig.1 Examples of use of automotive pressure sensors

sure of heat pumps used in electric vehicles and the hydraulic pressure of transmissions. In this way, the scope in which automotive pressure sensors are applied is rapidly expanding and their demand increasing.

2.2 Installation environment of automotive pressure sensors

Conventionally, the medium (target) to be measured by intake or boost pressure sensors was mostly air. However, the scope of application of pressure sensors is expanding as described earlier, and the media to be measured have become severe such as those containing exhaust gas and vaporized fuel including gasoline and diesel oil. Accordingly, sensors need to have corrosion resistance against these media to be measured and electrification resistance against charged vaporized fuels.

In addition, engine rooms are being made smaller and mounting density increased for the purpose of increasing the cabin space intended for improving fuel efficiency and comfort. This has caused a temperature increase in the ambient environment for pressure sensors and exposure to electromagnetic noise generated from various electronic devices. This is why increase in the guaranteed operating temperature and strengthened electromagnetic compatibility (EMC) are required.

3. Features of 6.5th-Generation Pressure Sensor

3.1 Product overview

Figure 2 shows the appearance of the 6.5th-generation automotive pressure sensor and the previous 6th-generation automotive pressure sensor. Table 1 shows the specifications of the 6.5th-generation automotive pressure sensor.

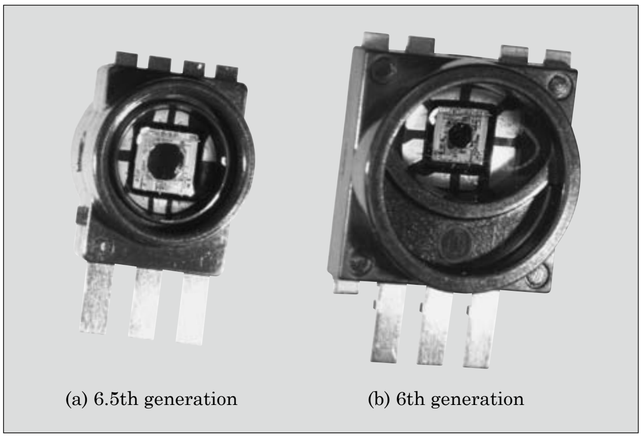

(a) 6.5th generation
(b) 6th generation

Fig.2 Automotive pressure sensor

The 6.5th-generation automotive pressure sensor is equipped with corrosion resistance and electrification resistance. Its maximum guaranteed operating temperature has been increased from 125 °C of the conventional product to 150 °C. For detecting failures, a clamp function has been added for separating the wire harness disconnection detection range (diagnostic voltage range) from the normal use range. The size of the sensor cell has been reduced to approximately 48% of that of the 6th-generation automotive pressure sensor in terms of the volume.

3.2 Corrosion resistance

Figure 3 shows the cross-section structure of the sensor cell of a pressure sensor. Against incoming foreign objects such as soot, the sensor chip and wire are protected by using gelled protection material capable of transmitting pressure. With this product, there is a need to prevent exhaust gas and vaporized fuel such as gasoline and diesel oil from passing through the pro-

Table 1 Specifications of 6.5th-generation automotive pressure sensor

Item	Specification
Product size (resin part)	W7.5 × H10 × D5.6 (mm)
Operating temperature range	−40 °C to +150 °C
Operating pressure range (intake pressure sensor)	20 to 120 kPa
Rated pressure	Pressure range × 3
Power supply voltage	5 ± 0.25 V
Output voltage (at power supply voltage of 5 V)	0.5 to 4.5 V
Sink and source capacities	Sink: 1 mA, Source: 0.1 mA
Clamp function	Clamp voltage 0.3 V/4.7 V (typ.)
Corrosion resistance	In accordance with JASO M 611-92/B Method (Gasoline/diesel component)
ESD (external interface terminals)	
MM (0 Ω, 200 pF)	±1 kV or more
HBM (1.5 Ω, 100 pF)	±8 kV or more
Transient voltage surge	ISO 7637 (2011) standard Pulse 1, 2, 3a, 3b LEVEL-Ⅲ cleared
Impulse	±1 kV or more
Latch-up (current injection method)	±500 mA or more
EMS (G-TEM) (100 V/m)	Variation: 1% FS or less
Overvoltage (between Vcc and GND)	16.5 V (max.)
Reverse connection (between Vcc and GND)	0.3 A (max.)

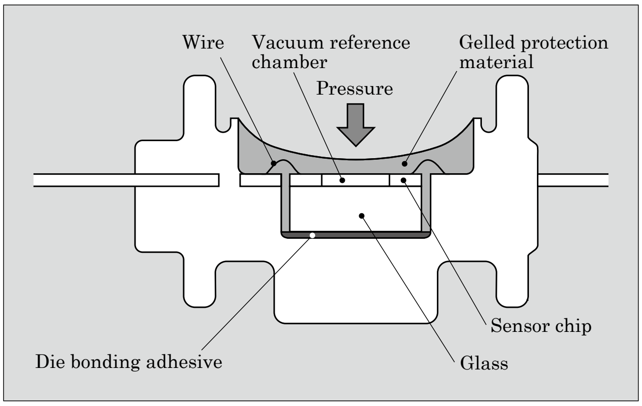
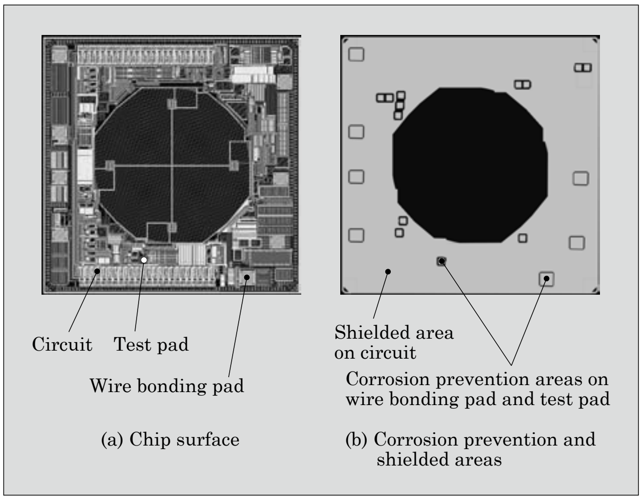


Fig.3 Cross-section structure of sensor cell

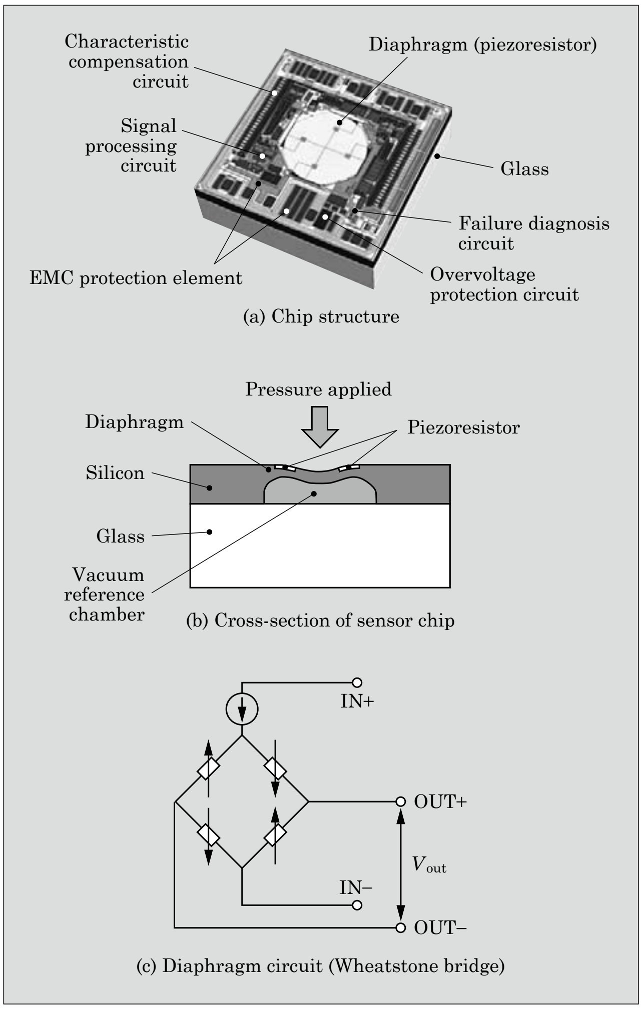
tection material since it would corrode the wire bonding pad on the chip surface. Hence, corrosion prevention areas have been provided on the wire bonding pad and test pad as shown in Fig. 4.



(a) Chip surface

(b) Corrosion prevention and shielded areas

Fig.4 Corrosion prevention and shielded areas



(a) Chip structure

(b) Cross-section of sensor chip

(c) Diaphragm circuit (Wheatstone bridge)

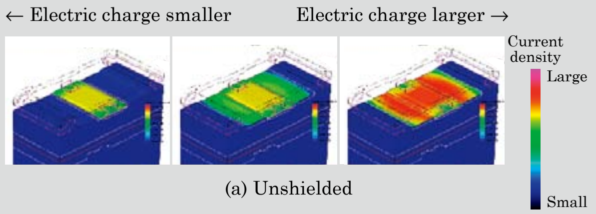
Fig.5 Overview of pressure sensing unit

3.3 Electrification resistance

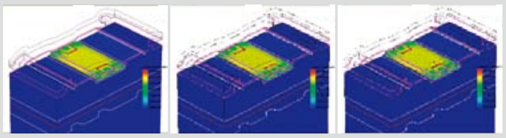
Figure 5 outlines the pressure sensing unit integrated in the pressure sensor. Fuji Electric's proprietary etching technology is used to process part of the silicon into a thin film to form a diaphragm. The 4 piezoresistors composed of the diffusion wiring provided on the diaphragm constitute a Wheatstone bridge. When the diaphragm is deformed by the pressure applied, the respective piezoresistance values change, generating a potential difference in the output of the Wheatstone bridge. The pressure sensing unit amplifies this potential difference to convert the pressure into an electric signal.

There is a need to prevent electrically charged vaporized fuel from attaching to the gelled protection material and causing a variation of the piezoresistance values since this would affect the sensor characteristics. Hence, this product employs a shielded structure with polysilicon used for the flexible part (diaphragm) of the MEMS. As shown in Fig. 4, the same layer as that of the corrosion prevention areas is used to form a shielded area. The intention is to improve the resistance to electrostatic charging of the circuit except for the diaphragm.

To optimize the structure, we have used device simulation for analysis. Figure 6 shows an example of changes in the chip surface charge and piezoresistor area. With an unshielded structure, the resistance value of the piezoresistor changes as the quantity of electric charge on the chip surface increases [see Fig. 6(a)]. To deal with this phenomenon, a shield has been provided in an appropriate location on the piezoresistor. This has made the piezoresistance constant regardless of the electric charge density on the chip surface [see Fig. 6(b)]. Figure 7 shows the result of actually applying electric charge to the product with this structure to obtain output characteristic changes. It has been confirmed that output is stabilized by appropriately locating the shield and the shielded area of the circuit shown in Fig. 4.



(a) Unshielded



(b) Shield-optimized

Fig.6 Example of changes in chip surface charge and piezoresistor area

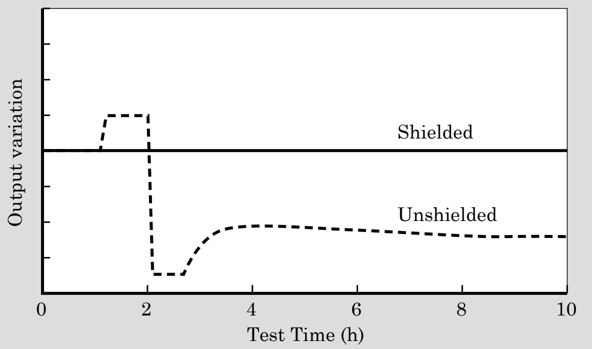


Fig.7 Result of electrification resistance test

3.4 High-temperature operation guarantee and clamp function

Figure 8 shows a circuit block diagram of this product. Deterioration of characteristics in the high-temperature operation range has been restrained by optimizing the temperature characteristics of the individual circuit blocks. This results in guaranteeing that the device will work at 150 °C.

Figure 9 shows a pressure-output characteristic diagram of this product. The sensor output is brought into the diagnostic voltage range when the wire harness is disconnected, which causes the upper-level system to detect a failure. Meanwhile, when overpressure or underpressure is applied the output is brought into the diagnostic voltage range, which may cause the upper-level to erroneously detect disconnection. This product is equipped with a clamp function, where a circuit is provided to clamp the output voltage and reliably separate the diagnostic voltage range from the normal output voltage range, thereby preventing erroneous detection.

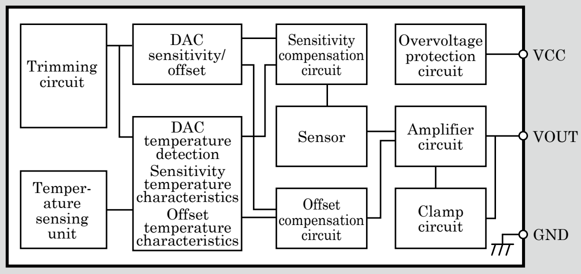


Fig.8 Block diagram of 6.5th-generation automotive pressure sensor

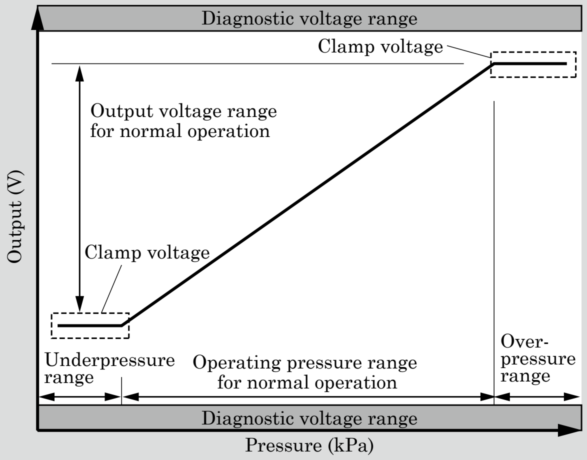


Fig.9 Pressure-output characteristic diagram of 6.5th-generation pressure sensor

4. Postscript

This paper has presented the 6.5th-generation automotive pressure sensor. Increasingly stringent requirements are expected for pressure sensors to see a widespread rollout in Japan and overseas. They will need to offer better product performance from the perspective of improved fuel efficiency and compliance with environmental and safety regulations. Fuji Electric intends to continue meeting market needs in and work on developing the products required by the market.

References

(1) Mutsuo, N. et al. 6th Generation Small Pressure Sensor. FUJI ELECTRIC REVIEW. 2011, vol.57, no.3, p.103-107.

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