SMD-type Small Atmospheric Pressure Sensor for High-altitude Compensation

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1. Introduction

The environmental activities in the automotive industry are increasing while the ervironmental regulations are tightened in Europe, United States, Japan, Asia environmental and else where throughout the world. In order to comply with such regulations, automobile systems are becoming more efficient and are realizing higher control accuracy. Moreover, the engine management functions that measure and control pressure in these systems have become increasingly important in recent years.

Fuji Electric has been mass-producing automobile pressure sensors since 1984. Responding to severe changing needs for lower cost and higher precision, Fuji Electric has proposed proprietary high reliability circuit technology and advanced MEMS (micro electro mechanical systems) technology that is being used in automobiles and motorcycles both in Japan and overseas. Since 2007, Fuji Electric has been mass-producing 5th generation digital trimming type automotive pressure sensors using a CMOS (complementary metal-oxide-semiconductor) process.

This paper introduces a SMD (surface mount device)-type small pressure sensor that has been developed using a 5th generation digital trimming type automotive pressure sensor chip and that can be mounted onto the surface of an ECU (electronic control unit) circuit board and used for high-altitude compensation when an automobile travels at high elevations.

2. Use for Atmospheric Sensors

Automotive pressure sensors are generally used in the electronic fuel injection system of a combustion engine to measure pressure inside the intake manifold in order to control the air-fuel ratio optimally. On the other hand, in order to compensate for error in the air-fuel ratio primarily at high elevations, atmospheric pressure sensors are used to measure the atmospheric pressure and to control the air-fuel ratio in consideration of the lack of oxygen due to thin air when traveling at high elevations. The basic specifications and appearance of Fuji Electric's newly developed atmospheric pressure sensor are shown in Table 1 and Fig. 1, respectively.

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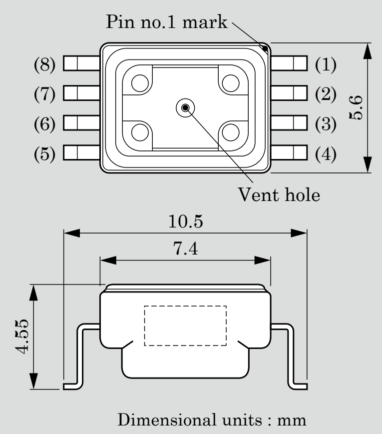
Table 1 Basic specifications of the atmospheric pressure sensor

Item	Specification	Remarks
Absolute max. voltage	16.5 V	< 1min
Absolute max. pressure	490 kPa abs	
Storage temperature	–40 to + 110 °C	
Usage temperature	–30 to + 105 °C	
Usage pressure	50 to 120 kPa abs	*3
Output range	0.5 to 4.5 V	
Interface	PU[*1]300 kΩ, PD[*2]100 kΩ	
Diag area	< 0.2 V, >4.8 V	*4
Sink current	1 mA	
Source current	0.1 mA	
Pressure error	< 3.0 %FS	
Temperature error	< 1.5×	
Electro-magnetic compatibility (EMC) standard	JASO DOO-87, CISPR 25, ISO 11452-2, ISO7637	

*1 : Pull Up *2 : Pull Down
*3 : Relative pressure and full-scale pressure can be changed arbitrarily
*4 : Detection of disconnected VCC wiring or VOUT wiring

Fig.1 Appearance of atmospheric pressure sensor



Pin number	Connection
(1)	VOUT
(2)	VCC
(3)	GND
(4)	NC
(5)	NC
(6)	NC
(7)	NC
(8)	NC

3. Package Design Technology for a Small Atmospheric Pressure Sensor

3.1 Miniaturized design

For board-mounted parts, the miniaturization of package sizes has the result of reducing the required mounting area, thereby enabling a reduction in the total area of the circuit board, and as a factor that greatly affects the overall cost of the ECU product, miniaturization is an essential aspect of the package development stage. To realize a miniaturized package, the resin thickness of the package was reduced, the bonding inner terminal was made narrower, and the pin pitch was also made narrower (1.27 mm) to achieve ultra miniaturization. Compared to a conventional package having the dimensions of 11.5 mm (length) × 11.5 mm (width) × 6.6 mm (thickness), the new package dimensions are 6.5 mm (length) × 7.4 mm (width) × 4.05 mm (thickness), and consequently, the mounting area has been reduced by approximately 65% compared to the conventional package, and the packaging volume, which includes the height dimension, was also reduced by approximately 76%. Figure 2 compares the appearance and size of the conventional package and the new package.

Fig.2 Comparison of conventional intake pressure sensor and atmospheric pressure sensor

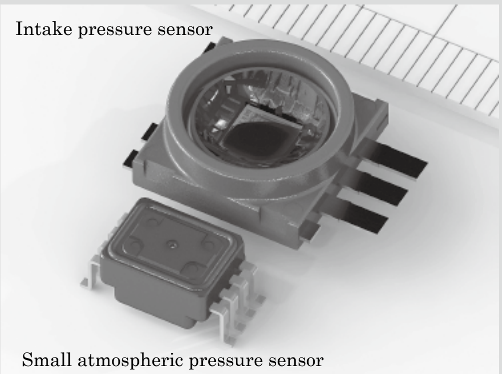
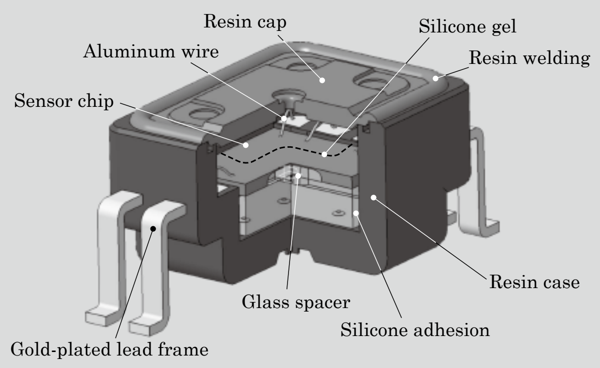


Fig.3 Cross-sectional structure of atmospheric pressure sensor

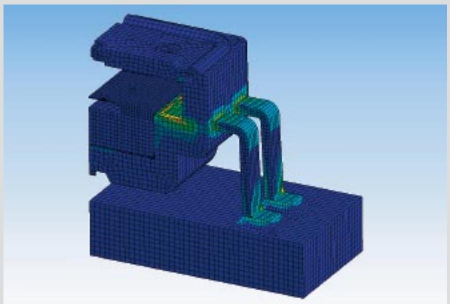


The internal structure of the atmospheric pressure sensor has the same basic configuration as a conventional product but is additionally provided with a resin cap for protecting a gold-plated lead frame used for the purpose of soldering to the ECU circuit board and for protecting the chip (silicon gel) surface. Figure 3 shows the cross-sectional structure of this atmospheric pressure sensor.

3.2 Package analysis technology

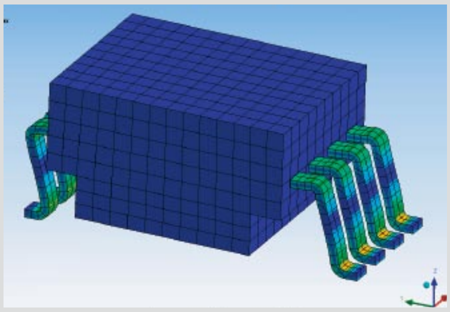
Because a pressure sensor is a semiconductor element that senses pressure as stress and converts that stress value into an electric signal, it can also be called a "stress sensor." Being sensitive to stress, the temperature characteristics, offset voltage and other sensor characteristics may be affected by various stresses

Fig.4 FEM analysis examples



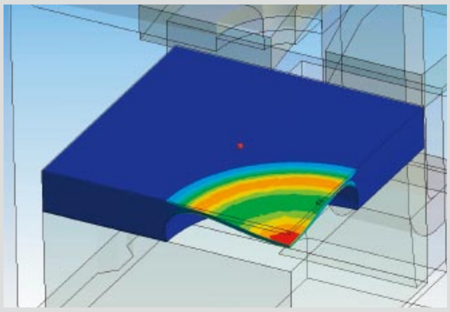
(Stress diagram at $\Delta t = -200$ °C)

(a) Thermal stress analysis



(Deformation diagram for 2nd mode of vibration)

(b) Vibration analysis



(Chip stress diagram during application of 200 kPa)

(c) Chip stress analysis

Fig.5 Example of bonding interference simulation

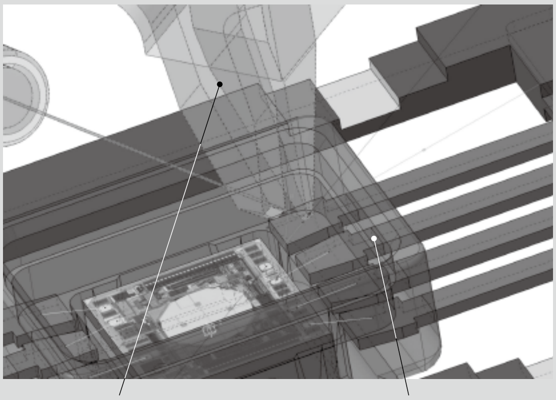
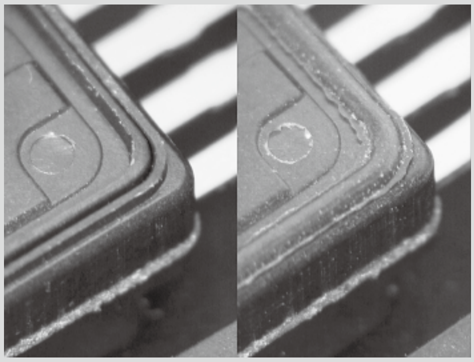


Fig.6 Comparison of appearance before and after impulse welding



received from the package. Accordingly, a key factor of the package design is the extent to which the structure prevents stress from being transferred to the chip. For this purpose, FEM (finite element method) analysis is extremely important so that the package stress can be analyzed in advance and the package structure optimized. The analyses actually performed include vibration analysis, pressure resistance analysis, terminal drawing strength, chip stress analysis, and so on. Here, examples of thermal stress analysis, vibration analysis and chip stress analysis are shown in Fig. 4.

3.3 Assembly design technology

(1) Aluminum wire bonding

The pressure sensor package is designed in consideration of interference that may arise between the package and the bonding tool when bonding aluminum wire during the assembly process. As a consequence of the reduction in size of the bonding area due to the package miniaturization, the extremely close proximity of the bonding tool increases the risk of interference. Therefore, during the design stage, care must be taken to prevent such interference from leading to bonding defects. The product is designed using 3-dimensional CAD (computer aided design), and during the design stage, using a CAD-generated model as shown in Fig. 5, a modeled tool reproduces the bonding operation by tracing the actual bonding path between the chip and the package bonding areas so as to check for interference with the package and to avoid the risk of interference during assembly.

(2) Cap joining

Impulse welding technology is used for joining together the cap and case. Impulse welding is a heat welding technique that forms tight joints by quickly heating resin so that it melts and then quickly cooling the resin so that it becomes fixed.

With the conventional method in which an adhesive agent was used to join the cap to the case, because the package had been miniaturized it was difficult to ensure a sufficient adherence margin, and adequate air tightness and adhesion strength were difficult to obtain. However, as shown in Fig. 6, the use of the impulse welding technology enabled these problems to be solved.

4. Postscript

This paper has presented an overview of Fuji Electric's small atmospheric pressure sensor for automobiles. As interest in environmental conservation intensifies and as the systems that control automobiles achieve higher levels of sophistication and performance, the requirements for pressure sensors are expected to become increasing severe. In the future, Fuji Electric intends to develop products having even higher accuracy and higher quality, and will strive to develop the highest level of technology in the world.