5th Generation Digital Trimming Type Automotive Pressure Sensors

Kazunori Saito
Mutsuo Nishikawa
Kimihiro Ashino

1. Introduction

The automotive industry's environmental activities are increasing at the same time as environmental regulations in Europe, United States, Japan, Asia and elsewhere throughout the world are being strengthened. To comply with such regulations, the systems used in automobiles are day-by-day becoming more efficient and are achieving higher control accuracy. Moreover, engine management that measures pressure and performs control is becoming increasingly important in these systems.

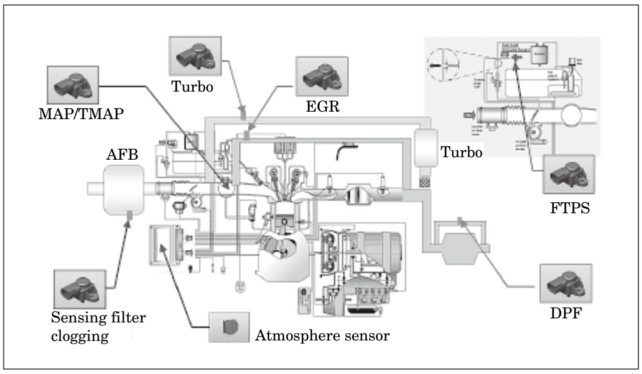
Fuji Electric began mass-producing automotive pressure sensors in 1984. In response to strict cost requirements and changes in the required accuracy, Fuji Electric has developed proprietary high reliability circuit technology and advanced MEMS (micro electro mechanical systems) technology to be used in Japanese and overseas models of automobiles and motorcycles, and since 2002, has been mass-producing automotive pressure sensors with digital trimming using a 4th generation CMOS (complementary metal-oxide-semiconductor) process.

A 5th generation digital trimming type automotive compact pressure sensor (hereafter referred to as the 5th generation pressure sensor) that maintains the equivalent features, performance (output accuracy) and EMC (electromagnetic compatibility) protection performance as the 4th generation digital trimming type automotive pressure sensor, while achieving a more compact size, has been developed and is introduced herein.

2. Pressure Sensor Applications in Automobiles

Figure 1 shows pressure sensor applications in automobiles. The electronic fuel injection system of an engine contains a MAP (manifold absolute pressure sensor) and a TMAP (temperature manifold absolute pressure sensor) that measure intake pressure, and in order to promote further widespread use of these fuel injection systems, and even apply them to motorcycles, requests for lower cost and smaller size sensors are accelerating. Pressure sensors are also used in sensing filter clogging of the AFB (air filter box) in an intake system and the DPF (diesel particulate filter) in an exhaust system, in a turbo pressure system that reuses exhaust gas, and in an EGR (exhaust gas recirculation) system. Pressure sensors are also used in atmospheric pressure sensors for high altitude compensating when an automobile travels at a high altitude, and in FTPS (fuel tank pressure sensors) to comply with regulations that have been enacted in Europe and South Korea for sensing leakage from a fuel tank.

Fig.1 Applications of automotive pressure sensors



3. Development History of Fuji Electric's Pressure Sensors

The development roadmap of Fuji Electric's automotive pressure sensors is shown in Fig. 2. In 1984, Fuji released a 1st generation pressure sensor, mainly for engine control in automobiles, which incorporated amplifier technology using bipolar ICs and surge protection. Thereafter, Fuji released 2nd and 3rd generation devices adopting one-chip and thin film trimming technology, and with the 4th generation, began mass-producing the world's first single-chip digital trimming type automotive pressure sensor that uses a CMOS process.

In order to satisfy the market demands for both low cost and high reliability, Fuji Electric has newly developed a 5th generation pressure sensor that carries on the "all in one chip" basic concept and maintains the functions, performance and EMC protection of the 4th generation device, while achieving a smaller size.

Fig.2 Development roadmap of Fuji Electric's automotive pressure sensors

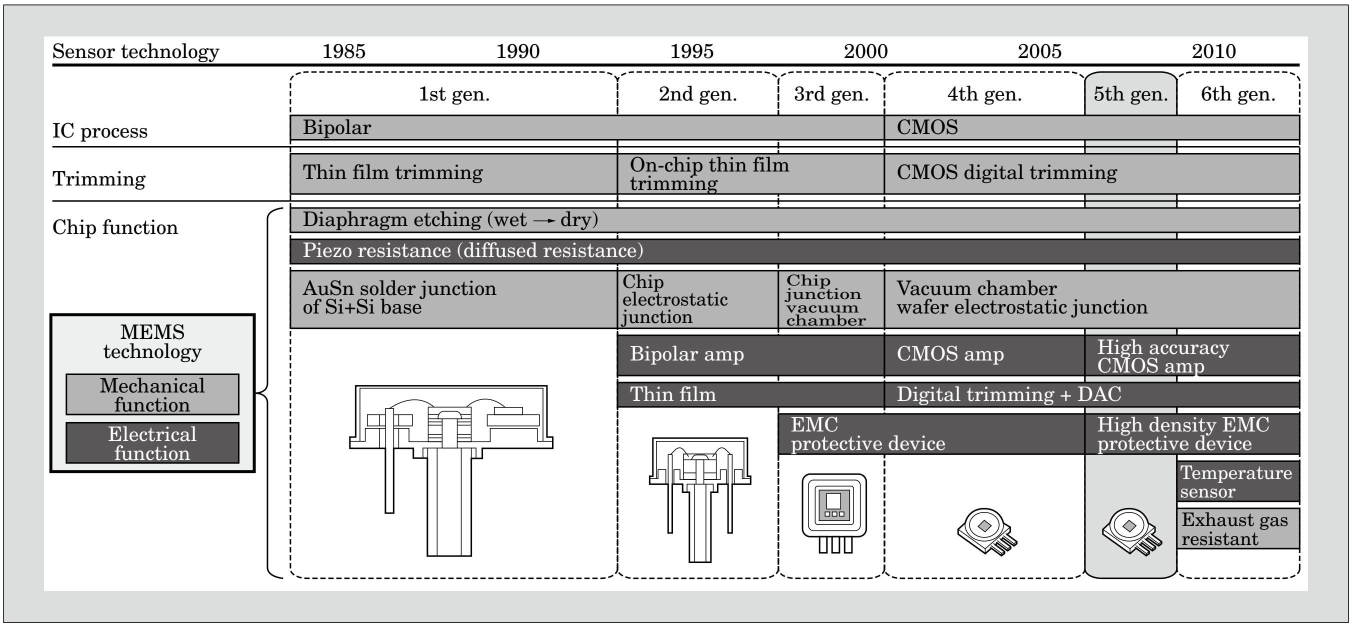
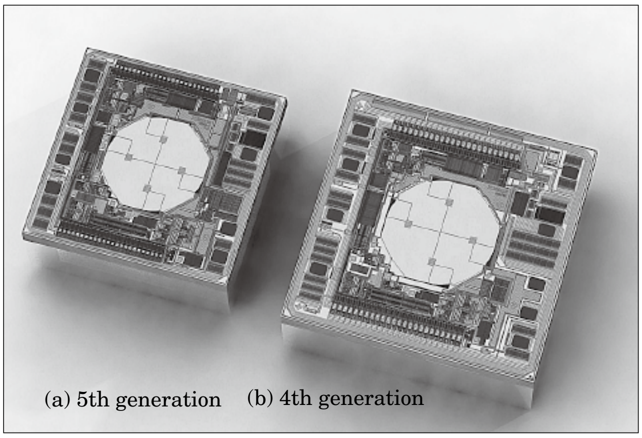


Fig.3 5th generation pressure sensor and 4th generation pressure sensor



4. Characteristics

Figure 3 compares the newly developed 5th generation pressure sensor to the 4th generation pressure sensor.

The 5th generation pressure sensor realizes the equivalent functionality and performance as the 4th generation pressure sensor, and its main characteristic is a reduction in size, achieved through optimization and limit design, to 70% that of the 4th generation device.

The optimized design used in the 5th generation pressure sensor is described below.

4.1 Diaphragm design

FEM (finite-element method) analysis was used to design and optimize the diaphragm that forms the sensor part.

Fig.4 Example of diaphragm optimization by FEM analysis

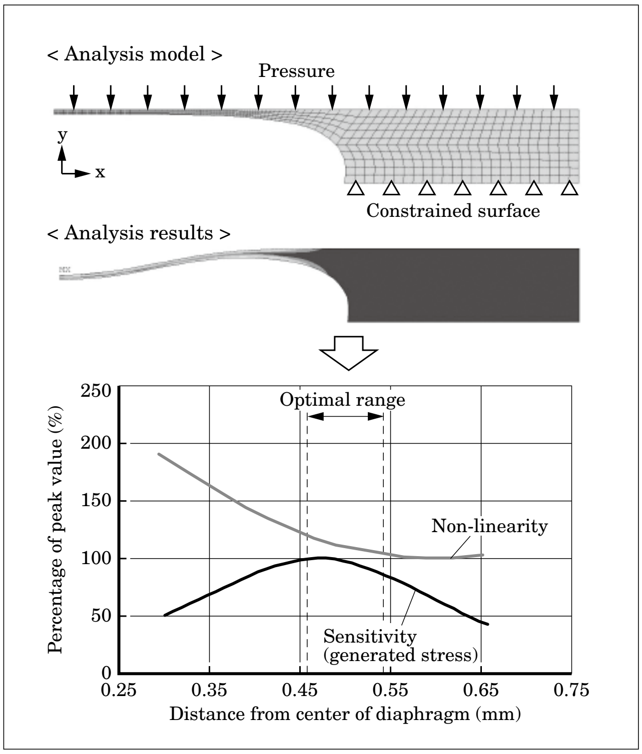


Figure 4 shows an example of this analysis. By modeling the cross-sectional shape of the diaphragm, the amount of displacement when pressure is applied and the stress generated on the chip are calculated, and additionally, the sensitivity and non-linearity of the sensor output are computed, and the optimal points for these parameters are obtained. As a result, the diaphragm area is reduced without decreasing sensor sensitivity and non-linearity, and performance equivalent to that of the 4th generation sensor is realized.

Fig.5 5th generation pressure sensor circuit block diagram

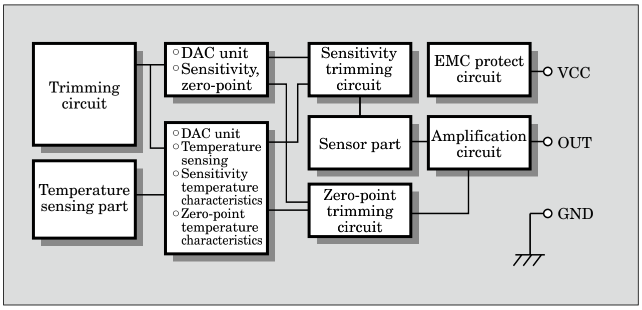


Table 1 Circuit block area ratios (compared to the 4th generation)

Circuit block		Area ratio
Sensor part	(IC pattern surface)	80%
Digital part	Trimming circuit part	70%
Analog part	D-A converter part	55 to 80%
	Temperature sensing part	100%
	Sensitivity trimming circuit	100%
	Zero-point trimming	100%
	Amplification circuit	100%
EMC, etc.	EMC protect circuit	60%
	Surge protection device	70 to 125%

Table 2 Noise resistant and surge resistant performance

Item		Performance
ESD	MM (0 Ω, 200 pF)	Analog : ±1 kV or more Digital : ±600 V or more
	HBM(1.5 kΩ, 100 pF)	±8 kV or more
ISO7637	Pulse1, 2, 3a, 3b	Satisfies level-IV
Impulse		±1 kV or more
Latch-up	Current injection	±500 mA or more
EMS (G-TEM)	100 V/m	Fluctuation : 1% of FS or less
Over voltage	Between VCC and GND	16.5 V
Wrong connection	Between VCC and GND	5 V / 0.3 A

Also at this time, the effect of stress, which has been generated at the diaphragm, acting on the circuit part (area other than the diaphragm) is assessed, and accordingly, the distance from the sensing part on the diaphragm to the circuit area (margin) is minimized, which leads to a reduction in area.

4.2 Circuit and layout design

The circuit block configuration of the 5th generation pressure sensor is shown in Fig. 5. This configuration is entirely the same as that of the 4th generation pressure sensor, and no functions or blocks have been removed.

Based on the successful track record of the 4th generation device, we reevaluated Fuji Electric's proprietary design rules for vehicle sensors to achieve greater miniaturization with higher integration, and were able to reduce the size of each part of the chip as shown in Table 1.

However, we did not reduce the size of the analog part, and in particular the amplification circuit, the sensitivity trimming circuit, the zero-point trimming circuit and the temperature sensing part, which is directly linked to output accuracy.

As a result, the functions, performance and trimming range were maintained as equivalent to those of the 4th generation device.

4.3 Noise resistant and surge resistant design

A design that is both noise and surge resistant is increasingly being requested so that an automobile does not malfunction when traveling in an area of strong electromagnetic waves or in an electrically or magnetically severe environment.

In the 5th generation pressure sensors which satisfy these requests, while the chip size was being reduced, some chip areas were enlarged to accommodate protection devices, and the chip design placed an emphasis on noise resistance and surge resistance.

The result, as shown in Table 2 for the ESD (electrostatic discharge) machine model (0 Ω/200 pF), verifies tolerated voltage of ± 600 V or more and the highest level of noise resistance and surge resistance by a single chip for automobile applications.

5. Postscript

An overview of the 5th generation digital trimming type automotive compact pressure sensor has been presented. With products being broadly developed for Japan and overseas, the accuracy, quality and cost requirements of pressure sensors are expected to become even more severe in the future. Fuji Electric intends to advance technical development for higher accuracy and higher quality products, and also to push forward with the development of products that are essential to the market.