

Thin-Film Air Flow Sensors for Automotive using the MEMS Technologies

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ABSTRACT

This paper presents two newly developed technologies of optimizing impurity diffusion concentration for silicon semiconductor material and controlling internal stress of the top SiN (Silicon Nitride) layer on a membrane of a silicon substrate to apply them to the manufacturing process of MEMS (Micro Electro Mechanical Systems) type air-flow sensor chips. Until today, in MEMS-type airflow sensors, poly-crystalline silicon (poly-Si) and platinum were widely used as a resistor material of key functional elements on a membrane of air-flow-rate measurement portion. The functional resistors on the membrane are required to monitor high temperatures of about 300 °C and to perform the self-heating operations at that temperature range because of the suppression of contaminant deposition by means of evaporation or incineration. However, the use of those resistor materials at such high-temperatures is very difficult because high-temperature use causes the problems of the sensing error expansion, the resistor material layer delamination etc. Therefore, we have developed a new MEMS-type air-flow sensor with high-temperature usable resistors which are formed in a single-crystal-semiconductor silicon of SOI (Single-crystal Si on insulator) substrate by applying a technique to optimize impurity diffusion concentration. In addition to the high-temperature use problem above, MEMS-type air-flow sensors have another problem that the membrane is fragile towards internal and external stress due to its extremely thin thickness. To solve this problem, we have developed a new technique to control the internal stress of the SiN layer of the membrane top surface using the LP-CVD (Low Pressure Chemical Vapor Deposition) method. Consequently, we have realized a new MEMS-type air-flow sensor with structurally strong membrane by making the SiN layer thicker.

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INTRODUCTION

Figure 1 shows a schematic view of the engine management system. Air-flow sensors are installed behind the air cleaner and have the role of monitoring the situation of air in manifolds for engine management in vehicles. In order to address the enhancement of emission regulations and the improvement of fuel efficiency in recent years, air-flow sensors are required to be highly accurate and reliable in order to respond to the demands of more highly accurate management of vehicle engine operation behavior. As an air-flow sensor, hot-wire-type sensors have been widely used since the 1980s. In regards to the structure of the hot-wire-type sensors, a platinum wire as a heater is wound on a cylindrical ceramic bobbin in a coil-shape state, and a glass layer is coated on the wire and bobbin. The air-flow rate is measured based on the concept that heat transfer quantity into air from the heater wire depends on the air-flow speed when electrically heating the platinum heater wire.

Lately, in response to the demands of stricter emission regulations and more severe fuel consumption regulations, engine development technologies have been rapidly progressing by employing the reduction technology of the engine cylinder number, high expansion ratio operation by the Miller-type Atkinson cycle, etc. in gasoline engines, and technology for a large amount of Exhaust Gas Recirculation in diesel engines. To address these demands, MEMS-

type air-flow sensors are widely used because they can provide the essential information to accurately control engines by measuring the air-flow rate of the reverse direction in addition to the accurate measurement of the forward-direction air-flow-rate in intake manifolds. Accordingly, we have developed highly accurate and reliable MEMS-type air-flow sensors based on extensively experienced MEMS-techniques of pressure sensors, acceleration sensors etc. [1, 2].

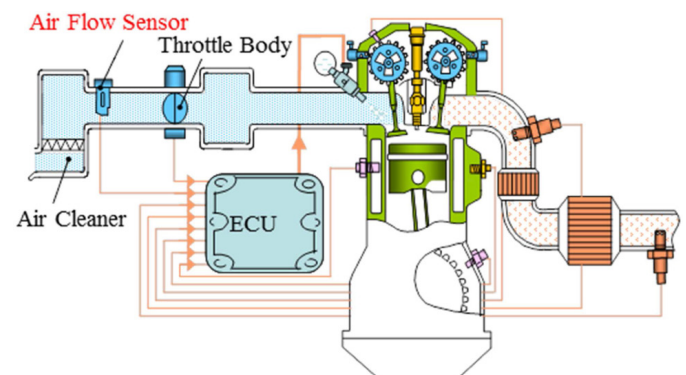


Figure 1. Engine management system

PRINCIPLE AND MANUFACTURING PROCESS OF CONVENTIONAL MEMS-TYPE AIR-FLOW SENSOR

Firstly, an overview of the air-flow sensors is shown in Figure 2. MEMS-type air-flow sensors are installed in the sub-bypass air-flow passage which branches from the bypass passage made in the intake manifold for the main air stream [3].

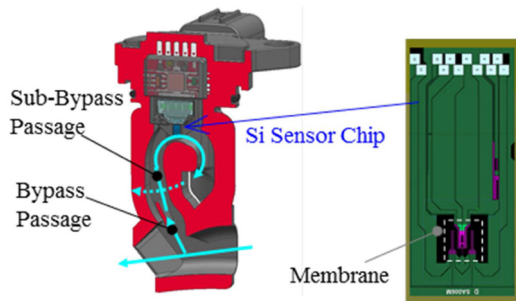


Figure 2. Overview of MEMS-type Air-flow Sensor

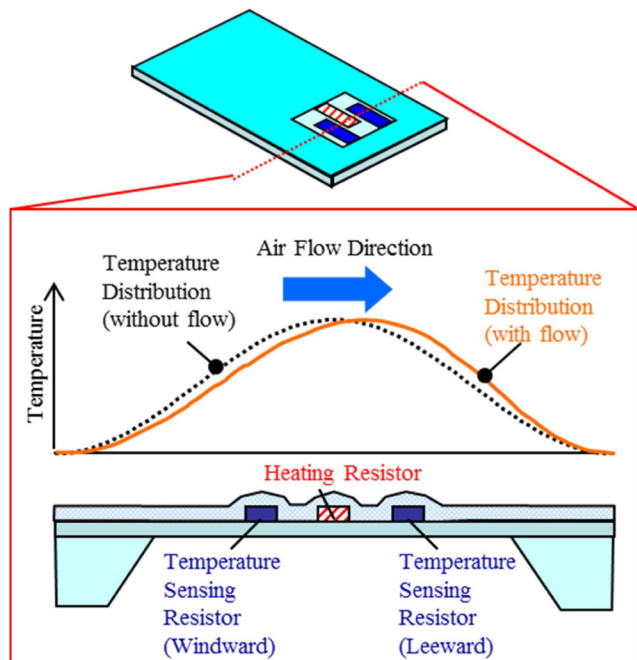


Figure 3. Measurement Principle of Conventional MEMS-Type Air-flow Sensor

Next, a measurement principle of MEMS-type air-flow sensors is described. MEMS-type air-flow sensor elements involve one heating resistor and two temperature sensing resistors. The two temperature sensing resistors are located at both sides of the heating resistor and play a key role of air-flow-rate measurement. These three resistors are formed on the membrane, which is extremely thin in thickness and small in heat capacity, in the silicon sensor chip. The measurement principle is shown in Figure 3. The electric current is supplied to the heating resistor to heat it and this state is kept without any change. In this state, the resistances of two sensing resistors have the same value because the resistors have the same temperature during no wind. Subsequently, when an air-flow occurs, the temperature of each sensing resistor becomes different due to the difference of heat transfer quantity from the heating resistor, and it leads to resistance

changes and a resistance difference between the two resistors. When the direction of the wind is reversed, the temperature distribution is reversed from the previous state, and it changes resistances according to the temperature distribution change. Thus, MEMS-type air-flow sensors can measure the air-flow rate and wind direction with quick responsiveness because of the extremely thin membrane with small heat capacity. The membrane of the silicon sensor chip is extremely small and thin in size and small in heat capacity. By the formation of the heating resistor and sensing resistors on the membrane, minute changes in heat transfer amount due to the change in air-flow-rate results in a change in temperature of the sensing resistors and this temperature change is measured as a resistance value change. Thus, the MEMS-type air-flow sensors can measure even slight changes in the air-flow rate by sensing it as a change in the minute heat transfer amount with high sensitivity and quick responsiveness.

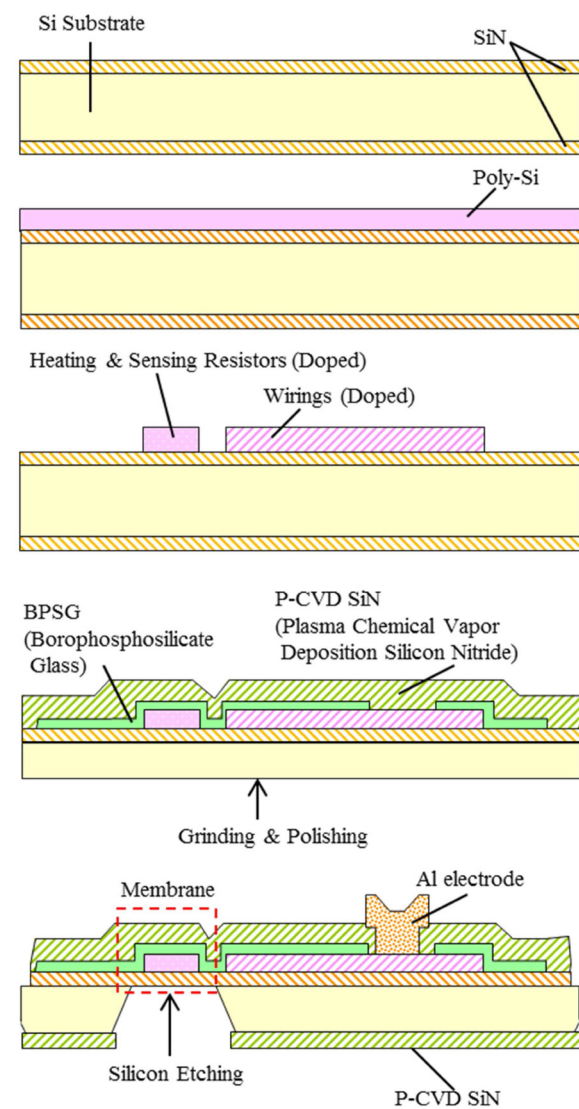


Figure 4. Measurement Principle of Conventional MEMS-Type Air-flow Sensor

Nextly, the manufacturing process of a general MEMS-type air-flow sensor chip with poly-Si resistors is shown in Figure 4. SiN Insulation layers are formed on a silicon sensor chip substrate as an internal stress adjustment layer. Pattern of the resistors is implemented by using the common semiconductor.