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Novel mass air flow meter for automobile industry based on thermal flow microsensor. II. Flow meter, test procedures and results

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ABSTRACT

A prototype of mass air flow meter for automobile industry was developed on the basis of thermal flow microsensor. Design and manufacturing technology of the flow meter are described. Test procedure and results are presented. Developed prototype of flow meter can diagnose gas flow rates in a wide range.

1. Introduction

Flow sensor is a key element in fluid flow meter. Automobile industry is one of the main consumers of fluid flow meters [1,2]. In particular, mass air flow meter is used in electronic fuel injection system to determine the amount of outside air entering the engine. Based on these measurements the correct quantity of injected fuel is estimated. Presently, fluid flow meters based on so-called thermal flow microsensors became a frequent practice [3,4].

The study is a follow up of our previous research [5,6]. The article [5] reveals principles of measurements using thermal flow sensors and a detailed review of current stage in study and development of thermal flow sensors is presented. The main result of the research [5,6] is a thermal flow microsensor prototype with optimal functional and technological characteristics. Microsensor design and manufacturing technology enable mass production, subsequent device assembly and reliable operation as well. In particular, the developed microsensor can be applied in mass air flow meter to be used in electronic fuel injection system.

Development and production of mass air flow meter based on our thermal flow microsensor became the purpose of the present study. An attempt to create an inexpensive and reliable flow meter with required functional and technological characteristics will be undertaken.

2. Mass air flow meter

A prototype of mass air flow meter contains the following elements: meter housing, microsensor and microsensor holder. The technologies of microelectronics and radio electronics are used in flow meter manufacturing, in particular, joining microsensor with external electric circuit is performed by micro welder machine that is used in manufacturing integrated microcircuits. Housing, holder and other assembly parts are manufactured by polyamide milling.

Overall and mounting dimensions of mass air flow meters widely used in automobile engines were taken as dimensions for flow meter prototype. In particular, flow meter housing of an inner diameter of 62 mm was used.

A holder that performs fastening and measuring functions was designed in order to locate microsensor in the flow under measurement. Design of the holder was specified by the requirement of locating smaller size sensor in measured flow, sensor protection from contaminations and mechanical damages and joining with external electric circuit.

Basic element of the holder is a measuring channel where microsensor is placed. A necessity for having a measuring channel is determined by the fact that sensor located directly in the flow meter housing will be producing a signal largely connected with air flow fluctuations while moving inside air line of complex configuration up to the point of change of sign for output signal in case when local reverse flow is over the sensor surface. The main role of measuring channel is to create directed air flow over the sensor surface in order to establish required heat flux and heat

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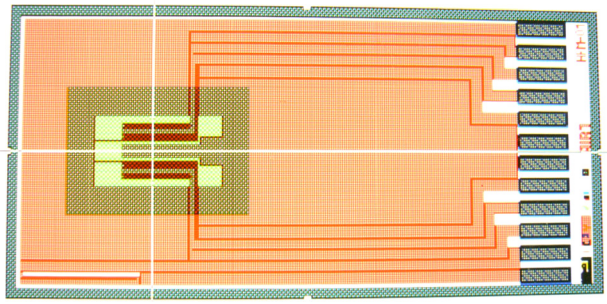

Fig. 1. Sensor topology.

transfer intensification. Another important function of the channel is protection of undesirable impacts, such as dust particles, engine oil and moisture vapors getting on sensor that can cause considerable change in parameters of thin membrane and thus distort the measurement results.

Obviously, creating a measuring channel with sensor in flow meter housing makes it necessary to take into account considerable difference in velocities of gas motion in meter housing and over the sensor surface. By changing size and configuration of measuring channel it is possible to vary the range of measured values of gas flow rate. In particular, the value of maximum gas flow rate to be measured can be significantly increased by decreasing a diameter (or height) of the channel. In this case it is necessary to know the percentage of flow going over the sensor with respect to the total flow rate.

Sensor configuration has to allow its setting in two isolated cavities simultaneously: in measuring channel and in tight isolated cavity containing circuit board. Fig. 1 shows formed sensor topology meeting this requirement. A membrane containing heater and 4 measuring resistors (that positioned relatively as presented in our previous study [5]) is located in the left part of the sensor. Bonding areas for connecting conductors leading from measuring resistors to circuit board are located in the right part. Additional measuring resistor is located in the left lower corner. The resistor is designed to register environment temperature, therefore in order to ensure minimum heat connection with the heater it is located on the massive part of the sensor.

To minimize temperature losses to the massive part distance between heater and massive part is larger than membrane thickness. In developed sensor prototype this distance is about 300 μm with membrane thickness less than 2 μm. The crystal size on which the described sensor topology was formed is 2.8 mm × 6.8 mm.

An image of created microsensor in ultraviolet spectra range was obtained (Fig. 2). On the image, elements of formed electric circuit are clearly seen on one side of the sensor and membrane configuration—on the other side of the sensor. The absence of membrane shadow proves that membrane is really thin.

Air flow meter manufacturing technology includes 2 main operating sets: meter assembly and adjustment. During flow meter assembly process, sensor setting on bronze base is initially performed, that is then placed in the measuring channel. Fig. 3 shows the location of sensor with circuit board in the measuring channel. Sensor fastening is made in such a way that membrane is not sealed from ambient air from both sides. Then circuit board connected to sensor with thin golden conductors is mounted on the holder.

Then upper part of the channel with sensor and circuit board is covered. Channel sealing and thin golden conductors protection are performed by sealant potting in corresponding areas. The final flow meter assembly is made by placing holder in meter housing. Required procedures of meter sealing are made during assembly.

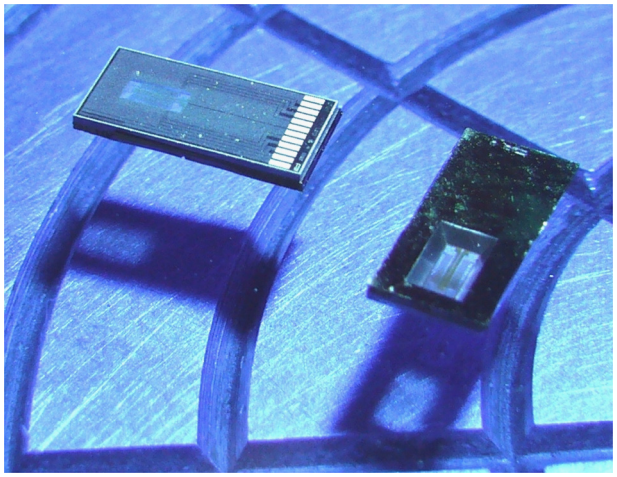

Fig. 2. Image of sensor in ultraviolet spectra range.

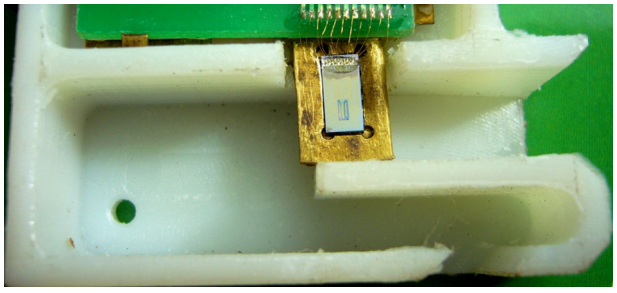

Fig. 3. Location of sensor in measuring channel.

At the end the flow meter is placed on test stand using rubber gaskets.

Standard procedure of meter adjustment consists of setting output signal of tested meter according to the value of reference meter output signal for required range of gas flow rate. Meter adjustment procedure represents a special scientific and technical task and is made after in-depth prototype testing.

3. Testing procedure

A test stand (Fig. 4) was designed for carrying out tests of mass air flow meter prototype. The stand consists of the following elements: air circulating system, air pipe with control valves, reference flow meter and measuring tools.

Controllable fan creates air motion that is transferred to air pipe. Then air flow passing through heating system is heated up to required temperature. Excess part of air flow is cut off with the help of rough control valve. In order to obtain more accurate air flow values a fine control valve with quite a small slit for air drain is used. Generated air flow goes through tested flow meter and reference flow meter, installed in series. Thus meters measure the same air flow rate in the system. Air flow rate range used in test stand is 0–130 kg/h.

Carefully selected Bosch HFM5 mass air flow meter [7] (see Supplementary material) which undergoes repeated checks on calibrating stand and has measurement error no more than 1% is used as a reference flow meter. Calibrating stand measures gas flow rate according to pressure difference on certified diaphragm.

Air flow control is carried out by using voltmeter connected to reference meter output. For determining gas flow rate calibration curve of meter is used. It converts output voltage of reference meter in gas flow rate value.