PEROVSKITE-BASED MASS AIR FLOW SENSOR: MANUFACTURE AND TEST

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1. Introduction: the overview of MAF sensors

Mass air flow sensor (MAF) is the frequently used in many monitoring devices, one of the common case is the modern automotive Electrical Fuel Injection (EFI) engines [1]. There are two basic varieties of MAF sensors: hot-wire and hot-film. Unlike the old-type vane air flow (VAF) sensors that have a mechanical spring-loaded flap to measure air flow, MAF sensors have no moving parts. Instead, they use a heated sensing element to measure air flow. Usually the sensor is placed within a close-spaced area, e.g in the gate to throat body and monitors the air flow within a given cylinder by converting the resistance outputs to mass air flow as the air provides cooling effect on sensing element, being heated by a constant current.

In a hot-wire MAF, a platinum wire is heated about 212^0C above the incoming air temperature and in a hot-film MAF, a foil grid is heated about 167^0C above ambient air temperature. The cooling effect increases the current needed to keep the sensing element at a constant temperature and this cooling effect varies directly with the temperature, density and humidity of the incoming air, so the current change is proportional to the air "mass". The correct measurement of the mass air is necessary for the engine's computer to calculate and maintain the proper air/fuel ratio for optimum performance and emissions.

The output signal produced by the MAF sensor varies according to the application. The hot-wire Bosch MAF sensors, which are found on some cars with LH-Jetronic fuel injection as well as Tuned Port Injection (TPI) engines, generate an analog voltage signal that varies from 0 to 5 volts. Output at idle is usually 0.4 to 0.8 volts increasing up to 4.5 to 5.0 volts at wide-open throttle. The hot-film MAFs (e.g. on some AC Rochester's Buick Turbos, Chevrolets and GM engines) produce a square-wave variable frequency output. The frequency range varies from 32Hz to 150Hz, with 32Hz being average for idle and 150Hz for wide-open throttle. Another difference between the hot-wire and hot-film sensors is that the Bosch hot-wire units have a self-cleaning cycle where the platinum wire is heated to 1000^0C for one second after the engine is shut down. The momentary surge in current is controlled by the onboard computer through a relay to burn off contaminants that might otherwise foul the wire and interfere with the sensor's ability to read incoming air mass accurately. On GM hot-film MAFs, one can also read the sensor's output in "grams per second" (gps), which corresponds to frequency. The reading should go from 4 to 8 gps at idle up to 100 to 240 gps at wide-open throttle. The older AC Delco MAF sensors show a steady reading of 32 Hz at idle to about 75 Hz at 3,500 rpm. The later model units (with Hitachi MAF sensor) should read about 2.9 kHz at idle and 5.0 kHz at 3,500 rpm.With GM Delco MAF sensors, the sensor should output a steady 2.5 volts while the engine is idling. With Bosch hot-wire MAF sensors, the output voltage can be read directly and should be around 2.5 volts.

The typical arrangement for a hot-wire sensor is illustrated in Fig.1 and a construction block-scheme for a hot-film sensor is given in Fig.2. For the hot-wire case, as the platinium wire is heating by a constant current, the Pt wire develops its resistance to some equilibrium state R(flow=0). In the absence of the flow, the air cooling effect depends only on the temperature gradient between the wire and the environment, so R(flow=0) is a function of temperature gradient. For the temperature of a heated platinium wire may be quite high above room temperature, the temperature gradient is usually enough large so that the variation of room temperature affects the gradient only a little. In occurence of a flow, the gradient decreases exponentially with air velocity, following with resistivity change of Pt wire. For the sensors using metals as sensing media, the decrease of temperature of the metals Raises their conductivity so reduces the output voltage.

Fig.1 *The arrangement of the Pt wire in the Hitachi hot-wire MAF sensor (real size)*

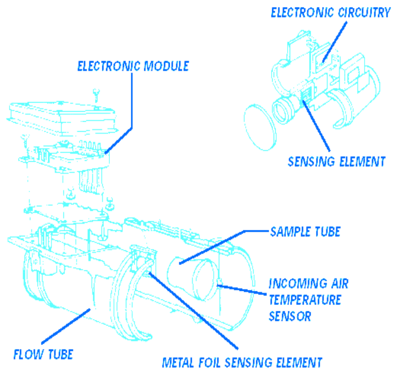

Fig.2 *A block-scheme of a hot-film MAF sensor*

Because of the exponential behaviour of output voltage, the sensors were usually manufactured so that they only work in a narrow gradient range within which the output voltage was linear to the air flow. The main advantages of the metal sensors are compactness, flexible wiring, durability and the disvantages are cost, narrow flow limits, limited sensibility.

In this article we introduce a new MAF sensor using a perovskite-based semiconductor as sensing medium. In contrast to the metal-type sensors, this kind on sensor working mode is inverse: its temperature gradient always maximalizes at some largest possible value instead of being stabilized at some intermediate state. The reason for this behaviour is obvious: as the current provides heating effect on the semiconductor, its conductivity rises until the maximal possible value, at which the cooling effect is balanced with the heating effect. In the metal sensors, the temperature of the metals can not get so far due to the raising of the metals resistivity according to rasing temperature. The internal conduction mechanism of the metals themselves set limits on the maximal temperature gradient between sensor and environment. The reason why the achievement of larger temperature gradient is important is that this gradient allows wider linear-correlation range between voltage outputs and air flows.

2. Structure and thermoelectric property of the perovskite-based semiconductors

The sensing wires were made from the perovskite-based semiconductors of $CaMnO_3$ family of thermoelectric perovskites doping with La [2]. The samples of the composition $La_{1-x}Ca_xMnO_3$ where x=0.865, 0.855, 0.845 (denoted as sample No.1, 2 and 3) were prepared using the traditional ceramic technique as follows. The powders of $CaCO_3$, La_2O_3 and $MnCO_3$ (all of 99.9% purity) were weighed in desired proportions and milled together for at least 10hours, then the mixture was presintered at 1050^{0}C for a next 10hours in free air. The powder was then compressed into rectangular bars of dimension 2x2x10mm and sintered at 1400^{0}C again in air for 10hours. The phases and structures of the samples were determined by X-ray powder diffraction (Fig.3, Table 1) and the electric resistivity was measured by the standard four electrods technique in the temperature range from 300 upto 700K, the results are featured in Fig.4.

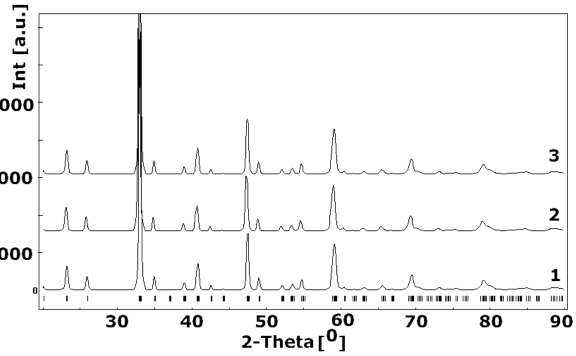

Fig.3 *X-ray diffraction patterns of the samples*

Fig.3 shows clearly the typical perovskite-structure diagrams that are of good quality, homogeneous and single-phased. The further analysis led to the orthorhombic structural type for all samples with the possible space group Pbnm (No.62) (see Table 1). The substitution of La seemed to have only a small effects on the cell constant and volume change.

Table 1. Cell parameters of samples

No.	*Samples*	*Type*	*a, b, c* (Å)/ V(Å)^3
1	$La_{0.135}Ca_{0.865}MnO_3$	Orthor.	5.403, 5.439, 7.630/ 224.2
2	$La_{0.145}Ca_{0.855}MnO_3$	Orthor.	5.406, 5.436, 7.634/ 224.3
3	$La_{0.155}Ca_{0.845}MnO_3$	Orthor.	5.408, 5.434, 7.636/ 224.4

Fig. 4. shows the linear segments in the resistance dependence on temperature for all samples. The insets show the whole exponential development of resistance in the 300-800K range. All samples are the semiconductors with the negative temperature coefficient of resistivity. As seen, the linear segments lie in the temperature range 300-600K and show well behaviour of samples in this temperature range (the correlation coefficient R^2>0.99). The degrees of sensibility were determined as 253, 190 and 127Ω/K for samples No.1, 2 and 3 consequently. These values themselves are not large in this class of

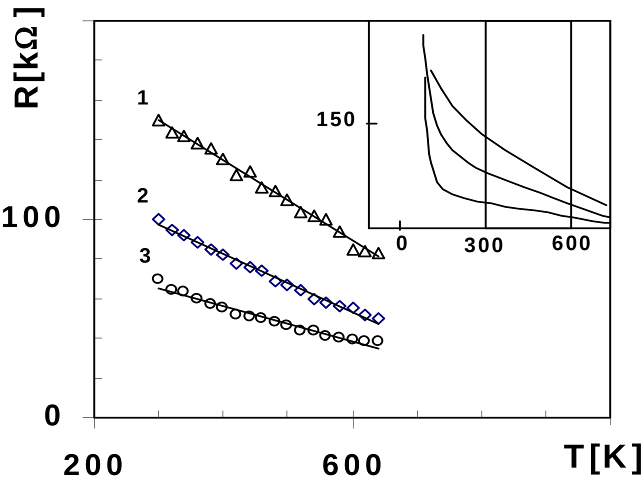

Fig. 4 *The linear segments (300-600K) in the temperature dependence of resistance of samples. The insets depict the general exponential behaviours of resistance. For these compounds, the resistance jumped over 10^3kΩ in lower temperature range.*

compounds, but the stable linearity in their functional dependence on temperature (within working 300-600K range) is important for sensing media. In lower temperature range, e.g. for T near 150K, the resistance might peak as high as 1000kΩ but the linearity worsened visibly.

3. Sensor wiring and testing

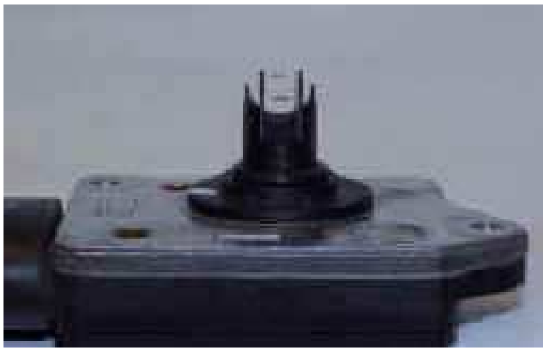

Fig. 5 *Semiconductor sensors settled in the Hitachi cover (with onboard circuit). A control Pt wire was available and used for reference testing.*

For sensor wiring we used a schematic arrangement as seen in Fig.1. The samples were ground into a small bars of dimension 1x1x5mm and covered at both ends by Cu (approx. 1μm thickness) using the vacuum evaporation technique. The bronze sticks were then welded at these ends, holding the sensing medium fixed in direct position to the air Fig.5 [3]. A simple circuit was used to filter sensor signals and to provide the voltage outputs within the range 0-4V. The input current should be adjusted to hold the working temperature range of the sensor within 300-600K. This adjustment is important to maintain the sensor linear responses. Fig.6 shows the exponential development of the temperature gradients over air velocity and the insets show the linear segments with which the sensors were tested.

This picture clearly tell us about the sensibility of our sensors: while the commercial sensors could in maximum scale 1 output voltage on 40K gradient, the perovskite sensors could provide near 100K gradient on each 1V. The gradient sensibility calculated on the basis of 1V output is 100, 89 and 68K for sample No. 1, 2 and 3 respectively. Since the onboard computer do read signals in mV, these values resulted in about 0.10, 0.08 and 0.068^0/mV for samples. By rescaling them on air velocity, one obtained 1mV change for each 1.11, 1.14, 1.55 cm/s for sample No.1, 2 and 3 consequently. By average, the semiconductor sensors could produce for 1m/s change in velocity a corresponded output change of about 80mV or 6.6K gradient.

The last Fig.7 compares the sensor responses to some commercial ones. The insets show the recovering of signals during the turn-on and switch-off cycle (the air flow was turned on/off suddenly). Due to their larger temperature gradients, the semiconductor sensors show clearly more sensitive and faster response. Further improvement was due to the higher operational temperature that the burn-off cycle was not needed to maintain the cleaning of moisture.

During the test, all sensors were functioned non-stop 3 times, each of for 100 working hours, then they were demounted and their structures and electrical properties were re-investigated. None of changes was observed but one of sensor piece showed mechanical weakness and has been broken. The mechanical weakness is the significant disvantage of semiconductor sensors and this problem argues for further study to fix it. The perovskite-based sensors, however, open a new way to measure the air flow with higher accuracy and stability and should be considered for the next development.

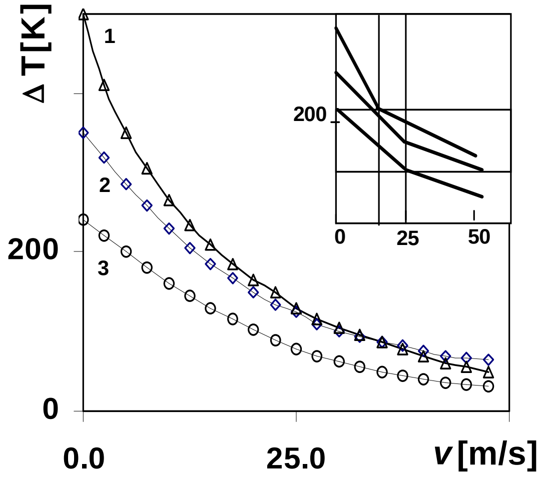

Fig. 6 The exponential decay of the temperature gradients on the air flow velocity. The insets show the linear response approximation segments. The input current needs to be adjusted to keep these segments within the desired temperature range

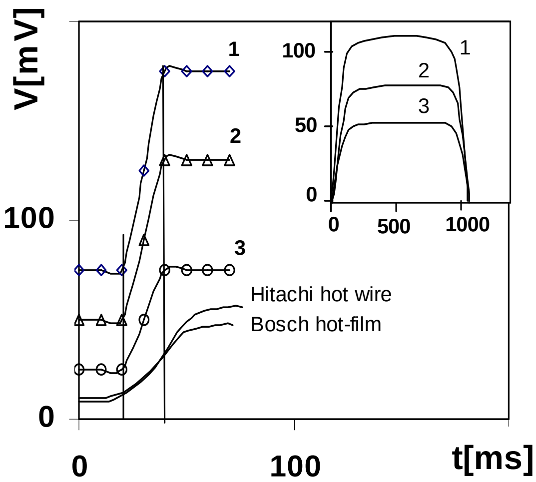

Fig. 7. The time response in the 1m/s velocity change. The insets show the system reaction to a sudden 1s start-stop of a 1m/s flow

Tóm tắt

Bài báo đề cập đến việc ứng dụng của loại vật liệu mới (perovskite) để làm cảm biến đo tốc độ gió không cần thay đổi cơ học. Kết quả đưa ra là làm mới có ý nghĩa về phương pháp đo và ứng dụng đo nhiệt độ trong buồng khí thổi.

Summary

The new mass air flow sensor (MAF) is clearly presented in the acticle. The sensor is based on the use of a newly manufactured temperature sensitive perovskite-type material which reacts to the change of cooling rate (air flow) by varying the resistance. The sensor produces stable, highly sensitive and immediate output within the range 0-4V. It may be practically used in devices monitoring the air flow, e.g. for the Electrical Fuel Injection (EFI) system in modern automotive engines.

Keywords: Mass Air Flow, Sensor, Perovskite
PACS: 85.30 De, 71.55 Cn, 72.15 Jf, 72.20 Jv

References

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