Co-fired Platinum High Temperature Sensor Element

Tsutomu Sugawara, Hiroshi Matsumoto, Hiroki Ito, Shingo Sato, Masanari Kokubu
Kyocera Corporation
Ceramic Materials Semiconductor Components R&D Division
Corporate Ceramic Materials Semiconductor Components Group
Address: 1-1 Kokubu Yamashita-cho, Kirishima-shi, Kagoshima, 899-4396, Japan
Tel: (81) 995-46-1100, Fax: (81) 995-47-1290
E-mail: tsutomu.sugawara.ke@kyocera.jp

Abstract

In recent years, initiatives for improving the fuel consumptions have been accelerated to reduce the CO_2 emissions in exhaust gas from an automotive engine; as a measure against global warming. One of the known techniques to reduce CO_2 emissions, is more accurate temperature measurement of the engine. For such application, sensors such as thermistors or thin-film platinum temperature sensors have been widely used for sensing exhaust gas temperature. Especially, the thin-film platinum temperature sensors were favorable because of its linearity in resistance to temperature dependensy and accuracy in temperature measurements. However, the deformation of a resistor circuit in thin-film platinum temperature sensor elements have been observed after used in high temperature. The deformation causes the resistance drifts which leads to less accurate temperature measurements. In this study, durability of the co-fired platinum temperature sensor element was examined for high temperature application. As of result, we found that the resistance drift of the co-fired platinum temperature sensor elements were smaller than that of the thin-film platinum temperature sensor elements; after storage test at 1100 ºC. Thus, the co-fired platinum temperature sensor elements can be used for higher temperature sensing, which can contribute to the reduction of CO_2 emission of automotive engines.

Key words: exhaust gas, platinum temperature sensor element, resistance drift, co-fired

1. Introduction

In recent years, initiatives for improving the fuel consumptions have been accelerated to reduce the CO_2 emissions in exhaust gas from an automotive engine; as a measure against global warming. To enhance efficiency of the fuel consumption, technologies such as regulating the Air/Fuel (A/F) ratio, optimizing the combustion temperature, and downscaling the turbo-charged engine are applied to recent automotive engines.

Furthermore, the exhaust gas temperature is measured to estimate the combustion temperature. Then the A/F ratio is regulated successively to optimize the condition of combustion. For the purpose of more accurate and rapid estimation of combustion temperature, a temperature sensor is placed in exhaust pipe; in which the exhaust gas temperature is over 900°C. Moreover, by the application of the downscaled turbo-charged engine, the exhaust gas temperature can instantaneously be ramped up to 1100°C.[1] [2]

Conventionally, to measure exhaust temperature, a sensor such as thermistors or thin-film platinum temperature sensors have been used. The thermistors are not suitable to measure such high temperature due to its non-linear resistance dependency at higher temperature range. The sensitivity at high temperature is less than that of the platinum temperature sensors, because the changes in resistance at higher temperature becomes smaller. In addition, there are no known materials for thermistors in which it can withstand such high temperature. On the other hand, thin-film platinum temperature sensor has high linearity in resistance to temperature dependency, which enables accurate measurements for temperature upto 900°C. However, if the application temperature exceeds 900°C, the thin-film platinum temperature sensor is known to experience the resistance drift; which becomes larger in case of long term use, causing a decay in temperature sensing accuracy. Therefore, we believe that the development of the durable and accurate platinum temperature sensors for application over 900°C can contribute to improve a performance of the automotive engines.

2. Technical Issues of the Platinum Sensor Elements

The platinum temperature sensor element is one of the Resistance Temperature Detector (RTD). A temperature is measured by utilizing linear changes in the resistance as a detector temperature changes. The platinum has high linearity in resistance to temperature dependency in wide range of temperature, thus it has high sensitivity and accurate sensing capability at high temperature.[3] [4] It is applied for automotive parts due to its stability of various physical properties at high temperature; for example temperature coefficient of resistance (TCR).

Hermann Jehn (1984) reported that a platinum was oxidized, and formed platinum oxides, which were evaporated in oxidizing atmosphere at high temperature.[5] Based on the report, we hypothesized that the causes of the resistance drift are oxidation and evaporation of platinum resistor circuit, thus conducted a preliminary test as follows. As shown in figure 1, co-fired platinum resistance sensor element was prepared. A platinum resistor circuit was patterned on the surface of alumina (Al_2O_3) ceramic substrate. Then we have conducted a high temperature storage test at 850 ºC and 1100 °C. After storage test at 850°C, no visible changes were observed in platinum resistor circuit. Figure 2 shows the scanning electron microscope image of the platinum resistor wire before and after a storage test at 1100 °C for 600 hours. A width of the platinum resistor wire changed from 40 μm to 20 μm. Figure 3 shows the resistance drift after storage at each temperature. The resistance drift is defined by the resistance change between before and after the storage test at 0 ºC. In the case of 850 °C storage test, the resistance drift is less than 0.1% after 600 hours. However, in the case of 1100 ºC storage test, the resistance drift reached 33%. Thus, we made an assumption that the evaporation of the platinum at 1100 ºC has reduced the width of the platinum resistor wiring, which resulted into the resistance drift.

3. The Purpose

In order to suppress the platinum evaporation, we hypothesized that a cover layer to protect the platinum resistor circuit from oxidation would be effective. In this study, we propose the method to embed the platinum resistor circuit within dense ceramic layer by utilizing co-firing and Multi layer technologies. Furthermore we studied that by employing the proposed method, the resistance drift can be improved at temperature exceeding 900 ºC.

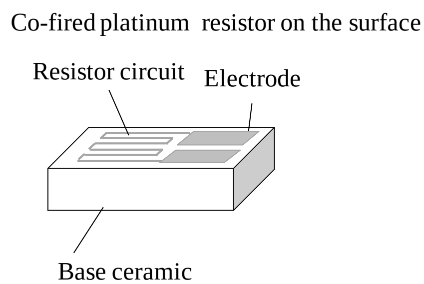

Fig. 1 Schematic diagram of the platinum resistance sensor element for preliminary test

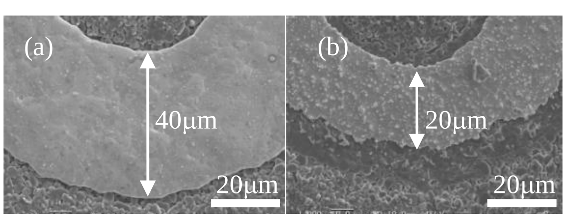

Fig. 2 Scanning electron microscope image of a platinum resistor wire
(a) before storage test (b) after 1100 ºC storage test for 600 hours

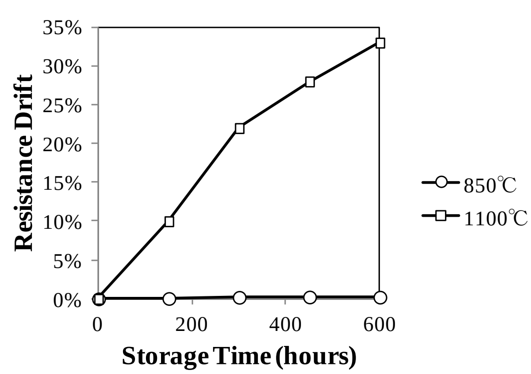

Fig. 3 The resistance drift of the preliminary test

4. Materials and methods

To examine the effect of embedding the platinum resistor circuit within the ceramics layers, we have prepared co-fired platinum temperature sensor elements and conventional thin-film platinum temperature sensor elements. To compare the resistance drift, we have conducted a high temperature storage test and observed the elements using scanning electron microscope.

4.1 The Co-fired Platinum Temperature Sensor Element

Figure 4 shows the design of co-fired platinum temperature sensor element (hereinafter referred to as the Co-fired Pt Element). At first, the via holes are punched through an alumina (Al_2O_3) ceramics-green-sheets on corresponding layers. Then the via holes are filled with platinum conductive paste. On each green-sheet, platinum conductive paste is screen-printed to form the resistor circuit. Next, the sheets are laminated to connect electrically with corresponding layers. Only electrodes are printed on the surface layer. Thickness of the surface layer is 50 μm (approx.). Thereafter, multi-layered green-sheet is co-fired at temperature more than 1500 ºC. Thickness and width of platinum resistor wire is 5~10 μm and 50 μm (approx.), respectively. [6] [7]

4.2 The Thin-film Platinum Temperature Sensor Element

Figure 5 shows a schematic diagram of the thin-film platinum temperature sensor element (hereinafter referred to as Thin-film Pt Element). The platinum resistor circuit is covered with cover glass layer and ceramic cover plate. The platinum resistor circuit is formed by sputtering and plating on alumina (Al_2O_3) substrate, and its thickness and width are 1~2 μm and 18 μm (approx.) respectively. A role of cover glass and ceramic cover plate is to protect the platinum resistor circuit from evaporating. Thickness of cover glass is 20 μm (approx.).

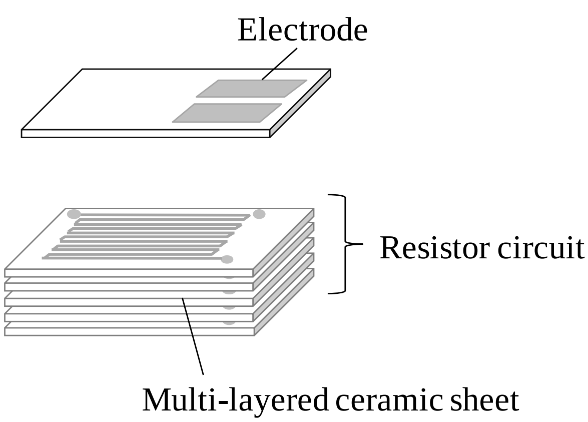

Fig. 4 Schematic diagram of Co-fired Pt Element

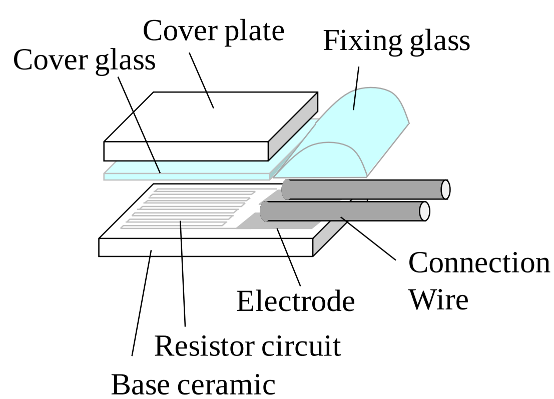

Fig. 5 Schematic figure of Thin-film Pt Element

5. Result

5.1 The Resistance drift

Figure 6 shows a result of the resistance drift after high temperature storage test for 1000 hours.

In the case of 850°C storage test shown in figure 6(a), the resistance drifts for both Co-fired and Thin-film Pt Elements are less than 0.2% after 1,000 hours.

Figure 6(b) shows the resistance drift at 1100 °C. The resistance drift of the Co-fired Pt Elements were 0.4%, whereas the Thin-film Pt Elements were 1.8%. The resistance drifts for both sensor elements have improved in comparison to a result of the preliminary evaluation as previously described in section 2. Furthermore, in comparisons, a Co-fired Pt Element can achieve the resistance drift less than 1/4 of a Thin-film Pt Element.

5.2 Micro-structural changes in platinum resistor wiring after high temperature storage

Figure 7 shows a cross-sectional structure of the Co-fired Pt Element before and after the high temperature storage test (1100°C for 1000 hours). Neither an obvious change in shape nor crystal grains were observed.

Figure 8 shows a shape of a platinum resistor wire of the Thin-film Pt Element before and after the high temperature storage test (1100°C for 1000 hours). Cover glass layer was etched and removed from the surface using acid solution for observation. The platinum resistor wire is partially deformed, and its width has decreased from 18 μm to 12 μm. An obvious deformation in the platinum crystal grains were observed, and grain boundaries became more visible after the storage test.

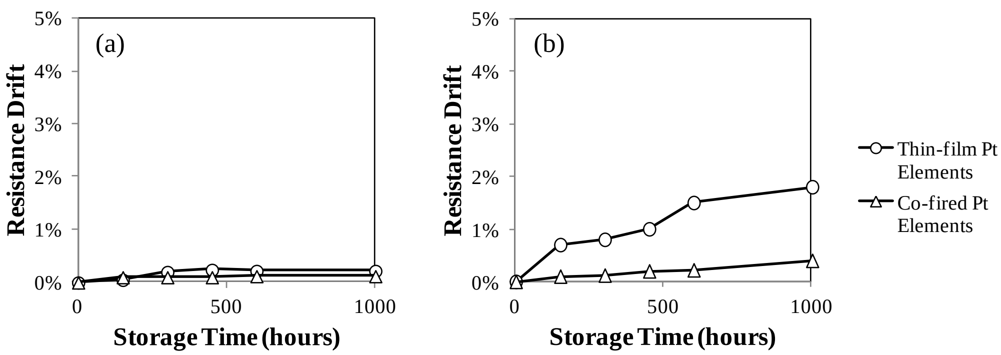

Fig. 6 The resistance drift of the sensor elements after storage (a) 850°C (b) 1100°C

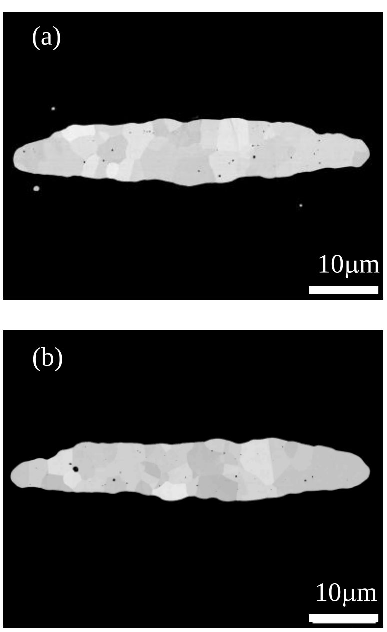

Fig. 7 A cross-sectional view of the co-fired platinum resistor wire (a) before storage (b) after storage 1100°C for 1,000 hours

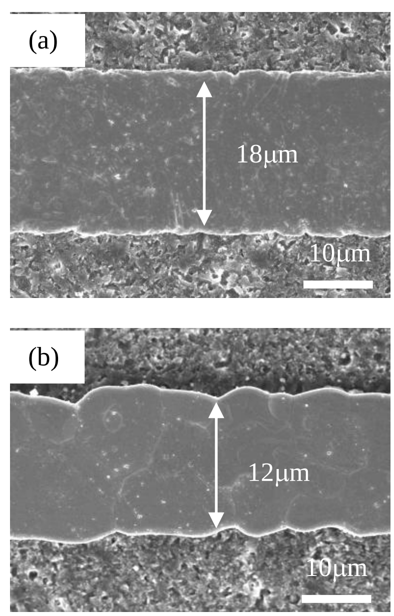

Fig. 8 Surface view of a thin-film platinum resistor wire (a) before storage (b) after storage 1100°C for 1000 hours

6. Discussion

In the case of Co-fired Pt element, resistance drift after 1100ºC storage is minimal compared to that of the platinum resistor circuits examined in preliminary evaluation. We believe that the improvement is due to an effect of the platinum resistor circuit being surrounded by dense ceramic layers, which protected it from being exposed to an oxidized atmosphere and being evaporated. Additionally, the resistor wire did not deform after 1100 ºC storage test, because the wire was fired at a temperature over 1500ºC, and the crystal grains were sufficiently stabilized. In the case of the Thin-film Pt Element, oxidation and evaporation of the platinum resistor circuit was suppressed significantly, because a cover glass and ceramic cover plate protected it. However, we assumed that the resistance drift of the Thin-film Pt Elements were greater than that of the Co-fired Pt Elements; because of a partial deformation and decrease in wire width due to both evaporation of the platinum resistor circuit and platinum crystal grain growth.

7. Conclusion

In this study, we were able to confirm an improvement in the resistance drift by Co-fired Pt Element at 1100ºC storage test. The main causes of the resistance drift after long-term storage at high temperature are as follows: 1. the resistor circuit deformation caused by evaporation, and 2. the resistor circuit deformation caused by crystal growth.

We were able to contain the above two phenomena by utilizing Co-fired Pt Element as shown in figure 9. The element structure proposed in this study with reduced resistance drift at high temperature can be applied to a sensor near an automotive engine; in which the operation temperature is over 900ºC. We believe that the Co-fired Pt Element can be used to improve fuel consumptions of the automobiles and reduce CO_2 emission in exhaust gas; which would greatly contribute to our struggle against global warming.

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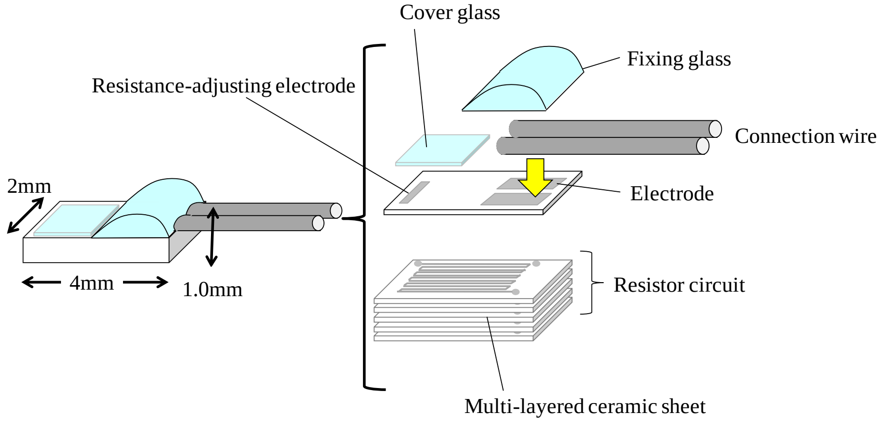

Fig. 9 Schematic structure of Co-fired Pt Element