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Note

Application of Screen Printing in Flexible Miniature Thermocouple Process Development

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Thermocouple is a highly effective means of determining exactly fuel cell temperature. This work presents a method for producing flexible micro thermocouple by using screen printing rather than micro-electro-mechanical systems (MEMS). The proposed method can implement the production process in a normal ambient atmosphere, i.e. a production process which can be mass produced. The proposed method is characterized by the ability of the production process to use screen printing at a lower cost than when using MEMS.

Keywords: Flexible micro thermocouple, screen printing; MEMS

1. INTRODUCTION

In recent years, the earth's major resources reduce dramatically, and the resources of daily needs are also affected. Therefore, countries in the world are actively developing zero pollution alternative energy, and even recyclable alternative energy, resulting in much room of the development of fuel cell.

However, the internal temperature control of fuel cell is very important to achieve high performance. Therefore, the monitoring of the temperature of each battery stack becomes relatively important.

To measure the temperature of the heating of the resistance, Chu [1] designed a miniature thermocouple with the sensing area of 200nm × 300nm, using gold and nickel as the sensing materials fabricated on silicon. The results suggested that the miniature thermocouple is consistent with the results of simulation.

To measure the change in temperature of a small area, Atherton [2] fabricated the sheet-type miniature thermocouple and micro-heaters on polyimide (PI) substrate, using nickel and chrome as the sensing materials. The miniature thermocouple line width is of 20μm, and the thermocouple and heater spacing is 75μm. Using PI as a substrate has the advantages such as flexibility, strength and good chemical resistance, etc. The author proposed to measure 100μL gasoline/water mixed fluid and applied the sensors in wet wipes to test the impact of humidity on thermal conductivity, finding the thermal conductivity decreases when the paper is drier. The results verified the practical application of the sensing device.

Ali [3] fabricated on Kapton substrate T-type thin-film thermocouple to measure high temperature proton exchange membrane fuel cell (HT-PEMFC). By the magnetron coating technology, the thin-film thermocouple of 2μm in thickness was deposited on Kapton thin sheet of 75μm in thickness. Kapton sheet was processed by argon plasma to enhance the adhesion between thin-film thermocouple and Kapton. By spin coating technology, thin-film thermocouple was covered by 7μm liquid Kapton layer to protect it from the ageing effects of the environment. The thin-film thermocouple-deposited Kapton sheet is used in the sealing of the internal of the single battery of polybenzimidazole (PBI). It can measure the changes in internal temperature of the working fuel cell membrane electrode assembly (MEA). The thin-film thermocouple performance can minimize the interference of the battery in operation.

Krebs [4] successfully applied screen printing technology in making the large-area flexible polymer solar cell in the atmospheric environment. The proposed process improves the process speed and the quantity of production, significantly reducing the cost of production.

2. THEOREM AND DESIGN

The principle of the thermocouple is to form the circuit loop by connecting the wire of two metals at both ends as shown in figure 1. When the two contact points of the thermocouple element are in contact with objects of different temperatures, as the conduction electron diffusion rates in metals are different, different diffusion currents are generated in the different two metals. Therefore, a minute current will be formed in the circuit loop of two metals. The multiplication of the minute current with the contact point contact resistance will generate a small open circuit voltage in the loop known as the Seebeck electromotive potential, and defined as shown in Eq. (1). The thermocouple voltage magnitude is the function of the temperature difference between the end points. Seebeck coefficient (α_S) is defined as:

$$\alpha_s = \frac{(V_1 - V_2)}{(T - T_0)} \quad (1)$$

where, the open circuit voltage:

$$V_T = V_1 - V_2 \quad (2)$$

Therefore, it can be inferred that:

$$V_T = V_1 - V_2 = \alpha_{s1}(T - T_0) - \alpha_{s2}(T - T_0) = (\alpha_{s1} - \alpha_{s2})(T - T_0) \quad (3)$$

By measuring the voltage difference, the temperature difference with the reference temperature can be inferred to obtain the actual temperature. The thermocouple is usually based on two metal wires with two different Seebeck coefficients, such as copper-nickel or silver -nickel, etc. In the sensing end, two metal wires are connected to form a circuit loop. As the micro-sensors are subject to a combination of stress in the fuel cell assembly, it can cause changes in micro-sensor resistance value. Therefore, we used the thermoelectric temperature sensors by using gold and nickel as the materials of the two electrodes. The wire width is set as 140μm, the width of the sensing end is set to 150μm, the sensing area is set to 150μm×750μm. The temperature is measured in the above settings as shown in figure 2.

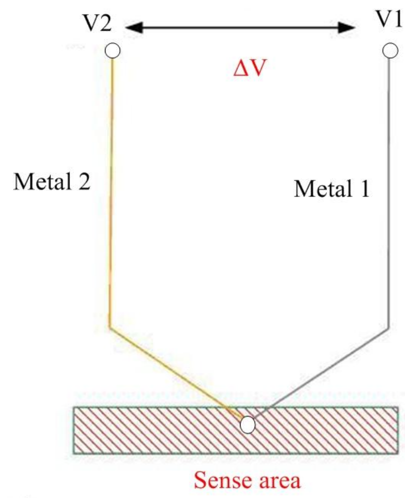

Figure 1. Thermocouple theorem.

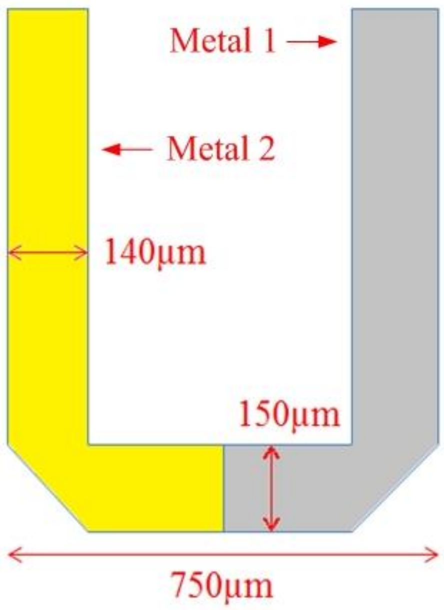

Figure 2. The design of micro-thermocouple.

3. FABRICATION

The production process of flexible micro-thermocouples are as shown in figure 3. As shown in figure 3(a), the copper (Cu)-contained PI is brushed with the first layer ink barrier by screen printing. The PI with ink is immersed in the copper etching liquid for about 15 to 20 minutes until the copper around the barrier layer is etched. The etched copper wire PI is immersed in sodium hydroxide liquid of weight percentage at 4%. The container with sodium hydroxide and PI is input into the ultrasonic cleaning tank for vibration. The ink on PI is then vibrated off to get the first layer of metal of the micro-sensor as shown in figure 3(b). The PI is then coated with the second ink barrier by screen printing as shown in figure 3(c); the PI with the second ink barrier layer is input in the deposition machine for nickel (Ni) coating as shown in figure 3(d); the nickel-coated PI is immersed in sodium hydroxide liquid of weight percentage at 4%, the container is then input into the ultrasonic cleaning tank for vibration to get off the nickel on the ink. Figure 3(e) illustrates the thermocouple comprising two metals. Figure 4 illustrates the microscope image of a flexible micro-thermocouple; a 15cm×15cm copper-contained PI can make about 15 groups of flexible micro-thermocouples.

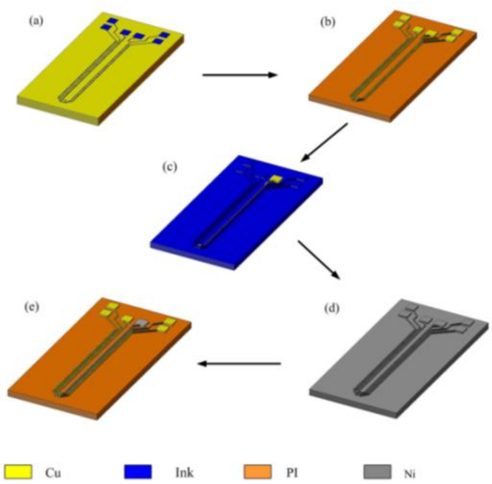

Figure 3. The production process of flexible micro-thermocouples.

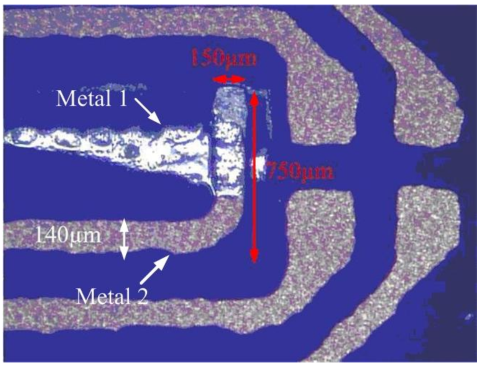

Figure 4. The OM photo of a flexible micro-thermocouple.

4. CORRECTION

After the flexible micro-thermocouples has produced, we corrected the flexible micro-thermocouples. In this study, we used temperature control chamber be the model of the correction, we also used National Instruments (NI) PXI-1033 to correct as showed in figure 5. We took the sense area of the flexible micro-thermocouples on the heater heat. The correction temperature is between 30°C to 80°C. The curves of "temperature difference – voltage" are showed as in figure 6. The curves show that the flexible micro-thermocouples has reconstruction, so we can know that this flexible micro-thermocouples has highly trusty.

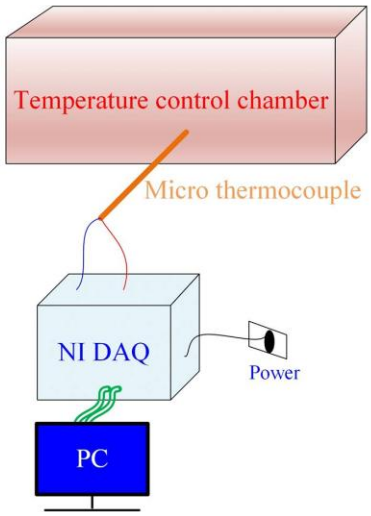

Figure 5. The experimental set-up of corrected the flexible micro-thermocouples.

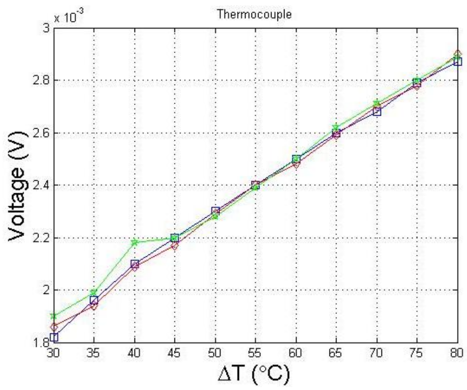

Figure 6. The correction curves of a flexible micro-thermocouple.

5. CONCLUSION

In this study, we successfully completed the production of miniature flexible micro-thermocouples by using the screen printing method. Although the new process cannot produce the flexible micro-thermocouples of micro-electromechanical level, the process is absolutely beneficial to the test objects do not need such a precision level. In the future, the flexible micro-thermocouples coupled with the wireless reception technology to realize real-time information monitoring. It is believed that the proposed process can facilitate the development of flexible micro-thermocouples of large demand and low cost.

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