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Flexible micro sensors for in-situ diagnosis of proton exchange membrane fuel cell

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ABSTRACT

The temperature and flooding phenomenon during operation can strongly influence a proton exchange membrane fuel cell (PEMFC) performance. Non-uniform conditions exist in each segment of fuel cell. Previous studies have investigated these conditions on the mm scale using destructive methods or simulation, but none has been able to obtain exact data from within the fuel cell.

This research applies micro-electro-mechanical systems (MEMS) to develop a flexible micro temperature, pressure and flow sensor. It is composed of main two parts: 1. Fabrication of flexible micro sensors on polyimide (PI) film by MEMS; 2. Embedding flexible micro sensors into a PEMFC for in-situ diagnosis and performance.

Internal temperature data demonstrate that the downstream exceeds upstream and midstream, because the generated heat is carried by gas from the inlet and downstream, where it undergoes a severe reaction. Monitoring the inner pressure for a long period revealed that the accumulation and elimination of water in flow field may be responsible for increased pressure and the recovery. The flow rate that is supplied by the flow controller in the testing system exceeds those measured by the upstream and downstream sensors. This deviation is consistent with the results of a fuel cell leak test.

Introduction

The water and thermal management and membrane electrode assembly (MEA) operating states [1–4] inside the fuel cell can affect the performance of the fuel cell and even result in dry membrane or rupture and acceleration of ageing to lose effectiveness [5]. Overly high moisture content will result in flow channel and MEA flooding and prevent the gas from passing through. Dehydration and flooding can cause decline in battery performance and the performance will become difficult to predict.

Many studies have discussed the fuel cell flooding and thermal monitoring information, such as observing the flooding near the outlet of proton exchange membrane fuel cell (PEMFC) by transparent flow channel [6], using hydrogen–deuterium exchange method to compare the magnetic resonance imaging to learn about the dynamic distribution of the water inside PEMFC [7]; interpreting the water generation or flooding inside the fuel cell by observing the drop in voltage [8–10].

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Zhang [11] et al. proposed the embed 10 T-typed thermal couples in the cathode of the fuel cell to observe the changes in the temperature inside the fuel cell when the air or hydrogen is insufficient in the case of controlled current and voltage. Jiao [12] et al. measured the temperature distribution of the fuel cell in cold actuation in case of various different conditions by using the thermal couple in the cathode end. He [13] et al. embedded the thermal sensitive resistance made of gold in between the Parylene thin film of 16 μm in thickness to measure the changes in fuel cell temperature.

This study uses the MEMS to develop the flexible micro temperature, pressure and flow sensors. The proposed flexible micro sensors have advantages such as small volume, big flexibility, high reliability, real time response and flexible measuring positions. By applying the flexible micro sensors in fuel cell for real time monitoring to obtain the local temperature, flow, and determine the flooding or water generation state accurately. Coupled with the adjustment of operating parameters, we can improve the working efficiency and service life of the fuel cell.

Micro sensors design and principle

Micro temperature sensor

The resistance of the metal conductor will rise due to the rise of the ambient temperature. This is caused by the "temperature coefficient of resistance" (TCR) of the conductor, and it is defined as shown in Eq. (1).

$$\alpha = \frac{1}{\rho_0}\frac{d\rho}{dT} \tag{1}$$

where, α is the TCR; ρ is the resistivity; ρ_0 is the resistivity when the temperature is 0 °C.

If the resistance temperature sensors are used in the linear range of the resistance of the conductor, it can be represented as shown in Eq. (2).

$$R_t = R_0(1 + \alpha_1 \Delta T) \tag{2}$$

The proposed micro temperature sensors use the thermal resistance temperature detector (RTD) of the above principles. Therefore, the range of temperature sensing is large and the linear degree is good. The snake-shaped sensing electrode line width is 11 μm, and the interval is 9 μm.

Micro pressure sensor

In the past, capacitive pressure sensors were widely used. For example, Elbuken [14] et al. applied the capacitive sensors in microfluidic devices to detect the micro droplet type, size and speed. Perdigones [15] et al. used the capacitive low pressure sensors to measure the micro gas flow under the negative pressure. Montanini [16] et al. used the capacitive pressure sensors to measure the relationship between the fuel cell closure pressure and MEA real pressure distribution and the back shell deformation.

The capacitive pressure sensors can be divided into two types by structure: (a) using the groove as the dielectric layer; (b) using polymer as the dielectric layer, sandwiched between two parallel metal electrodes as the non-conductive dielectric layer, the capacitance as given by Eq. (3),

$$\Delta C = \varepsilon_r \varepsilon_0 \frac{A}{\Delta d} \tag{3}$$

where, ε_r is the material dielectric constant, ε_0 is constant 8.854×10^{-12} (F/m), A is the overlapped area of the projection of two parallel electrodes, Δd is the change in the vertical distances between two parallel electrodes. In Eq. (3), the dielectric constant and the projection area of two parallel electrodes only affect the initial capacitance, mainly the change in capacitance and the distance between two parallel electrodes.

To enable the capacitive pressure sensors to display the linear response, enhance sensitivity and consider the process convenience, this study chose PI 7320 of compliant rigidity, dielectric constant, and flexibility coefficient and process convenience as the dielectric layer. As the cavity between two parallel electrodes is replaced by the polymer material, it can ensure the deformation of the thin film electrode is even. The capacitive sensing area of design is 800 μm × 800 μm.

Micro flow sensor

The thermal linear flow sensor's main measuring structure is the thermal resistance heater to generate the source of heat by fixed voltage input to form the stable temperature field. In the flow field, the heater-generated temperature field will change with the strong thermal convection of the fluid. If the external heater provides a fixed amount of heat, with increasing fluid volume and heat being taken away, the resistance of heater will drop accordingly. By controlling the heat provided to the thermal line to keep the temperature difference between the thermal line and flow volume constant, the heating power should be increased with rising fluid volume. By the fixed temperature circuit design, the flow volume can be converted into electronic signal outputs.

As the thermal line flow sensor measures the flow volume by heating, the substrate material should be low in thermal conductivity to avoid the heat dissipation caused by the heat conduction of the substrate. Hence, this study selected the polymer material PI as the substrate.

Process of flexible micro sensors

Micro sensor production process

The production process of the flexible micro sensors is as shown in Fig. 1. The process is conducted by using the surface micromachining technology, and the details of the process are as follows. The finished micro sensor is as shown in Fig. 2.

Process of micro temperature and flow sensors

The procedural steps of the micro temperature and flow sensors are: (a) to sequentially place the PI specimen in the acetone and methanol solutions for vibration and cleaning; (b) to coat the chromium by evaporation as the adhesion layer between gold and the substrate PI layer to increase the