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Ultrasonic radiation to enable improvement of direct methanol fuel cell

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ABSTRACT

To improve DMFC (direct methanol fuel cell) performance, a new method using ultrasonic radiation is proposed and a novel DMFC structure is designed and fabricated in the present paper. Three ultrasonic transducers (piezoelectric transducer, PZT) are integrated in the flow field plate to form the ultrasonic field in the liquid fuel. Ultrasonic frequency, acoustic power, and methanol concentration have been considered as variables in the experiments. With the help of ultrasonic radiation, the maximum output power and limiting current of cell can be independently increased by 30.73% and 40.54%, respectively. The best performance of DMFC is obtained at the condition of ultrasonic radiation (30 kHz and 4 W) fed with 2 M methanol solution, because both its limiting current and output power reach their maximum value simultaneously (222 mA and 33.6 mW, respectively) under this condition. These results conclude that ultrasonic can be an alternative choice for improving the cell performance, and can facilitate a guideline for the optimization of DMFC.

1. Introduction

DMFC, as a renewable source of fuel, can offer high energy density, low emissions, ambient operating conditions, fast and convenient refueling. These features make it become an appropriate power supply for electronic devices, such as cell phones, laptop computers, PDAs [1–4]. Currently, compared with traditional battery, DMFC has no advantage on the prices; however, DMFC is desirable as a secondary power source at long-term time scale, because of the decrease of fossil fuels [5–7]. For these reasons, DMFC becomes a hot topic which is increasingly investigated by researchers and industry engineers all over the world [8–15].

Although many researchers have made great progress, two major challenges which limit the commercialization of DMFC remains: (1) the permeability of methanol from the anode to the cathode through the membrane is termed as methanol crossover, which creates a mixed potential and decreases the cathode potential. (2) The activity of catalyst and cell performance has been reduced, because the intermediate products generated in the electrochemical reaction adhere to the surface of the catalyst and hinder the electrochemical reaction. Such phenomenon is named catalyst poisoning [16], which is the focus of present research.

In recent years, to overcome the challenges and to improve the cell performance, researchers over the world have proposed lots of methods. The mostly used solution to release catalyst poisoning can be divided into two categories: One is using multiple catalytic methods [17–19] to improve the activity of catalyst. It is the common method to solve the poisoning problem by improving the oxidation performance of the catalyst and reducing the generation of the intermediate products of DMFC. However, the commercialization of DMFC is limited by the utility of catalyst which made of rare metal. The other method is based on applying special carrier material [20,21], to improve the cell performance. Although it can effectively improve the cell performance, for DMFC applications, this method is costly with complex functions, and cumbersome to control, thereby limiting the application and promotion of DMFC.

For the past 20 years, the power ultrasonic was widely applied [22,23] in the chemical and processing industries, aiming to enhance both synthetic and catalytic processes and to generate new products. In the application of DMFC, a few reports on the use of ultrasonic for fabricating noble metal nanoparticles, catalysts and other fuel cell materials [24–26], were found in literatures. The works done by Han et al. [27] and Nagahata and Wu [28] reported the methods that can significantly improve the performance of DMFC by using ultrasonic. In our preliminary research [28], the ultrasonic transducer is installed outside of the DMFC to radiate the ultrasonic energy, whilst it is installed in fuel supply

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channel outside the DMFC in the devices developed by Han et al. In this paper, a new DMFC structure with three small ultrasonic transducers which are integrated in the anode flow field channel has been proposed and tested.

2. Experimental

2.1. Model of DMFC

In this paper, a transparent DMFC was designed and fabricated for this performance study. As is shown in Fig. 1, this DMFC consists of bipolar plates, MEA (Membrane Electrode Assembly) and ultrasonic piezoelectric transducers (PZT). They were clamped between two enclosure plates by eight M4 screw joints, and a gasket was used for sealing purposes. The MEA was embraced by the bipolar plates with gaskets.

In this experiment, a Nafion117 polymer membrane (DuPont) was used to fabricate MEA. The multi-layer MEA, in this work possesses an active area of 25 cm^2, which is constructed by a Nafion® 117 membrane, two catalyst layers, two back layers and two gas diffusion layers. The catalyst loading were prescribed with 4.0 mg cm^{-2} [Pt:Ru] Ox(1:1a/o) at anode and 2.0 mg cm^{-2} 40% Pt with VulcanXC-72 carbon black at the cathode, respectively. To protect the anode catalyst layer from being destroyed, the catalyst is coated on the Nafion membrane instead of GDL. Therefore, a CCM approach is employed to fabricate the MEA. The back layer for the anode comprises VulcanXC-72 carbon black and 5 wt.% of Nafion ionomer (E-TEK), and the cathode back layer comprised VulcanXC-72 carbon black and 15 wt.% of PTFE. Furthermore, 0.8 mg cm^{-2} Nafion® was applied onto the surface of each back layer. Both anode and cathode diffusion layers are carbon cloth with MPL-W1S1005. They were hot-pressed to form a complete MEA at 160 °C and 5 MPa for 5 min.

In order to avoid corrosion, the bipolar plates shown in Fig. 2, were made of 304 stainless steel plates with thickness of 5.0 mm [29]. Fig. 2 illustrated the two components of bipolar plate: flow field and electrode area. Flow field is used to distribute the supplying fuel and oxidant to MEA, in which a single serpentine channel, 5.0 × 5.0 mm, acted as current collector as well. The serpentine channel consists of 6 serially-linked horizontal segments (50.0 mm in length) and 5 vertical segments (9.0 mm in length). The width of the ribs was 4.0 mm and the width of the vertical segments was 6.0 mm. The opening ratio of the flow field is 64%. There were three piezoelectric ceramic installation slots with a size of 5.0 × 2.0 mm in the first channel of anode flow field plate. The electrode area of the bipolar plates was used to connect the current collector with the external testing circuits.

PZT-8 was chosen as the ultrasonic components of this system, because it has the advantages of low electromechanical coupling coefficient and piezoelectric constant, and possesses the features of large mechanical quality factor. Table 1 listed the performance parameters in detail.

2.2. Testing system and testing conditions

As is shown in the Fig. 3, the testing system mainly included the fuel cell's ultrasonic system, fuel supply system and testing equipment. In the ultrasonic system, a function generator (*Tektronix AFG3022C*) was employed to generate a sinusoidal signal which was amplified by a power amplifier (*E&I 1040L*). An impedance matcher (*E&I Lo-Hi-Z-8-500*) was used to improve the effective output power of the signal. The signal was fed to the PZTs to convert electric energy into mechanical vibration to generate the ultrasonic radiation field in the flow field. The impedance of system was measured by the impedance analyzer (*Hioki IM3570*) before experiment. Fig. 4 illustrates the characteristic of the PZT. According to the solid curves in Fig. 4, the minimum impedance of the PZT is observed at approximately 30 kHz, while the phase angle (dashed curve) has a significant pulse. Therefore, when PZT works at 30 kHz, the PZT system can be considered as working at its resonance condition [30]. A peristaltic pump is employed to feed the liquid fuel with different methanol concentrations to the DMFC at a flow ratio of 1 ml/min in the following experiments.

In this work, electronic load (*ITEC8512+*) was used to control the operating conditions and record the cell performance. A prewritten program has been input before the experimental approaches. During the experiments, all data were recorded by a computer program. And the electronic load is scanned from current 0 to cell possible maximum current under the constant current model. The experimental results were measured under the same conditions of air breath cathode. Three kinds of specific operating conditions for DMFC have been listed in Table 2.

3. Results and discussion

3.1. General performances of DMFC with/ without ultrasonic radiation

The cell performances with different concentration methanol solution at the feed rate of 1 ml/min with/without ultrasonic radiation are shown in Table 3. At first, let's compare the experimental

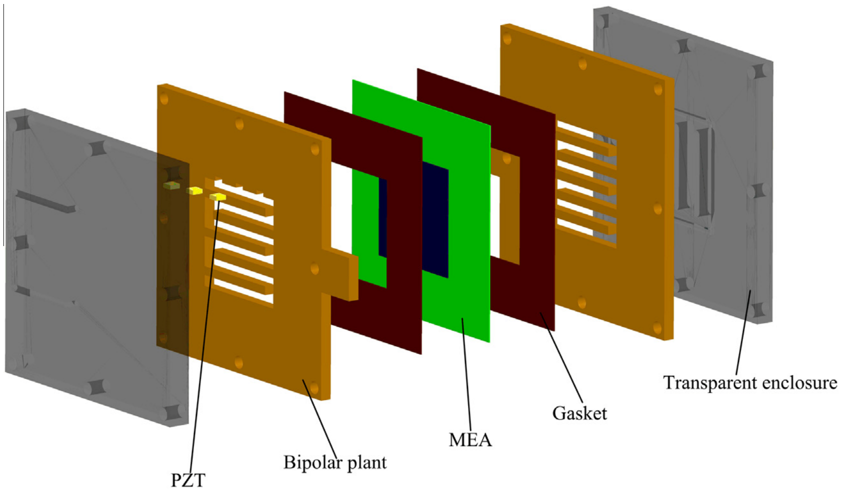

Fig. 1. DMFC with PZTs.