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Effect of Different Liquid/Gas Diffusion Layers on the Performance of Proton Exchange Membrane Water Electrolysis

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ABSTRACT

Proton exchange membrane water electrolysis (PEMWE) is a potential method of hydrogen production. The liquid/gas diffusion layer (LGDL) is of great significance for PEMWE performance. In this work, the untreated carbon paper, titanium mesh and titanium fiber paper are adopted as the anode LGDL, respectively. The polarization curves and electrochemical impedance spectroscopy are measured and compared in detail. The results indicate that the carbon paper as the anode LGDL shows the best electrolysis performance with the low ohmic resistance and interface resistance. And the high interface resistance is the dominated factor that affects the electrolysis performance of PEMWE with the titanium mesh and titanium fiber paper.

Keywords: Proton exchange membrane water electrolysis, Hydrogen production, Anode liquid/gas exchange layer

1. INTRODUCTION

Hydrogen is an environmental and renewable energy which is an excellent choice for future energy structure optimization [1]. The proton exchange membrane water electrolysis (PEMWE) for hydrogen production is favored for compactness, safety, high efficiency and high purity of production [2].

The core component of PEMWE is membrane electrode assembly (MEA) which is composed of gas-liquid exchange layer (LGDL), catalyst layer and proton exchange membrane. In the water electrolysis reaction, hydrogen evolution reaction (HER) in cathode is rapid, while the oxygen evolution reaction (OER) in anode that will causes serious performance loss is relatively slow. Therefore, improving the anode performance of water electrolysis is of great significance for optimizing the performance of water electrolysis. Among the many factors like high potential and acidic environment that affect anode performance, the material choice of LGDL is particularly important [3,4]. In the anode OER, the liquid water flows through the flow channel and enters the LGDL to contact the catalyst layer. The oxygen product is also removed from the flow channel through the LGDL. The anode LGDL plays roles of supporting the catalyst layer and enabling the timely exchange of gas and liquid. And the anode LGDL affects the charge conduction and interface resistance, which have a significant effect on the OER. Therefore, the choice of LGDL will not only affect the ohmic resistance but also the interface resistance of PEMWE.

Bystron T et al. [5] prevented excessive passivation of the titanium fiber paper via appropriate titanium etching (in acid) to reduce the interface resistance. Hwang CM et al. [6] investigated the effects of different structural properties (such as porosity and fiber diameter) of titanium fiber paper as the anode LGDL on the performance of electrolysis mode in reversible fuel cell. However, the studies on carbon paper, titanium mesh and titanium fiber paper as LGDL are relatively rare. In this work, carbon paper, titanium mesh and titanium fiber paper are used as the anode LGDL, respectively, and the polarization curve and electrochemical impedance spectroscopy are compared in detail.

2. EXPERIMENTAL SECTION

2.1 Proton exchange membrane water electrolysis

The schematic of PEMWE is shown in Fig. 1. It mainly consists of MEA, bipolar plate, current collector and end plate. In particular, the anode and cathode bipolar plates are made of the pure titanium and the commercial graphite, respectively. They are both engraved with the parallel flow field containing inlets, outlets and temperature measurement points. Moreover, the material of sealing gasket is teflon.

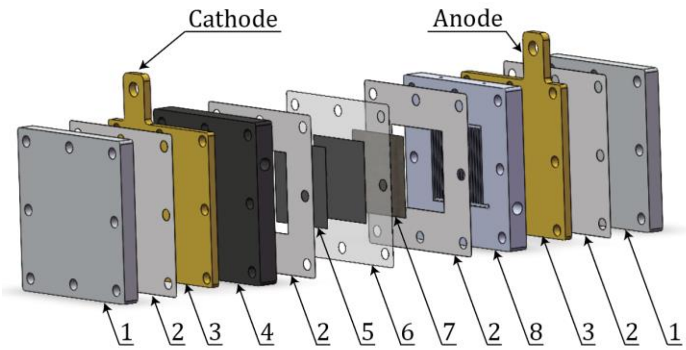

Fig. 1. Schematic diagram of PEMWE
(1: End plate, 2: Insulating spacer, 3: Current collector, 4: Carbon plate, 5: Carbon paper, 6: Catalyst coated membranes, 7: LGDL, 8: Titanium plate)

2.2 Membrane electrode assembly

A single water electrolysis is used in this experiment, and the reaction area is 25 cm^2. MEA is produced by WUT HyPower Technology Co., Ltd. The anode catalyst is IrO_2 with a loading of 2.0 mg cm^{-2}, while the cathode catalyst is Pt/C with a loading of 0.8 mg cm^{-2}. The proton exchange membrane is Nafion® 115. The anode LGDLs are the untreated carbon paper, titanium mesh and titanium fiber paper, respectively, of which the specific parameters are listed in Table. 1. The cathode LGDL is carbon paper.

Table. 1. Parameters of different LGDLs

Material	*Thickness/mm*	*Aperture/μm*
Carbon paper	0.18	28
Titanium mesh	*0.30*	*150*
Titanium fiber paper	0.26	50

2.3 Experimental procedure

The specific experimental procedure is shown in Fig. 2. Before the operation of PEMWE, the nitrogen is used to purge residual gas in flow channel, to eliminate initial interference from each experiment. Then under atmospheric pressure, the running flow of deionized water with a temperature of 70℃ in anode is set as 40 ml min^{-1}. Meanwhile, the temperature of PEMWE also maintains at 70 ℃ through heating the end plates. During the test process, the DC power supply control is in constant current mode. At the beginning, the current density of PEMWE is set as a low value of 0.05 A cm^{-2}, and then the voltage maintains steady for 20 min at least. When the water electrolysis process reaches a steady state, the polarization curve is measured at the current density of 0-1 A cm^{-2} with a step of 0.05 A cm^{-2}. Meanwhile, the electrochemical impedance spectroscopy is also measured under the interference of sinusoidal alternating current density at 0.30, 0.45, 0.60, 0.75, A cm^{-2}, respectively. The maximum disturbed current density is 5-10% of the current density of PEMWE during operation. And the frequency is 100 mHz-100 kHz.

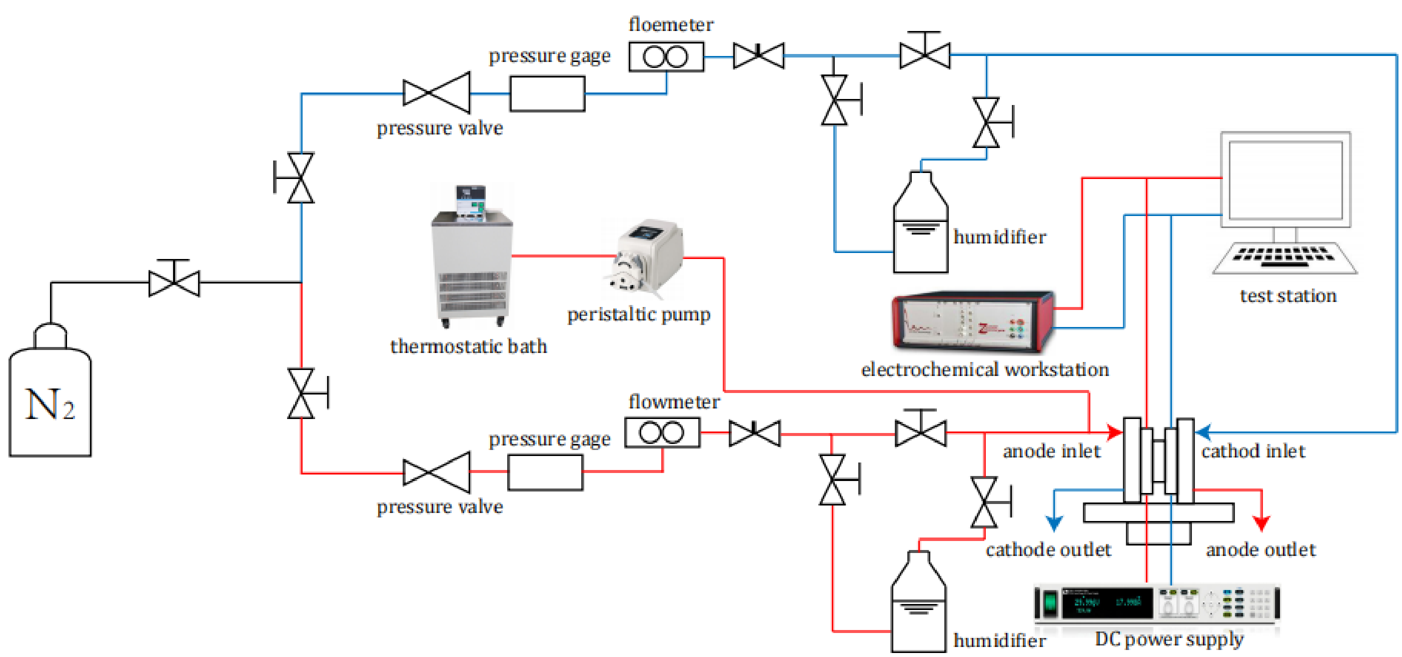

Fig. 2. Schematic diagram of PEMWE test system

3. RERESULTS AND DISCUSSION

3.1 Effect of assembly pressure

First, the effect of assembly pressure is explored. The carbon paper and titanium mesh are chosen as LGDL, considering the different structures of paper and mesh. The different assembly pressures are obtained by setting different torques of the torque wrench. And the torques are set as 2, 3, and 4 N m, respectively. Then the polarization curves of PEMWE with carbon paper and titanium mesh as the anode LGDL are measured and shown in Fig.3 and Fig.4., respectively.

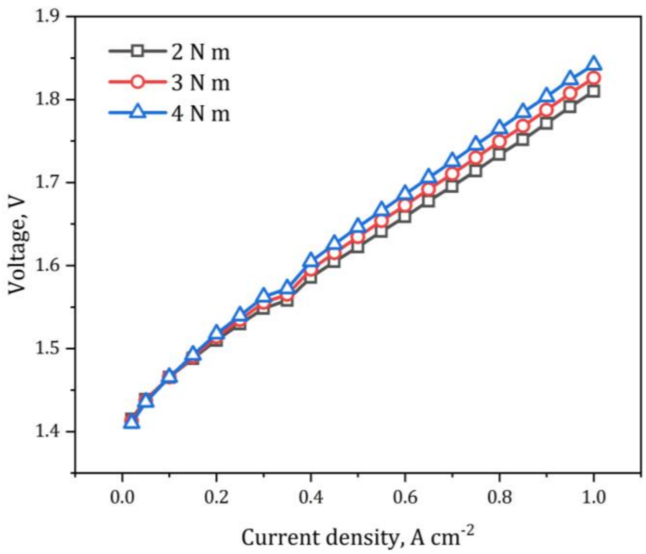

Fig. 3. Comparison of carbon paper as anode LGDL under different torques (2 N m, 3 N m and 4 N m)

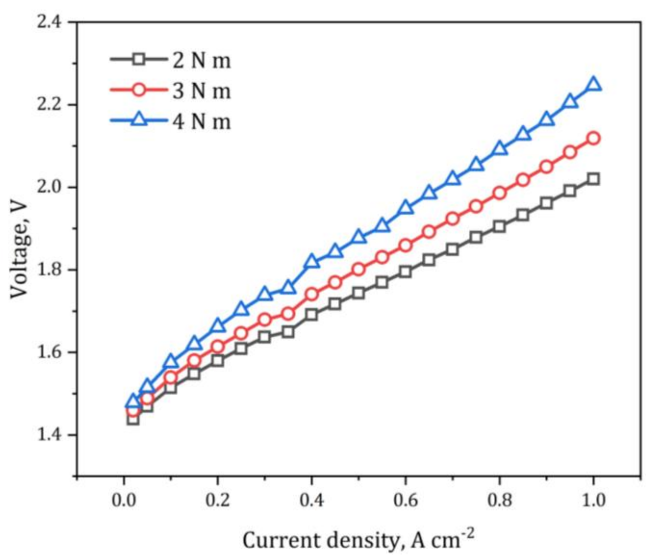

Fig. 4. Comparison of titanium mesh as anode LGDL under different torques (2 N m, 3 N m and 4 N m)

As shown in Fig. 3, the voltages of PEMWE with carbon paper at different torques are almost the same at low current density because the contact between carbon paper and catalyst layer is better and less affected by the assembly pressure. However, the differences of the voltages of PEMWE with titanium mesh at different torques are larger at low current density as shown in Fig. 4. At the current density of 0.02 A cm^{-2}, the voltage difference between 2 and 4 N m is nearly 20 mV. The reason is that the titanium mesh is uncompressible and its contact with catalyst layer becomes much closer with increasing assembly pressure. At the high current density of 1.0 A cm^{-2}, the voltage differences of PEMWE with carbon layer and titanium mesh between 2 and 4 N m are less than 20 mV and nearly 100 mV, respectively. Therefore, the performance of PEMWE is better at lower assembly pressure regardless of carbon paper and titanium mesh. But the air leakage will occur when the assembly torque is less than 2 N m, which is not allowed in experiment. Therefore, the torque of 2 N m is chosen during assembly.

3.2 Effect of LGDL

The effect of LGDLs (carbon paper, titanium mesh and titanium fiber mesh) is investigated in this subsection. The polarization curves and electrochemical impedance spectroscopy at the current density of 0.45 A cm^{-2} have been measured and shown in Fig. 5 and Fig. 6. As shown in Fig. 5, the PEMWE with carbon layer as the anode LGDL shows the lowest voltage and best performance, while that with titanium fiber paper shows worst performance. A lower current density, the

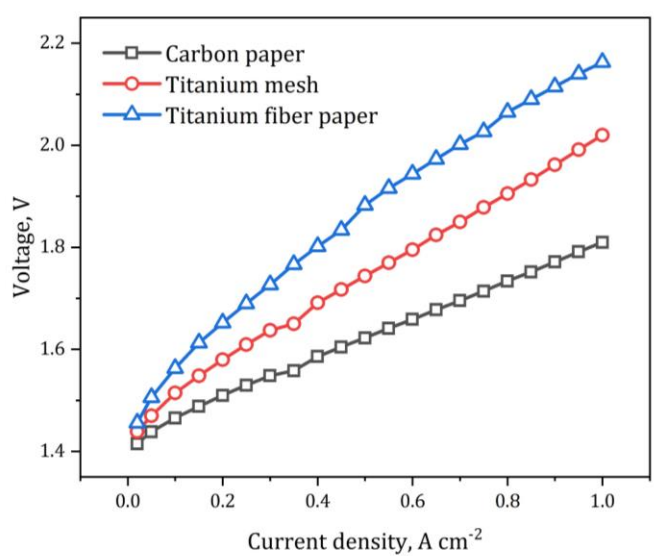

Fig. 5. Polarization curves of PEMWE with different LGDLs

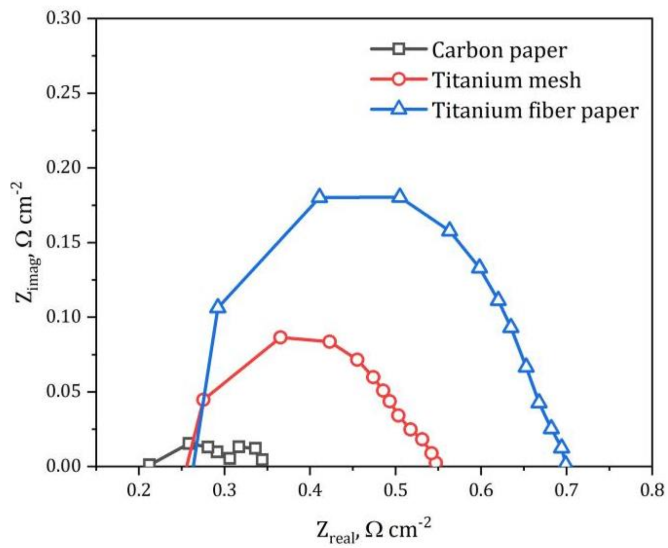

Fig. 6. Electrochemical impedance spectroscopy of PEMWE with different LGDL

difference of voltage is relatively smaller. At the current density of 0.02 A cm^{-2}, the voltages of PEMWEs with carbon paper, titanium mesh and titanium fiber paper are 1.415, 1.438 and 1.456 V, respectively. The voltage difference increases with the increase of current density, which is mainly ascribed to their interface resistance of different materials due to the different contact degrees with catalyst layer. The electrochemical impedance spectroscopy shown in Fig. 6 shows that the impedance consists of three parts caused by the ohmic resistance, interface resistance and charge transfer resistance. And the interface resistance of titanium fiber paper and titanium mesh is much larger than that of carbon paper, because the untreated titanium surface is covered by a dense oxide film, which impedes the charge transfer of the surface between anode electrode and deionized water. Moreover, the titanium surface is also too hard to have good contact with catalyst layer. Therefore, the carbon paper is the best choice from the aspect of performance. However, the carbon paper is easily corroded at the oxygen-rich and high-overpotential environment. Therefore, developing the titanium with a treated surface is necessary in future.

4. CONCLUSION

In this work, the untreated carbon paper, titanium mesh and titanium fiber paper are used as the anode LGDL of PEMWE, respectively. First, the torque of torque wrench representing the assembly pressure is optimized to be 2 N m based on the measured polarization curves. Then the polarization curves and electrochemical impedance spectroscopy of PEMWE with different LGDL materials under the torque of 2 N m are measured. The results show that the carbon paper as the anode LGDL shows the best electrolysis performance with the voltage of 1.810 V at the current density of 1.0 A cm^{-2} at 70℃, which has both lower ohmic resistance and interface resistance. The PEMWE with the untreated titanium fiber paper and titanium mesh shows much higher interface resistance compared with carbon paper due to the coverage of dense oxide film on the surface, which highly affects the PEMWE performance. Based on the results, the carbon paper is the best choice of anode LGDL from the aspect of electrolysis performance. However, the titanium with a treated surface is also a promising material considering the corrosion in anode.

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