DEVELOPMENT OF A NOVEL AIR-BREATHING MICRO DIRECT METHANOL FUEL CELL STACK USING MEMS TECHNOLOGY

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Abstract: A four-cell air-breathing micro direct methanol fuel cell (μDMFC) stack with two double-side patterned PDMS distributors was designed, fabricated, and tested in this paper. A novel n-inlet and n-outlet (NINO) smooth parallel flow field was first introduced. Based on the NINO smooth parallel flow field, the other three kinds of parallel flow field: square protrusion parallel flow field, semicircle protrusion parallel flow field, and triangle protrusion parallel flow field were proposed. Both the results of the stimulation and the test show that the square protrusion parallel flow field plate has the best performance.

Keywords: μDMFC stack, PDMS, flow field, anode

INSTRUCTION

In the past few years, the demand for the efficient, renewable and environmentally friendly energy sources is rising rapidly with the increasing functionalities of portable devices. As a leading candidate power source for portable devices, direct methanol fuel cell(DMFC), especially micro-DMFC (μDMFC), has drawn increasing attention recently due to its high energy density, easy recharging, low pollution and room temperature operation. Most of the previous researches have focused on design and fabrication of μDMFC to improve the performance. Great progress has been made in fuel cell stack, methanol crossover, management of heat and water, removal of CO2, fuel transport, etc. It is well known that flow structure design is critical for the fuel transport and the DMFC performance. The design of the anode flow field has an effect on achieving the optimal performance of a DMFC system. In this paper, a 4-cell air-breathing micro direct methanol fuel cell (μDMFC) stack with two double-side patterned PDMS distributors was designed, fabricated, and tested. To overcome the shortcoming of conventional flow fields [1.2], a novel n-inlet and n-outlet (NINO) flow field with micro-features was developed for the μDMFC anode. For the first time, PDMS adopted in this work was used not only for the stack packaging [3, 4], but also for the uniform distribution of methanol solutions through the connected double-side patterns.

DESIGN

A schematic of the basic structure and key components of the μDMFC stack which are connected in series is shown in Figure 1. The stack is composed of two stack fixers, two end plates, two distributors, one anode monopolar plate, three one-side bipolar plates, one cathode monopolar plate, one membrane electrode assembly (MEA) of four pairs of electrodes, and sealing gaskets. The electrical interconnection is achieved by Ti/Pt/Au layers sprayed on the one-side bipolar plates. Through the drilled ducts of the polycarbonate (PC) fixer and end plates, methanol solutions can be fed into the micro-channels of back sides of the PDMS distributors, and then distributed to each individual μDMFC at the front sides via the holes evenly. Meanwhile, several windows were fabricated on the end plates and distributors to make cathode ventilated to air. Figure 2 shows the design of the NINO flow field with an active area of 0.64cm^2, including photographs of micro-features fabricated in the flow channels, which are detailed as rectangle, semicircle, and triangle (represented by NINO-2 to 4).

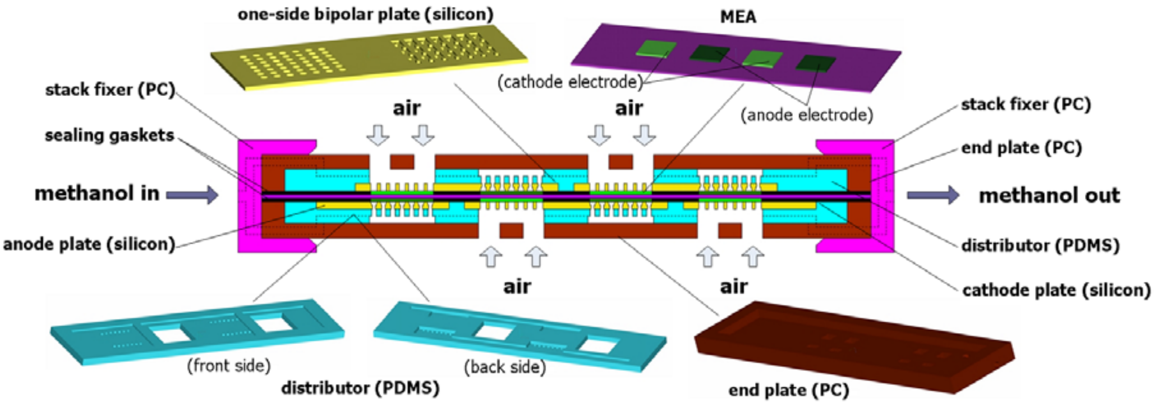

Fig. 1: Schematic of the μDMFC stack.

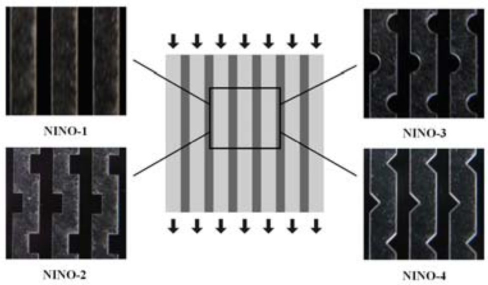

Fig. 2: Pictures of the NINO flow field structure and microfabricated micro-features.

SIMULATION

A three-dimensional model was established to study the four types of NINO flow fields. The transmission of methanol solution in the plate channel and diffusion layer takes two mass transports into account. Therefore, this model uses the convection - diffusion equation to describe the distribution of the amount of methanol in the channel and diffusion layer is described as

$$\nabla\cdot(-D\nabla c)=R-\mathrm{u}\nabla\cdot c \qquad (1)$$

C ——the methanol concentration $(mol\cdot m^{-3})$;

D ——coefficient of mass transfer $(m^2\cdot s)$;

u ——Vector speed $(m\cdot s^{-1})$

The flow of methanol solution in the flow channel is a kind of sheet flow, so we use Incompressible Navier-Stokes Equations to describe momentum transfer.

$$\rho\,\mathrm{u}\cdot\nabla\,\mathrm{u}=\nabla\left[-p+\eta\left(\nabla\,\mathrm{u}+(\nabla\,\mathrm{u})^T\right)\right]+\mathrm{F} \qquad (2)$$

$$\nabla\cdot u=0 \qquad (3)$$

ρ ——density $(kg\cdot m^{-3})$;

F ——Volume force (N) ;

η ——Dynamic viscosity

The diffusion layer is porous medium, and the momentum transfer of material in porous medium obeys Darcy's law:

$$\mathrm{u}=-\frac{\kappa}{\eta}\nabla p \qquad (4)$$

$$\nabla\cdot(\rho\,\mathrm{u})=0 \qquad (5)$$

κ ——permeability of porous materials (m^2)

Based on the 3D model, we have analyzed the impact of anode struture. Simulated results show that micro-features have a significant influence on the performance of an individual μDMFC, and the NINO-2 flow field exhibits the best in enhancing the mass transport and electrochemical reaction efficiency. Figure 3 shows different mass transport velocities of anode reactants in the porous diffusion layers ,that means the velocity distribution in the interface of the anode electrode and the anode diffusion layer of four differents kinds of flow structures. From the figure we can see that, triangle protrusion parallel flow field, semicircle and square protrusion parallel flow field appear more distinctly uneven distribution of velocity than the smooth parallel floor. Specifically, the velocity distribution is influenced by the protrusion in the floor seriously. Velocity field will be larger in the appropriate position which there is a protrusion in the floor channel, while its distribution shape will match the corresponding raised shape. Based on figure 3, square protrusion parallel flow field has more advantage than the other three flow fields in the distribution of velocity. The protrusion in the flow channel resulted in the uplift of the local laminar flow during the flow methanol solution, while the square bulge has the largest influence. Local laminar flow enables the solution to have greater disturbance, and thus strengthen the methanol solution in the diffusion of mass transfer, while reducing the concentration polarization.

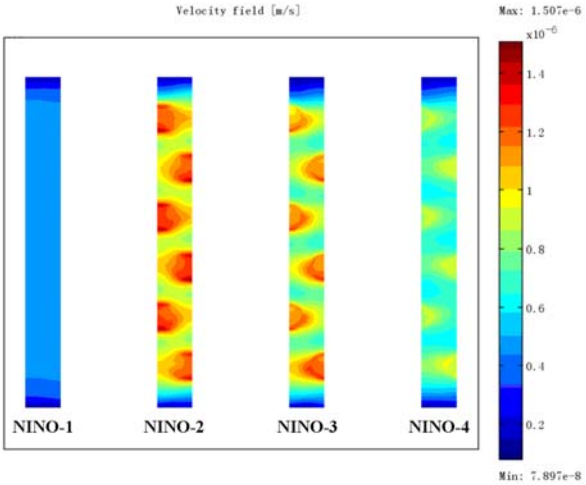

Fig.3: Simulated mass transport velocities of reactants in the porous anode.

FABRICATION AND ASSEMBLY

In this study, a μDMFC based on silicon was utilized in order to determine the optimal anode flow field. It consisted of two plates (anode and cathode) as current collectors and a membrane electrode assembly (MEA) between them, constructing a sandwich structure. The current collectors were manufactured following a series of MEMS fabrication steps including CVD, photolithography anisotropic etching and sputtering. Double-side fabrication process of the PDMS distributor is described in Figure 4. Two 2mm-thick stainless steel plates were first milled and cleaned, and then separately micromachined with the patterns. Afterwards, stainless steel plates were hot-embossed onto the 3mm-thick PMMA plates for 10 minutes, under the pressure of 2Mpa and the temperature 90℃ Then, a vacuumed 10:1 weight ratio PDMS elastomer and curing agent was poured into the face-to-face PMMA molds in a vacuum drying oven at 65℃After 1 hour, the PDMS distributor with double-side patterns was molded. At last, holes and windows were produced using the laser cutting technology.

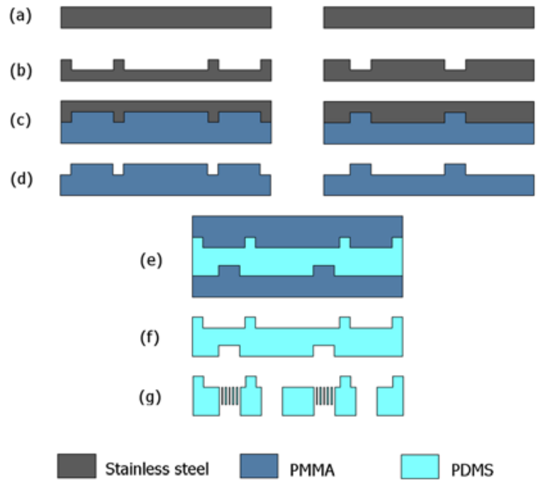

Fig. 4: Fabrication process of the PDMS distributor.

RESULTS

The assembled batteries are used for experiments. The concentration of the input methanol solution is 1mol/L and the input velocity is 0.05mL/min. Under the normal operating conditon, we test the voltage and electric current of the μDMFC.The air-breathing μDMFC stack with four different anode flow fields were tested and compared at room temperature. The experimental results are in accordance with the simulated ones that the stack with the NINO-2 flow field yielded better performance than those with the other flow fields, and the maximum power density generated was about 19.97mW/cm^2 as showed in Figure 5.

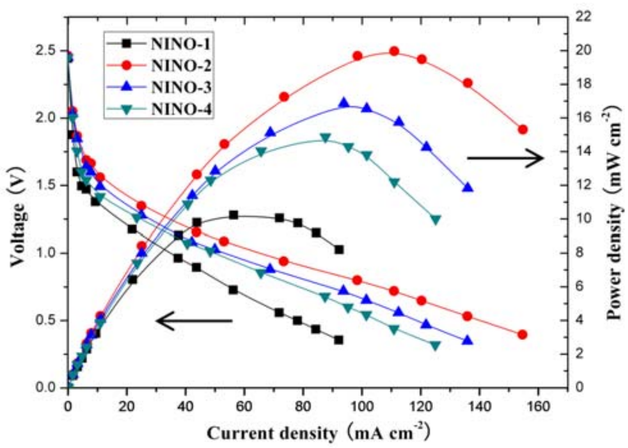

Fig.5: Performance curves of the μDMFC stack with different NINO flow fields.

CONCLUSION

In this paper the n-inlet and n-outlet smooth parallel flow field was first introduced, which is developed from traditional parallel flow field. Based on the n-inlet and n-outlet smooth parallel flow field, we came up with the other three kinds of parallel flow field: square protrusion parallel flow field, semicircle protrusion parallel flow field, and triangle protrusion parallel flow field. Afterwards, we established a model to simulate the four kinds of flow fields, the result of the stimulation shows that the square protrusion parallel flow field plate has the best performance. Finally we installed the four kinds of flow field on the direct methonal fuel cell respectively to test the performance of the four kinds of flow field and the result of the test conincided with the result of the simulation,which proved the validity of the model.Ultimately we apply the square protrusion parellel flow fields to the μDMFC.

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