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Investigation of Microchannel Based Fuel Cell

Ramandeep Singh[1], Randhir Singh[2], Parveen Lehana[3#]

M.Tech. Student, Dept. of ECE, Sri Sai College of Engineering & Technology, Punjab, India[1]

Associate Professor, Dept. of ECE, Sri Sai College of Engineering & Technology, Punjab, India[2]

Associate Professor, Dept. of Physics & Electronics, University of Jammu, Jammu, India[3]

ABSTRACT: Portable devices rely on battery systems that contribute largely to the overall device form factor and delay portability due to recharging. Microfluidic fuel cells are potentially cost effective and robust because they use low Reynolds number flow to maintain fuel and oxidant separation instead of ion exchange membranes. Current microfluidic fuel cell designs suffer from reactant cross-diffusion and thick boundary layers at the electrode surfaces, which result in a compromise between the cell's power output and fuel utilization. The fuel cells are tested over a wide range of conditions including variation of the loads.

KEYWORDS: Microfluidic, Fuel cell, PDMS, Power.

I. INTRODUCTION

A typical microfluidic fuel cell consists of a T- or Y-shaped microchannel. In such systems, the fuel and oxidant are introduced in the microchannel through the two separate inlets. The aqueous anolyte and catholyte solutions travel down the channel side-by-side forming a co-laminar flow between the anode and cathode which are typically positioned on the side walls along the channel. The laminar flow in the microfluidic fuel cells maintains the separation of the fuel and oxidant and thus plays a similar role to that of the solid membrane in PEMFCs. The invention of the microfluidic fuel cell in 2002 [1] based on this concept was a significant step forward in the development of the miniaturized fuel cells because this novel design overcomes the problems and limitations imposed by the traditional miniaturized PEMFCs with the solid membrane [2]. In addition to the technical benefits of the microfluidic fuel cell, there are some cost-related advantages. For instance, the cost of fabrication and maintenance associated with the membrane is also eliminated. Microfluidic fuel cells also benefit from using liquid fuels which have higher energy densities as opposed to the gaseous fuels used in typical PEMFCs [3]. As the anolyte and catholyte travel toward the outlet of the channel, the laminar nature of the flow prevents convective mixing of the two solutions and keeps the fuel and oxidant largely on their own sides of the channel. However, diffusion in a direction transverse to the flow creates a thin region around the liquid-liquid interface in the middle of the channel where the solution contains both fuel and oxidant. This region is called mixing region shown in Figure 1. The thinner the mixing region the better the performance of the device. A thin mixing region indicates better fuel/oxidant separation which provides each side (anode and cathode) with more available reacting species. In other words, the mixing region limits the amount of the reactants that can be potentially available to the electrodes. This also limits the extension of the electrodes from the wall toward the middle of the channel (which is desirable since it increases the active surface area) due to the cross-over issue (i.e., reactants reaching the wrong electrode) [8]. Basically, if the electrodes are extended to overlap with the mixing region, fuel crossover results in a mixed potential (which tends to lower the equilibrium electrode potential) at the cathode and hampers the fuel cell performance [4-5].

The transport of the reactants is predominantly by convection along the channel and mainly through diffusion across the channel. Thus, the mixing region thickness can be controlled by changing the fuel and oxidant flow rate which changes the relative rates of streamwise and transverse mass transport. This ratio of convective to diffusive mass transport is commonly quantified in terms of the Peclet number [6].

$$Pe = \frac{UH}{D}$$

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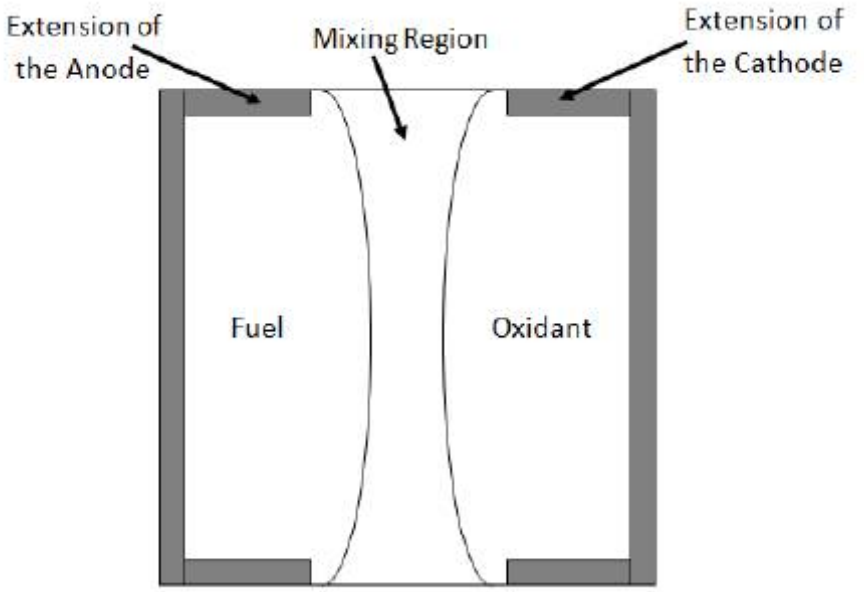

Fig. 1 The extension of the electrodes up to the point that they do not reach to the mixing region to avoid fuel crossover.

By increasing the inlet velocity, the Peclet number increases which means that the rate of the transverse diffusion is becoming much less than the streamwise convection. In other words, the time that the fuel/oxidant species are in diffusional contact is reduced. Thus, the reactants have less time to diffuse to the other side of the channel which leads to a thinner mixing region.

The mixing region is wider at the top and the bottom. This phenomenon is due to a lower velocity at the vicinity of the walls which increases the duration of the diffusional contact between the anodic and cathodic streams and causes the mixing region to take on an hourglass shape. The maximum width of the mixing region (δ) which occurs at the wall is experimentally demonstrated [18] to scale as the one-third power of the axial distance, x , along the channel and inversely as the one-third power of the average flow velocity. The following expression represents the calculated width of the diffusive mixing region at the walls of the fuel cell [18, 19]:

$$\delta \approx \left(\frac{DHx}{U} \right)^{1/3}$$

where, x represents the distance that the fluid travels down the channel, D, H and U are the diffusion coefficient, the height of the channel and the average flow velocity, respectively. The exact extent of this inter-diffusion interface can be theoretically quantified by solving the convection-diffusion equation for the steady-state transport of chemical species assuming that the Peclet number is high so the diffusion along the channel can be neglected compared to the convection [7-10].

II.METHODOLOGY

Experimental setup used is shown in Fig. 2 where alligator clip cables to hook the battery pack (which should be switched off), resistor, and reversible fuel cell in a circuit. The experiments were carried out with various load combinations. The experiment was further extended with microchannel integrated with Fuel cell setup. Portable vacuum system was designed to microchannel fabrication in PDMS shown in Fig. 3. 12 V power supply was provided to system and sample were placed inside the system to remove the bubbles from the PDMS syrup. A zigzag structure was placed inside the PDMS and structure was peeled off from PDMS. Microchannels formed over the surface of the PDMS were placed in the fuel cell and the experiments were carried out with same procedure.

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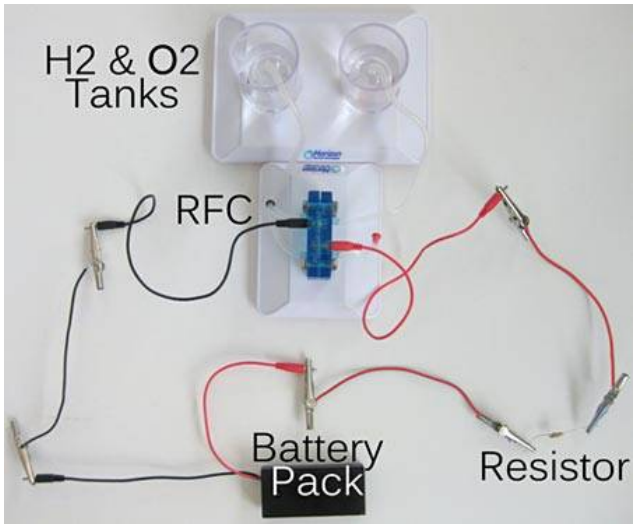

Fig. 2 Fuel cell setup.

Fig. 3 Portable vacuum system.

III. RESULT AND DISCUSSION

Investigations were carried out with various load resistance and system is run for 15 sec in each iteration. set of experiment microchannel fabricated over the surface of PDMS was inserted inside the fuel cell and experiment were carried out with 10 KΩ and 5 KΩ resistances. Table 1 and Table 2 shows the various electrical characteristics of microchannel based fuel cell with two different load resistance. Figure 4 shows the voltage drop across 10 KΩ and 5 KΩ load resistance. Fluctuation in the voltage drop across the load resistance is observed for initial time period and after 6 sec voltage stabilizes. Figure 5 shows the current flowing in the load resistance for 10 KΩ and 5 KΩ resistances. Also the power develop in the load resistance is shown in Fig. 6.

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Table 1 Electrical parameters across 10 KΩ load resistance.

Voltage (V)	I (µA)	Power (µW)
1.5	1.38	2.07
1.4	1.34	1.876
1.3	1.29	1.677
1.1	1.21	1.331
1.1	1.20	1.32
1.1	1.20	1.32
1.1	1.20	1.32
1.1	1.20	1.32
1.1	1.20	1.32
1.1	1.20	1.32

Table 2 Electrical parameters across 5 KΩ load resistance.

Voltage (V)	Current (µA)	Power (µW)
1.4	0.48	0.672
1.2	0.37	0.444
1.2	0.30	0.36
1.2	0.30	0.36
1.2	0.28	0.336
1.1	0.28	0.308
1.0	0.27	0.27
1.0	0.27	0.27
1.0	0.27	0.27
1.0	0.27	0.27

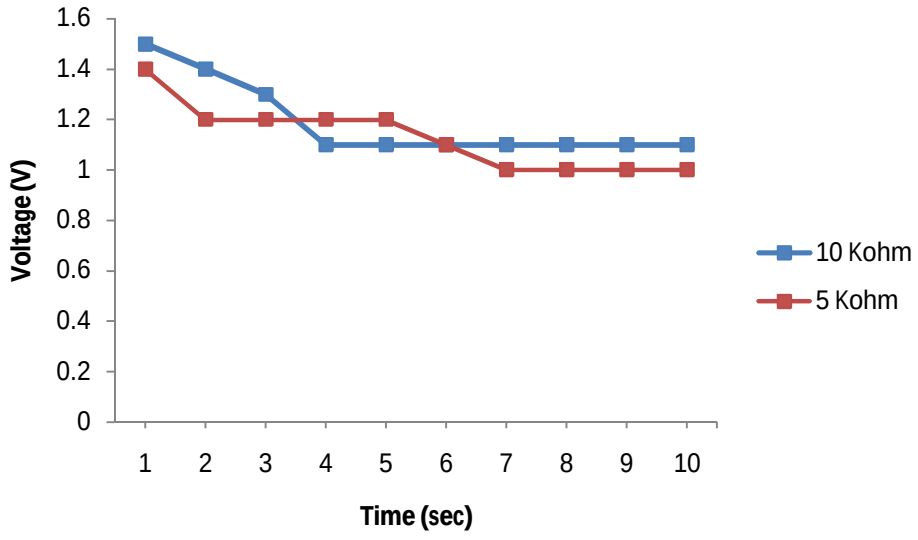

Fig. 3 Output voltage across load resistance

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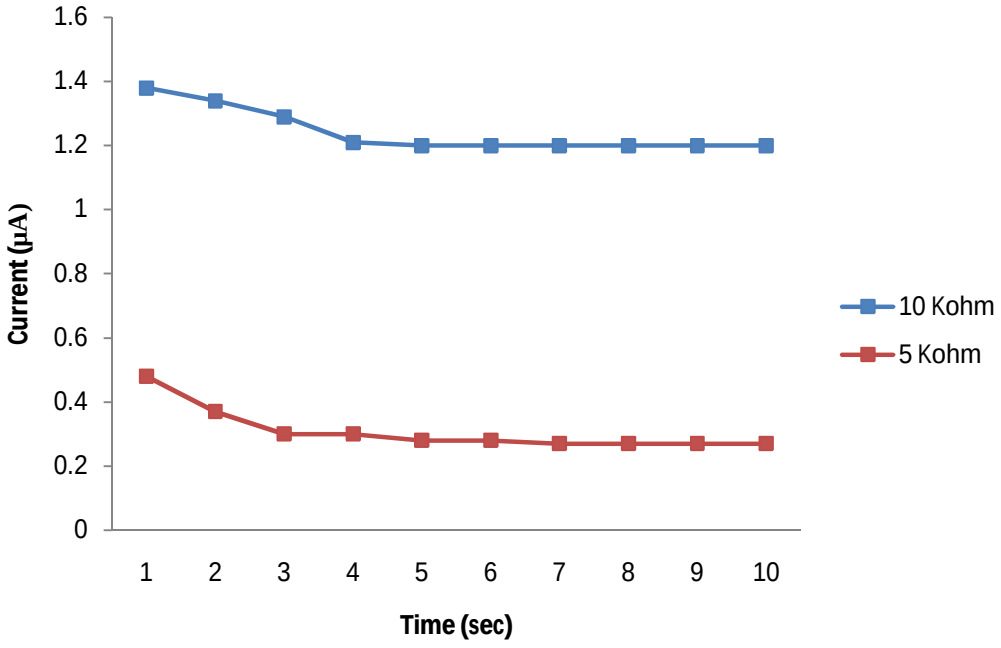

Fig. 4 Current flowing through load resistance

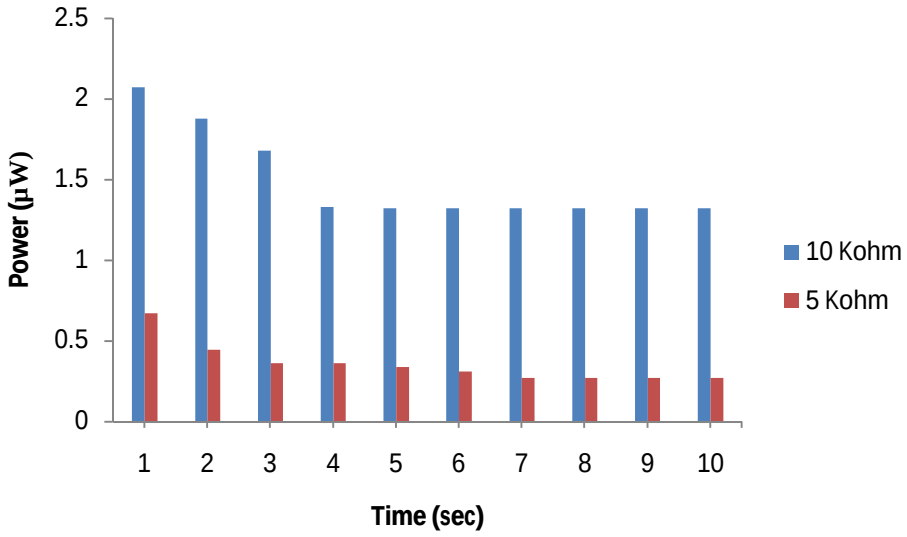

Fig. 6 Power at different interval of time.

IV.CONCLUSION

Microfulidic channel based fuel cells are next generation power sources. Experiments are carried to investigate the loading effect on microfludic fuel cell. PDMS based microchannels were fabricated ad integrated with hydrogen fuel cell. Two set of experiments were carried with load resistance 5 KΩ and 10 KΩ. Power computed for both the load shows that with higher value of load resistance high power was obtained.

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