International Journal of Applied Science and Engineering
2012. 10, 4: 273-280

Effects of Channel Depths and Anode Flow Rates on the Performance of Miniature Proton Exchange Membrane Fuel Cells

Dyi-Huey Chang[a,*] and Jung-Chung Hung[b]

[a]Department of Environmental Engineering and Management, Chaoyang University of Technology, Wufeng District, Taichung, Taiwan, R.O.C.
[b]Department of Mechanical Engineering, National Chin-Yi University of Technology, Taichung, Taiwan, R.O.C.

Abstract: This study examines the effects of channel depths and anode flow rates on the performance of miniature proton exchange membrane fuel cells. The flow field is a three-pass serpentine structure, of which both the rib and channel widths are 500 μm and the channel depths are varied as 200, 400 and 600 μm, in a reaction area of 4cm^2. During the test, this study assemblies a cell with the carbon-paper membrane electrode assembly (MEA). The performance of the cell is evaluated based on three different channel depths with varying anode flow rates. The impact of MEA deformation is also examined. The results indicate that the impacts of MEA deformation might not be significant for a cell with sufficient channel depth. For all tests, the cell with median channel depth (400μm) yields best results. The cell with shallower channel depth prefers high flow rate because a higher flow rate can provide sufficient pressure to force the reactant to pass through channels in small cross-sectional area. The cell with deeper channel depth prefers low flow rate. This is because deeper channel depth does not require higher pressure to force the reactant to pass through channels. Instead, too high flow rate excessively increases flow velocity, which upsets the water balance in MEA and decreases cell performance.

Keywords: Metallic bipolar plate; MEA; fuel cell; channel depth.

1. Introduction

Fuel cells are a promising power technology due to their compactness, silent operation, high power density, and nearly no pollution. Among various types of fuel cells, the proton exchange membrane fuel cell (PEMFC) is a promising alternative to lithium-ion batteries because of its low-temperature operation suitable for portable electronic devices [1]. A significant knowledge base exists that focuses on development of high-efficiency PEMFCs [2-14]. It is generally agreed that the flow-channel geometric parameters have strong influence on the performance of PEMFCs.

Various simulation studies have been conducted on the effects of flow-channel geometric parameters on cells with diverse reactive areas. Simulation results of a 130 cm^2 cell predicted that narrow channels are preferable for high current densities, whereas wider channels are favored at low

---

* Corresponding author; e-mail: changdh@cyut.edu.tw

Received 3 June 2012
Revised 29 August 2012
Accepted 17 October 2012

current densities [15]. Modeling results of a 200 cm^2 cell indicated that the flow-channel path length and other channel geometric dimensions affect cell performance [11; 16]. They also found that too deep channel depth tend to reduce the local gas pressure, leading to variances in fuel distributions. Simulation results of channel depths in a 24.6 cm^2 cell revealed that the performance of a PEMFC with a serpentine flow channel is insensitive to channel depth in certain operation conditions [4]. Investigations on the effects of the aspect ratio (defined as the ratio of channel depth to width) on the performance of a 2.56 cm^2 miniature cell indicated that cells with a high aspect ratio yield higher current densities [17]. This result differs from other simulation results, in which channel depth had no significant effects [4; 7]. This disagreement may result from the differences in channel scales. Deeper channel depths provide sufficient space for reactant transportation and water removal. However, it also enlarges the channel cross-sectional area and slow down flow velocity, which subsequently affects mass transfer rate and water balance in the membrane electrode assembly (MEA) [18].

Although numerous papers explore flow-channel geometric variables using simulation, few papers have experimentally examined this issue, especially in miniature scale. It is more challenging to experimentally examine the effects of flow-channel geometric parameters on efficient miniature fuel cells. One of the reasons is that the preparation of tools for fabricating various channel dimensions is time consuming. Based on our previous study of fabricating micro-flow channels in bipolar plates [19], this study examines the effects of channel depths and anode flow rates on the performance of miniature PEMFCs. The flow field is a three-pass serpentine structure, of which both the rib and channel widths are 500 um in a reaction area of 4 cm^2. The performance of the cell is evaluated based on three different channel depths (200, 400 and 600 μm) and various anode flow rates (40, 60 and 80 cc min^{-1}).

2. Methodology

2.1. The fabrication of bipolar plates

In this study, the stainless steel SUS316L was chosen as the plate material because of its excellent heat and corrosion resistance. Serpentine flow field was adopted as the flow design because of its excellent drainage characteristics and cell performance [2; 20]. As shown in Figure 1, the rib and channel widths are 500 um and the channel depths are varied as 200, 400 and 600 μm, in a reaction area of 4cm^2. The open area rate (defined as the ratio of channel area to reaction area) is 53.3 %. Larger open area rate increases the reaction space between fuel and MEA, but also increase the contact resistance because of insufficient rib area. Generally, the open area rate falls between 50 and 85%.

This study applied die-sinking micro-EDM to fabricate metallic bipolar plates. Micro-EDM is a thermal process that uses electrical discharges to erode electrically conductive materials. The maximum aspect ratios of this process associated with various tool pieces range from 10 to 100, and the minimum feature size ranges from 3 to 30 μm [21]. Die-sinking micro-EDM is an area-processing technique, in which a cubic electrode is used and the processing path is a single direction.

2.2. The MEA compression test

In a PEMFC, usually a strong clamping force is required to prevent the leakage of reactants and to reduce the contact resistance between MEA and bipolar plates. However, the clamping force also protrudes the MEA into the channel, clogging the reactant flow and water removal. Such deformation might limit the channel space and affect the performance of fuel cells. This study explored deformation of MEA through the MEA compression test. During the test, a bipolar plate with channel depth of 600 μm was fabricates, as shown in Figure 2(a). In order to measure the magnitude of deformation, the bipolar plate is cut into half using wire machine and assembled to become a "half-cell", as shown in Figure 2(b). The clamping torques ranging from 10 to 25 kgf-cm were applied to the half-cell to measure the MEA deformation.

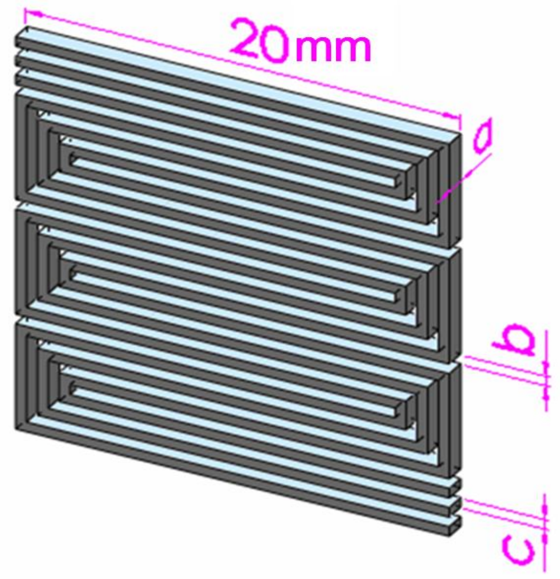


Figure 1. Schematic representation of the flow design: (a) channel depth = 200, 400 and 600 μm, (b) rib width = 500μm, and (c) channel width = 500μm

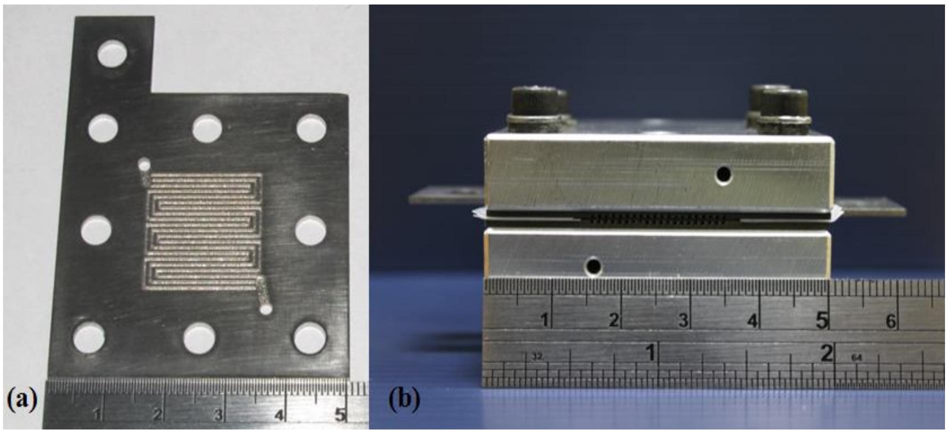


Figure 2. (a) SUS316L bipolar plates; (b) MEA compression test

2.3. The performance of PEMFC

The metallic bipolar plates with various channel depth were tested for cell performance using the surveying instrument TEI-P300-1AB2CS. During tests, this study assembled a single cell 50×50×23 mm in dimension, as shown in Figure 3(a). The cell was fabricated with end plates, gaskets, bipolar plates, and MEA, as shown in Figure 3(b). Table 1 shows the cell specifications.

The MEA comprised a proton exchange membrane (PEM) and two gas diffusion electrodes (GDE) with 0.25 mg cm^{-2} Pt for both the anode and cathode. Pure hydrogen and oxygen were supplied to the anode and cathode electrodes. The anode flow rates are varied as 40, 60, 80 cc min^{-1}; and cathode flow rate is fixed at 60 cc min^{-1}. The clamping torque is fixed at 20 kgf-cm. The cell operation is under the pressure of 1 atm at room temperature without gas humidification.

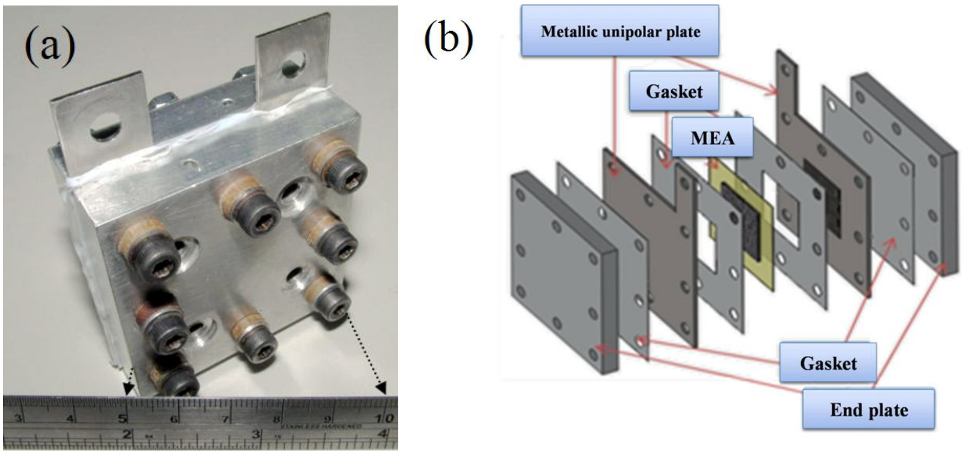


Figure 3. (a) Assembled cell; (b) the schematic representation of cell assembly

Table 1. Cell specifications

Part	Specification
PEM	DuPont NRE212 Dimension: 30×30×0.05 mm
GDE	Pt 0.4mg/cm^2 Reaction area: 20×20 mm Dimension: 23×23×0.3 mm
Metallic bipolar plate	Stainless steel SUS316L Dimension: 50×50×1 mm
Clamping torque	20kgf-cm
Gasket	PTFE film Dimension: 50×50×0.15 mm
End plate	Aluminum Dimension: 50×50×10 mm

3. Results and discussion

3.1. The MEA compression test

This test is based on a carbon-paper MEA of 0.4 mm in thickness. As shown in Figure 4, for the clamping torque of 10 kgf-cm, the minimum thickness of MEA is 0.355 mm and the maximum is 0.375mm. About 10 μm (=(0.375-0.355)/2 ×1000) of MEA is protruded into both anode and cathode flow channels. In a similar manner, about 23, 33, and 29 μm of MEA is extruded to the channels for the clamping torques of 15, 20, and 25 kgf-cm, respectively. It is interesting to note that the extrusion of MEA is slightly more serious using 20 kgf-cm of clamping torque than that with 25 kgf-cm of clamping torque. This is because the deformation of MEA has achieved to its extreme with the clamping force of 20 kgf-cm for the parts touching the rib while the parts exposed to the channel still can be compressed with higher clamping force.

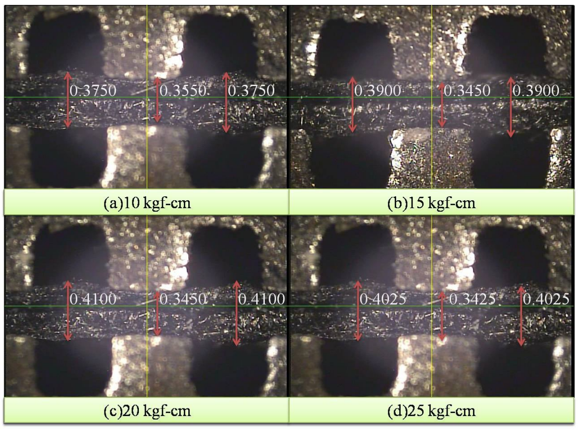
3.2. The effects of anode flow rates

Figure 5 shows the cell performances for different anode flow rates. The effects of channel dimensions were examined with respect to the anode flow rates of 40, 60, and 80 cc min^{-1}. For all tests, the peak power density falls between 570 to 602 mW cm^{-2}. As shown in Figure 5(a) for the 200 μm channel depth, the peak power density through the 80 cc min^{-1} anode flow rate is 590 mW cm^{-2}, slightly better than those with lower flow rates. It indicates that shallow channel depth prefers high flow rate because a higher flow rate can provide sufficient pressure to force the reactant to pass through channels of such a small cross-sectional area.

In contrast, deeper channel depth prefer low flow rate. As shown in Figure 5(c) for the channel depth of 600 μm, the peak power density of the flow rate of 40 cc min^{-1} is 596 mW cm^{-2}, witch outperforms those with higher flow rates. This is because deeper channel depth does not require higher pressure to force the reactant to pass through channels. Instead, applying a higher flow rate excessively increases flow velocity, which upsets the water balance in MEA and decreases cell performance. Although a higher flow velocity also improves convective mass transport, our result indicates that this effect is less significant than the water-balance effect in a miniature fuel cell. Figure 5(b) reveals the evolution of different effects of anode flow rate appearing in Figure 5(a) and 5(c).

3.3. The effects of channel depths

Figure 6 rearranges Figure 5 to set channel depths as comparable variables, The effects of channel dimensions were examined with respect to the anode flow rates of 40, 60, and 80 cc min^{-1}. In general, the impacts of MEA deformation might not be significant for all cases, because there was no limiting current density in all polarization curves. The performance of cell with 200 μm channel depth tends is generally worse than those of other cells, regardless of different anode flow rates. This is because the too fast flow velocity from small cross-section area results in insufficient reaction time. In addition, the smaller cross-section area may limit water removal. In contrast too deep channel depth requires longer path for vertical flow. As a result, medium channel depth (400μm) yields best cell performance.



(a)10 kgf-cm (b)15 kgf-cm

(c)20 kgf-cm (d)25 kgf-cm

Figure 4. The deformation of compressed MEA

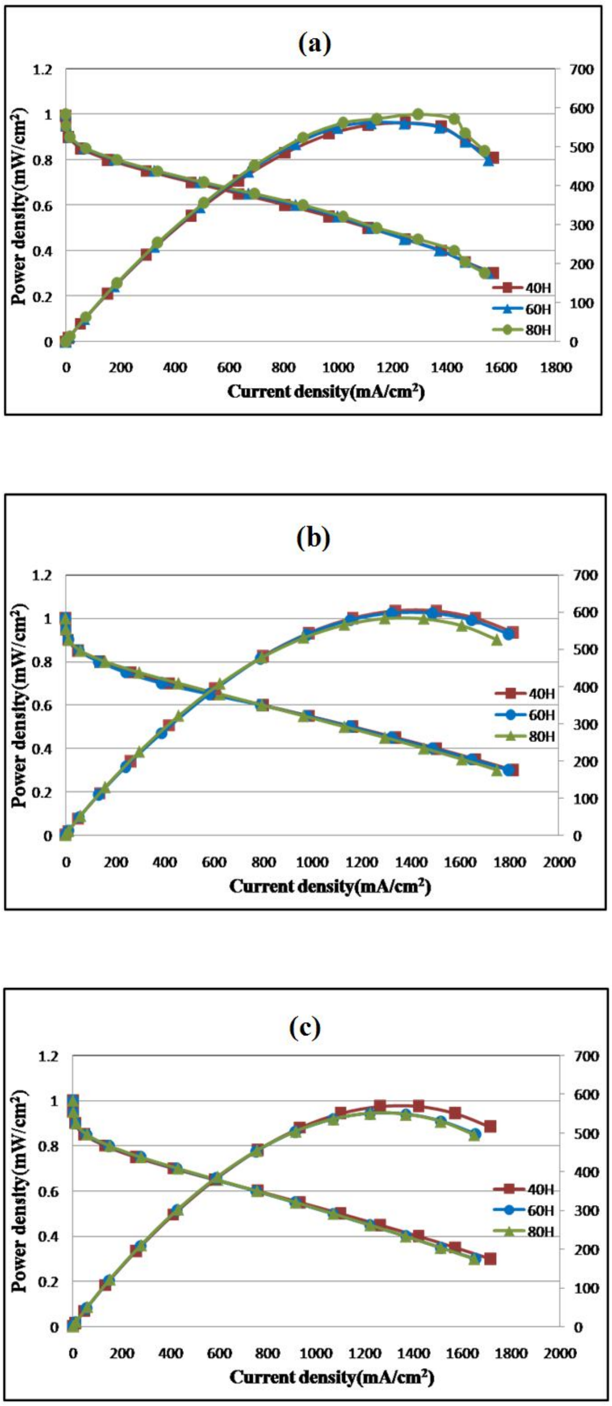


Figure 5. The I-V and I-P plots of various channel depth: (a)200, (b)400, and (c)600 μm, where 40H, 60H and 80H represent the anode flow rates of40, 60, and 80 cc min-1, respectively

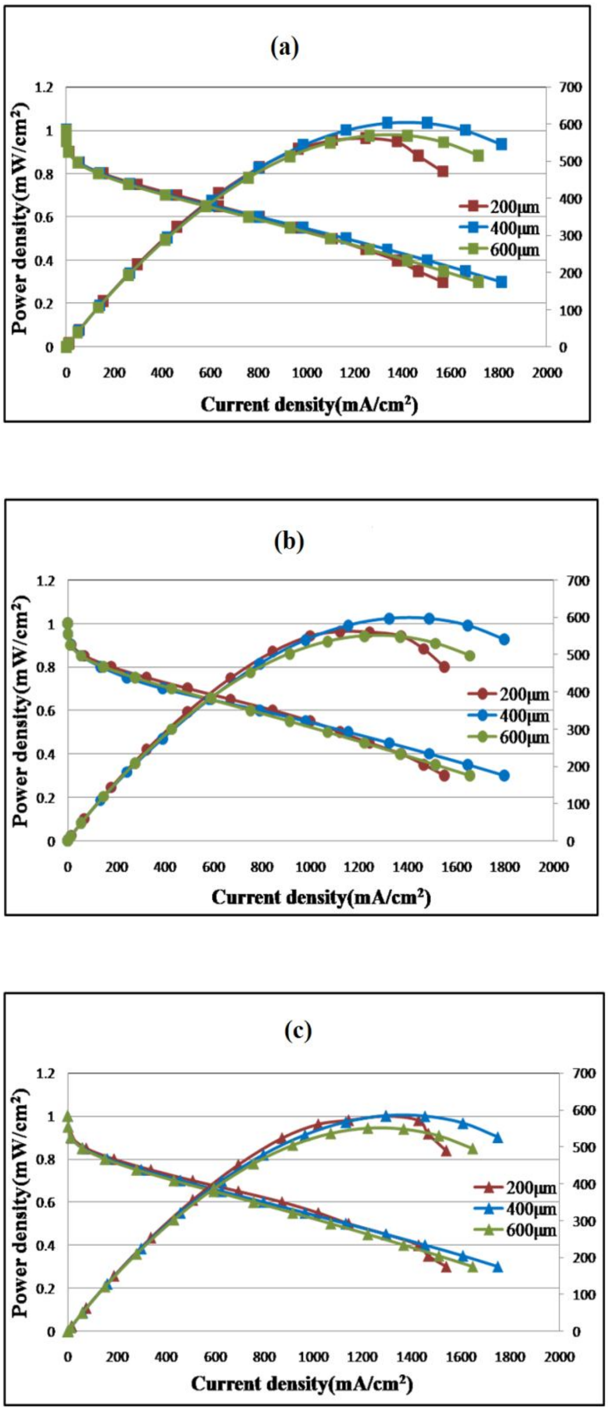


Figure 6. The I-V and I-P plots of various anode flow rates: (a)40, (b)60, and (c) 80 cc min-1

4. Conclusion

This study used die-sinking micro EDM to prepare micro flow channels in metallic bipolar plates. The effects of channel depth and anode flow rate on the performance of PEMFC are examined and discussed. Our conclusions are as follows:

The peak power density falls between 570 to 602 mW cm^{-2} for all tests, demonstrating the excellent performance of fuel cell with micro metallic plates. For the MEA compression test, the MEA extrusions into channel space are about 10 to 33 μm for various clamping torques. The impacts of MEA deformation might not be significant for a cell with sufficient channel depth. Fuel cell with shallow channel depth prefer high anode flow rate; and the cell with deep channel depth prefer low anode flow rate.

In spite of anode flow rate, medium channel depth (400μm) yields best cell performance.

References

[1] Tawfik, H., Hung, Y., and Mahajan, D. 2007. Metal bipolar plates for PEM fuel cell-A review. *Journal of Power Sources*, 163: 755-67.

[2] Aricò, A. S., Cretì, P., Baglio, V., Modica, E., and Antonucci, V. 2000. Influence of flow field design on the performance of a direct methanol fuel cell. *Journal of Power Sources*, 91: 202-9.

[3] Choi, K. S., Kim, H. M., and Moon, S. M. 2011. Numerical studies on the geometrical characterization of serpentine flow-field for efficient PEMFC. *International Journal of Hydrogen Energy*, 36: 1613-27.

[4] Ferng, Y. M. and Su, A. 2007. A three-dimensional full-cell CFD model used to investigate the effects of different flow channel designs on PEMFC performance. *International Journal of Hydrogen Energy*, 32: 4466-76.

[5] Higier, A. and Liu, H. 2010. Optimization of PEM fuel cell flow field via local current density measurement. *International Journal of Hydrogen Energy*, 35: 2144-50.

[6] Hsieh, S. S. and Chu, K. M. 2007. Channel and rib geometric scale effects of flowfield plates on the performance and transient thermal behavior of a micro-PEM fuel cell. *Journal of Power Sources*, 173: 222-32.

[7] Inoue, G., Matsukuma, Y., and Minemoto, M. 2006. Effect of gas channel depth on current density distribution of polymer electrolyte fuel cell by numerical analysis including gas flow through gas diffusion layer. *Journal of Power Sources*, 157: 136-52.

[8] Jeon, D. H., Greenway, S., Shimpalee, S., and Van Zee, J. W. 2008. The effect of serpentine flow-field designs on PEM fuel cell performance. *International Journal of Hydrogen Energy*, 33: 1052-66.

[9] Kumar, A. and Reddy, R. G. 2003. Effect of channel dimensions and shape in the flow-field distributor on the performance of polymer electrolyte membrane fuel cells. *Journal of Power Sources*, 113: 11-8.

[10] Lobato, J., Cañizares, P., Rodrigo, M. A., Pinar, F. J., Mena, E., and Úbeda, D. 2010. Three-dimensional model of a 50 cm2 high temperature PEM fuel cell. Study of the flow channel geometry influence. *International Journal of Hydrogen Energy*, 35: 5510-20.

[11] Shimpalee, S. and Van Zee, J. W. 2007. Numerical studies on rib & channel dimension of flow-field on PEMFC performance. *International Journal of Hydrogen Energy*, 32: 842-56.

[12] Wang, X. D., Yan, W. M., Duan, Y. Y.,

Weng, F. B., Jung, G. B., and Lee, C. Y. 2010. Numerical study on channel size effect for proton exchange membrane fuel cell with serpentine flow field. *Energy Conversion and Management*, 51: 959-68.

[13] Yoon, Y. G., Lee, W. Y., Park, G. G., Yang, T. H., and Kim, C. S. 2004. Effects of channel configurations of flow field plates on the performance of a PEMFC. *Electrochimica Acta*, 50: 709-12.

[14] Yoon, Y. G., Lee, W. Y., Park, G. G., Yang, T. H., and Kim, C. S. 2005. Effects of channel and rib widths of flow field plates on the performance of a PEMFC. *International Journal of Hydrogen Energy*, 30: 1363-6.

[15] Scholta, J., Escher, G., Zhang, W., Küppers, L., Jörissen, L., and Lehnert, W. 2006. Investigation on the influence of channel geometries on PEMFC performance. *Journal of Power Sources*, 155: 66-71.

[16] Shimpalee, S., Greenway, S., and Van Zee, J. W. 2006. The impact of channel path length on PEMFC flow-field design. *Journal of Power Sources*, 160: 398-406.

[17] Manso, A. P., Marzo, F. F., Mujika, M. G., Barranco, J., and Lorenzo, A. 2011. Numerical analysis of the influence of the channel cross-section aspect ratio on the performance of a PEM fuel cell with serpentine flow field design. *International Journal of Hydrogen Energy*, 36: 6795-808.

[18] O'Hyre, R., Cha, S. W., Colella, W., and Prinz, F. B. 2009. "*Fuel Cell Fundamentals*". New York: John Wiley & Sons.

[19] Hung, J. C., Chang, D. H., and Chuang, Y. 2012. The fabrication of high-aspect-ratio micro-flow channels on metallic bipolar plates using die-sinking micro-electrical discharge machining. *Journal of Power Sources*, 198: 158-63.

[20] Tüber, K., Oedegaard, A., Hermann, M., and Hebling, C. 2004. Investigation of fractal flow-fields in portable proton exchange membrane and direct methanol fuel cells. *Journal of Power Sources*, 131: 175-81.

[21] Rajurkar, K. P., Levy, G., Malshe, A., Sundaram, M. M., McGeough, J., Hu, X., Resnick, R., and DeSilva, A. 2006. Micro and Nano Machining by Electro-Physical and Chemical Processes. *CIRP Annals - Manufacturing Technology*, 55: 643-66.