# Micro Fuel Cell Performance with Segmented Contacts Attached to Gas Diffusion Layer

P. Ramesh [1*],S.P.Duttagupta[2] , A. Soman[3] ,N.G. Thoppan[4] and V.Sukumaran[5]
IIT Bombay[1,2], College of Engineering Munnar[3,4,5]
*Department of Electrical Engineering, IIT Bombay, 400006

**Abstract:** Proton exchange membrane fuel cells (PEMFCs) are very promising for both mobile and mid-power stationary applications. One of the key component of fuel cells is the flow field plate through which hydrogen fuel will reach the anode and oxygen reach the cathode. Another function of the flow field plate is the electron collection. Traditionally flow field plates are made of graphite which makes them good for current collection. But with the development of miniature fuel cells, authors have reported flow field plates in silicon and other technologies such as PCB.As silicon is not a good electrical conductor, electrical contacts has to be attached to the Gas Diffusion Layer (GDL) for taking the power to outside world. This is achieved by attaching segmented contacts to the GDL area which are not covered my flow plates. Here we build a three dimensional model for a fuel cell in which current collection is carried out by segmented contacts attached to the GDL. Seven different ways of attaching contacts to the GDL is studied. The results were compared with a fabricated un segmented cell .The 3-D model was done using Comsol Multiphysics

**Keywords:** PEM Fuel cell; 3-D modeling; Segmented contacts;Gas Diffusion layer; Membrane Electrode Assembly.

## 1. Introduction

Fuel cells [1] are emerging as the power sources of the future. PEM fuel cell [2] are the most popular type of fuel cells which use hydrogen as the fuel. The necessary improvements for fuel cell operation [3] and performance demands better design and optimization. These issues can be addressed easily if mathematical models[7][9][10] are available. Traditionally the flow field plates are made of graphite and the current collection is carried out from the flow field plates. But in literature, many authors [4][5][6] have reported building micro fuel cells, where the flow field plates are also made of silicon. In this case, the current collection cannot be carried out from the flow field plates. So electrical contacts have to be attached to the Gas diffusion layer for tapping power from the fuel cell. Eight different ways of attaching electrical contacts for tapping power are discussed and compared.

## 2. Governing Equations for the Fuel Cell Model

Mass conservation or continuity equation tells that the change of mass in a unit volume must be equal to the sum *of* all species entering or exiting the volume in a given time period. This law applies to the flow field plates, GDL and the catalyst layer. Momentum conservation relates net rate of change of momentum per unit volume due to convection, pressure, viscous friction and pore structure. This law applies to the flow field plates, GDL and the catalyst layer.

Species conservation relates the net rate of species mass change due to convection, diffusion and electrochemical reaction. The most commonly used one is the Stefan-Maxwell diffusion equation.

Charge conservation corresponds to the continuity of current in a conducting material. This is applied to the GDL, catalyst layer and the membrane.

## 3. The Model

A 3 dimensional model[8] of a PEM fuel cell is implemented using COMSOL Multiphysics. The present model is established based on the following assumptions:

- Flow is laminar everywhere due to small gas pressure gradient.

- Reactant gases behave as the ideal gas mixture.
- The electrodes and membrane are made of homogeneous materials.
- The temperature distribution across the cell is uniform.
- Water exists only in the gas phase in the fuel cell.
- The polymer electrolyte membrane is impermeable to reactant gases.
- Protons can only transport through the electrolyte, and electrons through the solid phase.
- Three species including oxygen, water and nitrogen are considered on the cathode side while only hydrogen and water are considered on the anode side.
- The fuel cell is operating at the steady state.

The following are the operating conditions of the model.

- Cell length (L) 0.02m
- Channel height 0.001m
- Channel width 0.7mm
- Rib width 0.9mm
- GDL width 0.3mm
- Porous Electrode Thickness 0.5mm
- Membrane Thickness 0.05mm
- DL Porosity 0.4
- DL Electric Conductivity 1000S/m
- Inlet $H_2$ mass fraction (anode) 0.743
- Inlet $H_2O$ mass fraction (cathode) 0.023
- Inlet oxygen mass fraction (cathode) 0.228
- Anode inlet flow velocity 0.2m/s
- Cathode inlet flow velocity 0.5m/s
- Anode viscosity 1.19E5Pa.s
- Cathode viscosity 2.46E5Pa.s
- Permeability (porous electrode)2.36E-12 $m^2$
- Membrane conductivity 10 S/m

Seven different ways of connecting contacts to GDL is analyzed in the current study.3-D models for all the seven schemes were also developed. TABLE 1 shows the various schemes of current collection.

L is the length of the cell. The width and height of all the contacts remain the same. Figure 1 shows the structure of the model with nine contacts on the anode side and one contact in the cathode side.

TABLE 1: SCHEMES OF CURRENT COLLECTION

| Case | No of contacts (anode side) | Total Length of contact (anode side) | No of contacts (anode side) | Total Length of contact (anode side) |
|---|---|---|---|---|
| 1 | 3 | 0.66 L | 3 | 0.66 L |
| 3 | 4 | 0.5 L | 4 | 0.5 L |
| 4 | 5 | 0.625 L | 5 | 0.625 L |
| 6 | 5 | 0.625 L | 1 | L |
| 7 | 8 | 0.5 L | 1 | L |
| 8 | 9 | 0.41 L | 1 | L |
| 9 | 8 | 0.4 L | 1 | L |
| 10 | 9 | 0.375 L | 1 | L |

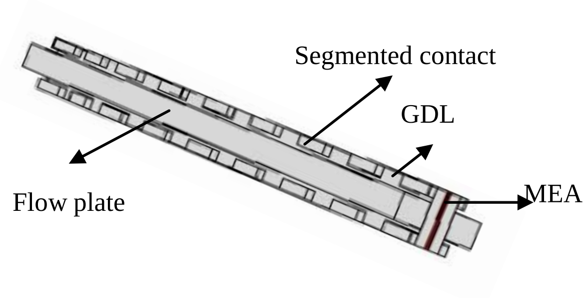


**Figure 1**. The schematic of pem fuel cell model with 9 contacts

## 4. Results

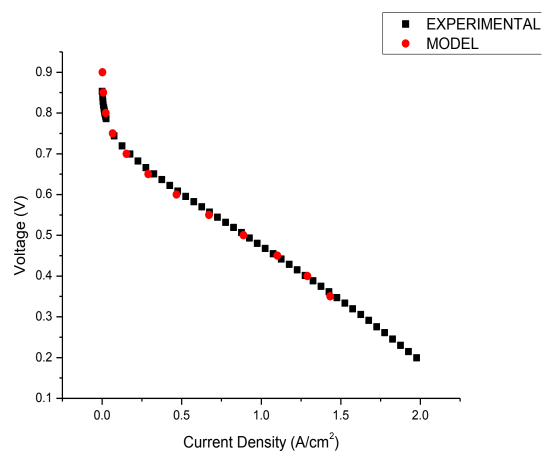


**Figure 2.** Polarization plot for experimental and modelling results

.

Figure 3 shows the electrode potential profiles along the line in the cathode electrode below the segmented contacts for two cases from table 1. As can be seen from the graph potential variation depends on the applied potential and the inter-contact distance. Increase in electrode potential with increase in inter-contact distance results in local decrease in over potential resulting in the lower current density which is more pronounced at higher applied potential. As the number of contacts is increased and inter-contact distance is reduced the electric potential becomes more uniform as can be seen from figure 3.

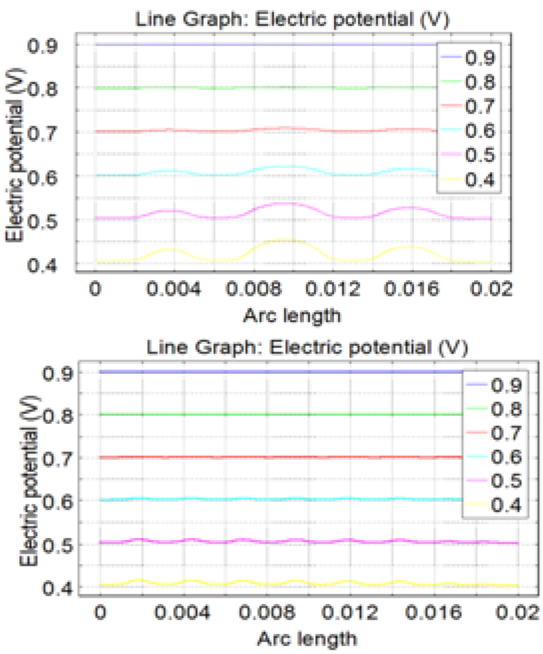


**Figure 3.** Electric potential variation along the length (a) case 1 on the top, (b) case 8 on the bottom.

Figure 4 shows the oxygen mass fraction variation in GDL below the contacts. Apart from the decrease in the mass fraction towards the outlet, peaks are observed below the gaps in the contacts which indicates the lower current density regions. Although the total contact length is same in both cases 1 and 3, the overall lower mass fraction in case 1 amounts to slightly higher performance of the fuel cell. No peaks are observed in case 8 due to small inter-contact distance.

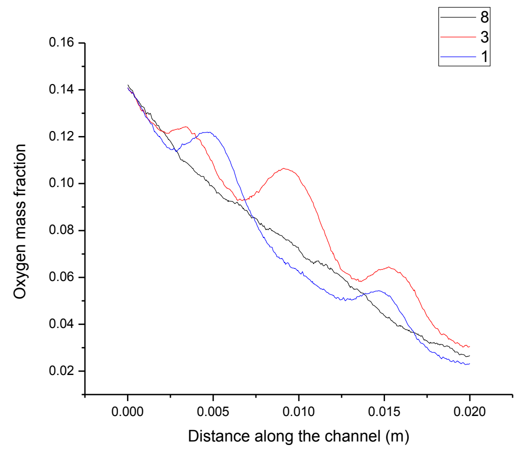


**Figure 4.** Mass fraction variation along the length in GDL

From Figure 5 it is clear that the performance of the cell gets degraded when segmented contacts are used. The effects are prominent in middle and high current ranges. The cell in case 3 having largest contact length has poor performance while the cell in case 8 having smaller contact length has performed better. This shows that the distribution of contact is more important than the length of the contact. Not much difference is observed in case of cells in case of 6,7,8,9 and 10 which shows that there exist critical number and length of contact above which the performance is independent.

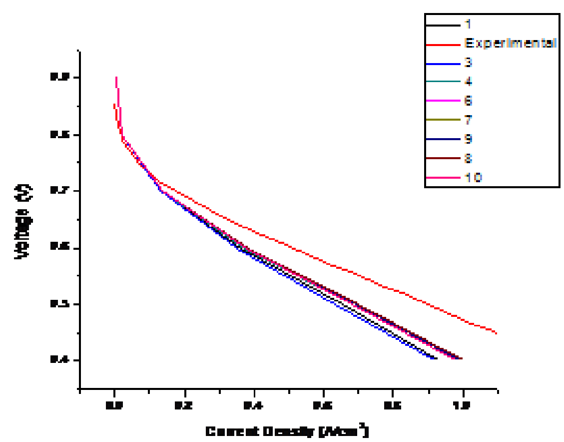


**Figure 5.** Performance curves for the cases in Table1

## 5. Conclusions

A 3-dimensional model for PEM fuel cell is validated under the experimentally feasible assumptions. The effect of segmented contacts on the fuel cell performance is studied by considering eight different cases employing different distributions and dimensions. The gaps between the contacts reduce the local over potential in the electrode reducing the local current density. Reducing the gaps by segmentation reduce this effect. It is also observed that the dimension of the contacts are not playing a big role in fuel cell performance while the distribution of contacts across the GDL has a significant impact in fuel cell performance.

## 6. References


1. B Viswanathan, M Aulice Scibioh. FUEL CELLS Principles and applications. Chennai: University Press , 2006.

2. Ryan O Hayre, Suk Won Cha,Whitney Collela,Fritz B Prinz. Fuel Cell Fundamentals. New york: John Wiley and sons, 2005.

3. T.S.Zhao, K.D Kreur .Trung Van Nguyen. Advances in Fuel cells. Great Britain: Elsevier, 2007.

4. C.Xie, J.Bostaph,J.Pavio. "Development of a 2W direct methanol fuel cell power source." Journal of power sources 136 (2004): 55-65.

5. Zhen Guoa, Amir Faghri. "Development of planar air breathing direct methanol fuel cell stacks." Journal of power sources 160 (2006): 1183-1194.

6. SStefan Wagner Roger Hahn, H. R. (2003). *Development of Micro Fuel cells with MEMS.* Geramny: MINATEC

7. Adrew Rowe, Xianguo Li. "Mathematical modeling of proton exchange membrane fuel cells." Journal of power sources (2001): 82-96.

8. S Dutta, S shimpalee ,J W Van Zee. "Three Dimensional numerical simulation of straight channel PEM Fuel Cells." Journal of Apllied Elecrochemistry (2000): 135-146.

9. Sukkee Um, C Y Wang , K S Chen. "Computational Fluid Dynamics Modelling of Proton Exchange Membrane Fuel Cells." Journal of the Electrochemical society (2000): 4485-4493.

10. Vladimir Gurau, Hongtan Liu, Sadik Kakac. "Two Dimensional model for proton exchange membrane fuel cells." AIChE Journal (1998): 2410-2422.

11. E. Bradley Easton, P. G. (2005). An electrochemical impedance spectroscopy study of fuel cell electrodes. *Electrochimica Acta* , 2469–2474.


## 9. Acknowledgements


We acknowledge the MCL lab of IIT Bombay for allowing us to use COMSOL Multi Physics.