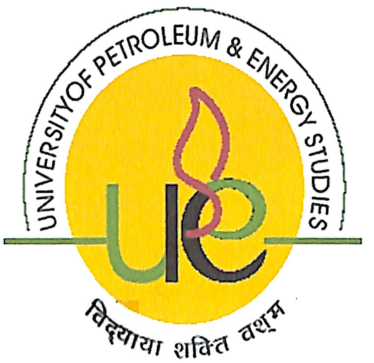
SMALL FUEL CELL FOR PORTABLE ELECTRONIC EQUIPMENT

By
NIKIL SRIDHAR



College of Engineering
University of Petroleum & Energy Studies
Dehradun
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SMALL FUEL CELL FOR PORTABLE ELECTRONIC EQUIPMENT

(A thesis submitted in partial fulfillment of the requirements for the Degree of Master of Technology
(Refining & Petrochemical Engineering)

By
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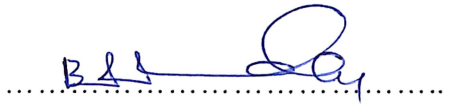
A Project of

International Advanced Research for Powder and Metallurgy

Medavakkam, Chennai

Approved



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CERTIFICATE

This is to certify that the work contained in this thesis titled "Small Fuel Cell for Portable Electronic Equipments" has been carried out by Mr. Nikil Sridhar under the supervision of Dr. G.Velayutham, K.S.Dhathathreyan and myself and has not been submitted elsewhere for a degree.

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ABSTRACT

Recently, there has been great interest in the use of miniature/micro fuel cells as replacements for batteries for portable applications. In the conventional fuel cell, graphite plates have been used for current collector-cum-gas distributor plates. This increases the size of the small fuel call. Also, making micro channel on the plate is difficult. In the present study Printed Circuit Board (PCB) has been used in place of graphite as current collector-cum-gas distributor plates for both anode and cathode. Two different types of cells, namely rectangular and circular type configuration were evaluated. For the anode, forced flow is used for both the configurations. For the cathode, the oxygen required by the electrochemical reaction is taken directly from the surrounding air by diffusion and/or natural convection. Dry hydrogen is used for all the experiments. The small Polymer Electrolyte Membrane Fuel Cell (PEMFC) was connected to various portable electronic equipments and their behavior is discussed here. The present study shows that the fuel cell with circular shape has performed better compared to rectangular cell. The flow rate of hydrogen is considerably reduced for the circular fuel cell stack design.

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NOMENCLATURE

GHG	Green House Gases
SOx	Oxides of Sulfur
NOx	Oxides of Nitrogen
CO	Carbon Monoxide
CO_2	Carbon Di Oxide
SLPM	Standard Litre Per Minute
PEM	Polymer Electrolyte Membrane
V_{cell}	Voltage of cell
V_{max}	Maximum Voltage of cell
η_{ideal}	Ideal Thermal efficiency
η_{max}	Ideal Thermal efficiency

CHAPTER 1

1. Introduction

The energy demand worldwide is growing at an alarming rate. Global energy demand had increased by a formidable 71 percent within the period 2003-2030.The demand for energy including transport fuels, is increasing at an alarming level particularly in developing countries like India and China. With obnoxious emission rates, specifically of Green House Gases (GHGs), there has been significant climatic change, resulting in global warming. This is due to the GHG emissions. There is a noted rise in concern over deteriorating air quality and its effect on human health with increasing pollution levels (NO_X,SO_X,CO) especially in developing countries. Carbon monoxide (CO) reduces the blood's ability to carry oxygen, aggravates lung and heart disease, and causes headaches, fatigue, and dizziness. Sulfur oxides (SOx) when combined with water vapor in the air become the major contributor to acid rain. Nitrogen oxides (NOx) cause the yellowish-brown haze over cities, and when combined with oxygen becomes a poisonous gas that can damage lung tissue. Carbon dioxide (CO_2), although naturally occurring, can cause problems. In large quantities it allows more sunlight to enter the atmosphere than can escape – trapping excess heat giving rise to the "greenhouse effect" and cause global warming. As power demands continue to increase for portable electronic devices, it is likely that conventional – primary (non-rechargeable) and secondary (rechargeable) batteries may not be able to meet these increased power demands. In view of this situation, fuel cells have been hoped to be the key solution for the current and next century energy problems, enabling clean and efficient production of heat and power from a diversity of primary sources. Fuel Cells are one of the promising technologies that could address these needs.

Fuel cells offer an attractive solution to the ever-increasing need for portable electrical power. In particular, mobile electronics and communications drive a rapidly expanding demand for power sources with lightweight packaging and very small volume. To answer this need, much development work in past decades has focused on the performance improvement of polymer electrolytes, electro-catalysts, and electrode materials. More recently, attention has been geared toward micro-fabrication as an enabling set of technologies for fuel cells in the power range from a few milli-Watts up to many tens of Watts. One fundamental objective of this research is to adapt appropriate micro fabrication methods for the production of miniature fuel cells within this range of application. Some of the strengths of micro fabrication techniques include fine feature resolution, high repeatability, batch operations, integrated process sequences, and a variety of material transfer options.

1.1 Technological Overview

Fuel cells operate similar to batteries, converting chemical energy into electrical energy. Unlike batteries, however, fuel cells never run down or require recharging. Fuel cells will continue producing electricity as long as fuel is supplied. Because fuel cells rely on electrochemical oxidation instead of burning fuel, they significantly reduce harmful emissions such as oxides of nitrogen and sulfur. They also offer a more efficient alternative to conventional combustion-based methods for generating electricity. Researchers around the world are developing several kinds of fuel cells because different technologies offer certain advantages in size, fuel flexibility and operating temperatures. The total energy is

usually referred to in units of Watt-hours (Wh), calculated as power in watts times operating time of system.

Fuel cells were first demonstrated by lawyer and scientist Sir William Grove. Here in the experiment he conducted, water was electrolysed into hydrogen and oxygen by passing electric current. The power supply was replaced by an ammeter, and a small current was observed. The electrolysis when reversed the hydrogen and oxygen recombined, and an electric current was produced. The main reasons for the current are:

- The low contact area between the gas and the electrode and the electrolyte just being a small ring where the electrode emerges from the electrolyte.
- The large distance between the electrodes- the electrolyte resists the flow of current.

A fuel cell consists of two electrodes sandwiched around an electrolyte. Oxygen passes over one electrode and hydrogen over the other electrode generating water, electricity and heat. The electrodes are generally made very flat with a thin layer of the electrolyte. The electrode is generally made very porous as it has to let the electrolyte as well as the gas to penetrate through it. This helps in maximum permissible contact between the electrodes, electrolyte and the gas.

The hydrogen gas (H_2) passes through the anode compartment of the fuel cell. This gas is forced through the catalyst by the pressure. When an H_2 molecule comes in contact with the platinum on the catalyst, it splits into two H^+ ions and two electrons (e^-). The electrons are conducted through the anode, where they make their way through the external circuit and return to the cathode side of the fuel cell. On the cathode side of the fuel cell, oxygen gas (O_2) is being forced through the catalyst, where it forms two oxygen atoms. Each of these atoms has a strong negative charge. This negative charge attracts the two H^+ ions through the membrane, where they combine with an oxygen atom and two of the electrons from the external circuit to form a water molecule (H_2O). The schematic PEM Fuel Cell and their reaction are shown in Figure.1

Anode reaction: $2H_2 \rightarrow 4H^+ + 4e^-$

Cathode reaction : $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

Net Fuel Cell Reaction $\rightarrow 2H_2 + O_2 \rightarrow 2H_2O$ **+ electrical Energy + Heat**

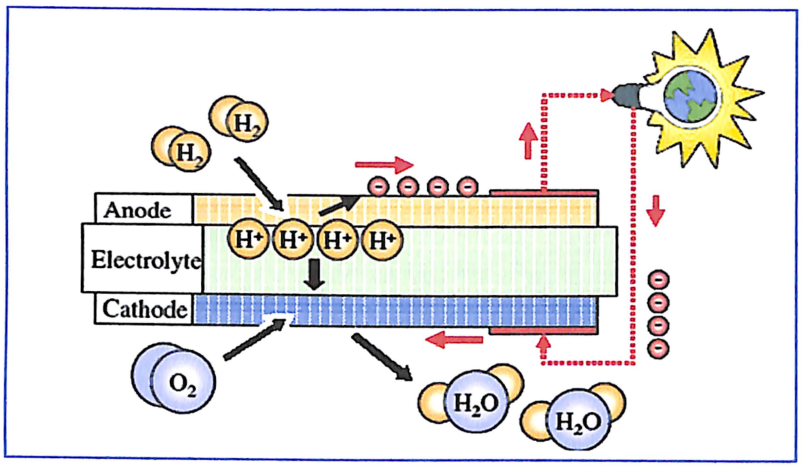

Figure 1: Working of a Fuel Cell

Source: Fuel Cells Handbook[6]

The minimum energy supplied to the reactant in order to cross the energy barrier and get converted to products is termed as activation energy. This energy has to be supplied in order to cross the energy hill. When the molecules have less energy then the reaction will proceed very slowly which is not the case at high temperatures. The three ways of tackling the problem is by extensively using catalysts, increasing the temperature and by increasing the electrode area.

1.2 Comparison Between Fuel Cells and Batteries

Fuel cells provide higher total energy for a given size or weight than batteries, calculated as Watt-hours per liter (Wh/l) or Watt-hours per kilogram (Wh/kg). Polymer Electrolyte Membrane Fuel Cells offer a current density between 1400-1900 Watt hour/ litre while a normal battery produces a current density of 350 Watt hour/ litre to commercial cells to 400 Watt hour /litre for prototype cells. One of the most fundamental differences between fuel cells and batteries is that a fuel cell is an energy conversion device while batteries are both energy storage and conversion devices. Either the depletion of reactants or the

accumulation of by-products will eventually stop the delivery of power. The battery must be either recharged by reversing the reaction or replaced. On the other hand in a fuel cell energy system the conversion and storage functions are separated from on another. It can operate as long as the reactants are supplied to the electrodes i.e. the fuel cartridge can be replaced and the system continues to provide power. Batteries use less expensive materials while in the case of fuel cells the initial cost is high. There is a high degree of non-safety and improper disposability when it comes to end user usability in batteries whereas in fuel cells there is instant re-fuelling. Figure 2 illustrates how the technology has evolved to power portable applications. It also gives a comparative study of the different technologies that have emerged and evolved for powering portable applications. As seen from the figure, the Ni-Cd batteries have a wide operating range but limited energy density. NiMH batteries have a high energy density but limited operating range. Many types of batteries have evolved over the years but none of them have been able to meet the requirements. Lithium ion batteries have been currently found to be best suited to meet the power demands but fuel cells promise to be the everlasting solution to the high power demands of portable devices. Some of the issues related to fuel cells like storing hydrogen safely and the operating ranges have not yet been optimized as studies relating to these constraints are still on and one might expect that these problems will be solved in the next few years.

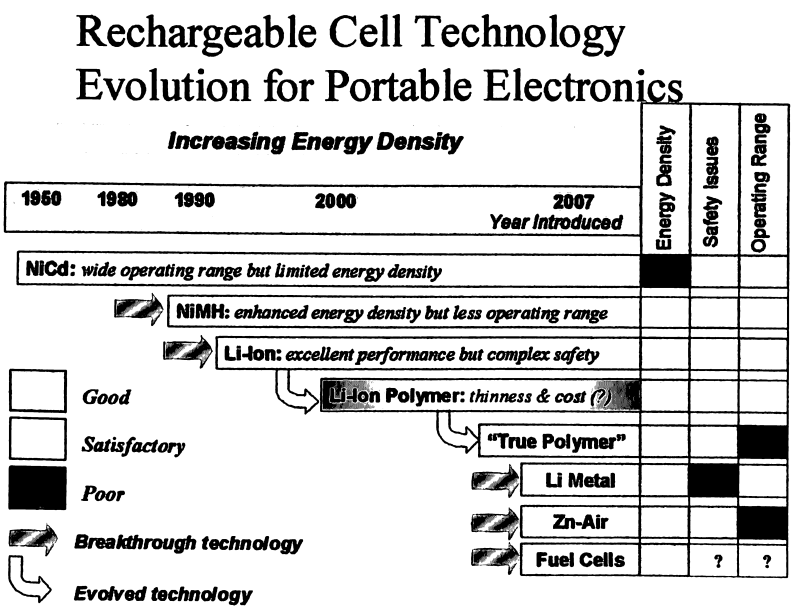

Figure 2: Evolution of Portable Electronics.

CHAPTER 2

THEOROTICAL DEVELOPEMENT

2.1 Micro-fuel cell Design and Construction

Advances in micro-machining technologies have opened many possibilities for miniaturization of power sources. Based on the scaling laws, higher efficiency and performance of power generating devices can be achieved. This also applies to fuel cells. Micro-fuel cell, sometimes also called mini fuel cell or miniature fuel cell, is also an electrochemical device that converts chemical energy of a fuel directly into electricity. Since energy is stored as a fuel rather than as an integral part of the power source, fuel cells have several advantages over batteries. A micro fuel cell power source can be realized by combining thin film material with micro technologies. Micro-fuel cells which have microstructures and generally generate less than 5 W of electricity, are the recent focus of the fuel cell research community. Micro fuel cells can run on three main fuels, namely ethanol, hydrogen and methanol. When hydrogen is the anode material (fuel), the theoretical energy density is much higher than that compared to using methanol or ethanol as fuel; 42000 Watt hours/Kg and 5960 Watt hours/Kg respectively which is the main advantage of using hydrogen as the fuel. When we use a fuel like ethanol there are no regulatory barriers but when we use methanol we have current regulations that forbid airlines to carry methanol in customer compartments. So hydrogen regains its position in the portable market for producing electricity.

In future, more compact, long-lasting sources of power are needed. As the device become smaller and more complicated and energy consuming, battery technology will not be able to keep space. Next generation devices packed with energy-intense gadgets threaten to drain batteries in just tens of minutes instead of the few hours. Even with improvement, batteries cannot keep up with the need. Theoretical power densities of fuel cells are clearly higher than those of batteries as shown in Figure 3.

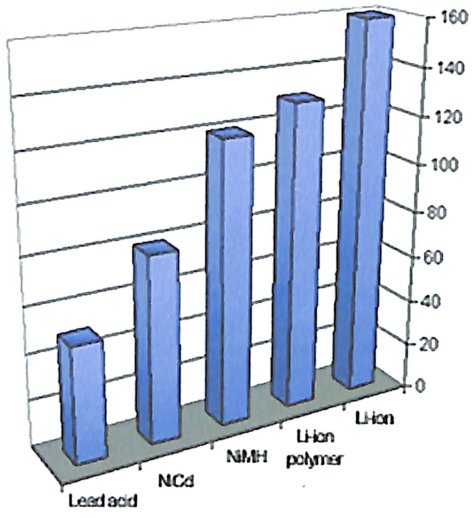

Figure 3: Theoretical power densities
Source:http://www.bikemagic.com/news/images/batteries_energydensity_sml.png

The ideal efficiency of a micro fuel cell can be estimated as follows:
$\eta_{ideal} = \eta_{max} V_{cell} / V_{max}$
where η_{max} is the maximum thermal efficiency, which is 83% for hydrogen and 97% for methanol. The maximum cell voltages of hydrogen and methanol at 25°C are 1.23 V and 1.21 V Figure 4 illustrates the basic components of fuel cell.

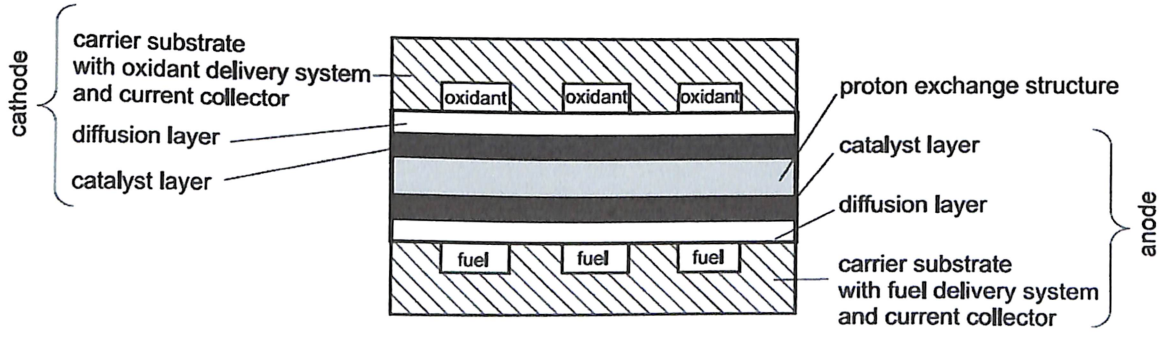

Figure 4: Basic components of a typical micro fuel cell

Source: FC Handbook

2.1.1 Carrier substrate:

Miniaturization of the fuel/oxidant delivery system and the deposition of electrodes and electrolyte materials can be done by traditional silicon-based micro fabrication technologies including **anisotropic etching, deep reactive ion etching (DRIE), chemical vapor deposition (CVD) and physical vapor deposition (PVD)**. The silicon/glass-based structures are mechanically more stable than traditional polymer-based membranes, especially in higher temperatures. Also they do not swell as polymer membranes may do. One other advantage is that Si-based substrate also facilitates the possible integration of the fuel cell with other electronic devices on the same chip.

However, silicon is brittle and can easily fracture because most of the silicon-based micro fuel cells are assembled by press-fit and have a relatively large size; in the order of centimeters. Stainless steel is one of other alternatives. Etching, laser machining or punching are used widely to incorporate flow design on to the stainless steel foils. Polymers are regaining their position as an alternative because of recent advances in polymeric micromachining technologies such as reactive ion etching, polymeric surface micromachining, hot embossing, soft lithography and laser machining.

2.1.2 Proton exchange structure:

Proton exchange membrane (PEM) is a central part of a micro fuel cell. Nafion is the dominant PEM material. Porous membranes made of silicon or other materials have also become attractive, because of advances in micro fabrication. The greatest challenge for the mass production of micro fuel cells is the monolithic integration, combining all the parts into a single process. Thus swelling of Nafion during silicon processes is a big problem. An anodization process in a buffered HF solution is used to fabricate porous silicon membrane.

2.1.3 The diffusion layer:

The diffusion layer has several roles. These roles are: bringing fuel and oxidant to the proton exchange structure, removing water from the membrane and conducting the current. Thus, the diffusion layers are often made of electrically conductive porous materials such as carbon paper. Filling carbon paper with electrically conducting powder such as carbon black improves the conductivity. To ease the removal of the water from the pores of the

diffusion layer, the diffusion layer can have hydrophobic material such as polytetrafluroethylene (PTFE). Many micro fuel cell designs forego the diffusion layer by using a thin catalyst layer sputtered directly on the PEM. Miniaturization and the scaling laws may lead to news designs of a diffusion layer. The interface between fuel and oxidant flows could replace both the PEM and the diffusion layer.

2.1.4 The catalyst layer:

Platinum (Pt) and Ruthenium (Ru) are the most common catalyst materials for micro fuel cells. Catalyst layer thickness ranges usually from few nanometers 100 nanometer. The cost of using pure platinum could hinder the commercialization of micro fuel cells. Thus, replacing some of the platinum with less expensive materials is desirable. The catalyst layer can be made of Nafion bonded platinum on carbon, which extends the three-phase boundary area (gas–catalyst–electrode), which improves electrochemical reaction. Catalyst layer can be deposited either on current collector or PEM. Using carbon nanotubes instead of carbon powder (carbon black) as the support material for platinum in the catalyst layer improves performance. Aligning tubes improves conductivity and hydrophobicity of the catalyst layer further. The structure of nafion is shown in figure 5.

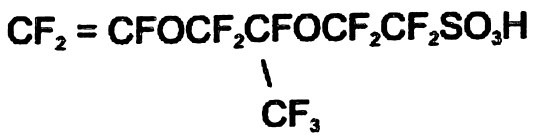

Figure 5: Structure of Nafion

Source: http://www.asyncbrain.baf.cz/sanatorium/1/h2fuel/index.htm

2.1.5 Bipolar and planar design:

Currently, there are two basic design approaches for delivery of fuel and oxidant: the traditional bipolar design and the planar design. In the bipolar design all the components of a micro fuel cell are layered in a stack. Fuel and oxidant supply channels are separated by the PEM. Most bipolar designs have separated fuel and oxidant delivery systems. Bipolar design guarantees the separation of fuel and oxidant and prevents them from coming

together before the reaction. The bipolar design is only suitable for hybrid integration in which the components are micro machined separately and assembled together into a complete device. The planar design is better suited for monolithic integration because both fuel and oxidant channel networks are at the same side of the PEM. Because fuel and oxidant channels are inter-digitated reaction can occur between them. The planar design is two-dimensional and thus requires a larger surface area to deliver the same performance as the bipolar design.

2.1.6 Flow field design: channel

The most important to micro-fuel cell scaling is the flow field design and reactant distribution over the electrolyte membrane. Decreasing the diameter and pitch of micro channel arrays forming the flow field should reduce dead space, thus increasing the effective area over which reactants are able to diffuse to the electrode-electrolyte interface. In theory, this should increase the power density of the fuel cell for the same flow rates. Computational models predict constant improvement in fuel cell power density as channel width and spacing are decreased, for comparable fuel cell membrane area and reactant flows, the effective area of the electrode is increased without significantly changing the pressure drop.

2.2 Stack Configurations

For practical applications, several unit cells are combined in series to produce the desired voltage. The different types of stacks are illustrated in Figure 6. The fuel cell stack design shown in Figure 6 (e) is the one mostly used for stacks with higher capacities. But this design has its limitations when used for a hydrogen-air fuel cell stack without forced conduction of air. The amount of air that enters the stack is limited and it also leads to a complex design and gas distribution becomes difficult because of the small electrode area. Assembling the cell also becomes increasingly difficult.

All these problems can be overcome by the use of the Banded Structure Membrane design (Figure 6 c). Here, a single membrane is used with the catalyst present only at certain points (on both sides of the membrane) that constitute the individual cells. Current collectors are

placed at the corresponding points on the supporting plates. These individual cells are then connected in series as shown in the figure. This can be done internally (on the inner sides of the plates) if the membrane is discontinuous and externally if a single membrane is used. Holes can be drilled on the cathode side for air supply to the electrodes. This type of stacking is best suited for fuel cells without forced convection of air. The lesser the thickness of the cathode plate, the better the air supply. In case of oxygen shortage, we can always increase the size of the holes without compromising on the compression required. This type of stacking ensures sufficient air supply to the cathode. It also makes designing the flow field for hydrogen simpler because the flow field can be continuous in the plate and the individual cells can be differentiated by placing the current collectors at the corresponding points alone. This design lets us minimize the active electrode area of the individual cells to any extent based on our needs. In a given plate with a particular flow field, we can reduce the cell size and increase the number of cells for a higher voltage or we can increase the cell size in case higher current is required. This type also lets us use a variety of charge collectors. Graphite is the most commonly used current collector in fuel cells because of its properties like conductivity, light weight etc. But the difficulties in machining these plates and the need for miniaturization have led to the use of novel current collectors like copper, gold and titanium meshes. But we must be very careful in selecting the thickness of these current collectors because improper contact with the electrodes can affect the performance of the fuel cell.

We might also go for a combination of normal stack and banded structure membrane type (Figure 6 d). We might also combine the concept of bipolar plates along with the banded structure membrane type to get a higher voltage and to cut down the volume occupied by the cell. Here, the flow field for hydrogen is machined on both sides of the bipolar plate and the cathode plates are placed on both sides of this bipolar plate. But in this design, going beyond two layers of stacks becomes difficult because of the constraint in the oxygen supply.

This work uses mainly the Banded Structure membrane type of stack design. A number of designs were tried with improvements in sophistication in each design. Proper justification has also been provided for each change in design.

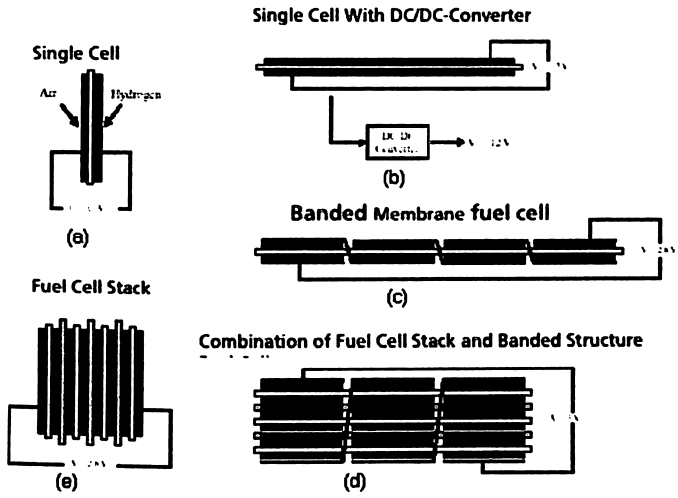

Figure 6: Construction principles of PEMFC

Source: Lateral Ionic Conduction in Planar Array Fuel Cells[1]

2.3 Multi-Cell Interconnection

Practical implementation of miniature fuel cells necessitates interconnection of multiple cells, to meet application-specific voltage requirements. For integrated layer manufacturing, complexity within a layer is generally preferable to complexity between layers. A banded membrane configuration has been proposed in prior literature, and this design is well suited for planar interconnection. Three-dimensional features, however, add complexity to the electrode-electrolyte boundary, so it is desirable to have even further simplification at this interface. Therefore, a novel interconnection layout with continuous membrane is proposed for multiple cells, as illustrated in Figure 7.

Multi-Cell Interconnection with "Flip-Flop" Configuration as shown in Figure 7 is not only membrane processing simplified by continuity, but current collection is also simplified because interconnection from the cathode of one cell to the anode of the next cell is made entirely within one plane. A trade-off is the fact that fuel and oxidant chambers must alternate in the flip-flop configuration, but this can be readily achieved by appropriate design as illustrated in Figure 8. Interlaced channels, as shown in figure , offer relatively

simple inlets and outlets, with only one perimeter seal required per gas. It is more effectively used.

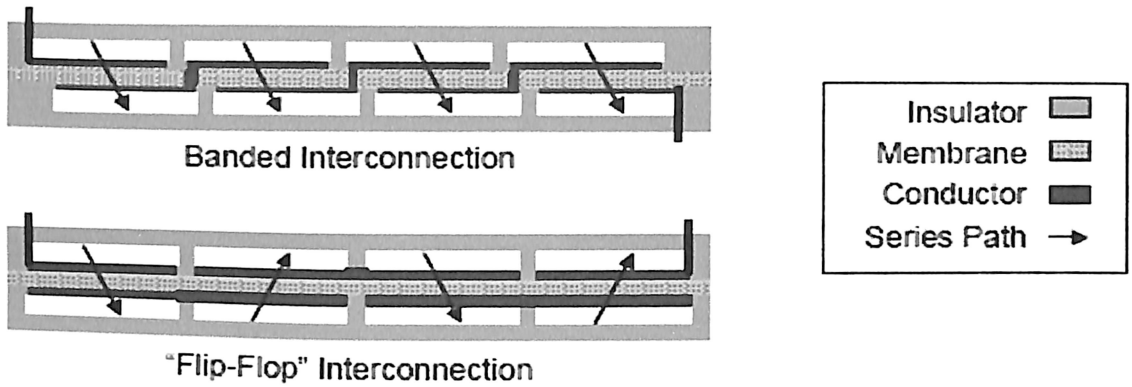

Figure 7 : Multi-cell interconnection with Flip-Flop configuration

Source : High Power-Density Polymer-Electrolyte Fuel Cells By Micro Fabrication [4]

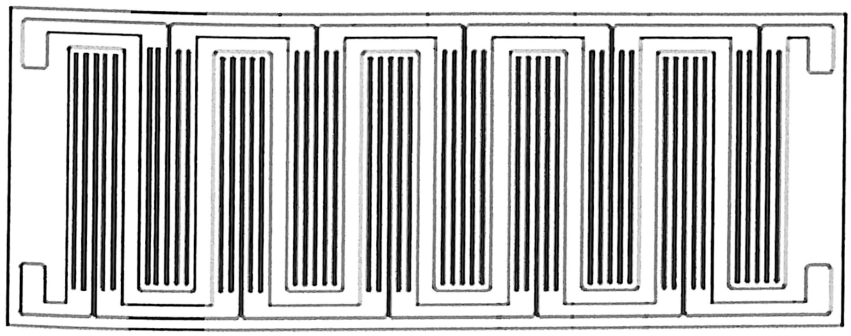

Figure 8 : Interlaced Flow Channels with Alternating Fuel/Oxidant Chambers

Source: High Power-Density Polymer-Electrolyte Fuel Cells By Micro Fabrication [4]

2.4 PCB based PEM Fuel cell

Recently, there has been great interest in the use of miniature/ micro fuel cells as replacements for batteries for portable application. The development of miniature/micro fuel cells is driven by the increasing power and energy requirement of electronic devices.

The most promising fields of the use of miniature/micro fuel cells are that of consumer electronics, sensors and medical devices. For many applications, an integrated power source should have a flat geometry that enforces a planar design of fuel cells. In addition, planar fuel cells can be integrated in the housing of electronic devices and serve as part of the housing itself. For example, it could be integrated into the screen's backside of a laptop computer or into the backside of a cell phone. The dual use concept allows us to optimize the volume of power-consuming devices. As shown in Figure 9, the planar fuel cell has been realized in printed circuit board (PCB) technology. The most crucial advantage of PCB technology is the mass production that largely reduces the costs. Other advantages of the PCB technology include mature technology, lightweight and stiff composite materials, and design flexibility comprising complex conductor/ insulator patterns, either as a mono- or multi-layer design. Furthermore, electronic circuits can be integrated on the board, which might act as a power consumer itself or as an auxiliary unit with, e.g. dc/dc converter.

The oxygen required by the electrochemical reaction is taken directly from the surrounding air by diffusion and/or natural convection. Although, the planar fuel cell running in a passive mode has the benefits of minimizing the number of power consumed auxiliary devices, the power density of cell itself is not as good as that runs in an active mode due to poor transport mechanisms. Thus, one of the most important challenges in the design of passive fuel cells is how to feed the electrode with reactants and remove the products from the electrode appropriately.

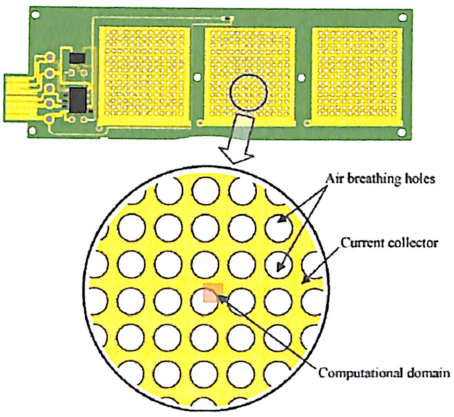

Figure 9 : Computational Domain Magnified

Source : species electrochemical transports in a free breathing cathode of a PCB based fuel cell[5].

CHAPTER 3

ANALYSIS

3.1 Printed Circuit Boards Design and Construction

10-cell planar fuel cell array description (rectangular). —Using printed circuit board (PCB) technology, a 10 cell banded configuration planar fuel cell array was constructed shown in Figure 10 and Figure 11. PCB technology was employed to provide both flow routing and electrical interconnection for the fuel cell array. Gas inlets and macro flow routing were implemented on the backside of the PCB. The micro-flow-channeled electrode areas were made on the front side of the PCB by selectively etching copper, which was subsequently protected by tin plating. Series electrical interconnection between cells in the planar array was accomplished via pin interconnects at the edge of the PCB board. This electrical interconnection methodology allowed the use of a single, uninterrupted membrane shared by all the 10 fuel cells. Furthermore, this scheme provided individual electrical access to every pole (cathode and anode) of the 10cells in the array. The behavior of any individual cell or arbitrary group of cells could be monitored during an experiment. The active dimensions of each of the cells in the array were 20 by 20 mm, giving per cell active areas of $4cm^2$. The 10cells were arrayed in two columns of five cells. The five cells within a column were separated from each other with 4 mm spacing. The two columns were separated from each other by 15 mm. Serpentine flow design is used for anode. The ribs width is 2mm, and the groove width and depth is 2mm and 0.7mm respectively. On the cathode side the 3mm hole was made to breath oxygen from atmospheric air. The PCB has provision to monitor the individual cell voltage with the help of Plated Through Hole (PTH) arrangement on the PCB. The flow rate of hydrogen is kept at 250cc per minute; the OCP of the fuel cell battery is around 7.0 Volts.

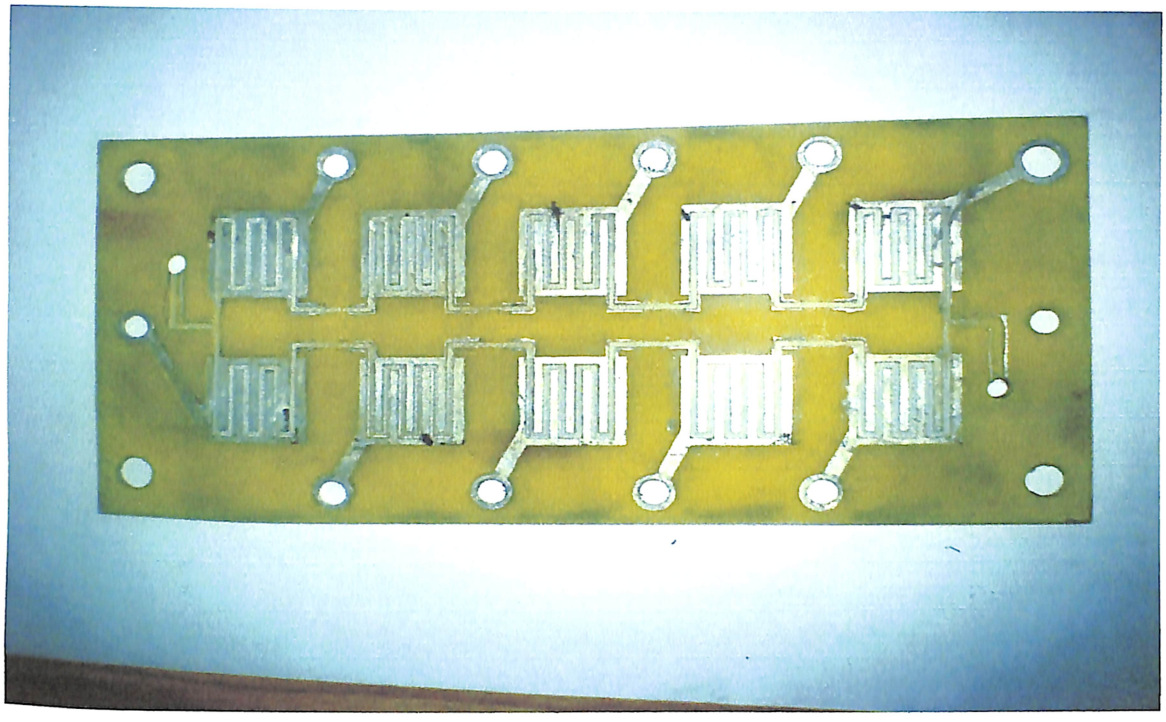

Figure 10 : Anode PCB plate

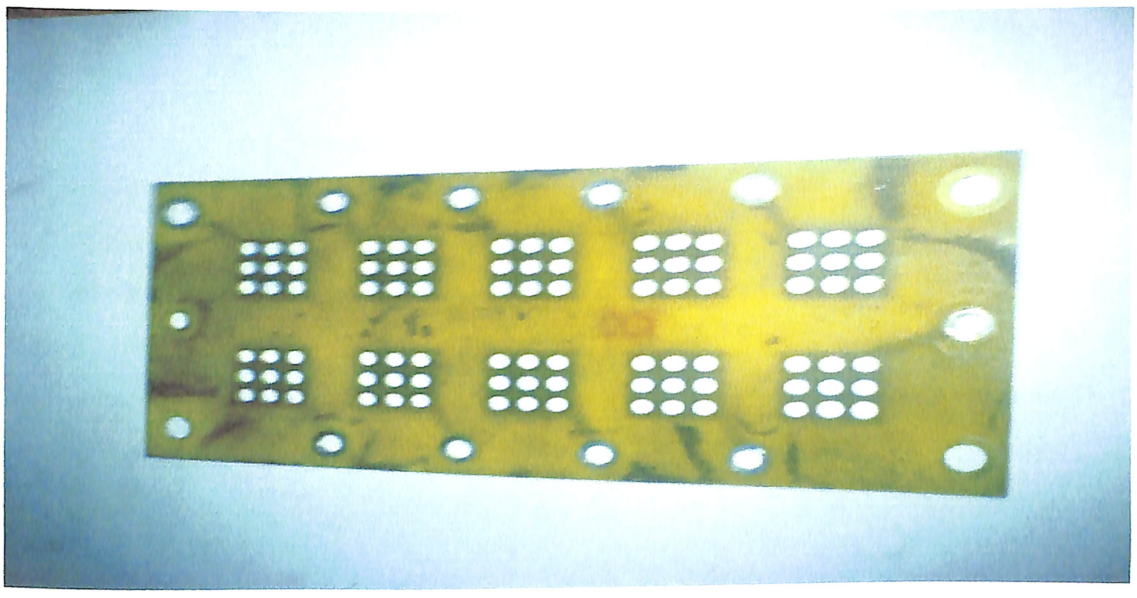

Figure 11 : Cathode PCB Plate

The various electronic equipments are connected with small fuel cell and their behaviors are discussed.

3.1.1 Transistor Radio:

The 3.0 V transistor radio was connected to the fuel cell. The fuel cell voltage dropped down to 3.6 volts from 7 volts. The current drawn is around 150mA. The current drawn depending on the sound level of the transistor radio. Even the sound level of the transistor is kept at constant; the current fluctuation is seen depending on the voice modulation and also the type of musical instruments played. The current varied from 100mA to 175mA.

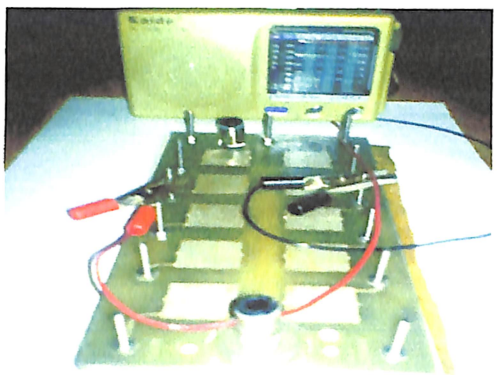

Figure 12: Photograph of small fuel cell with transistor radio

3.1.2 Timepiece:

Timepiece operates with 1.5 volts. So the 10 cells configuration the number of cell required is only 4 cells. The initial voltage of four cells is around 2.8 volts. When the timepiece is connected to the fuel cell the voltage dropped down to 2.1volts. The current required to run the timepiece is around 40mA. When the alarm is set the current consumed is almost double i.e., 85mA. The voltage dropped down to 1.6 volts.

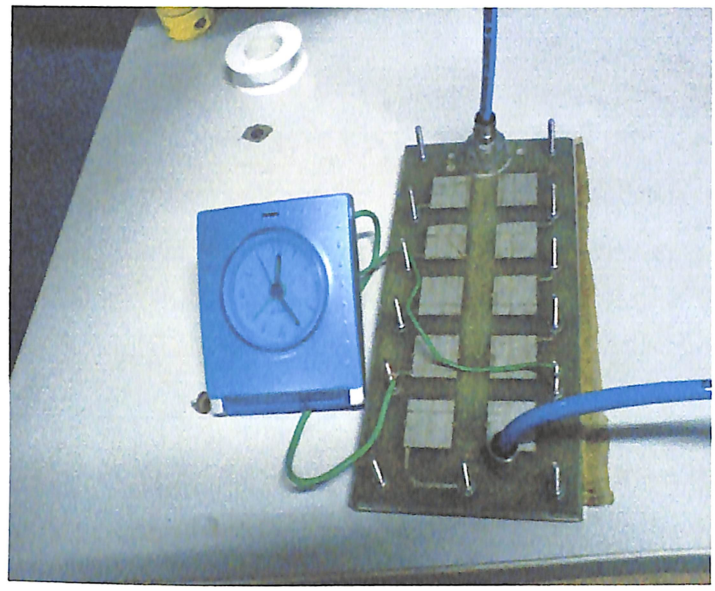

Figure 13 : Photograph of fuel cell with timepiece

3.1.3 Small table lamp:

Table lamps generally consume very low voltage. One such table lamp used had a power requirement of 6V and 300mA current. When the lamp was connected to the 10 cells stack the voltage comes down to less than 3.0V, so fuel cell is unable to deliver the power and the lamp didn't glow.

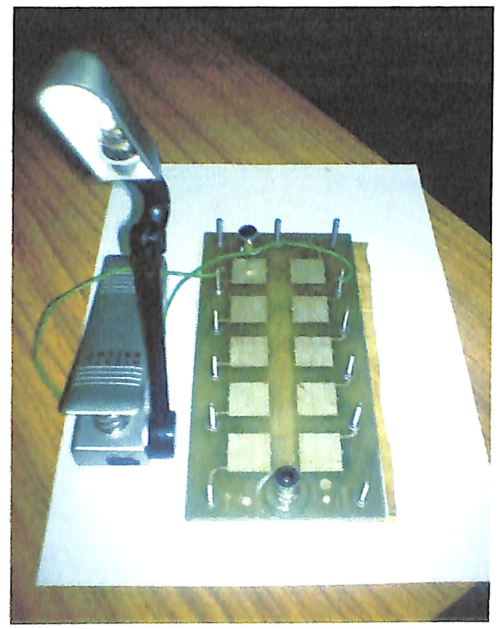

Figure 14 : Photograph of fuel cell with table lamp

The drawback of the rectangular design is, when the flow distribution arrangement is in parallel, some of the cells do not get proper gas flow. But when the flow arrangements is in series (out let of the first cell is connected to the inlet of the second cells and so on) the flow requirement is high and this will affect the performance of first two cells and the wastage of hydrogen gas is also high.

3.2 The circular design:

The flow distribution of circular design cell is better compared to rectangular design cell. The flow distribution in the rectangular is single pass, so it requires higher pressure and flow to distribute to all the cells. In the case of circular design the flow field can be designed with multi-pass. The hydrogen flow required for the rectangular design is 250 SCM. In the case of circular design, the flow requirement is only 100SCM.

Design of multi-cell (Circular): The flow field design for the anode was made using CAD diagram is shown in Figure 15 for the cathode side hole is provided for breath air from the atmosphere is shown in Figure 16. The cathode and the anode design were etched on the PCB. Then the hole was made on the cathode PCB plate for the air breath. For the anode side the plate is machined to achieve a multi-pass flow field design. The ribs act as a current collector and grooves are used to distribute the hydrogen flow. The groove width is 2mm and the depth is 0.7mm. The width of the ribs is around 2mm. Circular Fuel cell with 8 cells configuration has been made.

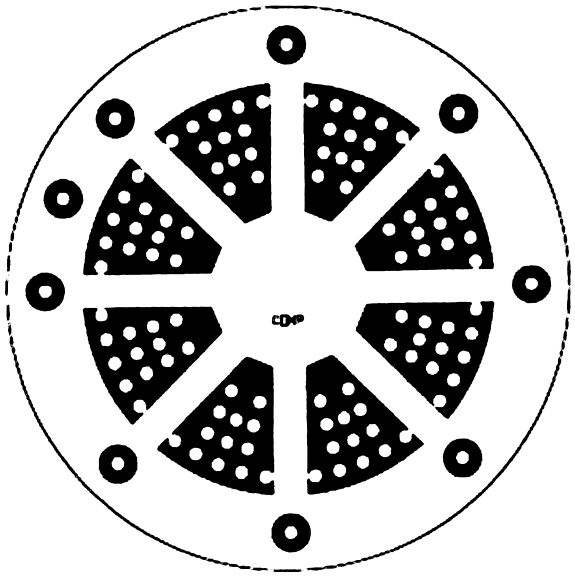

Figure 15 : Cathode CAD diagram

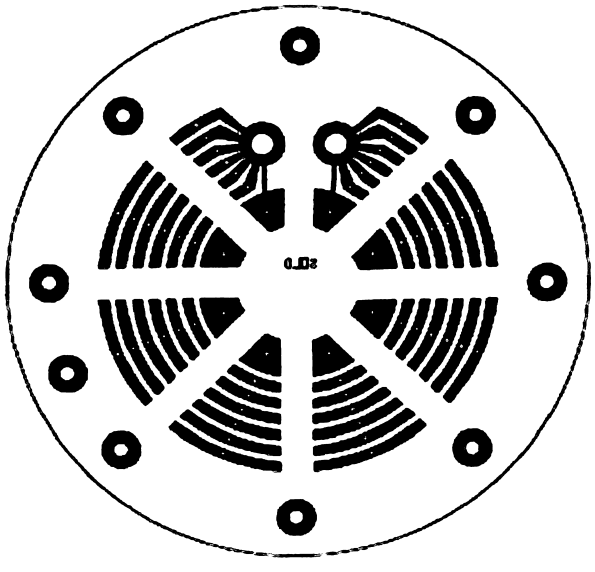

Figure 16 : Anode CAD diagram

Figures17,18 shows the photo graph of anode PCB plate with front and rear views

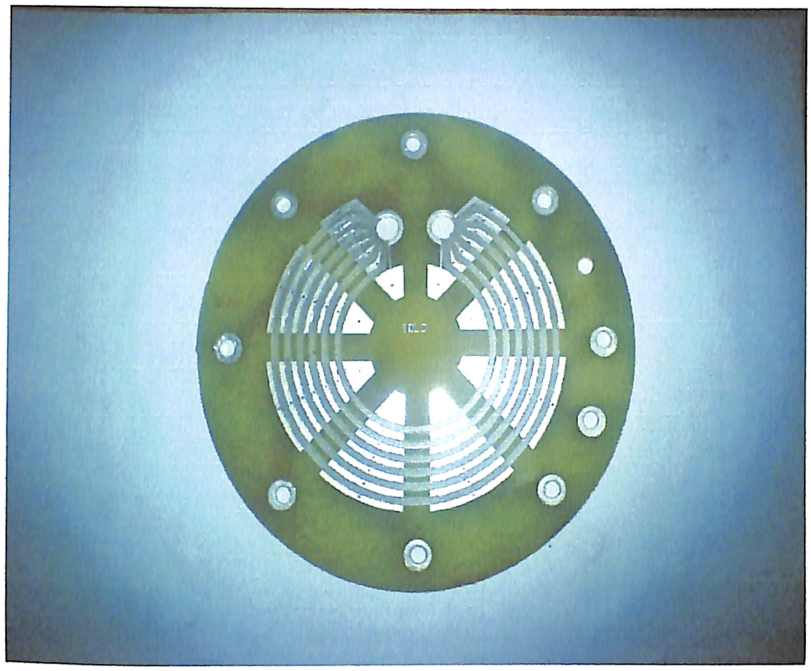

Figure 17 : Front View

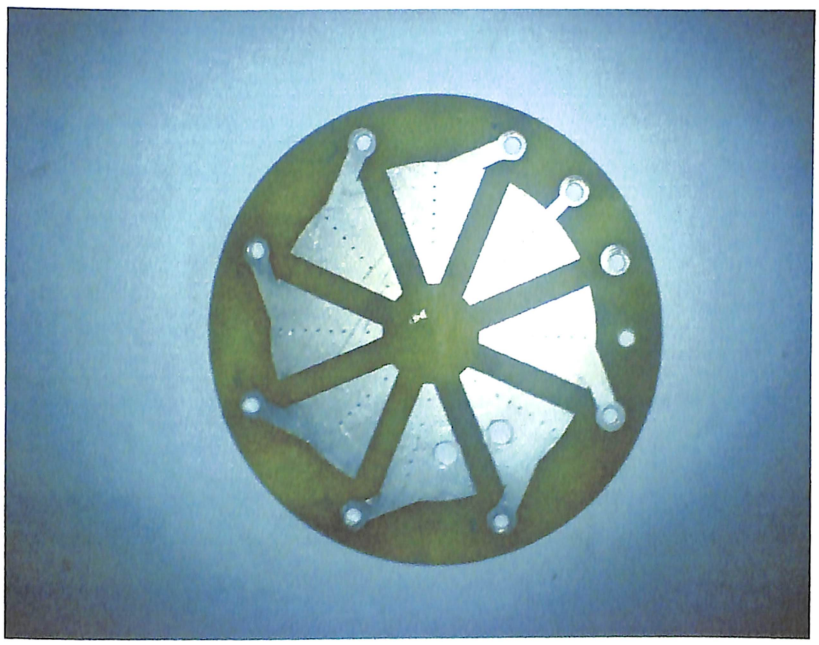

Figure 18 : Rear View

Figures 19, 20 show the photo graph of cathode PCB plate with front and rear view

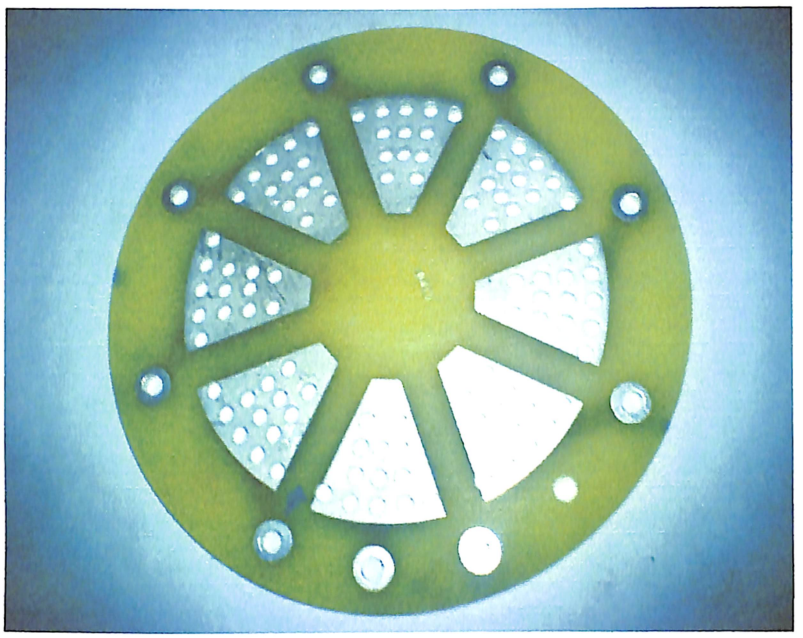

Figure 19 : Front View

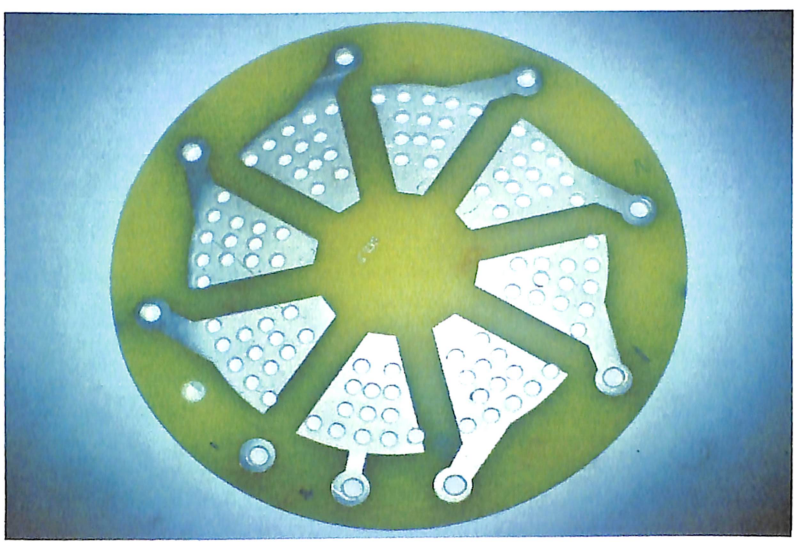

Figure 20 : Rear View

3.2.1 Transistor Radio:

The 3.0 V transistors were connected to the circular type fuel cell. The fuel cell voltage dropped down to 3.6 volts from 5.8 volts. The current drawn is around 150mA. The current drawn depends on the sound level of the transistor Radio. The flow required is around 100SCM, which is much less compared to rectangular design PCB design. We were able to minimize the hydrogen flow rate in the fuel cell. Figure16 shows how the transistor was connected to the circular fuel cell.

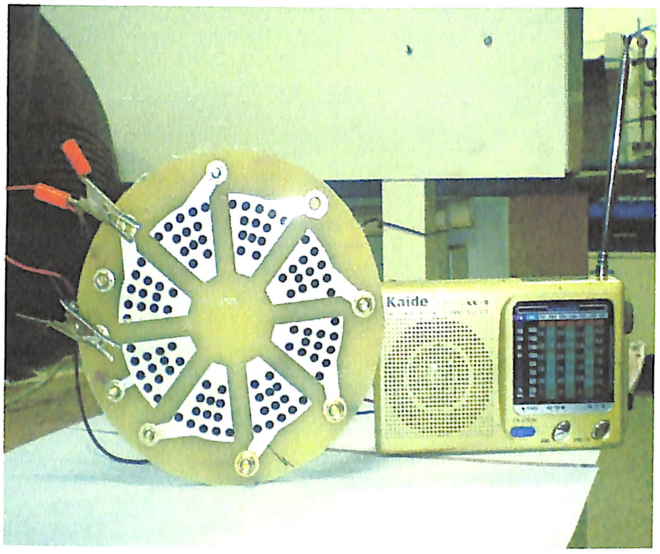

Figure 21 : Transistor Radio running on a circular fuel cell

3.2.2 Timepiece:

Timepiece operates with 1.5 volts. So the 8 cells configuration the number of cell required is only 3 cells. The initial voltage of four cells is around 2.2 volts. When the timepiece is connected to the fuel cell the voltage dropped down to 1.7 volts. The current required to run the timepiece is around 40mA. When the alarm is set the current consumed is almost double i.e., 60mA. The voltage dropped down to 1.5 volts. Figure 17 shows a timepiece running on the circular fuel cell designed.

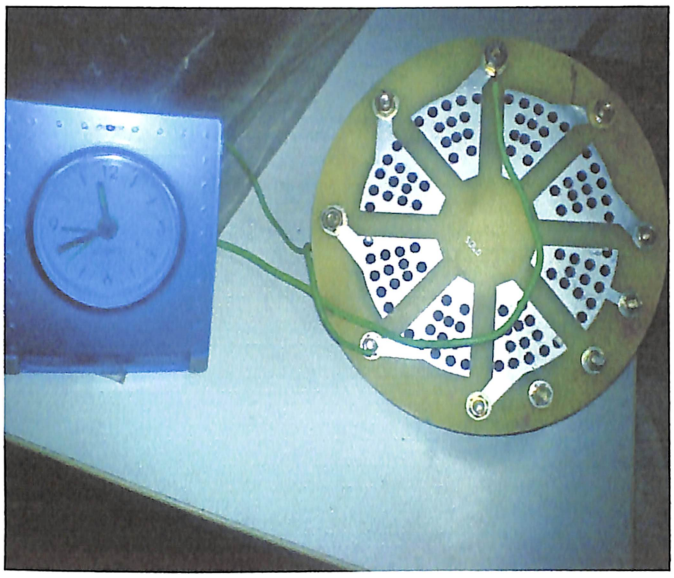

Figure 22 : Timepiece running on a circular fuel cell

3.2.3 Small table lamp:

The power requirement of the lamps is 6V and 300mA current. When the lamp is connected to the 8 cells stack the voltage comes down to less than 4.0V, the lamp was working but the intensity of the light is very low, this is because the supply of voltage from the fuel cell is low. With rectangle fuel cell design stack even with 10 cells the lamp did not glow. But with circular design fuel cell we were able to operate the lamps. This clearly indicates with the circular design more current can be drawn compared to rectangular design because the cell to cell voltage variation is less in the circular design compared to rectangular design fuel cell. Figure 18 shows a table lamp running on the circular fuel cell.

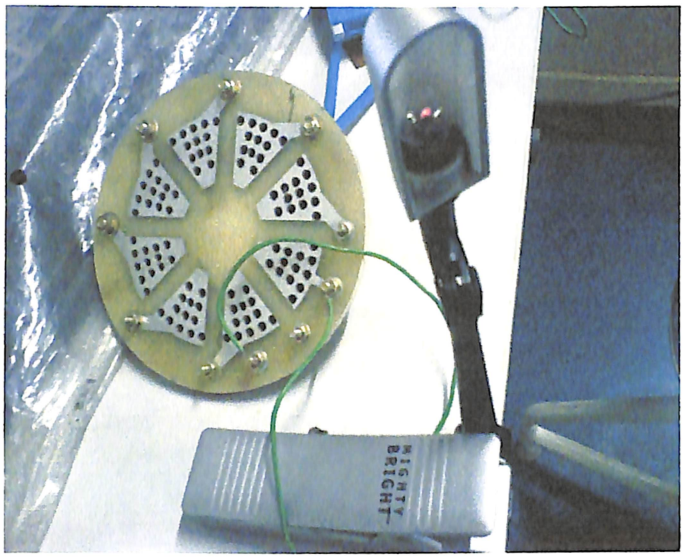

Figure 23 : Table lamp running on a fuel cell

Based on the above experimental results the circular fuel cell design is suitable for uniform distribution of hydrogen fuel. The wastage of the fuel was very less compared to rectangular fuel cells. However in both the design the limitation of current drawn is due to air breathing cathode. The cathode electrode structure needs to be modified to improve the current drawn from the small fuel cells.

3.3 The Hydrogen Source for portable applications

The increase in environmental awareness has begun in the last few years to drive development of more efficient, less pollutant power sources. The key technical issue that will delay the wide-scale introduction of fuel cell devices onto the portable power market relates to the hydrogen which many of them see as the fuel of the future as it is less expensive and non polluting. The hydrogen source and storage issue is pervasive across the entire spectrum of hydrogen energy devices.

Generally these pressurised vessels are bulky and heavy due to the large quantities of thick steel plate used in their construction. They have a very low energy density as only ~1% of their mass is hydrogen. The latest trend in hydrogen storage has been development of composites, such as carbon fibre wrapped vessels, which are lighter and stronger although more expensive. Metal hydrides on the other hand offer a low-pressure, compact, and moderately inexpensive storage system, and the technology for making and processing them is also well developed. Sodium aluminium hydride is already manufactured at low cost. The nickel-metal-hydride battery is a common energy source. The main disadvantage of using hydrides is that they are either heavy in comparison to the hydrogen they carry or require high temperatures to release the stored hydrogen. One advantage of using a metal hydride is that it is much safer than the high-pressure gas and are the storage medium of choice and have been incorporated into a number of prototype portable appliances. The main source of hydrogen is almost entirely derived from fossil fuels.

Apart from the environmental issues it remains a fact that hydrogen is difficult to store in sufficient quantity, within small, lightweight and robust containers. Consequently, although numerous PEMFC devices exist for portable power applications, their portability or operational longevity can be severely compromised by the size and weight of the hydrogen storage and supply apparatus.

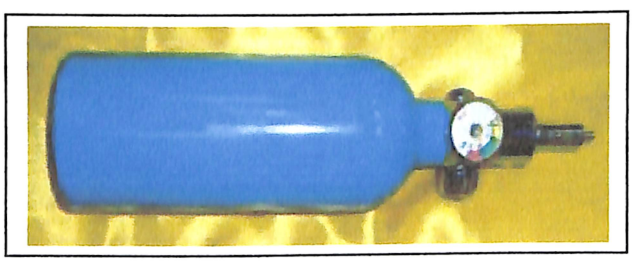

Figure 24 : Hydrogen Storage Vessel
Capacity 150sl (standard liter)

For example, the commercial metal hydride cylinder, which can store hydrogen up to 150 standard liters, can be used for potable applications. When the metal hydride container is connected with fuel cell, depending on the applications the duration of operation may vary, the details are shown in Table 1.

Table 1: Duration of operation for a given capacity of Metal Hydride Storage Vessel

Metal hydride cylinder	Portable electronic equipments	Current requirements	Duration of operations
Capacity 150 sl	Transistor	150 to 200 mA	75 days
	Timepiece	50 to 100 mA	150 days
	Small lamp	300 mA	50 days

Sample calculations:

1 gram of Hydrogen gives 26.6AHr

1 gram of Hydrogen gives 11200cc of Hydrogen

26.6AHr of Hydrogen gives 11200cc of Hydrogen

1AHr gives 430cc

1A gives7cc/min

0.1A gives 0.7cc/min

Converting cc/min to cc/hr

0.7*60*24 = 1008cc/hr

For 150sl= 148 days ~150 days.

CHAPTER 4

Results and Discussion

Rectangular design:

As shown in the photograph the small fuel cell was assembled with rectangular PCB plate with 10 cells in series. The ideal cell voltage is around 1.0V per cell. When the fuel cell is operated with dry reactant the maximum voltage obtained is only 0.7V per cell. When the 10 cells are connected in series the voltage of fuel cell battery is around 7Volts.

The various portable electronic equipments were coupled with fuel cell and the cell performance was studied.

Transistor:

The fuel cell voltage dropped down to 3.6 volts from 7 volts when connected. The current drawn is around 150mA. The current varied from 100mA to 175mA.

Timepiece:

When the timepiece was connected to the fuel cell the voltage dropped down from 2.8volts to 2.1volts. The current drawn was around 40mA. When the alarm is set the current consumed is almost double i.e., 85mA and the voltage dropped down to 1.6 volts.

Small table lamp:

When the lamp was connected to the 10 cells stack the voltage came down to less than 3.0V, so fuel cell is unable to deliver the power.

Circular Design

A Circular design with 8 cells was made. The overall voltage was found to be 6 volts for 8 cells. The flow given is around 100SCM.

The cell performance with different accessories were as follows:

Transistor:
The fuel cell voltage dropped down to 3.6 volts from 5.8 volts when it was connected to the circular fuel cell. The current drawn was around 150mA.

Timepiece: There was a drop in voltage from 2.2 to 1.7 volts when connected to the circular fuel cell. The current drawn was 40mA. When the alarm is set the current consumed is almost double i.e., 60mA. The voltage dropped down to 1.5 volts.

Small table lamp: When the lamp is connected the voltage comes down to less than 4.0V, the lamp was working but the intensity of the light is very low, this is because the supply of voltage from the fuel cell is low.

Based on the above experiments, apart from the flow distribution of hydrogen gas, the air-breathing cathode plays a major role in altering the performance. The electrode, which is used, have very high diffusion layer. When these electrodes are used in the small fuel cell applications, the penetration of air into the gas diffusion media becomes difficult. Based on the above experiments it is very clear the electrode, which is used for the forced flow fuel cell stack, can't be used for the air-breathing fuel cell. So, for the air breathing small fuel cell, the electrode structure needs to be modified. The cathode needs more porous structure and also needs the chemicals which can retain some amount of oxygen molecule in the porous structure. Adding substance like MnO_2, activated carbon etc. along with carbon black in the diffusion layer will improve the oxygen availability at the electrode interface. The catalyst-coated membrane followed by thin diffusion layer can be coated over catalyst layer to improve the diffusion of air.
We can't use any external fan to improve the wattage of the small fuel cell, because the wattage requirement by the fan is about 5 to 6 watts. It is inappropriate to draw 5 to 6 Watts to produce 1 watt of electricity from small fuel cell.

CHAPTER 5

Conclusions and Recommendations:

We were able to design and fabricate the PCB based micro fuel cell for the portable applications. The micro fuel cell made with circular design is better with respect to hydrogen flow, because the flow rate is reduced considerably. Based on our studies it appears that in order to improve the power density of the micro fuel cell, the cathode electrode structure needs to be modified as the electrode needs self-breath oxygen from the air.

The cathode electrode structure needs to be more porous to enable the air to reach the interface without any forced flow. Chemicals, like MnO_2, activated carbon etc, can be added to the diffusion layer to improve the oxygen availability at the interface.

In general, micro fuel cell system technologies have progressed greatly and are nearing the stage of being commercially viable. Significant issues still remain to be resolved to improve fuel cell performance to be able to compete with rechargeable batteries in consumer electronics. This may be achieved within few years. The cost is, primarily an important factor in the hand-made nature of existing systems and thus there is need for major reductions through the application of mass production techniques.

CHAPTER 6

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