

VII.K.7 Direct Methanol Fuel Cell Power Supply for All-Day True Wireless Mobile Computing

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Objectives

- Design, fabricate, and validate a cost-effective, fully integrated direct methanol fuel cell (DMFC) system for mobile computing applications.
- Develop a high performance membrane electrode assembly (MEA) structure with optimized membrane, catalyst, and gas diffusion layer (GDL) structures for a DMFC system.
- Develop a high performance stack design coupled with a simplified system design to increase the overall system power density while decreasing the parts count.
- Test the completed system under real world operating conditions and demonstrate 1,000 hours of operation.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells, and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- B. Cost
- C. Electrode Performance
- D. Thermal, Air, and Water Management
- F. Fuel Cell Power System Integration

Technical Targets

Progress Toward Technical Targets for Consumer Electronics (sub-Watt to 50 Watt)

| Characteristic | Units | 2006 Target | 2010 Target | System Status |
|----------------|-------|-------------|-------------|------------------|
| Specific Power | W/kg | 30 | 100 | 40 ¹ |
| Power Density | W/L | 30 | 100 | 50 ¹ |
| Energy Density | W·h/L | 500 | 1000 | 325 ² |
| Cost | \$/W | 5 | 3 | 10 ³ |
| Lifetime | hours | 1000 | 5000 | N/A ⁴ |

¹ Specific power status is based on calculations and early component selection based on fuel cell system only. Fuel tank and battery are not included. Full system construction not planned until 2006.

² Specific energy density is based on complete fuel cell system including the fuel tank.

³ Based on a rough cost analysis for production at 100K units per year.

⁴ Lifetime for the catalyst coated membrane (CCM) in a conventional system is over 2,000 hours. Lifetime in the proposed system has not yet been measured.

Approach

- Start by using PolyFuel's proprietary DMFC membrane technology.
- Develop aggressive approach to system simplification by incorporating more system functions into the fuel cell stack itself.
- Adjust the properties of the MEA by creating novel polymer membranes, new catalyst and GDL structures to meet the requirements of the simplified system architecture.
- Design fuel cell subsystems including fuel tank, fuel delivery, cooling system, power conditioning, and controls.
- Test completed systems under real world operating conditions.

Accomplishments

- System requirements have been written, several candidate system architectures were evaluated, and the most promising identified.
- Approximately 25 unique polymers have been synthesized, cast into membrane sheets.
- The candidate polymers have been tested to measure properties such as conductivity, swelling, tensile strength, and methanol stability, yielding some with improved stability in higher concentrations of methanol and higher conductivity.
- A process was developed for bonding the hydrocarbon membranes to catalyzed GDL materials, enabling a lower compression fuel cell stack and higher power densities.
- Developed a heat transfer and pressure drop model to assist in the design of the overall cooling system, leading to a very low predicted load on the cooling fan of about 0.75 watts.
- Developed a tool for measuring the current density distribution within the test fuel cell with a spatial resolution of 0.5 cm² and an accuracy of about 2 mA/cm².

Future Directions

- The present work is concentrating on improving the characteristics of the MEA, especially the engineering of the GDL and the membrane.
- In the second year, the remainder of the system components will be selected and tested.
- In the final year, the complete system will be tested for lifetime characteristics.

Introduction

There is a growing gap between the demand for electrical storage capacity in mobile devices and the ability of batteries to supply ever increasing power needs for longer periods. As more features requiring more power are incorporated into wireless devices, higher power density energy sources will be required. The leading candidate to fill the looming energy gap is the DMFC. DMFC systems to date have shown rapid improvement, but there are still significant improvements in energy density and cost reduction needed for DMFC systems to be adopted widely in wireless devices.

The basic intent of this project is to reduce costs and improve energy and power density by component elimination and system simplification. Conventional DMFC systems have a large number of fans, valves, pumps, and sensors to operate to maintain reactant flows, reactant compositions, temperatures, and humidity inside the fuel cell stack. Simply miniaturizing these elements will not likely achieve the required cost and energy density targets. By designing the fuel cell to operate under harsher conditions and perform more functions internally, it becomes possible to eliminate many of the supporting components.

Approach

To achieve the project objectives, PolyFuel is building on its proprietary DMFC membrane technology. The hydrocarbon based polymer membrane is being modified to improve its tolerance of higher concentrations of methanol, increase its conductivity, improve water transport properties, and improve its dimensional stability. The newly developed membranes along with new GDL materials with engineered properties will enable the operation of a dramatically simplified system with higher power density and lower overall cost. Once prototype systems have been constructed, they will be tested for performance under expected conditions in a fully integrated laptop computer.

Results

The design of the power supply is driven by the overall system requirements. A summary of the key requirements is shown in Table 1. Based on the

Table 1. Summary of Fuel Cell System Requirements

| Characteristic | Value |
|-------------------------|--------------------|
| Average Power Level | 15 Watts |
| Peak Power Level | 40 Watts |
| Output Voltage | 8.0 to 12.6 Volts |
| Operating Life | 1000 hours |
| Cost | \$100 @ 100k units |
| Ambient Temperature | 5 to 40 °C |
| Fuel Cell System Volume | 250 cc |
| Fuel Cartridge Volume | 120 cc |
| Fuel Composition | Pure Methanol |
| Max. Noise Level | 40 dBA at 0.5 m |

requirements, several system architectures were evaluated, and the one with the simplest final configuration was selected. A preliminary packaging study was conducted to understand how the system elements will need to fit together. An overall system model was developed that estimates the losses of each of the system components and predicts the requirements for the fuel cell stack such as cell voltage, active area, cell count, cell pitch, and aspect ratio.

One of the key challenges is to remove the large amount of waste heat (approximately 40 watts) from the power supply from a very small space within the laptop without using a large fraction of the fuel cell power. A detailed heat transfer and pressure drop model was developed and cooling fans were roughly sized.

Building on PolyFuel's current generation membrane, approximately 30 unique polymer films have been produced, analyzed, and the promising ones evaluated in cells. Table 2 shows the ex-situ and performance properties of some of the more promising polymers.

One important element to constructing fuel cell stacks for ease of manufacture and small stack compression hardware is a bonded MEA structure. Until recently, bonding MEAs with hydrocarbon membranes was not possible. This project has further developed a surface treatment that can be

Table 2. Sample Measured Membrane Properties

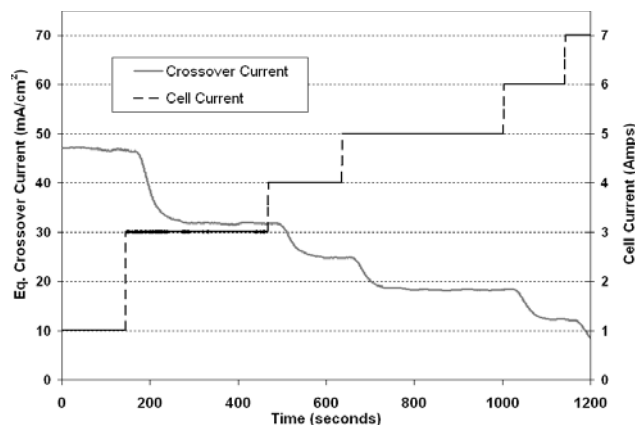
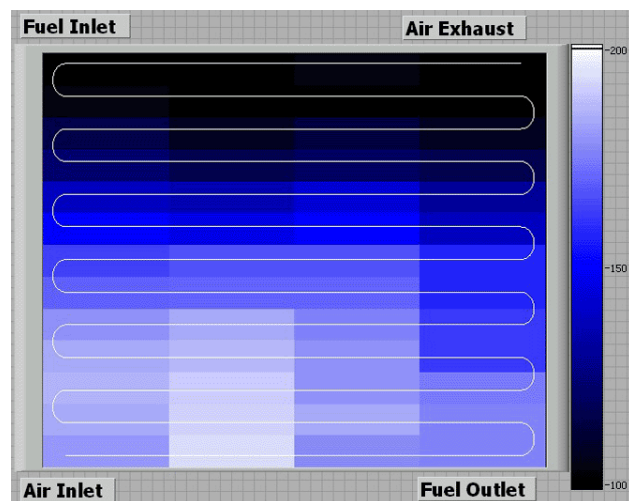
| Membrane Name | Hydrated Conductivity (S/cm) | Swelling (%) | Water Uptake (wt%) | Yield Stress (MPa) | Performance in 1M MeOH* (mW/cm ²) |
|---------------|------------------------------|--------------|--------------------|--------------------|---|
| D505-2 | 0.0321 | 30.3 | 26.7 | 72.6 | 129 |
| D505-3 | 0.0389 | 30.3 | 24.1 | 73.2 | 133 |
| D505-23 | 0.0344 | 36.5 | 25.9 | N/A | 128 |
| D505-26 | 0.0344 | 41.4 | 27.3 | N/A | 131 |
| D505-29 | 0.0394 | 28.6 | 25.0 | 74.0 | 120 |
| D505-30 | 0.0375 | 36.5 | 37.5 | 75.1 | 100 |
| JC67-66 | 0.0259 | 17.7 | 20.4 | 76.4 | 127 |
| JC67-137 | 0.0304 | 39.3 | 23.1 | 72.1 | 133 |

* Conditions: 60°C, Air Stoich 2.5, Fuel Stoich 5.0, Cell Voltage 0.40 V

applied to the hydrocarbon membranes that allows hot bonded MEAs to be formed. There are still several variables to the hot bonding process that are being optimized, but MEAs that do not delaminate when exposed to high concentrations of methanol have been demonstrated.

In order to better understand the internal operations of the test cells, new apparatus was designed to measure methanol crossover real time in a cell. The real time measurements permit a more thorough understanding of the effects of cell conditions (temperature, humidity, reactant flows) on the cell, particularly during transients. The methanol that passes through the membrane from the anode to the cathode is oxidized to carbon dioxide and water at the cathode. The test apparatus uses an infrared-based sensor to measure the CO₂ content of the exhaust after the removal of most of the water and infer the amount of methanol crossover. Figure 1 shows the changes in methanol crossover during load changes. At higher cell currents, there is a greater methanol concentration gradient in the anode GDL and a correspondingly lower crossover current. The figure also illustrates the delay time between the load change and the concentration measurement change due to the dead volume between the cell and the sensor and the response time of the sensor itself.

A second tool that has been developed as a part of this project is a current mapping plate [1]. The plate is inserted into a cell or stack and measures the

**Figure 1.** Real Time Methanol Crossover Current During Load Changes**Figure 2.** Fuel Cell Current Density Distribution Sample

current density distribution flowing through the cell (or stack). There are 44 elements that are 0.5 cm² in area that can take discrete measurements and have an accuracy of about 2 mA/cm². The tool gives very good insight into the operation of the fuel cell under different operating conditions. A very high performing cell has a uniform current density distribution while a low performing cell has a very uneven current density distribution. The tool can show regions receiving insufficient reactants, inactive or damaged catalyst, damage to membrane integrity, and hot/cold zones in the cell. Figure 2 shows operation of a cell with a deliberately reduced air flow. Notice the difference in current density from the cathode inlet to cathode outlet varies by a factor of two as the oxygen concentration drops.

Conclusions

In the first nine months of this project, the requirements have been defined, the cell component requirements have been defined, and a significantly simplified system concept has been selected. The first set of experimental membranes has been cast and measured both in-situ and ex-situ and a method for hot bonding the membrane to the electrodes has been developed. Future work will focus on GDL development and testing of the experimental cells under expected system conditions.

FY 2005 Publications/Presentations

1. B. Wells, 2005 DOE Hydrogen, Fuel Cells, and Infrastructure Technologies Program Review Meeting, May 23-26, 2005, Arlington, VA, Presentation FC33.

References

1. E. Gülzow, S. Schönbauer, "Tools for the Investigation of Current Densities in Fuel Cells", 2003 Fuel Cell Seminar Abstracts pp., Miami Beach, FL, November 3-7, 2003.