IV.H.4 Fiber Optic Temperature Sensors for PEM Fuel Cells

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Ellis Optical Technologies, San Jose, CA
Oregon State University, Corvaillis, OR

Objectives

Based upon inputs from fuel cell developers and end users, the objectives of this research are:

- Demonstrate low cost, durable, and accurate fiber optic temperature sensors in operating fuel cells;
- Optimize sensor performance so that very small thermal gradients can be detected within the gas diffusion layer;
- Develop a sensor platform capable of high spatial resolution thermal mapping of the membrane electrode assembly; and
- Provide precise thermal data to fuel cell developers for model verification.

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. Sensors
- C. Thermal Management

Approach

- Evaluate fiber optic temperature sensor probe designs for accuracy, response time, and durability.
- Through collaboration with industrial partners, design a series of field experiments to determine optimum probe implementation strategies and evaluate performance.
- Conduct field experiments and review data with industrial partners to evaluate performance.
- Identify additional field experiments that maximize thermal information gathering for fuel cell developer model verification.
- Perform data analysis with feedback from industrial partners, complete design for low cost, multi-channel fiber optic temperature measurement system and document.
- Design future experiments to generate enhanced fuel cell model verification data.
- Develop design strategies for high spatial resolution thermal mapping.

Accomplishments

- Demonstrated low cost (<\$100.00), fast responding (<25 millisecond), accurate (<0.25°C), and durable fiber optic temperature measurement system in operating fuel cell.
- Demonstrated both monolithic fiber optic probes and free space temperature measurements in operating fuel cells.
- Demonstrated five-channel fiber optic temperature measurement system in operating fuel cell.
- Demonstrated low spatial resolution thermal mapping in operating fuel cell.
- Identified a potentially high spatial resolution thermal mapping, 2-photon doped fiber temperature measurement and verified in the lab.
- Expanded collaborations to include three fuel cell OEMs for testing.

Future Directions

- Continue field experiments with industrial partners.
- Continue development of high resolution thermal mapping techniques as per input from industrial reviewers.
- Explore emerging possibilities to sense other important parameters or leverage to other related applications (e.g. humidity and flow, other fuel cell types, etc.).

Introduction

The need for accurate, reliable and fast-responding temperature sensors has been identified as a critical need for fuel cells. Temperature, gradients, thermal maps, and thermal history play a key role in determining the health of a fuel cell. Real-time diagnostics allow designers to increase stack power density by reducing operating margins and quickly identify hot spots that reduce operational life.

This project is focused on development of an optical fiber temperature sensor utilizing unique luminescence properties of materials. The persistence of light emitted (luminescence) by these materials is proportional to their absolute temperature. One can measure luminescence lifetime as a means of accurately determining temperature. The technique can be applied over a wide range of temperatures (-270°C to >1700°C) and is potentially very accurate and durable.

Approach

The development process was initiated by an in-depth study of fuel cell designs and operating conditions. A clear picture of the measurement needs and operating environment was gathered and exploratory research was performed to identify and characterize candidate luminescent materials for measurement. These materials were studied in the laboratory and optimum materials were selected. Candidates have now been implemented into probe designs for testing in operating fuel cells. Probe designs resulting from field data are being analyzed to identify design weaknesses, durability issues, failure modes etc. Ongoing experiments are planned to gather information about system compatibility, performance, and durability.

Parallel to the development effort described above, alternate probe/system design and implementation strategies are being conducted with the goal of providing a multi-measurement platform for high fidelity thermal mapping. During this process, two novel discoveries have been made in response to the challenge of creating a measurement technique that would be accurate, reliable and scalable to many measurements distributed throughout the fuel cell. One concept involves development of embedded wave guides within the fuel cell, thus minimizing the need for intrusive probes. The other concept involves a single doped fiber sensor that measures temperature at a selected and localized (<1 cm) region anywhere along its length. This technique may facilitate many temperature measurements throughout a fuel cell stack with a single probe.

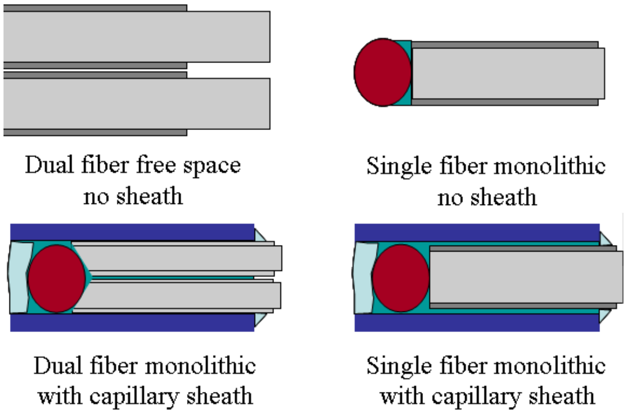

Figure 1. Four Fiber Optic Probe Designs Constructed for Testing

Results

Significant progress has been achieved in a number of areas during this period of performance, including:

1) Probe construction, characterization and validation;
2) Signal processing electronics development;
3) System verification in operating fuel cells;
4) Demonstration of a low-cost system that meets or exceeds all design requirements imposed by the DOE HFCIT Multi-Year R,D&D Plan and additional performance requirements imposed by industrial partners; and
5) Development of a high spatial resolution thermal mapping concept utilizing counter-propagating 2-photon excitation within a doped optical fiber.

Figure 1 depicts four probe concepts. Initial experiments included three dual fiber, free space, no sheath probes, and two single fiber, monolithic, no sheath probes. Probes were installed as proposed by one of our industrial partners. Their location was chosen to ascertain whether thermal gradients are supported across a cell. Figure 2 shows three of the actual probes that were installed. The dual fiber probes were utilized to look across the flow channel at deposited luminescent material on the gas diffusion layer.

Figure 3 depicts the luminescent decay from one probe along with transformed signal output from the signal processing. Instead of performing computationally intensive curve-fitting to accurately

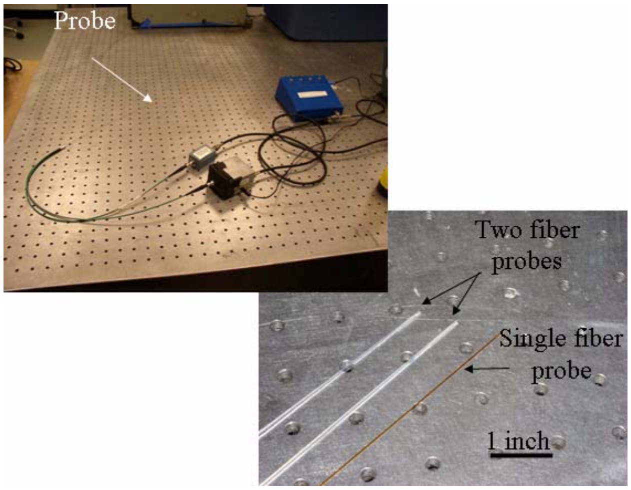

Figure 2. Photographs of Actual Probes Used in Field Experiments

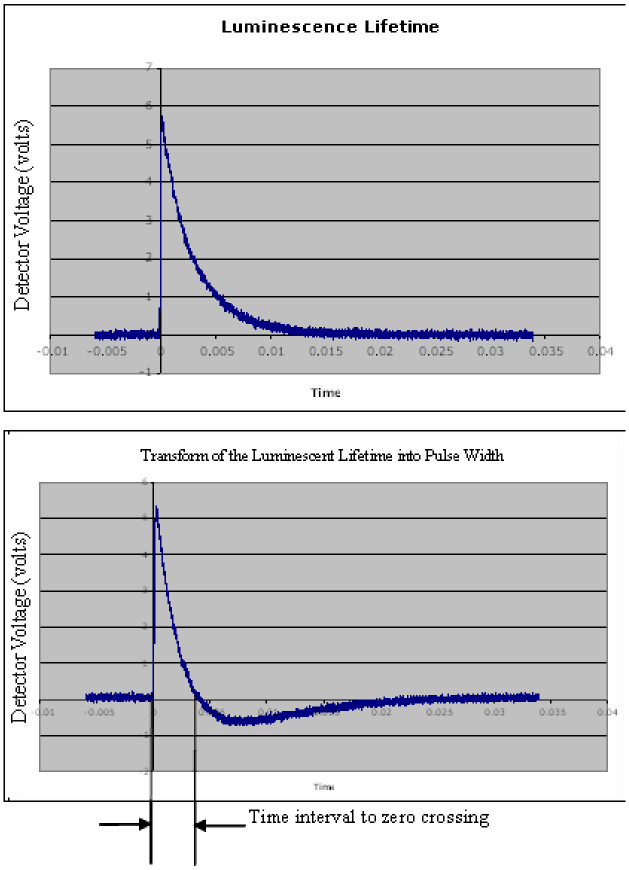

Figure 3. TOP: Luminescent Decay Signal Received From Fiber Optic Probe;
BOTTOM: Transformed Luminescent Decay into Pulse Width

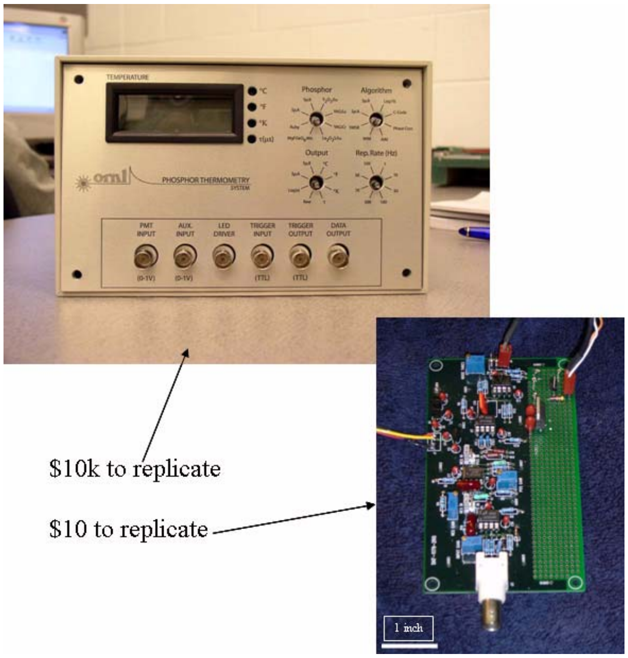

Figure 4. Signal Processing Electronics Package Showing Significant Size and Cost Reduction

determine the luminescent decay lifetime from the exponential curve shown at the top, the signal processing electronics converts the lifetime into a proportional pulse width. The pulse width is calibrated versus temperature and stored in a look-up table.

The signal processing electronics developed for the transformation process were developed with two goals in mind: 1) low cost and 2) high signal-to-noise ratio for determining temperature accurately. Figure 4 shows the progression from a signal processing development platform to a prototype circuit board as the pulse width conversion technique was implemented.

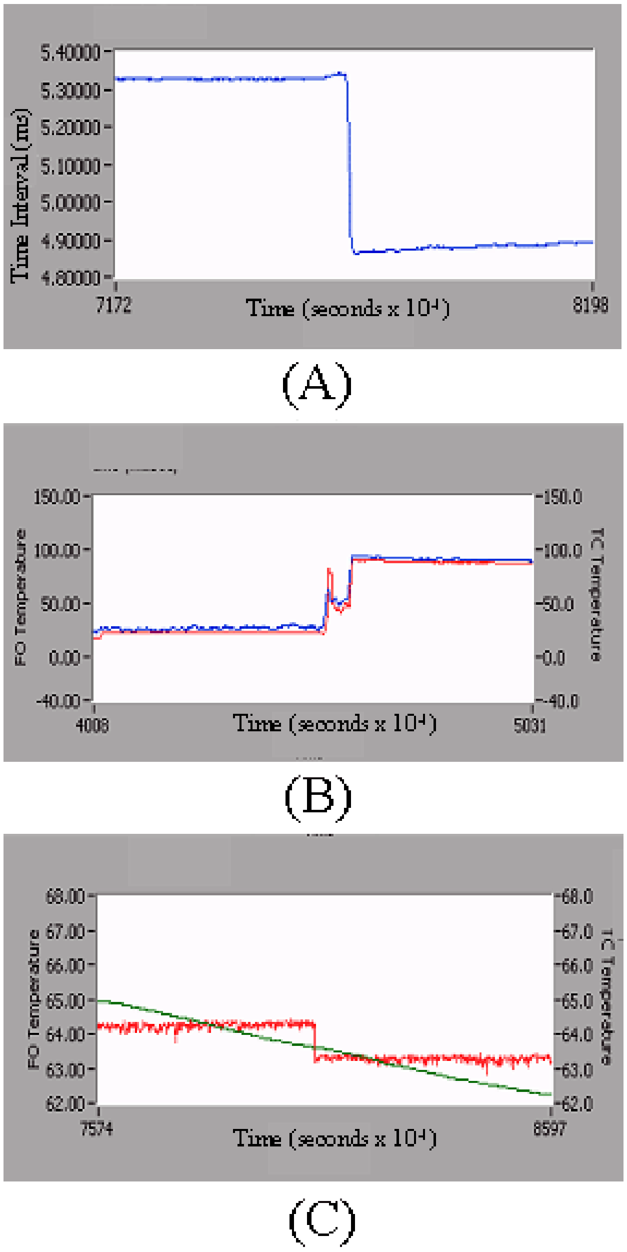

Figure 5. System Performance Data Including: **(A)** optical fiber probe system step response for a 60°C step; **(B)** the fiber optic probe 67°C step response compared to type-K thermocouple (notice the thermocouple overshoot); and **(C)** a gradual cool-down curve showing both the fiber probe and the thermocouple (notice the thermocouple output shows a step change due to the analog-to-digital converter readout device).

Figure 5 below illustrates the performance of an unsheathed monolithic probe. Figure 5A illustrates the step response. Step response in the lab is >100°C/second and the time response of the system is ultimately limited by the luminescent lifetime of the transducer. Our system practical response time will be 15 to 20 milliseconds. Figure 5B shows performance compared to a thermocouple. The thermocouple reading overshoots due to the digitization of the readout device. Figure 5C displays a cool-down curve being tracked precisely. The thermocouple reader suffers from digitization error and is noisier than the fiber optic equivalent.

Considerable progress has also been made on a novel temperature mapping technique that utilizes counter-propagating ultra-short light pulses, launched down opposite ends of a doped optical fiber. This technique leverages the unique properties of certain materials that only undergo luminescence via specific allowed energy transitions requiring two-photon excitation. By controlling the timing of the counter-propagating pulses and the width of the pulses, in principle a single fiber optic temperature sensor could be constructed that enables 1 millimeter spatial resolution and 0.1°C temperature accuracy.

Conclusions

1. Probe designs have been validated in the lab and operating fuel cells.
2. Low cost electronics for system readout have been demonstrated.
3. Field experiments show probe designs are robust and perform well over 100 hours of operation.
4. Significant progress toward the goal of a low-cost (<$100), durable (>100 hours) and accurate (<1.0°C) temperature measurement system for PEM fuel cells.
5. High fidelity thermal mapping is being pursued; a multi-sensor implementation has been demonstrated with the low-cost system that enables low-density thermal mapping.
6. Longer term field testing is still needed to fully verify material compatibility between the fuel cell and the sensor probes and to characterize probe durability.

FY 2004 Publications/Presentations

1. Presentation titled “Fiber Optic Temperature Sensors for PEM Fuel Cells” was presented at the Department of Energy Hydrogen, Fuel Cells, and Infrastructure Program Review Meeting in Philadelphia, PA.

2. Paper presented titled “Progress Report on Fiber Optic Temperature Sensors for PEM Fuels” at the Fuel Cell Expo in San Antonio, TX.

3. Paper titled “Converting Luminescence Decay to Pulse Width for Accurate Determination of Temperature” submitted to the IEEE Journal of Electronics.

Special Recognitions & Awards/Patents Issued

1. A patent disclosure has been filed on embedded wave guide sensors.

2. A patent disclosure has been filed on spatially resolved fiber optic temperature measurement.