Fiber Optic Temperature Sensor for PEM Fuel Cells

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Program Goals: Temperature Sensing

Program Target
- Operating Range: -40 to 150 C
- Response time: <0.5 sec with 1.5% accuracy (-40 to 100 C)
  <1 sec with 2 % accuracy (100 to 150 C)
- Gas environment
- Insensitive to flow velocity

Demonstrated by ORNL
- Operating Range: -250 to 1700 C
- Response time: <0.001 sec with 1.0% accuracy (-0 to 750 C)
- Gas environment: inside operating jet engine, induction furnace,
  and many laboratory atmospheres including PEM/MEA
- Insensitive to flow velocity: needs to be tested
Project Objectives

• Develop a low cost, robust temperature sensor for monitoring fuel cell condition and performance;
• Develop a fiber optic probe that could provide intra-cell thermal information;
  • thermal mapping;
  • location of hot spots;
• Develop a low-cost architecture for integrating the FO temperature sensor into the fuel cell control electronics -> plug-and-play modular design; and
• Establish a partnership with an approved equipment vendor to facilitate technology commercialization and implementation.
Why a Waveguide Temperature Sensor?

- **Reliability** - fiber optic sensors are immune to oxidizing or reducing atmospheres, they are electrical insulators and don’t drift over time
- **Speed** - temperature measurements can be made in milli- to micro-seconds
- **Simplicity** - a fluorescent material, optical waveguide, LED, detector and some simple signal processing are all that is required
- **Cost** - the production cost is potentially very low, <$5.00
- **Flexibility** - our concepts will provide single point or multiple measurements of temperature and may enable measurement of other parameters (e.g. thermal gradients, stack compression uniformity and humidity)
Approach: Fluorescence Temperature Sensing

- Atoms in a matrix have electrons thermally excited
- Excited electrons de-excite
  - Radiative and Non-radiative processes compete
  - Non-radiative process increases with temperature
- Time characteristic of the net radiative de-excitation indicates temperature

We will exploit this radiative (fluorescence) behavior to measure temperature.
Approach: Fluorescence Temperature Sensing

Temperature sensitive phosphor illuminated by excitation light from LED or laser diode

Phosphor glows. If excited by a short pulse, the glow duration indicates temperature. If excited by an oscillating signal, temperature is indicated by phase shift.

\[ \tan(\phi) = 2\pi f \tau \quad \text{where} \quad \tau = f(T) \]
Choosing the best phosphor for the measurement of interest is critical.
Approach: Our Current Laboratory Setup

Fuel cell demo kit with 400 micron fiber inserted.

Demonstrated a temperature measurement without causing degradation to fuel cell performance.
Approach: Some Preliminary Probe Data

Signals from Phosphor-tipped Fibers

- 400 μm single fiber tipped with Gd$_2$O$_2$S:Eu
- excited by 375 nm Nichia LED

- YAG:Cr in the Fuel Cell
- detected with metal coated
- 400 micron fiber LED at 405 nm

Graphs showing amplitudes and times for different conditions.

- 5KΩ termination
- 4 volt TTL 1 ms duration
- room temperature 25°C
- hot tap water 48°C
- water heated w/microwave oven 88°C

- Signals for two different pulse widths constant temperature
Approach: Our Future Setup to Explore Probe Designs
Approach: Various Probe Options Will Be Explored

Ways to exploit the concept of fluorescence in conjunction with optical fibers for measuring temperature

- Phosphors coated onto fiber end and side provide highly localized temperature sensing
- Rare earth doped fiber provides increased signal and offers novel sensing method
Some Advanced Concepts are Emerging

Two Photon Excitation

Embedded Micro-structures in PEM
(Initial test sample)

Micro-structures

Arbitrary section of NaFion

125 Micron cross section
Accomplishments

Project Began in January, 2003

• Identified and tested several effective phosphors and crystals.
• Fibers as small as 50 micron core/110 micron clad have been used in probe trade-off studies.
• Operated demonstrator fuel cell with phosphor deposited on PEM and fiber probe inserted.
  • Verified no degradation to FC operation
  • Attempting to measure very small internal temperature changes caused by operation of cell (200mW power output)
• Identified some novel probe/measurement options that may lead to very precise and low cost sensor options.
Collaboration Efforts

We are Already Working with:

• FreedomCAR Tech Team and Big-3 delegates to gain insight into system-level functional requirements;
• Fuel cell developers to understand implementation strategies and specific operational measurement needs;
• PNNL to fabricate custom fibers for studies;
• NuFern and Translume to develop sensor concepts and advanced concepts that may lead to novel, low cost and versatile probe designs;
Key Milestones

12 months
- Probe Fabrication: complete probe design
- Testing and Evaluation: demonstrate probe performance
- Opto-electronics System: demonstrate opto-electronics, achieve + or - 1°C system performance

24 months
- Integrated System Test & Evaluation

36 months
- Successfully complete field trial

Project Milestone
Future Plans

- Continue expanding our collaboration activities to ensure maximum benefit is provided to FC developers and end users - need more input from designers and end users.
- Need access to prototype MEAs or detailed guidance to fully explore the design space - HELP!
- Our plans include a parallel development effort on probe designs
  - Simple terminal sensing to prove concept
  - Advanced designs to push the utility envelope
- We think we can measure other parameters with the same or similar sensor implementation - we need your input.