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Fiber Optic Temperature Sensors for PEM Fuel Cells

T. J. McIntyre,
S.W. Allison, M.R. Cates, S.M. Goedeke, L.C. Maxey,
W.P. Partridge,

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

Fiber Optic Temperature Sensors for PEM Fuel Cells

- **Program Objectives**
- **Luminescence Thermometry Fundamentals**
- **PEM Fuel Cell Measurement Methods**
- **Discussion of Experimental Results**
- **Future Directions**

PEM Fuel Cell Measurement Objectives

Provide measurement and diagnostic tools to fuel cell developers

- **In-situ measurement of temperature distributions**
- **Characterization of temperature transient events**
- **Evaluation of conditions affecting water transport**
- **Validation of temperature models**
- **Identification of operational or design limitations**

Luminescence Thermometry Measures Temperatures Optically

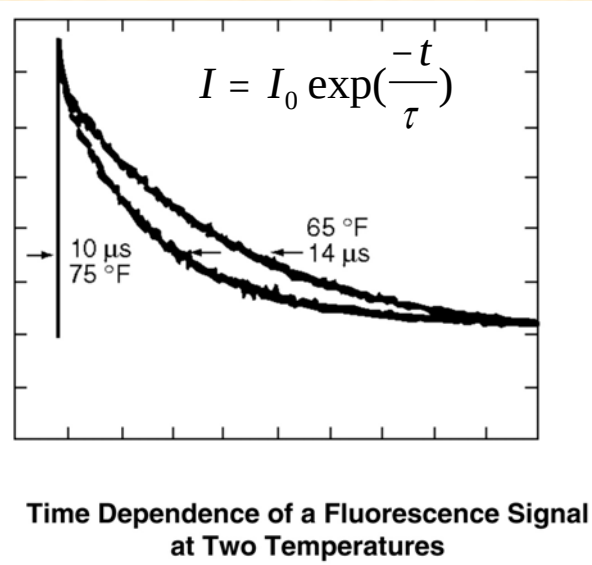
- **Luminescence decay time varies inversely with changes in absolute temperature**
- **Luminescent materials can be selected for various temperature ranges**
- **Excitation sources may be pulsed (laser or LED) or continuously modulated (e.g. sine wave)**
- **Applicable in many harsh environments**

Luminescence Thermometry Fundamentals

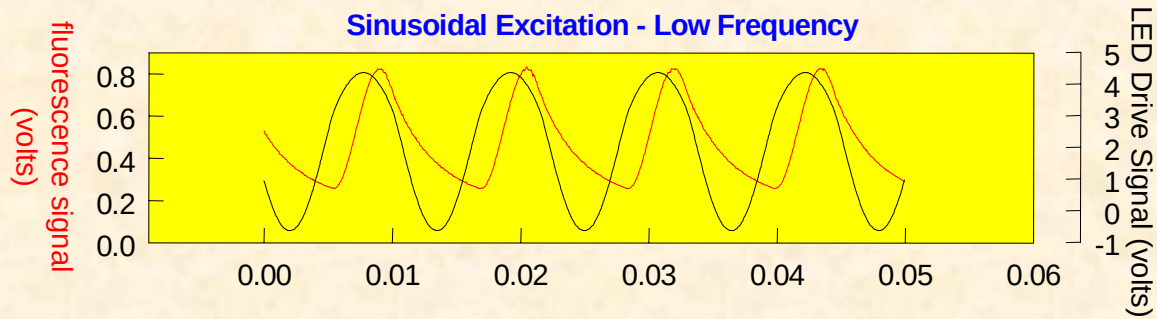
Temperature sensitive phosphor illuminated by excitation light from LED or laser diode

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.

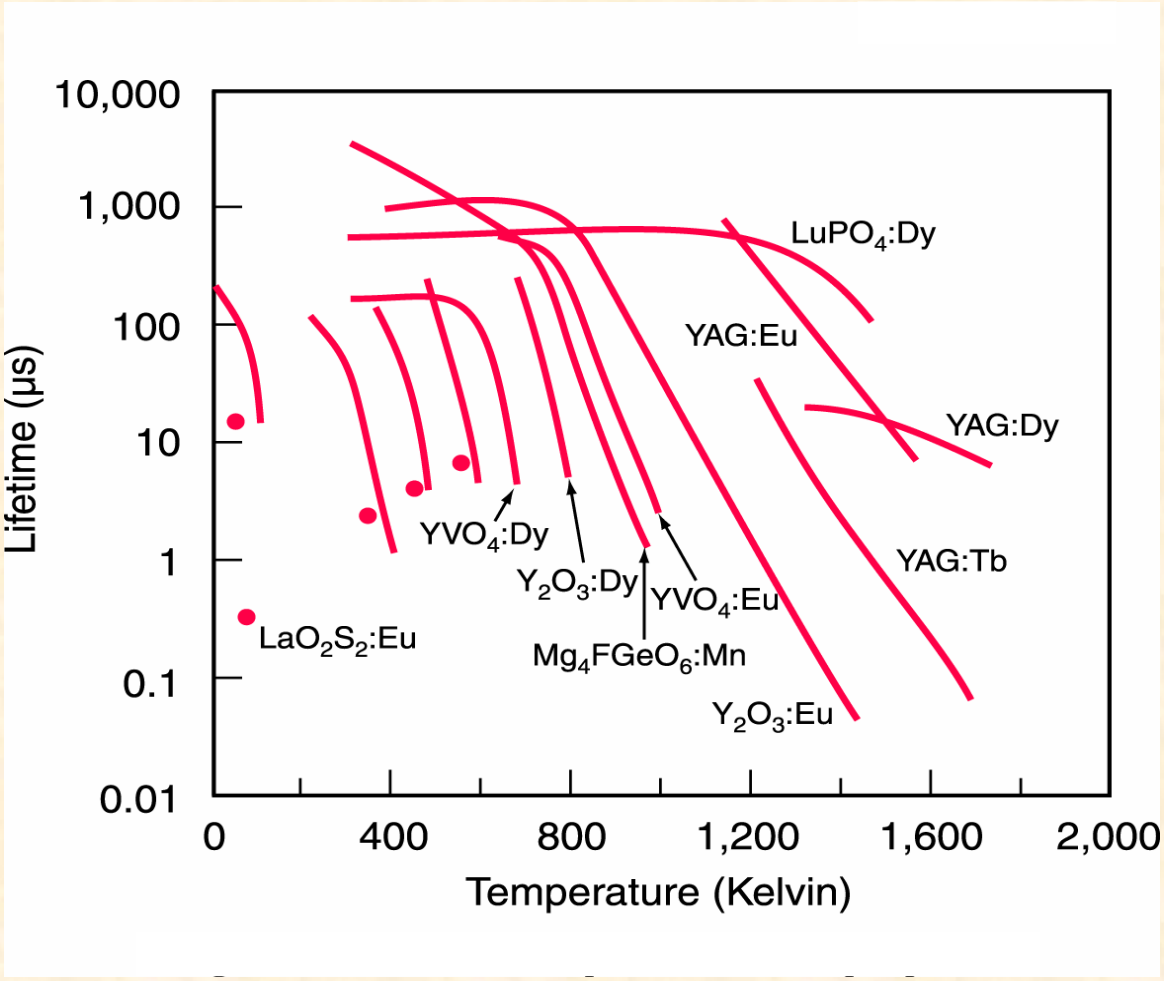
$$\tan(\phi) = 2\,\pi\,f\,\tau \qquad \text{where } \tau = f(T)$$



Time Dependence of a Fluorescence Signal at Two Temperatures

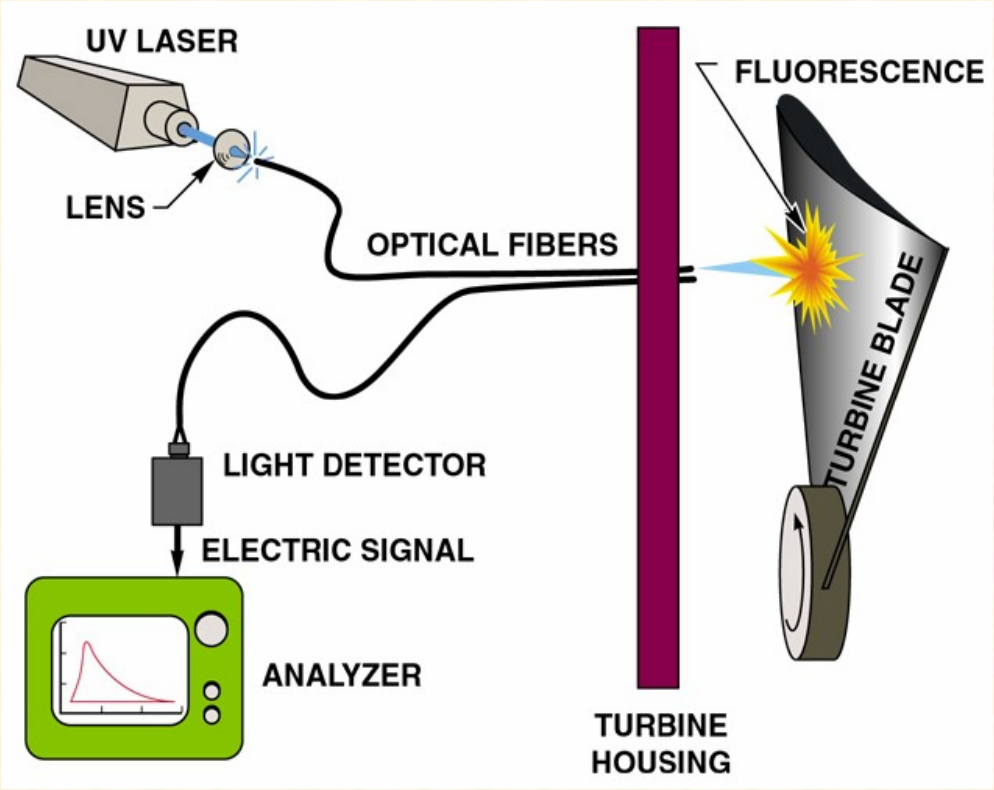


Phosphors may be selected for a wide variety of temperature ranges



Luminescence Thermometry Example

Temperature is sensed by measuring luminescence properties of phosphors coated onto end of optical fiber or on other surfaces



Generic turbine application illustration

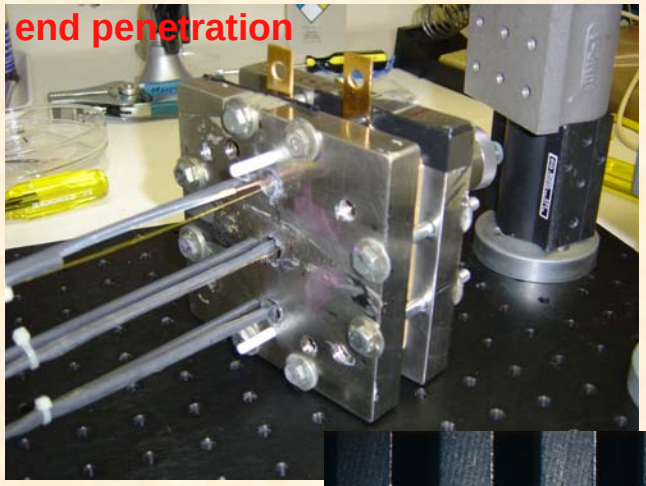
Red fluorescence of phosphor stripes visible through flame

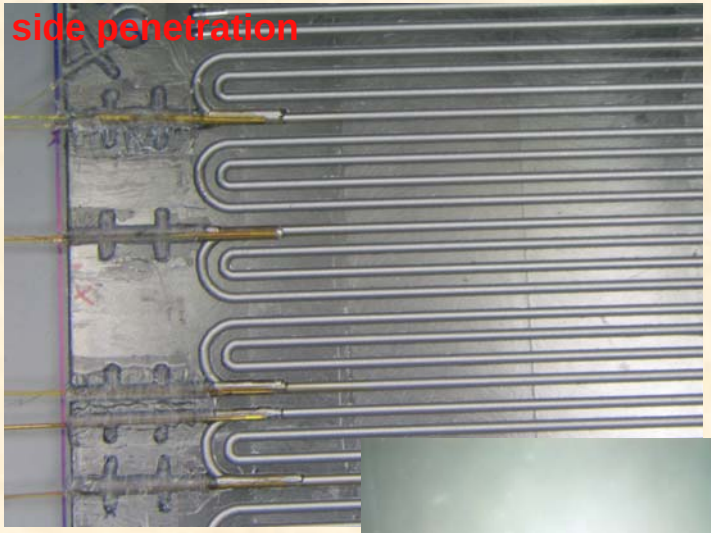
PEM Fuel Cell Measurement Challenges

- **Chemically sensitive membrane and catalyst**
  - **Many chemicals can poison the cell, making it inactive**
  - **All adhesives, sealants, etc. must be approved**
  - **There is no general set of "approved" materials**
- **Potentially harsh operating environment**
  - **Both oxidizing and reducing conditions may be present**
- **Measurement methods must not affect gas flow**
  - **Small probe geometries are needed**
  - **penetration via side or endplates each have challenges**
  - **only side penetrations are viable for assembled stacks**

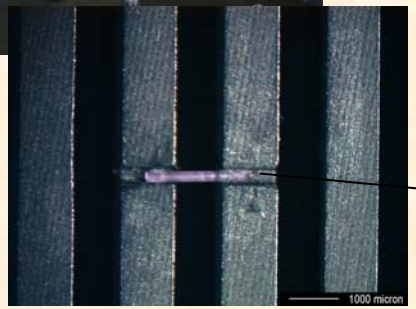
PEM Fuel Cell Measurement Methods

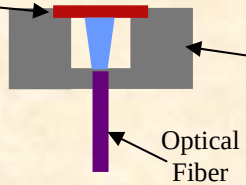
- **Construct free-space and monolithic sensors w/micro-ruby transducers**
- **Instrument fuel cells with both side and end penetrations**
- **Obtain data during various operating conditions**





Fuel cell courtesy of plug power



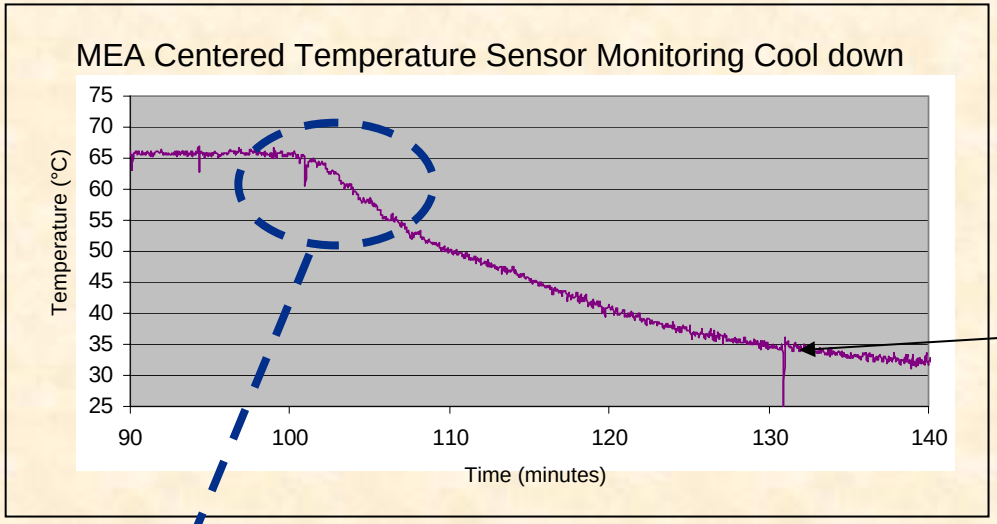


Free-space Configuration

Monolithic Probe Configuration

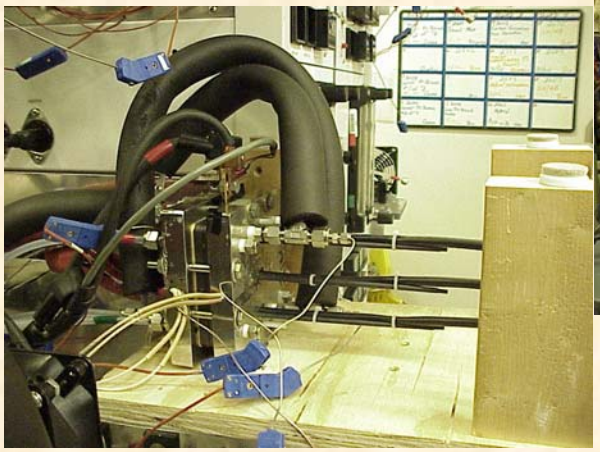
Fuel Cell Tests - Plug Power Inc

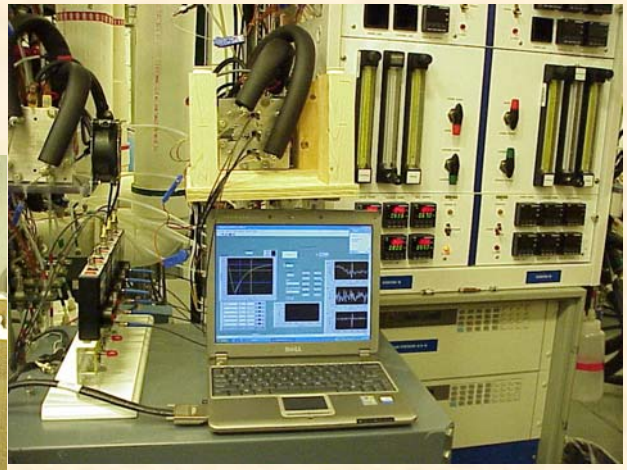
Free-space probe "sees" water droplet passage, yielding additional information



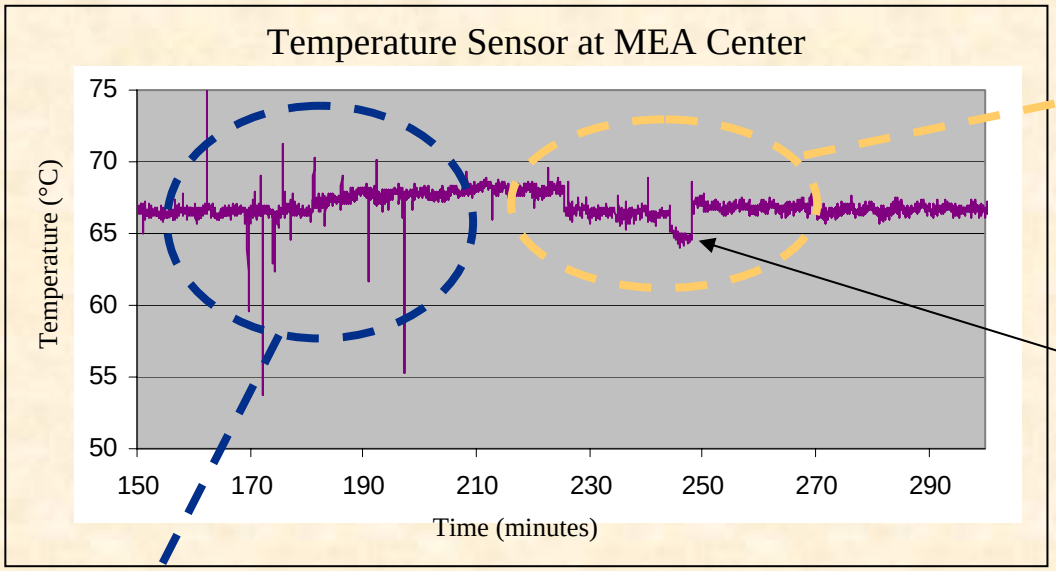
Water droplet passing sensor due to nitrogen purge

Water droplet events observed prior to shutdown



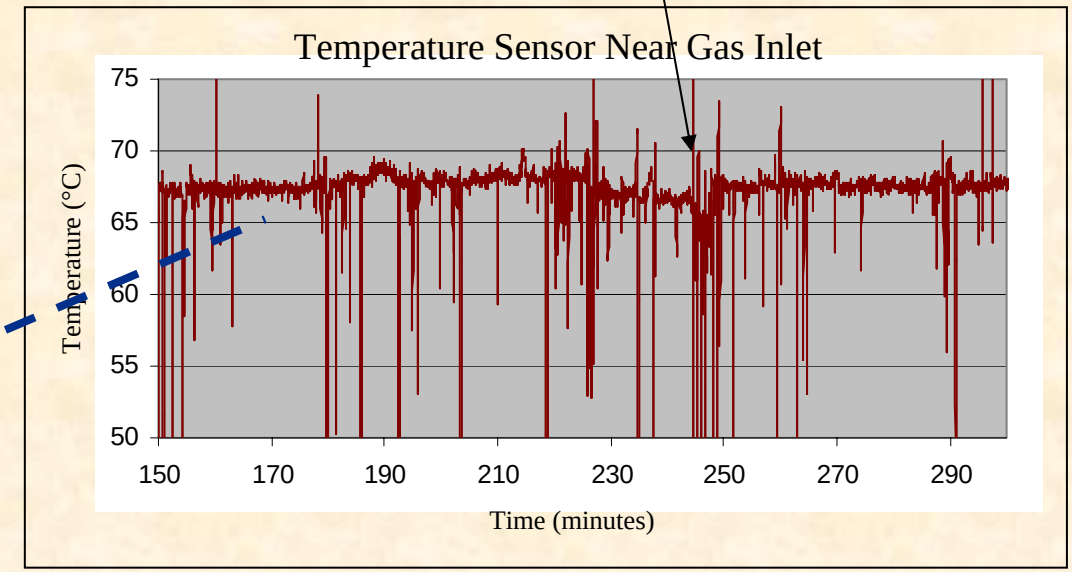


Thermography Data from Experiments at Plug Power



Cell temperature varies with applied load and operating parameters

Sensors show similar trends in fuel cell temperature.

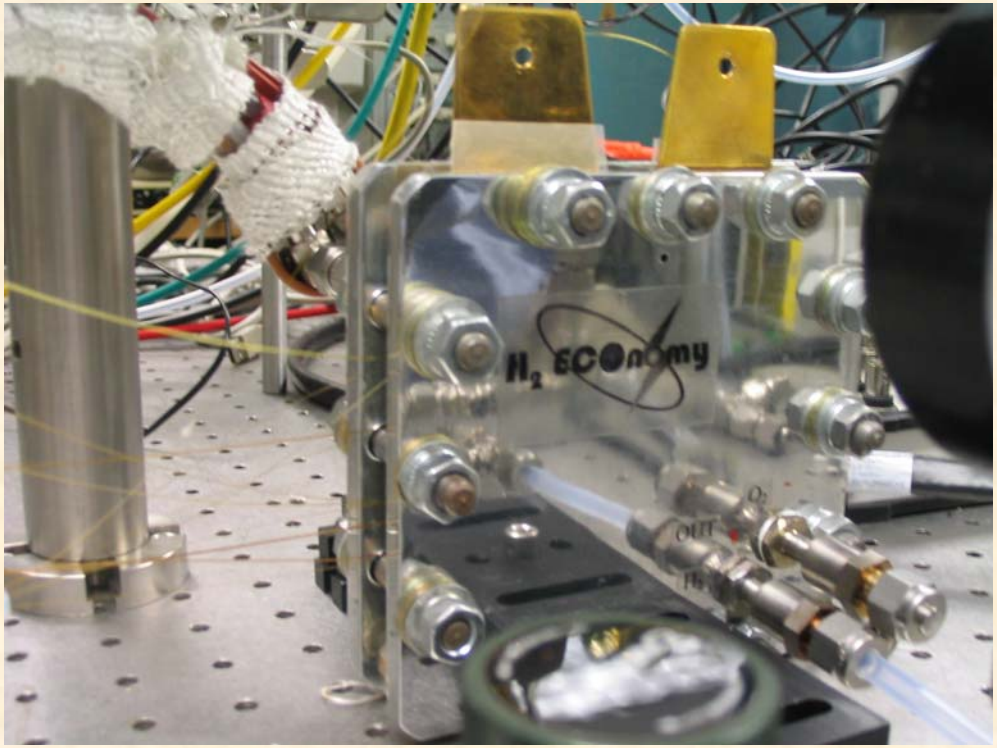


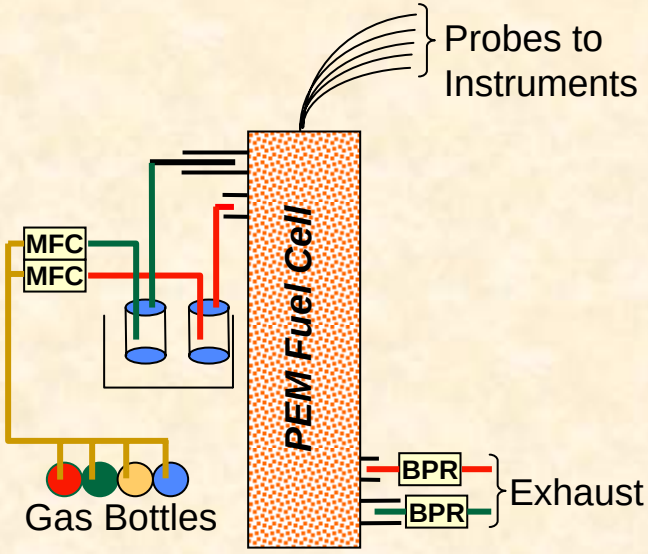
Water droplet formation rate varies with operating parameters

and position in cell

Fuel Cell Test Platform - ORNL

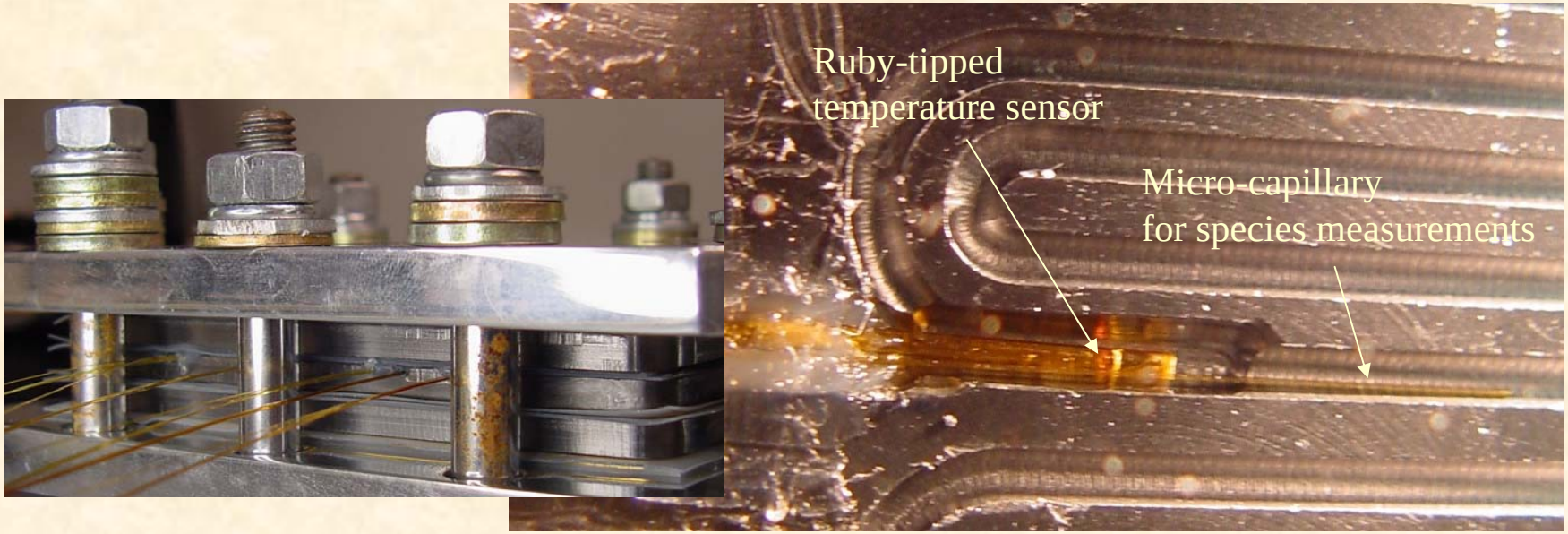
- Commercially available 2-cell stack
- 7-cm x 7-cm active area per cell
- Flow path: 13-pass, 918-mm dual-serpentine, crossed anode-cathode flows, ~1.27-mm diameter half channel, 0.633-mm^2 flow area



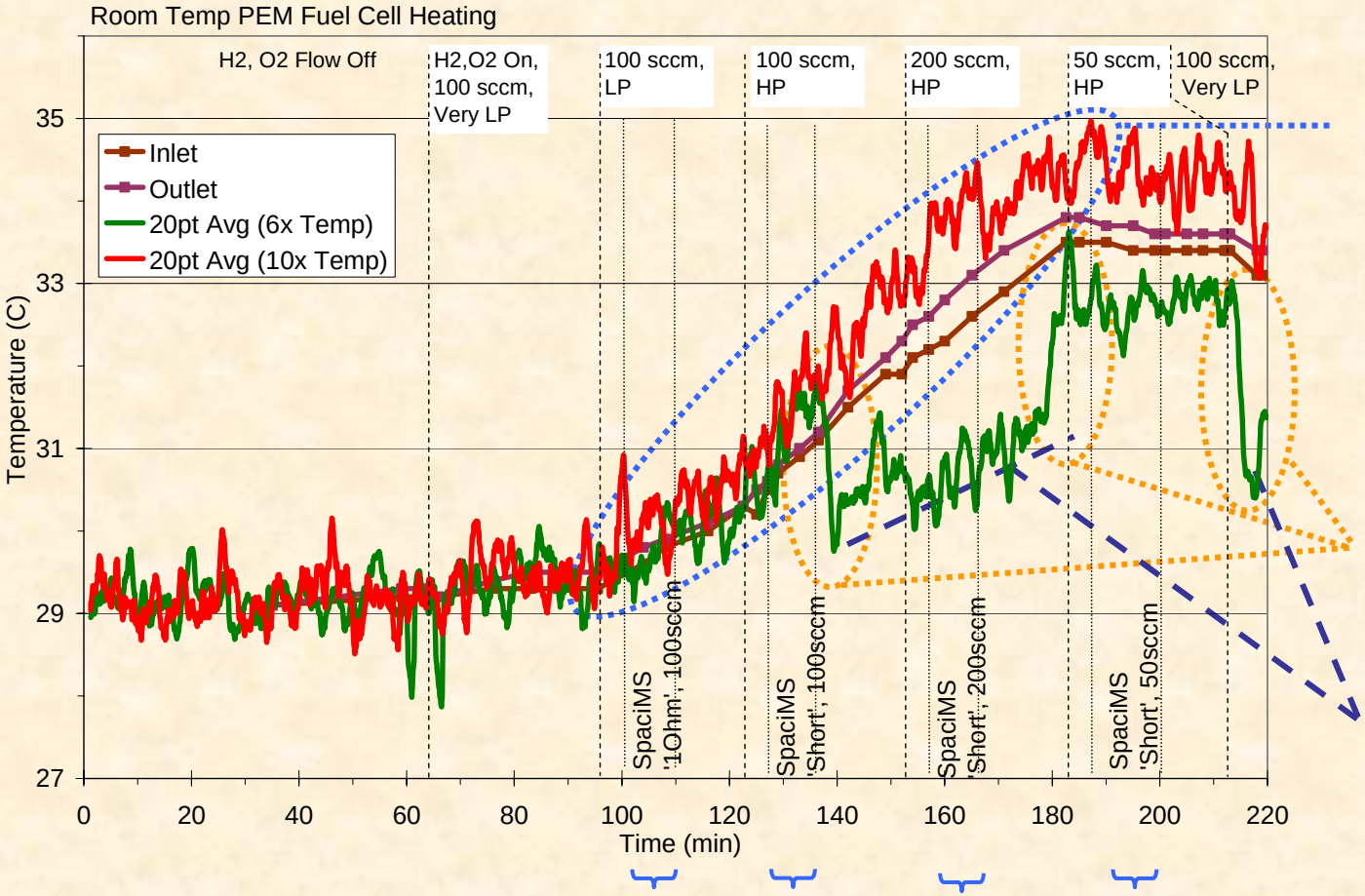


Probe Access for Fuel Cell Stack Measurements

- Fiber and capillary probes were installed at the inlet, 2x, 6x, 8x, 10x, (0, 0.2, 0.4, 0.6, 0.8, and 1L) and outlet positions
- Temperature Probes ~0.4-mm OD: 19.9% flow area (next generation 80 micron probe: 0.8% flow area)
- Thermocouples at fuel cell inlet and outlet



Phosphor Thermography Resolves Transient Intra Fuel Cell Temperature Distributions



Slow heating, ~5°C/hr

Fast Transients occur on 1-2 minute timescale

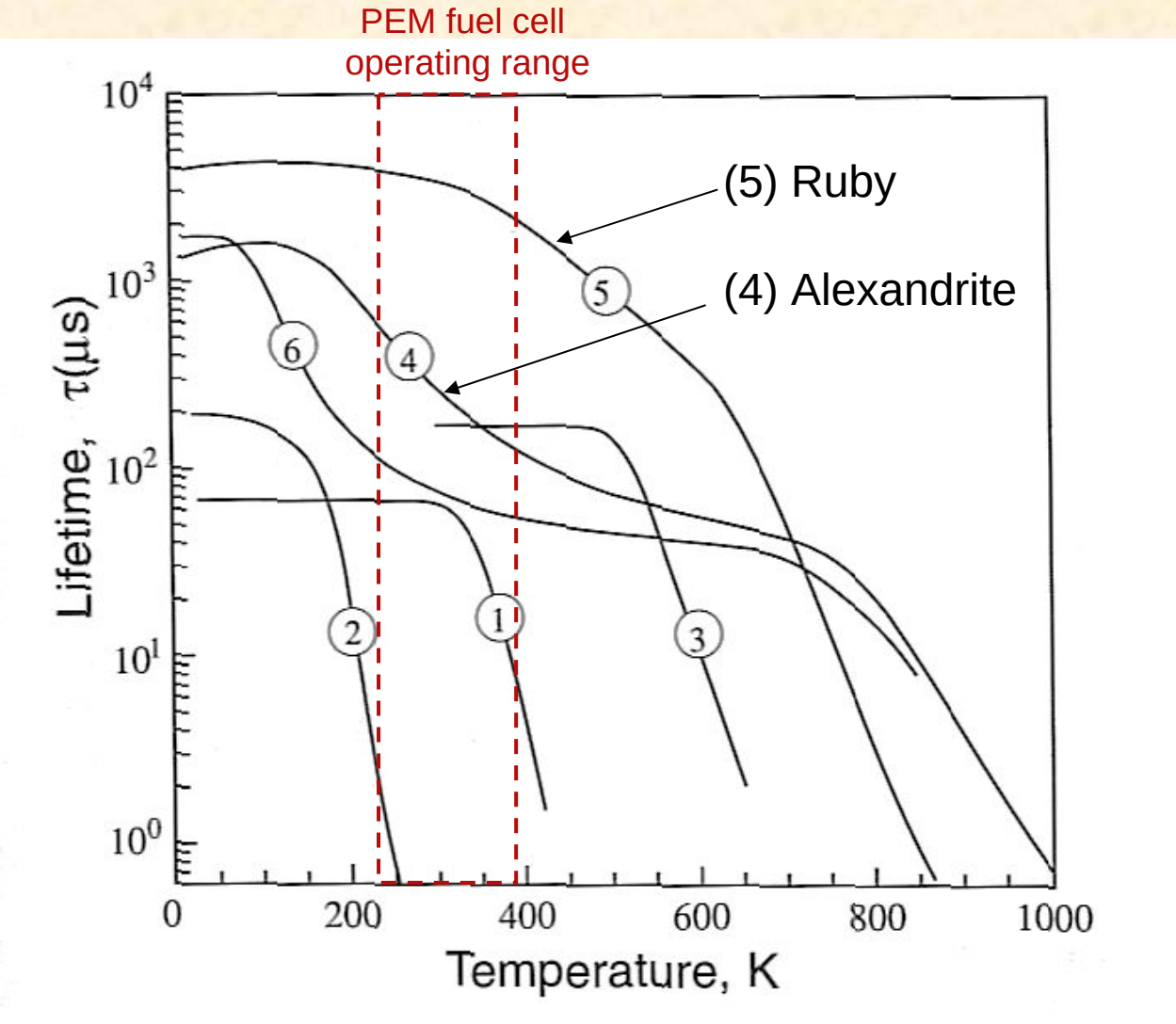
Intermittent cooling event(s)

Species Measurements

Discussion of results to date

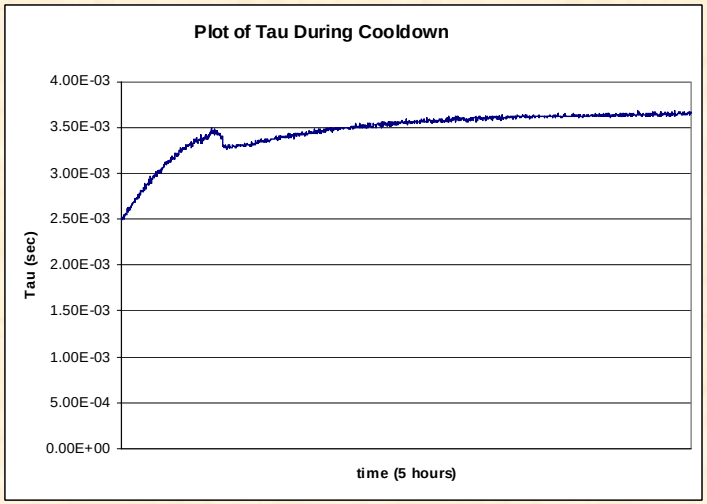
- **Temperature measurements in both experimental platforms have provided insights into fuel cell operating dynamics**
- **Ruby-based probes have been useful for preliminary experiments**
- **Two specific issues suggest an alternate luminescent medium may be preferred**
  - **Temperature resolution (+/-1ºC noise)**
  - **Anomalous calibration shifts**

Alexandrite may offer sensitivity advantages



Spontaneous calibration shifts have occurred with the ruby sensors

After observing these events, research revealed that others (Hu, et al.) have observed variations in decay time when large ruby elements were used. Absorption and re-emission is the probable mechanism. Variations in optical coupling could affect the performance of ruby elements.



Example of spontaneous calibration shift in ruby-based sensor

No reports of similar observations have been encountered for Alexandrite

Future Directions

- **Further refinement of optical sensors and signal processing is on-going**
- **Integration of other sensing options (e.g. spatially resolved capillary mass spectrometer) is providing greater depth of information related to fuel cell operating parameters**
- **Development of sensor enhancements to provide humidity sensing and water transport information are of significant interest**