University of Pittsburgh

Kick-off Meeting

DE-FE0031175: Robust Optical Sensor Technology for Real-Time Monitoring of Solid Oxide Fuel Cells with High Spatial Resolutions

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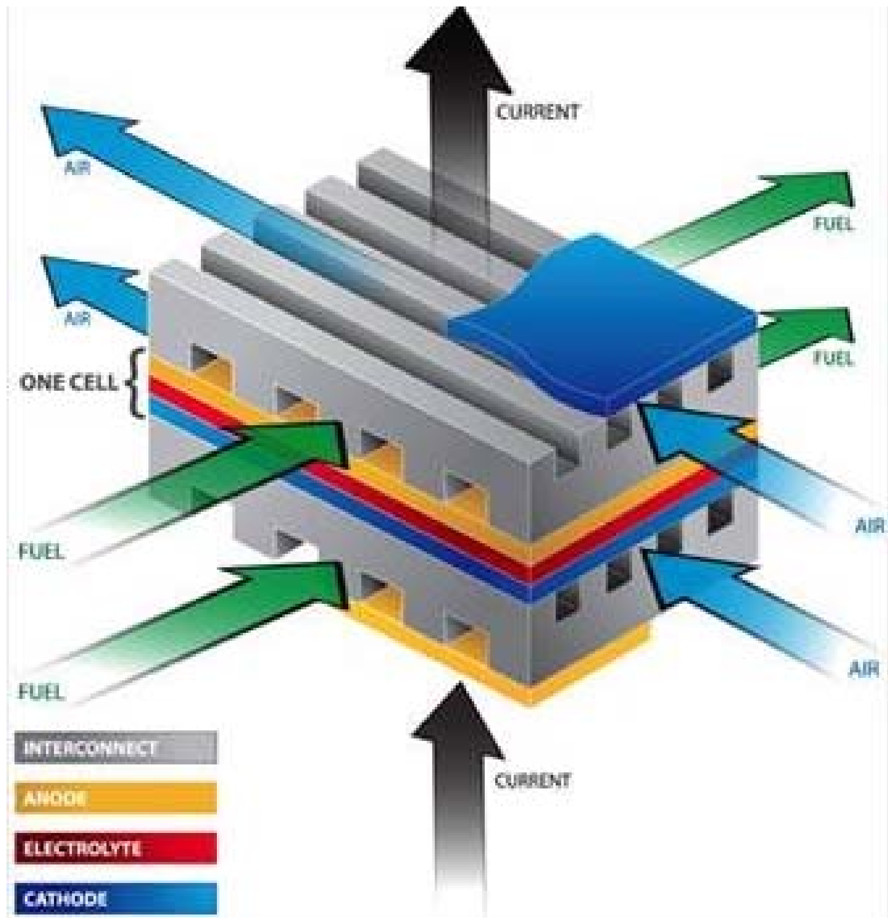
Outlines

- **Background**
- **Objective/Vision**
- **Team Description and Assignments**
- **Project Structures and Task Descriptions**
  - Objective
  - Previous Works
  - Current Status
- **Gantt Chart: Schedules**
- **Project Management Plan**

Solid Oxide Fuel Cell Basics: Fuel-in Electricity Out

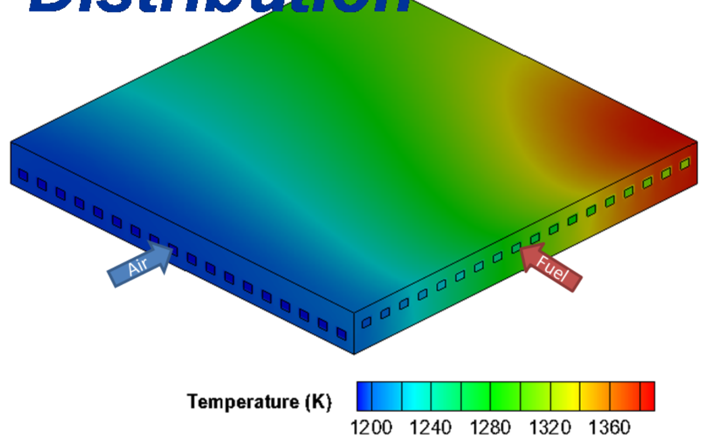
- **High-temperature (600-850C) operation**
- **Varying atmospheres**
- **0-100% H_2 at the Anode**
- **0-20% O_2 at the Cathode**
- **High current / stack voltage**
- **60% efficient (fuel to electric)**
- **One of major hope for fossil fuel energy**



Objective/Vision: Probing Operations of SOFC with High Spatial Resolution

- **Develop an integrated sensor solution to perform direct and simultaneous measurements of temperature and strain profile with 5-mm spatial resolution during SOFC operations to understand factors impacts to its operations and longevity.**

Example : Solid Oxide Fuel Cells Internal Gas and Temperature Distribution

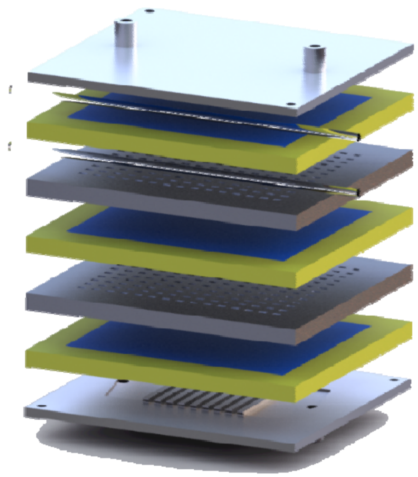


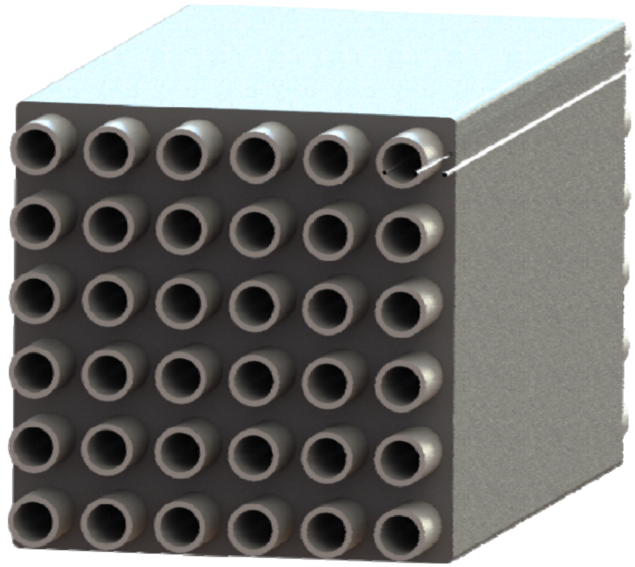
Pakalapati, S. R., 'A New Reduced Order Model for Solid Oxide Fuel Cells,' Ph.D Thesis, Department of Mechanical and Aerospace Engineering, West Virginia University, Morgantown, WV

- **Fuel consumption not uniform**
- **T profile not uniform (>150C)**

Fully embedded Sensor in Fuel Cell Structures!

- **Fusion of fiber sensors in Fuel-Cell interconnect via 3D printing**
- **Perform strain and temperature measurements**
- **Perform high-spatial resolution measurement in fuel cell stacks (Team up with WATTS Technology)**
- **Perform measurement over long-term.**





- **Fiber Optics Sensors**
  - Miniaturized sensors: fully embeddable
  - Harsh environment resilience (up to 900C)
  - High spatial resolution measurements

Team Description and Assignments

- **University of Pittsburgh: PI: Kevin P. Chen**
  - Thomas Boyer (Ph.D. student): Sensor manufacturing
  - Rongtao Cao (Ph.D. student): Sensor Platform
  - Guangquang Liang (Research fellow): Integration and additive manufacturing
- **NETL Collaborators**
  - Drs. Paul Ohodnicki and Michael Buric's group: Sensor Platform (Silica and Sapphire) and Integration
  - NETL Fuel Cell Testing Team
- **Industry Collaborators**
  - Corning: Specialty fiber fabrication
  - WATTS Technology Inc: sensor implementation and test
  - NEC America: Industry outreach (large scale)

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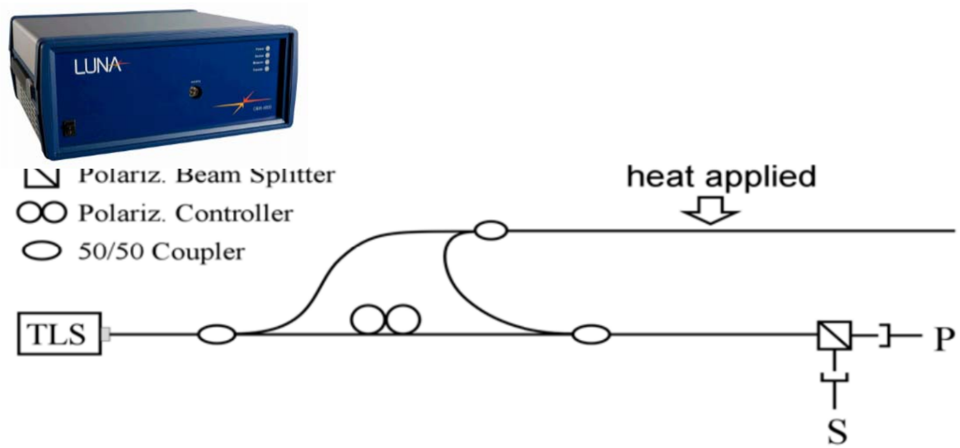
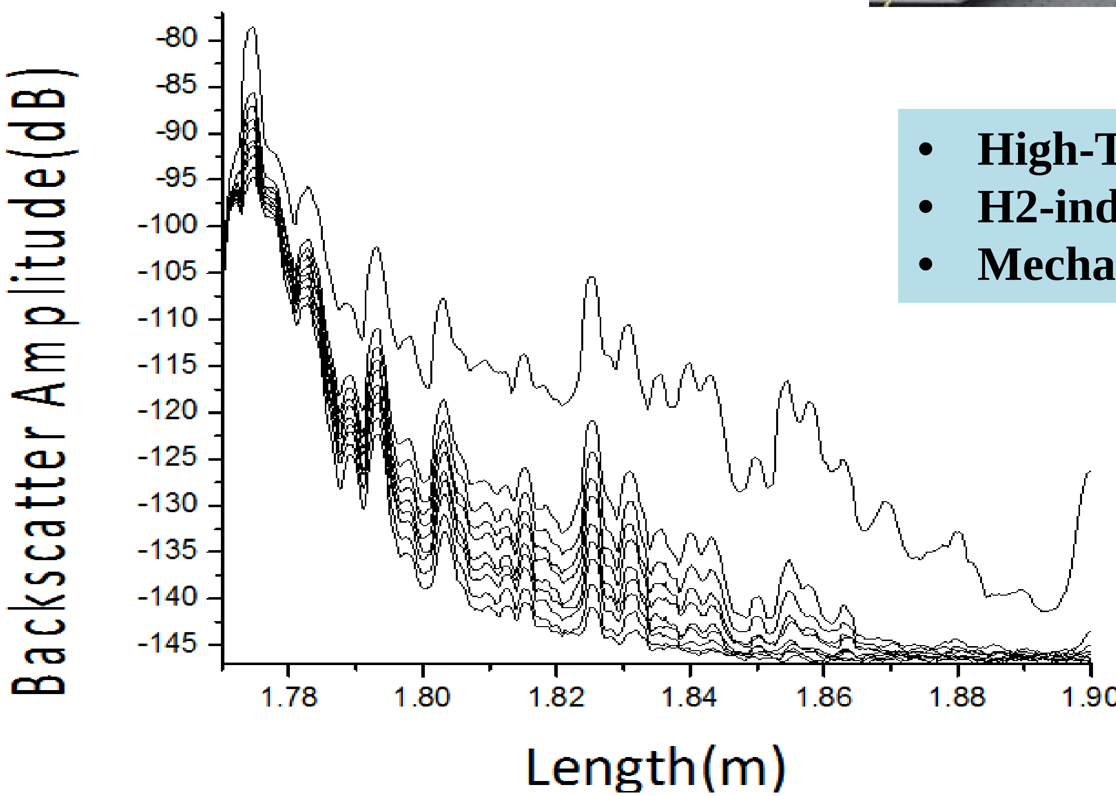
Distributed Fiber Sensor Failed at high-T





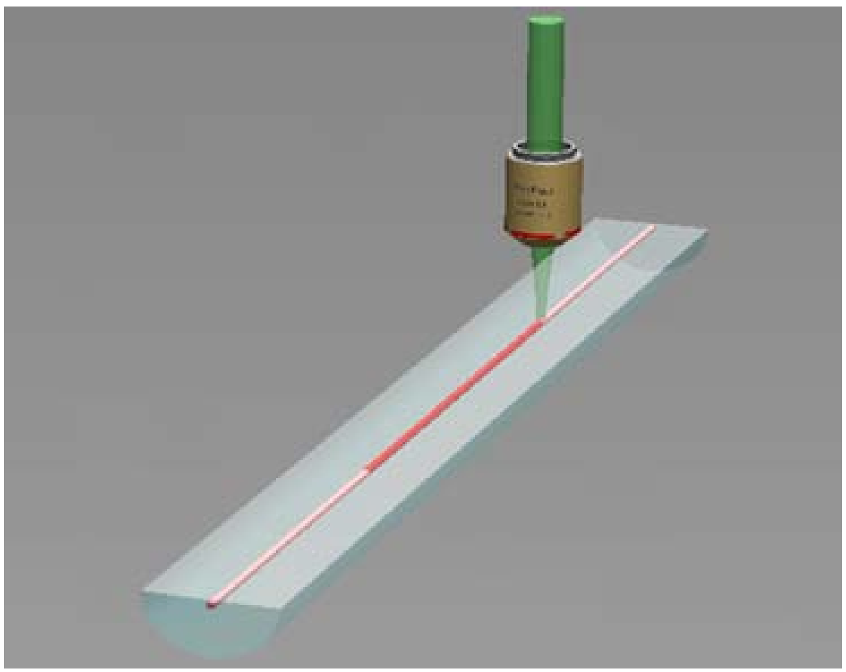
- **High-T modifies fiber structures**
- **H2-induced chemical reactors**
- **Mechanical degradation**

Developments of Distributed high-T fibers

Our fiber is too "good" for sensing applications…

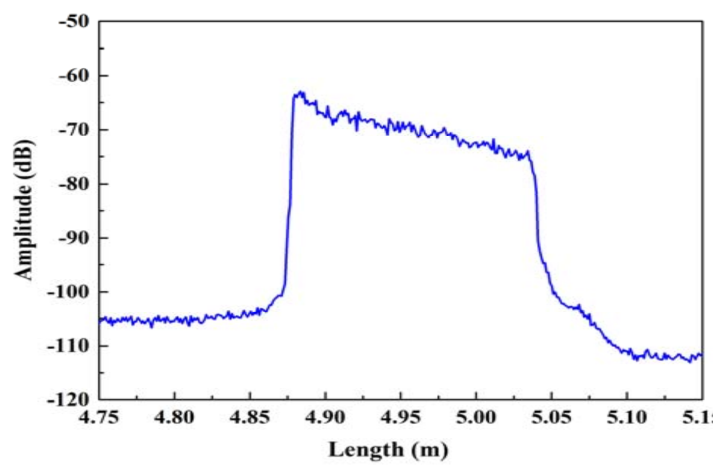
Rayleigh scattering profile is too weak (like weak type I FBG)

Technical Solutions… Enhanced Backgroundd Rayleigh Scattering …

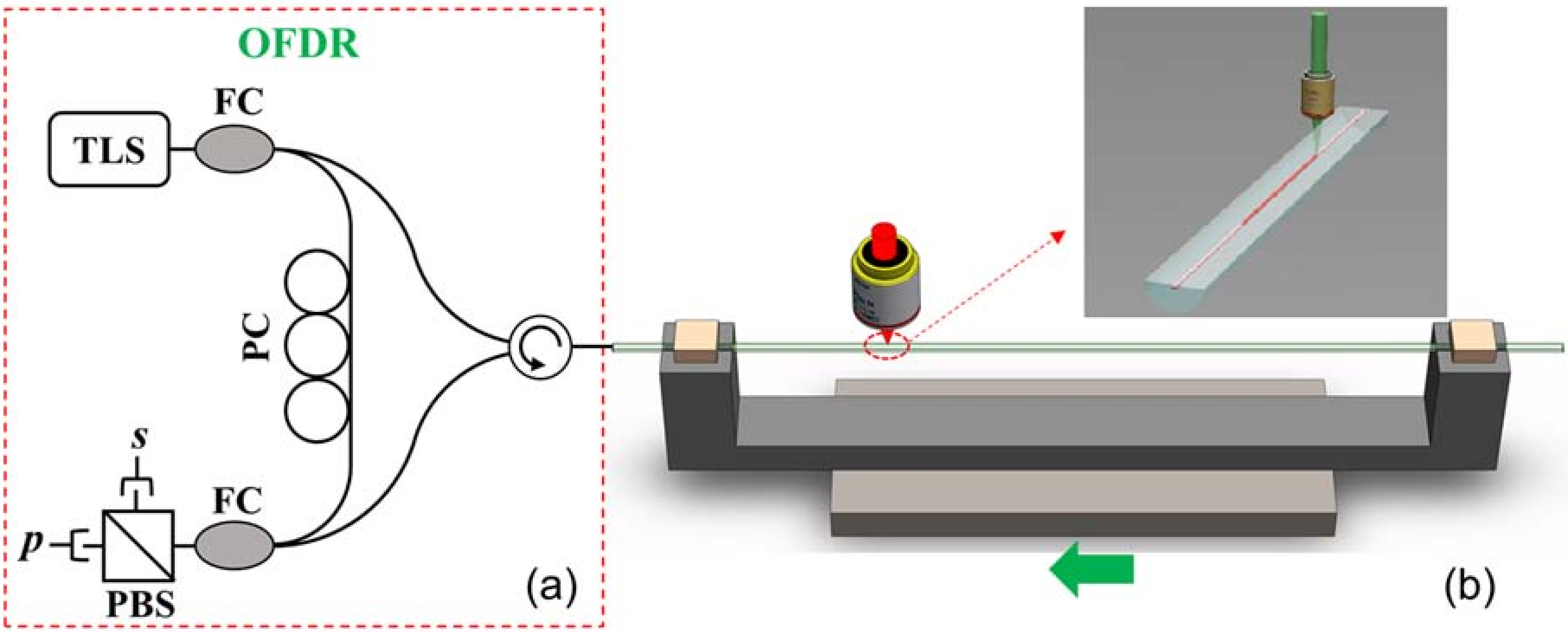


Ultrafast laser irradiation

- **Ti:Sapphire 250-kHz, 180-fs, 780-nm**
- **0.2-0.5 μJ**
- **0.5-10 mm/s**

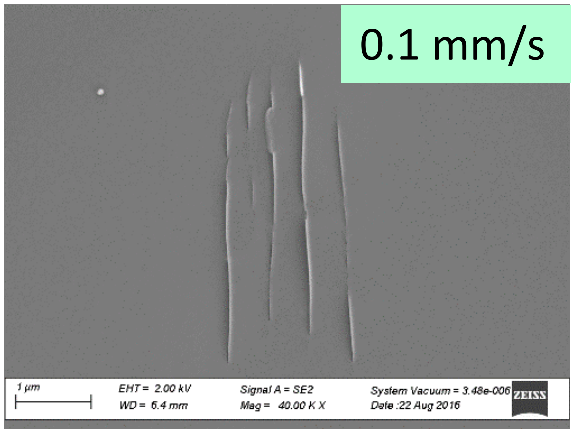


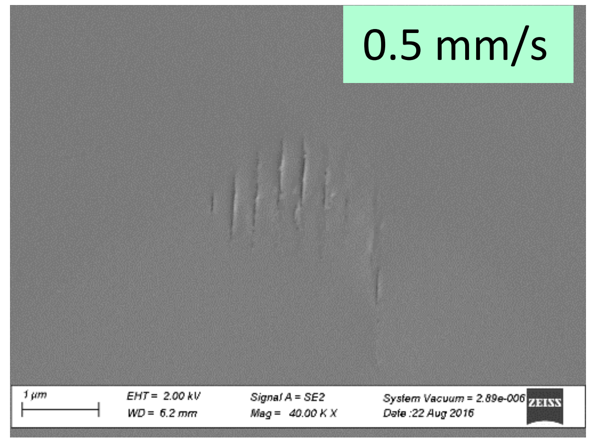
Increasing Rayleigh scattering stability

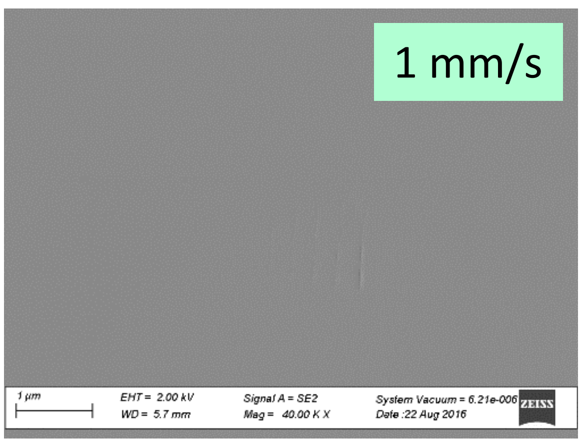


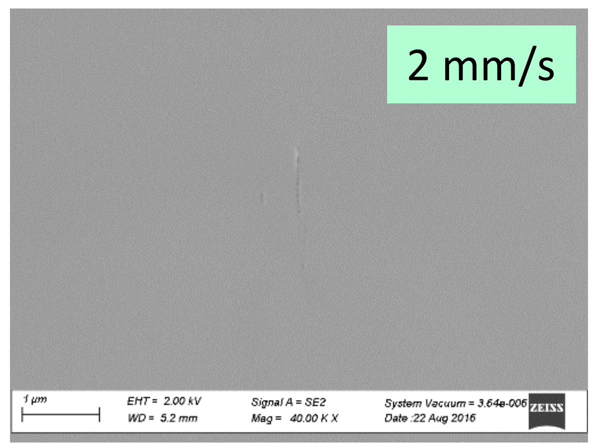
Increasing Rayleigh scattering stability

- **SEM image of the fiber cross section at different scanning speed**
- **Minimize the transmission loss and smooth the profile**



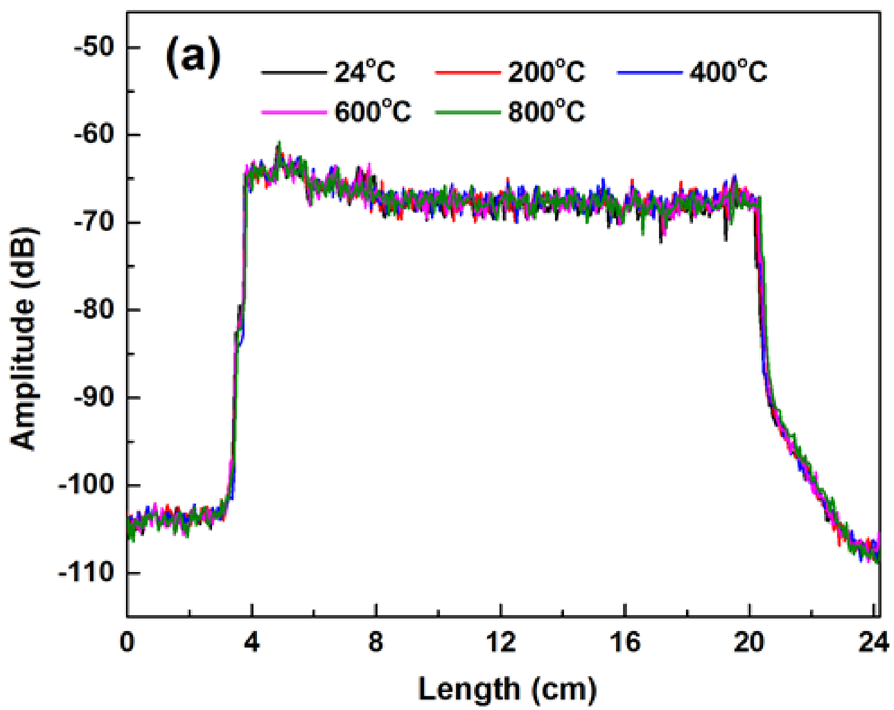




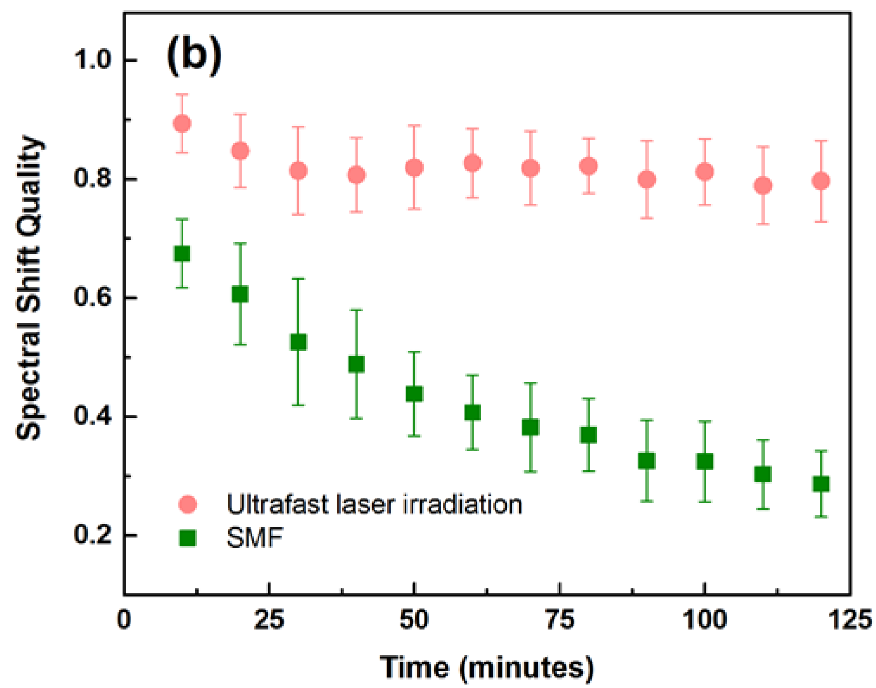


High-Stable T Profiles

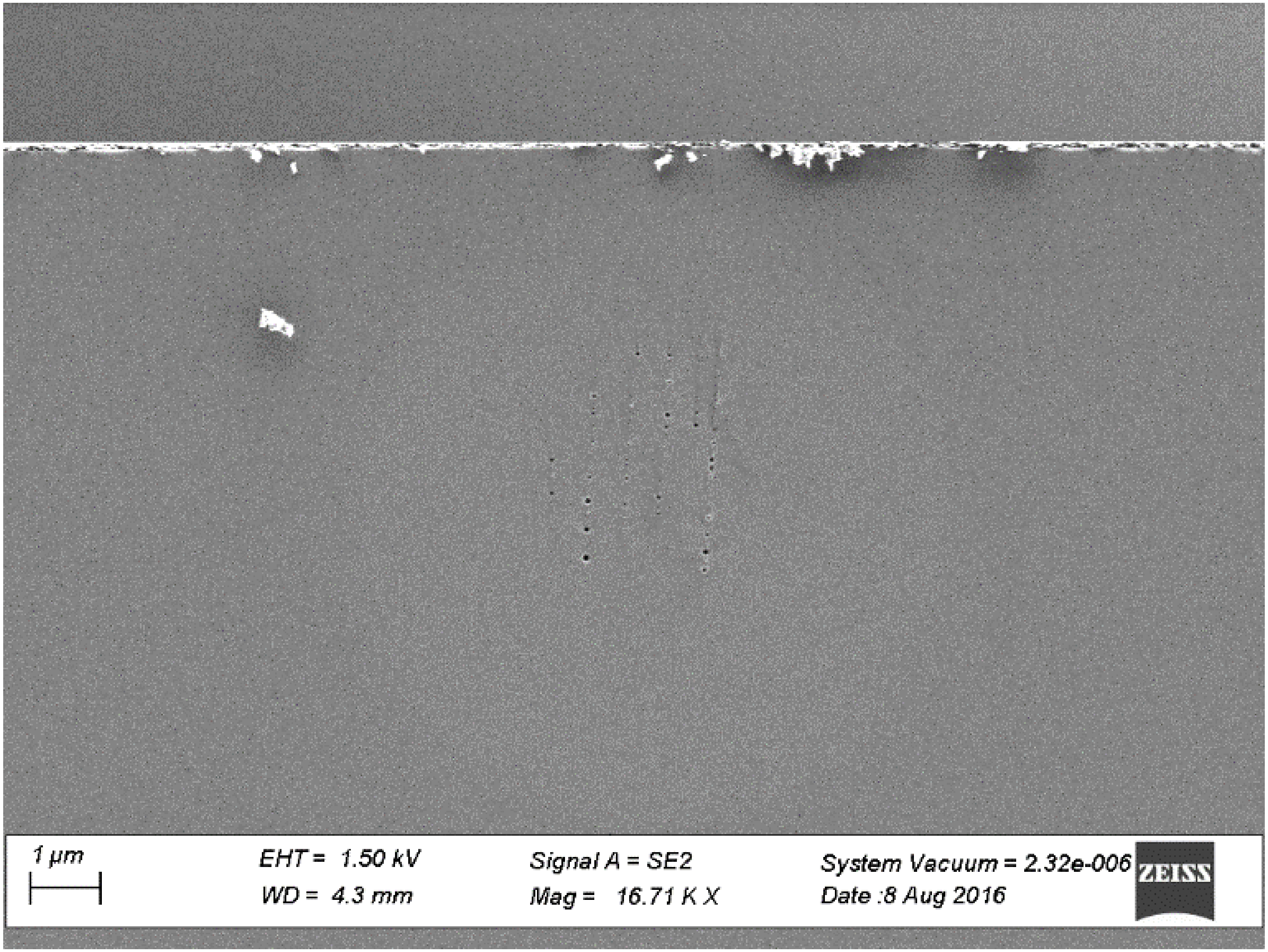
Rayleigh Scattering Profiles



Spectral Shift Quality



Nanograting Change after H2 exposure



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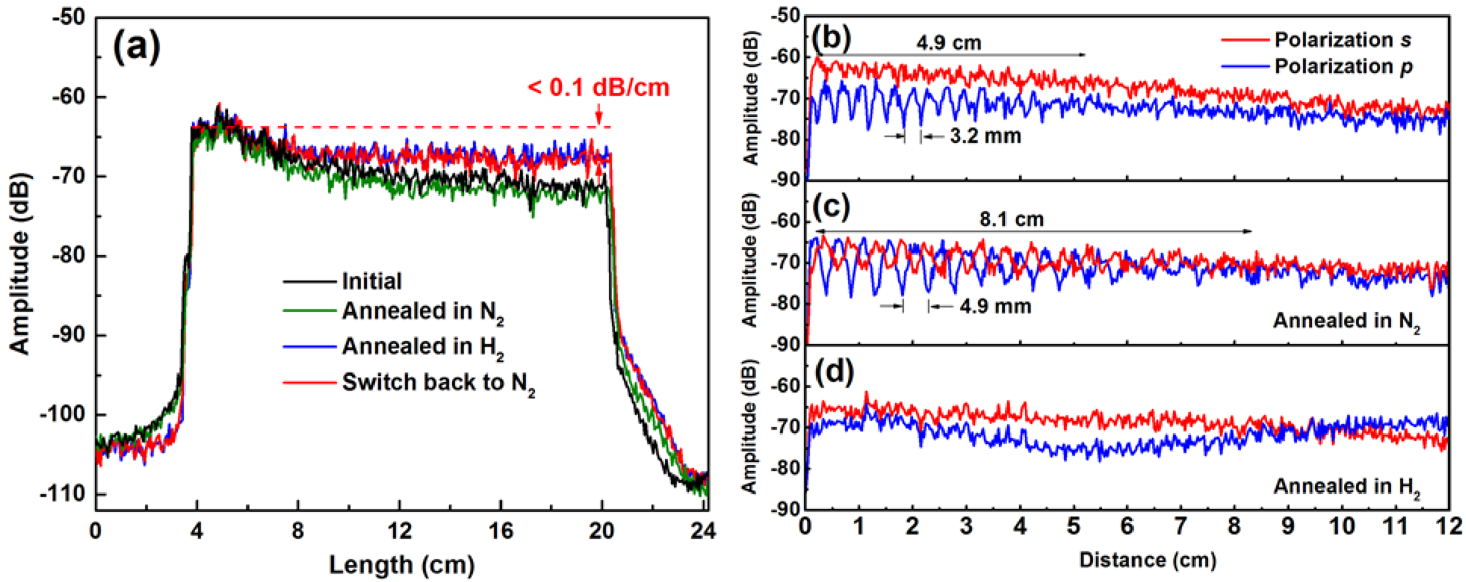
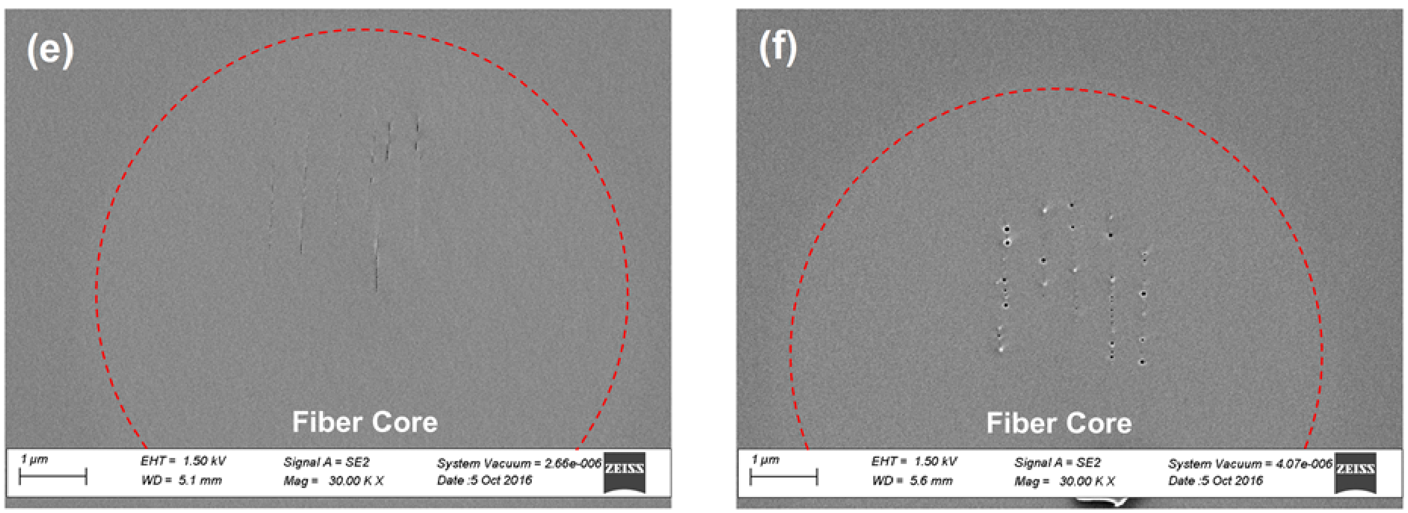
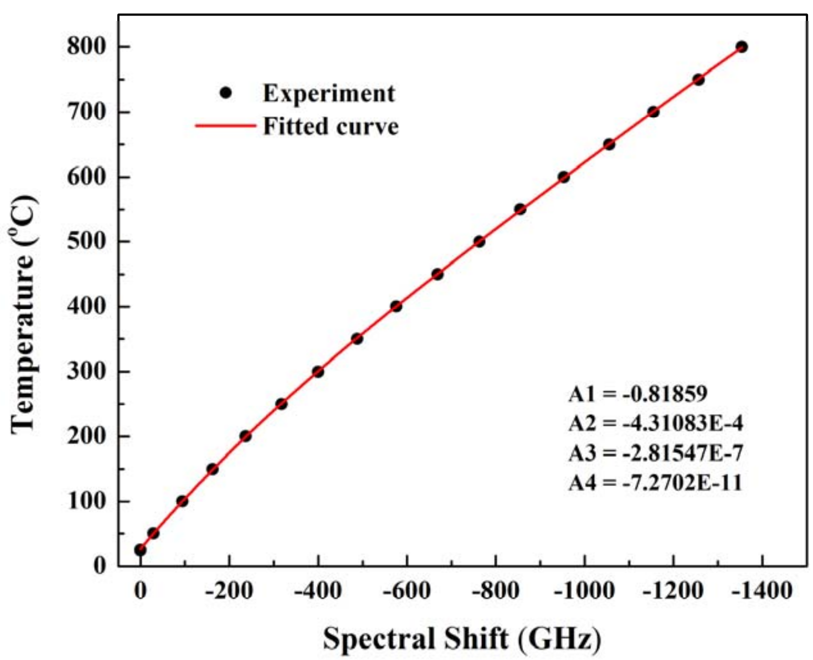
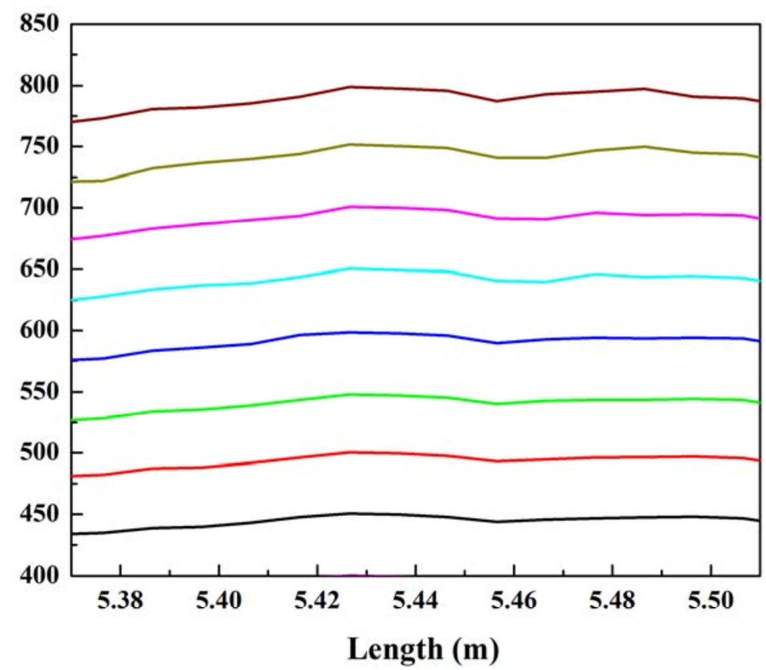




Temperature coefficients determined to 800C

- Temperature can now be measured at 800C with H2 atmosphere
- Stability verified for ~72 hours at 800C
- 4C accuracy with heat/reheat cycles (10 cycles tested).





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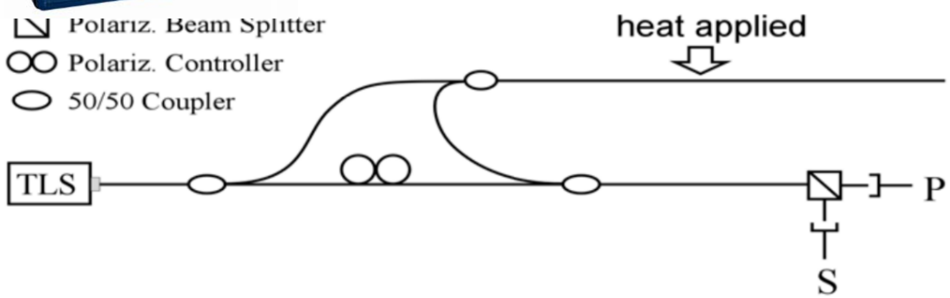
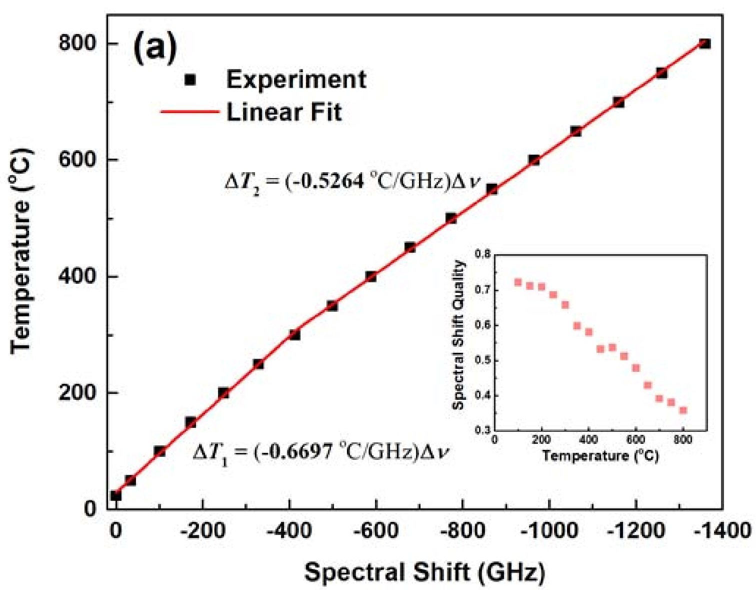
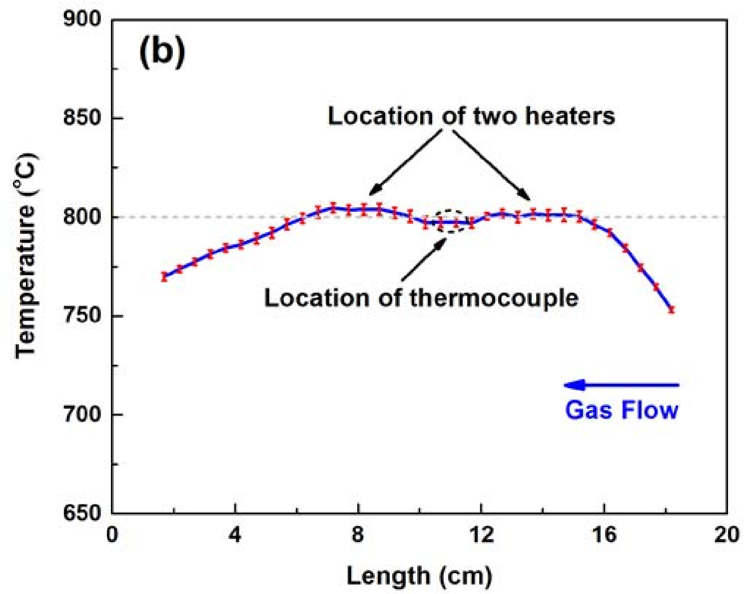
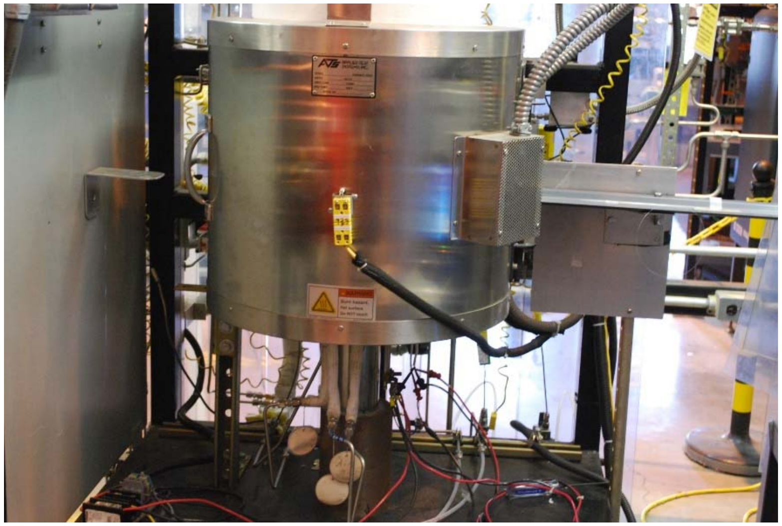
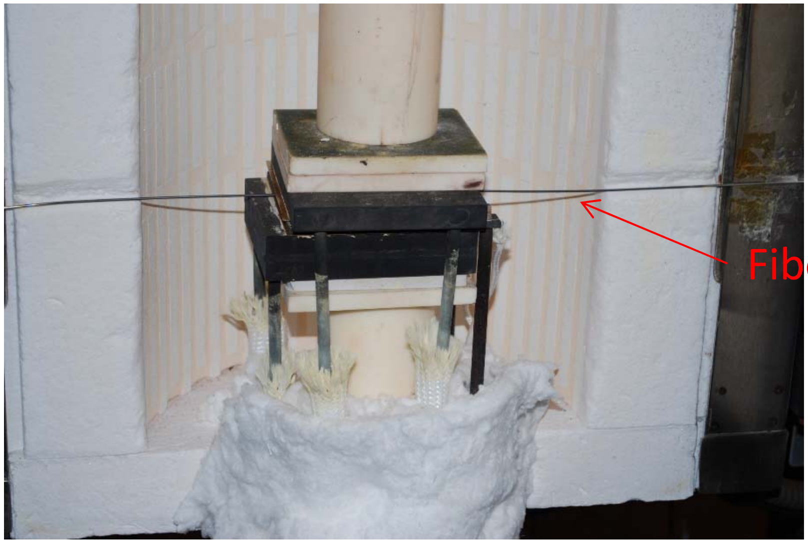






Fuel Cell Tests





- Preliminary Tests carried out at NETL fuel cell facility
- Single plane fuel cell (not stack), testing temperature up to 800C.

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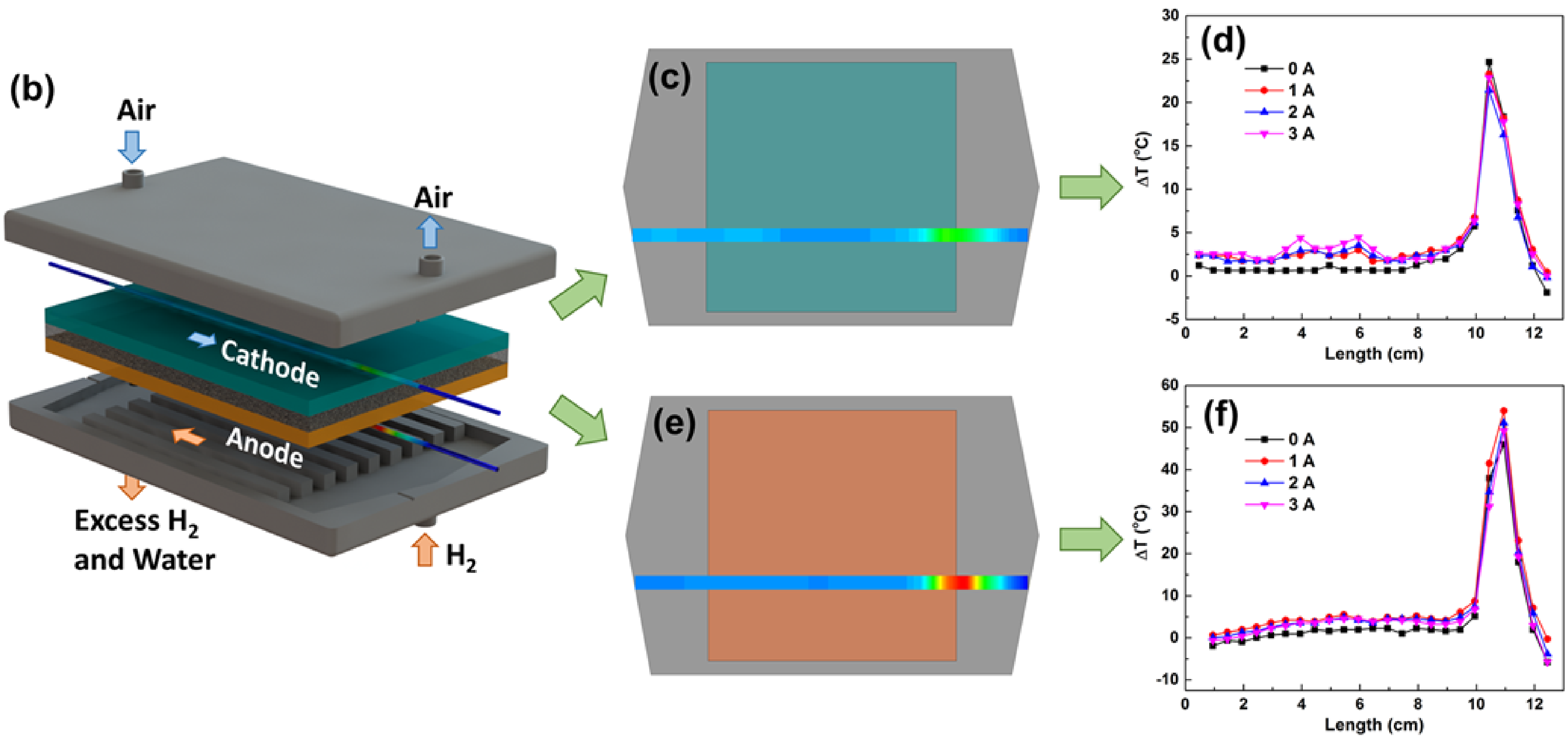
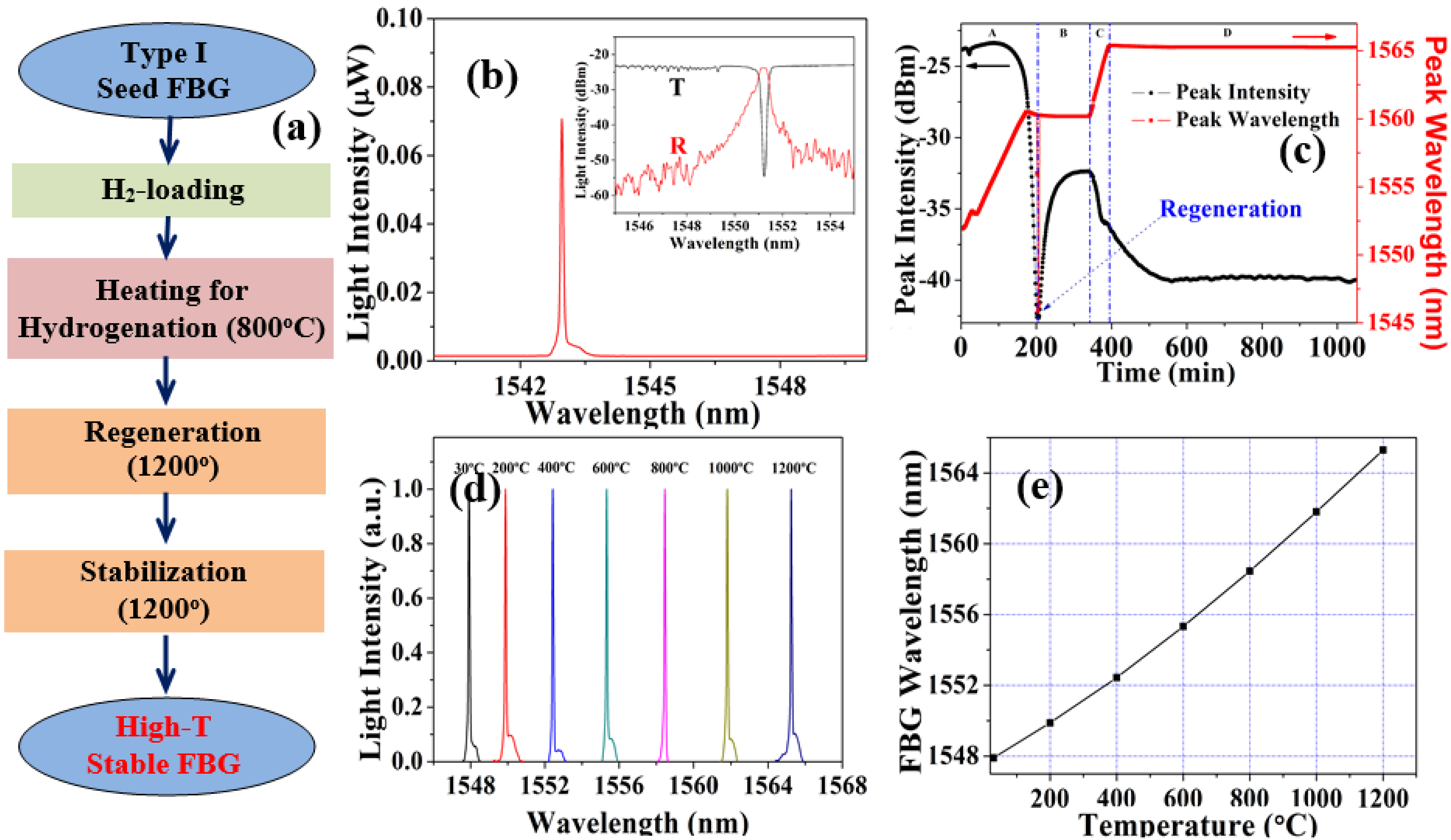


Interrogation Instrument too Expensive??

Low-Cost Regenerative FBG Arrays



Fully embedded Sensor in Fuel Cell Structures!

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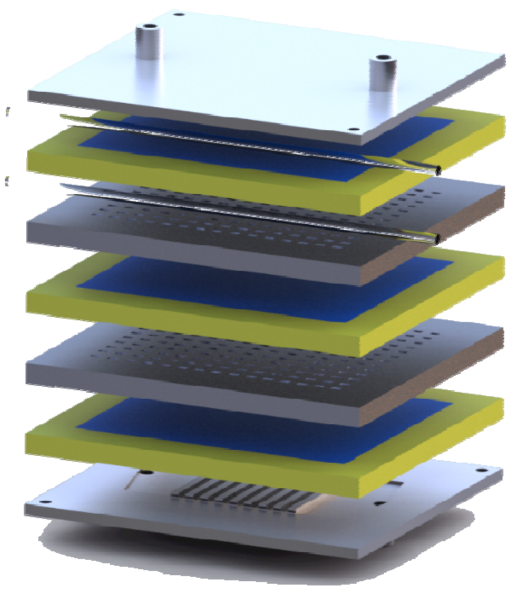
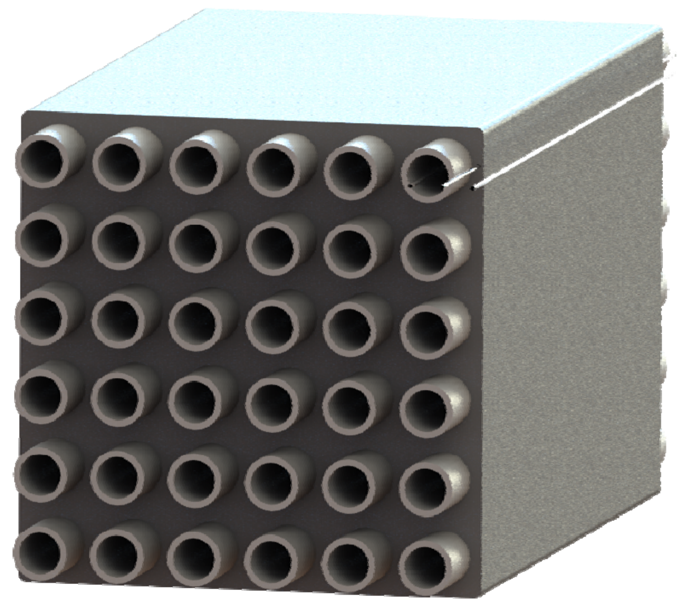
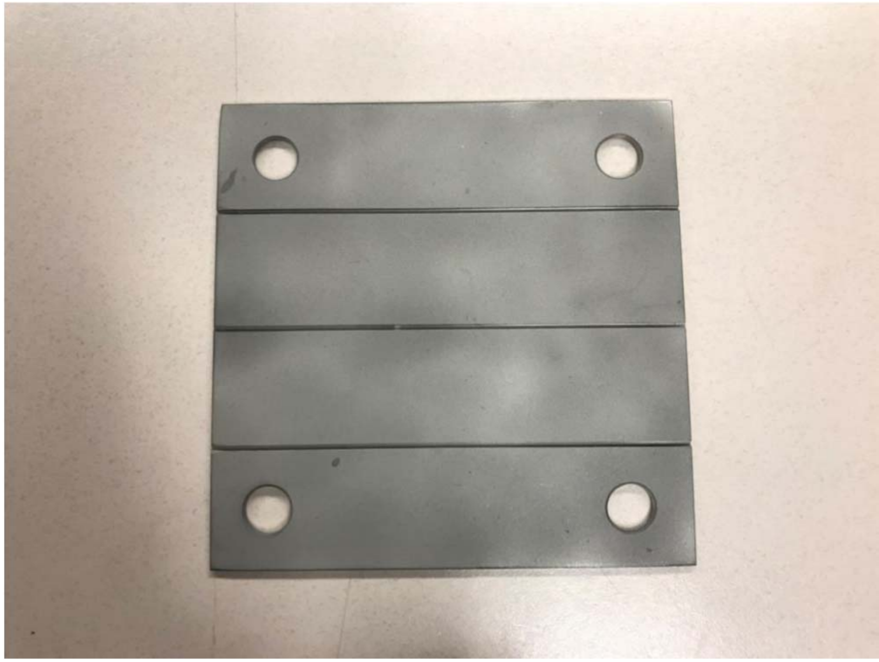
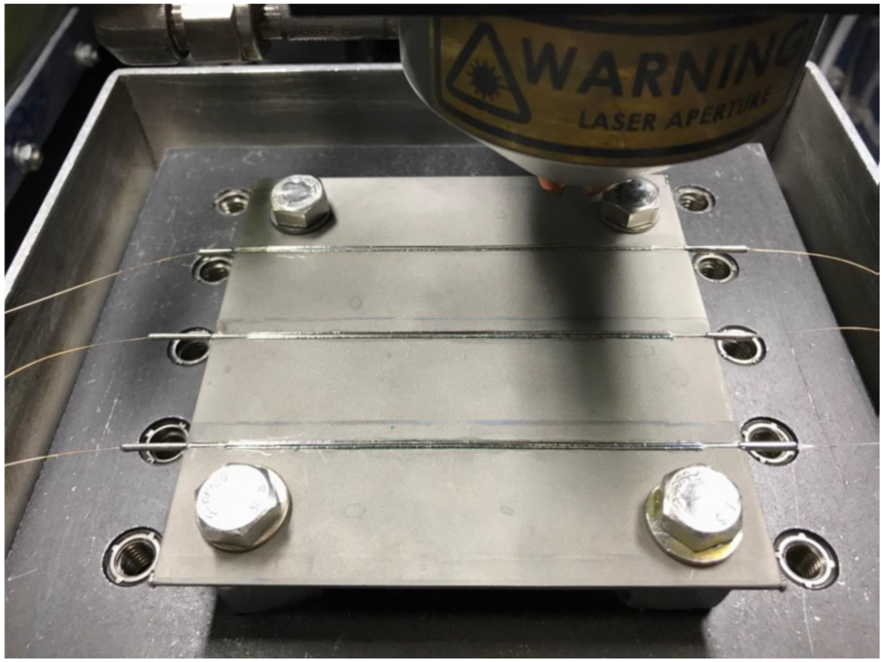




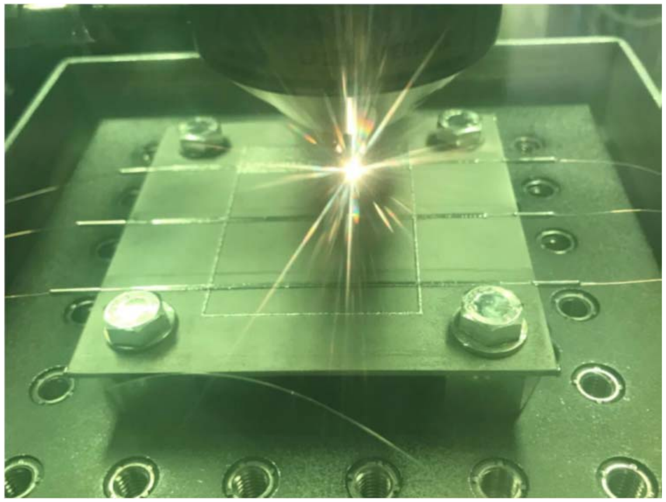
Fully embedded Sensor in Fuel Cell Structures!

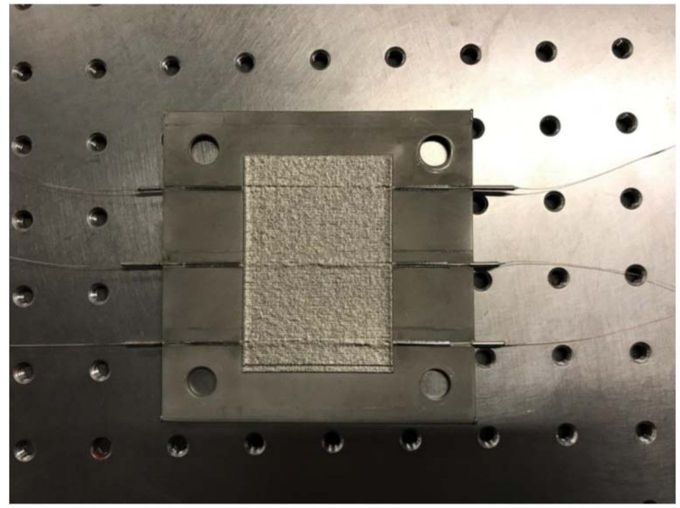




Fully embedded Sensor in Fuel Cell Structures!

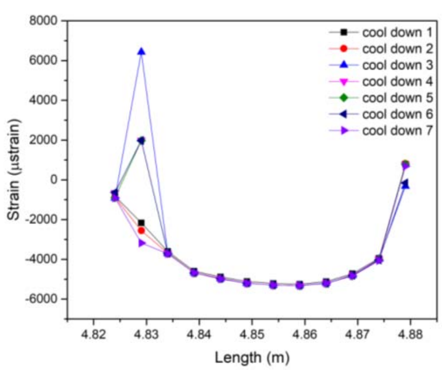
Laser Engineered Net Shaping Additive Manufacturing



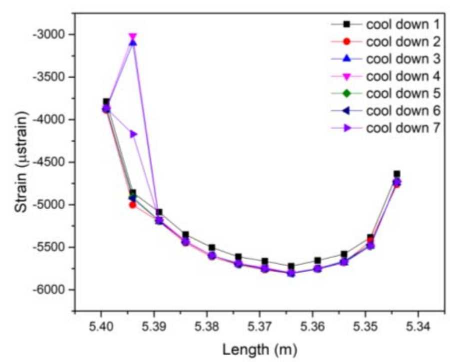


Strain measurement performed by fiber sensors

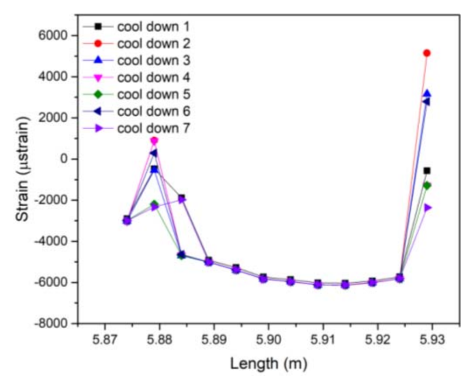
Top



Middle



Bottom



Project Schedule

	Year 1			Year 2		
	4	8	12	16	20	24
Task I: Fabrication/Test of High-Temperature Distributed Sensors						
Subtask 1.1: Establish optical imaging setup to fabricate distributed fiber sensors in cylindrical fibers using an ultrafast laser direct writing scheme.	■	■				
Subtask 1.2: Develop feedback control algorithm to optimize the laser writing setup.	■	■				
Subtask 1.3: Comprehensive bench-top testing of distributed fiber sensors in various reactive gas mixtures at high temperatures up to 850ºC.		■	■			
Subtask 1.4: Microstructure studies of laser-induced nanograting in fibers to understand high-temperature performances of distributed fiber sensors.		■	■			
Task 2: Fabrication/Test of High-Temperature FBG array						
Subtask 2.1: Fabrication of phase masks amendable to produce FBG array using one laser exposure.	■	■				
Subtask 2.2: Perform laser fabrication to produce Type I FBG arrays in a wide range of optical fibers.		■	■	■		
Subtask 2.3: Perform the chemical regeneration process to convert Type I FBG arrays into high-temperature stable FBG. The temperature stability will be evaluated at typical operational temperatures of SOFCs.		■	■	■		
Subtask 2.4: Perform bench-top testing of FBG sensor arrays in various optical fiber in a large variety of reactive gas mixtures including H_2, O_2, CH_4, C_2H_6, and other fuel gases.		■	■	■		
Task 3: Sensor Packaging, Fuel Cell Testing, and Technology Maturations						
Subtask 3.1: Sensor packaging and embedding using ceramic coating and ceramic tubing.		■	■	■		
Subtask 3.2: Sensor packaging and embedding in metal materials using additive manufacturing techniques.		■	■	■		
Subtask 3.3: Sensor testing in both planar and tubular SOFC and SOFC assembly as functions of fuel compositions, temperatures, and reaction cycles.		■	■	■	■	
Subtask 3.4: TRL analysis of both distributed sensors and FBG sensor arrays, and action plan to further develop TRL and commercialize sensors for fuel cells.		■	■	■	■	■

Milestones

	Year 1			Year 2		
	4	8	12	16	20	24
Task I: Fabrication/Test of High-Temperature Distributed Sensors						
Milestone 1: Successful development of an optical imaging setup and computer control algorithm for the ultrafast laser processing system.		■				
Milestone 2: Successful demonstration of highly stable distributed fiber sensors in cylindrical fibers in reactive fuel gas stream at temperatures to 850ºC.			■			
Task 2: Fabrication/Test of High-Temperature FBG array						
Milestone 3: Successful establishing of FBG array fabrication setup using the phase mask in photosensitive fibers.		■				
Milestone 4: Successful demonstration of highly stable regenerated FBG arrays in reactive fuel gas stream at high temperatures up to 850ºC.				■		
Task 3: Sensor Packaging, Fuel Cell Testing, and Technology Maturations						
Milestone 5: Using high-temperature stable fiber sensors, successful demonstrations of temperature measurements with high spatial resolution in both planar and tubular fuel cells during their operations.					■	
Milestone 6: Delivering of final report and TRL assessment reports to demonstrate that fiber sensors reach TRL6.						■

Thank you!

Questions?

Collaboration Welcomed!

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