Optical Fiber-based Real Time Chemical Sensor Development for SOFC Applications

Youngseok Jee[*,a,b], Shiwoo Lee[a,b], Michael P. Buric[a], Harry W. Abernathy[a,b], Thomas L. Kalapos[a,b], Gregory A. Hackett[a]

[a]National Energy Technology Laboratory, [b]Leidos Research Support Team, *YOUNGSEOK.JEE@NETL.DOE.GOV, (412) 386-5756

Research & Innovation Center

NATIONAL ENERGY TECHNOLOGY LABORATORY

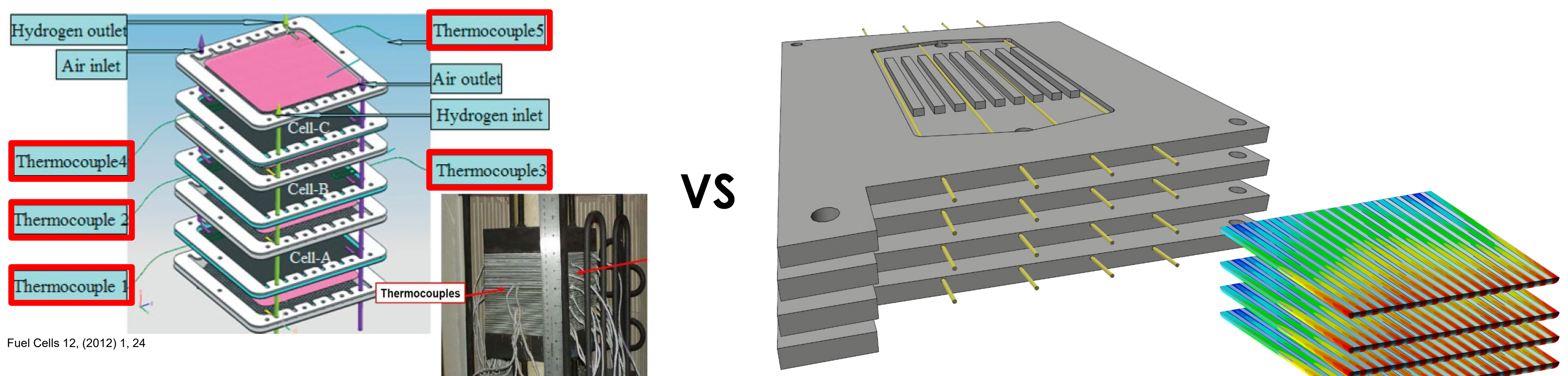
21th Annual Solid Oxide Fuel Cell (SOFC) Project Review Meeting

Abstract

Optical fiber-based sensors exhibit inherent advantages such as the electrical wiring-free configuration, compatibility with broadband wavelength and distributed interrogation, and the elimination of electrical sparks in flammable atmospheres. For these reasons, the SOFC and sensors groups at the National Energy Technology Laboratory have collaborated to develop sensors that will allow for in situ distributed measurements of temperature and/or gas composition with centimeter-scale resolution. An overview of the gas sensing program will be presented focusing on recent results on developing functional coating materials for the optical fibers that allow (1) distributed oxygen monitoring across the cathode or (2) monitoring of $H_2/H_2O/CO/CO_2$ across the anode. The impact of the coating composition, thickness, and deposition will be discussed.

Optical fiber sensing platform for the SOFC application

1) Small diameter → compatible with anode and cathode flow field integration
2) No electrical wiring → enhanced stability & compatibility with electrified systems
3) Robust in harsh environment / high temperature conditions
4) Distributed sensing → able to monitor parameters spatially internal to SOFC

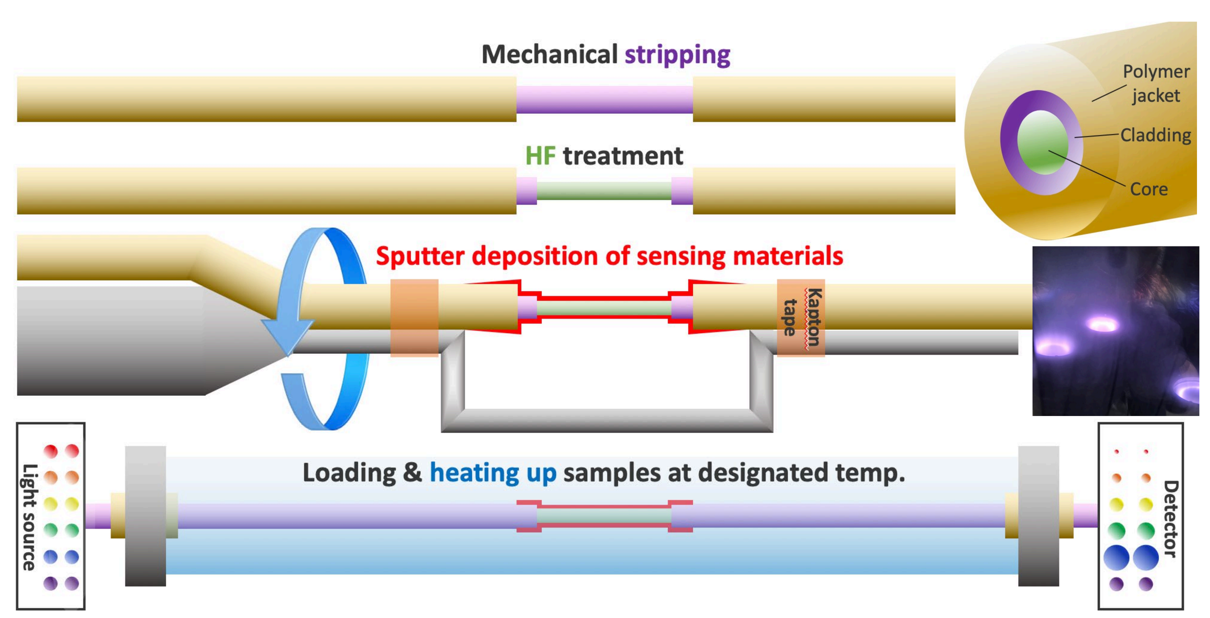


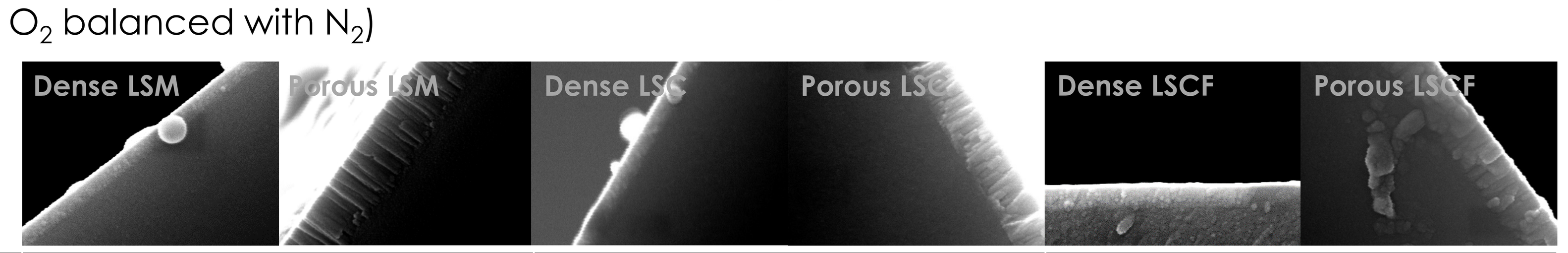
Needs a lot of TCs and wirings
: high chance of issues on sealing, degradation, noise and etc.

Optical fiber sensor preparation procedure

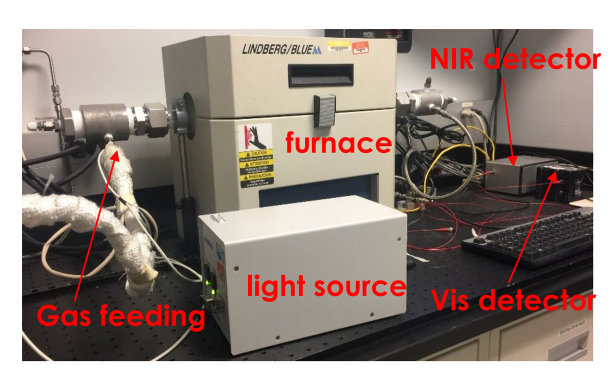
Sensitivity test procedure for the perovskite decorated optical fiber sensors

1) Plastic jacket (stripping) and cladding (HF etching) removal **exposing** the **core** of multi-mode fiber. (Thorlabs FGA105- LCA)
2) **Sputter** deposition (Lab18, Kurt J. Lesker) with 3-inch targets of $(La_{0.8}Sr_{0.2})_{0.95}MnO_{3-\delta}$ (**LSM**, Feldco), $(La_{0.8}Sr_{0.2})_{0.95}CoO_{3-\delta}$ (**LSC**, Feldco) and $(La_{0.8}Sr_{0.2})_{0.95}Co_{0.2}Fe_{0.8}O_{3-\delta}$ (**LSCF**, Feldco) at 50W(RF) in $Ar\&O_2$(4:1) environment using a custom-made rotational fixture.
3) Placement of the prepared fiber in a gas feeding tubular furnace and connection to the light source (DH-2000-BAL, Arcoptics) and both visible (**Vis**) and near infrared (**NIR**) range **detectors**. (Jaz, Ocean optics, Inc.; FTNIR-U-09-026, Arcoptics)
4) Ramping the temperature in N_2 up to 800˚C and **pre-treatment** in several O_2 concentration cycles.
5) **Sensitivity test** exposing the film to the operational gas conditions. (1-19% O_2 balanced with N_2)

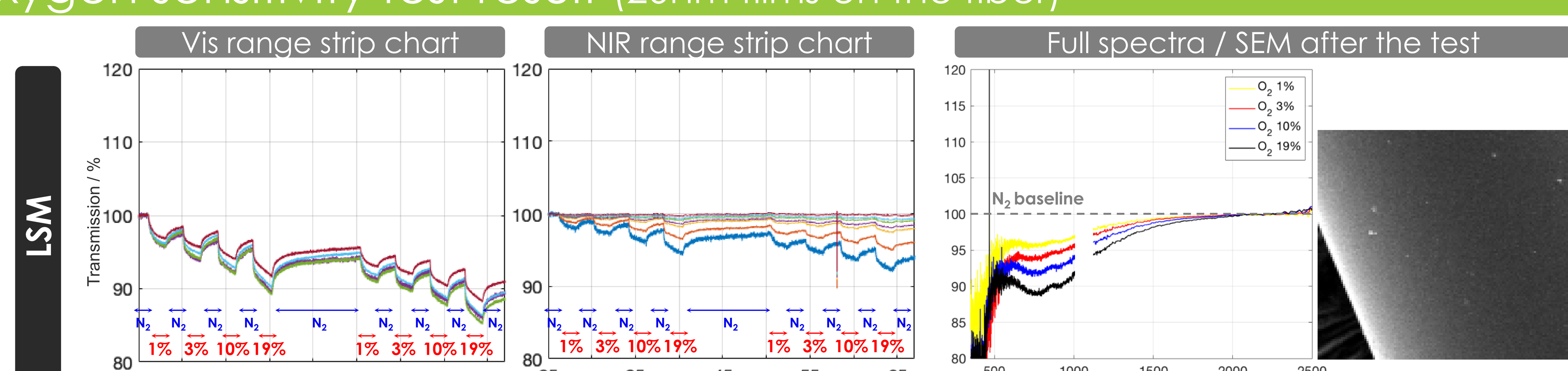


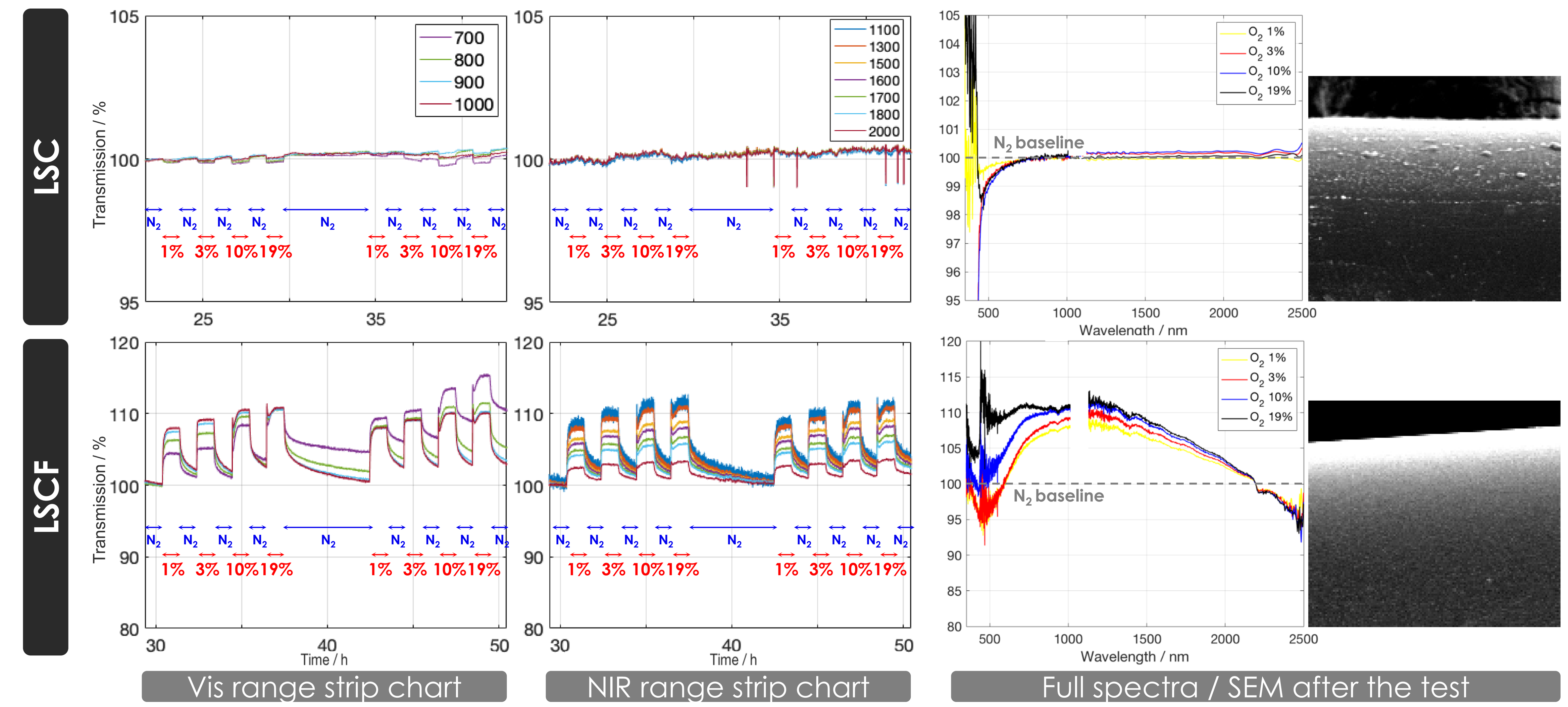


	LSM		LSC		LSCF	
Pressure (mTorr)	3	100	3	100	3	100
Growth rate(nm/min)	0.170	0.553	0.195	0.413	0.197	0.392



Oxygen sensitivity test result (20nm films on the fiber)

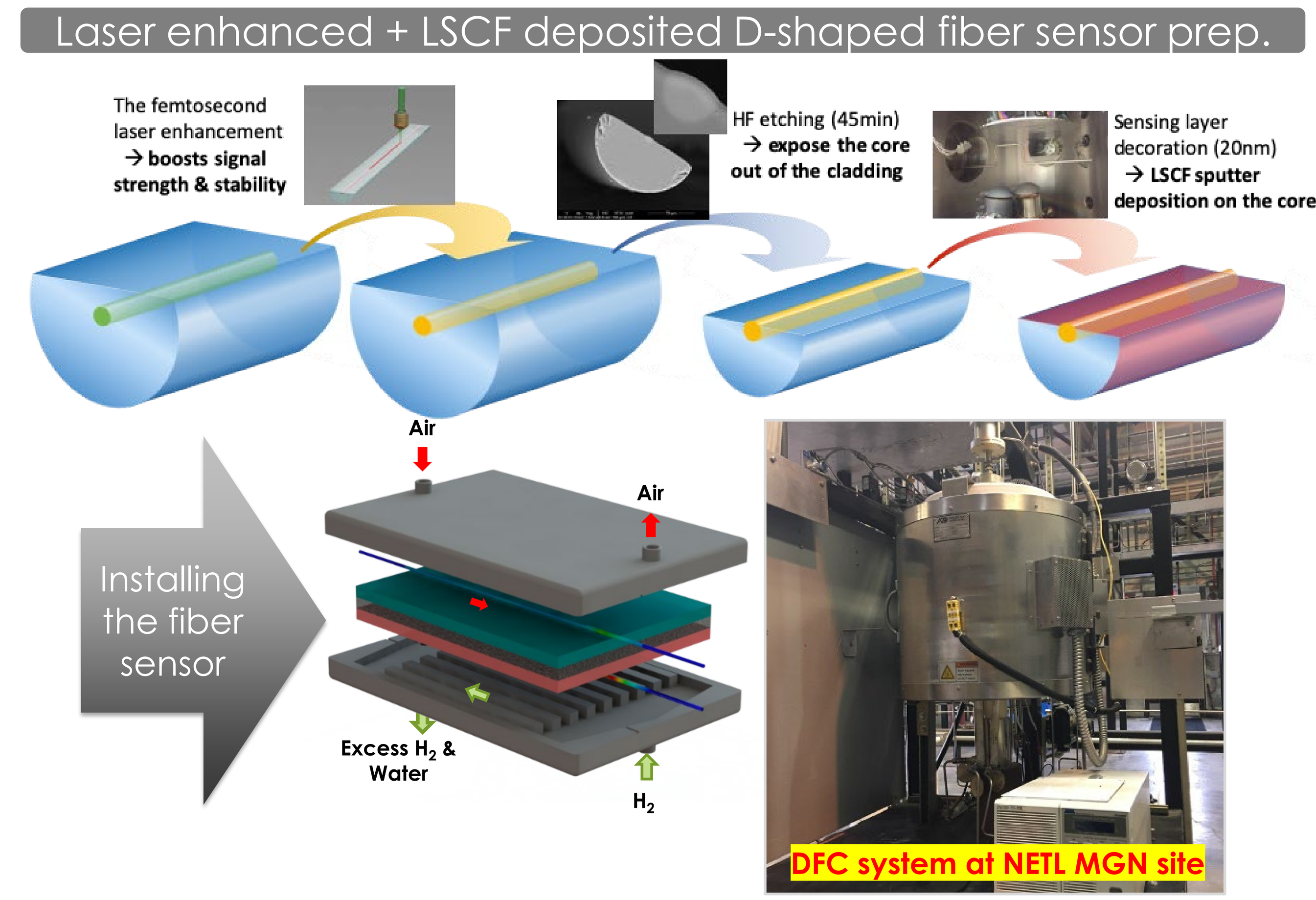




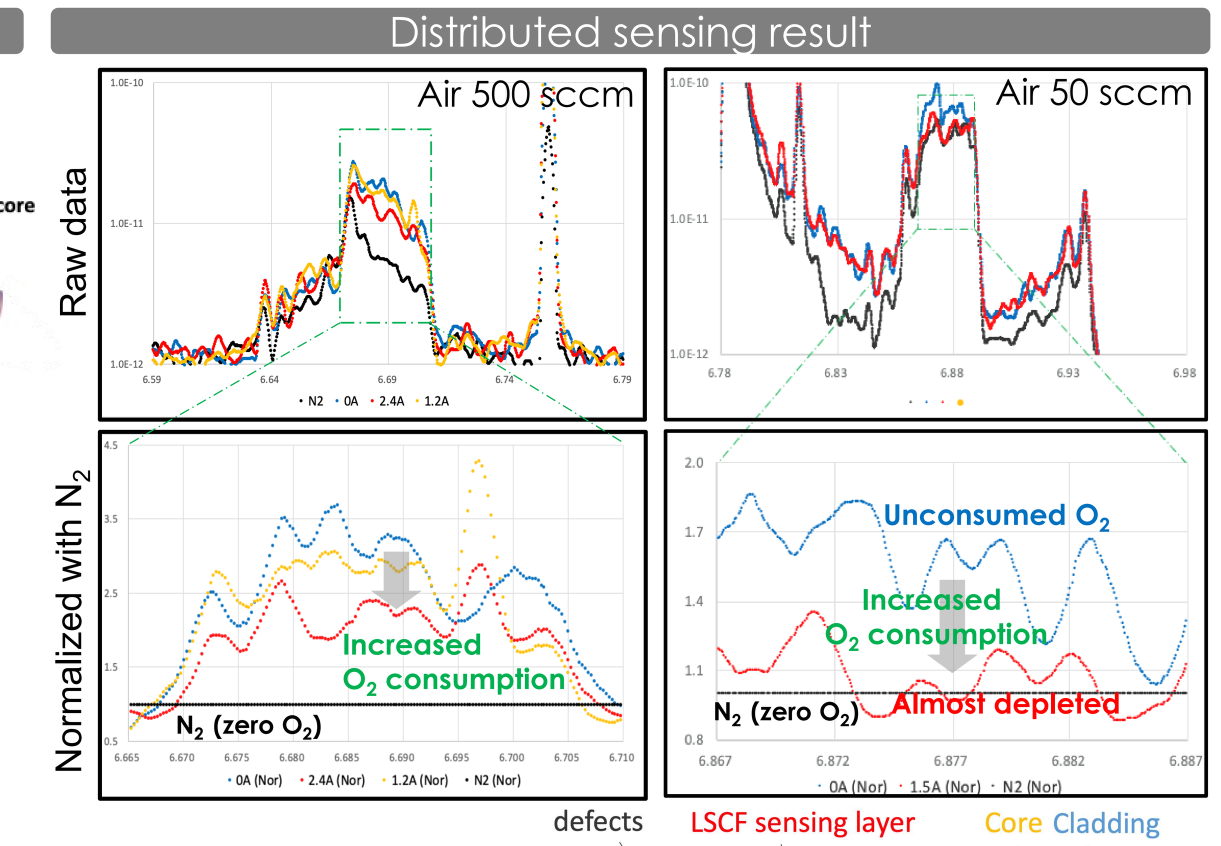
1) **LSM** films showed a **relatively slow** response speed. (incomplete response / recovery during 2h gas exposition durations)
2) For 20 nm **LSC** case, a **very weak** response is observed, which may be the result of a **delaminated and cracked microstructure**.
3) 20 nm **LSCF** optical fiber sensor displays an increased transmittance in the Vis and NIR upon O_2 expositions. The magnitude of the intensity change is the most obvious, and it shows the **best performance in terms of the response speed and N_2-recovery**. Considering LSCF has a higher ionic conductivity, this material property can be one of the primary reasons for a more rapid response and recovery.

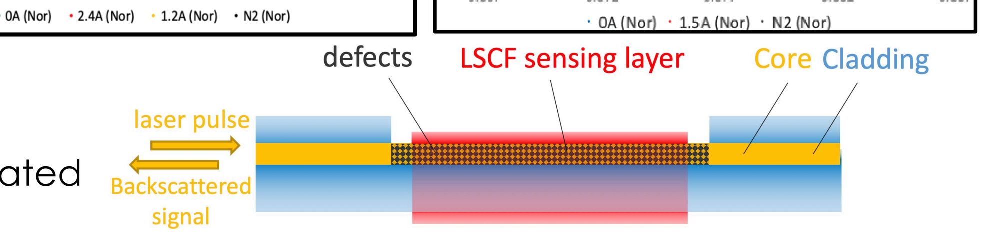
Distributed oxygen sensing test in the actual SOFC system

Laser enhanced + LSCF deposited D-shaped fiber sensor prep.



Distributed sensing result

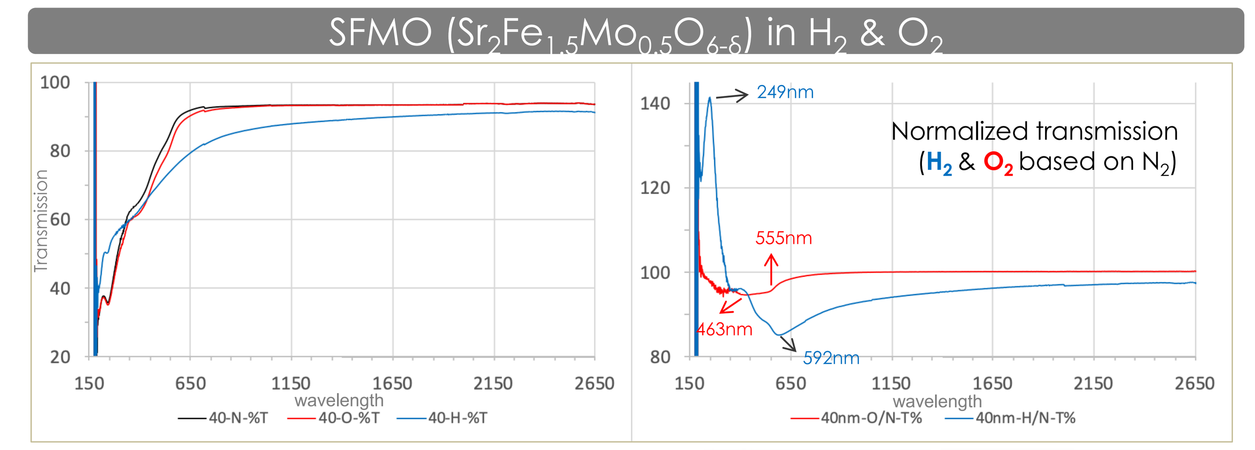


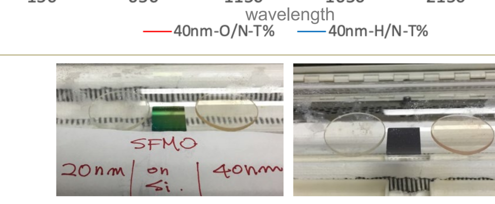


1) **Femtosecond laser-enhanced + LSCF deposited D-shaped fiber sensors** were fabricated and utilized for O_2 sensitivity tests in the actual fuel cell system **for the first time**.
2) During the DFC system operation, the sensor **detected the consumed O_2 content corresponding to current loading conditions.**
3) At the extremely low air flow rate and high current loading, the depleted O_2 signal intensity approached to the value for pure N_2.

New material applications for reducing environment sensing (ongoing)

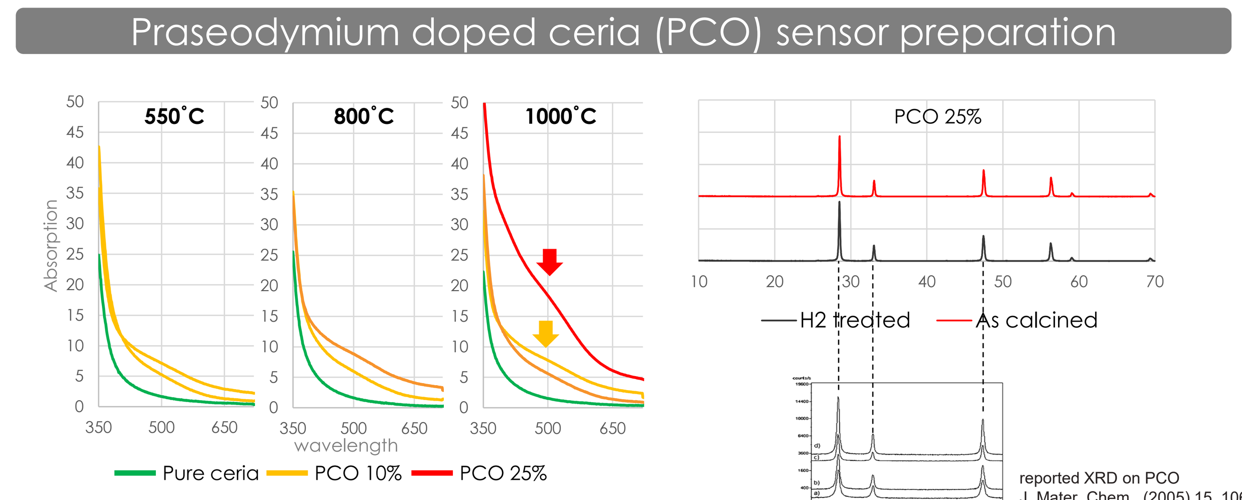
SFMO ($Sr_2Fe_{1.5}Mo_{0.5}O_{6-\delta}$) in H_2 & O_2





Obvious optical change between reducing and oxidizing conditions

Praseodymium doped ceria (PCO) sensor preparation



Optical characterizations for checking Pr-doping feature at different sintering temp.

Confirmed the structural stability in reducing condition

U.S. DEPARTMENT OF ENERGY

This work was performed in support of the US Department of Energy's Fossil Energy Crosscutting Technology Research Program. The Research was executed through the NETL Research and Innovation Center's Solid Oxide Fuel Cells Research performed by Leidos Research Support Team staff was conducted under the RSS contract 89243318CFE000003.
This work was funded by the Department of Energy, National Energy Technology Laboratory, an agency of the United States Government, through a support contract with Leidos Research Support Team (LRST). Neither the United States Government nor any agency thereof, nor any of their employees, nor LRST, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Science & Engineering To Power Our Future