UPISC UNIVERSITY OF PITTSBURGH INFRASTRUCTURE SENSING

COLLABORATION WORKSHOP

NATIONAL ENERGY TECHNOLOGY LABORATORY

FINAL REMARKS AND POSTER SESSION SUMMARY

Prof. Paul R. Ohodnicki, Jr.
UPISC Co-Chair; Associate Professor, Mechanical Engineering & Materials Science;
Director, Engineering Science Program,
University of Pittsburgh

Ruishu F. Wright, Ph.D.
UPISC Co-Chair; Research Scientist, Co-PI-MEMS Adjunct, NETL

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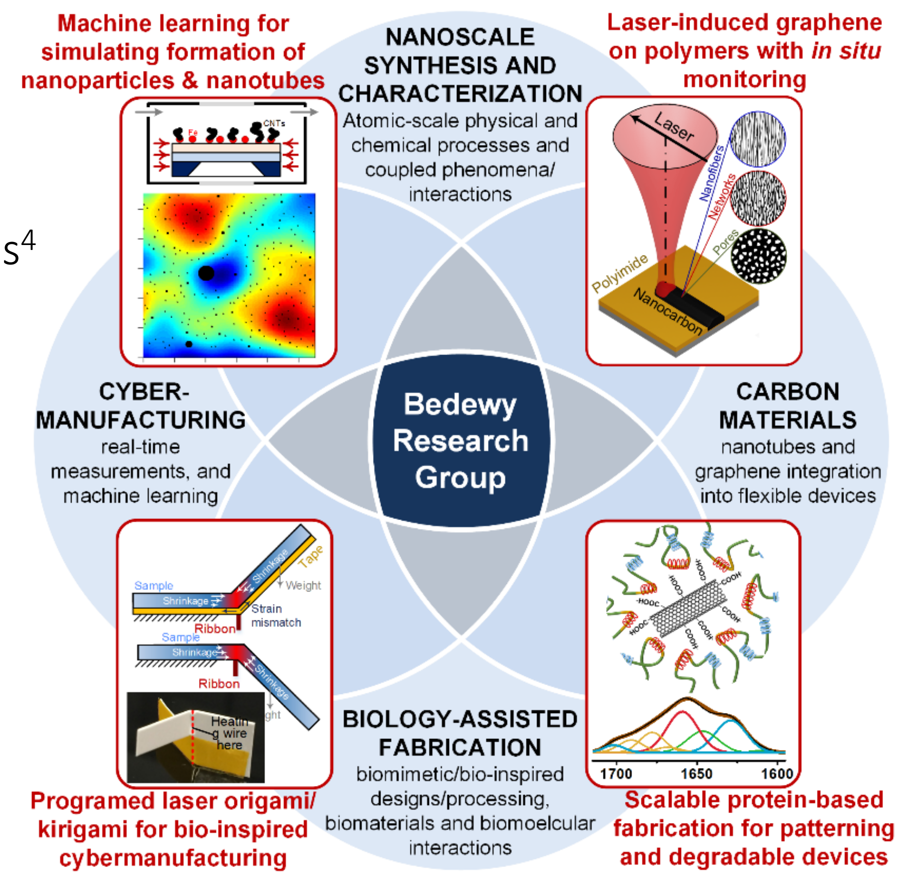
Nanomaterials & Manufacturing in NanoProduct Lab @ Pitt

Mostafa Bedewy, Swanson School of Engineering

- ✓ Spatially controlled laser-induced graphene[1]
- ✓ Electrochemical sensing of biomolecules[2]
- ✓ Superhydrophobic fluorinated graphene[3]
- ✓ Dynamic chemical vapor deposition: nanotubes[4]
- ✓ Engineering catalytic activity and lifetime[5]
- ✓ Protein-nanocarbons for transient electronics[6]
- ✓ Sequential laser-based folding of polymers[7]
- ✓ Machine learning for process discovery[8]
- ✓ Data analytics for process improvement[9]



1. Abdulhafez, Bedewy, et al. *ACS Appl. Nano Mater.* (2021)
2. Nam, Bedewy, et al. *Carbon.* (2022)
3. Nam, Bedewy, et al. *Appl. Surf. Sci.* (2022)
4. Lee, Bedewy, et al. *J. Phys. Chem. C.* (2019)
5. Lee, Tomaraei, Bedewy, et al. *Chem. Mat.* (2021)
6. Cho, Bedewy, et al. *ACS Appl. Nano Mater.* (2018)
7. Abdulhafez, Bedewy, et al. *J. Manuf. Sci. Eng. Trans. ASME.* (2021)
8. Ezzat, Bedewy. *J. Phys. Chem. C.* (2020)
9. Lee, Bedewy, et al. *Ind. Eng. Chem. Res.* (2019)

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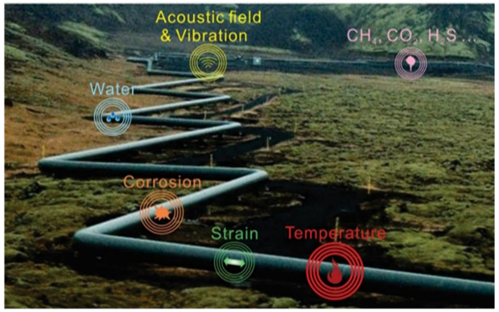
Corrosion and pH Monitoring of Pipelines and Subsurface Wellbores Using Optical Fiber Sensors

Nathan Diemler,[1,2] Alexander Shumski,[1,2] Nageswara Lalam,[1,2] Ruishu Wright[1]

[1] U.S. Department of Energy, National Energy Technology Laboratory (NETL), 626 Cochran Mill Road, Pittsburgh, PA 15236, USA
[2] NETL Support Contractor, 626 Cochran Mill Road, Pittsburgh, PA 15236, USA

Pipeline Corrosion Monitoring

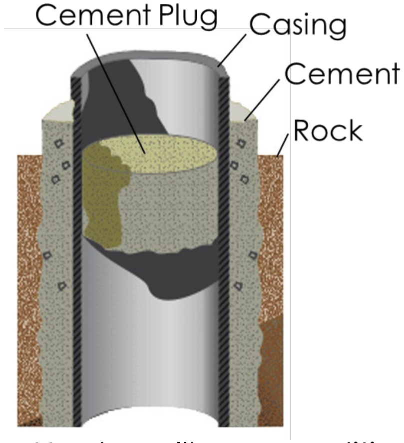
Pipeline Integrated with Distributed Optical Fiber > 100 km

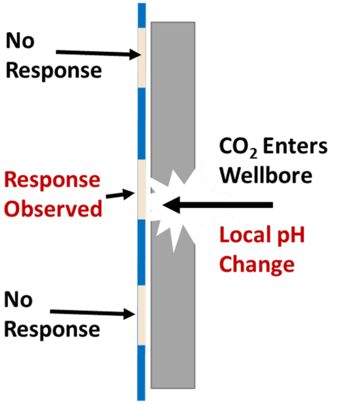


- Direct Early Corrosion Onset Detection inside the Pipeline
- Other parameters that can cause corrosion, e.g. water

- Pipeline corrosion costs billions of dollars annually
- Sensors have been field tested in pipeline conditions

High Temperature Wellbore pH Monitoring





- Harsh wellbore conditions limit pH sensor operation
- TiO_2 coating detects changes in pH at 80°C
- Sensor responds to pH changes under harsh conditions

Functionalized with sensing material coating, distributed optical fiber sensors were demonstrated for corrosion and pH monitoring in pipeline and harsh subsurface conditions.

Contact: Dr. Adam Lee
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Designing methods for more identity-obscuring, equitable sensing in shared spaces

- Shifting to smarter buildings and spaces comes at the cost of privacy
- Privacy-obscuring measures are necessary to preserve people’s trust in public, shared spaces
- Novel visual representations of spaces that obfuscate the space’s inhabitants while still revealing useful information about activities in the space
- Formative studies verified that people are comfortable with these visualizations in regards to obscuring identity

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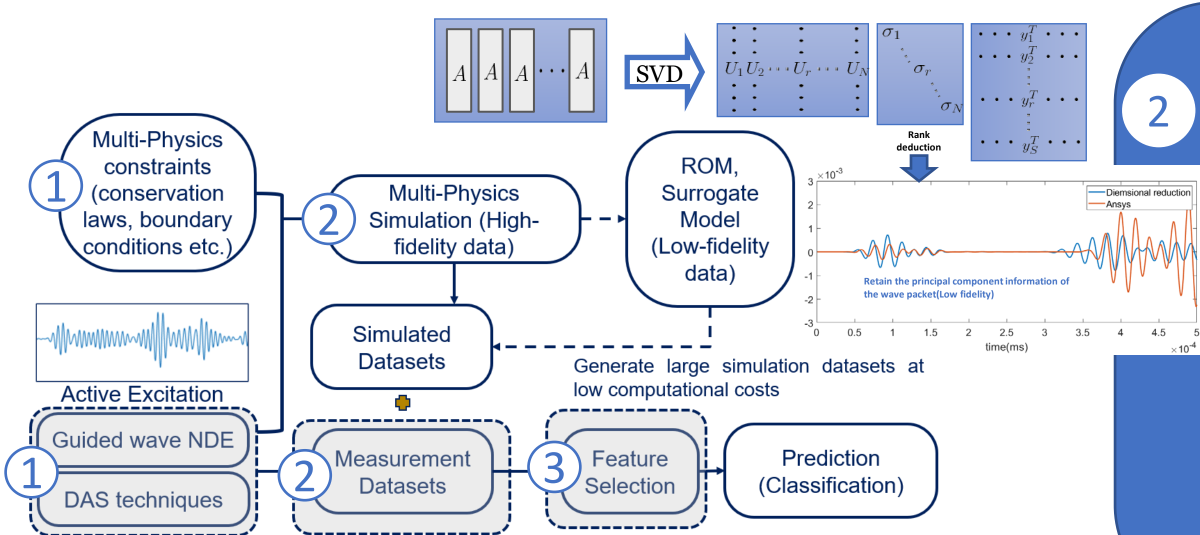
Distributed Fiber Optic Sensing + Physics Based Modeling + AI + Ultrasonic Acoustic NDE



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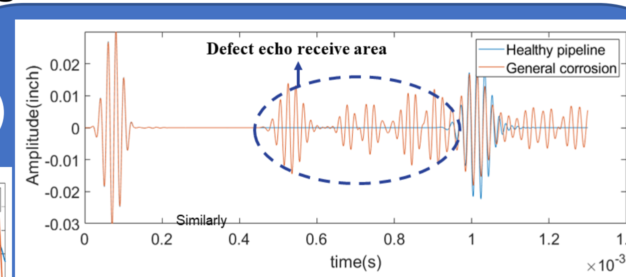
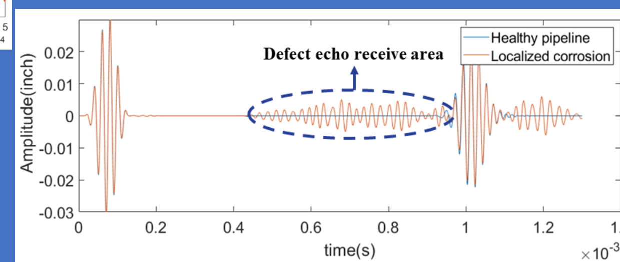
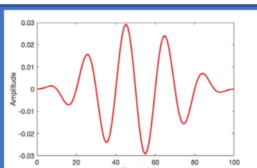


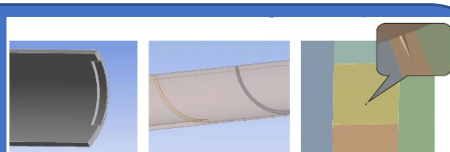
General corrosion

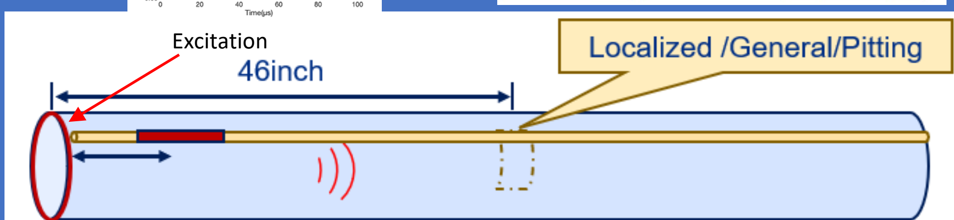


Localized corrosion

1

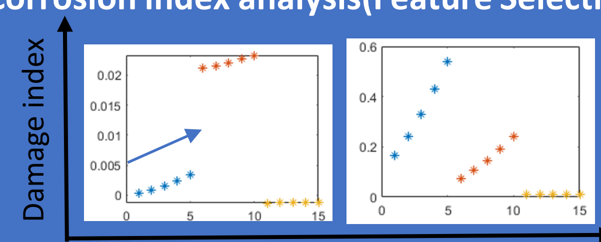






3

Corrosion index analysis(Feature Selection)



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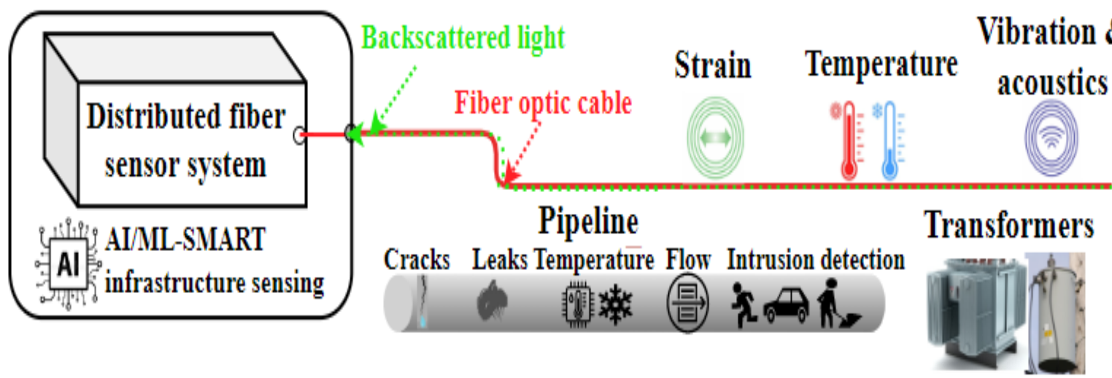
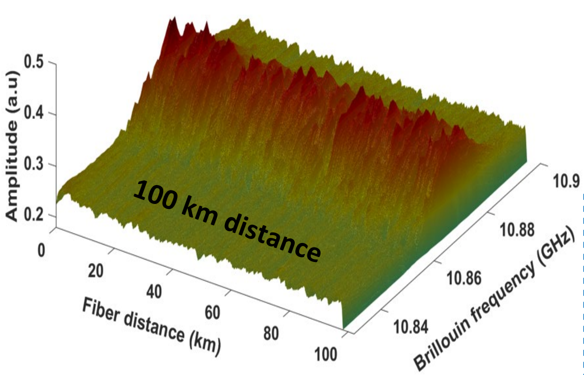
Distributed Fiber Sensor Interrogators for Multi-Parameter Monitoring

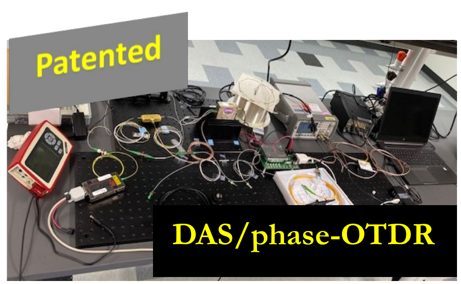
Nageswara Lalam (NETL), Ruishu Wright (NETL), Michael Buric (NETL), and Paul Ohodnicki (Pitt)

Distributed fiber optic sensor interrogators;

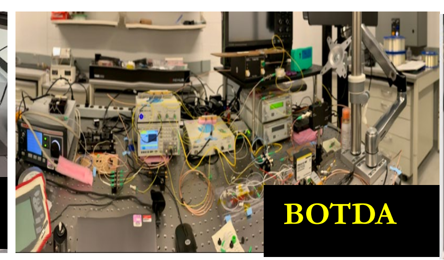
- ❖ Brillouin optical time domain analysis (BOTDA) for long distance strain and/or temperature monitoring
- ❖ Phase- sensitive optical time domain reflectometry (ϕ-OTDR), also called distributed acoustic sensor (DAS) for vibration/acoustic monitoring.
- ❖ Quasi-distributed single-mode–multi mode–single-mode (SMS) fiber sensor for vibration/acoustics monitoring.



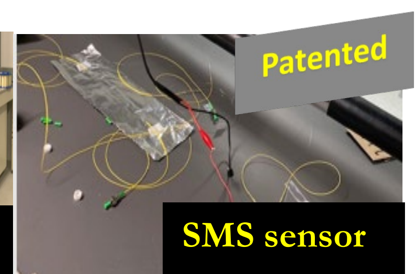




Sensing range = >10 km;
Spatial resolution = <1m;
Frequency range ≤20 kHz;
Frequency resolution <2 Hz;



Sensing range = ≤150 km;
Spatial resolution = <5m;
Temperature resolution: ±1°C
Strain resolution: 10 to 20 με



Frequency range: 1 Hz to 1.5 MHz;
resolution <1 to 2 Hz;

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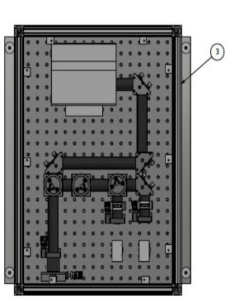
Michael Buric
National Energy Technology Laboratory, Pittsburgh PA /Morgantown WV (michael.buric@netl.doe.gov)

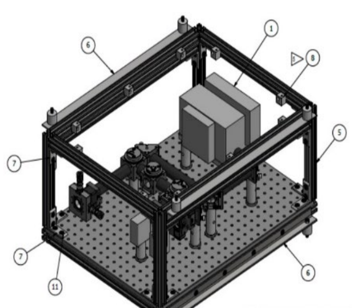
Distributed molten salt-loop development acceleration with single-crystal harsh-environment optical fiber-sensors

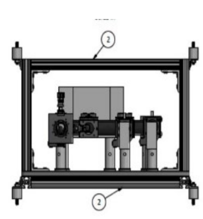
With Pattrick Calderoni (INL), Ruchi Gahkar (INL), and Koroush Shirvan (MIT) (co-PI's), Guensik Lim (Leidos), Gary Lander (Leidos), and Jeff Wuenschell (Leidos)

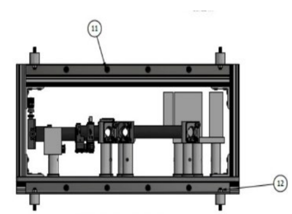
Technology Summary

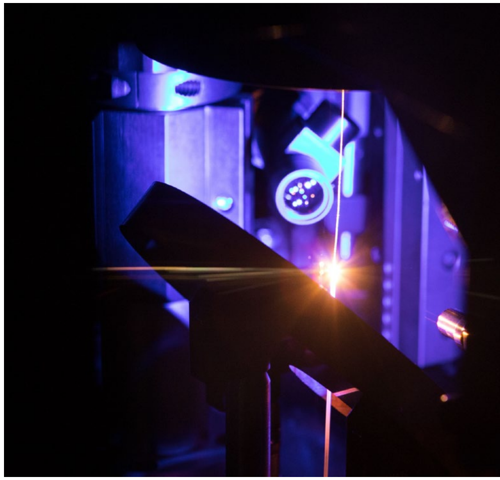
- New single-crystal fibers withstand harsh nuclear core conditions
- Distributed optical interrogation enables precise core and coolant control
- Allows measurement of loop temperatures, piping strain, or other important parameters
- Reactor automation accelerates Molten Salt Reactor designs, ushers in a new paradigm of distributed core-monitoring
- Sensor fibers produce thousands of data points to aid reactor designers or improve reactor operational awareness











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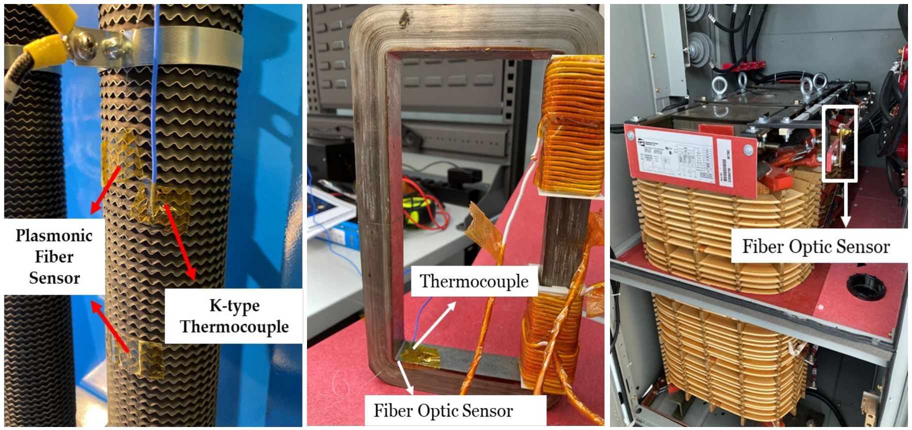
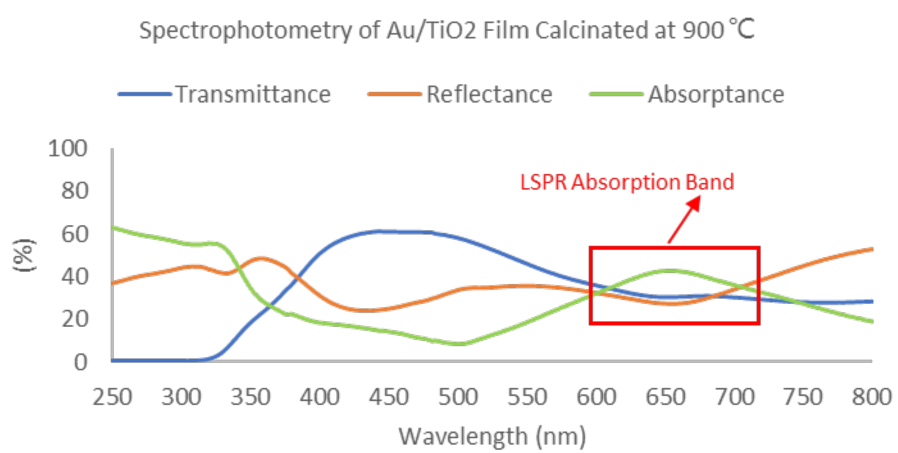
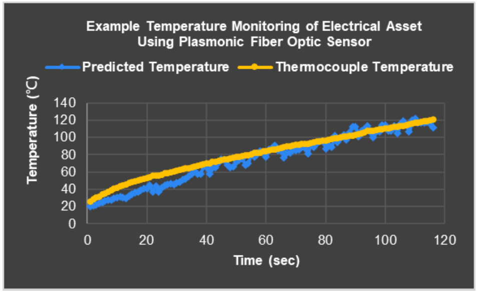
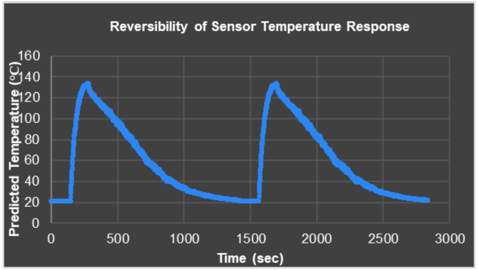
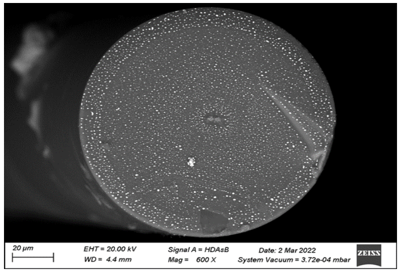
Electrical Asset Monitoring Using Optical Fiber Based Sensors

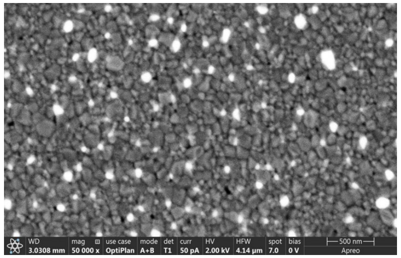




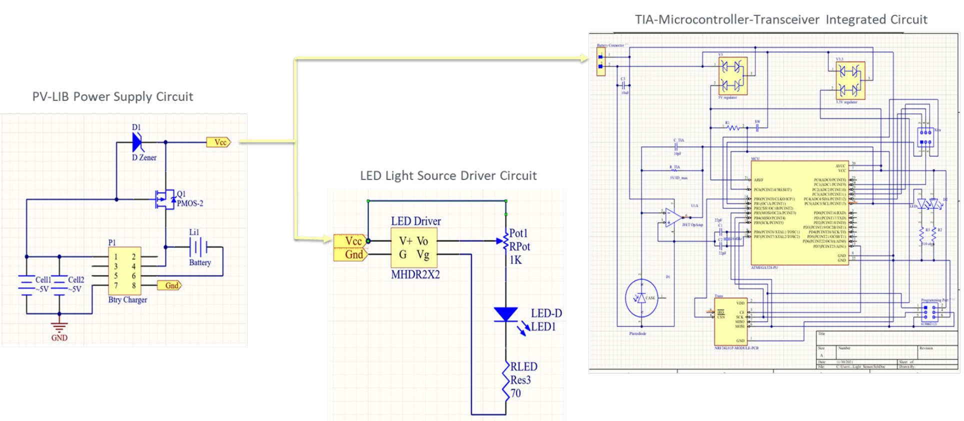








Low-Cost Light Source and Fiber Optic Interrogator



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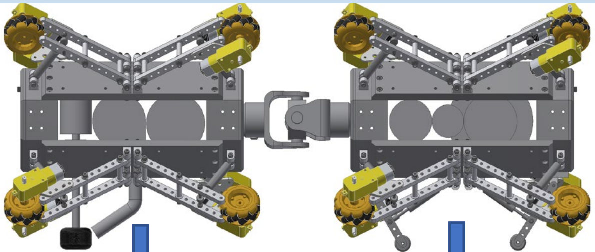
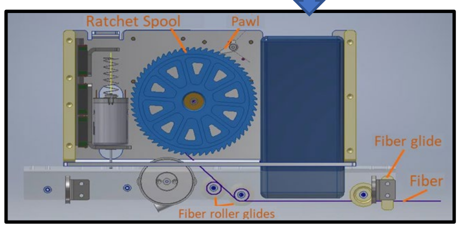
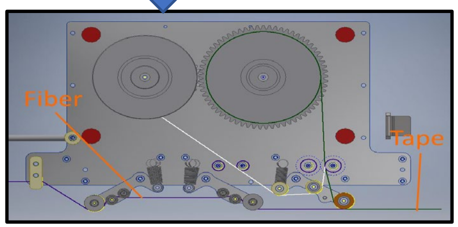
Fiber optic deployment tool (FODT) for pipeline applications

FODRT Prototype schematic







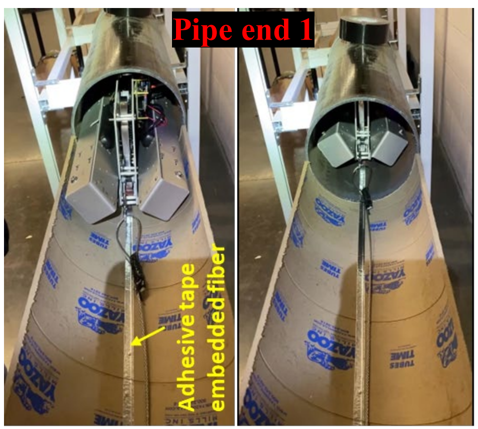
Pipe Diameter Range	8" – nominal (6" up to 12" and greater is possible)
Maximum Speed	15 feet per minute
Fiber Capacity	2500 Feet
Tape Capacity	250 Feet (per spool)
Material & Weight	Aluminum alloy / ~ 10lbs

BrainDrip — Joint Patent — University of Pittsburgh

FODRT during launch set-up

- ❑ Self-Propelled / Remotely Controlled
- ❑ Intrinsic Invert Orientation –COG /Mecanum/wheels / Scissor Centering
- ❑ Self- Contained Material Storage
- ❑ Mechanized Feed Systems
- ❑ Application Path Abrading and Air Blow Off

Snapshots of FODRT during fiber-embedding deployment internal to 8" pipeline



Technology Impact / Summary

Metric	State of the Art	Proposed
Deployed Fiber Optic Sensor Cost Per km	*>$5000 / km, external to pipe*	*< $500 / km, internal to pipe*

- ❖ *Unprecedented Capability for In-Situ fiber-sensor Embedding inside pipeline at Scale for an Economical Cost*
- ❖ *Fiber Optic Sensing and Commercial NDE Technique Synergy with Artificial Intelligence Data Analytics for Defect Identification and Localization*
- ❖ *New "Embedded Intelligence" Imparted By Real-Time Monitoring and an AI Classification System Approach*

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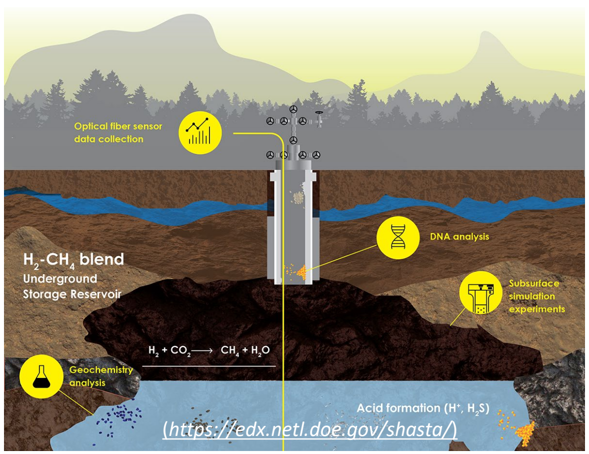
Gas Sensitive Materials Enabled Optical Fiber- and SAW- Sensors for Hydrogen and Methane Monitoring

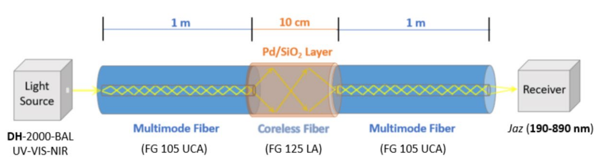
Daejin Kim[1,2], Jeffrey Culp[1,2], Jagannath Devkota[1,2], Ruishu Wright[1]

[1]National Energy Technology Laboratory, 626 Cochran Mill Road, Pittsburgh, PA 15236, USA; [2]NETL Support Contractor, 626 Cochran Mill Road, Pittsburgh, PA 15236, USA

Optical Fiber Hydrogen Sensor



- **Subsurface H_2 storage** to **mitigate the impact of varying H_2 production rates,** ensuring energy reliability.
- Needs to develop **H_2 monitoring sensors** to **manage H_2 leakage risks** and to improve the safety of subsurface H_2 storage.

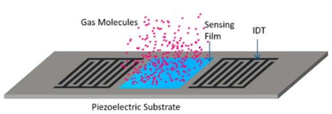


- Patented hydrogen sensitive materials for sensitive and selective optical fiber hydrogen sensors
- Broad sensing range of H_2 concentrations **from 100% down to 100 ppm**.

Surface Acoustic Wave Methane Sensor

- Detect **methane leaks** and monitor gas composition along **the natural gas pipelines.**
- Develop **SAW sensors** to detect methane **wirelessly**.

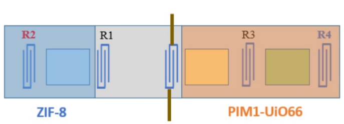
Surface Acoustic Wave (SAW) Sensor:

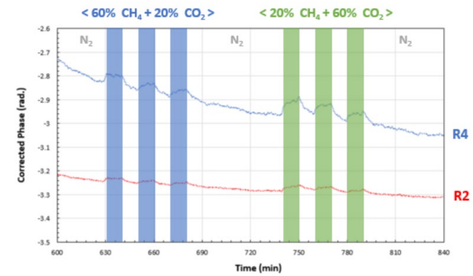


(Devkota et al. Sensors 2017, 17, 801)

- High sensitivity, fast response time, reversibility
- Small size, low cost, wireless mode

Multi-element SAW Sensor Array





- The **multi-elements SAW sensor** developed has shown sensing capability with mixture gas of **CH_4 and CO_2** in the wireless mode.

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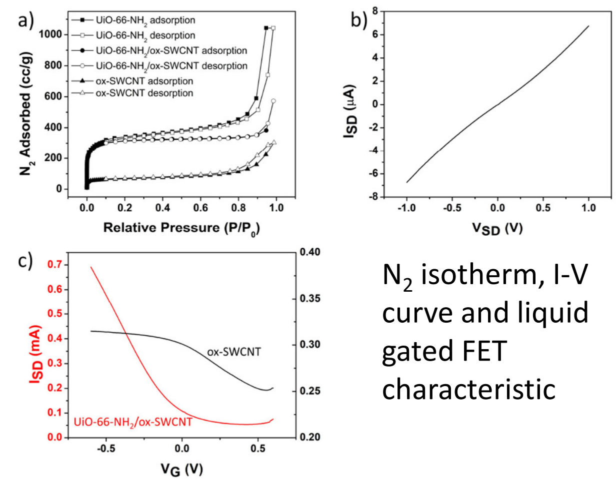
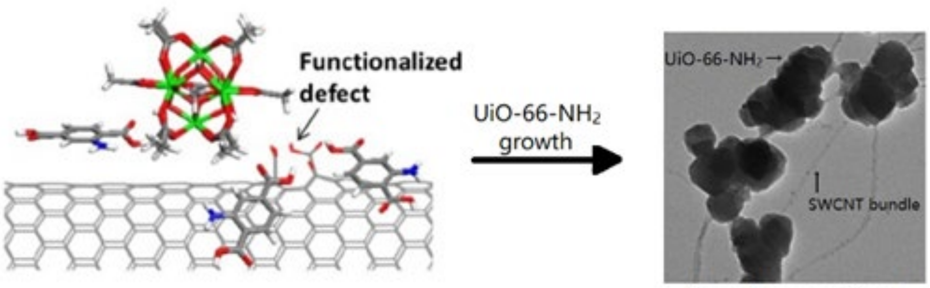
Heterogeneous Growth of UiO-66-NH_2 on Oxidized Single-Walled Carbon Nanotubes to Form “Beads-on-a-String” Composites

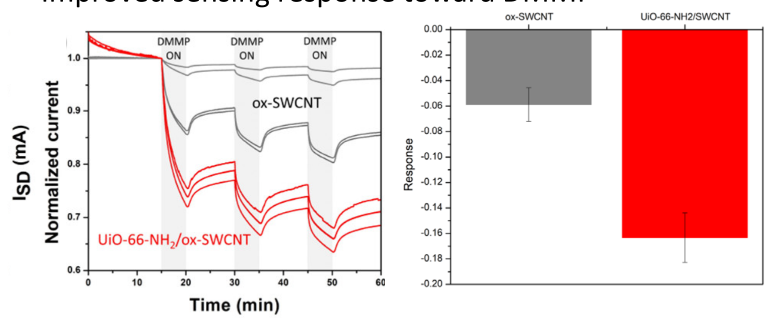
- Composites combine porosity with the electrical conductivity.
- DFT calculations to investigate heterogenous MOF growth on carbon nanotube sidewalls.
- Characterization of the interaction between CNTs and MOF metal precursors.
- Potential application as chemiresistor sensor.



N_2 isotherm, I-V curve and liquid gated FET characteristic



Improved sensing response toward DMMP



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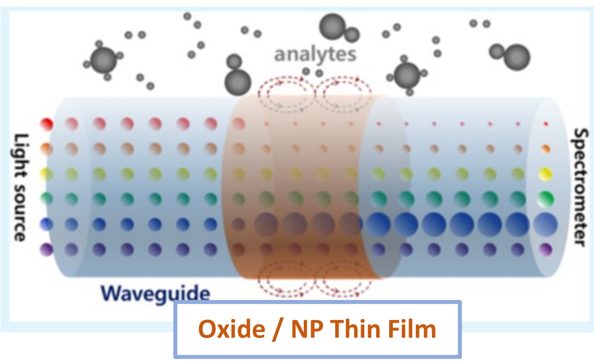
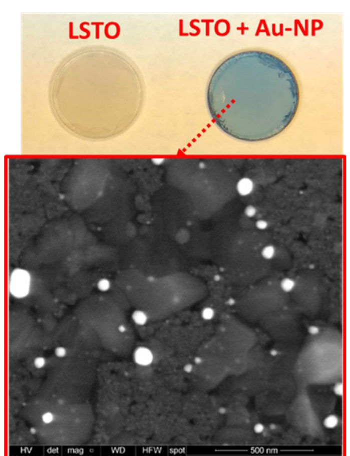
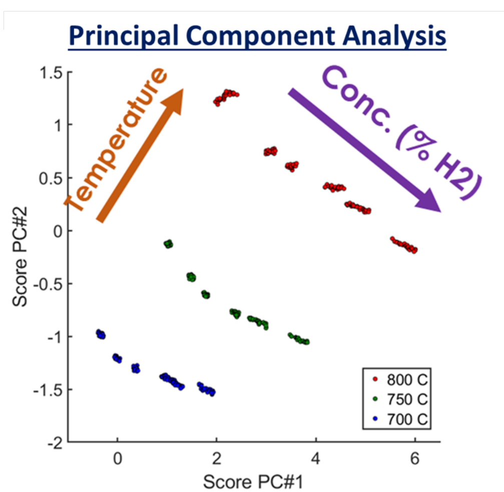
Nanocomposite Films for Harsh Environment Sensing Applications on Optical Fiber

Jeffrey Wuenschell[1,2], Ki-Joong Kim[1,2], Youngseok Jee[1,2], Michael Buric[1]

[1]US Department of Energy, National Energy Technology Laboratory, Pittsburgh PA /Morgantown WV; [2]NETL Site Support Contractor, Pittsburgh PA / Morgantown WV







- Areas of interest: **harsh environment sensing** – high temperature applications (>500°C), strongly oxidizing or reducing conditions, high EM interference.
- Oxide nanocomposites on optical fiber offer balance between stability and responsiveness to target process variables (temperature, gas detection).
- Results will be demonstrated for applications in oil-filled transformer dissolved gas detection, high-temperature gas monitoring for extreme temperatures (SOFCs, power generation).
- Demonstration of machine learning techniques applied to broadband spectral data for multi-parameter detection.

SAMi NETL's Science-based AI/ML Institute

- NETL established SAMI, a joint institute for AI and ML, in 2020.
- The Institute is a ***crosscutting catalyzer***, supporting the acceleration of AI/ML solutions across the NETL R&D mission space.
- SAMI addresses fundamental challenges of applying AI/ML: available data sets, data management, science-AI integration, and governance.
- SAMI has AI/ML capabilities in the applied energy domains (e.g., **subsurface**, **material**, **computational science**, and **system analysis**) and research **data curation, management & virtual computational capabilities** (EDX++). EDX https://edx.netl.doe.gov/about

SAMI's 5 key emphasis areas

- Accelerate AI Innovation
- Catalyze Partnerships & Collaborations
- Make Data Accessible
- Inform Governance & Standards
- Advance AI Workforce

Learn more about SAMI: https://edx.netl.doe.gov/sami/

Contact Us: SAMI@netl.doe.gov

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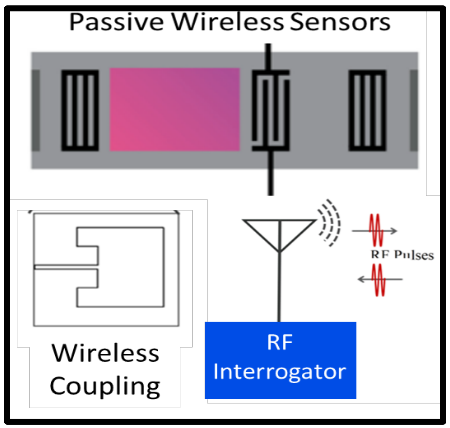
Passive Wireless Surface Acoustic Wave Sensors and Wireless Telemetry

Jagannath Devkota[1,2], Richard Pingree[1,2], David W Greve[3,4], Daejin Kim[1,2], Jeffrey Culp[1,2], Nathan Diemler[1,2], Ruishu Wright[1]

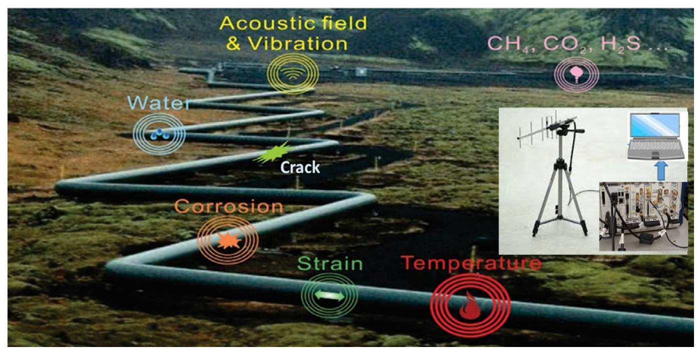
[1] U.S. Department of Energy, National Energy Technology Laboratory (NETL), 626 Cochran Mill Road, Pittsburgh, PA 15236, USA [2] NETL Support Contractor, 626 Cochran Mill Road, Pittsburgh, PA 15236, USA
[3] Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213, USA [4] DWGreve Consulting, Sedona, AZ 86336

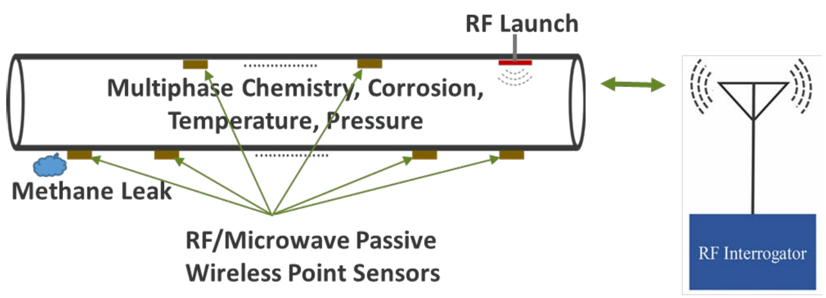


Advantages:

- Passive, Wireless, Matured Devices
- Sensitive, Low-cost Point Sensors
- Possible for Multi-Parameter Operation (Temperature, Pressure, Strain, Chemical Species, Corrosion etc.)

Pipeline Monitoring with Passive Wireless Sensors





Other Applicable Industries

- Subsurface Wellbores
- Harsh Environments in Energy Generation,
- Automotive
- Aerospace
- Manufacturing

Small (~5x10 cm^2), Low-Cost, Passive Wireless SAW Sensors to enable Ubiquitous Wireless Sensor Network for Energy Infrastructure Monitoring

UPISC UNIVERSITY OF PITTSBURGH INFRASTRUCTURE SENSING

COLLABORATION WORKSHOP

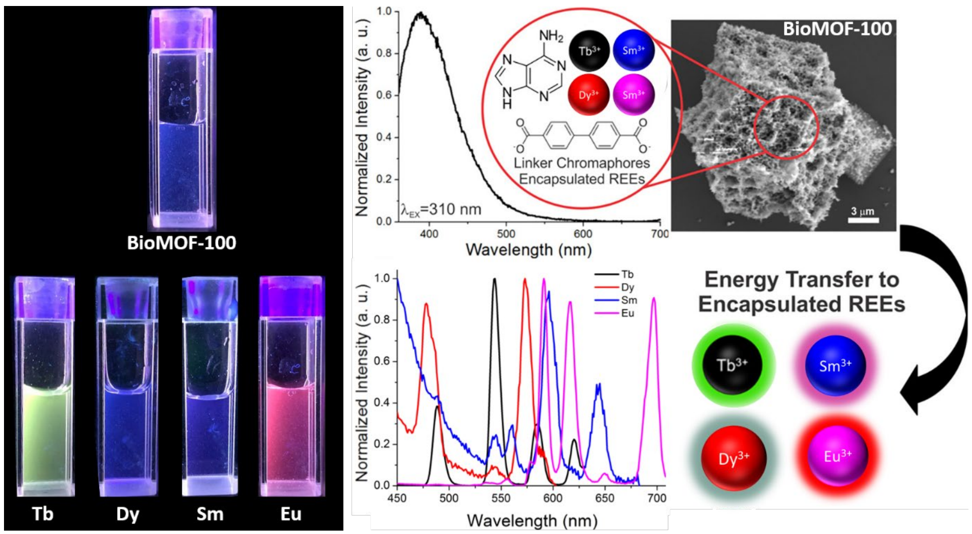
Contact: Dr. Scott E Crawford
Email: Scott.Crawford@netl.doe.gov

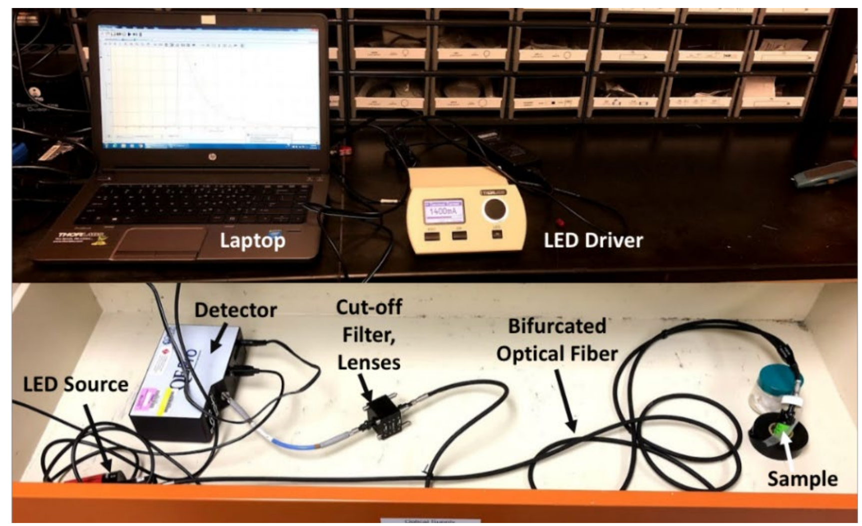
NATIONAL ENERGY TECHNOLOGY LABORATORY

Portable Photoluminescent Sensors for Critical Metals

Scott E Crawford, [1,2] **Ki-Joong Kim,** [1,2] **James E Ellis,** [1,2] **Nathan A. Diemler,** [1,2] **and John P. Baltrus**[1]

[1]National Energy Technology Laboratory, 626 Cochran Mill Road, Pittsburgh, PA 15236, USA; [2]NETL Support Contractor, 626 Cochran Mill Road, Pittsburgh, PA 15236, USA





- Luminescent sensing materials combined with **compact** fiber optic spectrometer for full portability
- Capable of **low part-per-billion** detection limits for a range of high value elements (rare earths, cobalt, aluminum) with ~**3 minute analysis time**.
- Intended applications include **process stream characterization** for critical metals extraction, field-deployable metals **prospecting**, and **wastewater quality monitoring**.
- Significant **cost savings** versus current state-of-the-art ($20,000 vs. $180,000 for ICP-MS) as well as time savings (minutes vs. hours/days)

Contact: Dr. Paul Ohodnicki
Email: pro8@pitt.edu

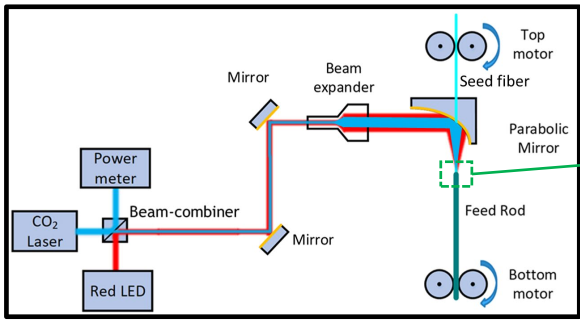
UPISC UNIVERSITY OF PITTSBURGH INFRASTRUCTURE SENSING

COLLABORATION WORKSHOP

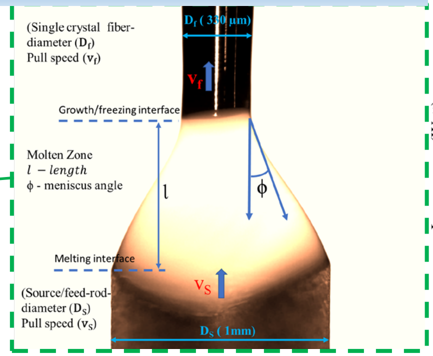
NATIONAL ENERGY TECHNOLOGY LABORATORY

Single crystal fiber growth via LHPG method for harsh environment sensing applications

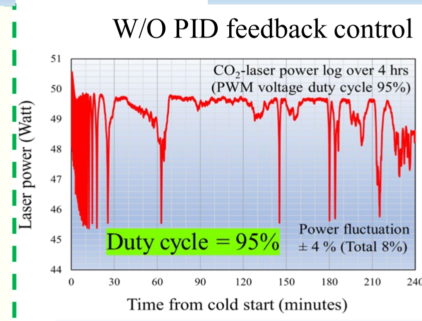
LHPG set up at UPitt

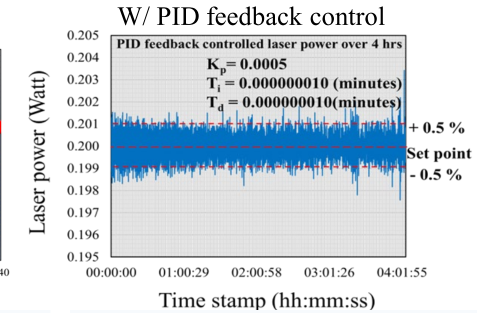


Molten-zone thermodynamics



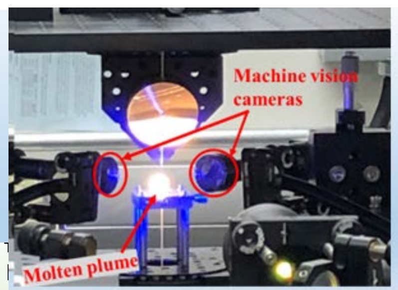
Laser power control (PID feedback loop)



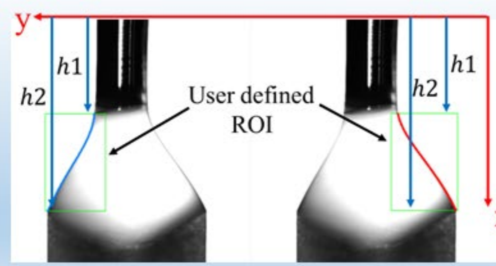


LabVIEW machine vision based in-situ

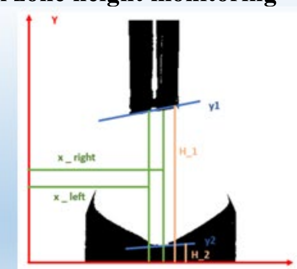
- ❖ Diameter tracking and measurement
- ❖ In-situ molten zone contour tracking and volume estimation
- ❖ Molten zone height/length tracking and measurement



Molten zone volume monitoring

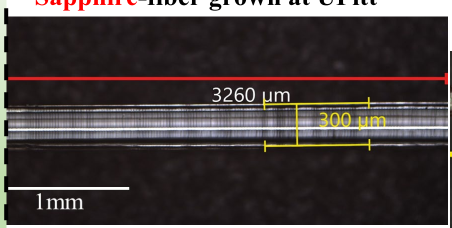


Molten zone height monitoring



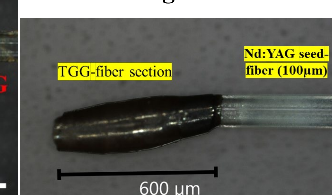
- Versatility in melting/growing refractory oxides sapphire, YAG, MO-oxides (YIG/TGG), EO-oxides (LN, $BaTiO_3$), …. (melting point up to 3000^0C)
- Crucible free , Purity, diameter < 100 µm
- High temperature (>2000^0C) sensing
- Radiation sensing
- EM field sensing
- Harsh chemical environment sensing

Sapphire-fiber grown at UPitt



YIG -fiber grown at UPitt

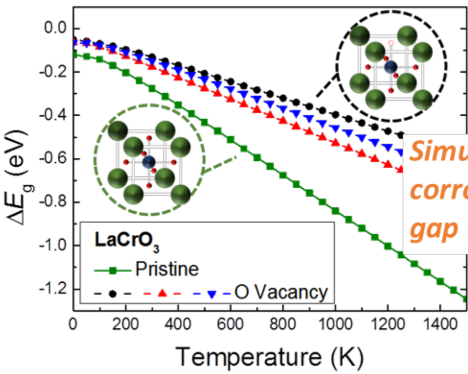
TGG -fiber grown at UPitt



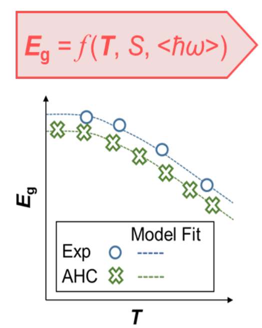
Theoretical Study of Temperature Dependence and Optical properties of Gas Sensor Materials

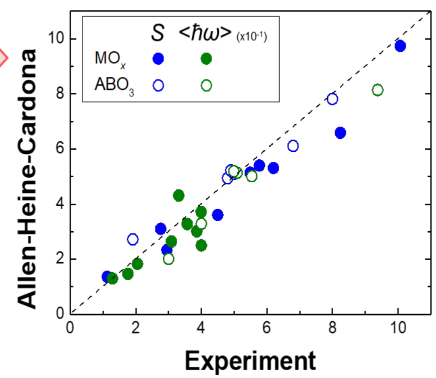
Jongwoo Park, Ting Jia, Benjamin Chorpening, Yuhua Duan*

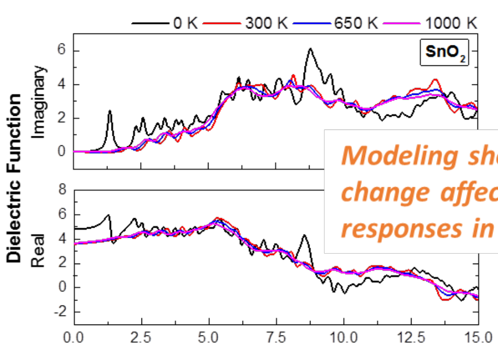
National Energy Technology Laboratory, U. S. Department of Energy, Pittsburgh, PA 15236 USA



Simulation/Experiment corroboration on band gap change in $LaCrO_3$







Modeling shows band gap change affects optical responses in SnO_2, SnO

- By the first-principles simulations, effects of elevated temperatures on the optoelectronic properties of perovskite-, metal oxide-based gas sensor materials were investigated
- To build a ML model, temperature dependence of electronic band gap data were populated via the first-principles simulations
- ML model was developed for the prediction of band gap shifts in gas sensor-utilized metal oxides

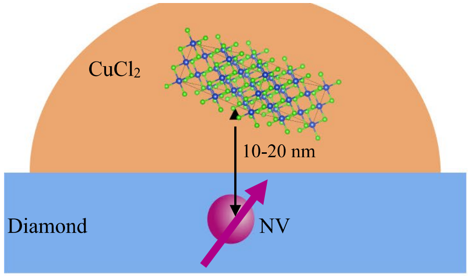
Contact: Dr. Gurudev Dutt
Email: Gurudev.dutt@pitt.edu

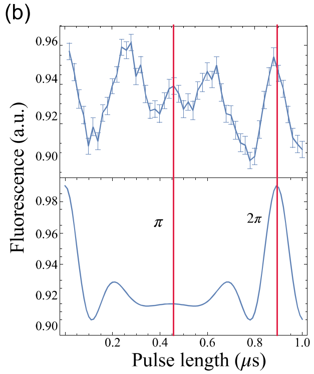
Quantum Sensors @ Pitt

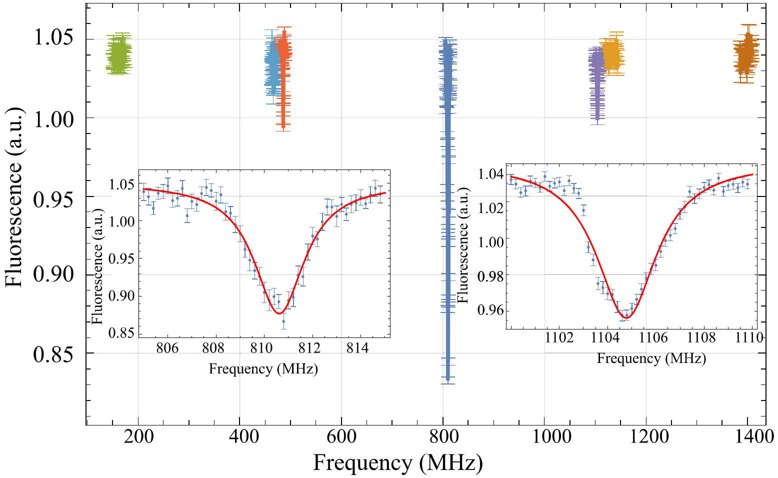
Gurudev Dutt, Dept. of Physics

- ✓ Phase estimation algorithms[1]
- ✓ Sub-shot noise scaling of sensitivity[2]
- ✓ Single spin dual-channel lock-in magnetometer[3]
- ✓ Geometric phase measurement in single spin qubits[4]
- ✓ Nanoscale electron spin resonance of molecules[5]

ESR of single Cu spins on diamond surface







1. N. M. Nusran, GD, Phys. Rev. B. 90, 024422 (2014).
2. N. M. Nusran, M. U. Momeen, GD, Nature Nanotechnology 7, 109-113 (2012).
3. N. M. Nusran, GD, Phys. Rev.B (Rapid), 88, 220410R (2013)
4. K. Zhang, N. M. Nusran, B. Slezak,GD, New J. Phys. 18, 053029 (2016)
5. K. Zhang, S. Ghosh, S. Saxena, GD, PRB 102, 224412 (2021)

University of Pittsburgh **Pitt AMPED**

UNIVERSITY OF PITTSBURGH ENERGY GRID INSTITUTE

Electric Power Technologies Laboratory

Medium Voltage Features

- 13.8kV, 4.16kV, 480V, and 208V AC voltage rails.
- Rated to handle 5MVA of power capacity.
- System is reconfigurable through Eaton reclosures to isolate parts of the lab OR create a ring architecture.

Notable Equipment Provided In-Kind

- Eaton MITS, MV circuit breakers, reclosers, power transformers, 500HP motor drive, LV motor drives, and ground fault indicator (**Donated by Eaton**).
- **Emerson Ovation** platform communicates with all major equipment.
- All equipment installed by **Sargent Electric.**

Virtual Tour of Medium Voltage Lab

https://my.matterport.com/show/?m=p85qmPtaFx

Contact: Dr. Brandon Grainger
Email: bmg10@pitt.edu

UPISC UNIVERSITY OF PITTSBURGH INFRASTRUCTURE SENSING

COLLABORATION WORKSHOP

NATIONAL ENERGY TECHNOLOGY LABORATORY

THANK YOU FOR ATTENDING!

Please remain for our poster session and social hour

5:15-6:30 pm