UPISC UNIVERSITY OF PITTSBURGH INFRASTRUCTURE SENSING COLLABORATION WORKSHOP

NATIONAL ENERGY TECHNOLOGY LABORATORY

Passive Wireless Surface Acoustic Wave Sensors for Methane Leakage and Corrosion Monitoring in Pipelines

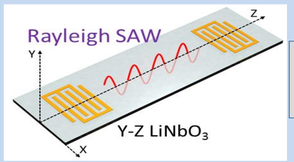
Richard Pingree[1,2]; David W. Greve[1,3]; Jeff Culp[1,2]; Daejin Kim[1,2]; Swetha Menon[1,2]; Matthew Brister[1,2]; Badri Mainali[1,2]; Ruishu Wright[1]

[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; [3]Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213, USA

Motivation

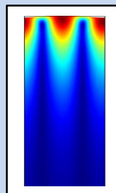
- Conventional monitoring techniques identify leaks and events once they have occurred but are limited in capability to identify failures before they occur.
- Continuous and real-time monitoring technologies are helpful to better identify, locate, and quantify methane leaks and corrosion events.
- Passive wireless sensors and their network are emerging platforms for remote and real-time monitoring of long pipelines where human access is a challenge.
- We help operators to reduce monitoring costs and simplify the inspection process by developing a low-maintenance, remote, and real-time capable multiparameter monitoring tool.

Sensor Device Design and Modeling

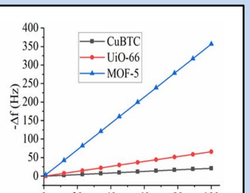


Array Devices

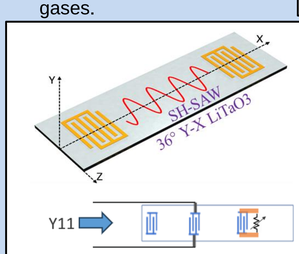
- Performed Finite element modeling (FEM) to predict the operating frequencies and optimize the device designs.
- Modeled "multi-component" devices and predicted the responses of metal-organic framework (MOF) coated SAW sensors to various gases.

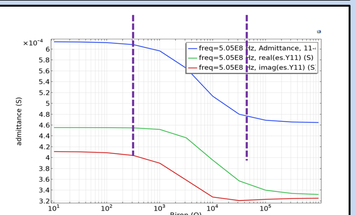


Surface displacements at resonance.



Predicted response.





Predicted admittance vs. terminal resistance.

- Proposed shear-horizontal (SH-) SAW devices for monitoring corrosion in pipelines.
- FEM simulation predicted a change in admittance at the emitter when the terminal resistance of a reflector is varied resulting in a change in phase.
- Configured Impedance Loaded Reflective Delay Line (IL-RDL) sensor.

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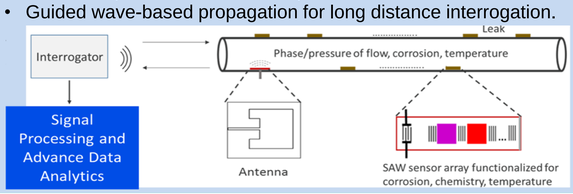
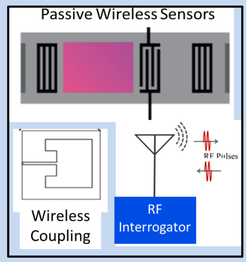
Proposed Wireless Passive Sensor Technology for Pipelines

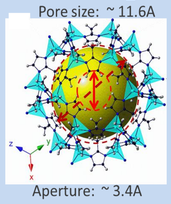
- Radio frequency (RF) Surface Acoustic Wave (SAW) microdevices with wireless capability.
- Matured technology with numerous applications including mobile communications, remote control, automotive sector, and sensors and actuators.
- Multi-parameter sensing capability (temperature, pressure, chemical species, corrosion, etc.).
- Guided wave-based propagation for long distance interrogation.

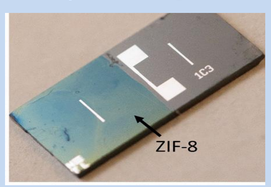




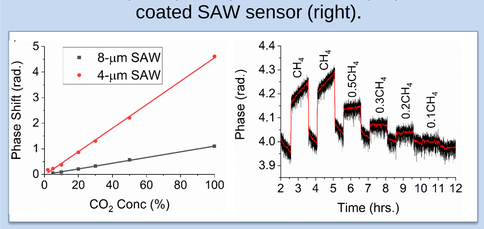
(US Patent: 11113594)

CO_2 and CH_4 Sensing



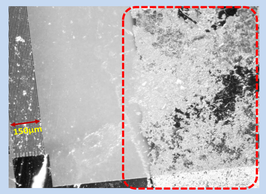


A MOF (ZIF-8) nanoporous material (left) and coated SAW sensor (right).

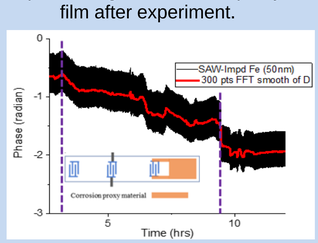


Mass-based sensing of CO_2 and CH_4 at room temperature.

Corrosion Sensing



Optical image of corrosion proxy film after experiment.



Phase response of a Fe (50 nm) coated IL-RDL sensor.

Summary

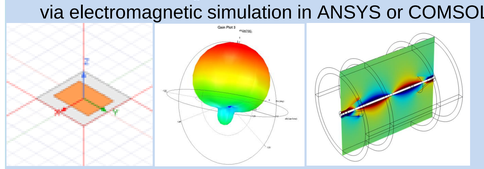
- Proposed wireless and passive sensor technology for large infrastructure monitoring.
- Demonstrated the wireless detection of leak-relevant CO_2 and CH_4 in humid environments.
- Demonstrated the wireless monitoring of corrosion at high pressure (>500 psi) in wet CO_2.
- Field work demonstrated the interrogation of functionalized SAW sensors at an abandoned well.
- Performed link budget analysis at a field site to estimate interrogation distance of SAW devices inside a pipeline.

Contact:
Ruishu.Wright@netl.doe.gov
Richard.Pingree@netl.doe.gov

Sensor Interrogation and Wireless Telemetry

Antenna Development

- Antennas are designed and performance is optimized via electromagnetic simulation in ANSYS or COMSOL.

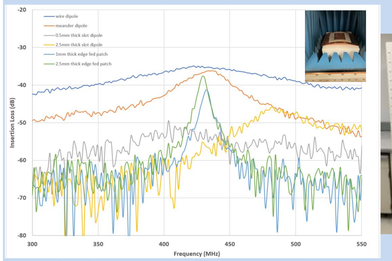


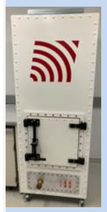
Edge fed patch geometry and 3D gain.

E-Field distribution of a Goubau surface wave.

- Planar antennas are fabricated with a printed circuit board plotter.

- Antenna performance is measured in an anechoic chamber.

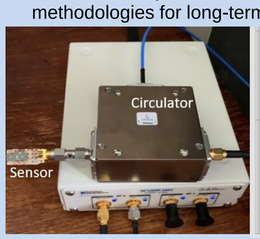


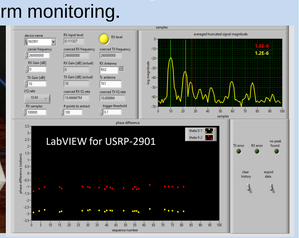


Insertion loss measurement comparing several antennas.

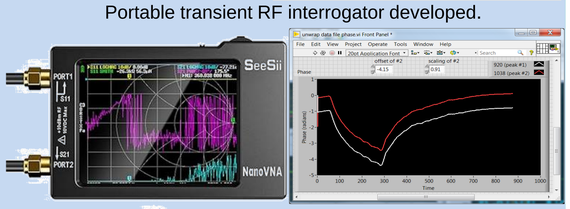
Sensor Interrogation Development

- Demonstrated portable SAW sensor interrogation methodologies for long-term monitoring.



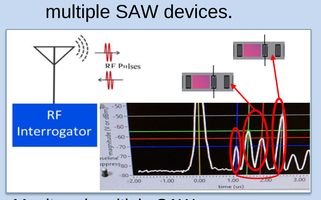


Portable transient RF interrogator developed.



Portable frequency domain RF interrogator developed.

- Demonstrated several methods of monitoring multiple SAW devices.



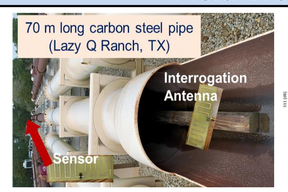
- Time domain diversity.
- Frequency domain diversity.
- Time sequential multiplexing.

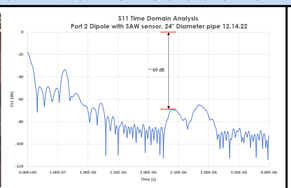
Monitored multiple SAW sensors simultaneously with time domain diversity.

Field Work Demonstrations

Lazy Q Ranch, TX

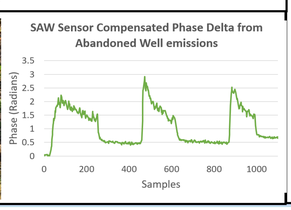
Link budget analysis performed at Lazy Q Ranch estimating interrogation distance of SAW devices inside a pipeline with several antennas.





Hillman State Park, PA

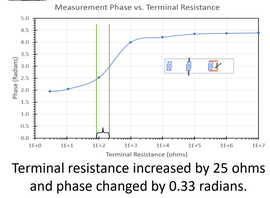
Gas from an abandoned well was monitored with a SAW device and portable interrogation system during pumped extraction.



NorthWest Natural Pipeline, OR

SAW devices inserted into a natural gas pipeline connected to a storage well and exposed to injection gas for >30 days.

Measurement Phase vs. Terminal Resistance



Terminal resistance increased by 25 ohms and phase changed by 0.33 radians.