Embedded Sensor Technology Suite for Wellbore Integrity Monitoring

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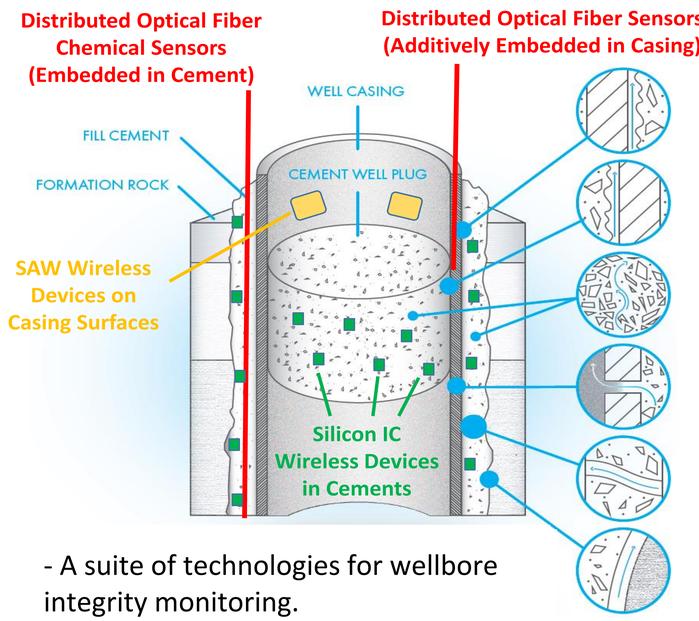
Prof. Kevin Chen, University of Pittsburgh (U Pitt) PI; Dr. Scott Frailey, Illinois State Geological Survey (ISGS) PI; Prof. David Greve, Carnegie Mellon University (CMU) PI

Research & Innovation Center

NATIONAL ENERGY TECHNOLOGY LABORATORY

Project Overview

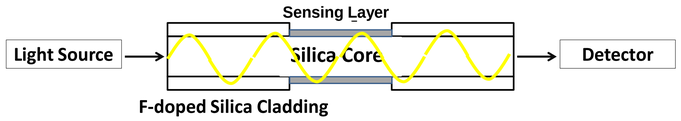


- A suite of technologies for wellbore integrity monitoring.
- Chemical sensing of high priority parameters (pH, corrosion onset, etc.)

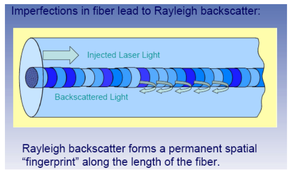
Distributed Fiber Optic Based Chemical Sensors

❖ Chemical/pH Sensing Layers (NETL)

➢ **Sensing Principle : Evanescent Wave Sensors**

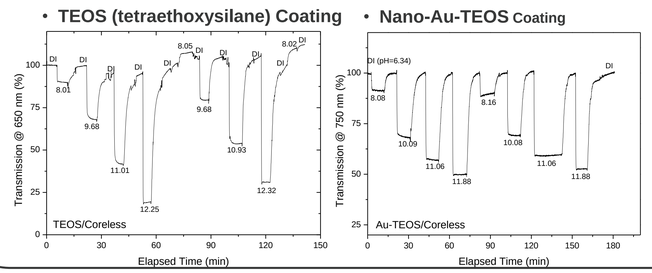


➢ **Distributed Sensing**



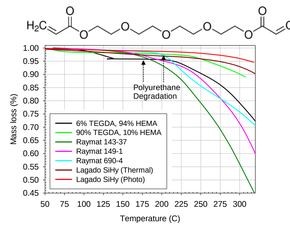
→ **Eliminate Electrical Wiring and Contacts at the Sensing Location**
→ **Tailored to Parameters of Interest Through Functional Materials**
→ **Compatibility with Broadband and Distributed Interrogation**

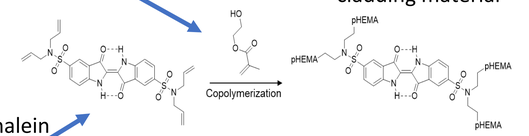
➢ **pH sensing materials: TEOS and Nano-Au incorporated-TEOS**



❖ Organic pH Sensitive Coating Fabrication/Deployment (IOS)

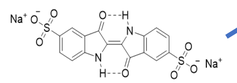
➢ **Polymeric Matrix:** pHEMA
-Stable up to 200 – 250 °C
-Excellent water permeability
-Translucent





➢ **Sensor Cladding:** pH Indicator copolymerized with pHEMA cladding material

➢ **pH Indicator:** thymolphthalein

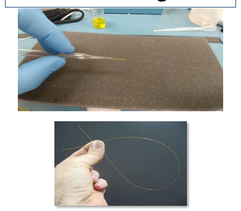


Vinyl functionalization

-Stable up to 248 °C
-Color variation from pH 7.5 to 11.5

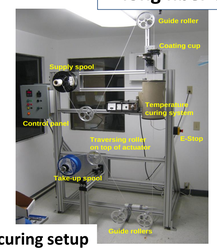
➢ **Fabrication and Scale-up Capabilities**

Manual fabrication of Short Sensor Segments



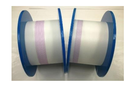
-Accelerated curing process < 60s
-Moderate curing temperature 100 °C or photocuring
-Controlled pre-polymer viscosity for uniform coating distribution

In-line fiber recoating of long fiber optic sensors



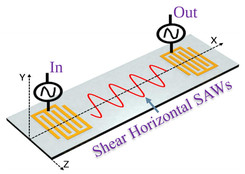
Thermal-curing setup

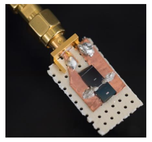
UV-curing setup



Passive, Wireless Surface Acoustic Wave (SAW) Sensors (NETL & CMU)

➢ **SAWs for Liquid Phase Application**





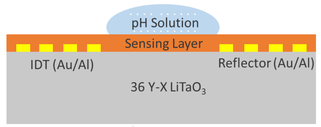
NETL's SAW Devices:

f_0 = 520 MHz
Substrate: 36 Y-X LiTaO3
IDTs: Al or Au

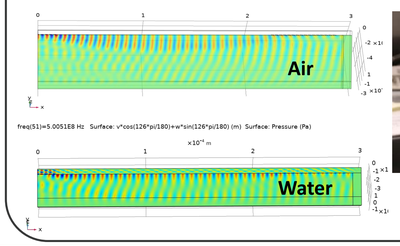
➢ **SAW Attenuation (α) and Velocity (v):**

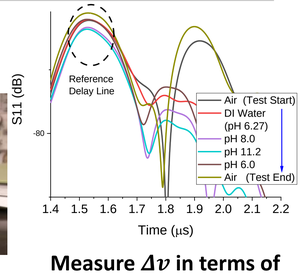
$$\Delta\alpha = \delta\alpha(\sigma, \epsilon, c, T, P)$$

$$\Delta v = \underbrace{\frac{\delta v}{\delta \sigma}\Delta\sigma + \frac{\delta v}{\delta \epsilon}\Delta\epsilon}_{\text{In pH solution}} + \cancel{\delta v(m, c, T, P)}$$



➢ **Simulation and Experimental Results**

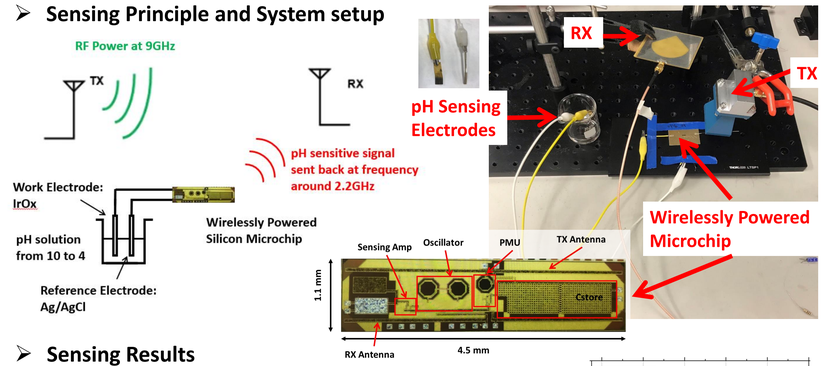




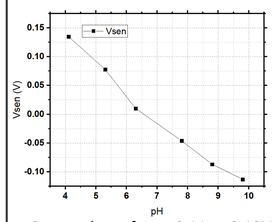
Measure Δv in terms of time delay.

Passive, Wireless Silicon Integrated Circuit Sensors (UCLA)

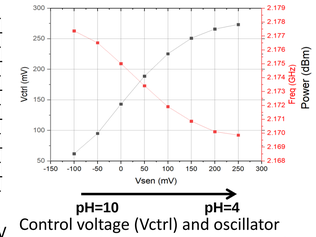
➢ **Sensing Principle and System setup**



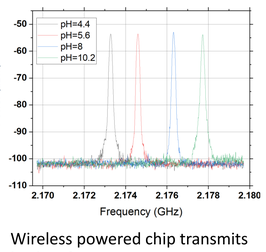
➢ **Sensing Results**



Open voltage from -0.11 to 0.13V for pH changing from 10 to 4



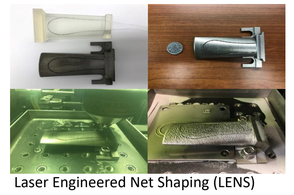
Control voltage (Vctrl) and oscillator oscillation frequency as a function of Sensed voltage (Vsen) from electrodes



Wireless powered chip transmits back at frequency 2.173~2.178GHz for different solution pH value

Embedding of Sensors in Cement and Casing Materials (NETL & U Pitt)

➢ **Embed fibers in high temperature metals, including curved parts.**

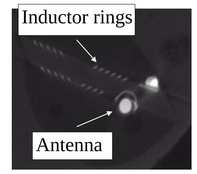


Laser Engineered Net Shaping (LENS)

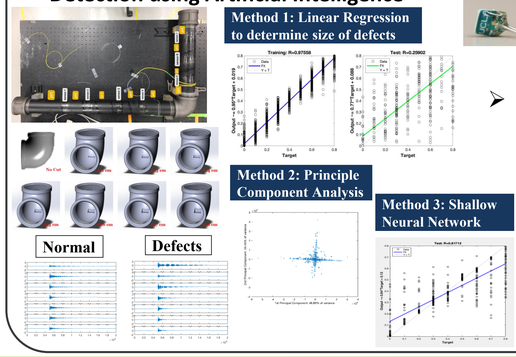
➢ **CT scans of cement samples with sensors embedded**

- Optical fibers embedded in cement (1''OD)

- SiIC chip (5-7mm) embedded in cement



➢ **Embedded Fiber Sensors for Defect Detection using Artificial Intelligence**



➢ **Mechanical testing of cement with sensors embedded**