U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

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Acousto-Optic Multimodal Sensors for Advanced Reactor Monitoring and Control

Advanced Sensors and Instrumentation Annual Webinar

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Project Overview

Goal and Objectives:

- The focus of this project is to design and develop a multimodal sensor for measurements of critical process parameters in advanced non-light water-cooled nuclear power plants (NPPs), for the early detection and characterization of atypical operating conditions.
- Objectives
  1. Developing an acousto-optic mechanism for measurement extraction from a SAW device;
  2. Integrating a SAW and/or optical sensing-based mechanism for gas composition into a dual-mode SAW sensor;
  3. Algorithms for deconvolving the effects of temperature, pressure, and gas composition to extract three measurements from an integrated multimodal sensor;
  4. Test and evaluation for accuracy and reliability assessment of the sensor.

Project Team: Pacific Northwest National Laboratory & University of North Texas

Schedule:

Year	Milestone/Deliverable	Description
1	M3CA-19-WA-PN -0702-014	Status Update of Multimodal Sensor Design
	M3CA-19-WA-PN -0702-015	Status Update of Evaluation Criteria for Assessing a Multimodal Sensor Concept and Data Analytics Deconvolution of Mixed Signals
	M2CA-19-WA-PN -0702-013	Year 1 FY20 Status Update of Smart Multimodal Sensor Design for Advanced Reactor Monitoring
2	M3CA-19-WA-PN -0702-018	Test Plan for Evaluating Sensor Concept Sensitivity
	M3CA-19-WA-PN -0702-019	Status update of Data Analytics Efforts for Isolating Measurement Parameters of Multimodal Sensor Data
	M2CA-19-WA-PN -0702-017	Year 2 FY21 Status Update of Smart Multimodal Sensors for Advanced Reactor Monitoring
3	M3CA-19-WA-PN -0702-0112	Status Update of Final Multimodal Sensor Design
	M3CA-19-WA-PN -0702-0113	Sensor Concept Testing/Evaluation and Analytics Update
	M2CA-19-WA-PN -0702-011	Final Report for (Project 19-17070) Acousto-optic Smart Multimodal Sensors for Advanced Reactor Monitoring and Control

Summary of accomplishments

Milestones

- **M3CA-19-WA-PN_-0702-014**: Status Update for Multimodal Sensor Design for Advanced Reactor Monitoring – Submitted
- **M3CA-19-WA-PN__-0702-015:** Status Update of Evaluation Criteria for Assessing a Multimodal Sensor Concept and Data Analytics Deconvolution of Mixed Signals – Delayed into early 2021 to allow for collection of essential laboratory data
- **M2CA-19-WA-PN__-0702-013:** Year 1 FY20 Status Update of Smart Multimodal Sensor Design for Advanced Reactor Monitoring – on schedule

FY20 Key outcomes

- Significant modeling of SAW parameters converging on appropriate designs for temperature and pressure concept sensors
  - Study of SAW propagation and velocity
  - Study of mechanical displacement and electrical potential of SAW pressure sensor
  - Simulation of crystal cuts effect on SAW velocity
  - Dispersion study of multi-layered SAW devices
  - Simulation studies of frequency response of AIN substrate, materials resonance, numerical simulation of SAW characterization
  - Modeling of SAW sensitivity to temperature and pressure and effect on SAW velocity
  - Modeling of 2D and 3D SAW propagation in LiNb03 and AIN
- Preparation of thin-film development laboratory for AIN film growth – Beginning thin film growth optimization
- Review of photolithography capabilities – Beginning IDT deposition on highly polished sample substrates

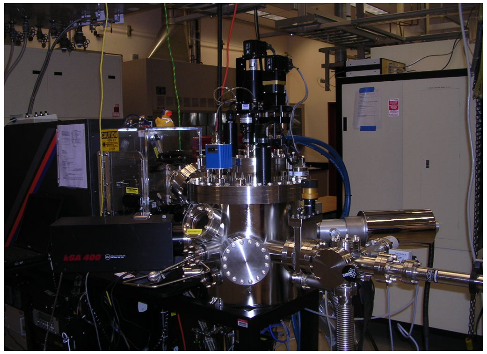
Technology Impact

- *Advances the state of the art for nuclear application:* This work scope address technical gaps in temperature, pressure and gas composition sensing capabilities for advanced reactors
- *Supports the DOE-NE research mission:* This work scope directly contributes to the DOE mission directives by developing enabling technology capable of reliable, higher-resolution process measurements for deployment of advanced reactors
- *Impacts the nuclear industry:* The resulting multi-modal sensing platform from this work scope will enable reduction of vessel penetrations in advanced reactors for condition monitoring sensors.
- *Commercialization:* Further development achieved by this work scope for deconvolving mixed measurements will enable development of multimodal sensors for a variety of harsh condition measurements across the NE space and into other harsh environment applications (advanced reactors, petrochemical, etc.)

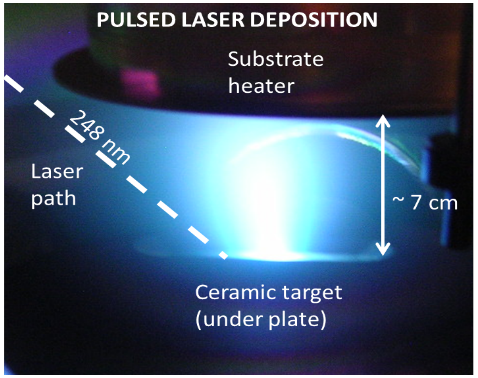
Accomplishments (1/2)

Review and preparation of thin film deposition capabilities:

- Using Pulsed laser deposition (PLD) vacuum deposition technique that uses a pulsed UV excimer laser to ablate material from a ceramic target
- The PLD system being used for this task features a coherent CompexPRO KrF excimer laser with a 248 nm wavelength and a 1 – 20 Hz repetition rate. The laser energy density incident on the target is ~2 J/cm2.
- Supports substrates up to 2” diameter (film thickness uniformity degrades at larger diameters)
- A heater capable of ~975° C is used as the primary growth condition which can be varied to optimize film quality
- Typical growth rates of ~0.25 Å/pulse are achievable
- Maximum film thickness can be between 1 to ~6 microns depending on the material and deposition parameters



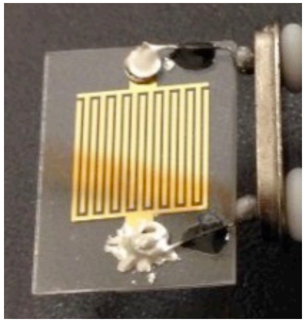
PNNL Thin Film Deposition Chamber



Ceramic Target Undergoing PLD

Review and preparation of IDT fabrication capabilities:

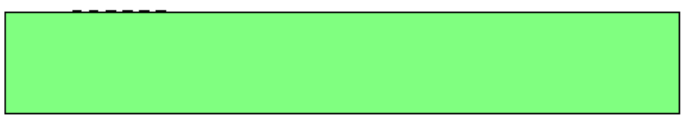
- Interdigital electrode deposition using photolithography
  - Photolithographic patterning of micrometer-scale features. This includes in-house photomask production, spin coating, photomask alignment and exposure, and other wet chemical processing
  - Thin film deposition with a multi-target sputtering system to deposit a wide array of materials on surfaces
  - Prepared to begin depositing electrodes on highly polished substrates in November 2020



IDT Humidity sensor with 300 µm gold wire deposited on quartz substrate with 400 µm pitch

Accomplishments (2/2)

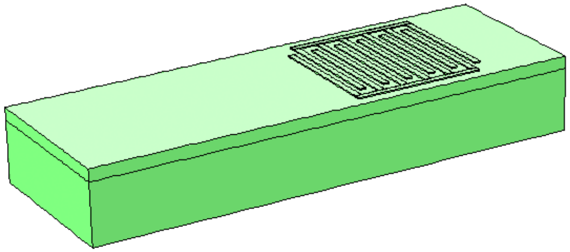
- 2-D wave propagation modeling on LiNb03 and AIN
  - Wave is excited with AC voltage (@ saw resonator resonant frequency) supplied to the IDTs.
  - Wave is constrained in the surface area (with 1~2 wavelength) of the piezoelectric substrate.



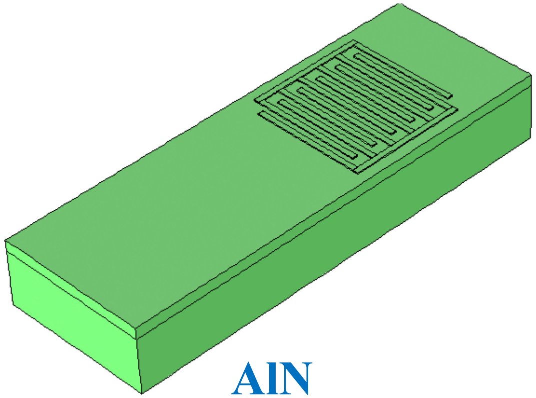
$LiNbO_3$

AlN

- 3-D wave propagation modeling on LiNb03 and AIN



$LiNbO_3$



AlN

Conclusion

In FY20 notable progress was made despite delays associated with the COVID-19 global pandemic

- Considerable modeling and simulation progress was made toward optimizing SAW sensor design criteria and study of SAW propagation in materials of interest
- Preparations were completed to begin parallel fabrication activities for optimization of fabrication activities
  - Thin film deposition optimization for AlN films
  - Interdigital electrode construction on COTs films
- This research directly contributes to the development of robust versatile sensors that will enable advanced reactor efforts consistent with NE R&D program goals.

- *Questions?*
- *Michael.Larche@pnnl.gov for any additional questions that may not be answered during the webinar.*