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

Clean. Reliable. Nuclear.

Materials Science and Advanced Manufacturing of Sensors at Boise State University

Advanced Sensors and Instrumentation Annual Webinar

November 12 , 2020

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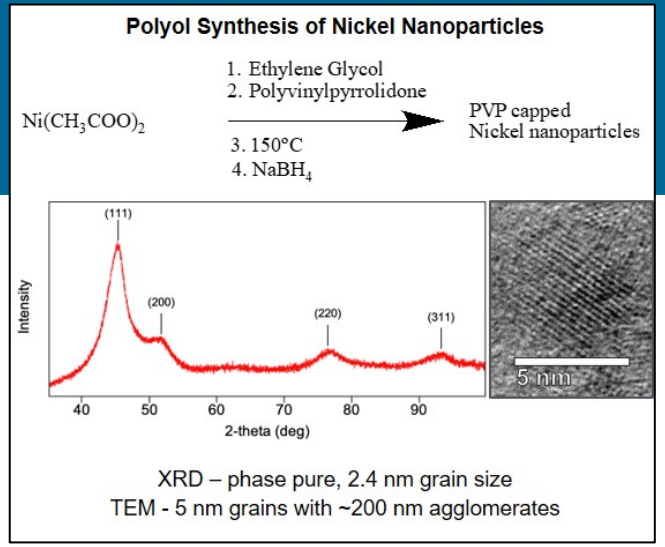
Project Overview

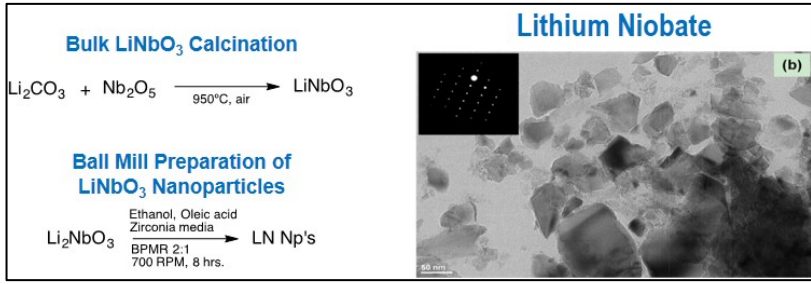
To establish research capabilities, analysis methods, sensor and materials optimization, and provide sensor fabrication support at Boise State University (BSU) in collaboration with the Idaho National Laboratory (INL). Several activities were performed to facilitate prototype sensor design, fabrication, and experimentation.

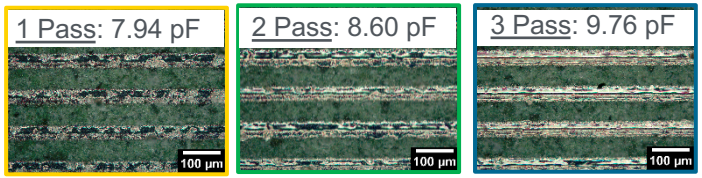
SENSOR R&D THRUSTS	INL	BSU					Deliverables
	TPOC	TPOC	FACULTY	STAFF	GRA	UGRA	
ADVANCED MANUFACTURING FOR SENSORS	Michael McMurtrey	David Estrada	5	1	3	3	Nanoparticle ink synthesis (piezoelectric and magnetostrictive ink development) AM process control via M&S (adhesion strengths between nanoparticles on substrates, effects of dopant concentration on diffusion, multi scale modelling of nanoparticle ink sintering processes)
HTIR-TC SENSORS	Richard Skifton	Lan Li	2	-	2	3	Calculate Seebeck Coeff via M&S, Optimize stabilization heat treatments, and characterize HTIR-TCs before and after heat treatments and aging via MSE
SENSORS FOR MECHANICAL PROPERTIES	Richard Skifton	David Estrada	3	-	3	3	CSGs: Deploy on fuel geometries, demonstrate at high temperatures, study interface reaction kinetics, and optimize geometry via M&S LVDT: Characterize and understand nuclear grade LVDT designs via MSE and M&S
ACOUSTIC SENSORS	Joshua Daw	Dan Deng	1	-	2	-	SAW: Literature review on alternative uses, model development for the advanced manufactured sensor UWT (Ultrasonic waveguide thermometer): Model development and experimental correlation of traditional and piezoelectric thin film printing and post processing
LINE SOURCE	Austin Fleming	David Estrada	1	-	1	-	Develop FEA and analytical model for the frequency response of an advanced (miniature, optimized material and fab) needle probe design. Assist in the fabrication and characterization of the design
RADIATION TOLERANT FIBER SENSORS	Austin Fleming	Nirmala Kandadai	3	1	3	4	Enabling R&D: Literature review on possible fiber techniques for local monitoring of fiber properties (RIA, RIE, compaction, index of refraction), develop model for fiber optic behavior Demonstrate coherent optical fiber bundles for infrared thermography on pre-cracked fuels
ELECTROCHEMICAL SENSORS	Hongqiang Hu	Michael Hurley	3	-	2	2	Support ongoing efforts at INL with partners to optimize performance in reactor relevant conditions: Validate sensor performance via MSE, report on progress of deployment of in-reactor EIS sensor testing, and develop an FEA model for EIS signal interpretation and performance prediction
NEUTRON GENERATOR FOR SENSOR DEVELOPMENT	Troy Unruh	Brian Jaques	1	1	-	1	Finalize documentation to install at BSU (ID suitable location and controls, modeling of appropriate shielding, Safety procedures, monitoring equipment, training documentation)

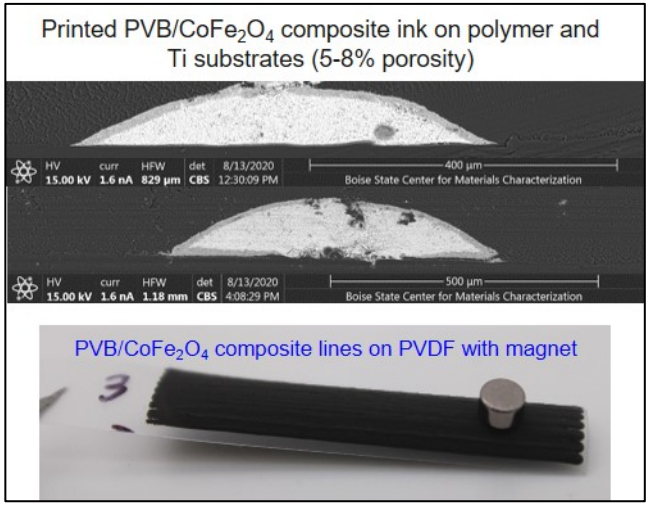
Accomplishments

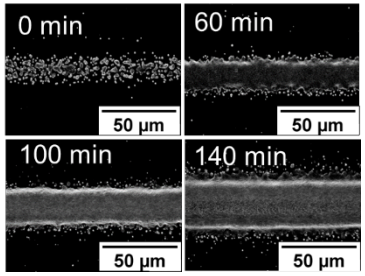
- Nanoparticle ink development:
  - Nickel
  - $LiNbO_3$ (piezoelectric)
  - $CoFe_2O_4$ (magnetostrictive)
- Print and post process optimization of commercial silver inks and novel inks
- AM Process control
  - M&S to calculate adhesion strengths between the nanoparticles and substrates
  - Effect of dopant concentration on diffusion (HTIR-TC)

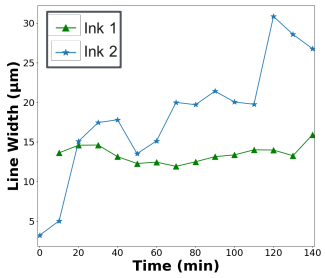


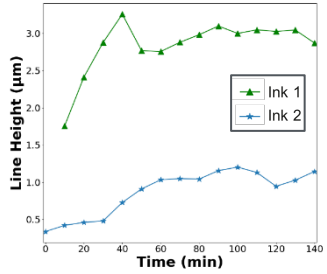






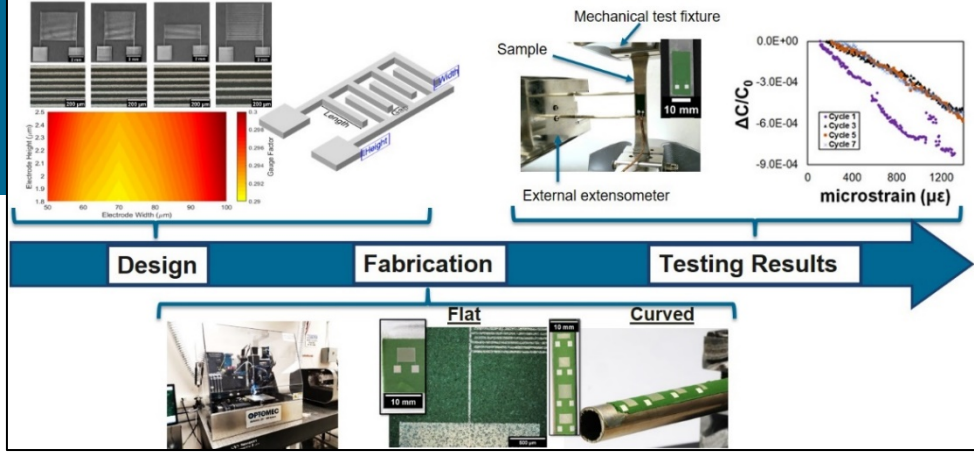


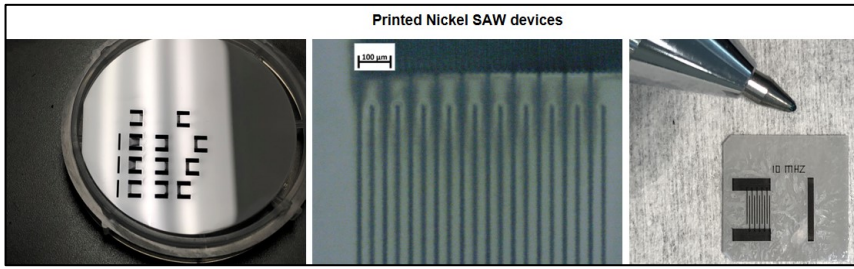


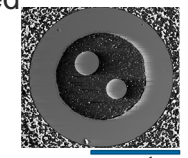


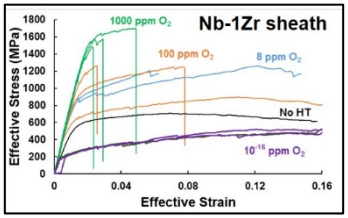
Accomplishments

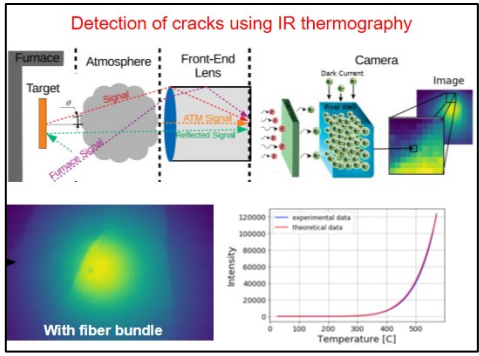
- AM Sensors
  - Capacitive Strain Gauges (CSGs)
    - Print optimization on flat and curved surfaces
    - RT testing
  - Surface Acoustic Wave (SAW)
    - Ag, Ni, and $LiNbO_3$
- Fiber sensors
  - Effects of RIA and RIC on gratings and performance
  - IR thermography for crack detection
- EIS sensors
  - In-situ cladding EIS signal acquisition during cladding oxide growth (data was modeled and validated via MSE)
  - High temp sensor was designed and developed
- HTIR-TCs
  - Stabilization heat treatment optimization
- Neutron Generators
  - Identified space and modeled using MCNP, NRC license mod request, infrastructure proposal
- LVDT
  - Displacement sensor and pressure sensor
  - Optimization and miniaturization via MSE and M&S

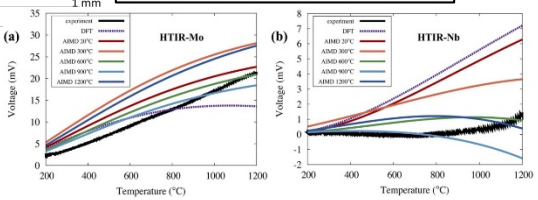


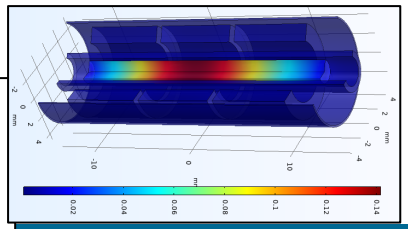


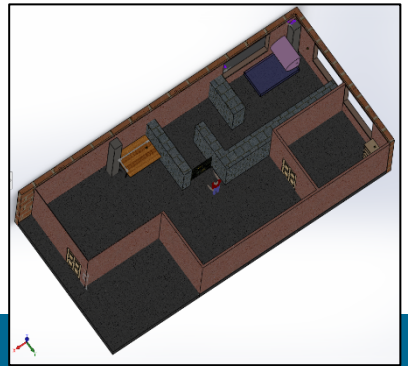


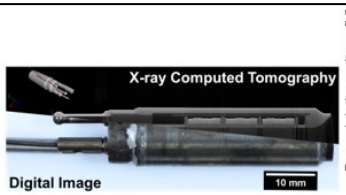


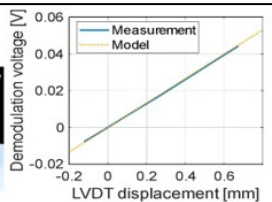


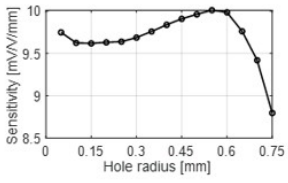




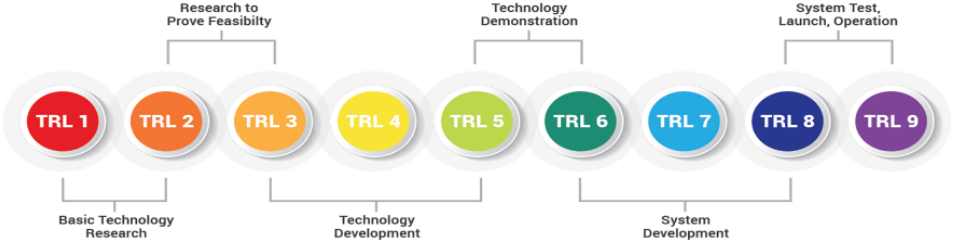








Technology Impact



Using advanced manufacturing processes in combination with a foundational materials science and engineering approach that includes modeling and simulation, is rapidly advancing the design and development of sensors at BSU in close collaboration with INL. These sensors are designed for in-situ and in-pile applications to be used in instrumented experiments.

The sensor R&D activities at BSU advances the state of the art, supports the DOE-NE mission, and impacts the nuclear industry through:

- Workforce training and development (growing the talent pipeline)
- Using a science-based approach for sensor development and deployment to increase spatial and temporal resolution of in-situ, in-pile phenomena
- A synergistic team that combines AM with MSE and M&S for nuclear, resulting in optimized materials and novel sensor designs with smaller form factors and rapid iteration times
- Supporting several DOE-NE programs beyond NEET; including Fuel Cycle R&D, NEAMS, NEUP, GAIN, and NMDQI via providing innovative solutions to instrumented experiments in TREAT, ATR, etc., which are key for technological and materials advancement
- Supporting key information and data for HTIR-TC commercialization
- Supporting key nuclear sensor gaps resulting from the Halden Reactor Project closure (e.g. LVDT, EIS)
- The development of nanoparticle nuclear grade inks for novel nuclear sensor development using advanced manufacturing processes (including AM process control)

Conclusion

The over-arching accomplishment of this program at BSU is that capabilities are being established and advanced materials are being developed and understood to conduct advanced sensor research and development for measurement for nuclear fuel and materials irradiation tests. The results of this program impact several DOE-NE research programs. Continued development of measurement technologies will contribute to the experimental capabilities available at material test reactors across the DOE complex and beyond. The investment in this program has led to the following:

- 4 patent applications
- 15 peer reviewed journal publications
- >40 research conference presentations and seminars
  - Including 15 invited presentations
- Several additional research funding opportunities through: NEUP, DOE and NASA SBIR and STTR, NSUF-RTE, CINR and others
- *The training of 11 GRAs and 14 UGRAs, 4 NEUP fellows and 1 INL graduate fellow*

Please send further questions or collaboration inquiries to:
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