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

ASI | Advanced Sensors and Instrumentation

Develop Melt Wire Arrays and Characterize Encapsulation Materials Combability

Advanced Sensors and Instrumentation (ASI) Annual Program Webinar
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Project Overview

- **Brief summary of research scope:**

Passive peak temperature monitors have been in use for many decades in irradiation testing experiments, but limited innovation has been applied to these technologies. One method to determine peak temperature involves placing wires of known composition and melting temperature in a test. In this method post-test examination of the wire is required to determine if the melting occurred, indicating that the corresponding melting temperature was reached or exceeded. Sensor development using **Advanced Manufacturing** methods enables the production of robust and miniaturized sensors for nuclear application and expands the current capability of using passive melt wires.

- **Project Schedule:**

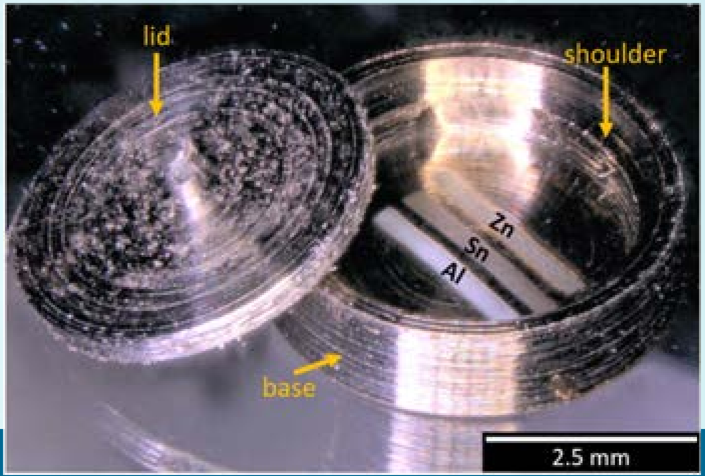
November 2022 (delayed by 1 month): Complete level 4 milestone (M4CT-22IN0702073) titled "Develop melt wire arrays and characterize encapsulation materials combability"

- **Participants:**

Kiyo Fujimoto, Lance Hone, Kurt Davis, Richard Skifton, and James Milloway

Malwina Wilding (WPM) and Austin Fleming (TPOC)

Idaho National Laboratory



Technology Impact

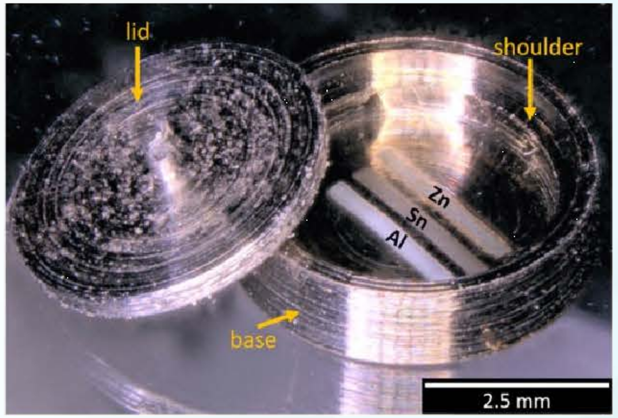
- Passive monitors provide a practical, reliable, and robust approach to measure irradiation temperature during post-irradiation examination while requiring no feedthroughs/leads comparable to current more-complex real-time temperature sensors
- They have been chosen because they have a proven history for use by stakeholders for deployment and require continued development and characterization to assure successful integration with program schedules and objectives
- Using advanced manufacturing techniques to develop and optimize advanced manufactured melt wires that expand the range of melt wire capability
- Facilitates the development of advanced sensors and instrumentation with cross-cutting technology development to support the existing fleet, advanced reactor technology and advancing fuel cycle technology development

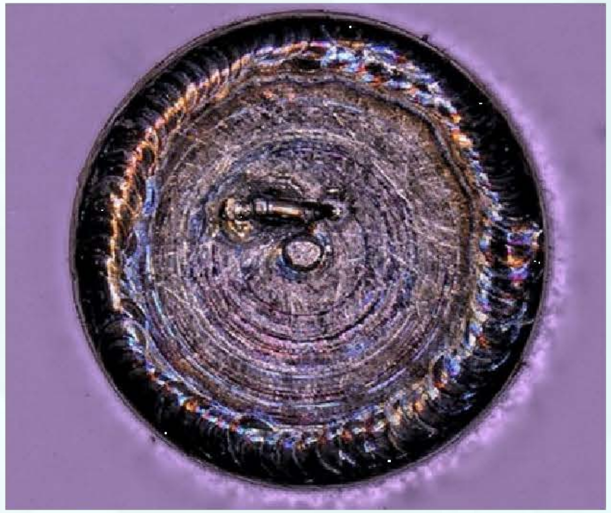
Printed Melt Wire Arrays

- Optimize for material selection of the encapsulation and printed melt wire array that were initially investigated in FY21

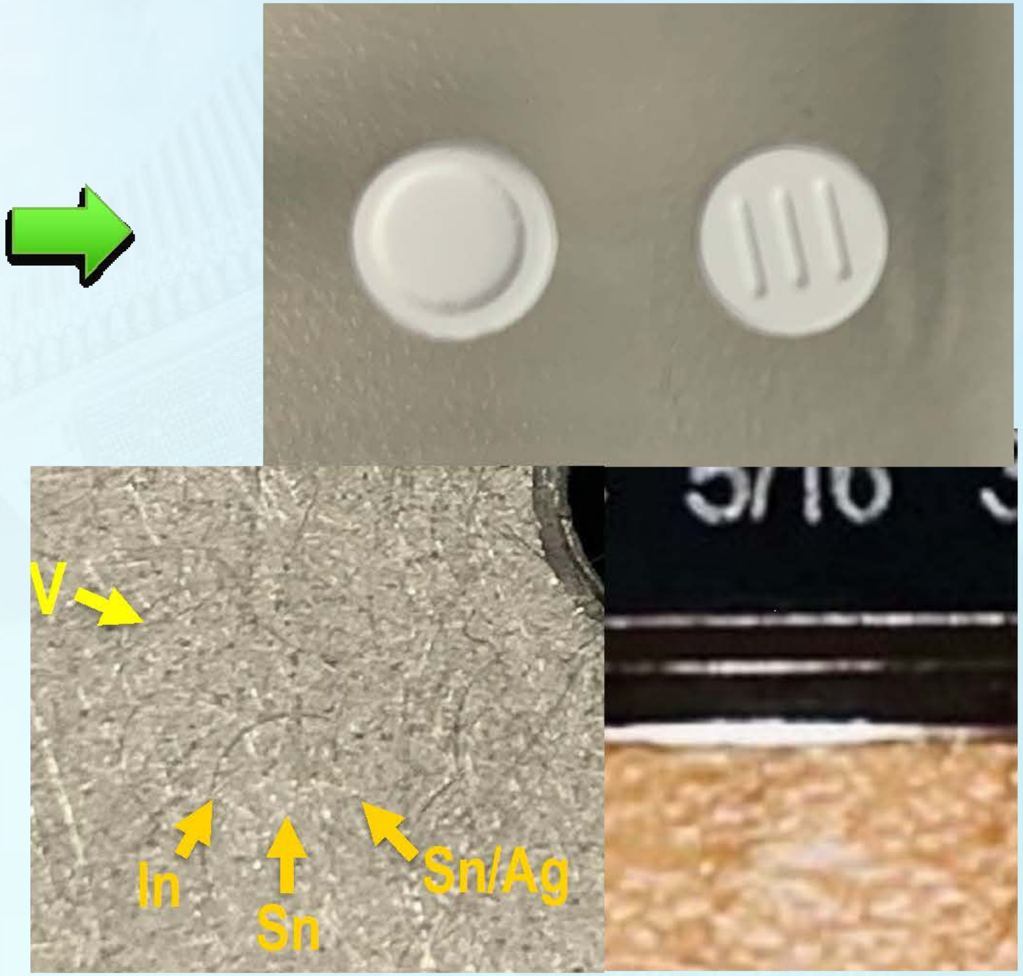
- Focus on materials combability that will lead higher resolutions then traditional quartz encapsulated melt wires

FY21 encapsulation design with XCT





FY22 encapsulation design for AM melt wires

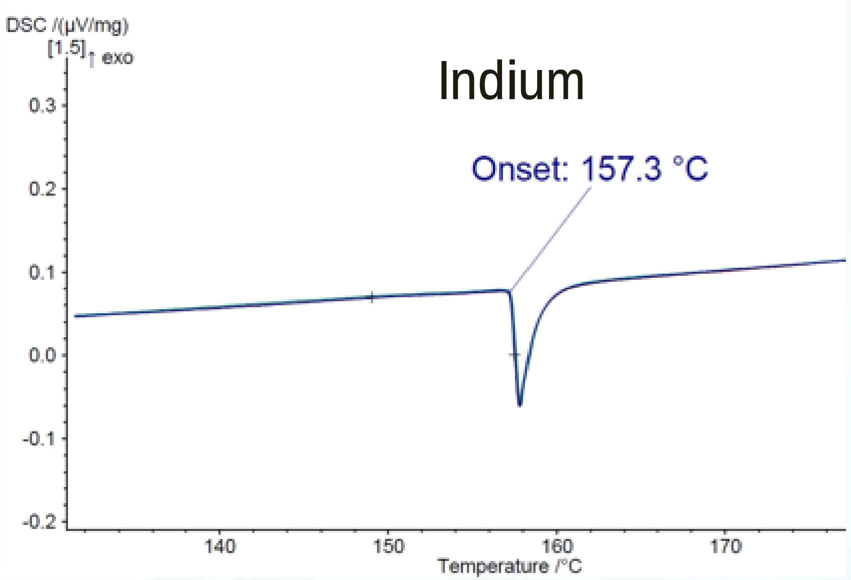


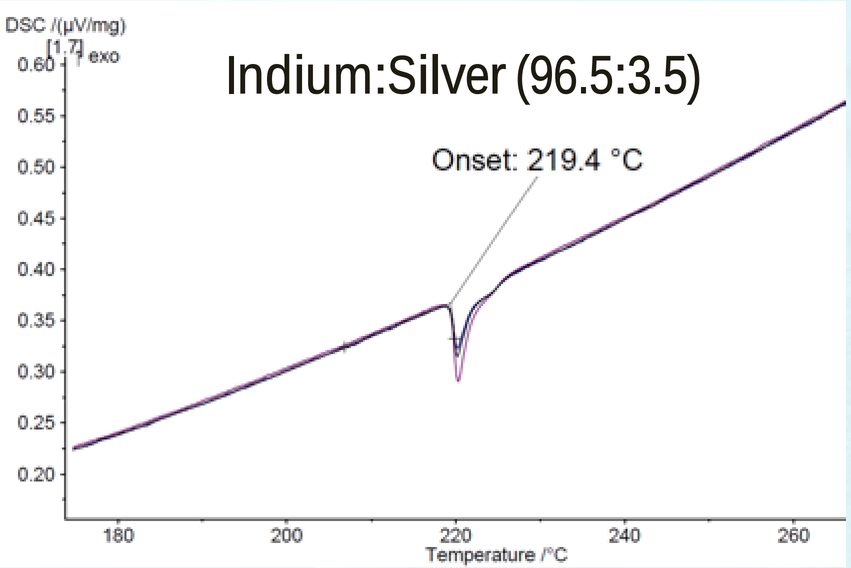
Issues (Schedule/Cost/Technical)

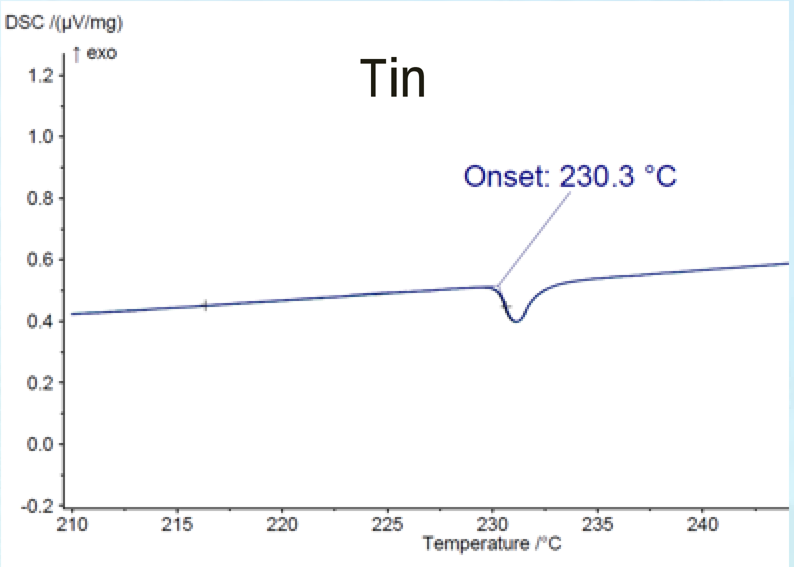
- Assessing material availability and receiving initial quotes
- Delays in receiving materials and fabrication time
- Experienced issues with Digital Light Processing -> required for fabricating ceramic sublayer
- Reprinted ceramic sub-layer
  - Printed too thin and not the right fit for the Vanadium containers before they were manufactured
- Problems with characterizing the synthesized in-house (Printed Sensors WP):
  - Zinc:Aluminum (90/10) ; Gold:Germanium (88:12); and Gold:Tin => 380℃, 356℃, 278℃
  - Tin (100%), Tin:Silver (96:4), and Tin:Zinc (91:9) => 232℃, 221℃, 199℃
  - Tin (100%), Tin:Silver (96:4), and Bismuth => 232℃, 221℃, 271℃
  - **Final Selection: Indium, Indium:Silver (96:4), and Tin (100%) => 157℃, 221℃, 232℃**

Results and Accomplishments

Differential Scanning Calorimetry of in-house synthesized nanoparticles







Nanoparticle System	Theoretical Composition (at.%)	Theoretical Melting Point (°C)	DSC Melting Point (°C)
Indium:Silver	96.5:3.50	221	219.4
Tin	100	231	230.3
Indium	100	157	157.3

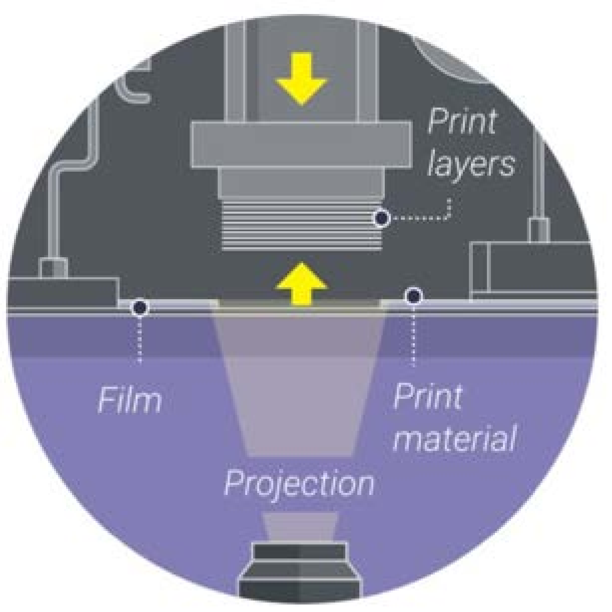
Results and Accomplishments – Ceramic Sublayer

Printing technology used:

Digital Light Processing or Vat Photo Polymerization

- Uses a projected light source to cure an entire layer at once
- Layer Thickness: 10 - 200 µm
- Wall thickness: 0.1 – 10 mm (alumina)
- Capable of printing ceramics and metals:
  - alumina, zirconia, fused silica, and hydroxyapatite, stainless steel 316L, stainless steel 17-4, inconel 625, and copper

Admaflex 130



Ceramic Sublayer:

- Alumina :
  - Diameter: 3.5 mm
  - Melt wire recess: 2 mm (L) x 0.5 mm (W) x 0.25 mm (H)
- Insulation layer to minimize premature melting

DLP alumina sublayer

Results and Accomplishments – Printed Melt Wires

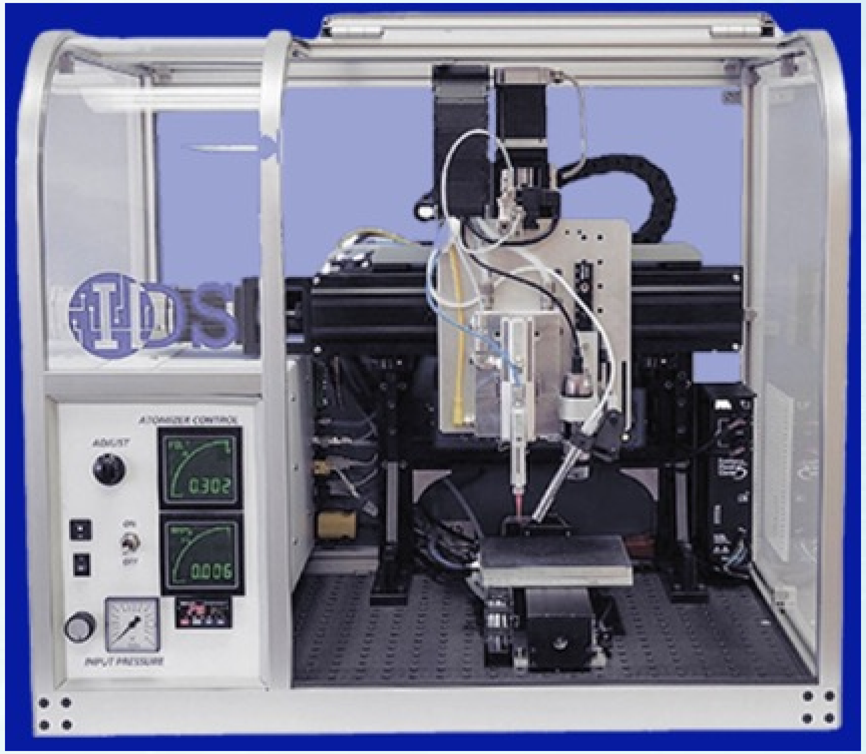
Aerosol Jet Printer – IDS Nanojet

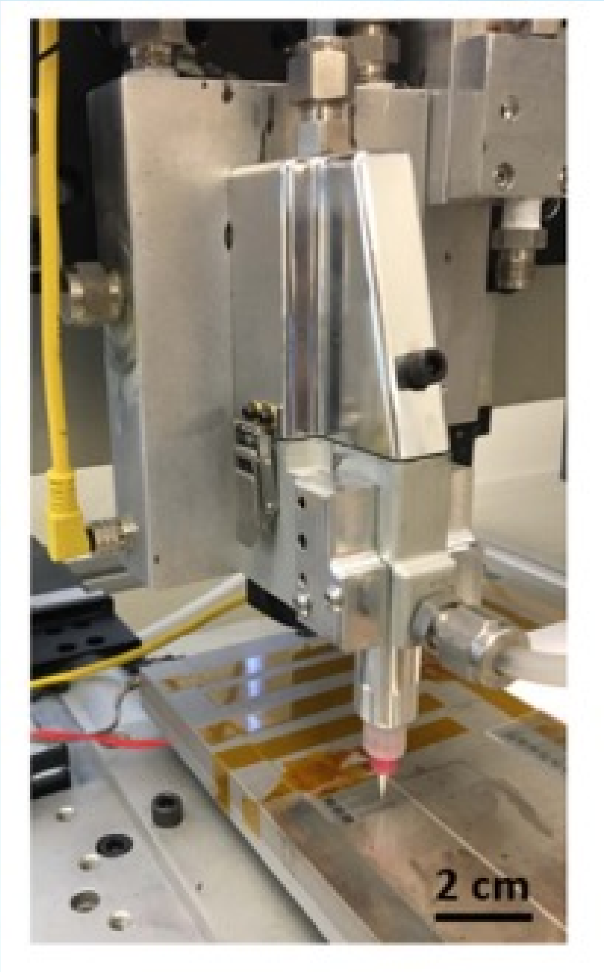
<u>Aerosol Jet Printing:</u>

- Creates an aerosol of an “ink” to deposit directly onto a substrate
- 10 µm – 5 cm linewidths
- 0.7 – 5000 cP ink viscosity
- 2 – 10mm working distance
- Can print a wide variety of materials
- Maximum particle size = 200 nm
- 3-axis motion control

Printed Melt Wires:

- Indium, tin and tin/silver melt wires were fabricated with AJP
  - 1.5 mm (L) x 0.25 mm (W)
- The entire capsule was sintered at 100 °C





Remaining Work for FY22

- Furnace testing of printed and sealed melt wires
- X-ray Computed Tomography (X-ray CT)
  - Images of melt wires after sealing process
  - Images of melt wires after furnace annealing
  - Compare before and after annealing images for melting of each melt wire
- Write Summary Report
  - Level 4 milestone report titled “Develop melt wire arrays and characterize encapsulation materials combability”

Concluding Remarks and Future Work

Summary

- Optimized for material selection of the encapsulation and printed melt wire array
- Tested sealing under argon to ensure no pre-melting of melt wires
- Addition of ceramic sub-layer will enhance the X-ray CT readout
- TMS 2022 – Oral Presentation (virtual) by Kiyo Fujimoto on “Advanced Manufacturing for the Development of Advanced In-Pile Sensors and Instrumentation” (Date: March 14, 2022)

Future Work

- A limiting factor in current passive peak temperature monitoring melt wires is the readout technology (X-ray CT)
- Careful design of the melt discs will enable us to use a simple series capacitance model to determine which capacitors have failed and which discs remain intact

Contact information ->

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Thank You