Overview of S3IP Expertise Area in Microsystems

Kanad Ghose
ghose@binghamton.edu
Site Director, Center for Energy-Smart Electronic Systems

S3IP Mission and Capabilities

A New York State Center of Excellence

Mission:

connect companies with university capabilities to generate economic impact, with focus on electronics manufacturing.

Technical capabilities:

- Thermal management
- Failure analysis & reliability for electronics packaging
- Manufacturing processes and materials
- Energy storage & harvesting

S3IP Organization Chart

SUNY RF The Research Foundation for The State University of New York

BINGHAMTON UNIVERSITY STATE UNIVERSITY OF NEW YORK

Dr. Bahgat Sammakia, Director and VP for Research
Benson Chan, Associate Director

NEW YORK STATE OF OPPORTUNITY. Division of Science, Technology & Innovation **COE**

S3IP A New York State Center of Excellence BINGHAMTON UNIVERSITY

Binghamton University Faculty & Students

Prof. SB Park Director

Prof. Bahgat Sammakia; Prof. Kanad Ghose; Prof. Ganesh Subbarayan (Purdue), Co-directors

Prof. Mark Poliks Director

Prof. Kanad Ghose Director

Prof. Tara Dhakal Director

Prof. Stan Whittingham Director

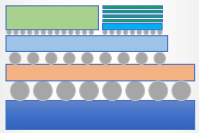
2019 Chemistry

IEEC
Electronics Packaging

NEW YORK STATE OF OPPORTUNITY. Division of Science, Technology & Innovation

NYS CAT

CHIRP
Heterogeneous Integration



SRC Semiconductor Research Corporation

SRC

CAMM
Flexible Electronics

NEXTFLEX

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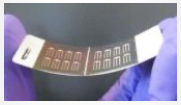
DoD Manufacturing USA
NYS CAT

ES2
Energy-Smart Electronic Systems

NSF

NSF I/UCRC

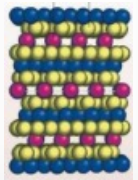
CASP
Advanced Solar Energy



NSF

NSF Early Career

NECCES
Advanced Batteries



U.S. DEPARTMENT OF ENERGY

DoE EFRC

Analytical and Diagnostics Laboratory Director Jennifer Sammakia

Electronics Packaging and Related Activities

- Diagnostics, Failure Analysis (ADL, IEEC)
  - 150+ years of collective expertise of ex-IBM experts
  - Cross-sectioning and other imaging
  - Reliability assessments
- Metrology and materials characterization of interconnections, interposers, solders, TIMs, printables (IEEC, CAMM, CHIRP, ADL)
- Flexible Electronics (CAMM)
  - Printable electronics
  - Flexible substrates
  - Applications
- Measurements in general at Advanced Diagnostics Lab (ADL)
- Modelling at all scales (IEEC, ES2, CHIRP)
  - Mechanical (stresses, warpage, evaluation of mechanicals for packaging) (IEEC, ES2)
  - Fluid dynamics in general (IEEC, CHIRP, ES2)
  - Evaluation of thermal and mechanical properties (IEEC, ADL)
  - Digital twins for microelectronics manufacturing and packaging (ES2)
- Advanced package cooling solutions (ES2, CHIRP):
  - Development of liquid cooling solutions and multi-scale evaluation using thermal test vehicles (TTVs)

Other Microelectronics-Related Activities

- Active participants and Chapter Leads:
  - IEEE EPS Heterogeneous Integration Roadmap
  - SRC's Microelectronics and Advanced Packaging Roadmap
  - iNEMI roadmap
- Co-founding member, executive board member and proposal co-authors for SRC's Manufacturing USA Institute:

Semiconductor Manufacturing and Advanced Research with Twins USA Institute
A Manufacturing USA® Institute

- Co-lead of SUNY-wide STRIVE initiative on Microelectronics and Advanced Packaging
- Co-organizer and alternate host for IEEE Packaging Conference
- Responded to several other CHIPS Act call with other partners

A New York State Center of Excellence

BINGHAMTON UNIVERSITY

Dr. Stephen Cain, Senior Research Support Specialist

ADL and IEEC Capabilities

April 28, 2025

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A Division of Empire State Development

ADL Industry Partners: last 12 months

ADL Staff

Jenny Sammakia
ADL Director & Research Assistant Professor
PhD, chemistry
University of Wales, Bangor

Yan Sun
Manager (HSCF) & Research Scientist
PhD, chemistry
Michigan State University

Anju Sharma
Senior Scientist
PhD, physics
Delhi University, Delhi

Dae Young Jung
Chief Senior Scientist
PhD, physical metallurgy
University of Illinois Urbana-Champaign

Matt Wahila
Chief Technology Officer & Research Scientist
PhD, physics
Binghamton University

Lan Yao
Research Scientist
PhD, biophysics
University of Rhode Island

Ola Habboub
Research Scientist
MS, materials engineering
Binghamton University

William Butler
Research Engineer
MS, mechanical engineering
Binghamton University

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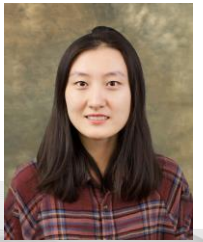


Zhilu Liang
Research Scientist
PhD candidate, mechanical engineering

William Blazey
Technical Analyst

Steve Cain
IEEC Lab Manager and interim Associate Director
PhD, Cornell

ADL Expansion:
Materials Science Core Facility (MSCF)

8000 ft^2, established 2007

50 pieces of major instrumentation (upgraded/new 2021)

Sample Prep Suite

Optical Microscopy Suite

Thermal Mechanical Suite

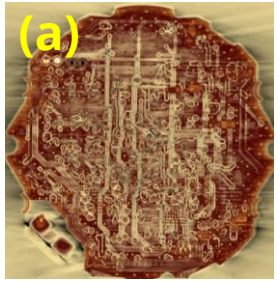
Electron Microscopy Suite

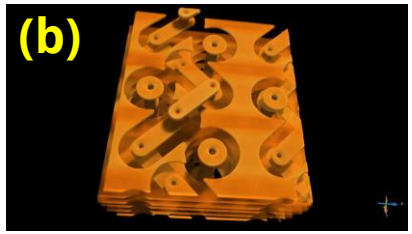
- ***FIB-SEM***
- ***TEM***
- Multiple FE-SEMs

X-ray Suite

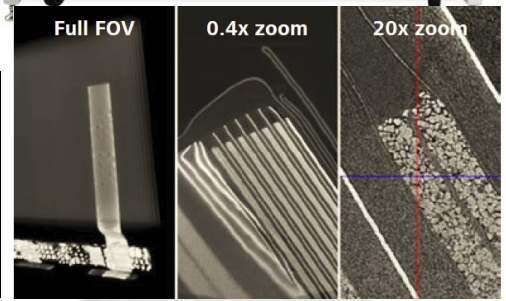
- XRD w/ Hot Stage
- ***X-ray tomography***

Equipment Spotlight:
Xradia CT Scan
Acquired 2023





(a) Smartwatch PCB XRM image and (b) XRM 3D video



Smart watch battery: XRM scans the intact battery to identify areas of interest and zooms-in for high resolution imaging

Zeiss X-Radia Versa 620 3D X-ray Microscope

- Non-destructive 3D X-ray CT imaging with 500 nm resolution for a broad range of sample shapes, sizes, materials, and sample working distances.

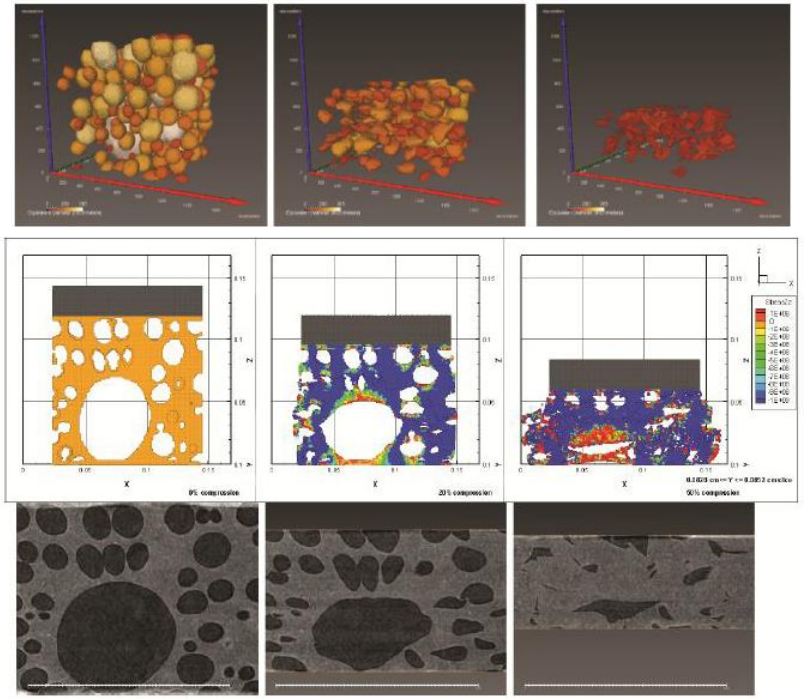
Max FOV	**5 cm diameter x 5 cm height**
Max FOV (with FPX detector)	**14 cm diameter x 9.3 cm height**
Max FOV (with auto stitching)	**14 cm diameter x 16.5 cm height**
Max Sample weight	**25 Kg**
Sample stage travel	**5 cm, 10 cm, 5 cm (x,y,z)**

- 160 kV, 25W X-ray source with set of (0.4X, 4X, 20X, 40X) objective lenses for 3D high-resolution images.
- Flat panel detector for fast imaging and large FOV.
- Tension/compression and thermal stage for in-situ imaging of microstructures in controlled environments.

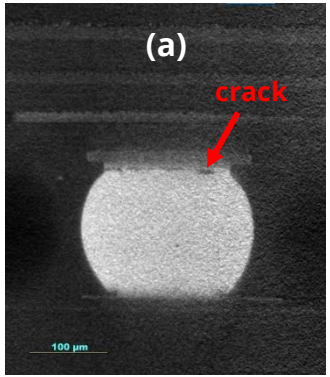
Applications:

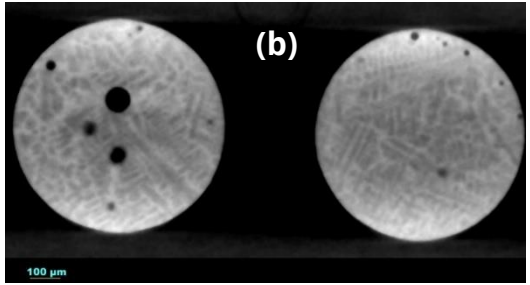
- Electronics Packaging, Life Sciences, Li-ion batteries, Additive Manufacturing, Materials Research and more….

Polymer foam compression studies using X-Radia's in situ capabilities.

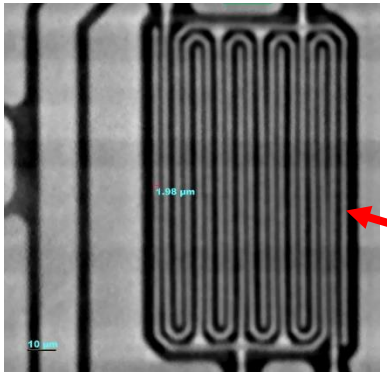


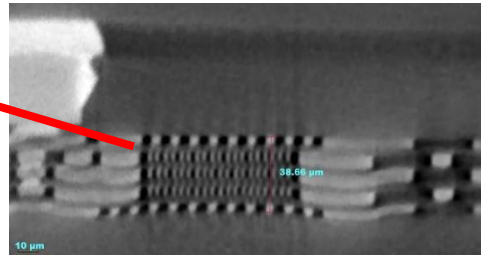
X-Radia – Examples of 3D X-ray Microscopy



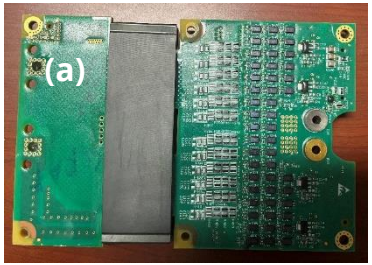


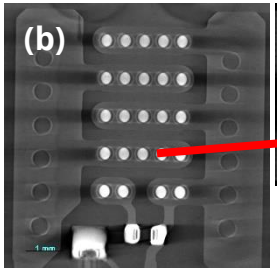
Virtual cross section of a 2.5D package reveals (a) C4 bump solder cracks and (b) internal microstructure.

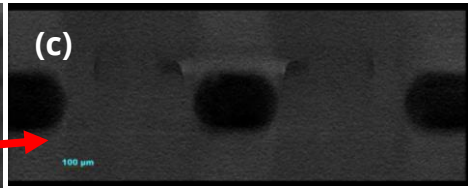




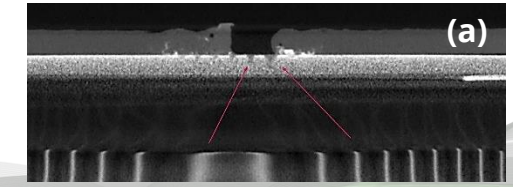
X-ray CT cross-sections of RDL layers and circuitry in a 3D package.

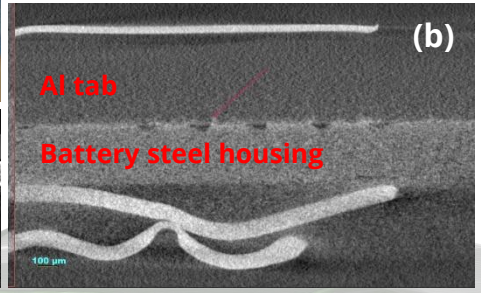






(a) Large board with flip chip FET devices, (b) CT slice of FET device at 11 µm resolution, and (c) scan at 2 µm resolution show solder ball cracks.





X-ray CT cross-sections of (a) bad and (b) good laser welds of busbar to battery cell.

FEI Dual Beam Focused Ion Beam Microscope

Parameters

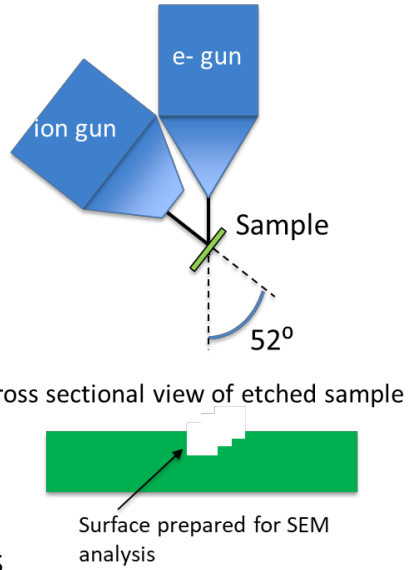
- 1-30 KV e-gun and i-gun (Ga ion)
- Secondary electron and through lens detectors
- Magnification 80X to >200 KX

Modes of operation

- E-beam imaging / EDS analysis
- Fine feature etching
- Pt deposition

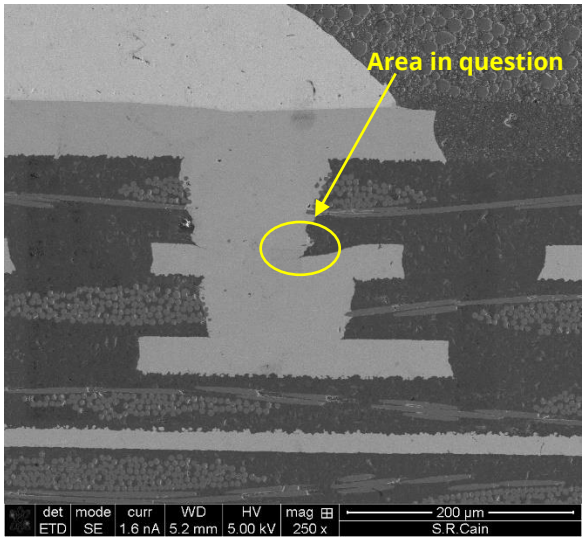
Applications

- Simple device fabrication via etching and deposition
- Failure analysis of electronic devices
- Sample preparation for transmission electron microscope



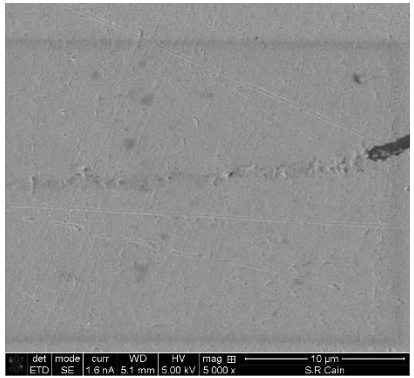
FIB - Typical Processing Sequence

Low mag image of the failed via

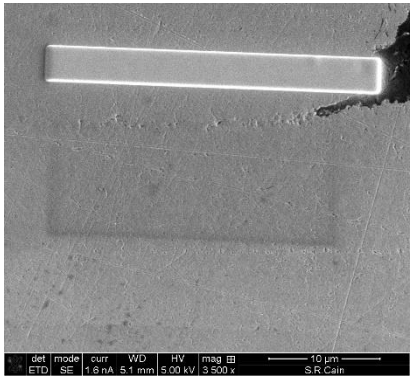


FIB cut made at a glancing angle, with etching being done across the interface

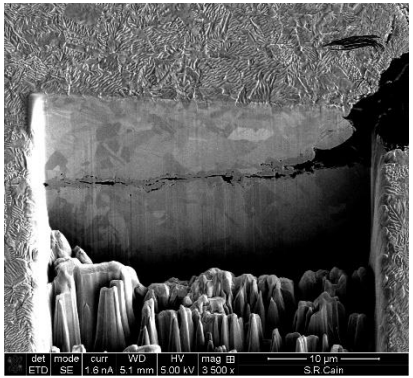
E-beam image of the area



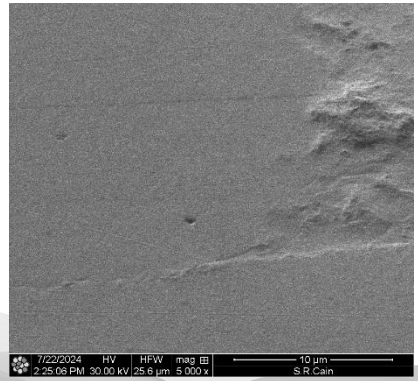
E-beam image of the Pt bar



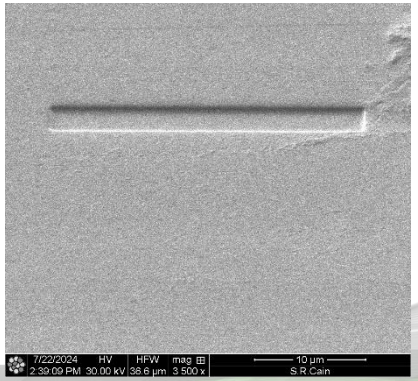
E-beam image of the FIB cut



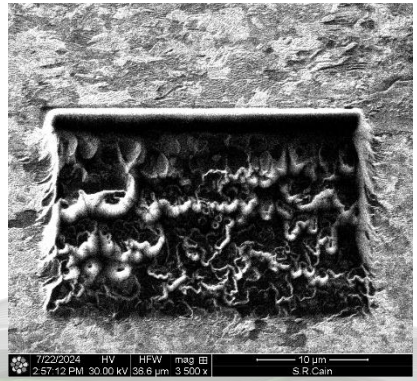
I-beam image of the area



I-beam image of the Pt bar

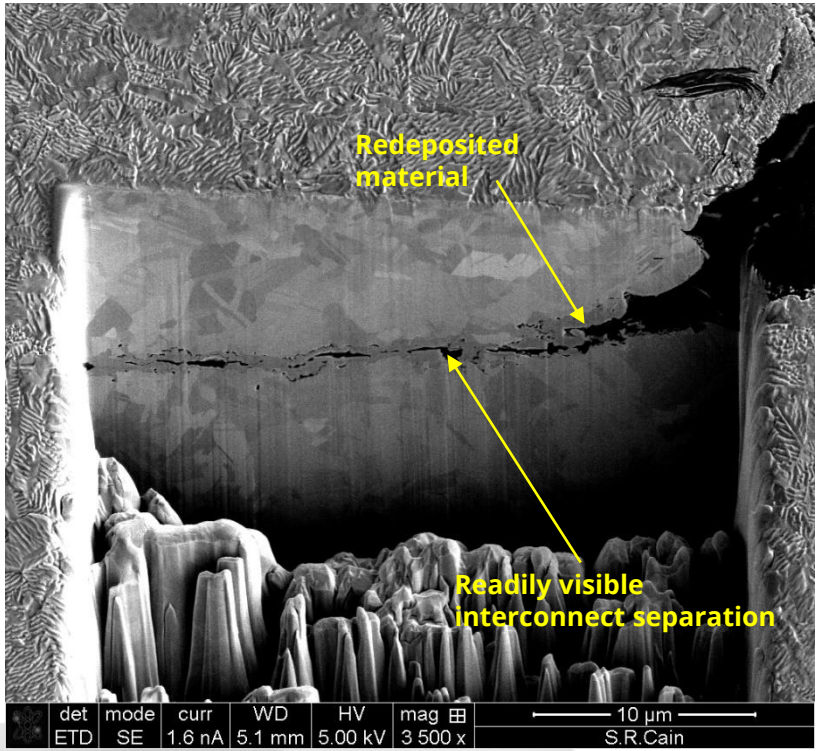


I-beam image of the FIB cut

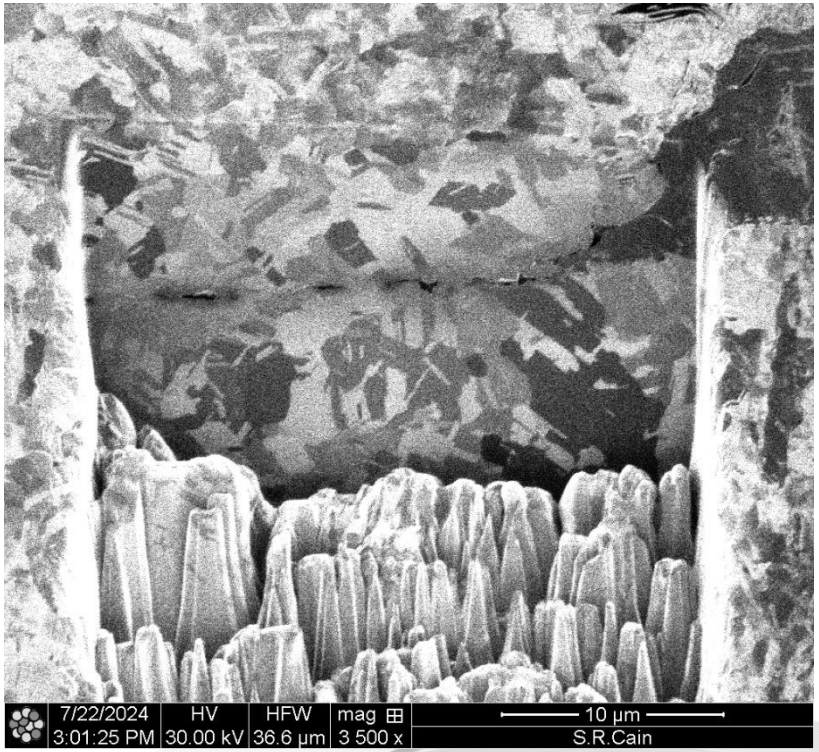


FIB - Final Cut of the Sample (3500X Mag.)

Electron image



Ion image (after 180º stage rotation)



Cu grain structure is readily seen in both images; very pronounced in the ion image

JEOL 2100F Transmission Electron Microscope

Parameters

- Acceleration: 200 KV
- Minimum spot size: 0.2 nm
- Magnification: up to 1.5 MX

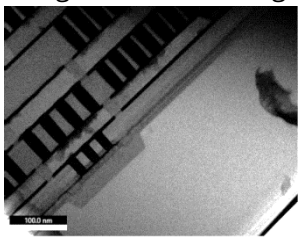
Modes of operation

- TEM with Gatan camera
- STEM with bright field detector
- Selected area diffraction
- EDS and EDS mapping (in STEM)

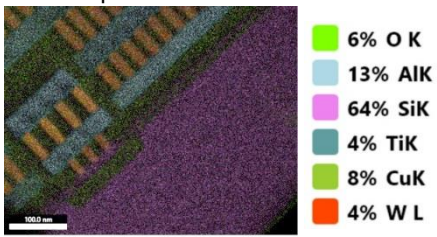
Applications

- Electronics / samples prepared via FIB
- Biological / samples prepared by dehydration and staining protocols
- Biological and thin film / samples prepared with microtome
- Nanoparticles / quantum dots, particulate dispersions, nanorods

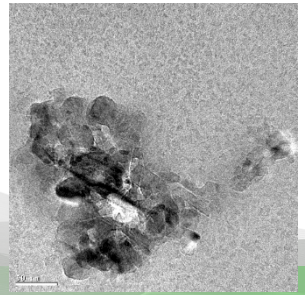
Integrated circuit image



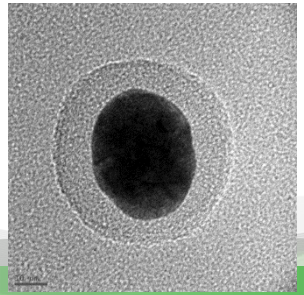
EDS map



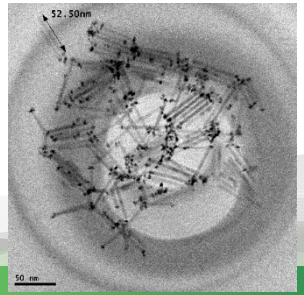
Al_2O_3 nanoparticle cluster



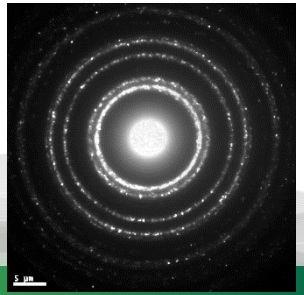
Au nanoparticle with organic coating



Nanorods

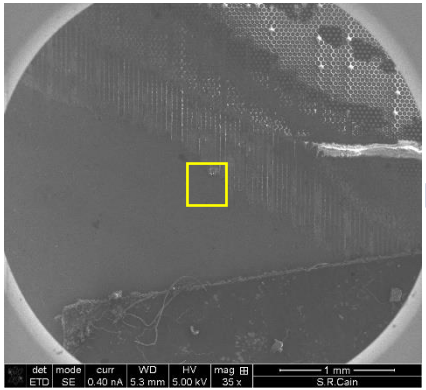


Polycrystalline Au

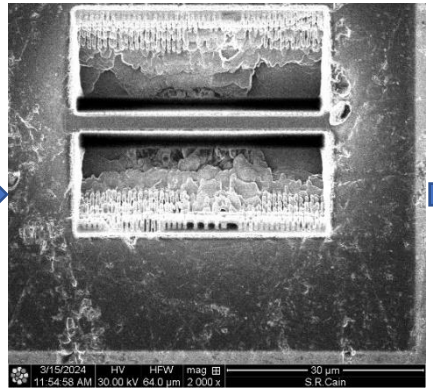


TEM - Analysis of Integrated Circuit with FIB Prep

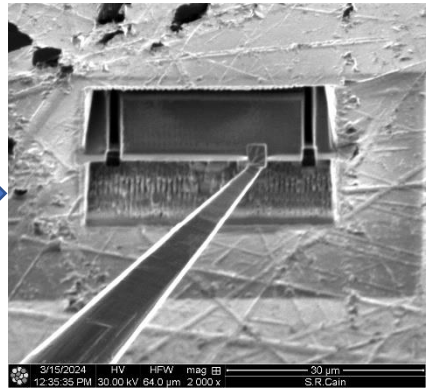
Region of interest



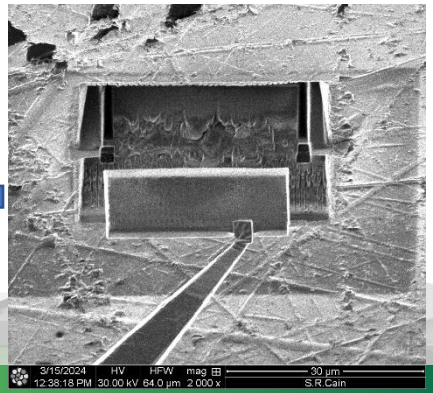
Dual FIB trenches



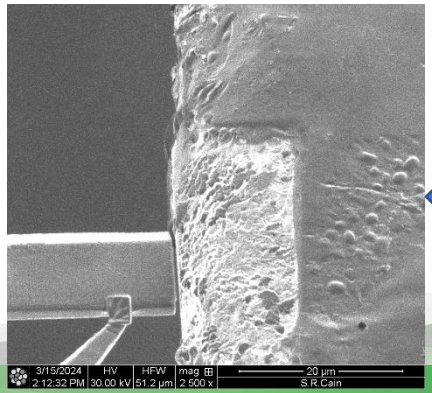
Probe connection



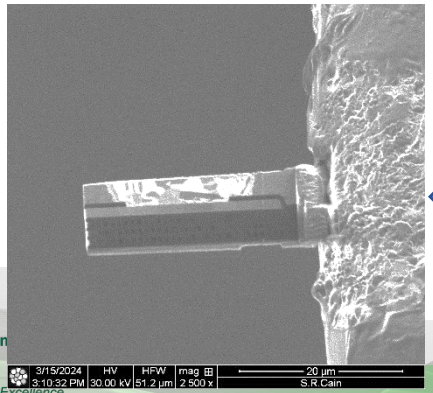
Slice removed



Slice mounted to TEM post



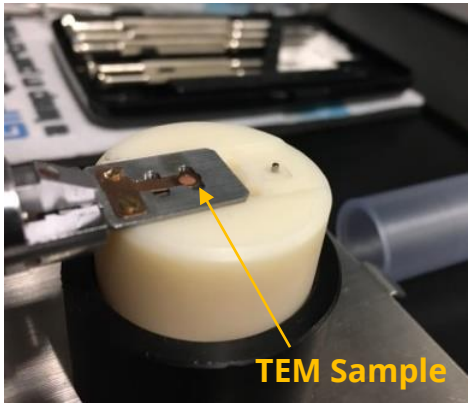
Thinned and polished

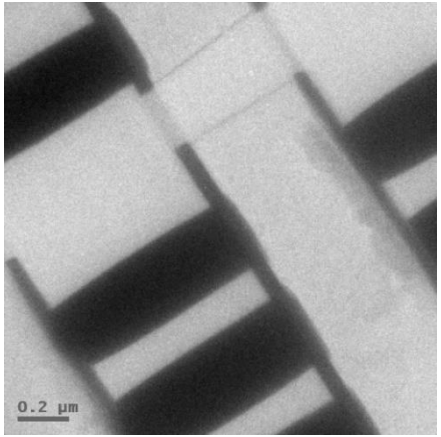


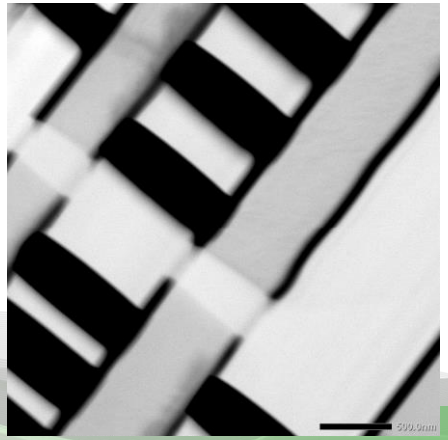
Target thickness is 200-300 nm

TEM - Imaging & EDS Analysis of Integrated Circuit

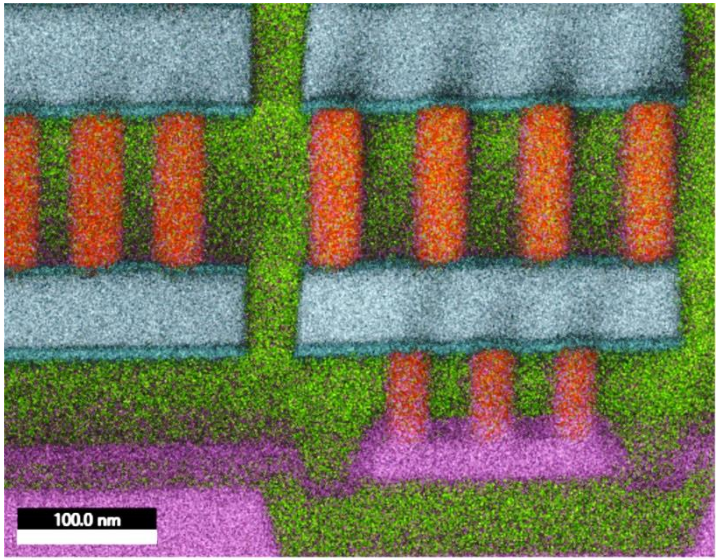
TEM Image at 50 KX





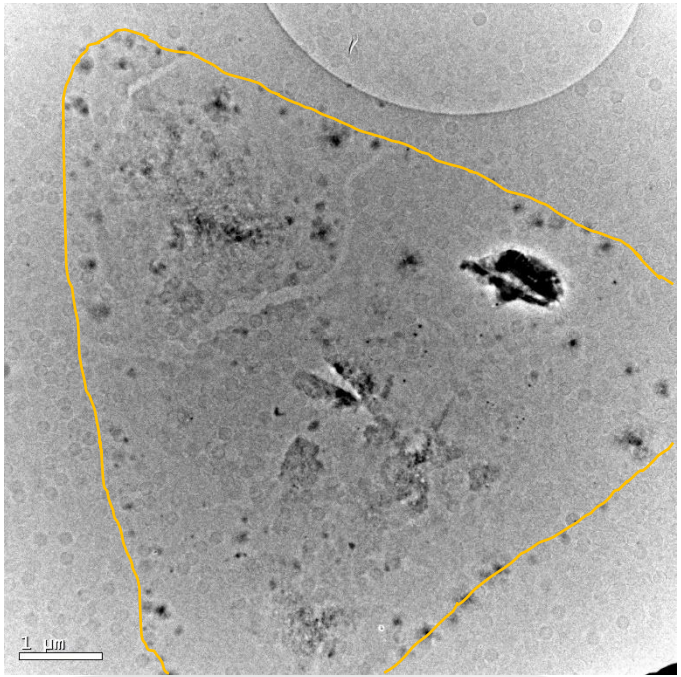


STEM Image at 50 KX
(run in scanning mode)



TEM - Electron Diffraction of Ultra-thin MoS_2

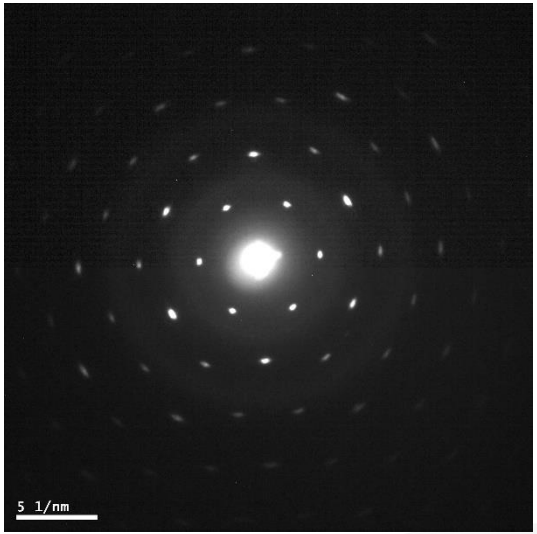
TEM image at 10 KX (outline of MoS_2 flake is sketched because it is nearly impossible to see)



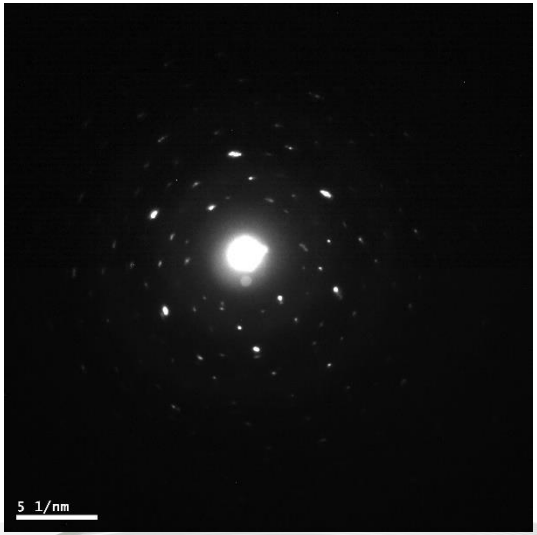
Graduate student research project

- Ruiqi Zhang
- Consulting staff member, S.R. Cain

Single phase



Mixed phase

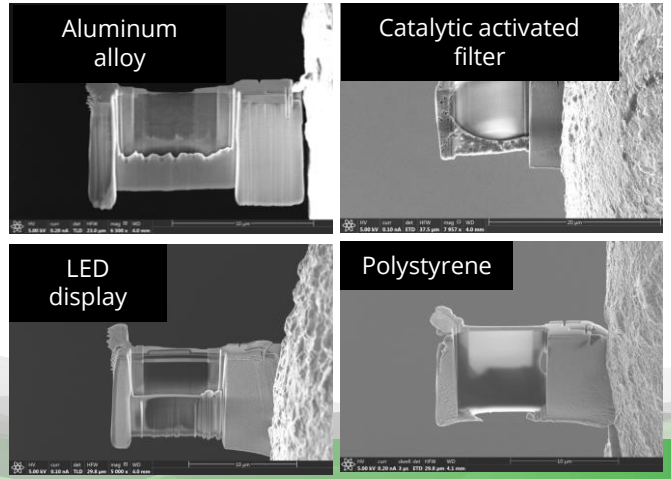


Thermo Fisher Helios 5 PFIB-SEM (coming Q1 2025)

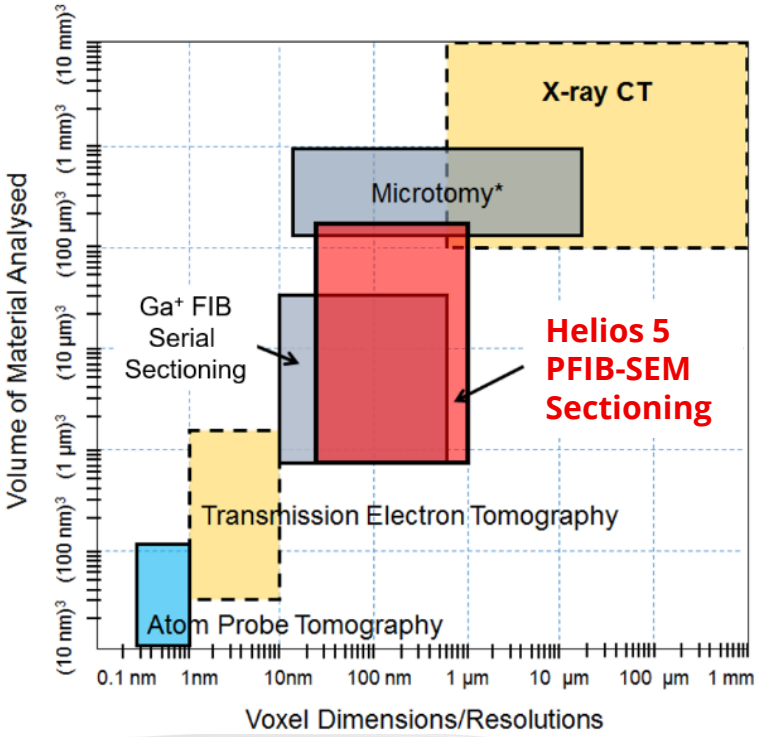
Base System

- ✓ Extreme high-resolution Field-Emission SEM
- ✓ Plasma-FIB etching with up to 4 ions (Xe, Ar, O, N)
- ✓ Easy-Lift™ nanomanipulator for TEM sample prep
- ✓ EDS for 2D and 3D compositional mapping

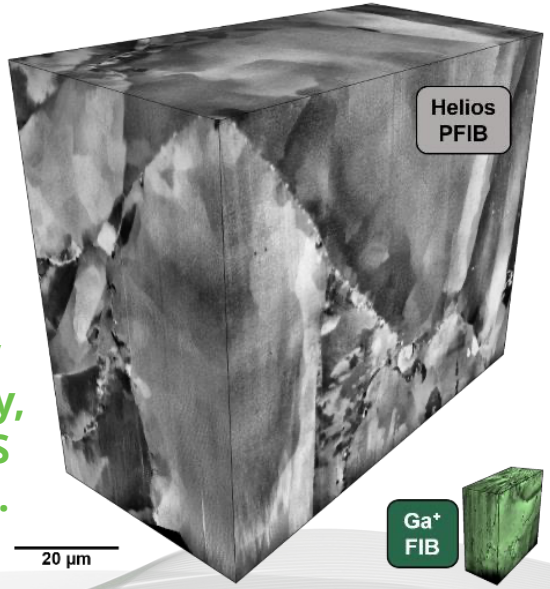
Multiple ion species enables efficient milling of a wide variety of materials.



PFIB - Benefits of the New *Plasma*-FIB



Compared to traditional Ga⁺ FIB, PFIB can etch orders of magnitude larger sample areas, **enabling large-scale 3D tomography.**



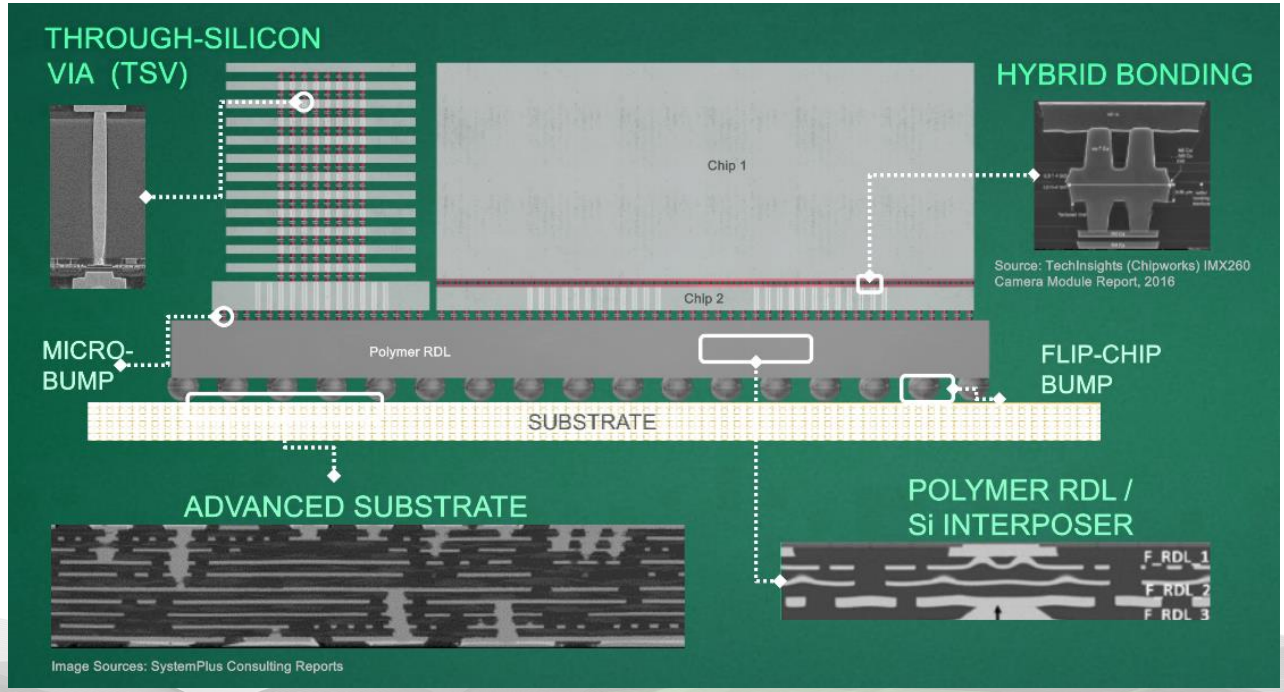
With the addition of inert transfer & cryo capabilities, this new PFIB-SEM **will greatly advance BU's battery, biological, and CHIPS Act related research.**

PFIB - Fully Investigating 3D Packages

A more flexible FIB platform is needed to support hardware characterization and failure analysis on the complex, next-gen, multi-scale, 3D packages being developed.

Investigating stacked chiplets requires both precise and large area milling of different types of materials.

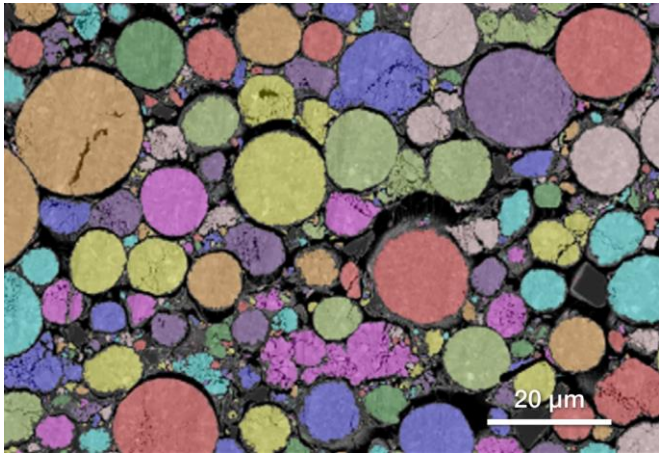
Helios 5 easily swaps between **high speed** (e.g., Xe) and **precise, smooth surface quality** sample milling (e.g., Ar).



PFIB - Analysis of Li-containing Materials

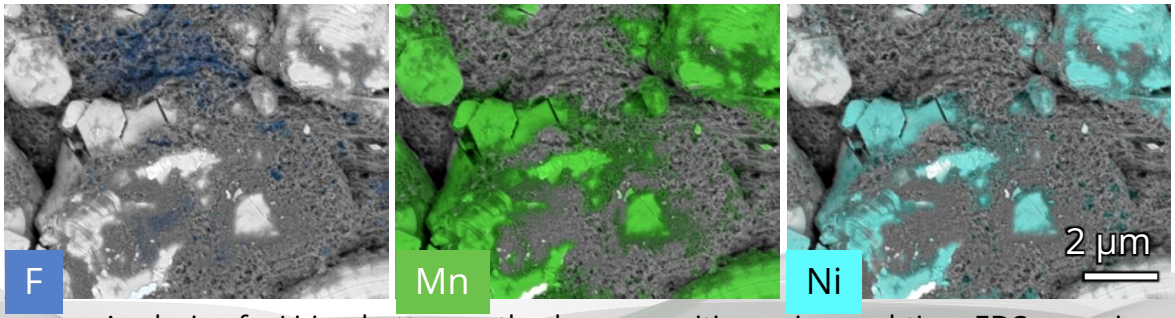
PFIB with CleanConnect and cryo-stage is ideal for investigating **Li-containing materials.**

CleanConnect allows samples to be introduced without air exposure, crucial for reactive samples like Li-ion battery cathode materials.



Phase fraction analysis on NMC cathode cross-sectioned with PFIB.

Cryo-stage reduces heat damage during milling **enabling study of unstable and/or delicate materials.**



Analysis of a Li-ion battery cathode composition using real-time EDS mapping.

ADL Expansion:
Surface Science Core Facility (SSCF)

Equipment Spotlight:
HAXPES-Lab
Acquired using NSF MRI Grant

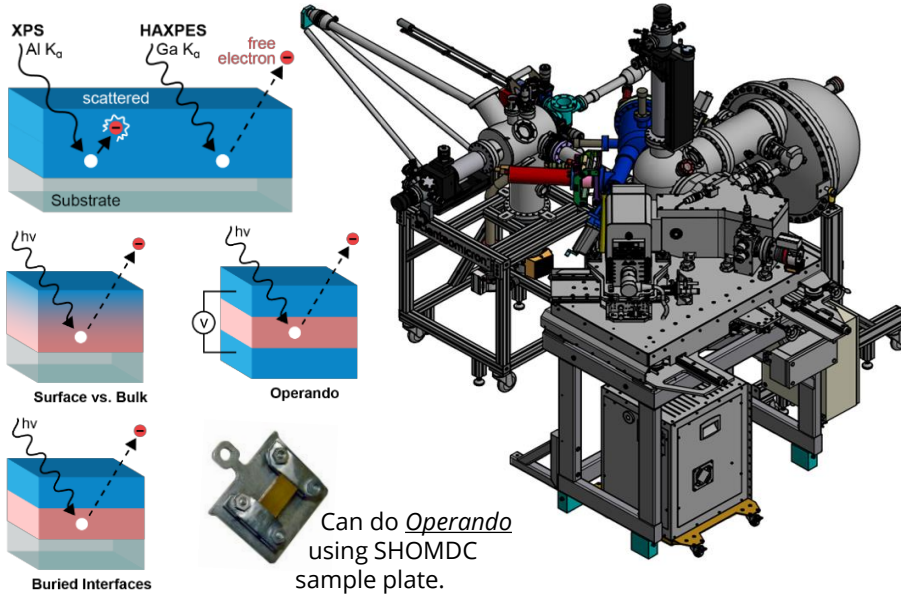
3000 ft^2, established 2022
10 pieces of major instrumentation with future expansion plans

Surface Analysis Suite

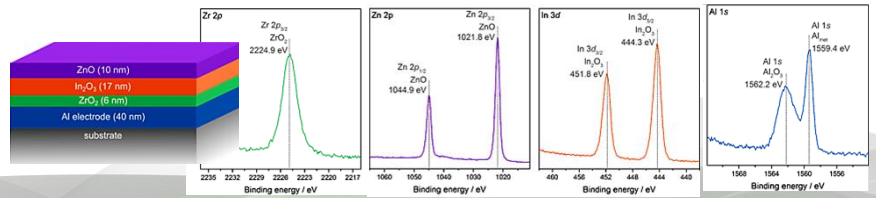
- **HAXPES-Lab**
- Easy XAFS w/ Battery Cycler
- FTIR Microscope
- Raman Microscopes
- SPM (AFM, STM, MFM, etc.)
- Optical & Stylus Profilers
- Laser Particle Size Analyzer

Sample Prep Suite

- Ar Glovebox
  w/ UHV Transfer Suitcase

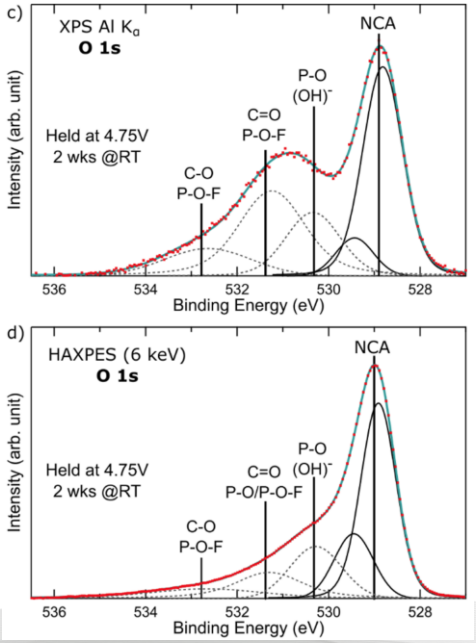


Can do *Operando* using SHOMDC sample plate.

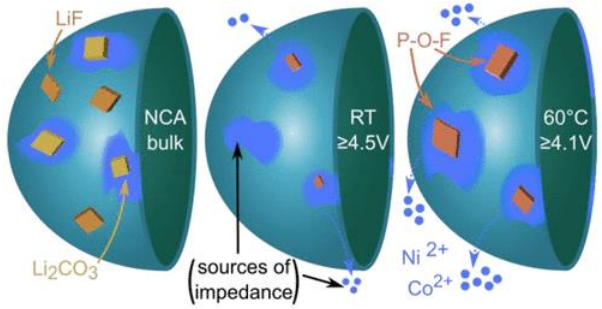


HAXPES - Surface Compounds in Li-ion Cathodes

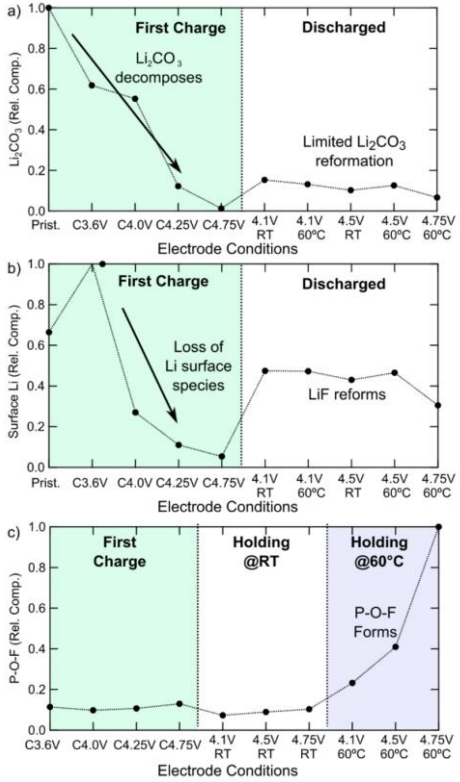
The combination of XPS and HAXPES enables comparison of surface *vs* bulk of battery cathodes & other materials.



Multiple photon energies provide information on the evolution of compounds formed at different depths during Li-ion battery cycling.



Lebens-Higgins, Z.W., *et al.* Evolution of the Electrode-Electrolyte Interface of $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$ Electrodes Due to Electrochemical and Thermal Stress. *Chem Mater* **30**, 3, 958–969 (2018).

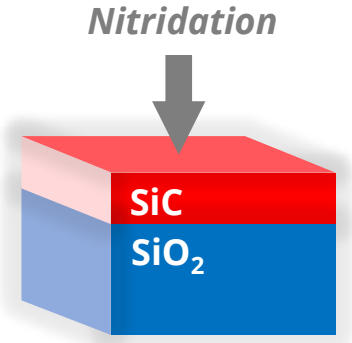


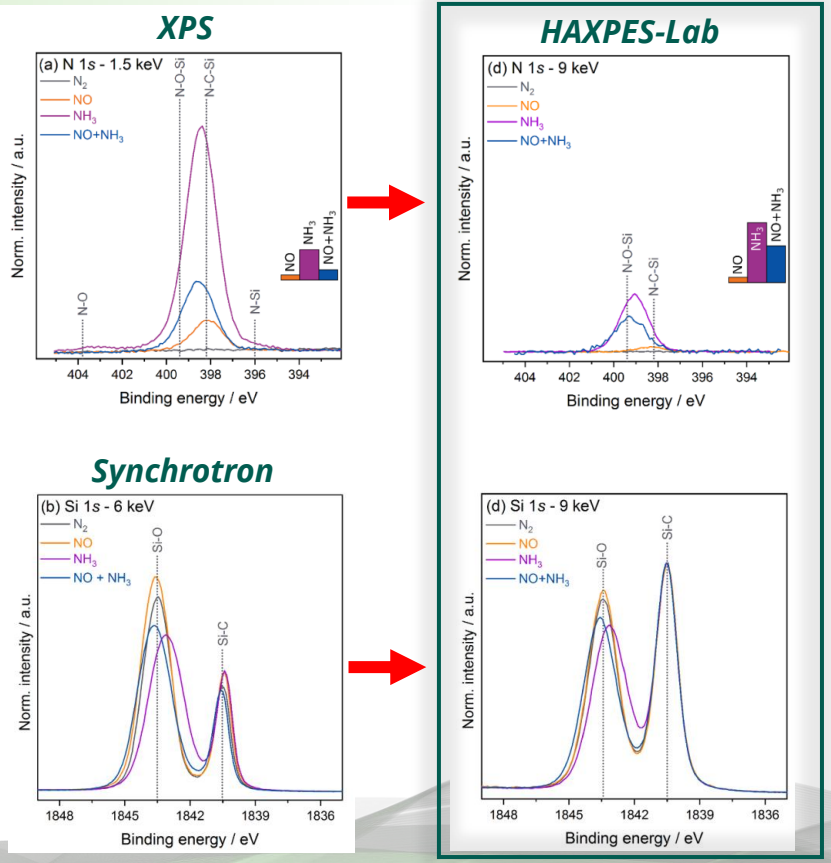
**6 keV HAXPES from synchrotron beamline (Diamond I09) with comparable capabilities.*

HAXPES - Study of Interfacial Compounds

The combination of both XPS and HAXPES enables non-destructive depth studies on individual samples.

Using multiple X-ray energies, the effects of different nitridation processes on the SiC and SiO_2 interface were tracked.





Berens, J. et al. Effects of nitridation on SiC/SiO_2 structures studied by hard X-ray photoelectron spectroscopy. *J. Phys. Energy* 2, 035001 (2020).

*6 keV HAXPES from synchrotron beamline (Diamond I09) with comparable capabilities.

ADL Expansion:
Nanofabrication Laboratory (NLAB)

1150 ft^2 class 1000 cleanroom space for 4” wafer process, established 2015

Photolithography Bay
- Mask/Contact Aligner
- Pattern Generator
- UV-Vis & 4-pt Probe

Deposition & Wet Etching Bay
- RF Magnetron Sputter
- E-beam Evaporator
- ALD

Metrology & Processing Bay
- RIE & Deep RIE
- RTP
- Profilometer & Microscope

Equipment Spotlight:
Photolithography Bay

NLAB instrumentation upgrade 2024-2025

About the IEEC

IEEC Staff

Benson Chan
S3IP Associate Director

S.B. Park
IEEC Director

Steve Cain
IEEC Lab Manager
Interim Associate Director

The IEEC team offers over 120 years of industry experience to help students, faculty and industry members solve THEIR research problems.

Son Tran
Staff Scientist

Bill Blazey
Staff Scientist

Jim Wilcox
Staff Scientist

Mike Gaynes
Staff Scientist

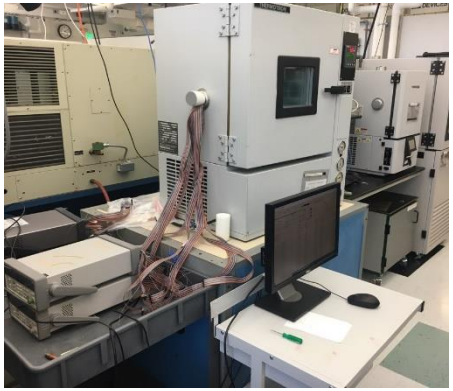
IEEC Reliability Laboratory

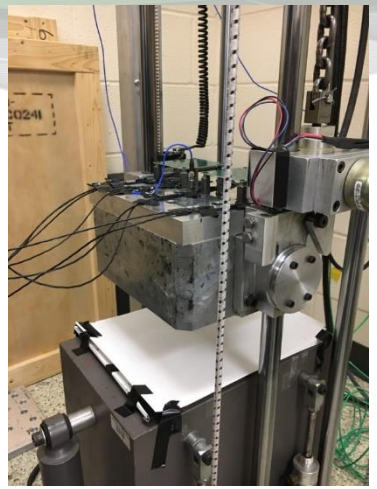
Environmental stress testing

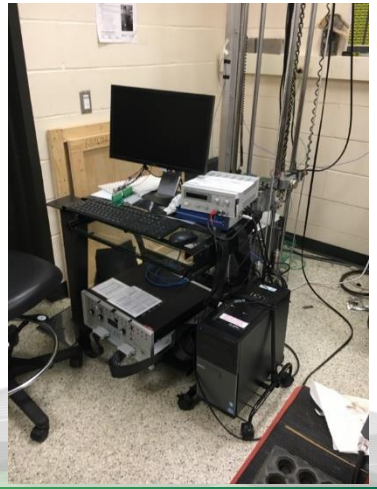
- High temperature storage
- Low temperature storage
- Thermal cycling
- Air to air thermal shock
- Temperature and humidity
- Mechanical shock and vibration
- Electromigration evaluation

Readout capabilities

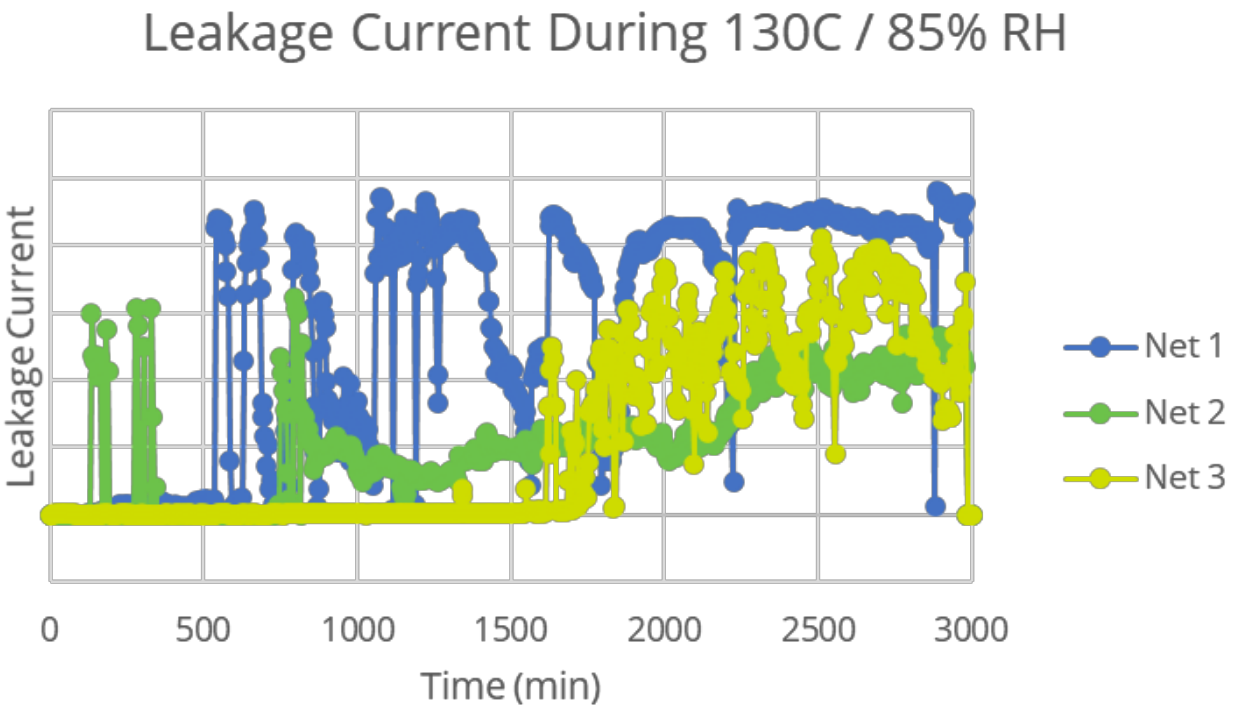
- Interval and/or in situ readout
- DAQ each with up to 60 channels (individual), or 120 channels (common ground)
- Event detection, up to 8 channels



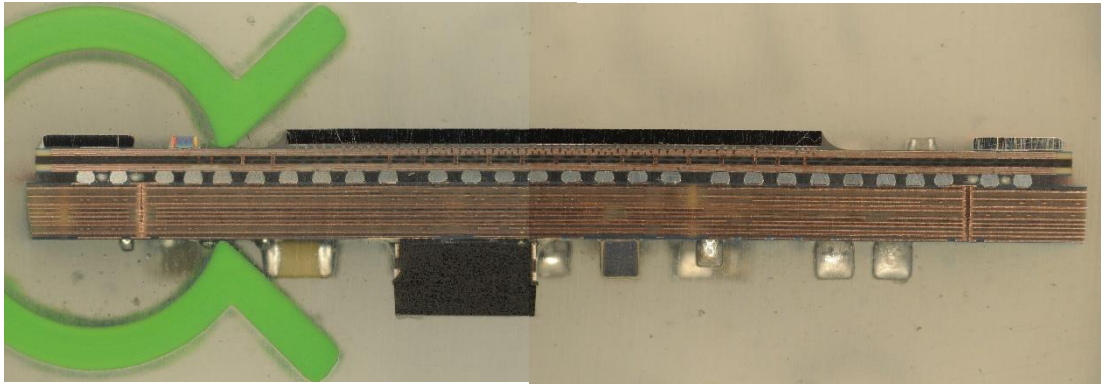


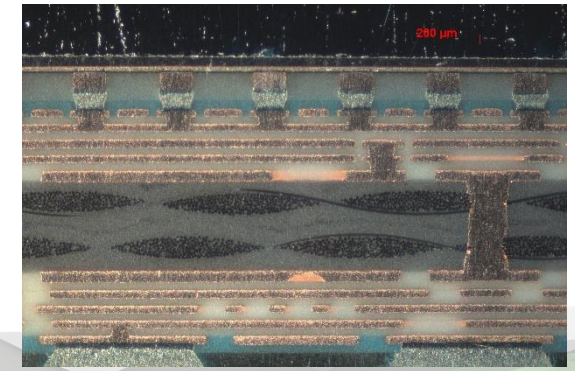


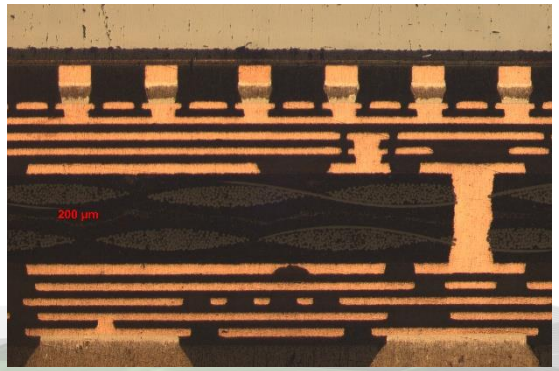
Example – HAST Test on Glass Wafers



IEEC Cross Section & Optical Microscopy





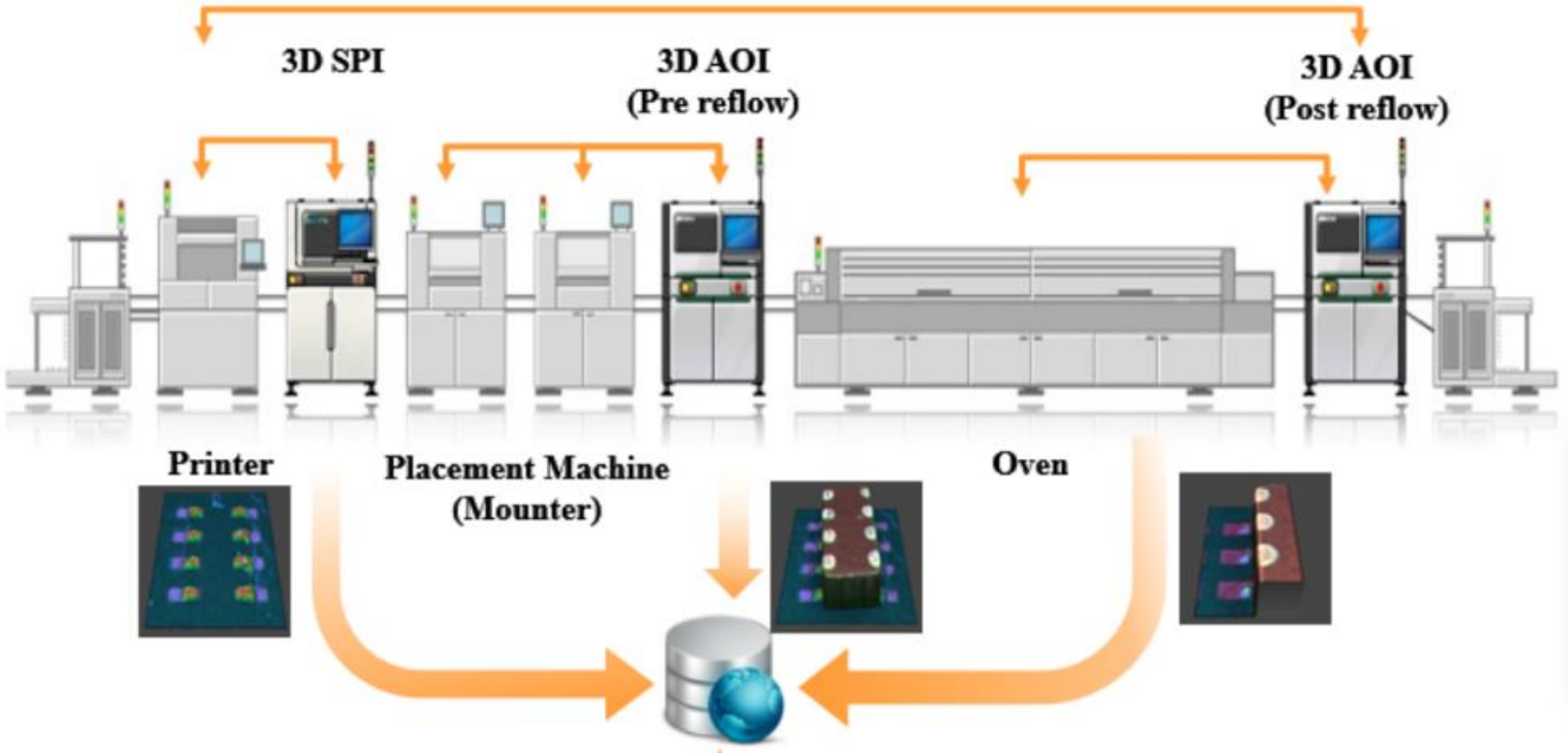


Smart Electronics Manufacturing Laboratory

SEML is a prototype circuit board assembly laboratory

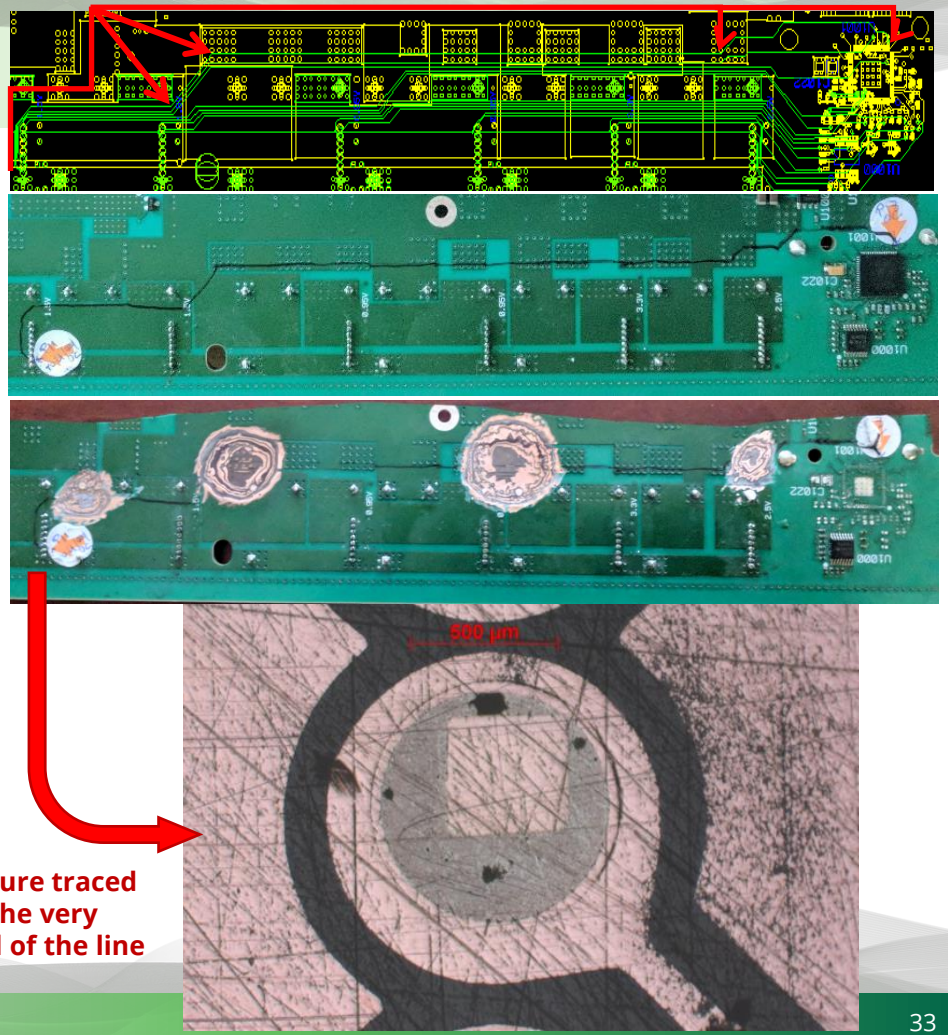
- Solder apply
- Component placement
- Automated inspection
- Reflow

SEML Research: System Learning and the Fully Automated Assembly Shop



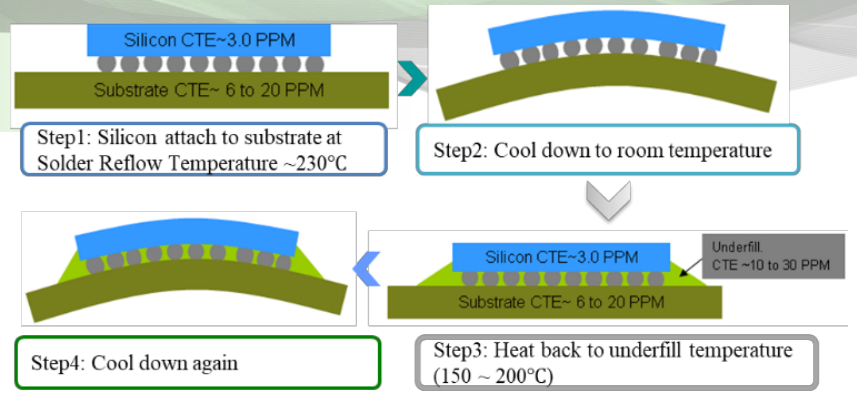
Failure Isolation and Analysis

- Defective printed wiring board, 22 layers, circuit ran on layer 17
- Reviewed design data to determine trace routing
- Dig into board to determine intermediate routing points to isolate the defect
- Cause was drill smear preventing electrical connection from the Plated Through Hole and the copper trace



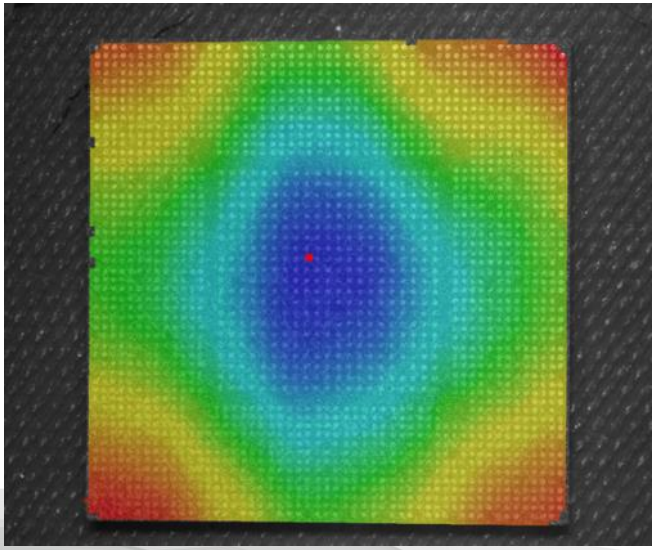
Failure traced to the very end of the line

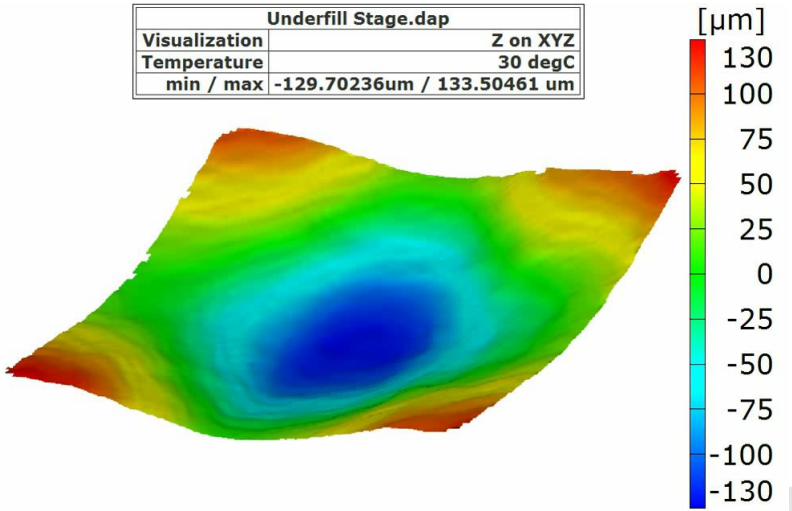
2.5D Warpage Studies



Mismatch of thermal coefficient of expansion

- Non-uniform expansion / contraction of die and substrate
- Warpage of the package (major reliability concern)





Industrial Pooled Research Projects

Project	Mentor Company
Soldering Below 150C – Superior Reliability?	Corning, BAE
Oxidation and Corrosion Induced Deterioration of Fatigue Resistance of Sintered Nano-Cu and Nano-Ag Bonds and Interconnects	Corning, AMD, BAE
SiC MOSFET Module Design for Ultra Low Inductance and Improved Thermal Conductivity for high Switching Frequency, High Voltage and High Current Applications	BAE, GE, ASE
µ+Net: Automating AdderNet Deployment and Acceleration on Microcontroller-based Platforms for Sustainable and Ubiquitous Edge AI	BAE, AMD
AI-Driven Inverse Design for Tailoring the Multidirectional Mechanical Properties of Stochastic Cellular Materials	AMD, Indium, Corning
Copper-based Nanoalloy Inks for Ambient- and High-Temperature Device Applications	BAE, GE
Smart Solutions for the Conformal Coating Progress: Optimizing Processes Parameters with AI-based Defects Detection	AMD, BAE
Simulating The Efficiency and Thermal Expansion of a Thermoelectric-Gated Transistor from First Principles	IBM
Modeling Current Flow through Interconnects with Thermal Atomic Motion and Alternating Bias	AMD

Annual Electronics Packaging Symposium

- **IEEC's flagship event: the premier packaging symposium in the Northeast**
- **33 consecutive years* with continued growth and returning participants**
- **2024 Hosted by Binghamton University**
  - Poster session with 26 entries
  - 2 keynote speakers
  - 25 talks by invited speakers
  - Panel session

ADL & IEEC Impact

With our current capabilities, we can serve the electronics packaging, material science, batteries, & health science research ecosystems.

How can we collaborate?

THANK YOU

Dr. Jennifer Sammakia

ADL, S3IP, Binghamton University

+1 (607) 232-3453

jamey@binghamton.edu