Failure Analysis of Electrically Conductive Adhesive Interconnects by X-Ray Tomography

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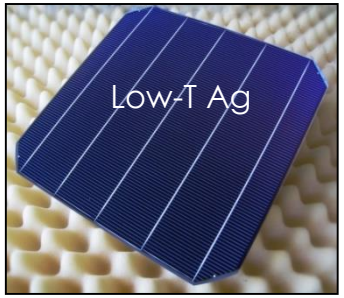
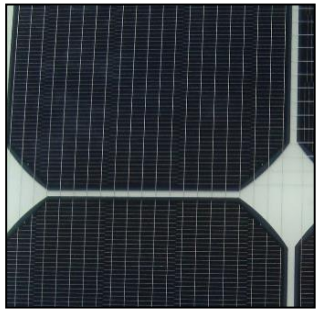
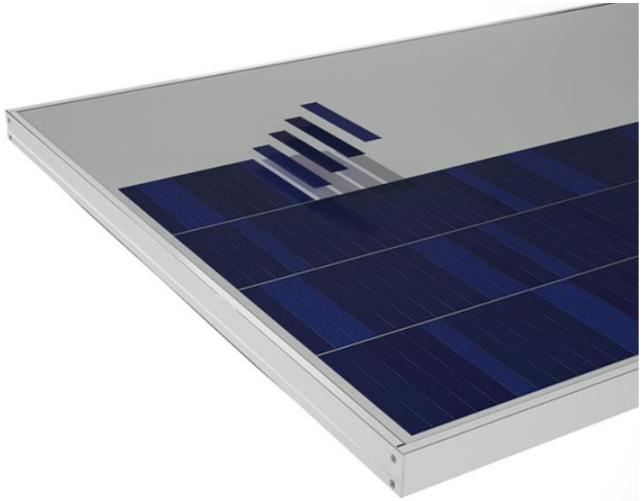
Electrically conductive adhesives (ECAs) solar applications



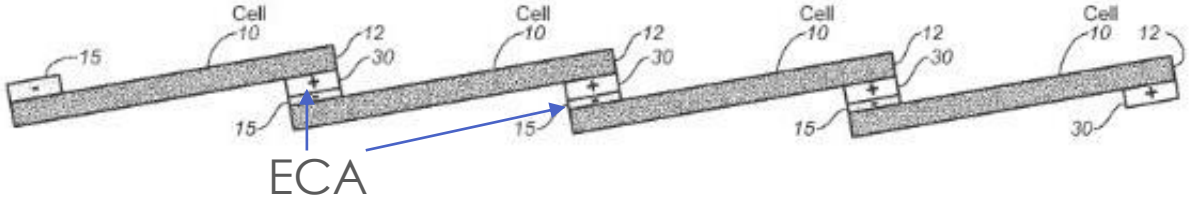


Silicon heterojunction cells

Sunpower P-series



Shingled modules



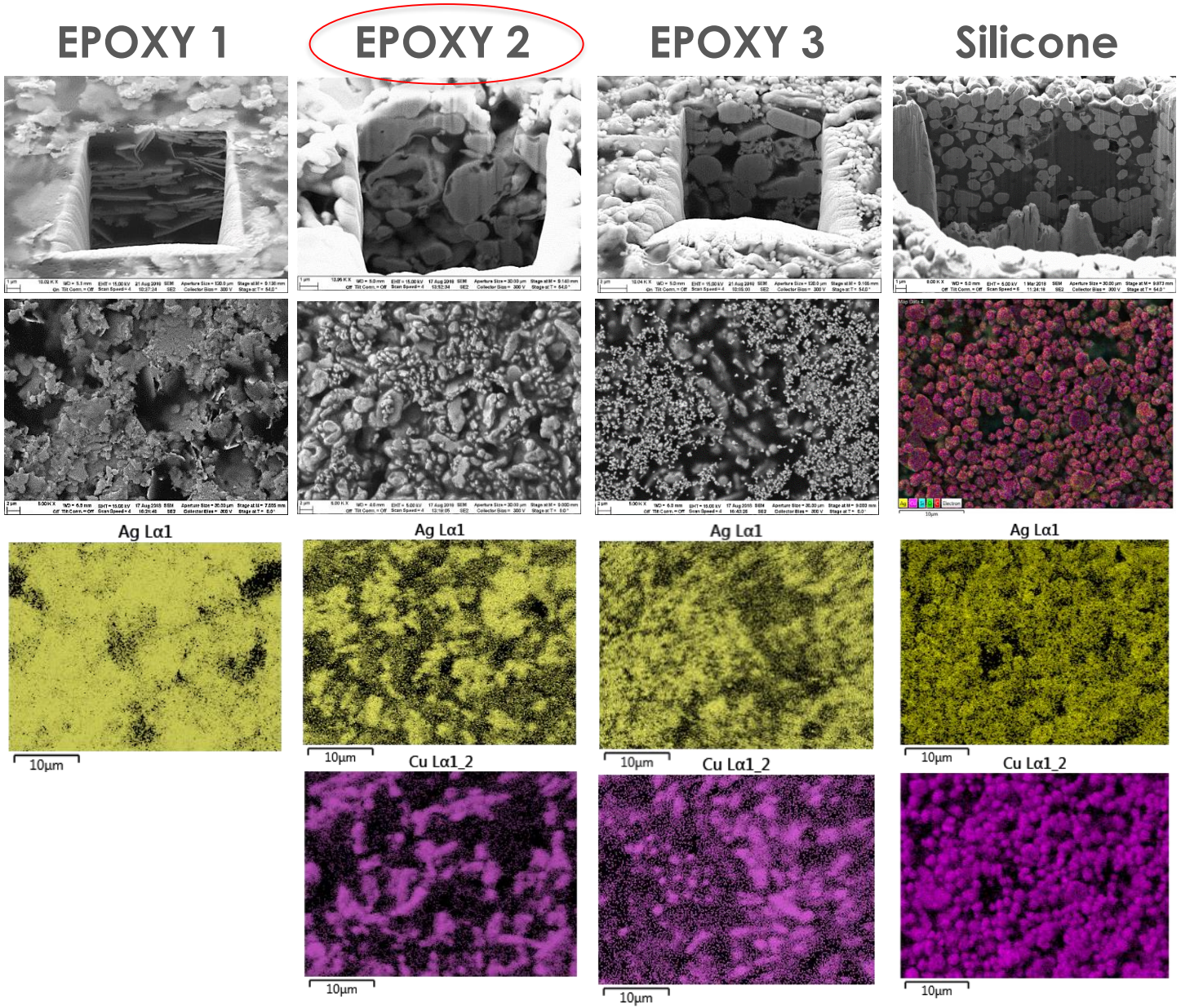
Cogenra patent

- ECAs present an exciting opportunity for the solar industry
- Commercial modules are relatively new and their failure mechanisms are widely not understood

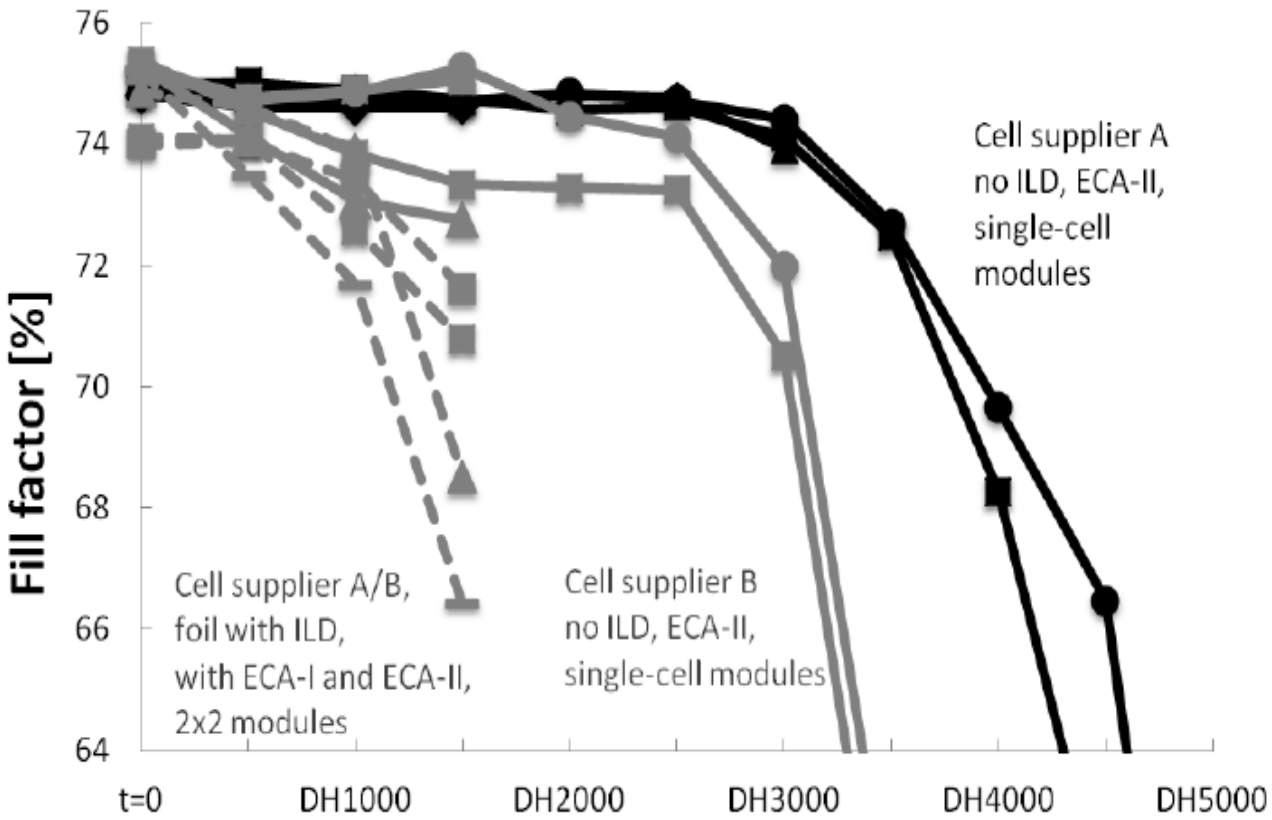
ECA material

ECAs are adhesive materials such as epoxy or silicone filled with conductive metal particles like silver and/or copper

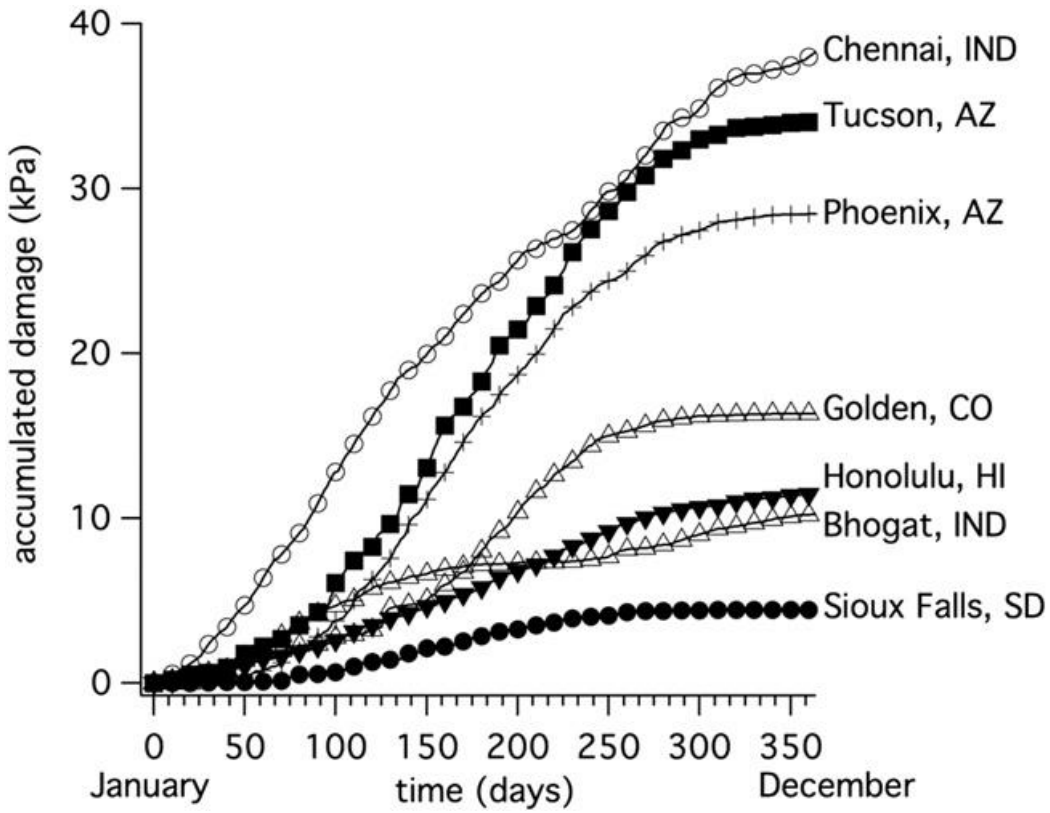
Paste	Filler	Metal %	ρ (mΩcm)	G @ 25°C (MPa)	T_g(°C)
EPOXY 1	Ag flakes	25-50	100		50-60
EPOXY 2	Ag & Cu flakes	60-100	0.4	1720	Onset: 55-90 Tandelta: 16
EPOXY 3	Ag & Cu flakes	70-100	0.5	160	Tandelta: -10
EPOXY 4	Ag & Cu flakes	70-90	0.32	212	Onset: -10 Tandelta: 16
EPOXY 5	Ag & Cu flakes	~ 80	0.3	80	Onset: -30 Tandelta: -15
EPOXY 6	Ag & Cu flakes	~ 80	0.2	170	Onset: -20 Tandelta: 0
SILICONE	Ag & Cu particles	83-88	0.18	Low	



Project motivation



ECA interconnections throughout damp heat[1]



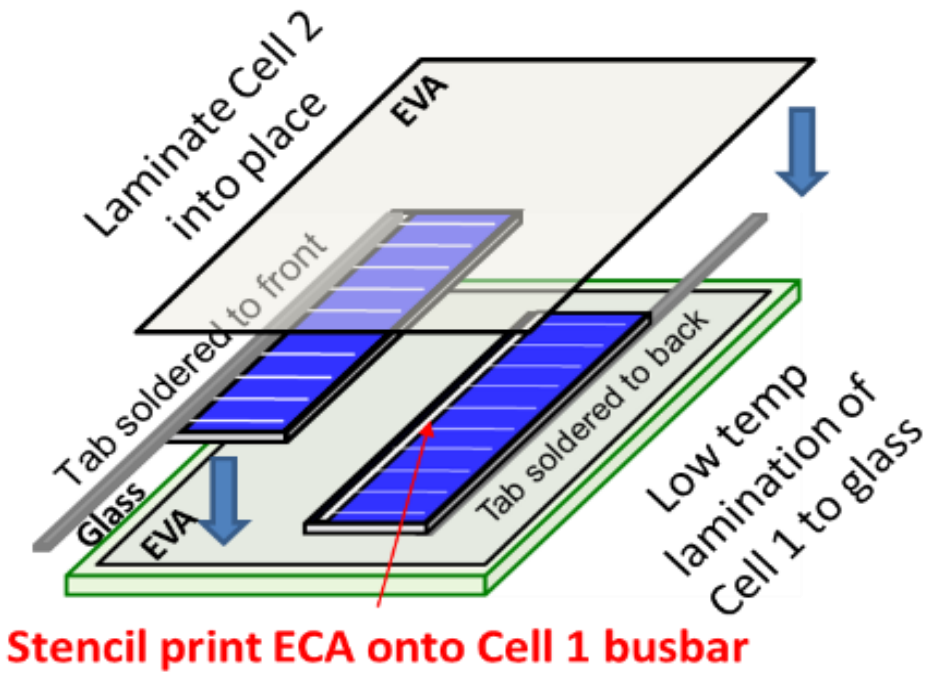
Solder damage modelled in different climates[1]

- Minimal literature about the mode of ECA failure
- Collaborating with Nick Bosco at NREL to produce a similar model but for ECA interconnections

[1]V. Rosca, et al. *Proceedings of SPIE.* (2012).

[1]N. Bosco, et al. *Microelectron. Reliab. 62,* 124-129 (2016).

Mini-module fabrication and failure monitoring



Accelerated ageing testing:

- Thermocycling (TC) (-40°C to 85°C)
- Damp heat (testing pending)

Failure monitoring:

- I-V and Suns V_{oc}
- Electroluminescence
- Series resistance mapping[3]

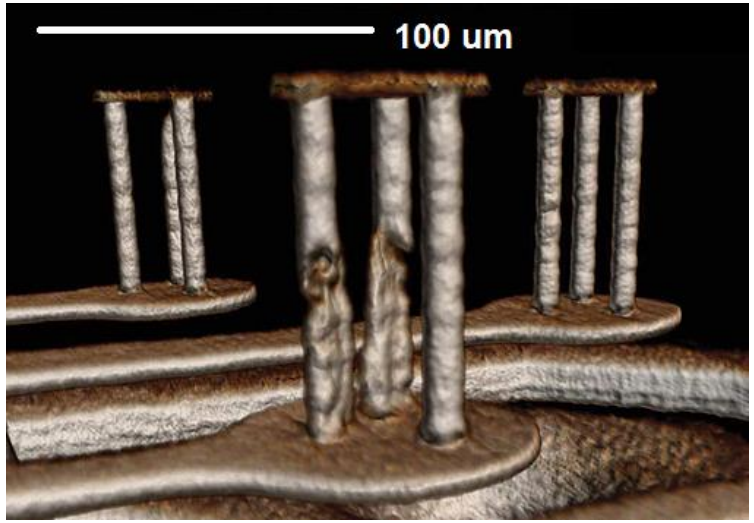
Failed sample analysis:

- X-ray transmission
- X-ray tomography
- Cross-sectional SEM
- Elemental mapping by EDXS

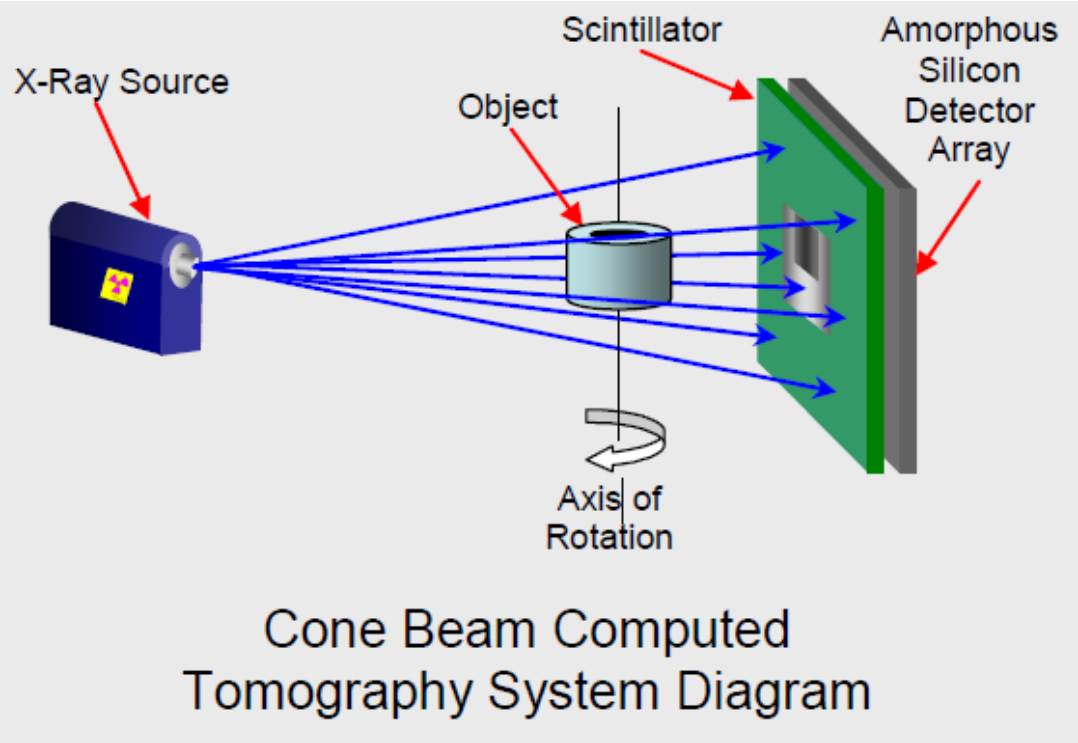
[3] J. Haunschild, et al. *Phys. Status Solidi RRL.* 3. No. 7-8, 227-229 (2009).

Introduction to x-ray tomography

- Based on x-ray transmission imaging
- Program processes transmission images into a 3D rendering of sample
- Up to ~1μm/pixel resolution
- Differentiates materials by densities

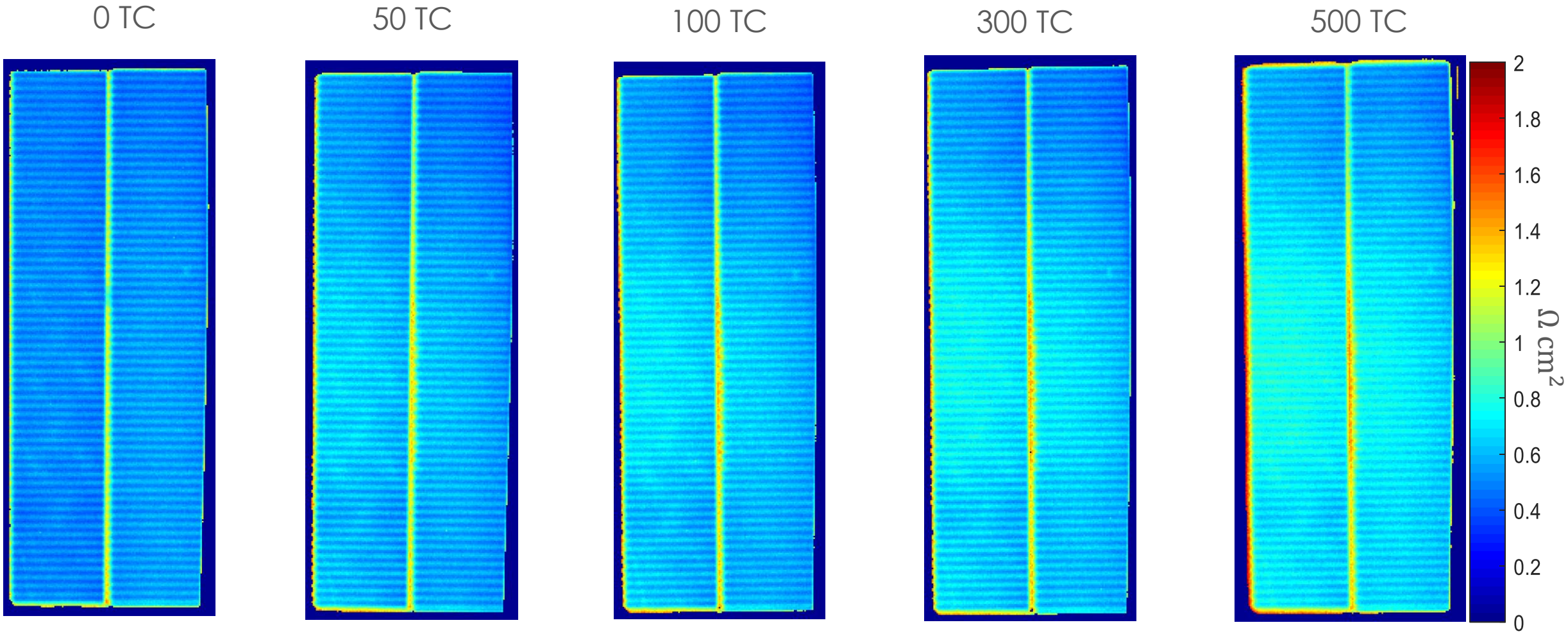


Example of a 3D rendering from x-ray tomography



E. Quintana, et al. *IEEE PVSC*. pp. 002031-002036. *(2009)*.

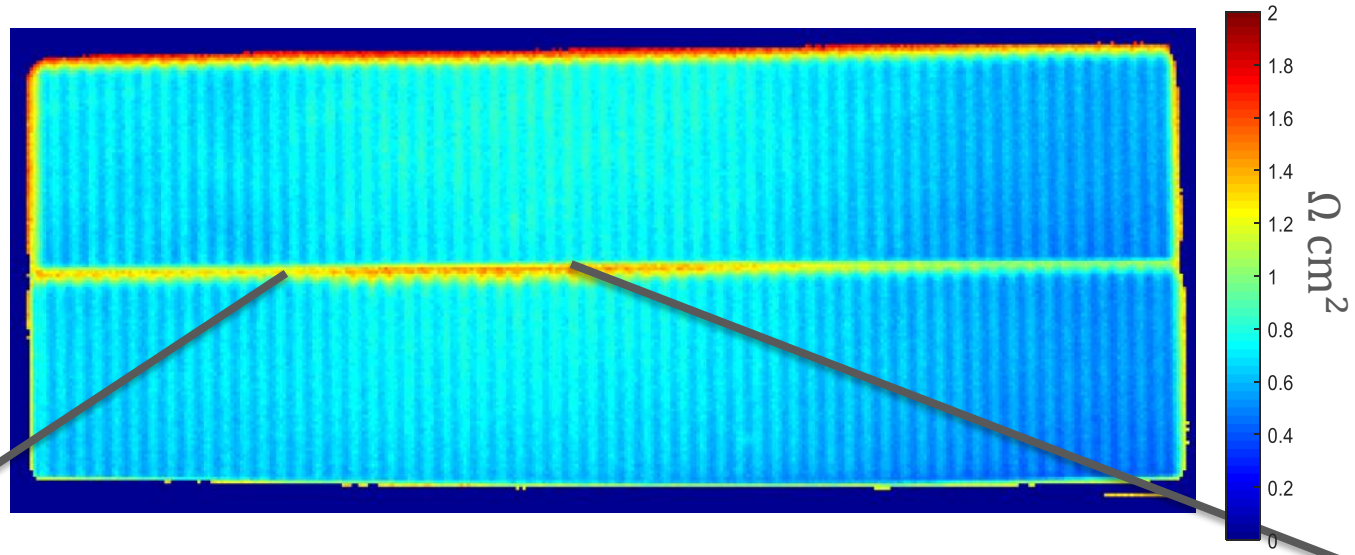
Series resistance mapping throughout thermocycling



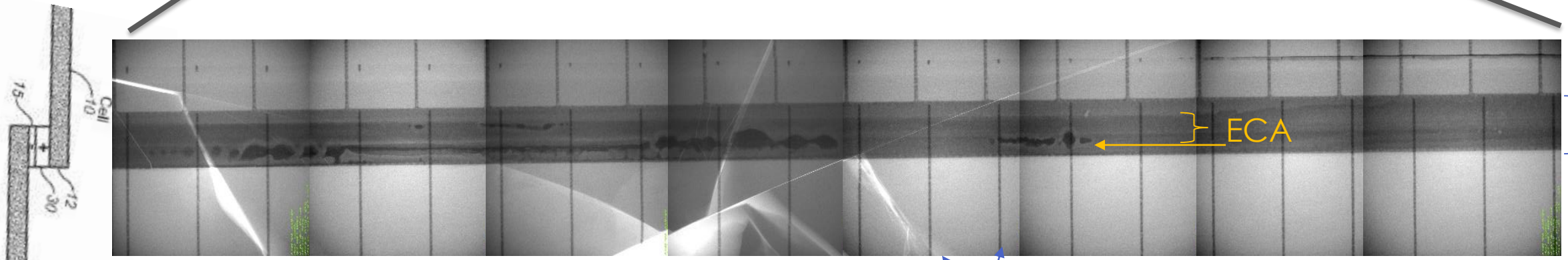
Total Device R_s

0.55 Ω cm²	0.61 Ω cm²	0.63 Ω cm²	0.66 Ω cm²	0.71 Ω cm²

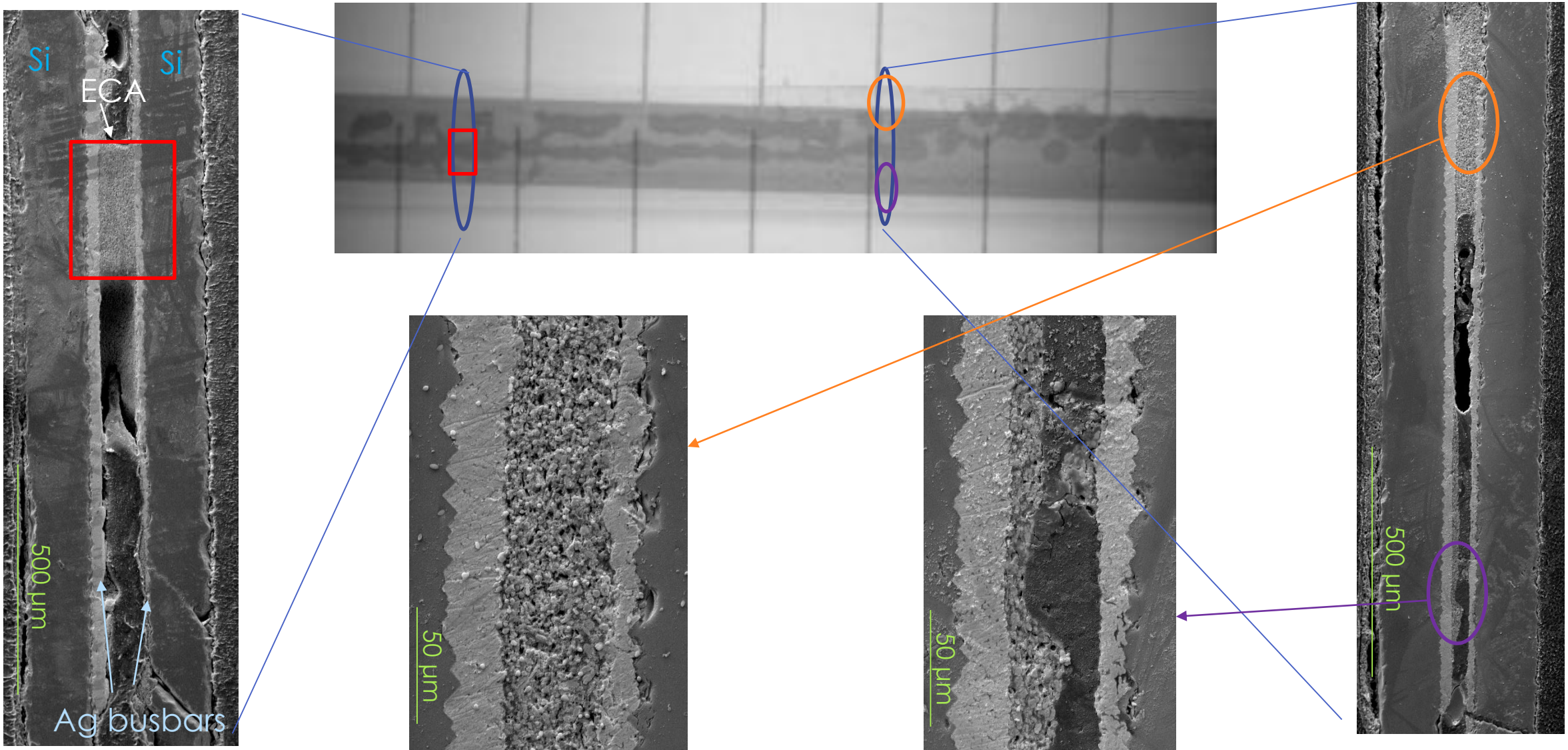
X-ray transmission imaging after 500 TC



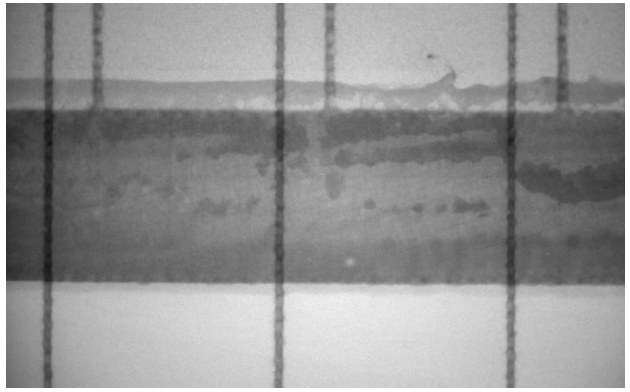
X-Ray transmission image of busbar

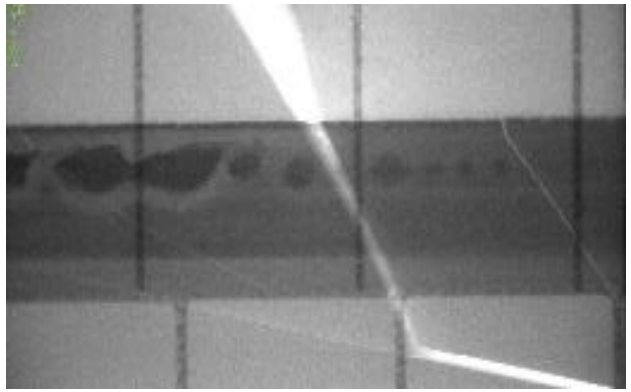


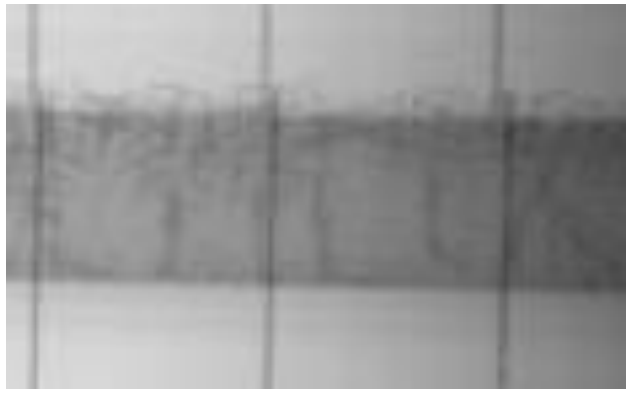
Comparing X-ray transmission with SEM cross section

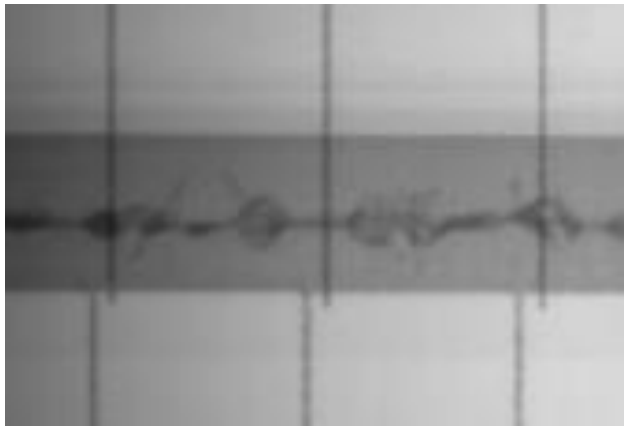


X-ray transmission images from different samples with same processing





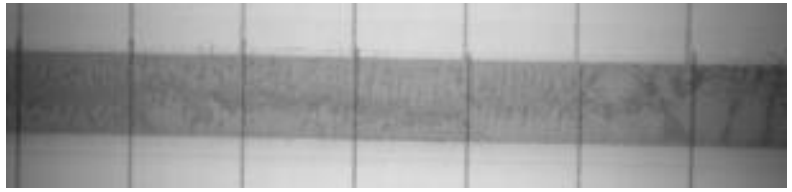




Processing analysis by transmission imaging

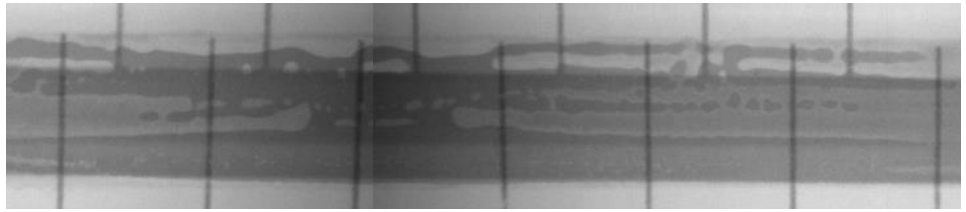
- Blade coating produces wide variability in the distribution of metal particles in ECA layer
- Lamination alone has no notable affect on ECA metal distribution

Lamination Curing



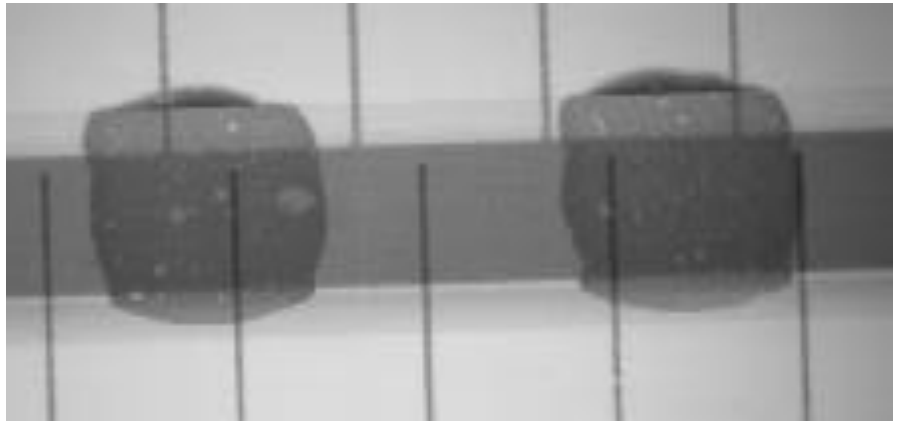
Hot Plate Cure, pre-lamination

Hot Plate Cure, post-lamination

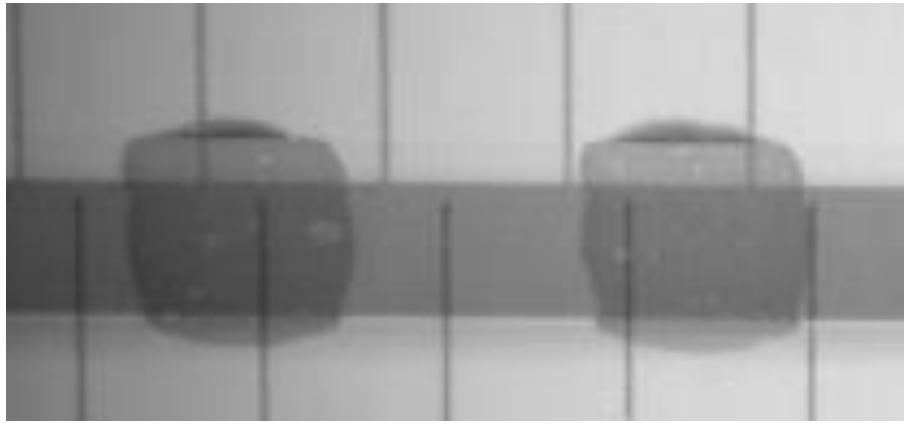


ECA dispensing tool

Before lamination:

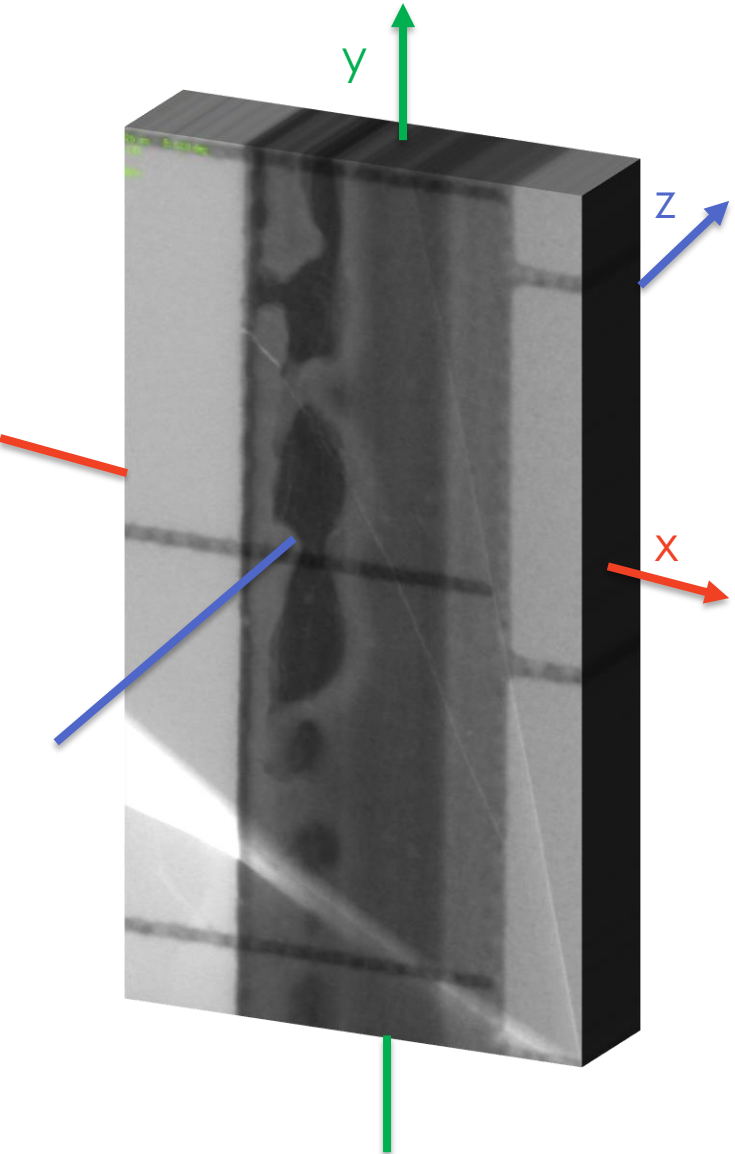


After lamination:

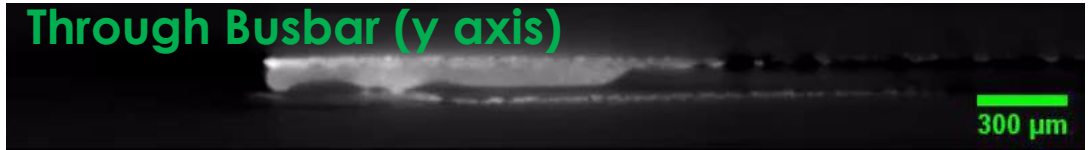


Tomography scan

Transmission image of scan area

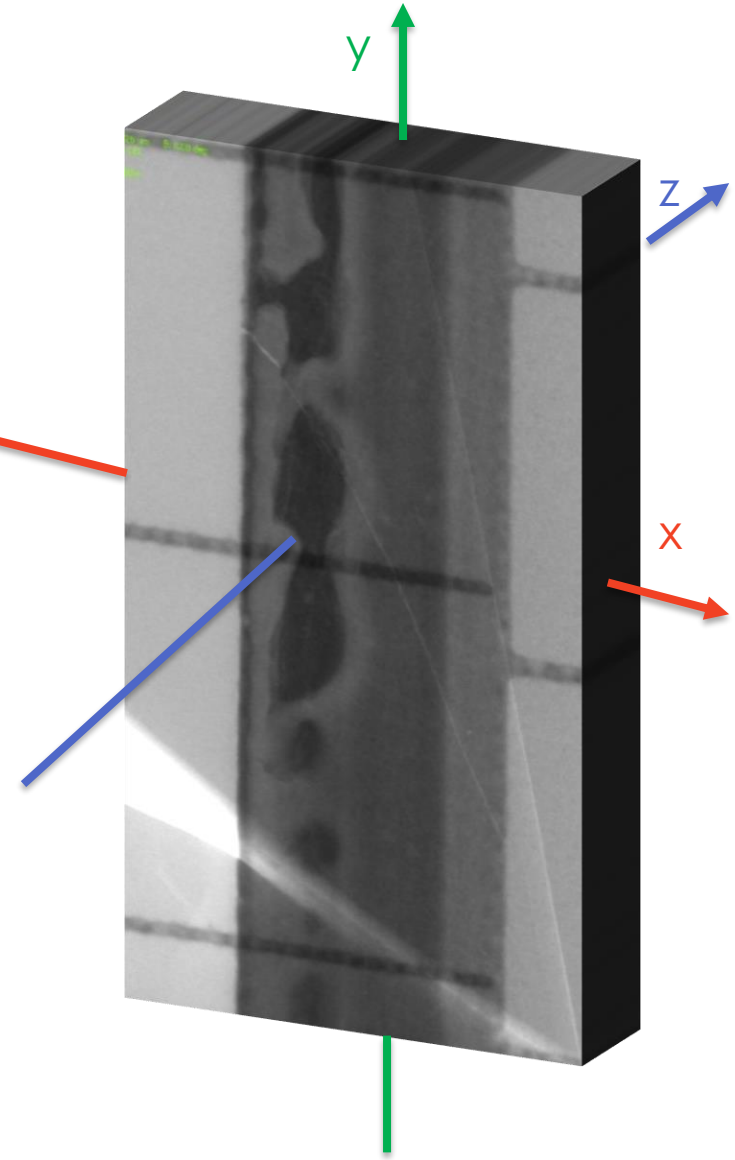


Left to Right (x-axis)

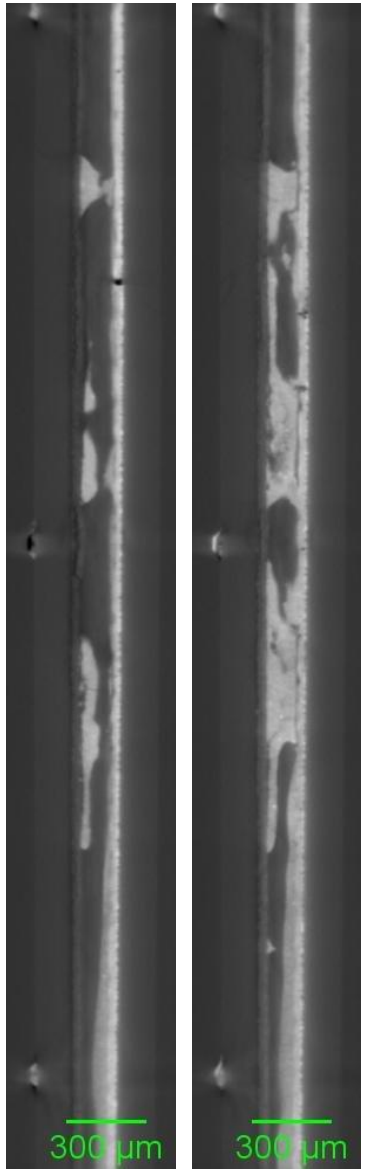


Tomography still images

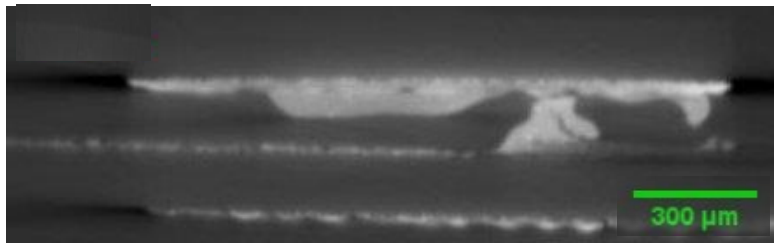
Transmission

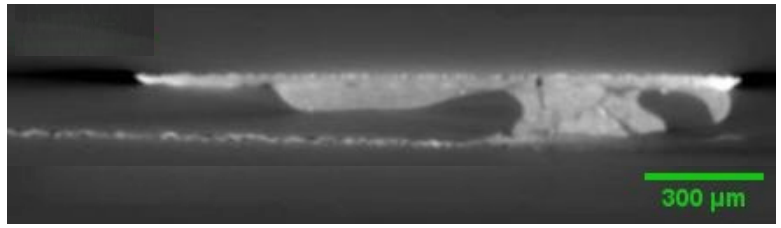


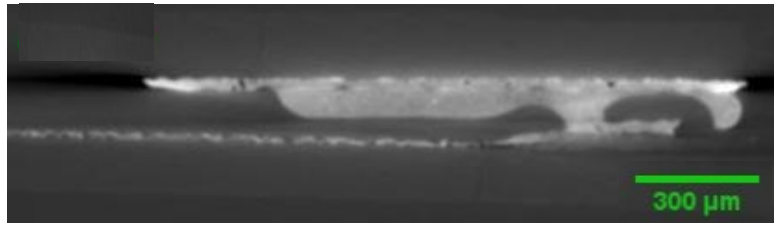
Side Profile

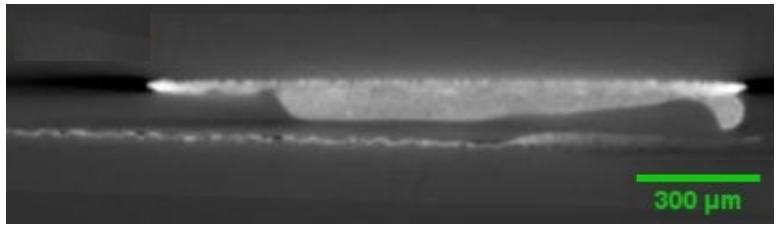


Cross Section

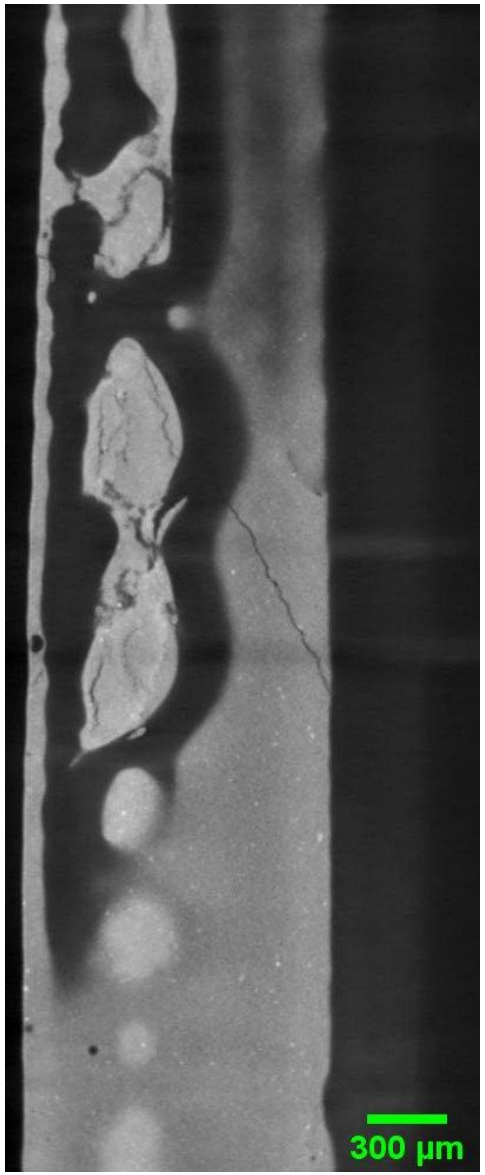






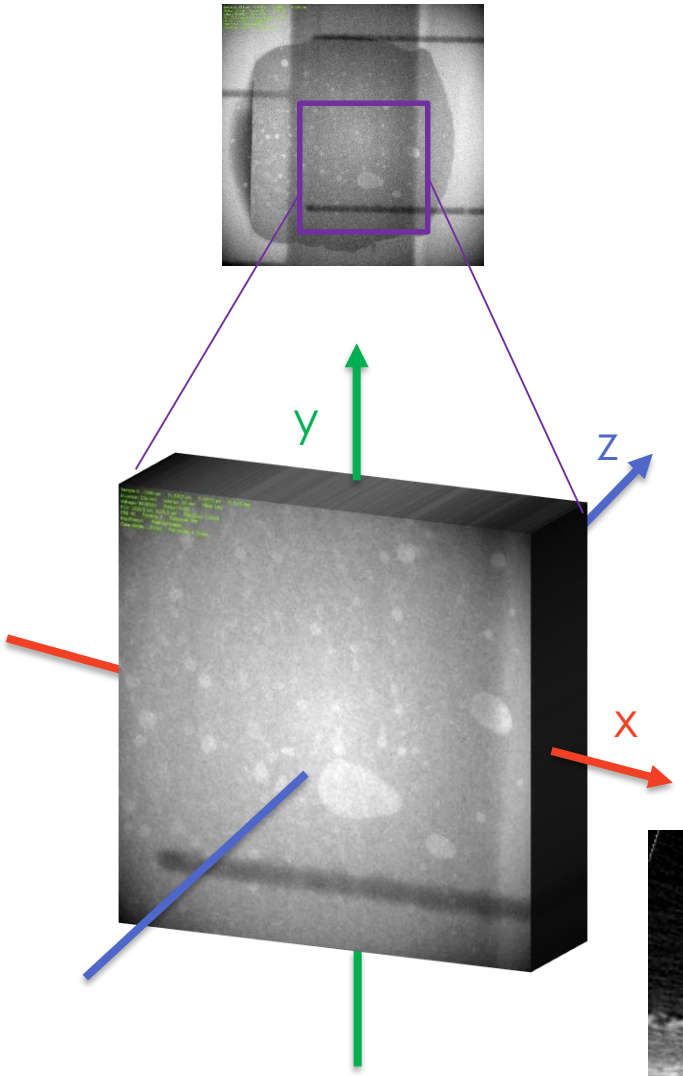


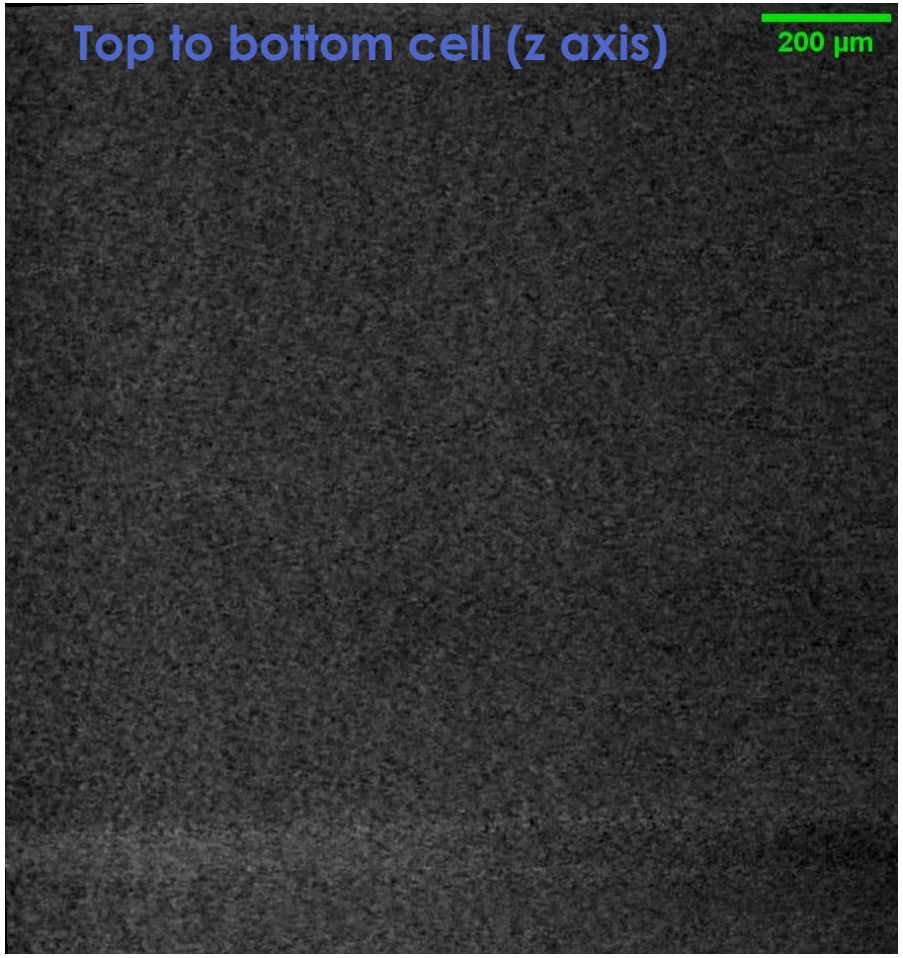
Top-Down

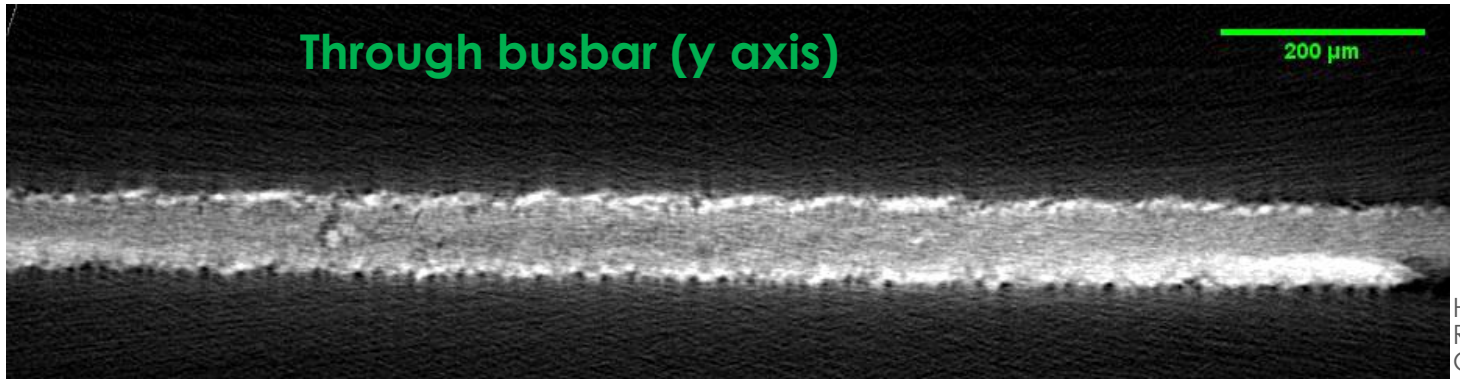


Tomography scan

Transmission

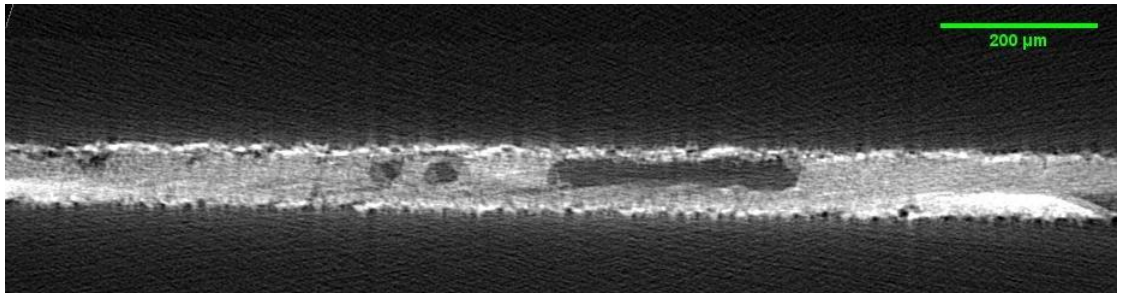


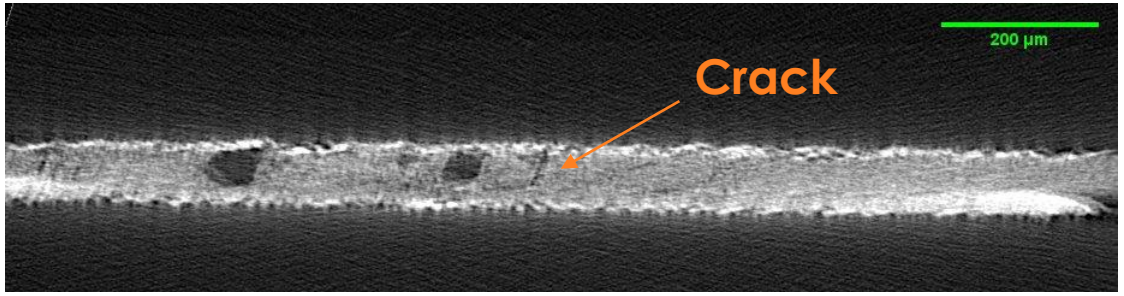


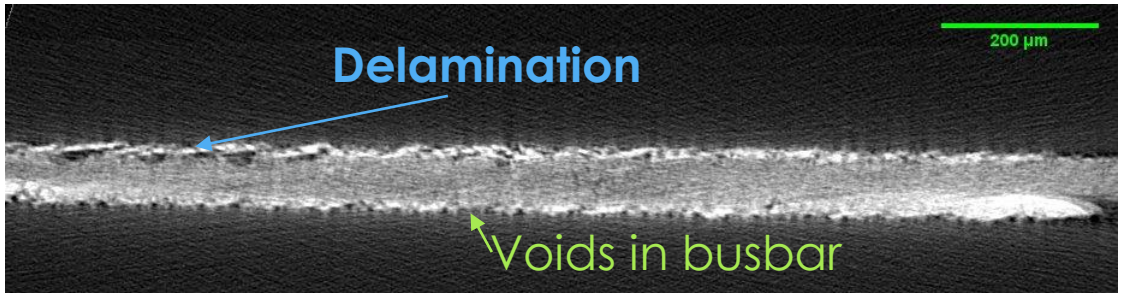


Features shown through x-ray tomography

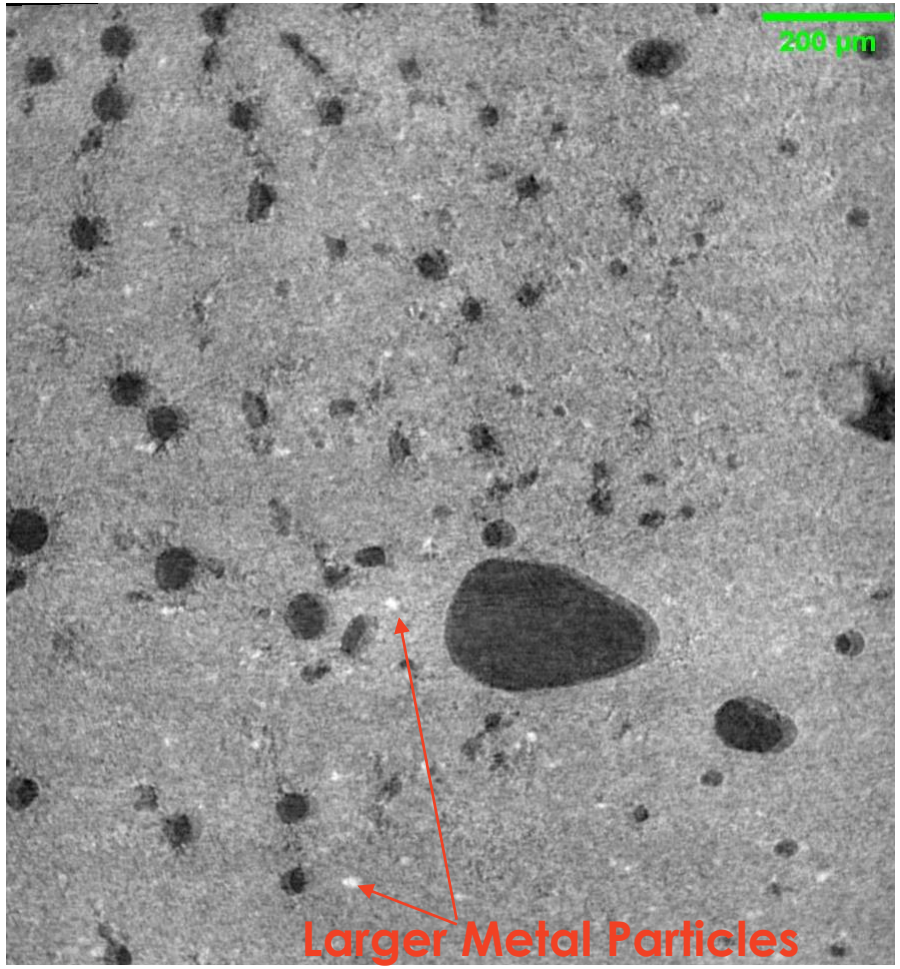
- Voids (~10-130μm)
- Cracks
- Delamination from busbar
- Larger metal particles
- Viable conduction pathways
- Voids in screen printed busbars





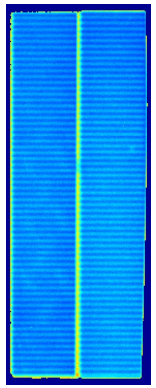


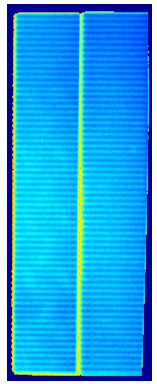
Interface of ECA and busbar

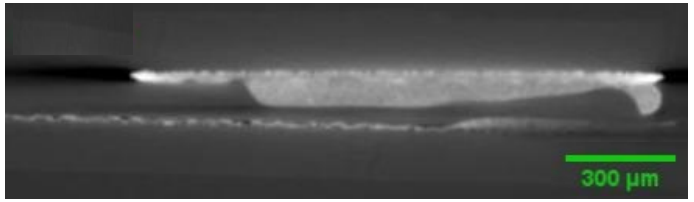


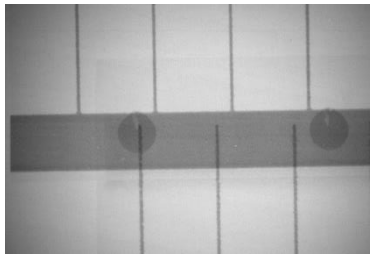
Future plan

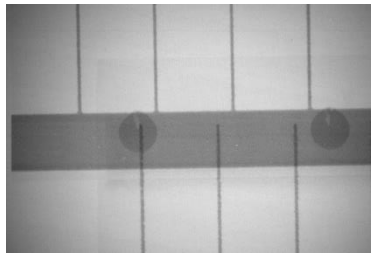
Fabricate mini-module	Initial characterization	Re-characterize through TC/DH	Cut sample for tomography and cross-sections
New module design using the ECA dispensing tool	0 TC	100, 200…TC	Failure demonstrated

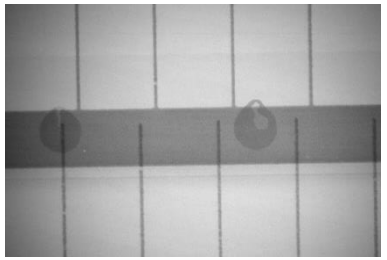


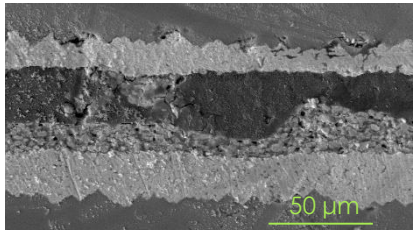










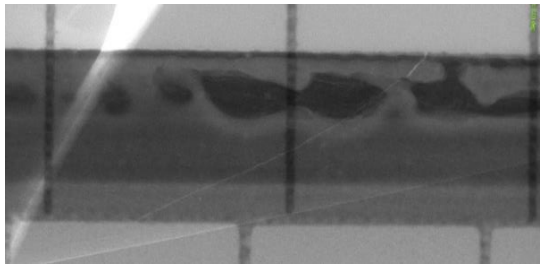


- We can begin here for failed industrial samples

X-ray transmission and tomography summary

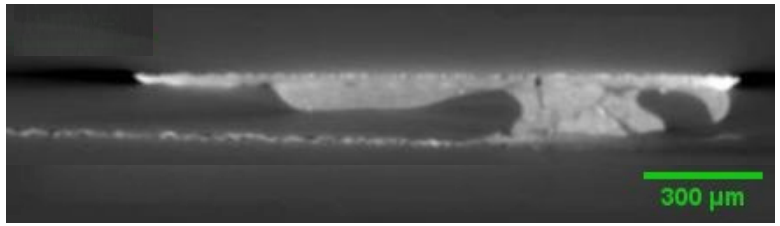
X-Ray Transmission

- Non-destructive
  - Can be added to characterization throughout TC/DH
- 2D imaging of metal distribution throughout ECA
  - Misalignment
  - Voids
  - Relative information about thickness
- Informs where to run tomography scan



X-Ray Tomography

- 3D imaging of metal distribution in ECA
  - 3D understanding of conduction pathways
  - 3D voids
  - Cracks
  - Delamination
  - Larger metal particles
  - Up to 1µm/pixel resolution
- Informs where to make cross section for SEM and EDXS



Thank you for your attention!

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Acknowledgements

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ASU
QESST
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Sandia National Laboratories
BERKELEY LAB
SLAC NATIONAL ACCELERATOR LABORATORY