# Thermal Runaway Failures of CPV Solar Cells

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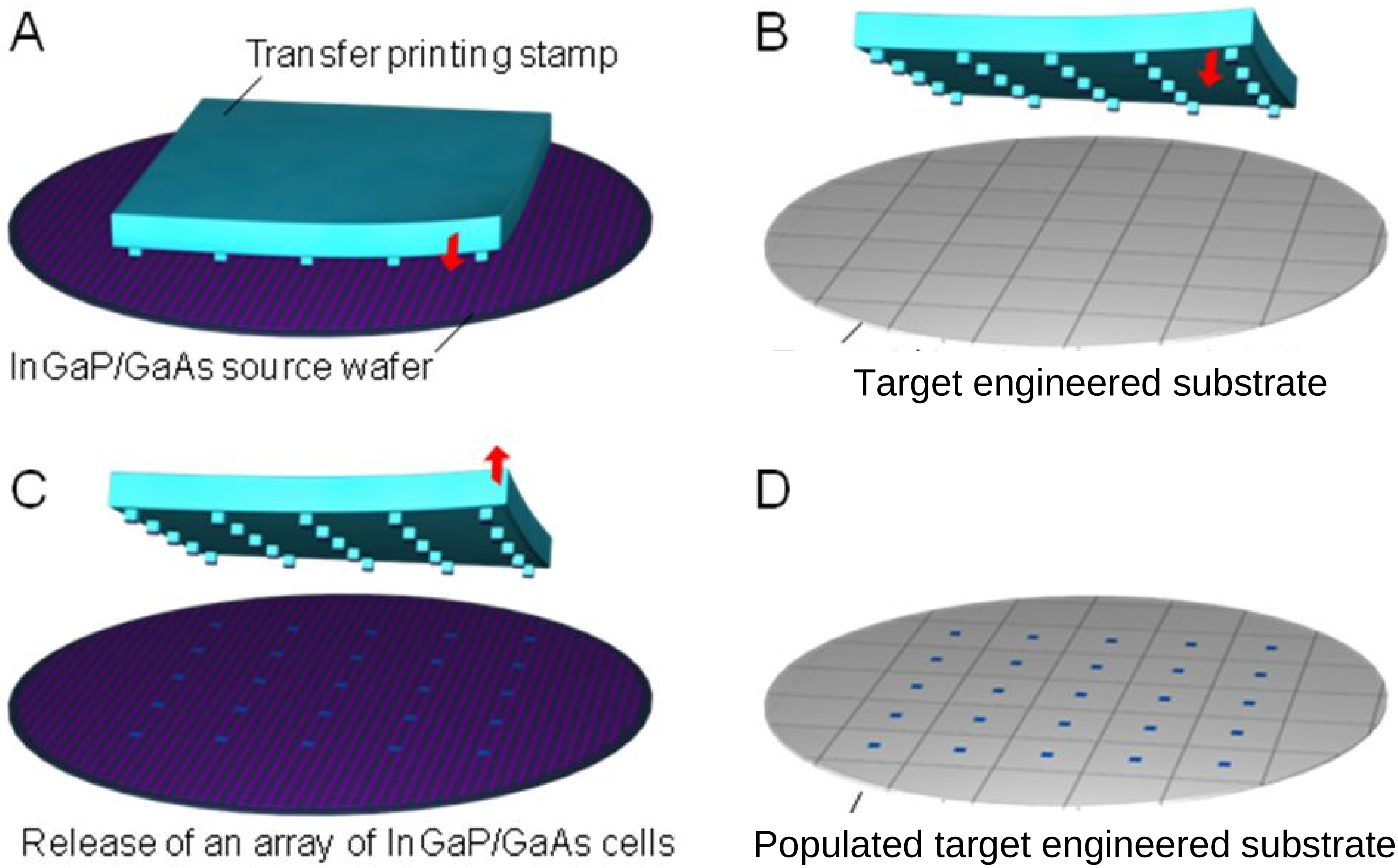
# Semprius Background

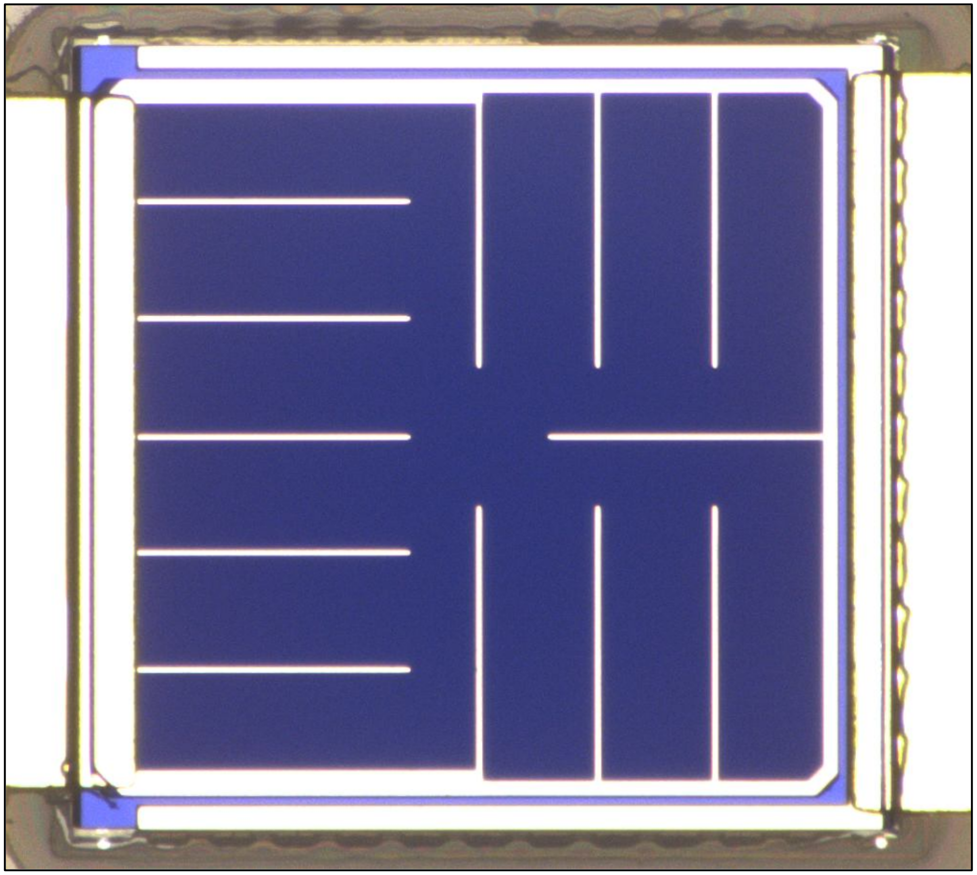
- Semprius is developing low cost, high performance concentrator photovoltaic (CPV) modules to make solar power generation economically viable in sunny, dry climates. The company's unique micro-transfer printing technology enables CPV modules with high performance, high reliability and low cost with scalability to high-volume production.

- Semprius is also licensing its micro-transfer printing technology for non-solar applications to enable a wide variety of new products requiring large-area, thin, lightweight form factors, unprecedented performance, high reliability and low cost. Applications include flat-panel displays, flexible electronics, large-area sensors, RF devices and other applications requiring heterogeneous integration of high-performance semiconductors.

# Transfer Printing Process

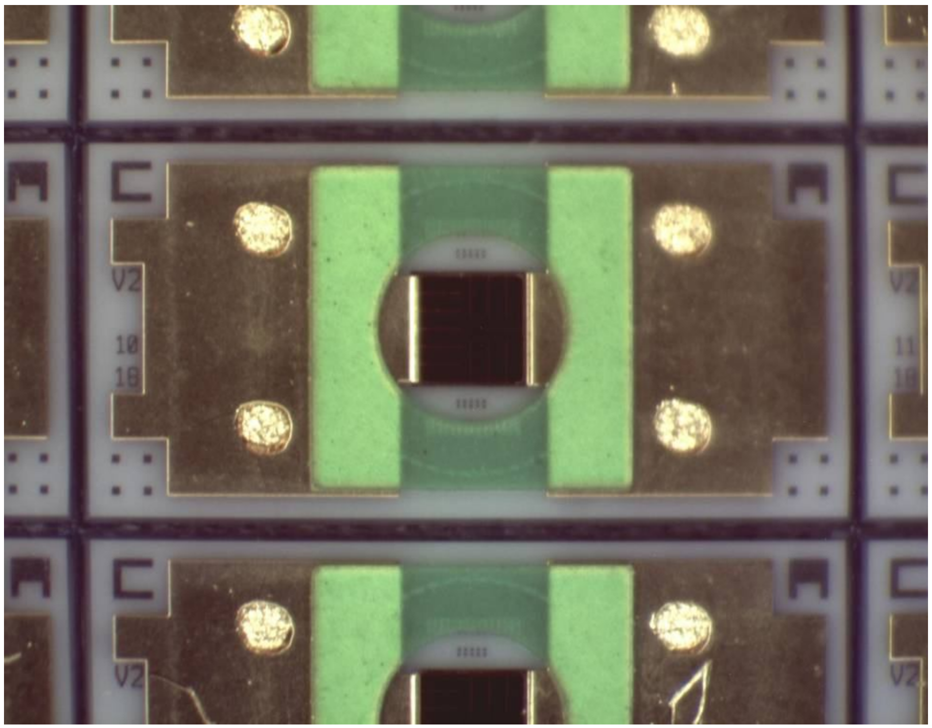


# Cell Geometry & Interconnection



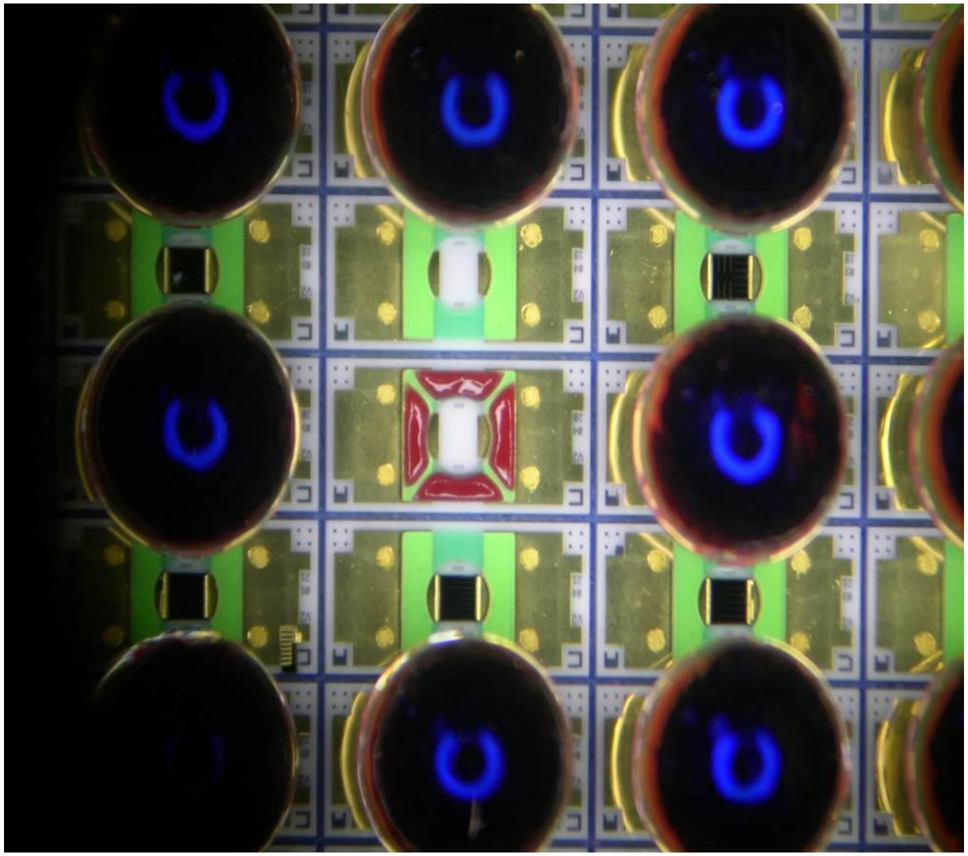
- 650um dual-junction unifacial GaInP/GaAs cell
- Thin film metallization creates anode/cathode interconnection
- 800 suns concentration at cell results in ~10 A/cm$^2$ current density

# Thermal Stack: Cell to Backplane



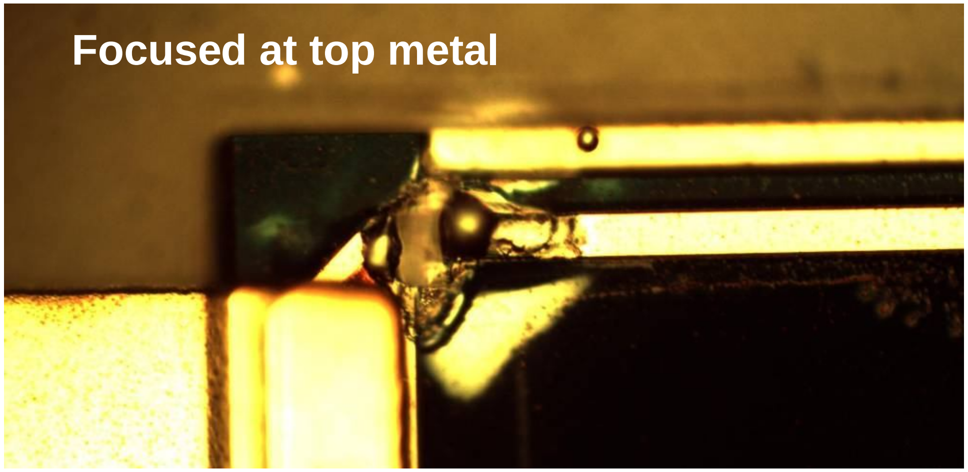
- ~5um-thick GaInP/GaAs solar cell
- Cell printed onto thin photo-imageable epoxy
- Evaporated + plated thin film interconnection
- Alumina interposer with thru-wafer vias
- Interposer soldered to Cu-dielectric-Al backplane

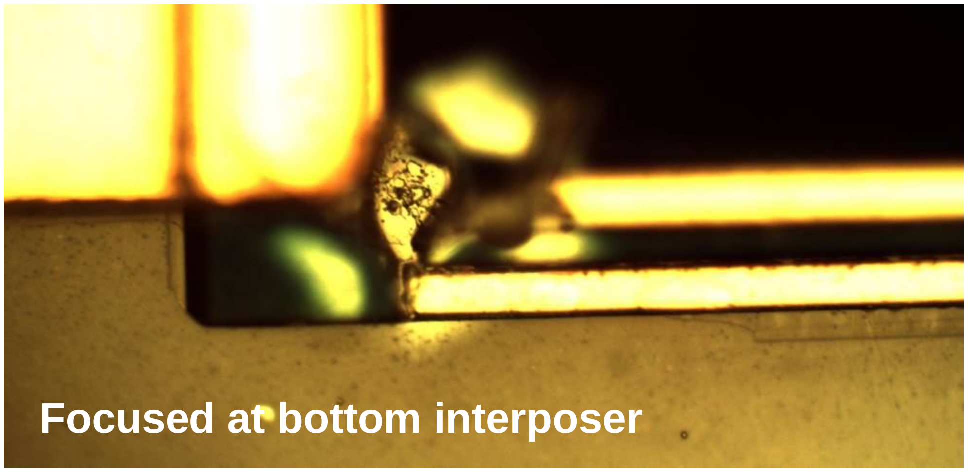
# Secondary Optical Element

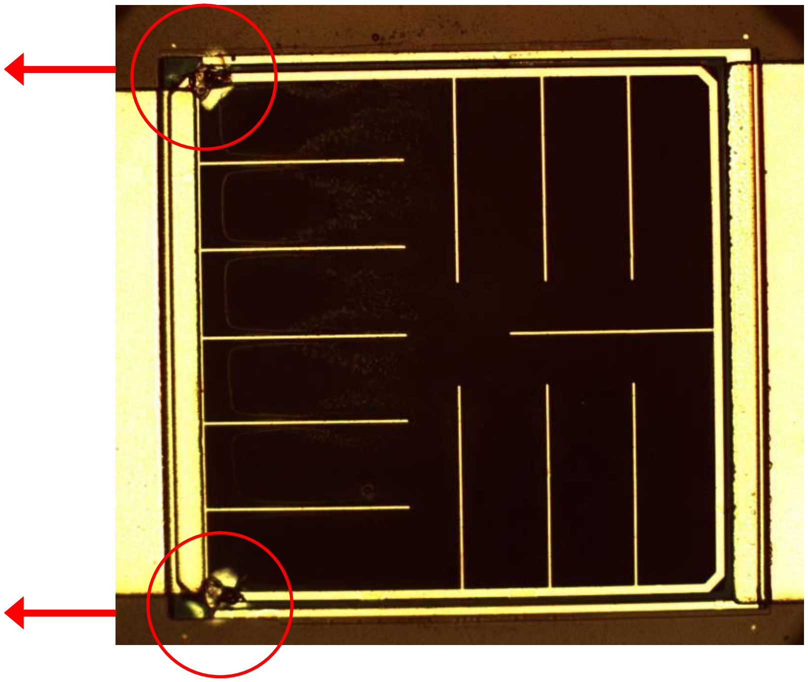


- Spherical ball lens attached to spacer with correct ball-to-cell distance
- Secondary optical element (SOE) provides uniform illumination across cell

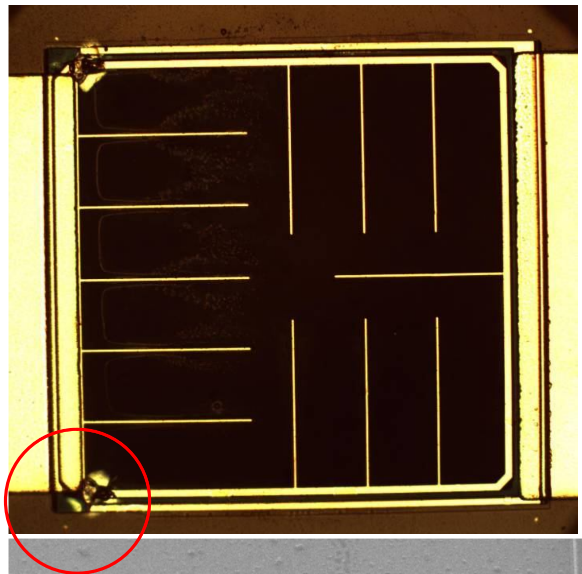
# Cell at 1000-Suns Failed Within Hours On-Sun



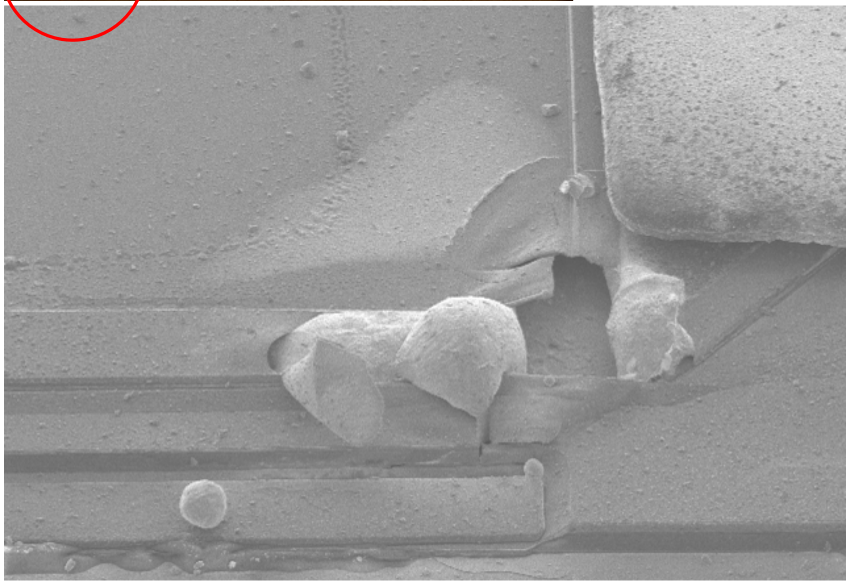



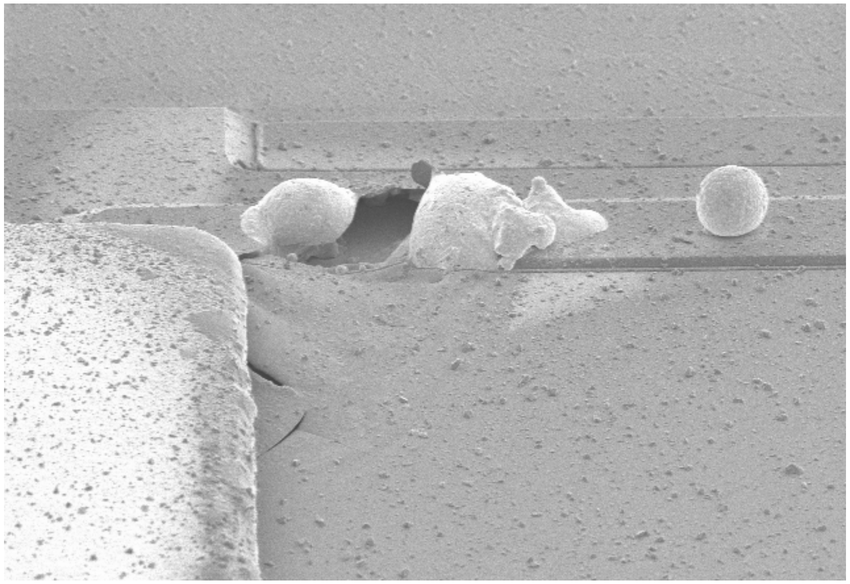



# SEM of Failed Cell on Interposer

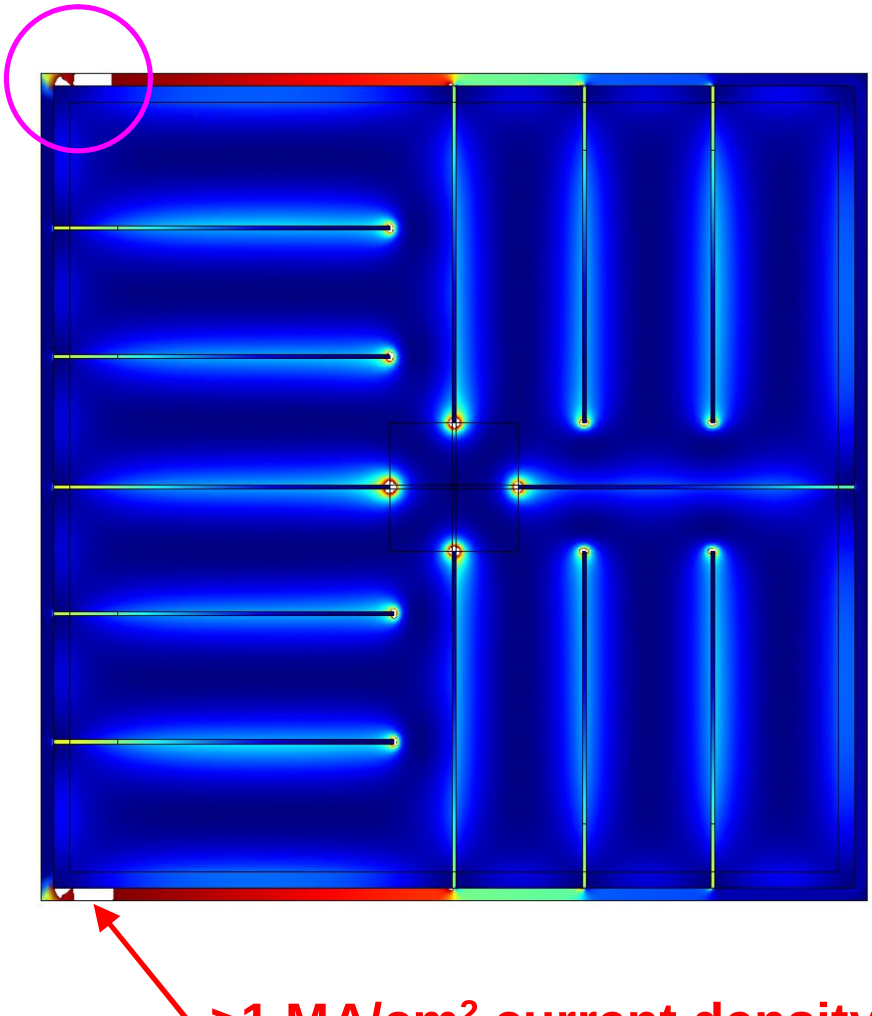


- SEM and XPS: metal and semi have melted together during on-sun failure!
- Failures almost always near junction of grid finger with busbar.





# FEA of Surface Resistive Heating



>1 MA/cm² current density

- Highest current density and heating in same location as failures.
- Regions with highest current density are also potentially locations with poor thermal contact.

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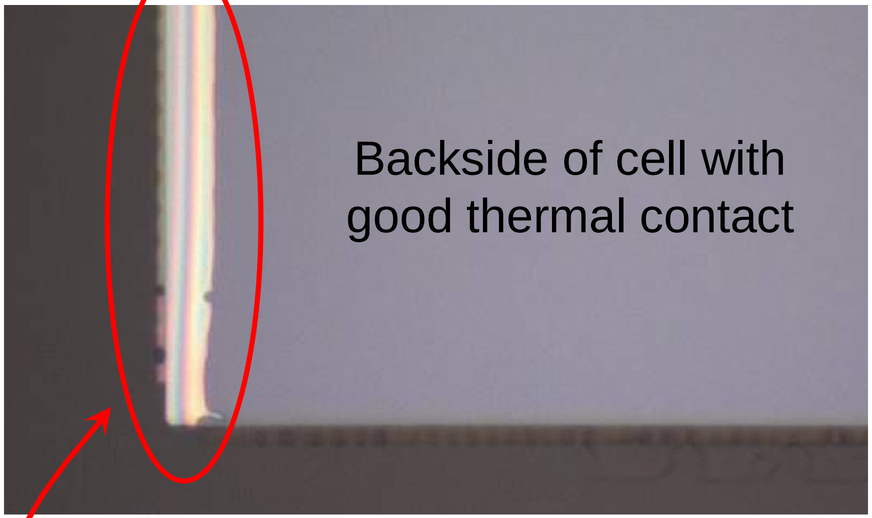
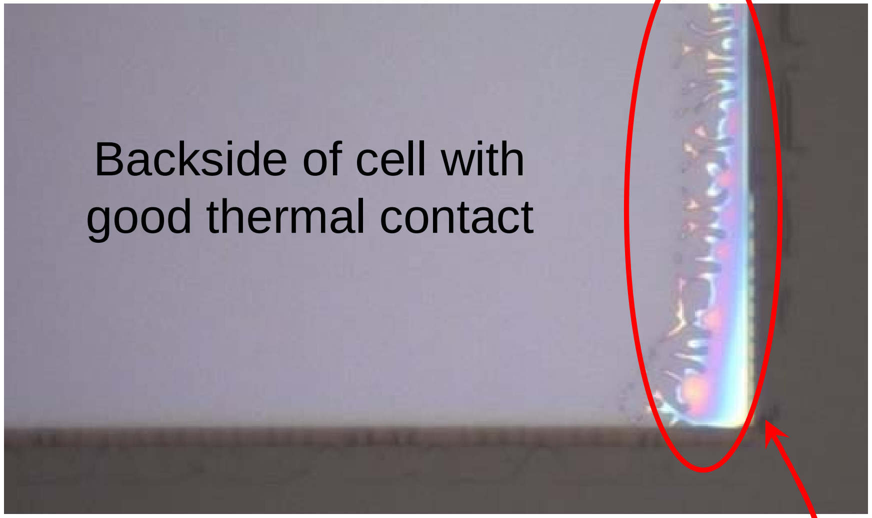
# Thermal Runaway Mechanism

- High current densities lead to Joule heating of semiconductor.
- Regions with poor thermal contact get hotter than the surrounding regions.
- Negative temperature coefficient of resistance in semiconductor causes more current to flow through hotter regions.

**Feedback loop results in catastrophic failure**

# Transfer Print of Cell to Glass Wafer




- Printing cells onto glass allows backside observation.
- Poor thermal contact between epoxy and cell observed along edges under busbar locations.

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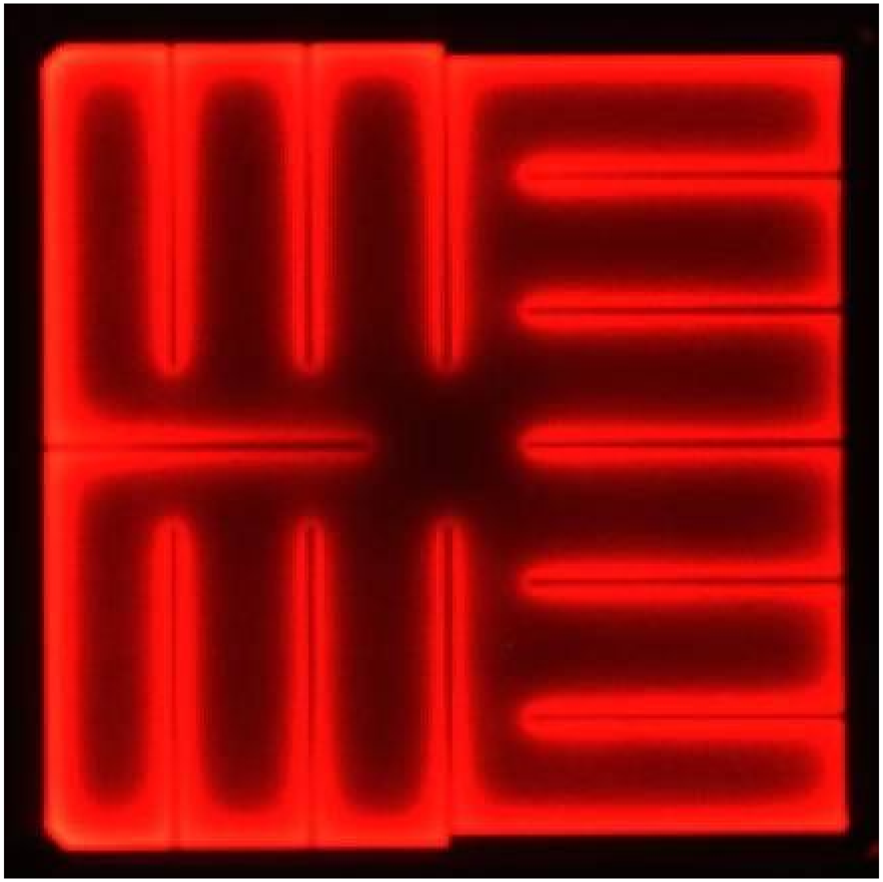
# Root Cause of Failure

- Unwanted removal of photo-imageable epoxy during photo develop step and oxygen plasma clean resulted in undercut of epoxy under cell and subsequent thermal runaway failure.
- Review of process traveler indicated that post-exposure bake (PEB) of epoxy had been inadvertently skipped.
- Next lot processed with PEB did not show any signs of epoxy undercut even with extended periods in developer and extensive oxygen plasma ashing.
- On-sun failure due to this failure mode has not been observed since corrective actions were implemented.

# Forward Bias to Failure

**100 $A/cm^2$ Forward Bias**

Electroluminescence of top cell



- Cells with poor thermal attach failed under forward bias at ~1$A/cm^2$ current density.
- After corrective action, >100 $A/cm^2$ for minutes without thermal runaway which is 10X normal operating conditions.