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Multi-scale investigations of solder bond failures

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Goal:

Develop techniques and perform failure analysis for improved reliability and lower cost of interconnects in Si modules.

Why study solder bonds?

- **Interconnect failures are the third most common module failure mechanism after discoloration and back sheet/EVA delamination.**
- **Non-cell solder bonds often have little or no redundancy, so failure of one of these bonds can lead to drop out of a cell string, a whole module, or even a whole string of modules.**
- **The transition from lead-containing to lead-free solder and electrically conductive adhesives in modules could exacerbate the problem, as the adhesion characteristics of these new materials are less well understood.**

Types of stresses:

- Moisture
- Temperature and thermal cycles
- High voltage and/or current
- Chemical contamination
- Electromagnetic interference
- Mechanical tension/torque/vibration
- Ultraviolet radiation

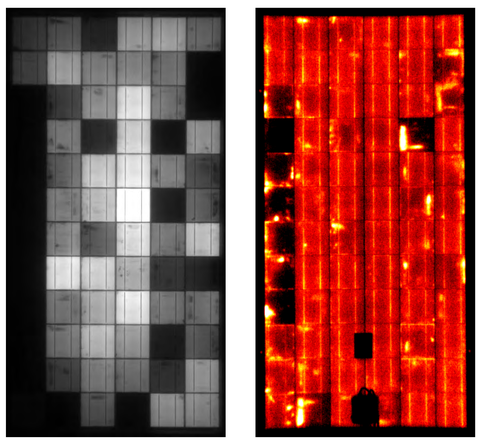
Areas of study:

- We propose to investigate the metallurgical, chemical, adhesive, and electrical properties of solder bonds using a multi-scale approach that spans the length scale from millimeters to sub-nanometer.
- This approach will be based on an NREL-developed suite of AFM-, SEM- and TEM-based techniques that have been successfully applied to Si and thin film modules.
- Particular emphasis will be placed on thermomechanical fatigue of the solder joints, grain coarsening associated with aging, the formation of intermetallics, corrosion, and delamination.
- Lead-containing solder, lead-free solder, and electrically conductive adhesives will be investigated.

Characterization tools to use:

Imaging (photoluminescence, electroluminescence, and thermal)

Example imaging of a silicon module:

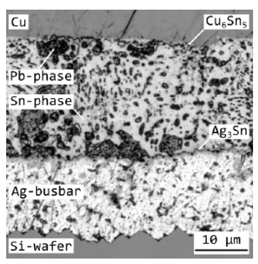


Electro-luminescence

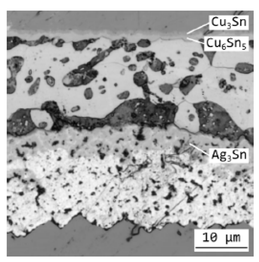
module size ~1 x 2 meters

Dark Lock-In Thermography (DLIT) image

Optical Microscopy



a



b

Images of Sn40Pb40 solder bond in: (a) Initial State, (b) After 155 hours at 130° C

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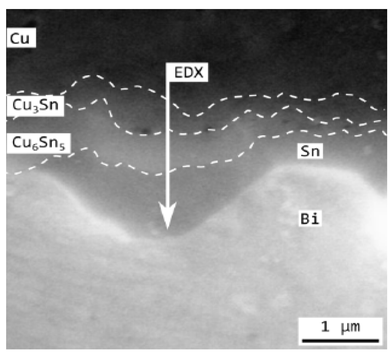
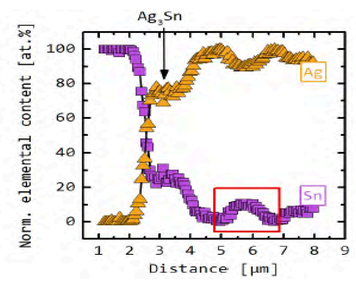
Scanning Electron Microscopy (SEM)



SEM image of the interface region of a Sn41Bi57Ag2 solder joint aged at 100° C for 155 hours.

SEM Energy-Dispersive X-ray Spectroscopy (EDS)

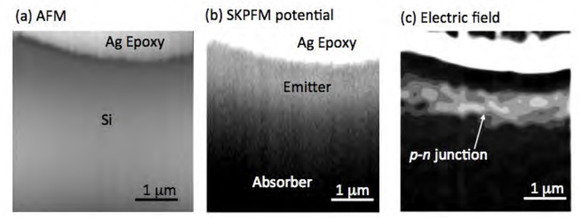


EDS Line scan across the interface in the SEM image above

Atomic Force Microscope (AFM) – based techniques

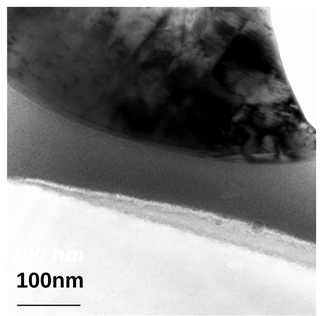
- Scanning Capacitance Microscopy
- Scanning Spreading Resistance Microscopy (SSRM)
- Scanning Kelvin Probe Force Microscopy (SKPFM)

Example of SKPFM on a silicon pn junction region.



Transmission Electron Microscopy (TEM)

High resolution analysis of ultra-thin samples. Electron Energy Loss Spectroscopy (EELS) and EDS for compositional analysis.

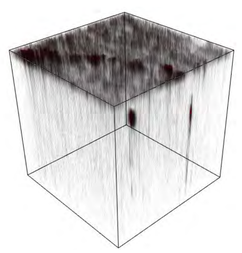


TEM Cross-section of a solder joint

Time-of-Flight Secondary Ion Mass Spectrometry (TOF-SIMS)

TOF-SIMS shows elemental analysis with 100nm spatial resolution in 3D using depth profile sputtering.

TOF-SIMS example of sodium profiling in a degraded silicon solar cell



3D Render of Na+

Measured area: 200 x 200 x 3.5µm

