Failure Analysis of Module-Integrated Electronics

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Goal: **Develop techniques and perform failure analysis for improved quality, reliability, and safety of integrated electronics. Lifetimes of electronics should match with the modules into which they are integrated.**

Why study electronics?

- **37% of unscheduled maintenance events and 59% of unscheduled maintenance costs are due to the inverter (largest category).**
- **51% of PV system failures due to the central inverter.**
- **Inverter is largest PV system failure category (43%) and responsible for most kWh lost (36%).**

L. M. Moore and H. N. Post, "Five years of operating experience at a large, utility-scale photovoltaic generating plant," Progress in Photovoltaics: Research and Applications 16(3): 249-259, 2008 "Reliability of Power Electronic Systems", Industrial Seminar, F. Blaabjerg, F. Iannuzzo, K. Ma, IEEE APEC 2016, March 2016.

"Owner/Operator Perspective on Reliability Customer Needs and Field Data", Sandia National Laboratories, Utility-Scale Grid-Tied PV Inverter Reliability Workshop, January 2011.

*A. Golnas, "PV System Reliability: An Operator's Perspective," IEEE Journal of Photovoltaics, **3**, pp.416-421, Jan. 2013.*

Types of electronics:

- **Central inverters**
- **Micro-inverters**
- **Distributed inverters with power optimizers**
- **Bypass diodes**

Types of stresses:

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

Types of failures:

- **Corrosion**
- **Solder joint fatigue**
- **Plated through-hole fatigue**
- **Conductive anodic filament formation**
- **Tin whisker formation**
- **Shock or vibration**
- **Potting induced (mechanical or corrosion)**
- **Flame retardant induced corrosion**
- **Solder flux adhesion and/or corrosion**
- **Component wear out**

Areas of study:

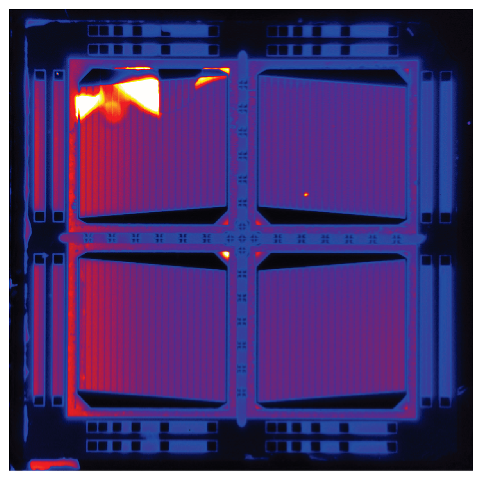
- **Device deconstruction**
- **Failure analysis methodologies**
- **Materials interaction/corrosion**
- **Adhesion**
- **Moisture ingress**
- **Thermal modeling**
- **Design for reliability**

Characterization tools to use:

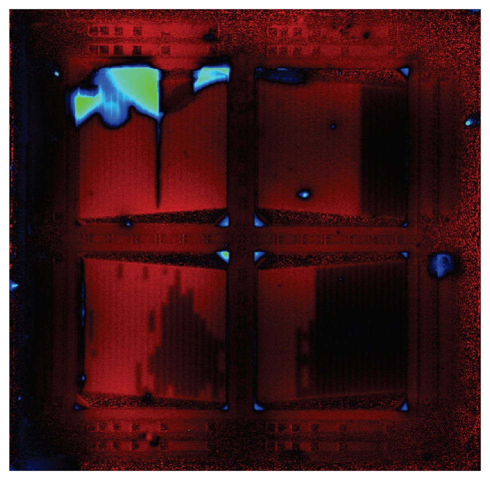
Thermal Imaging and Lock-In Thermography

Example thermal imaging of a solar cell stack

Amplitude lock-in image

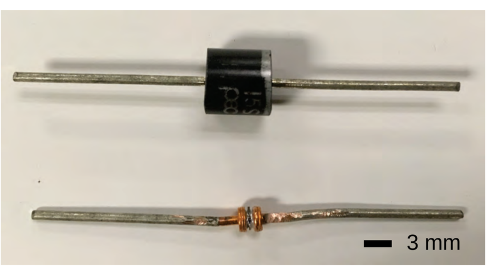


Phase lock-in image



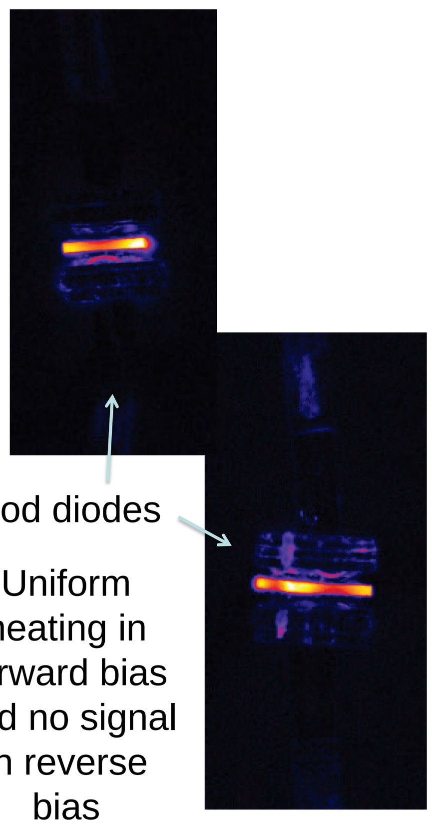
- Shunting seen in localized regions.
- Film delamination seen in phase image.

PV module bypass diodes



Mechanically remove the encapsulation to expose the semiconductor device.

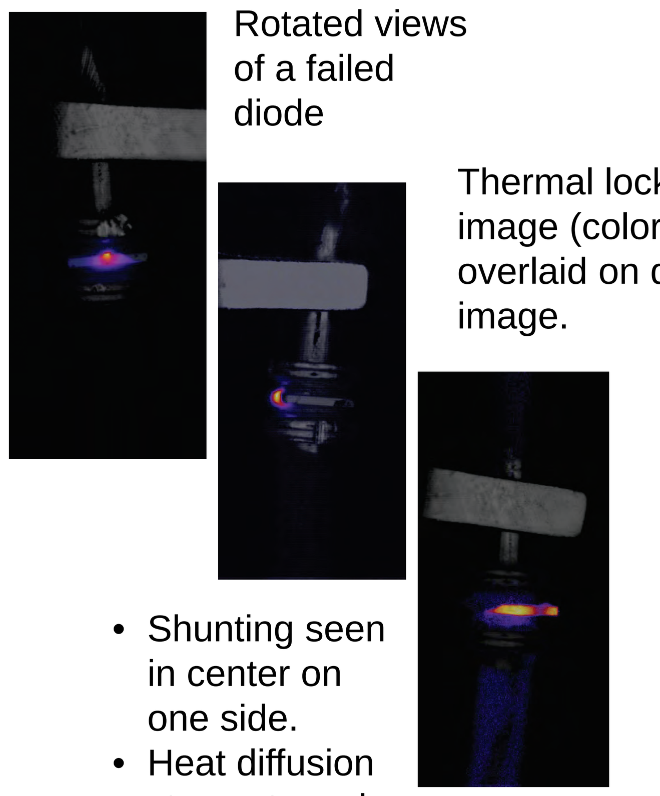
Examples of thermal imaging of bypass diodes



Good diodes

Uniform heating in forward bias and no signal in reverse bias

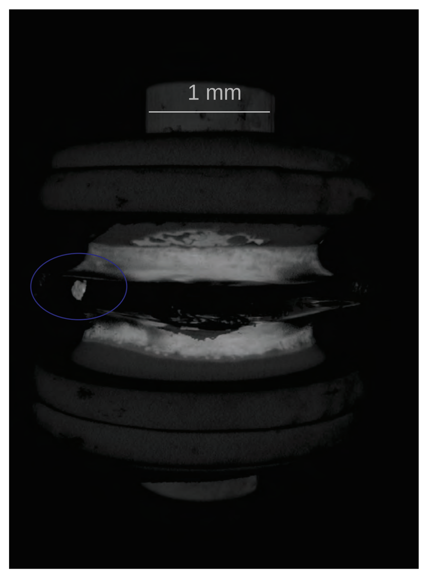
Rotated views of a failed diode



Thermal lock-in image (color) overlaid on diode image.

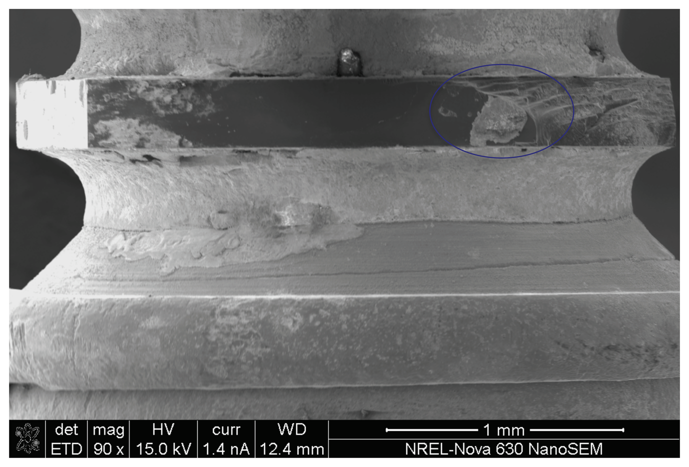
- Shunting seen in center on one side.
- Heat diffusion stops at crack.

X-Ray Tomography



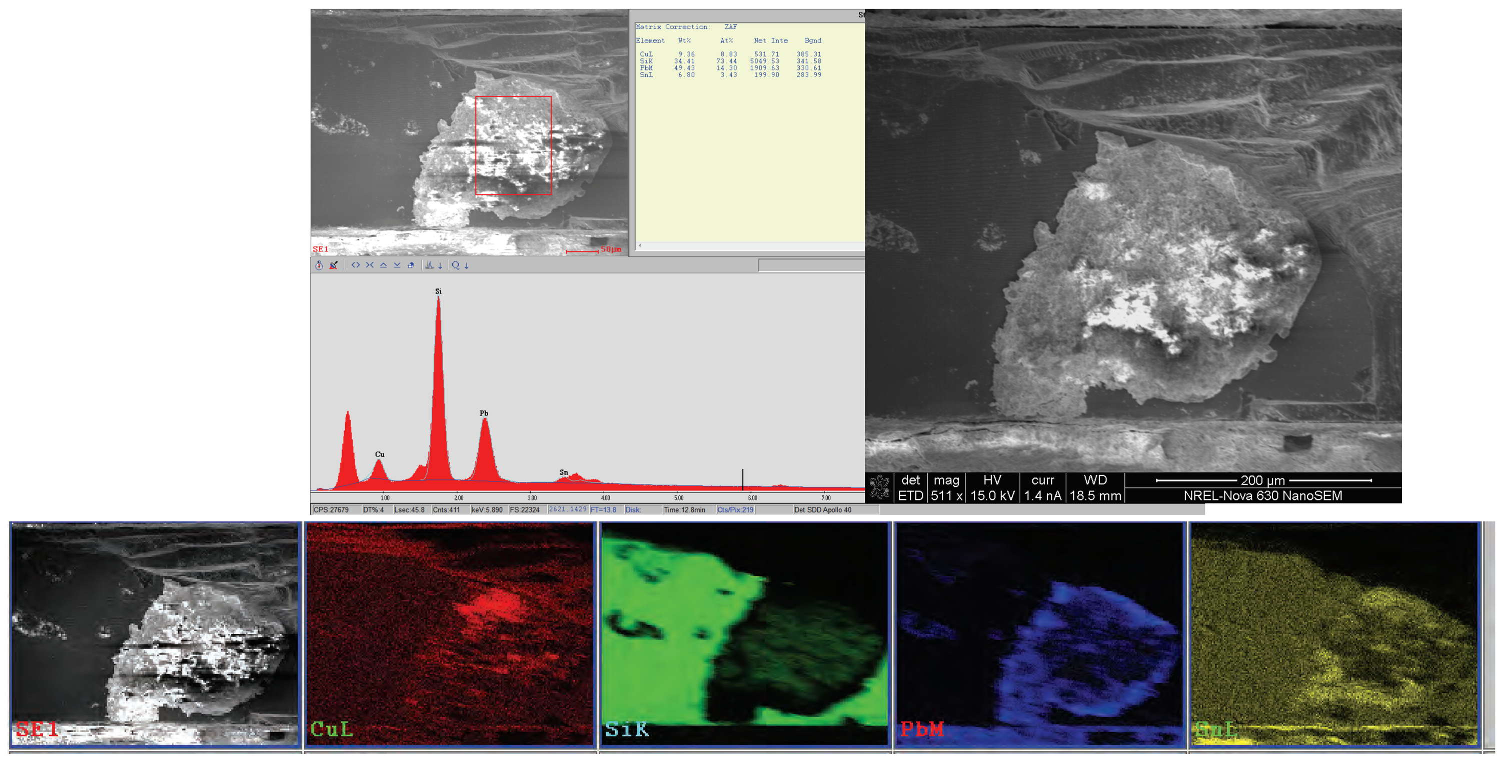
Examine devices through the encapsulation materials.

Scanning Electron Microscope (SEM)



High resolution imaging to examine defects and identify materials.

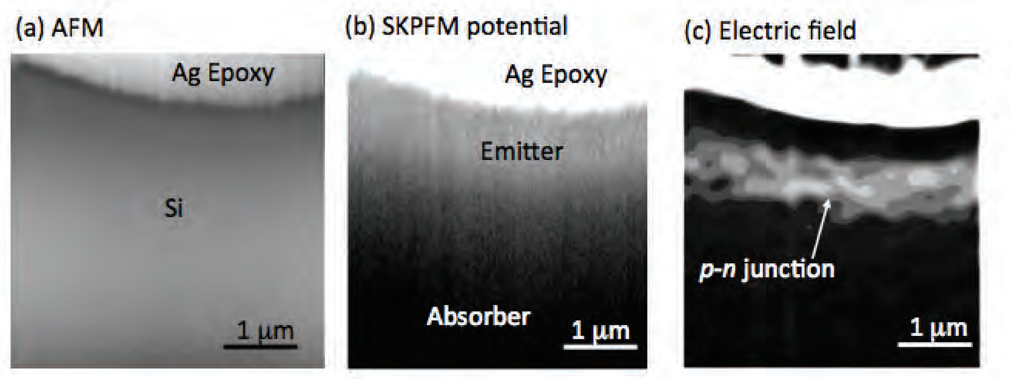
SEM Energy-Dispersive X-ray Spectroscopy (EDS)



Atomic Force Microscope (AFM) – based techniques

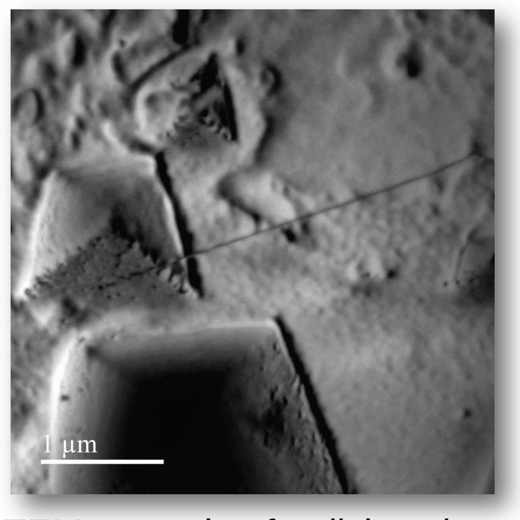
- Scanning Capacitance Microscopy
- Scanning Spreading Resistance Microscopy (SSRM)
- Scanning Kelvin Probe Force Microscopy (SKPFM)

Example of SKPFM on a silicon pn junction region.



Transmission Electron Microscope (TEM)

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

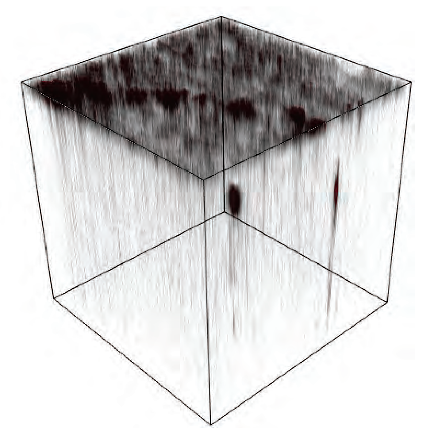


TEM example of a dislocation in a silicon solar cell

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

TOF-SIMS shows elemental analysis with 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

 DuraMat Workshop Golden, CO Oct. 10-11, 2016