Imaging Characterization for PV Module Reliability Studies

- **Imaging:** cameras and imaging sizes
  - Si camera (visible to near infrared)
  - InGaAs near-infrared camera
  - InSb thermal (mid-wave 3-5 µm) camera
  - Each camera has lenses for fields of view
    - meters down to mm sizes

- **Types of images**
  - Electroluminescence (EL)
  - Photoluminescence (PL)
  - Thermal: Lock-in Thermography (LIT)

- **Locating defects for microscopy**

- **Capacitance & Electro-optical measurements**
Imaging by thermography can show degraded cells within a module. Many companies offer such imaging services using unmanned aerial vehicles or drones.

PV Tech, vol. 08, Sept. 2016, pp. 70-76.
Cameras for EL/PL imaging

- Princeton Instruments PIXIS 1024BR
- FLIR SC2500N

**Si CCD camera**
- Smaller bandgap with higher QE for Si and CIGS
- Faster PL and EL imaging
- Si defect band imaging

**InGaAs camera**
- QE comparison
- Back-illuminated deep-depletion
- 808 nm excitation
- Si PL peak
- Si defect band

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Cameras for EL/PL imaging

- Princeton Instruments PIXIS 1024BR
- PL image of large-grain CdTe
- Si CCD camera QE back-illuminated deep-depletion
- CdTe PL peak
- 532 nm excitation
- Si CCD camera
- long-pass filter
Thermal Imaging – Lock-in Thermography

InSb camera

Cedip Silver 660M
FLIR SC5600-M

Lock-In Thermography
- Dark (DLIT)
  - forward bias
  - reverse bias
- Illuminated (ILIT)

DLIT – reverse bias
Module Imaging

- Power supplies to drive module-level currents and voltages.
- Stages to move cameras over modules for both:
  - Full module-view images
  - Zoomed-in images
Images of a degraded module

Indoor EL imaging

(Si camera, dark enclosure)

Outdoor EL imaging
(InGaAs camera, lock-in acquisition to subtract out daylight)

Dark lock-in thermography (laboratory)

Steady-state thermal image outdoors during sunny conditions
Imaging PV from modules to small features

Silicon PV module

Multi-crystalline Si

(CdTe grains)

~2 m

~10 cm

~10 mm

450 µm
Locate defects for microscopy study using laser burn marks

- Locate defect in camera field of view target area.
- Move camera away.
- Swing microscope optics into position.
- Stage program moves sample desired distance in four directions.
- At each end point, pause for laser pulse (open shutter).
- Swing optics away.
- Return camera to focused view.
Multi-scale characterization

EL – before coring

To locate the defect for microscopy, the area is marked by laser. Laser marks ~1 to 2 mm

EL – after coring

PL image –

Several shunts within the laser-marked area.

Electron Beam Induced Current (EBIC) imaging

Other microscopy: SEM, SIMS, TEM, AFM, APT, etc…

Select regions for coring samples from the module. (~10 to 25 mm sizes)

Part of a 156 mm size cell

DLIT, FWD bias

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Capacitance and Electro-Optical Measurements at NREL

- Closed-cycle He cryostats (~20 to 400 K)
  - Sample sizes ~25 to 50 mm
  - Probe contacts by hand or with micro-manipulators
- Dark or up to 1-Sun (broad spectrum lamp)
- Deep-Level Transient Spectroscopy (DLTS)
  - Various options (optical, CCDLTS, etc.)
  - Bio-Rad/Accent Optical/Nanometrics/Phys Tech
  - Sula
- Admittance Spectroscopy
- Capacitance/Voltage
  - Current/Voltage
  - Drive-Level Capacitance Profiling
- Transient Photocapacitance