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Photoluminescence-imaging-based Evaluation of Non-uniform CdTe Degradation

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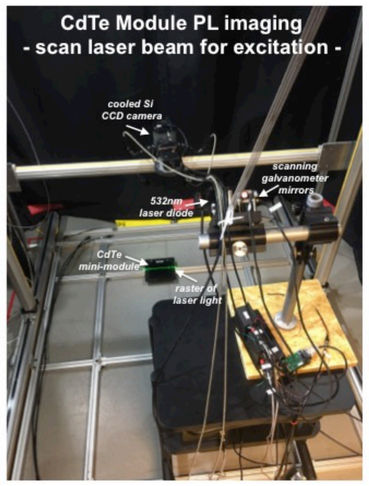
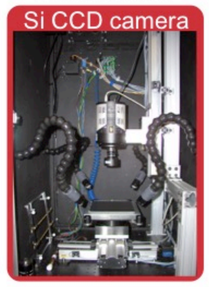
Study module degradation mechanisms by understanding the semiconductor device at the microscopic level, such as kinetics of impurities, changes in materials, and damage to device architecture.

Imaging for photovoltaics



Princeton Instruments PIXIS 1024BR

Si CCD camera

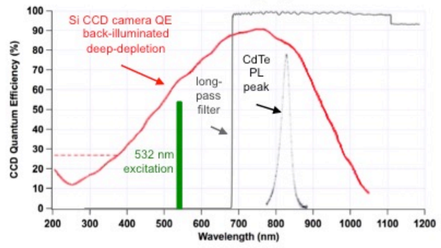


- Photoluminescence (PL) imaging
- Electroluminescence (EL) imaging

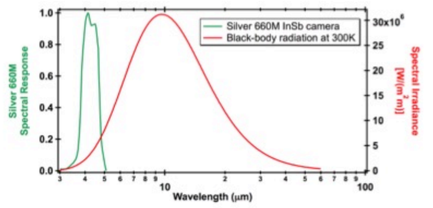
The cameras used for the various techniques are listed below:

- Silicon charge-coupled device (CCD) 16-bit camera with 1024 x 1024 pixels (13μm pixel pitch), cooled to ~-60°C
- InSb 14-bit lock-in camera with 640 x 512 pixels (15μm pixel pitch), cooled to ~80K

PL imaging



LIT imaging

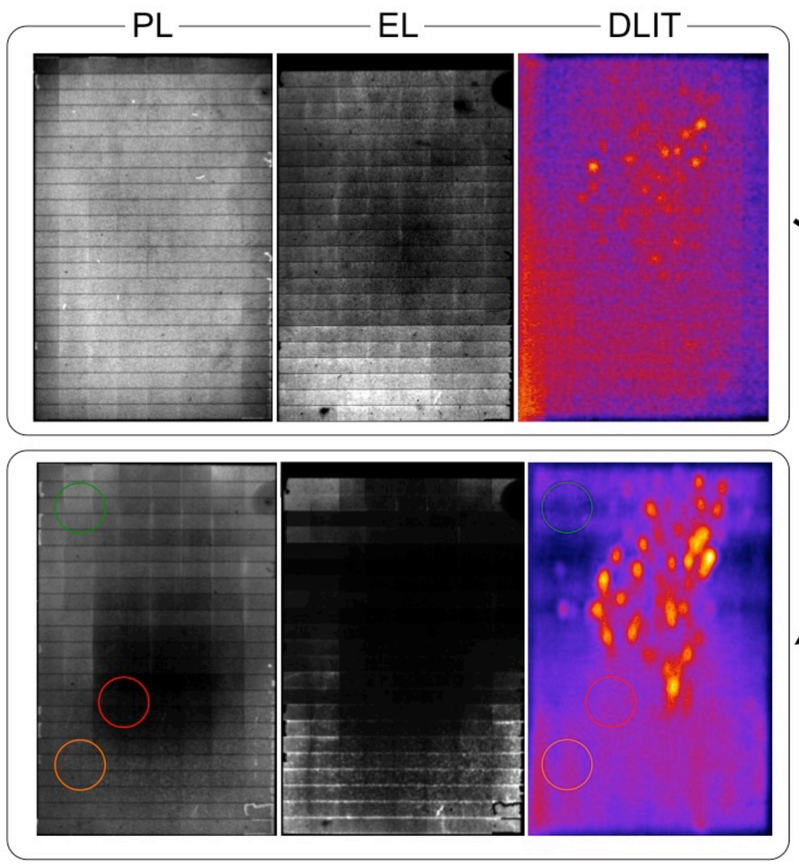


Cedip Silver 660M
FLIR SC5600-M

InSb camera

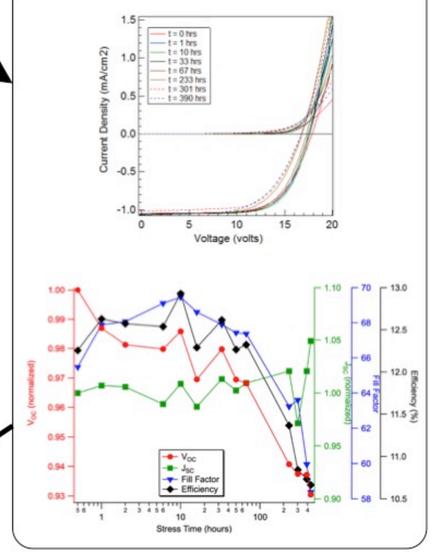
- Lock-In Thermography
  - Dark (DLIT)
    - Forward bias
    - Reverse bias
  - Illuminated (ILIT)

CdTe mini-module
(cells are ~5 mm wide)



- PL – raster pattern, 532 nm laser diode, ~1 mm spot size, ~1-Sun intensity excitation.
- EL ~1/3 J_{SC} current excitation.
- DLIT – forward bias, ~1/3 J_{SC} current excitation.

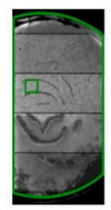
Stress (light/heat)



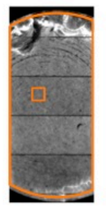
- Cut out samples from regions of interest.
- Avoid shunt areas with any grown-in defects.
- Based on PL image intensity: Least degraded, Mid-degraded, Most degraded

PL imaging on cored regions from degraded CdTe mini-module

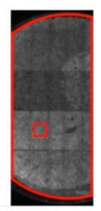
Least degraded
Average PL counts per minute = 8000



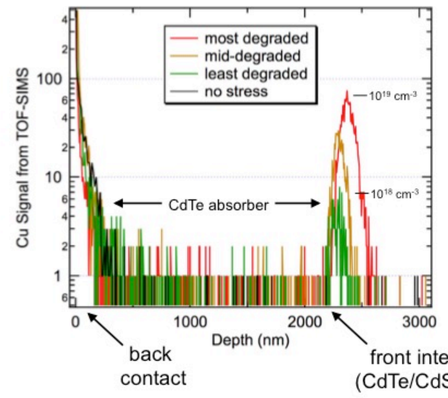
Mid-degraded
Average PL counts per minute = 6700

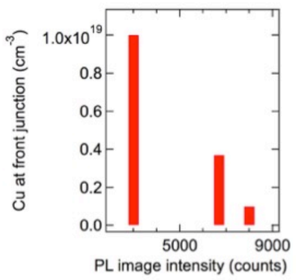


Most degraded
Average PL counts per minute = 3000



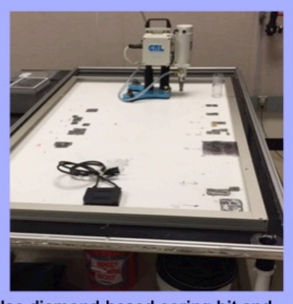
Cu profiles of stressed CdTe cores using Time-of-Flight Secondary Ion Mass Spectrometry (TOF-SIMS)





Reduced PL intensity correlates to more Cu at the front junction.

Core selected areas from degraded modules



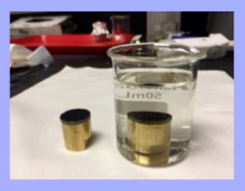
Use diamond-based coring bit and liquid-cooled drill to cut through Si cell or thin-film and glass.

Cut sample for extraction

Glue metal posts to cut silicon or glass samples using cyanoacrylate ("Super Glue").

On thin-film modules, glue posts to cored glass, or core completely through the module and dissolve encapsulation.

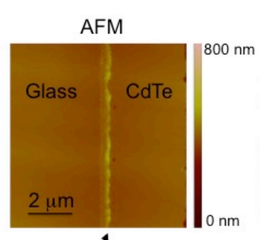
After the glue is set, use a wrench to shear the sample from the module.

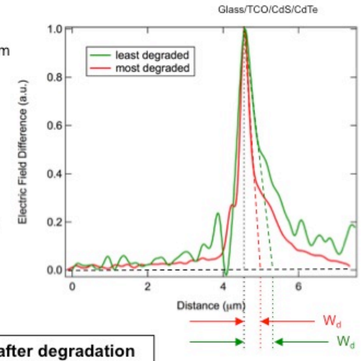


Soak in acetone to dissolve Super Glue and remove post. Or, use a short post that fits in measurement tools and does not need to be removed.

Cored samples from ~12 to 25 mm diameter

Kelvin Probe Force Microscopy (KPFM) potential imaging on cross-sections of stressed CdTe cored samples





Increased shallow acceptors after degradation leads to narrower space charge region.

Ion transport (Cu-ions) to front junction [1] leads to both:

- **shallow centers for increased doping, and**
- **deep defect generation**
  - **increased carrier recombination**
  - **reduced cell performance.**

In [1], TRPL was inconclusive, but here, PL intensity shows correlation to degradation.

[1] M. Nardone and D. S. Albin, "Degradation of CdTe Solar Cells: Simulation and Experiment," *IEEE Journal of Photovoltaics*, vol. 5, pp. 962-967, 2015.

