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Photoluminescence and Electroluminescence Outdoor Module Imaging

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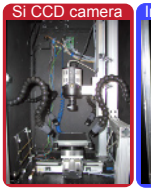
The goal is to use camera imaging to characterize modules while they are still mounted outdoors.

The benefits of outdoor imaging:
- Increased monitoring, especially if automated, leading to more certainty of expected operations and energy production.
- No increased chance for damage due to unmounting and remounting modules when performing imaging analysis.

These cameras were used to collect the images:
- Silicon charge-coupled device (CCD) 16-bit camera with 1024 x 1024 pixels (13□m pixel pitch), cooled to ~-60° C
- InGaAs 14-bit lock-in camera with 320 x 256 pixels (30□m pixel pitch), uncooled
- InSb 14-bit lock-in camera with 640 x 512 pixels (15□m pixel pitch), cooled to ~80K

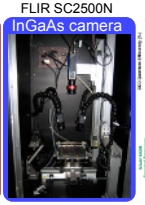
Imaging for photovoltaics

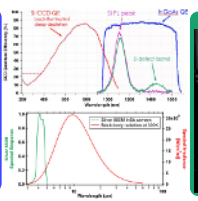
Princeton Instruments PIXIS 1024BR — Si CCD camera



- Photoluminescence (PL) imaging
- Electroluminescence (EL) imaging
- Reverse-Bias EL imaging (ReBEL)

FLIR SC2500N — InGaAs camera



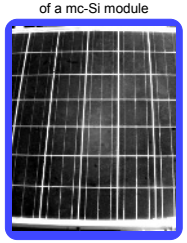


- PL imaging
  - Band-to-band
  - Defect band

Cedip Silver 660M FLIR SC5600-M — InSb camera

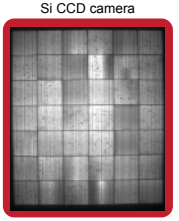
- Lock-In Thermography
  - Dark (DLIT)
  - Illuminated (ILIT)

Outdoor daylight image of a mc-Si module



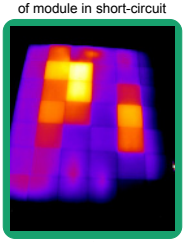
This module had been subjected to mechanical vibration resulting in broken tabs at various locations.

Indoor EL imaging using Si CCD camera



Comparison of EL image to thermal image

Steady-state thermal image of module in short-circuit

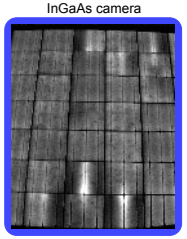


Comparison of indoor dark-enclosure EL image to outdoor daylight EL image

(The same current-crowding, bright EL features can be detected outdoors.)

Comparison of outdoor thermal image to outdoor daylight PL image

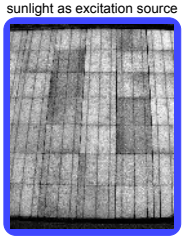
Outdoor EL imaging using InGaAs camera



Daylight EL: Apply bias for zero current to counteract sunlight current and pulse to larger bias to drive forward current. Average differences of images between zero current and forced forward current to ~same magnitude as J_{SC}.

Comparison of outdoor EL image to outdoor PL image

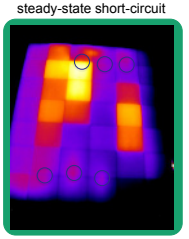
Outdoor PL imaging using sunlight as excitation source



Daylight PL: Apply bias for zero current to counteract sunlight current and pulse to zero voltage (short-circuit current). Average differences of images between open-circuit and short-circuit current.

In PL imaging the weaker cells are darker and less efficient. In short-circuit, these mismatched cells are heated, as shown above in the steady-state thermal image.

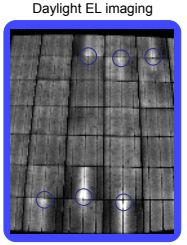
Daylight thermal imaging steady-state short-circuit

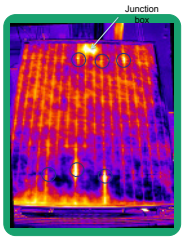


Heating at the current crowding regions is difficult to distinguish from the heated cells.

Perform thermal imaging lock-in data acquisition under same conditions as EL imaging - vary between zero net current and forward-bias current conditions

Daylight EL imaging

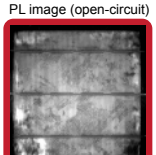




Heating in the lock-in thermal image matches the current crowding and bright regions of the EL image.

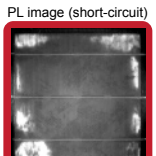
Imaging of a stressed and degraded Si mini module

PL image (open-circuit)

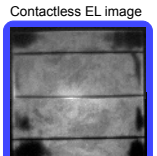


EL image

PL image (short-circuit)



Contactless EL image

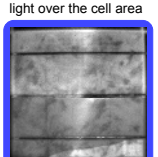


PL images are collected in both open-circuit and short-circuit conditions. High resistivity areas (grid corrosion) are bright in PL and further highlighted bright in short-circuit. The EL image is collected by applying bias. This image was collected in a dark enclosure and is shown for comparison to the light-induced EL image below. Areas of high series resistance exhibit bright PL and dark EL. High carrier recombination regions are dark in both PL and EL.

Imaging a cell within a Si module using no electrical contact

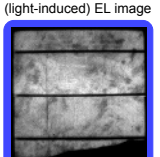
Such contactless PL and EL imaging has been performed on modules at night in either open circuit or when part of an array and connected to an inverter.

PL imaging using uniform light over the cell area



640 nm red LEDs (2 at 1.5 W each) used for these images

Contactless (light-induced) EL image

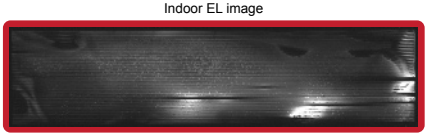


The PL image is collected by switching on and off a light excitation, such as LEDs or laser diodes, that uniformly excites carriers over the entire imaged area.

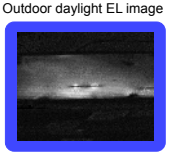
The contactless, light-induced EL image is collected by shining a small area light excitation on one half of the cell while imaging the other half. The light induces a voltage, which is then distributed by the cell conductivity (metal bus bars and grid) to the entire cell. Moving the light spot to the other half then allows the opposite half of the cell to be EL imaged.

Imaging of a CIGS module

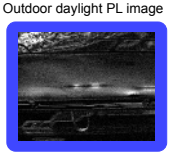
Indoor EL image



Outdoor daylight EL image



Outdoor daylight PL image



The indoor EL and outdoor EL and PL images all show similar defect features.

This poster presents options for outdoor module imaging that can be used to:
- Inspect modules for shipping or installation damage;
- Inspect modules for field damage, defects, or degradation;
- Monitor field performance and module aging;
- Assure investment by module inspection.

Reference: *Daylight Luminescence for Photovoltaic System Testing* http://www.ipv.uni-stuttgart.de/publikationen/wissenschaftliche-publikationen.en.html?id=2094 L. Stoicescu, M. Reuter, and J. H. Werner in Proc. 22nd International Photovoltaic Science and Engineering Conference, Hangzhou, China (2012).

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