Rethinking Photoluminescence for Understanding Solar Cell Degradation

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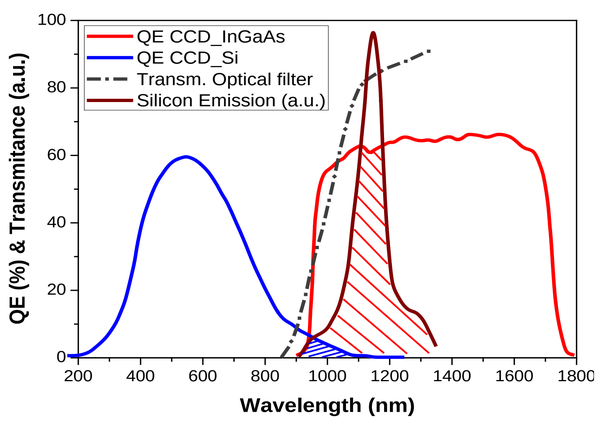
INTRODUCTION

- Electroluminescence (EL) and Photoluminescence (PL) are powerful tools for characterization of solar cells in the laboratory. While PL is influenced by native defects on the wafers, EL gives also information about solar cell contacts.
- EL is routinely used for the inspection of solar cells and modules in dark conditions, by using Silicon CCDs. This allows the inspection of a large amount of Silicon modules on-site, thus contributing to ascertain the degradation state of the solar cells without the need to dismount the modules.
- PL imaging has NOT been used for such inspection tasks of Si solar modules due to the need to excite the entire area of study.
- We have developed a daylight EL/PL characterization system, by means of an On/Off switch procedure [1]. In the PL configuration mode, excitation is carried out by the Sun light. This also enables on-site PL imaging characterization. However, due to the On/Off procedure, both daylight EL and PL are greatly influenced by the solar cell contacts, being very sensitive to fractures.
- In this work we compare EL and PL imaging results, both in-lab and on-site, for both solar cells and modules.

CHARACTERIZATION: PL and EL measuring equipment (InGaAs CCD Camera)

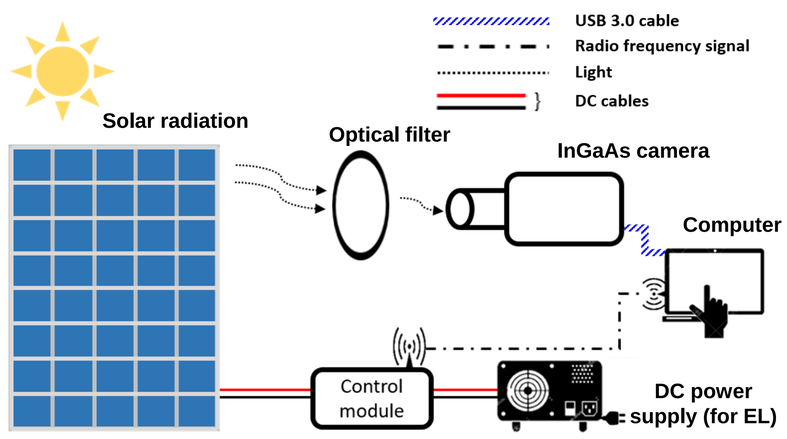
Hamamatsu C12741-03 (InGaAs CCD camera)



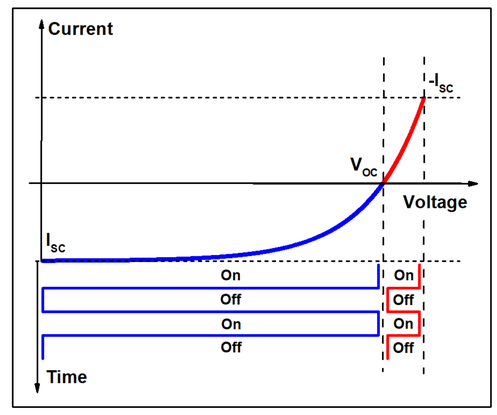
	InGaAs CCD
Maximum resolution	640 x 512 pixel
Maximum quantum efficiency	65% @ 1500 nm
Dynamic range	14 bit
Exposure times	100 μs to 1 s

InGaAs CCD has better quantum efficiency at intrinsic Si emission

Daylight PL/EL imaging system



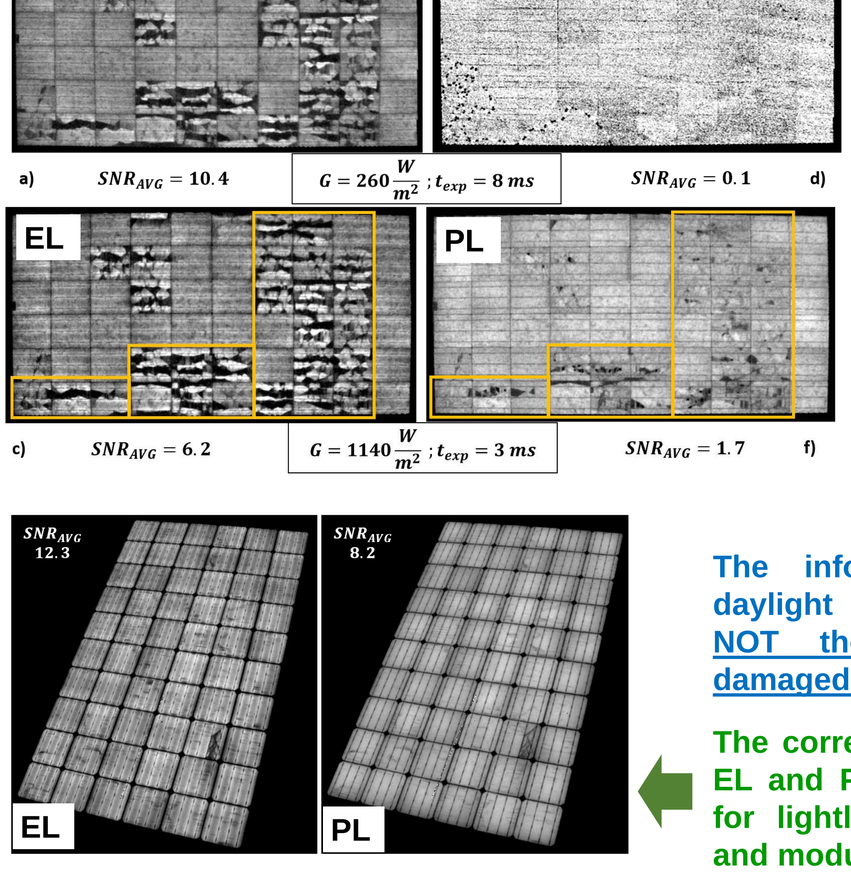
Daylight EL system diagram



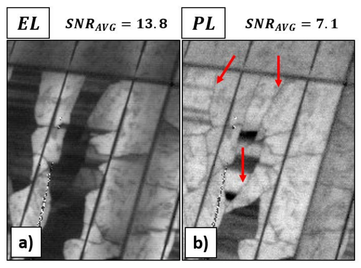
On/Off states (EL in red, PL in blue)

RESULTS AND DISCUSSION

Comparison between daylight EL and PL images



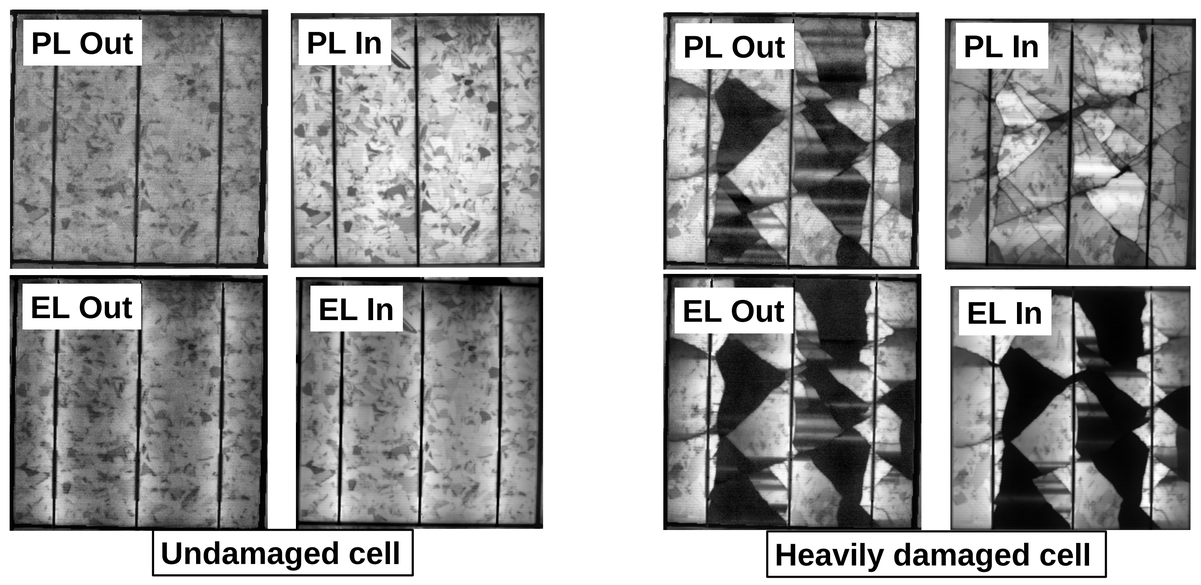
- Daylight PL needs large irradiation conditions
- EL displays higher performance than PL for low irradiation



The information provided by daylight EL and PL images is NOT the same for heavily damaged solar cells and modules

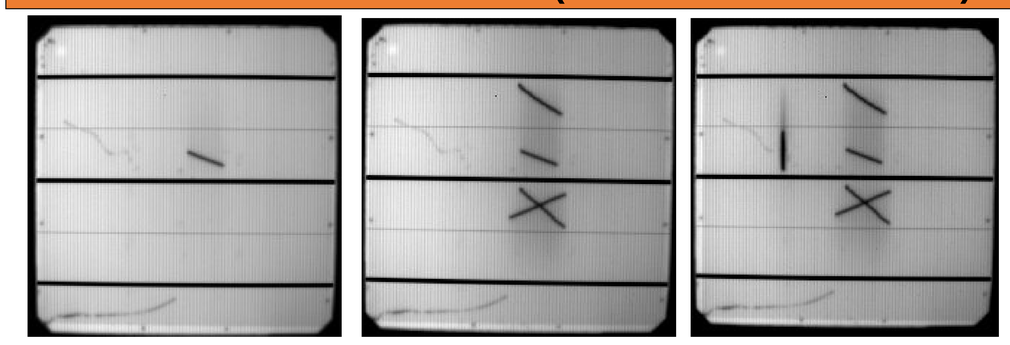
The correlation between daylight EL and PL images is very good for lightly damaged solar cells and modules

Detailed comparison between daylight EL and PL images (Indoor&Outdoor)



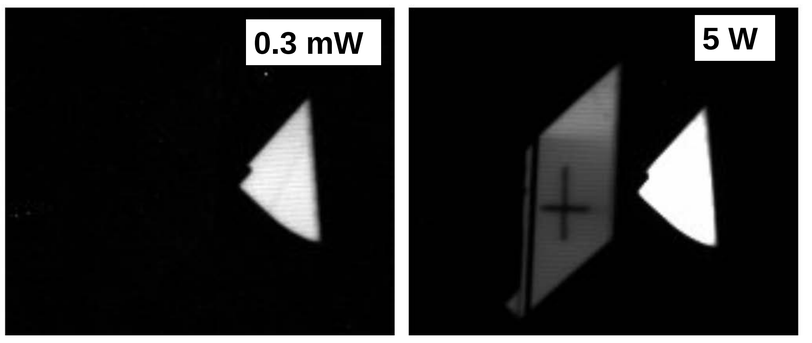
- Pristine PL images (PL Indoor, not On/Off method) provides the information about material quality (GBs, DL clusters, etc.)
- Daylight PL and EL images are affected by electrical contacts and their interruptions, but not in the same manner. This is due to the different acquisition conditions of the two images
- Both daylight PL and EL outdoor response depend on the ability of the exposed region to extract photocarriers, even if they operate on different regimes of the p-n junction (On/Off states, upper figure)

PL (808 nm laser excitation) on solar cells with artificially mechanical defects (scratches)



0.3 mW

30 ms



Undamaged (bright) and a damaged (dark, unnoticeable at low power) area of the same cell (120 ms)

- Dark halos parallel to the cell fingers around the scratches made with a diamond tip. Not observed in EL images (different excitation conditions)
- Progressive darkening of the PL image with increasing scratch density
- Varying the excitation conditions of the PL images permits to reveal different levels of degradation

CONCLUSIONS

- ❑ Both daylight PL and EL are effective onsite characterization techniques to study the degradation of solar cells and modules
- ❑ Daylight PL and EL give complementary information on device degradation, since they cover different regimes of operation of p-n junctions in solar cells
- ❑ Among others, PL and EL can provide data on the mechanical degradation, cracks, strains, effect of grain boundaries, quality of electrical contacts, and luminescence emission average power density
- ❑ PL imaging in lab displays additional information of non-local strain effects (e.g. halos around scratches) and photocarrier recombination channels (e.g GBs), which can help to unveil the pure material effects on the luminescence emission, as compared to the daylight ELi and PLi, where the fractures seem to play a major role

[1] M. Guada *et al.*, «Daylight luminescence system for silicon solar panels based on a bias switching method», *Energy Sci. Eng.*, vol. 8, n.º 11, pp. 3839-3853, nov. 2020.

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