DRIP XIX 19th International Conference on Defects-Recognition, Imaging and Physics in Semiconductors
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Online

Comparison of outdoor and indoor PL and EL images in Si solar cells and panels for defect detection and classification

C. Terrados, D. González-Frances, D. González-Fernández, V. Alonso, M.A. González, J. Jiménez, O. Martínez

GdS-Optronlab group, Dpto. Física de la Materia Condensada, University of Valladolid, Valladolid, Spain

oscar.martinez@uva.es

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Outline

- *Introduction*
  - *Solar PV. O&M*
  - *Defect characterization techniques*
- *Daylight EL/PL system*
- *Comparison among dEL/dPL and nEL/PL_{LD}*
- *Conclusions*

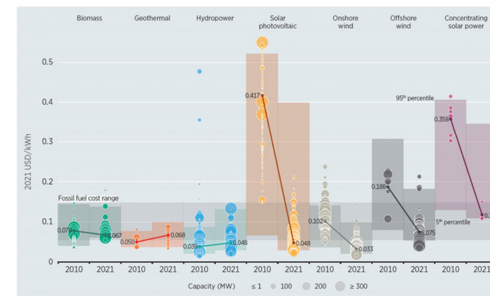
Introduction

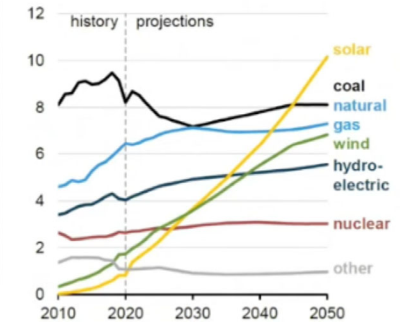
Solar PV Technology. O&M

- ❑ Photovoltaic solar technology is now the most promising technology for renewable energy production

- ❑ Large PV solar plants → millions of PV modules

- ❑ Operation and maintenance (O&M) activities of such large solar plants is mandatory in order to keep a large productivity, and to perform corrections on the different elements when necessary





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Introduction

Defect characterization techniques

- Visual Inspection (VI)
- I-V curves
- Infrared thermography (IRT)

- Luminescence techniques
  - EL (nighttime and daylight) → power source & electrical contacts
  - PL (daylight) → electrical contacts
  - (PL with an artificial light source → contactless)

Introduction

Electroluminescence (EL)

In EL, carriers are excited through an external power source. EL intensity distribution provides detailed information of the semiconductor and **electrical circuit properties**.

- Typical defects detected:
  - At cell level: cracks, wafer contaminations, soldering or ribbon interconnection failures, and chemical corrosion (snail trails).
  - At module level: PID, cell mismatch and short-circuited bypass diodes.
- Two different modalities are usually employed:
  - Low injection current (10% J_{SC}). Parallel resistance decreasing defects are well detected at low injection currents.
  - High injection current (90% or 100% J_{SC}). Series resistance increasing defects, such as inactive areas, are easier detected at high injection currents

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Introduction

Photoluminescence (PL)

In PL, carriers are excited through illumination. (A suitable light source is needed). PL imaging is electrically contactless and thus, does not require any change in the wiring or an external power supply as needed for EL imaging. **PL gives information on the material quality**.

The requirement for a uniform high-power large area illumination source makes it difficult to use PL for module inspection in the field.

Daylight Photoluminescence (dEL)

dPL uses the sun as excitation source.

In order to extract the luminescence coming from the solar cell and separate it from the reflected light from the sun, the PL should be acquired at two operation points:

- OC: high PL emission (no current extraction)
- SC: low PL (current extraction) → **need for electrical contacts**

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Dayligth EL/PL system

We have developed a daylight outdoor EL/PL system, which is quite useful for offering safe inspection of solar plants on-site.

The main elements of the system are:

- an InGaAs camera
- a band-pass optical filter
- a power supply (in the case of EL measurements)
- a solid-state relay system for switching from On to Off states.

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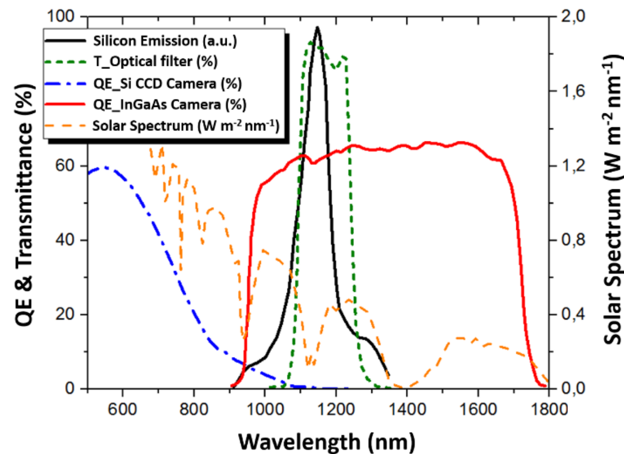
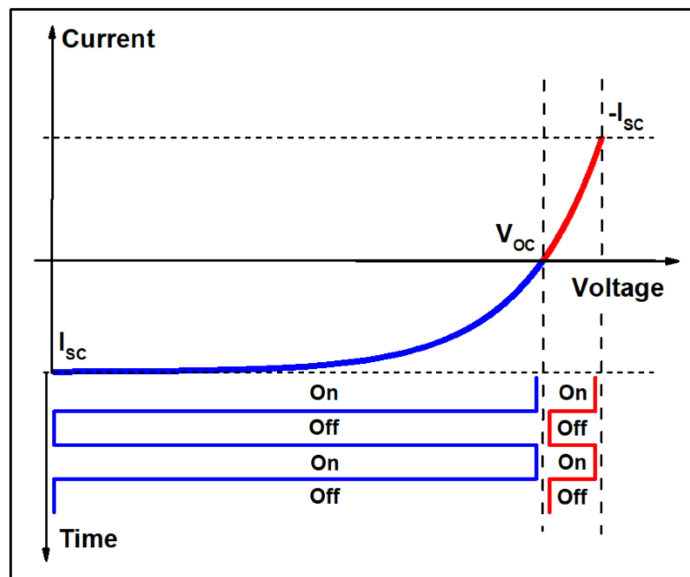
Dayligth EL/PL system

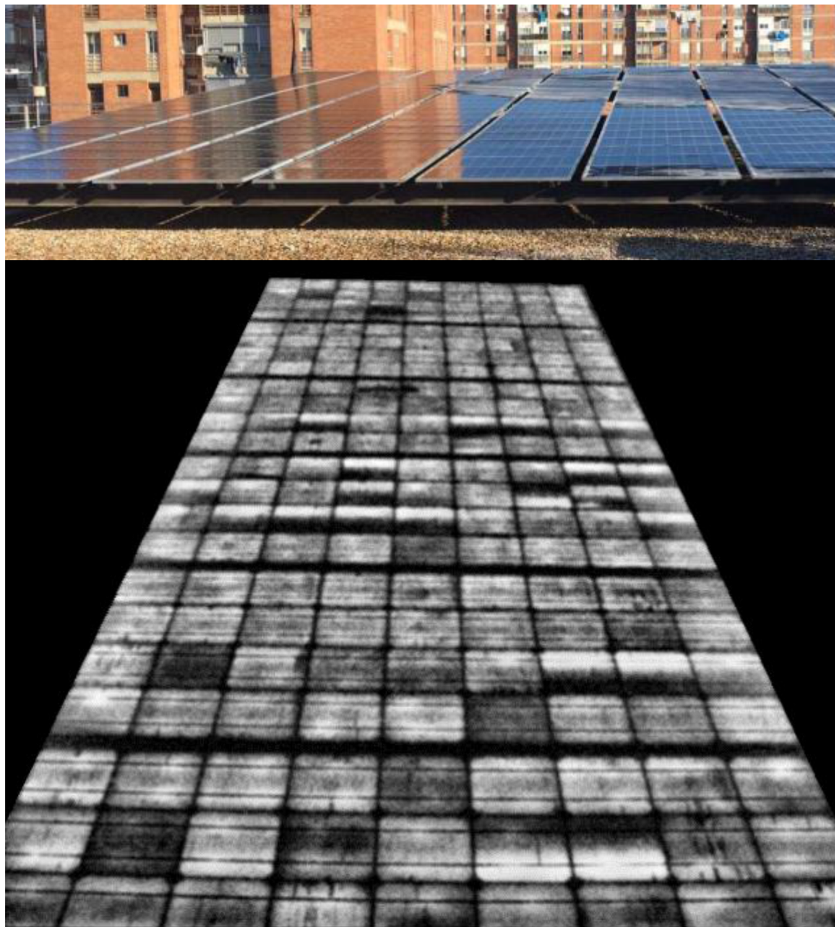


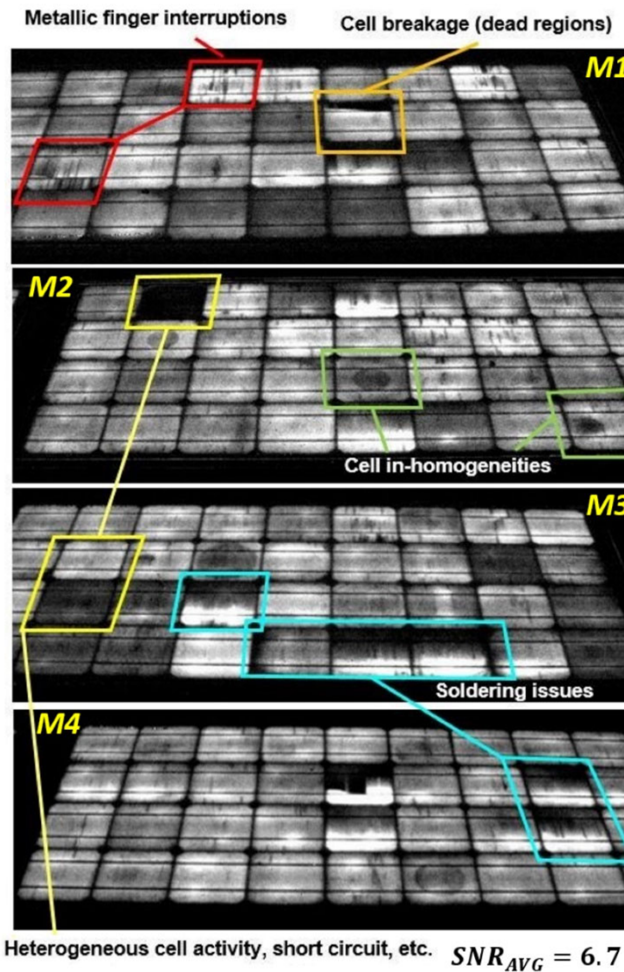


- An InGaAs camera is used, insted of a Si detector. Adittional optical filters are used
- **Bias switching method**: a pulsed luminescence signal is obtained by alternating the polarization state of the solar panels, synchronizing it with the luminescence image detection by an InGaAs camera.
- Fast switching and selecting an optimized exposure time are key to achieving high quality images.
- Both dEL and dPL are obtained, even under high solar irradiance conditions

Dayligth EL/PL system developed

dEL inspections on plant





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Dayligth EL/PL system

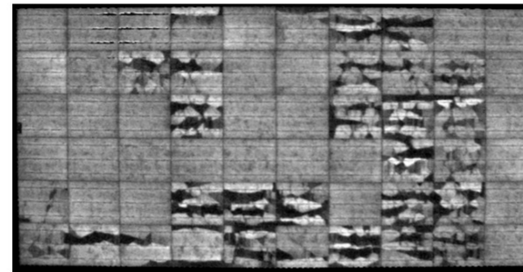
Daylight EL (dEL):

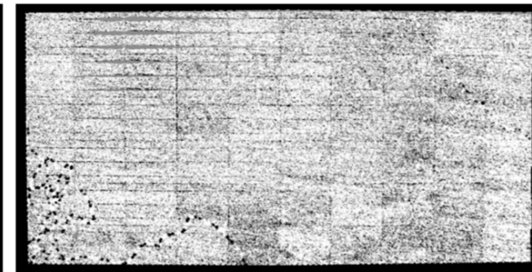
- Need of a power supply
- It is more convenient at low irradiation levels.

Daylight PL (dPL):

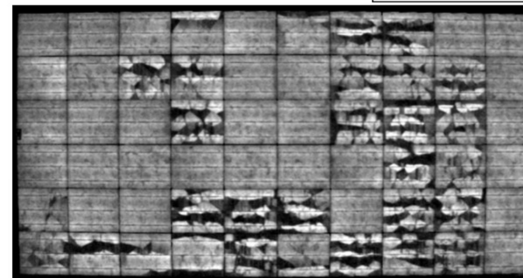
- On/Off: the Off state needs for electrical connections
- Only achievable for high irradiation levels.

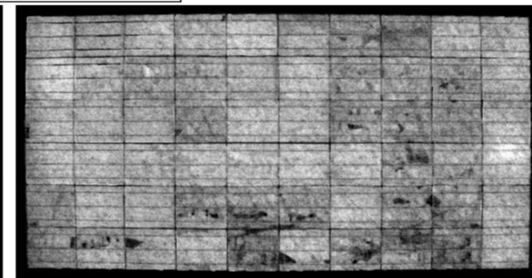
dEL | dPL



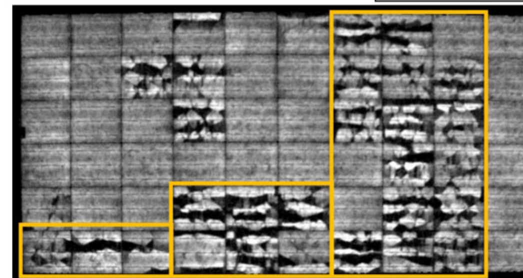


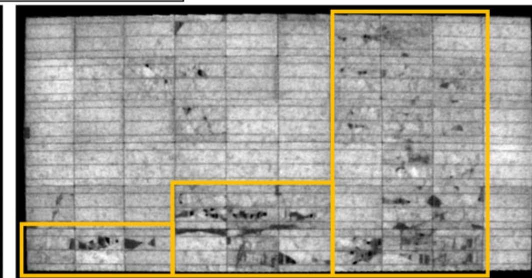
a) $SNR_{AVG} = 10.4$ | $G = 260 \frac{W}{m^2}; t_{exp} = 8\ ms$ | $SNR_{AVG} = 0.1$ d)





b) $SNR_{AVG} = 9.9$ | $G = 500 \frac{W}{m^2}; t_{exp} = 6\ ms$ | $SNR_{AVG} = 0.9$ e)





c) $SNR_{AVG} = 6.2$ | $G = 1140 \frac{W}{m^2}; t_{exp} = 3\ ms$ | $SNR_{AVG} = 1.7$ f)

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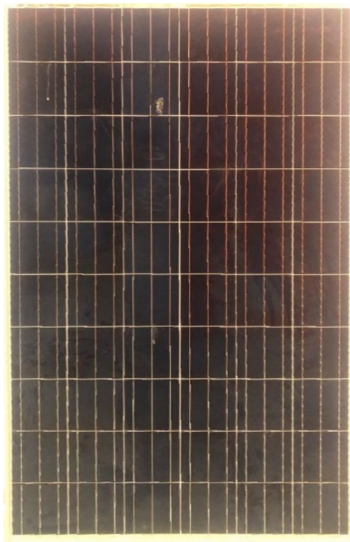
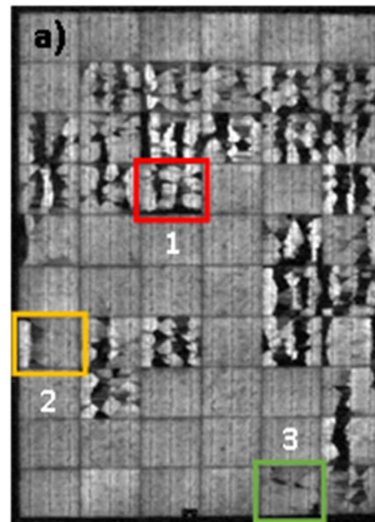
Comparison among dEL/dPL and nEL/PL_{LD}

(Multi-crystalline Si panel)

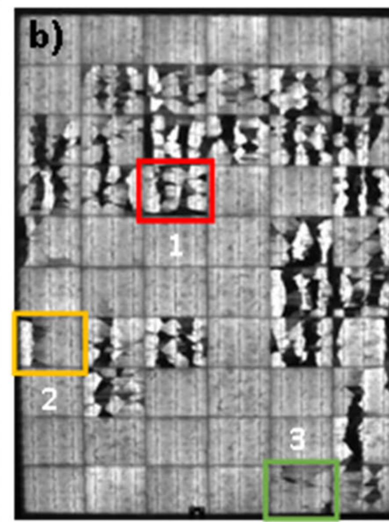
VI



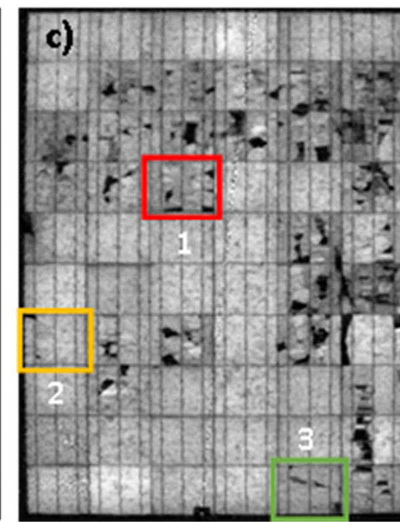
Luminescence images



dEL



nEL



dPL

- ❑ The quality of the daylight EL images is quite good, given essentially the same information than the EL image obtained indoor.
- ❑ The information provided by the daylight PL images is different

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Comparison among dEL/dPL and nEL/PL_{LD}

	❶	❷	❸
nEL			
dEL			
dPL			

Same information,

a bit more noisy

Differences

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Comparison among dEL/dPL and nEL/PL_{LD}

❶ ❷ ❸

PL_{LD}

a) b) c)

1 2 3

Influence of the material properties

HR-nEL

100% I_{sc}

d) e) f)

1 2 3

10% I_{sc}

Influence of the electrical contacts

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Comparison among dEL/dPL and nEL/PL_{LD}

Cracks

- Cell cracks are critical to the module failure. Not all the cracks have the same impact

- Depending on the electrical connection to other parts of the wafer, cracks can be classified into 3 modes:

  - **A** cracks are electrically connected and appear as thin, dark lines in the EL images.

  - **B** cracks are partially connected to their surrounding with a finite resistance. The EL image of the enclosed area depends on this resistance.

  - **C** cracks are fully isolated, and enclosed areas appear black in EL images

Comparison among dEL/dPL and nEL/PL$_{LD}$

Cracks

- ❑ Cell cracks are critical to the module failure. Not all the cracks have the same impact

In PL images:

- All electrically connected cell parts have roughly the same PL intensity, which is the case for areas separated by mode A and mode B cracks
- Areas separated by mode C cracks are completely disconnected and their PL intensity differs due to different recombination rates in the different cell parts.

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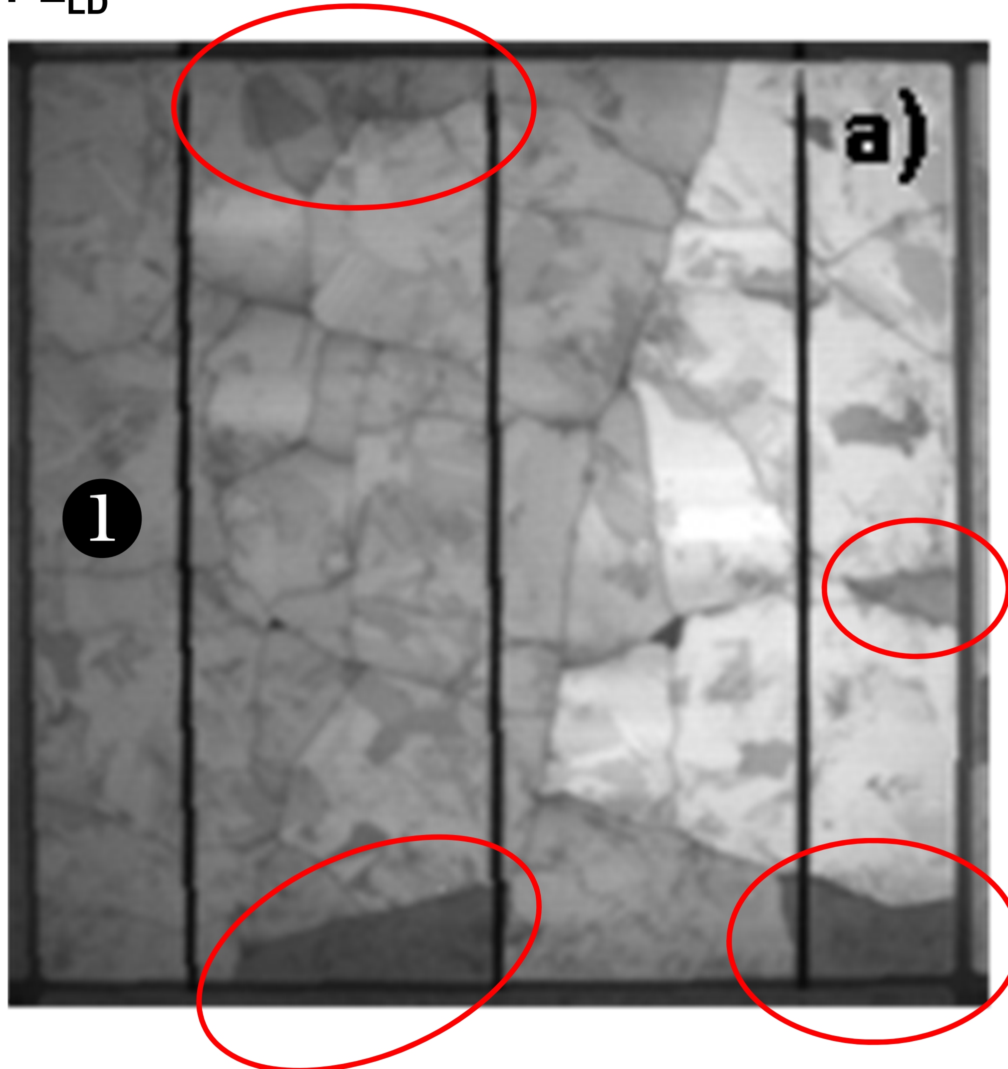
Comparison among dEL/dPL and nEL/PL_{LD}

PL_{LD}



Dark contrasted areas should be related to C mode cracks.

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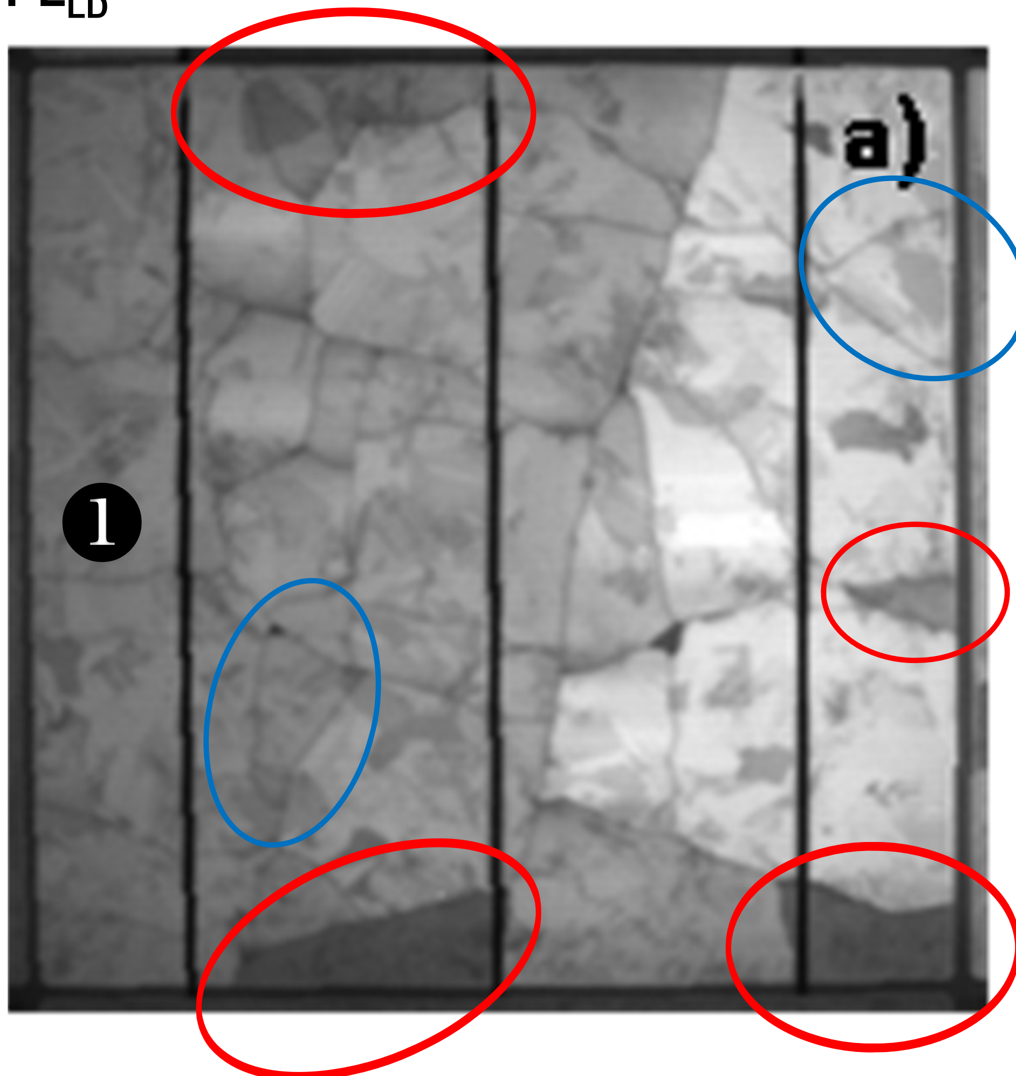
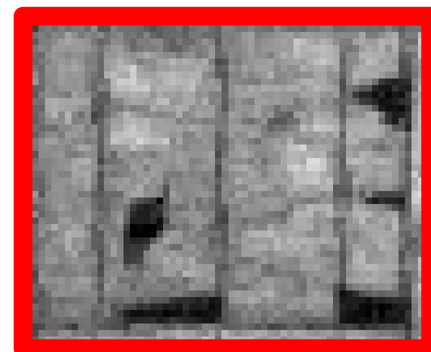
Comparison among dEL/dPL and nEL/PL_{LD}

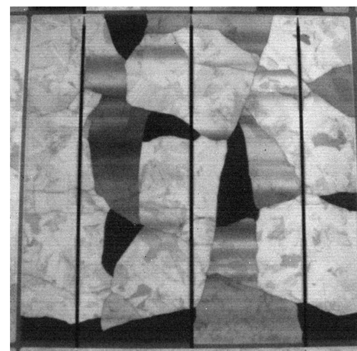
PL_{LD}



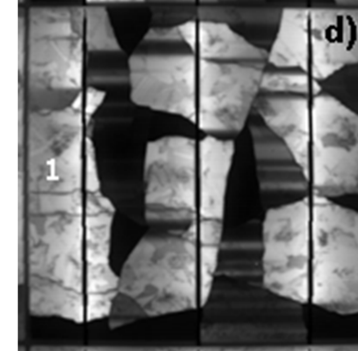


dPL

10% I_{sc}



100% I_{sc}



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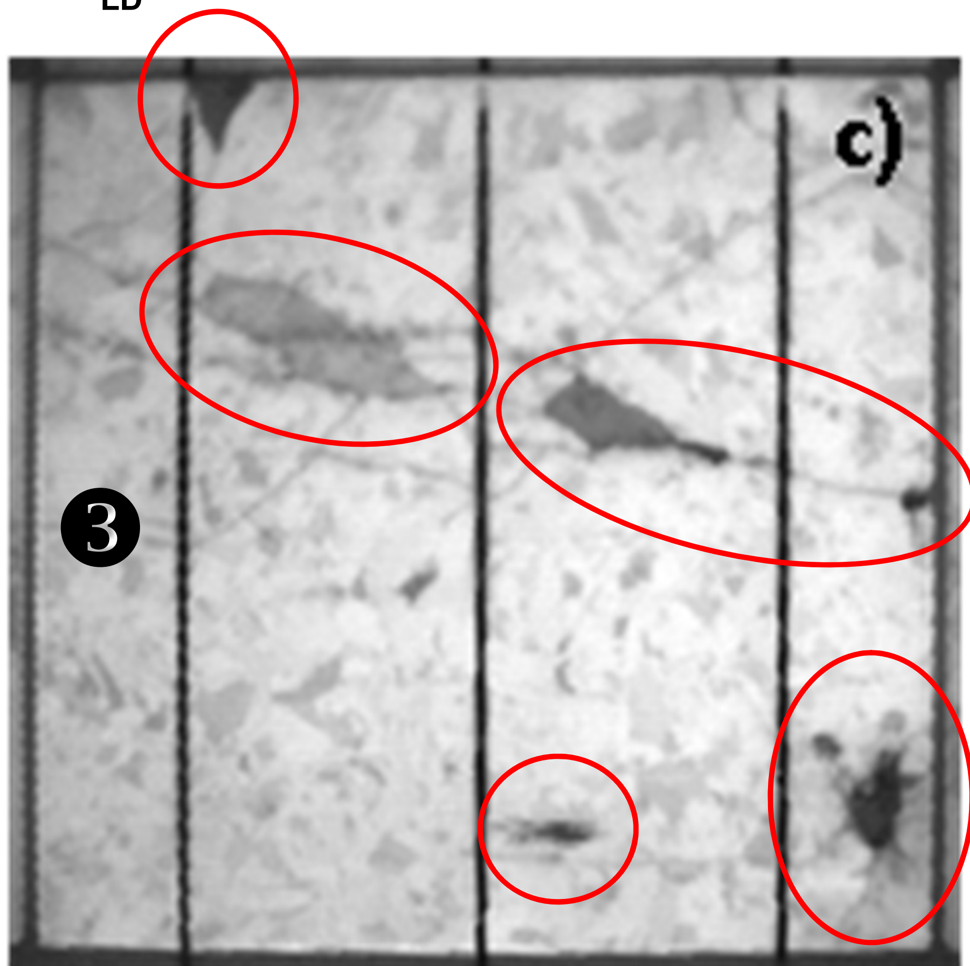
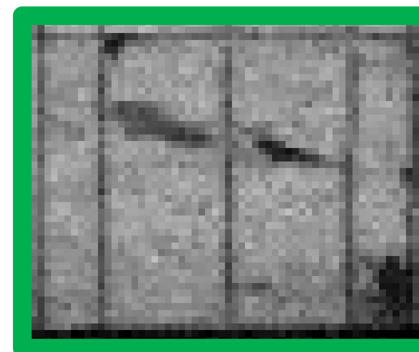
Comparison among dEL/dPL and nEL/PL_{LD}

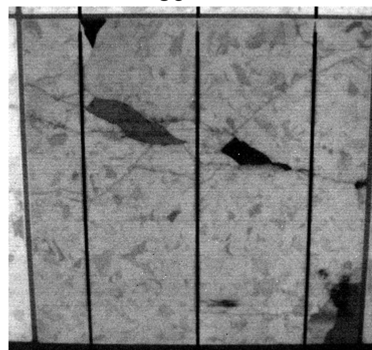
PL_{LD}



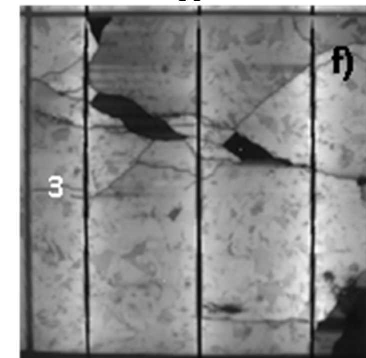


dPL

10% I_{sc}



100% I_{sc}



HR-nEL

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Conclusions

- Luminescence techniques are very powerful techniques for the detection and classification of defects in solar cells and panels.
- Daylight EL technique is quite useful for offering safe inspection of solar plants on-site, with clear advantages respect to night EL (providing the same information, although with lower resolution).
- Daylight PL does not need for a power source, although it still needs for electrical contacts.
  - The information provided is mainly related to C cracks or B/C cracks.
- PL with an external source gives also useful information of the defects present in a solar cell, also cracks can be visualized. However, it is complicated to be performed on-site.

Thank you very much for your attention