DTU Fotonik

Laser Induced Luminescence Imaging

34553 Applied Photovoltaics

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Abstract: In this exercise, you will perform a laser-line induced luminescence (LIL) image on PV devices as an additional diagnosis technique to traditional EL images.

References and links

- Slides from class (Block 4)
- Lecture slides from 34552, lecture 11.

Safety

- Always use the goggles we provide when the laser is on.
- Careful with the power supply connection and management: most of the experiment uses high current (~8A DC).
- If in doubt, ask an instructor.

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1. Introduction

As you may have heard before in the course, electroluminescence (EL) and photoluminescence (PL) have the same emission spectrum generated by different carrier sources: one electrical and the other optical (light source) respectively. Therefore, refer yourself to the same emission spectra shown in the EL imaging exercise.

When performing PL with a partially illuminated c-Si cell (i.e. using a line illumination or a circular laser beam), the PL is recorded where the laser beam is located, while contactless EL can be measured in the remaining unilluminated regions of the cell, due to its very efficient lateral current spreading. When we perform contactless luminescence imaging, it is inaccurate to call it EL or PL, therefore we refer to it as laser induced luminescence (LIL).

2. Background

In PL imaging of PV samples, the surface of the sample is excited by a light source to emit luminescence and a camera is used to acquire the spatially resolved map of the luminescent emission. The greatest potential of PL imaging is that the rate of spontaneous emission via band-band transitions is directly linked to physical quantities such as the product of electron and hole densities, the minority carrier lifetime, the splitting of the quasi-Fermi energies, and the diode voltage. These parameters can be quantified from PL imaging results using the generalization of Planck's radiation law [1] and variants of Peter Würfel's (Becquerel prize winner sept. 2018) understanding of the physics of solar cells [2].

In conventional open-circuit PL imaging, the PV device is uniformly illuminated, resulting in all local diodes having the same or very similar voltages. There is, thus, no driving force for lateral currents and consequently lateral variations in effective series resistance are not visible. A continuously line laser scan over the PV sample produces local excess carriers, which form a voltage difference between the illuminated and non-illuminated regions of the cell, resulting in a lateral current flow. In practice, PL is generated where the laser beam hits the cell and has energy extracted to generate contactless EL in the rest of the cell, while both signals are recorded by the camera simultaneously. In the literature, this technique is referred as line scan PL, however, it is more accurate to call it laser induced luminescence or LIL. With LIL imaging, it is possible not only to provide data concerning cracks and crystallographic defects, but also broken contact fingers and enhanced resistance areas [3], [4]. It is also valid to mention that this is a contactless luminescence imaging technique. Even though LIL has a lower luminescence signal than traditional EL, it has a higher potential of defects/faults detection and it presents high research possibilities in advanced characterization of PV modules. In our case, we will compare the mixed (EL/PL) LIL image with the traditional EL image and assess the defect detection difference between the two techniques. The acquisition of EL and PL signal simultaneously may not occur for thin-film PV, as lateral currents are often not observed with our LIL setup. In such case, we will observe only PL when performing the LIL technique. The difference in the carrier source in PL/LIL and traditional EL might indicate the nature of some faults and defects, and that is our focus in the exercise.

3. Equipment and methods

In Figure 1, you can see the LIL imaging setup for this exercise. The excitation source is an 808 nm laser diode. The line laser device provides a line shaped beam with a fan angle of 60 degrees and its power can be controlled increasing or decreasing the duty cycle of the waveform that generates its signal. 100% duty cycle corresponds to the laser maximum optical power of 5 W. The power supply unit (PSU) provides 12 V and 10 A to the laser. The line laser is mechanically scanned over the region of interest with the use of a hand crank, allowing approximate linear scanning speeds. The scan over the sample is performed in few seconds and the images is acquired with ~28 ms exposure time and 25 fps. The camera used is the Raptor camera you used before in the EL imaging exercise, with a long-pass filter to

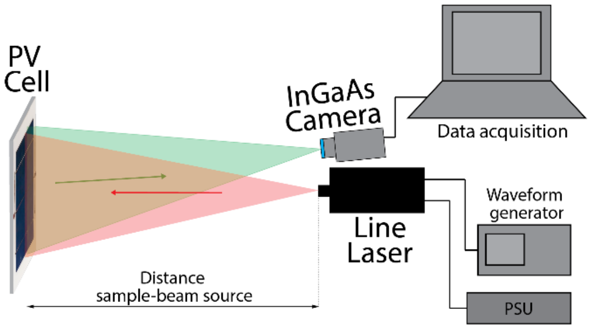

Figure 1 – LIL PV cell level setup

cut out the laser emission.

Task 1 – LIL of a section of your working module

Choose a section of your module, where you can see interesting defects and/or faults.

Position your PV module at ~80 cm from the laser light source and adjust the height of the laser source.

Put on the goggles and turn the laser on. Verify if the line beam is positioned vertically in the region you want to measure. Turn the laser off and verify that during the scan the beam will pass over the area of your module you want to measure. Do the corresponding adjustments if needed.

Position the camera above the laser platform. Check if the optic bench will not interfere in the camera field of view.

Prepare in the acquisition of 200 images while one of your colleagues scan the laser though the sample.

1. Acquire an image sequence of 200 images during the laser scan.
2. Check and write down the frames where the laser was in motion, to avoid saturation during the image processing.
3. Record laser power (duty cycle) and the approximate beam length and thickness.

Task 2 – Thin-film mini-module PL

Follow the same procedure of Task 1 now for a thin-film mini module.

Additionally, connect it to the PSU and acquire an 100% I_{SC} EL image.

4. Results presentation

The slides containing this exercise results should include:

- Short theory about LIL imaging. } 1 slide
- Presentation of the LIL processed images acquired and approximate laser intensity. } 1 slide

During the presentation, discuss about:

- Interpretation of the LIL images, compared with traditional EL images.

References mentioned in the text:

[1] P. Würfel, S. Finkbeiner, and E. Daub, "Generalized Planck's radiation law for luminescence via indirect transitions," *Appl. Phys. A Mater. Sci. Process.*, vol. 60, no. 1, pp. 67–70, 1995.

[2] P. Würfel, *Physics of Solar Cells - From Principles to New Concepts*. WILEY-VCH Verlag GmbH & Co.,

2005.
[3] M. Kasemann, L. M. Reindl, B. Michl, W. Warta, A. Schütt, and J. Carstensen, “Contactless qualitative series resistance imaging on solar cells,” *IEEE J. Photovoltaics*, vol. 2, no. 2, pp. 181–183, 2012.
[4] I. Zafirovska, M. K. Juhl, J. W. Weber, J. Wong, and T. Trupke, “Detection of Finger Interruptions in Silicon Solar Cells Using Line Scan Photoluminescence Imaging,” *IEEE J. Photovoltaics*, pp. 1–7, 2017.