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Powerful Characterisation of Photovoltaic Modules using Line Scan Luminescence Imaging

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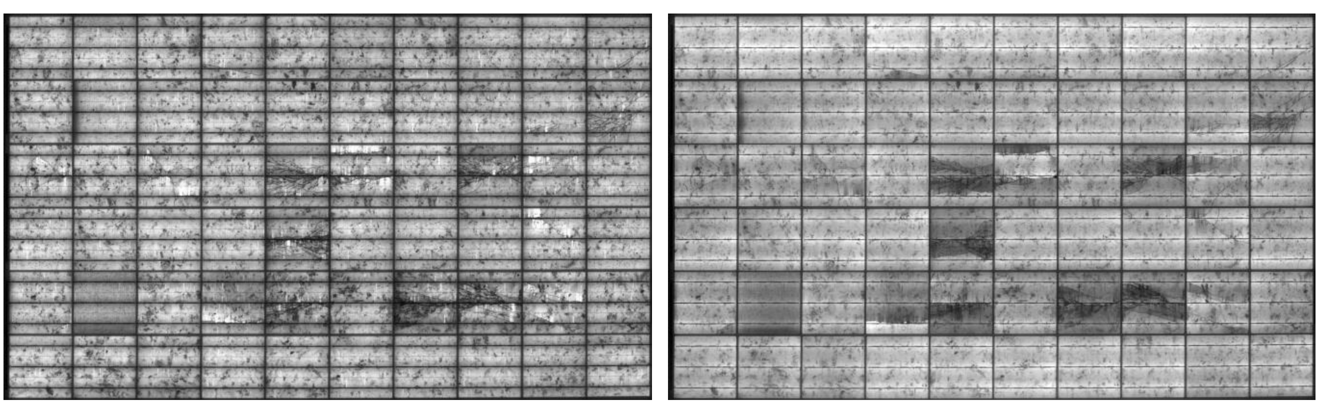
Introduction

Inspection of photovoltaic (PV) modules is vital for quality and reliability assurance in the industry. Luminescence imaging is readily being implemented for this purpose, since it can acquire spatially resolved information in very short times. Both electroluminescence (EL) [1] and photoluminescence (PL) [2] imaging provide similar information, although PL imaging has the advantage of being contactless. Recent work has shown that additional information can be obtained when PL imaging is employed using a line scan methodology [3-5], which is favourable for modules due to their large area. This work demonstrates detailed characterisation of PV modules using line scan EL (EL_{LS}) and line scan PL (PL_{LS}) imaging. Robust identification of both manufacturing and field exposure faults is shown, made possible by the high resolution images obtained using a prototype line scan imaging tool developed at UNSW Sydney [3]. From this it is demonstrated that luminescence imaging provides a metric that is proportional to the impact of series resistance (R_S) issues on power output [4, 6], and it is able to provide the voltage of each cell encapsulated within a module [7]. Furthermore, a key finding of this work is that voltage determined from luminescence is one order less sensitive to changes in sample temperature than the terminal voltage, which enables more accurate performance monitoring within variable measurement environments.

Identification of module faults

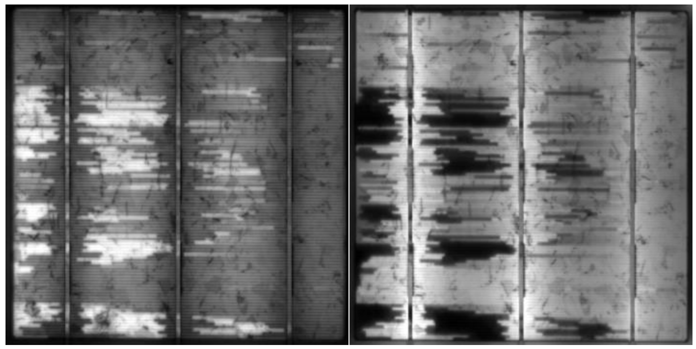
The prototype imaging tool can acquire EL_{LS} and PL_{LS} images of full area industrial modules up to 72 cells [3], with inspection speeds of up to 0.2 m/s having been demonstrated. Each cell within a full area module can be imaged with a maximum resolution of 1120 square pixels, allowing for very fine features such as micro-cracks to be readily identified. An example of these capabilities is shown by the EL_{LS} and PL_{LS} images of a defective module in Figure 1. Commercialisation of this tool is currently being undertaken by BT Imaging Pty Ltd.



(a) (b)

Figure 1. (a) PL_{LS} and (b) EL_{LS} images of a defective module acquired using the prototype imaging tool.

In EL_{LS} images regions of poor R_S and poor minority carrier lifetime both appear with decreased luminescence intensity. In PL_{LS} images these faults have opposite contrast: poor R_S regions result in increased intensity whilst poor lifetime regions result in decreased intensity. A detailed explanation of this phenomena is presented elsewhere [4, 5]. Hence, if EL_{LS} and PL_{LS} images of a sample are analysed in combination, the cause of the change in luminescence intensity can be determined with confidence. An example of this is shown in Figure 2, in which the numerous rectangular features can only be identified as a result of R_S issues if both images are observed.

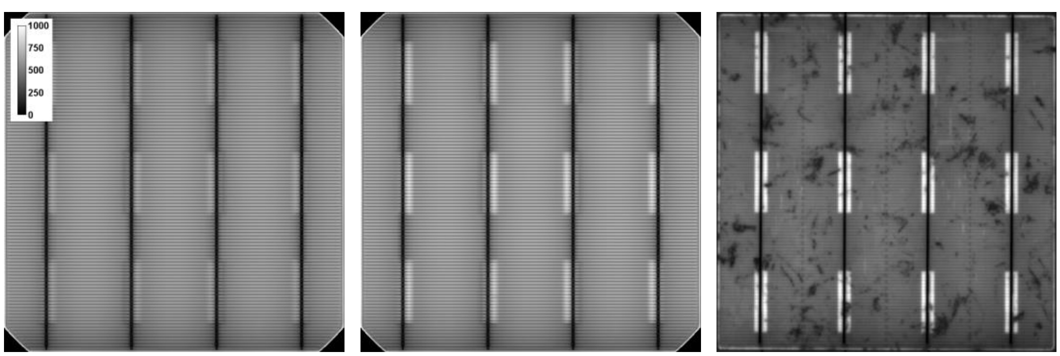


(a) (b)

Figure 2. (a) PL_{LS} and (b) EL_{LS} images of a cell cropped from a module image, exhibiting numerous R_S faults that appear with increased intensity in (a) and decreased intensity in (b).

Quantifying impact of series resistance

Previous work analysed front metal finger interruptions as a case study in characterisation of R_S features in line scan luminescence images [4, 6]. As discussed above, a region affected by a finger interruption has increased luminescence intensity in a PL_{LS} image, and it was shown that this increase relative to an unaffected cell region has a linear relationship with power loss. In this work we extend analysis to rear metal contact resistance issues. Simulations were performed on a uniform monocrystalline silicon PERC cell model using *Griddler 2.5 Pro* [8], during which the contact resistance of silver solder pads on the rear surface was varied. The simulated PL_{LS} images for 2 different rear contact resistances are shown in Figure 3, with the silver solder pads observed as the 12 bright rectangular regions. An increase in resistance results in an increase in the luminescence intensity around the affected region, and a PL_{LS} image of a multicrystalline silicon PERC cell affected by such a increase is shown in Figure 3c for comparison. Full quantitative analysis of the simulation results will be presented in the conference paper.



(a) (b) (c)

Figure 3. *Griddler* simulations with rear contact resistance in affected region (a) 6 times and (b) 26 times larger than unaffected region. (c) Experimental PL_{LS} image of a cell cropped from a multicrystalline silicon PERC module.

Evaluating the terminal voltage of cells within a module using luminescence

The link between the terminal voltage of a cell and its luminescence intensity is now well established [9]. A measurement of relative luminescence intensity can thus be used to calculate the terminal voltage of a cell with knowledge of a sample dependent calibration constant [10, 11]. Methods to determine this constant for cells within modules have previously been established [7], and were used to monitor the voltage of each cell individually during known module degradation modes. This method provides great insight into the nature of module faults, as cells within a module cannot be directly contacted through the encapsulant material. An example of such monitoring is shown in Figure 4, where the change in voltage for two cells within a module is observed to follow the well-established trend for light and elevated temperature induced degradation (LeTID) [12, 13]; however the two cells clearly have different degradation rates. In a full module, which consists of 60 or more cells, the impact of this difference in degradation cannot be evaluated from terminal measurements.

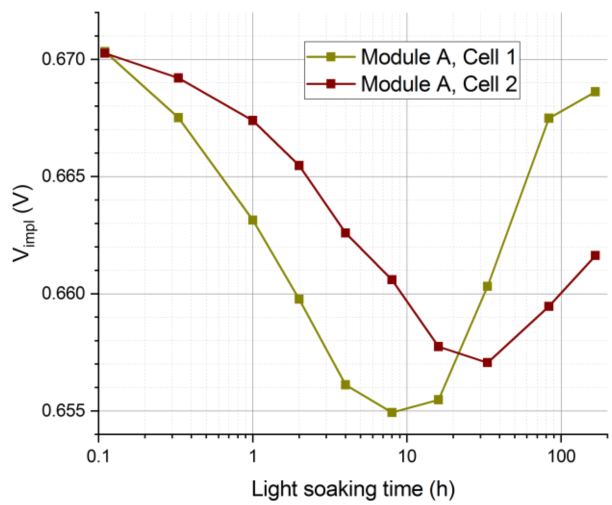


Figure 4. Implied voltage measurements of 2 cells determined from EL_{LS} images of a module. Imaging was performed during 166.6 hours of light soaking at elevated temperature.

Voltage determined from luminescence exhibits a temperature dependence that is an order lower than that of the terminal voltage, which is typically used when monitoring module performance [14]. An example of this robustness to temperature variations is demonstrated in Figure 5 by comparison of temperature dependent terminal voltage and voltage calculated from luminescence. The numerous issues associated with either obtaining an accurate measurement of sample temperature or varying ambient conditions are therefore improved when evaluating performance using luminescence.

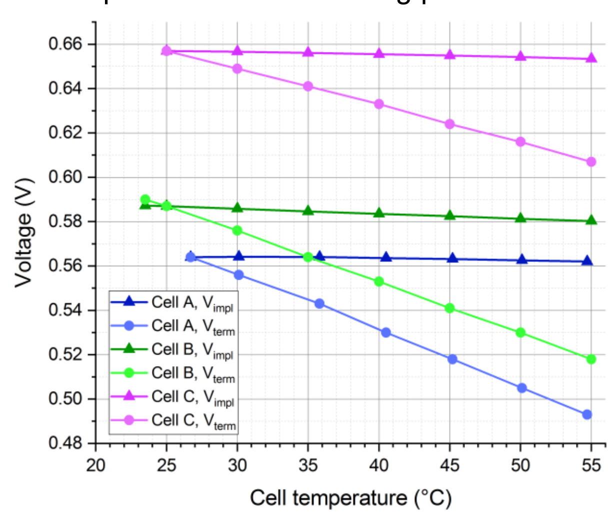


Figure 5. Terminal and implied voltage measurements of 3 cells as a function of cell temperature.

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