Using Low-cost Scanners for Luminescence Imaging of Solar Cells

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Introduction

This study investigates the possibility of using consumer flatbed scanners with minimum modification for electroluminescence (EL) and photoluminescence (PL) imaging of solar cells. Through the comparison between the luminescence images measured with a high-end lab tool LIS-R3 from BT imaging and the images of the same solar cell from a modified contact imaging sensor (CIS) based scanner, we demonstrate that the low-cost flatbed scanners (< 20 AUD) are suitable to produce luminescence images of solar cells with high resolution (> 50 MP, up to 8 μm pixel size). Such products have previously been demonstrated to be capable tools for optical inspection of solar cells [1].

Luminescence imaging is widely used in solar cell manufacturing for monitoring spatially resolved material properties [2]. It is an easy and fast non-destructive photographic method enabling inspection of the solar cell uniformity or monitor of any defects generated while handling. Defects such as cell cracks, scratches, soldering defects, potential induced degradation (PID), shunts etc. can be detected via luminescence imaging at each stage in an industry line [3]. Such inspection can be used to efficiently identify solar cells that do not meet the quality standard so that they can be excluded prior to module production and will therefore not have a negative impact on the final product where they could otherwise lead to poor efficiency and potential warranty claims.

In this study, we use a mass-produced low-cost consumer flatbed scanner to carry out electroluminescence and photoluminescence imaging of solar cells and compare the results with the EL and PL images measured with a conventional lab characterisation tool to demonstrate proof-of-concept that low-cost scanner luminescence imaging is possible and can achieve high resolution images. This novel approach makes a cost-effective setup possible for research groups with limited budgets, enabling broader access luminescence imaging of solar cells. Moreover, since the scanning area of a line scanner is not limited, low-cost scanners can potentially be used for luminescence imaging of large area cells or even modules.

Experiment Setups

The aim is to investigate if consumer electronics grade low-cost flatbed scanners with minimum modification can be applied to obtain EL and PL images of solar cells, with the resulting performance validated and evaluated via analysis of defects and series resistivity (Rs).

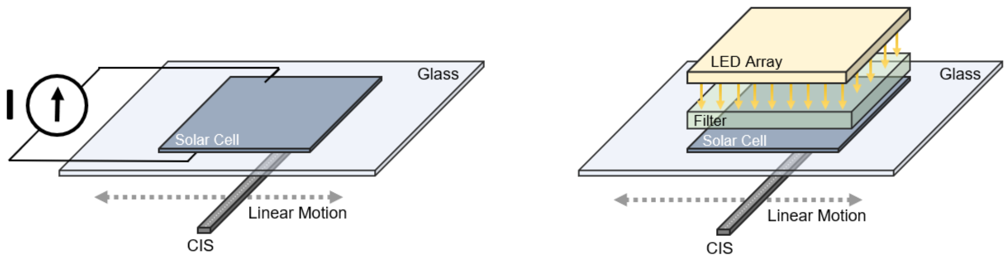

Figure 1. Schematic representation of an EL (left) and a PL (right) setup based on a CIS based scanner.

There are two common scanning technologies used in the consumer flatbed scanner market, Charge Coupled Device (CCD) and Contact Image Sensor (CIS) based systems. In this experiment, a CIS based flatbed scanner was used to acquire luminescence images of solar cells as shown in Figure 1. The reason a CIS based scanner was chosen over a CCD based scanner is the lower cost and that CIS scanner has the same field of view for each pixel across the sensor and hence does not suffer from vignetting (which would require correction), therefore it more directly reflects the true optical properties of solar cell.

Minimal modifications were implemented to achieve the EL and PL imaging. The addition of a current supply was included for EL images (30 V 6 A) which was also used to power the warm white LEDs for PL imaging as demonstrated in Figure 1. To enable control of the exposure time of the scanner a control board to directly control the hardware was designed and made. The board is based on the RP2040 microcontroller (microcontroller cost $5) and only included passive elements to avoid additional costs. This enabled exposure times from milliseconds to several seconds. To ensure there is no long wavelength light coming directly from the LEDs to the scanner, the LEDs were filtered by a 5 mm thick KG5 glass filter.

To demonstrate the potential of a CIS based scanner for EL imaging, a sample solar cell was imaged with both the modified scanner setup and a LIS-R3 tool from BT imaging under three different currents. For the initial proof-of-concept, EL imaging was used as it requires the least modification to the scanner hardware. The EL results were corrected for changes in the sensor temperature. To validate the PL images of solar cells measured with the CIS based scanner, a raw wafer was also imaged with the setup to test the transmission of the filter. Finally, the EL images were used to calculate Rs images [4].

To obtain the luminescence image, a background image is first taken, this contains the dark signal of the camera. A subsequent image is then taken with the solar cell under bias current for EL or light for PL and the luminescence image is obtained from the difference between the two images.

Electroluminescence imaging Results

An example of an electroluminescence images obtained with the CIS scanner (left) and from a BT image R3 (right) is shown in Figure 2.

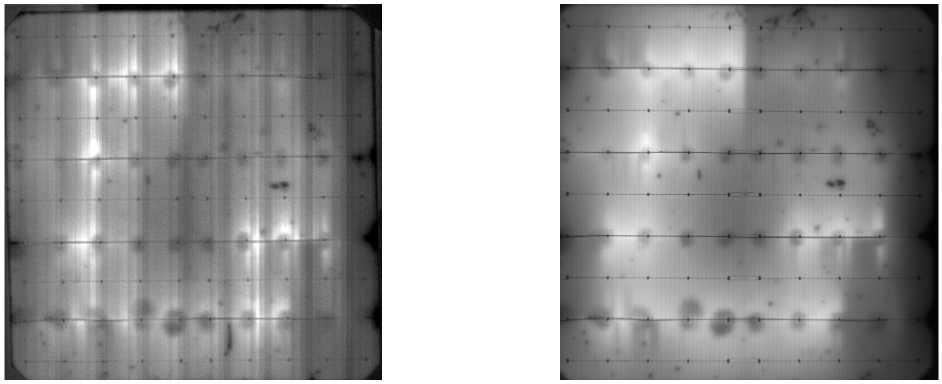

Figure 2. Comparison between a scanned image from a CIS based scanner (left) and the EL image of the same solar cell measured with LIS-R3 from BT imaging (right).

The features observed in the right image are also apparent within the CIS scanner's image (left). The similarities between the two images validates that the scanner detected a true EL signal, and that luminescence imaging of solar cells can be achieved via low-cost scanner technology. The soldering defects and scratches on the solar cell are shown clearly in both images and the bright spots around the soldering dots are likely to be a result of annealing during the soldering process. However, there are lines running down the image from the CIS scanners image that are not in the image from the BT image R3. These lines represent a changing sensitivity between each pixel. A separate calibration step was therefore implemented to correct for this sensitivity and used when processing subsequent EL image data.

Three EL images were acquired for an encapsulated solar cell using the same exposure time setting but for a range of currents on both the CIS scanner and BT Imaging tool, the results are shown in Figure 3.

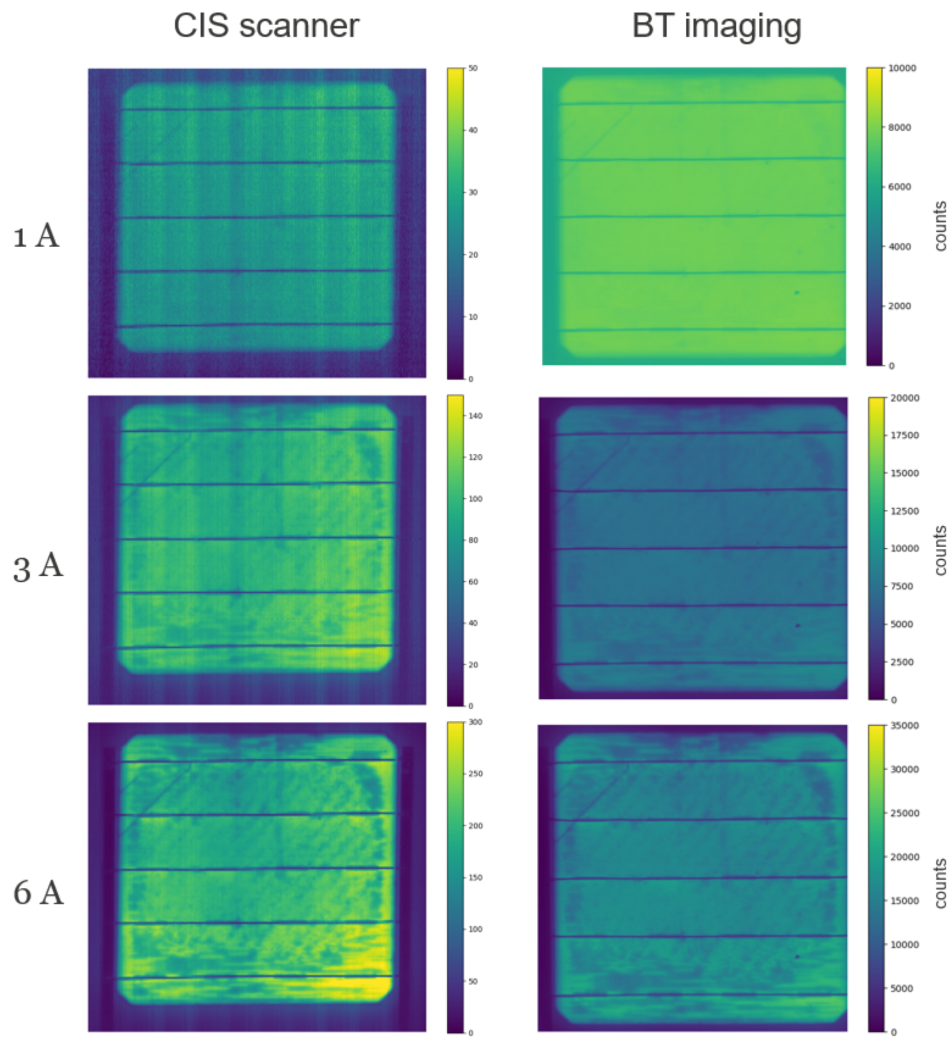

Figure 3. EL images of the same solar cell under 1 A, 3 A and 6 A (from top to bottom) measured with the scanner after flat-field correction (left) and a BT imaging tool LIS-R3 (right).

Both the background correction and pixel level correction techniques were applied to these images. The two sets of images again show the same features. In the images from the CIS scanner (left), some extra features are present in the 1A and 3A but not in 6A, appearing as ripples across the images. It is likely that these are from the same pixel level variations seen in Figure 2, but there was not a sufficient number of counts for the correction to be complete. Finally, these EL images were used to calculate a series resistance image (R_s) as shown in Figure 4 using Ohm's law. The features of defects such as inclined stripes and scratches are clearly shown in Figure 4.

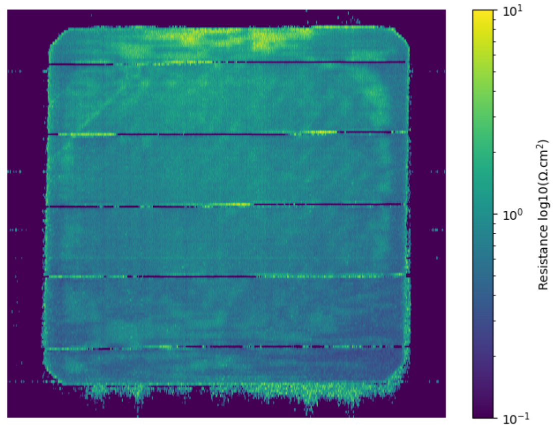

Figure 4. R_s result extracted from EL images from Figure 3.

Photoluminescence Imaging

Photoluminescence images were acquired with the CIS sensor in a transmission configuration and were both background corrected and adjusted for the pixel sensitivity. The cell used was a bifacial cell with a ~670 mV open circuit voltage. A key challenge when measuring photoluminescence of silicon is to prevent measurement of the light source itself, which is >4 orders of magnitude brighter than the luminescence. To demonstrate that we measured true photoluminescence of the solar cells rather than the illumination source without filtering on the detection side of the cell, we also measured a raw wafer. Raw wafers are not expected to provide much luminescence, and the results show that the signals are indeed orders of magnitude lower than that from cells as shown in Figure 5. Both acquired PL images are shown in Figure 5 and were measured with the same exposure time and set to the same intensity scale. Essentially, no signal is detected from the raw wafer (shown on the right), while there is a clear signal from the bifacial cell (on the left). This demonstrates that a PL signal is detected from the cell.

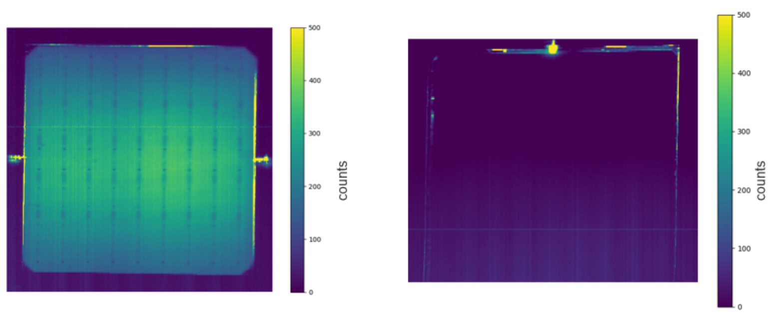

Figure 5. PL image of a solar cell with flat-field correction (left) and a raw wafer (right).

Conclusions

In this work, luminescence imaging of silicon solar cells is demonstrated using a low-cost consumer flatbed scanner. This creates the possibility of ultra-low cost for standard characterisation equipment of solar cells. The system cost of a commercial lab level luminescence imaging tool typically costs several hundred thousand dollars, whereas the prototype in this work has a total cost of less than $1,000. The prototype is based on a CIS line sensor that can be applied to in-line and off-line monitoring of solar cells. The main advantages of using our CIS scanner prototype is: Low cost, Accessible components, and high spatial resolution. A comparison of these details against an industry-leading commercialBT imaging R3 tool is shown in Table 1.

Table 1. Cost comparison between CIS scanner and BT imaging R3.

	Max resolution	Exposure time*	Well depth	System cost	Sensor cost
CIS sensor	8 µm	600 ms	2^{10} **	< $1000***	< $20
BT imager	160 µm	2 s	2^{16}	> $100,000***	> $10,000

* The exposure time per image or per line for the same solar cell in Fig. 3 for current of 6 A

** Limited by read electronics, the sensors outputs 216

*** Only for the hardware cost

References

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