

## A low cost electroluminescence system for solar cell laboratory

activities based on a commercial digital camera

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### 1. Introduction

Imaging techniques having become an essential tool in photovoltaic research, as they gather spatial resolved information of the solar cells electrical response. Such information is an essential tool for the detection and identification of defects and local failures on solar cells. Among the different imaging techniques, electroluminescence (EL) is the most popular method for the characterization of silicon solar cells. One of the major advantages of electroluminescence is the possibility to obtain images of the solar cell in short periods of time. Namely electroluminescence imaging obtains the mapping the minority carrier lifetime over the whole cell much faster than LBIC imaging [1]. Electroluminescence imaging not only allows the mapping of the carrier lifetime, but also gives an estimate of the solar cell ideality factor and open-circuit voltage [2].

The principle of electroluminescence is very simple, a current is injected in the solar cell (forward bias), and the radiative recombination of the electron and holes is detected by the camera sensor. In the case of Si-CCD sensor the sensitivity is limited by the silicon gap energy. The spectral sensitivity of Si-CCD sensors, is maximal between 500 nm and 800 nm, decaying to zero for higher wavelengths (Figure 1).

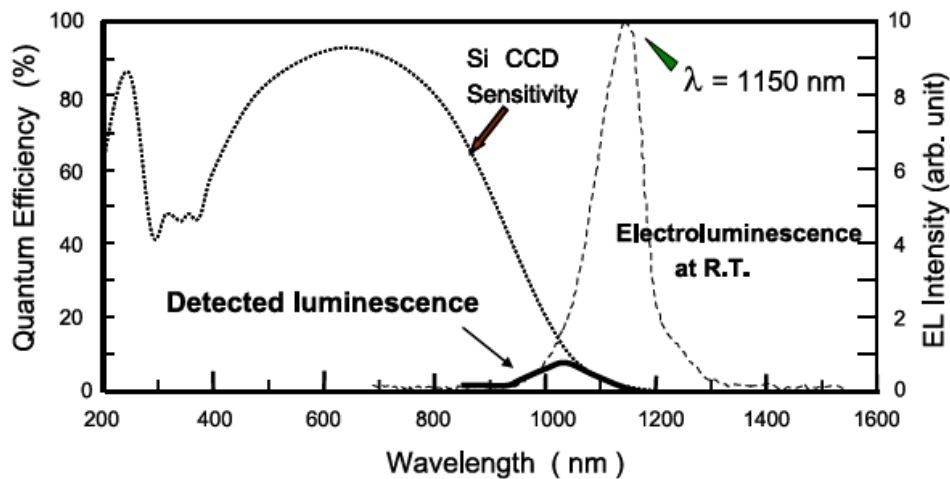


Figure 1: Typical Si-CCD camera sensitivity and silicon emission spectrum [1].

The typical emission spectrum for silicon is also displayed in Figure 1, where the radiative recombination peak, for  $\lambda=1150$  nm, can be identified. The luminescence detection range results from the intersection of these two spectra, and corresponds to a peak centred at  $\lambda=1050$  nm.

Another technique that as recently been developed is reverse bias electroluminescence (ReBEL). In this technique a current is injected in reverse polarization and the solar cell luminescence is detected. ReBEL is based and the acceleration and consequent recombination

or scattering of carriers in high electric fields. Luminescence has been attributed to interband recombination or relaxation. Nevertheless the exact nature of luminescence in ReBEL is however still under discussion. ReBEL as wide-band spectrum and includes contributions in the visible range [3].

Using ReBEL the breakdown and pre-breakdown behaviour of silicon solar cells can be detected and three different types of breakdown can be detected for different bias ranges [3]. Usually the high-cost of standard electroluminescence systems is a hindrance for its use in teaching laboratories. The existence of a low-cost electroluminescence setup for the characterization of solar cells, opens new opportunities for the photovoltaics teaching.

## 2. The Electroluminescence system

During this work, a low cost luminescence system, based on the use of a commercial digital camera, was developed.

The experimental setup developed is presented in Figure 2, where the different elements of the electroluminescence system can be identified. The vacuum system is used to improve the contact between the solar cell and sample holder, which not only assures a better electrical contacting of the back of the cell, but also improves the cooling of the solar cell.

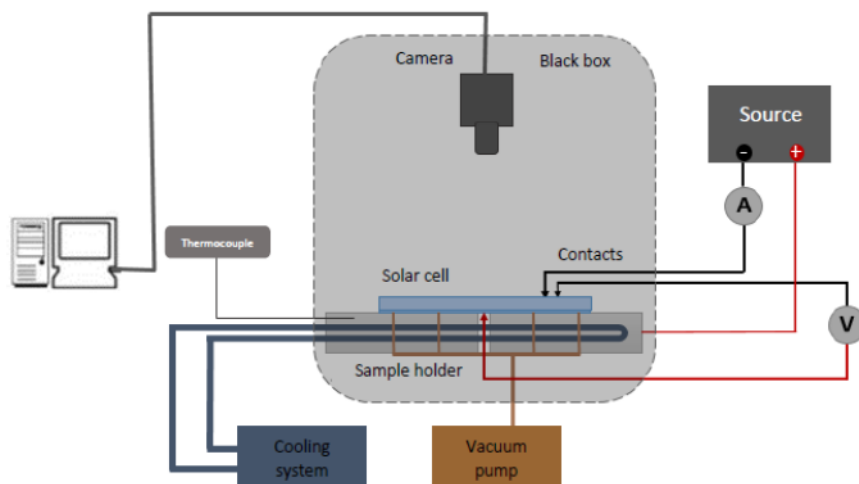


Figure 2: Electroluminescence experimental setup [4].

Using the home developed setup, EL and ReBEL characterizations were performed on monocrystalline and multicrystalline silicon solar cells.

During EL characterizations, the solar cells were injected with a current of 1 A and voltage of approximately 0.6 V. For ReBEL characterizations the voltage was varied between -4 V and 18 V.

### 3. Characterization results

On Figure 3 some examples of EL and ReBEL imaging of silicon solar cells are displayed.

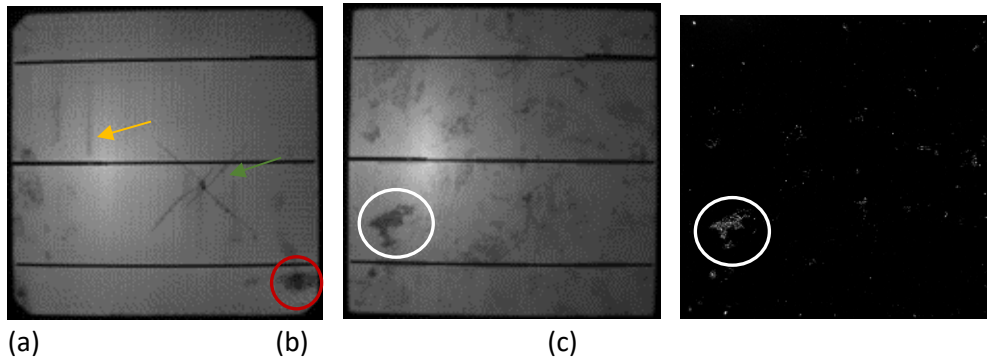


Figure 3: (a) EL imaging of monocrystalline silicon solar cell; (b) EL imaging of multicrystalline silicon solar cell; (c) ReBEL imaging ( $V=-12V$ ) of multicrystalline silicon solar cell [4].

On Figure 3(a) the EL imaging of a monocrystalline silicon solar is presented; three different defects can be identified. One corresponds to a contact failure (yellow arrow), a second one corresponds to a cell breakage that could be detected by visual inspection (green arrow), and a third identified by a dark spot visible in the solar cell surface (red circle) is possible due to a processing default occurred during the solar cell fabrication.

On Figures 3(a) and (b) EL and ReBEL images of the same multicrystalline silicon solar cell are presented. On both images a zone of higher recombination can be detected, identified by a lower luminescence on forward bias and higher luminescence on reverse bias. The higher recombination can be attributed to the presence of a cluster of impurities or a higher density of lattice dislocations.

### 4. Acknowledgements

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### 5. References

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