Electroluminescence of silicon solar cells using a CMOS sensor consumer grade digital camera

José A. Silva, K. Lobato, M. S. Frazão, J. M. Serra

Affiliations : José A. Silva - Instituto Dom Luiz, Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal

K. Lobato - Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal

M. S. Frazão - Instituto Dom Luiz, Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal

J. M. Serra - Instituto Dom Luiz, Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portuga,

An electroluminescence measuring system was developed based on a low cost Complementary Metal Oxide Semiconductor (CMOS) sensor digital camera. Electroluminescence (EL) and Reverse Bias Electroluminescence (ReBEL) imaging were performed on both monocrystalline and multicrystalline silicon solar cells.

EL measurements were performed with a bias voltage Vb near Voc and ReBEL measurements performed with Vb between 4 V to 18 V. The imaging obtained in this range of biases allows for the identification of different defect types. Defects such as metal contamination and cracks were induced in the solar cells and their effects were again characterized by EL and ReBEL. The imaging performed permitted the identification of defects such as metal contaminations, shunts, metal contact failures or cracks. Furthermore, luminescence measurements were performed at different temperatures which permitted the differentiation between intrinsic and extrinsic defects.

The newly developed system was validated by comparing EL and ReBEL images obtained with a similar setup employing a high sensitivity scientific grade Charge Coupled Device sensor camera specifically developed for luminescence imaging. Such comparison demonstrated the feasibility of the new system, validating its use for solar cell characterization.

To further analyse the influence of defects and confirm defect type (induced or not), the solar cells were also characterized by Suns-Voc, one sun iV and dark iV and localised external quantum efficiency.

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J. A. Silva[1]*, K. Lobato[1], M. Frazão[2], J. M. Serra[1]

[1] Instituto Dom Luiz, Faculdade Ciências, Universidade Lisboa, Portugal
[2] Faculdade de Ciências, Universidade de Lisboa, Portugal

*corresponding author: jose.silva@fc.ul.pt

Context

Electroluminescence (EL) and Reverse Bias Electroluminescence (ReBEL) are increasingly used to detect defects on silicon solar cells (Si SC). Such techniques are useful tools to be used both on photovoltaic research and teaching laboratories. However the cost of the conventional luminescence systems is a limiting factor for its generalized use.

The development a simple and reliable low-cost electroluminescence setup can enable a more widespread use of these techniques to characterize crystalline silicon solar cells.

A low cost electroluminescence imaging system was developed. The system was used to characterize industrial silicon solar cells. Different defects were detected and identified by EL and ReBEL. Furthermore, luminescence measurements were performed at different temperatures which permitted the differentiation between intrinsic and extrinsic defects.

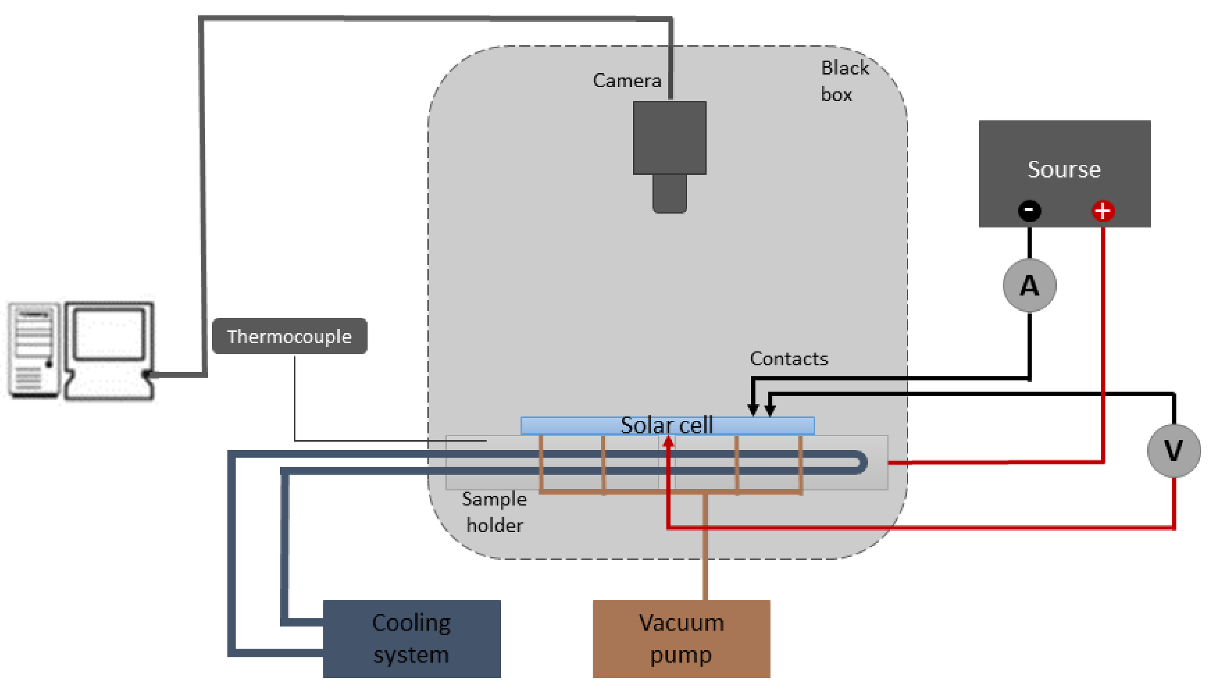
Method

System

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

The camera uses a silicon CCD sensor.

Its spectral sensitivity is maximal for λ between 500 nm and 800 nm decaying to zero for λ > 1150 nm. The Si-CCD sensor can detect the crystalline silicon solar cells EL signal between 950 nm and 1150 nm. Before using the camera to obtain EL images, the camera had its infrared filter removed.



Samples

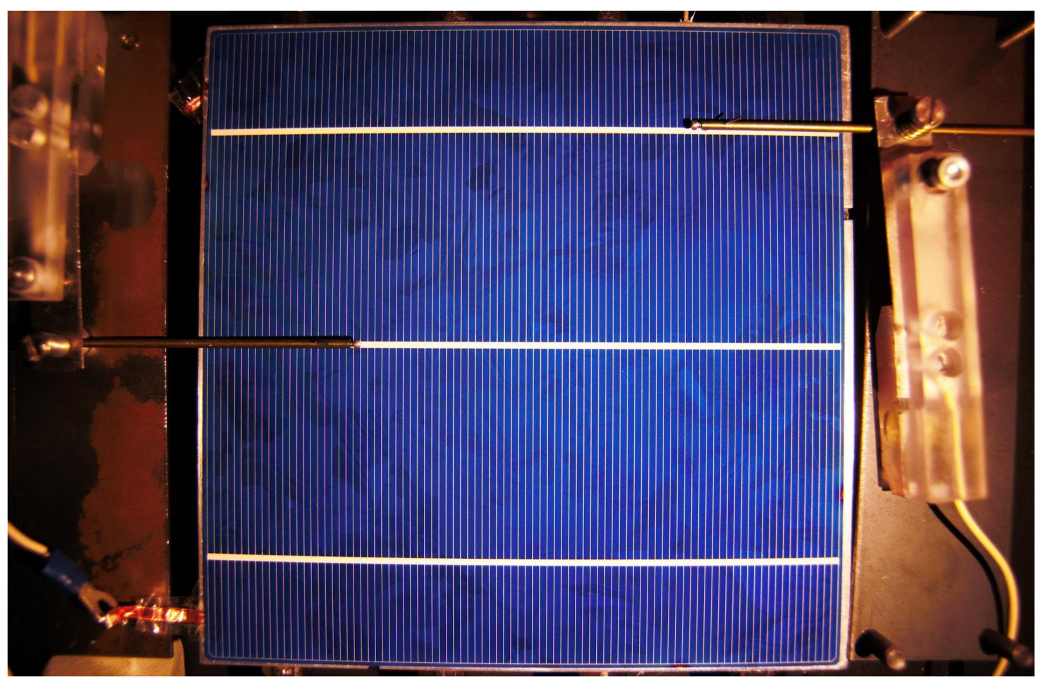
Multicrystalline and monocrystalline Si SC

156 × 156 mm^2

Characterization details

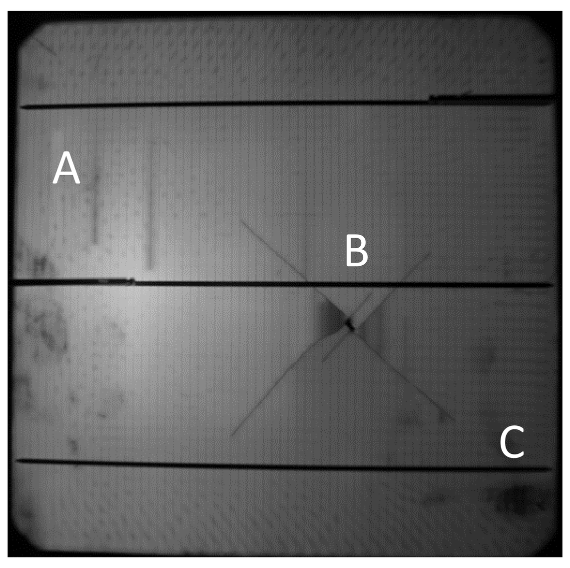
EL: 1 A; 0.6 V ; t=5 min

ReBEL: -4 V ≤ Voltage ≤ 18 V; t=15 min



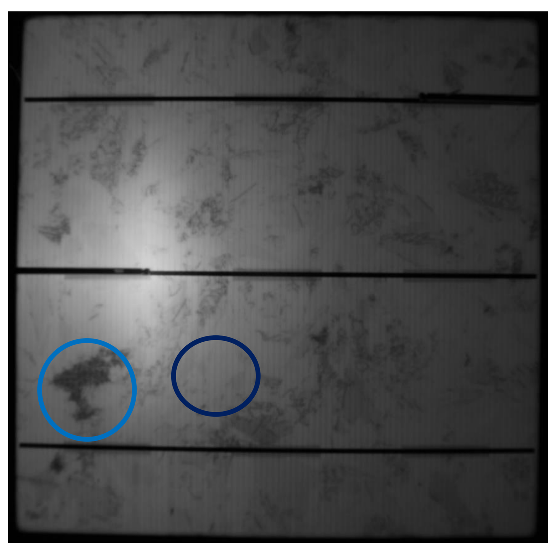
Results

EL mono-Si SC

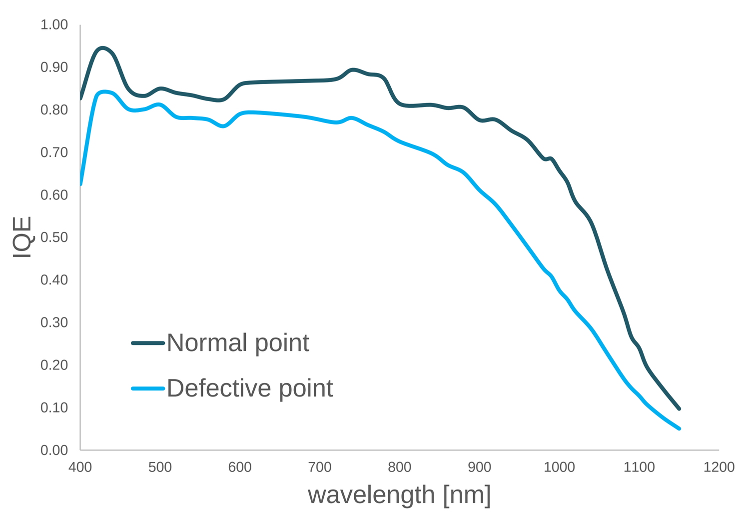


- Point A: contact failure;
- Point B: cell breakage;
- Point C: a dark spot possibly due to a processing default

EL multi-Si SC

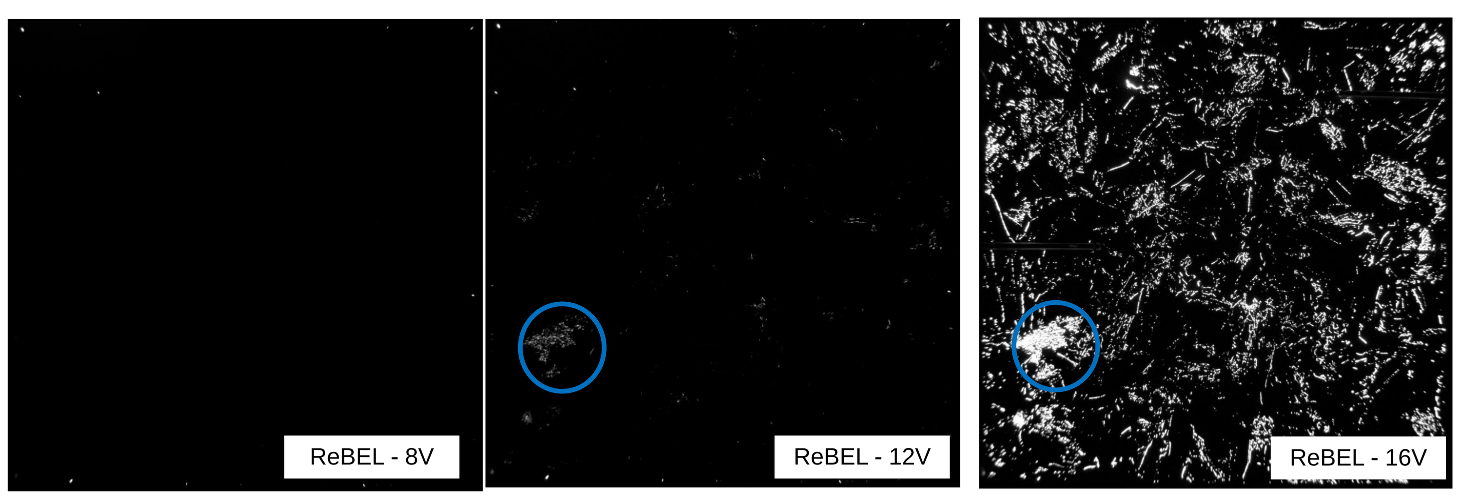


Local IQE

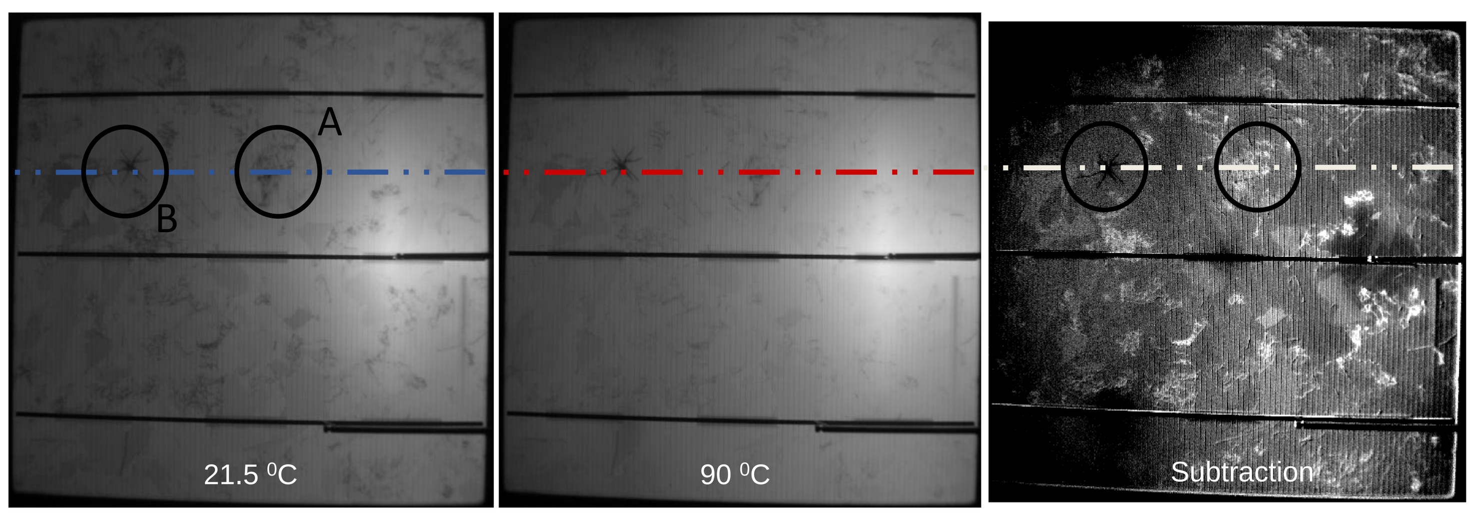


- A higher recombination region can be observed (dark region on EL).
- Local IQE measured on this region confirms its high recombination behavior.
- ReBEL imaging at different bias allows the identification of different defects (bright areas)
- The defect previously observed on EL arises at -12V, suggesting the presence of metal precipitates in the grain boundaries of mc-Si.

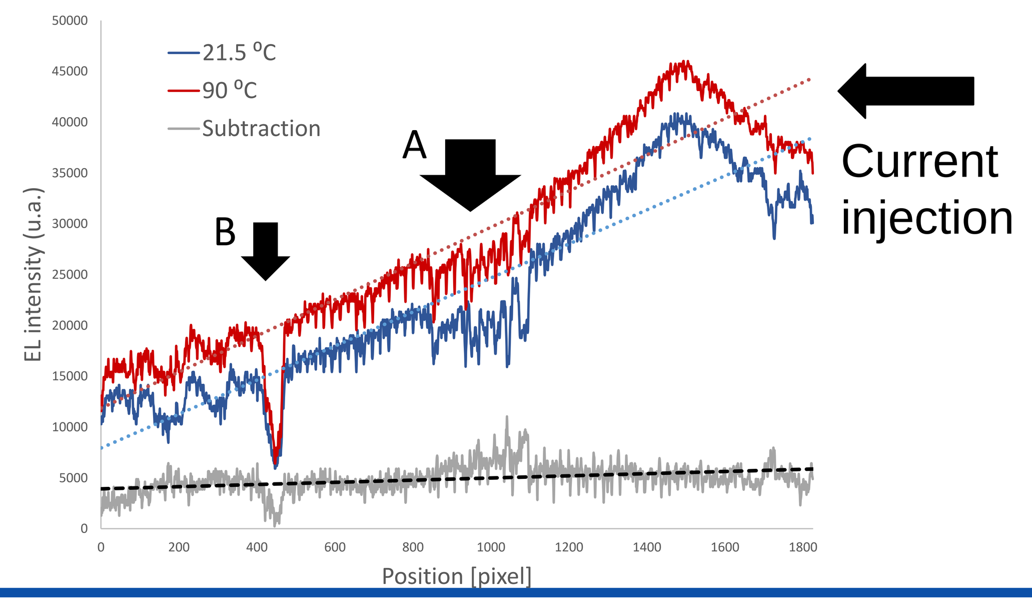
ReBEL multi-Si SC



EL images of one multi-Si SC at different temperatures



- Since at higher temperatures intrinsic defects are attenuated on EL imaging. Subtracting the two EL images obtained at different temperatures, intrinsic defects are highlighted (light areas).
- In the subtraction image intrinsic defects (A) exhibit luminescence values above average values while. extrinsic defects (ex: cracks) exhibit values below the average (B).



- Current is injected at the right thus the luminescence signal increases from left to right.
- To avoid the lack of homogeneity on EL and ReBEL imaging a multiple contact probe should be introduced.

Wrap up

- The developed luminescence setup produced good quality EL and ReBEL imaging on c-silicon solar cells. The characterizations performed both on monocrystalline and multicrystalline silicon solar cells allowed the identification of several defects both intrinsic and extrinsic.
- In order to obtain EL and ReBEL images with a better homogeneity, in the future the current and voltage probes should be replaced by multiple contact probes.

Acknowledgements: This work has been funded by FCT (Portugal) through the grant SFRH/BPD/82540/2011 and the project UID/GEO/50019/2013.