Forward bias (EL) and reverse bias luminescence (ReBEL) imaging of silicon solar cells using a consumer grade camera.

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An electroluminescence measuring system was developed [1,2] based on a consumer grade Nikon D40 digital camera equipped with a complementary metal oxide semiconductor (CMOS) sensor. The system was used to perform Electroluminescence (EL) and Reverse Bias Electroluminescence (ReBEL) imaging. Validation occurred by comparison with a similar setup employing a specifically developed scientific grade Sensovation HR-320 camera equipped with a charge coupled device (CCD) sensor [3].

The imaging performed permitted the identification of defects such as metal contaminations, shunts, metal contact failures or cracks. Defects such as metal contamination and cracks were also induced for observation. Furthermore, luminescence measurements were performed at different temperatures which permitted the differentiation between intrinsic and extrinsic defects [4]. Thermography imaging using a Xenics GOBI-2833 camera equipped with an amorphous silicon sensor was also undertaken for further comparison and validation.

Shown in Fig. 1 is an example of EL, ReBEL images of a mc-Si solar cell using the consumer grade camera. Also shown is a thermography image of the same solar cell.

The EL image is a typical image resultant from a mc-Si solar cell - darker areas of lower luminesce indicate high recombination regions. The observed darker lines are due to gran boundary recombination. The significantly brighter top-right area is a result of current collection concentration occurring via a point probe on the busbar. The image also shows that on the left-hand border there is an area with darker spots indicating problems in the either boron diffusion and/or passivation during solar cell manufacturing. These problems are not observed in the thermography image which is fairly homogenous with no hotspots indicating that shunting is not occurring.

The three ReBEL images serve the purpose of differentiating between types of defects [5]. In this type of imaging, areas of luminesce are indicative of recombination (unlike EL imaging). At 8 V no luminescence is observed suggesting that type-1 surface defects due to Al contamination are not present. At 12 V emission occurs in the same left-hand side border which has been highlighted as problematic from the EL images. This indicates the presence of type-2 defects induced by metal-containing precipitates lying within recombination-active grain boundaries. Finally, at the 16 V bias, type-3 avalanche breakdown is observed resulting from etch pits.

To further analyze the influence of defects and confirm defect type (induced or not), the solar cells were also characterized by Suns-Voc, AM1.5G iV, dark iV and local quantum efficiency.

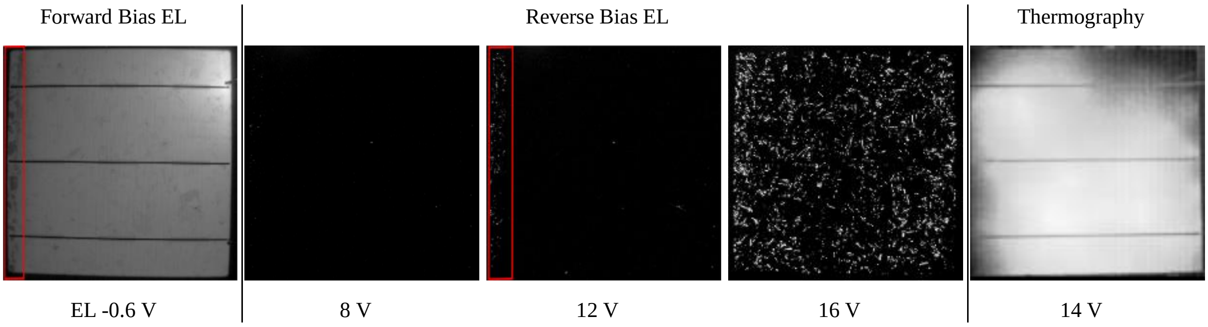

Fig. 1 –Forward bias EL image and reverse bias images of a 156×156 cm^2 mc-Si solar cell using a consumer grade CMOS camera. Also shown is a thermography image. On all images whiter indicates more luminescence emission for the EL and ReBEL images and higher temperature for the thermography image.

[1] M Frazão et al., *Measurement* **99**, p.7 (2017), doi: 10.1016/j.measurement.2016.12.017
[2] JA Silva et al., *EMRS 2016 Spring Meeting*, Lille France
[3] J Madeira et al., *EMRS 2012 Spring Meeting*, Strasbourg France
[4] T Fuyuki & A. Kitiyanan, *App. Phys. A* **96**, p189 (2009), doi: 10.1007/s00339-008-4986-0
[5] O Breitenstein et al., *J. Appl. Phys.* **109**, p.071101 (2011); doi: 10.1063/1.3562200

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Context

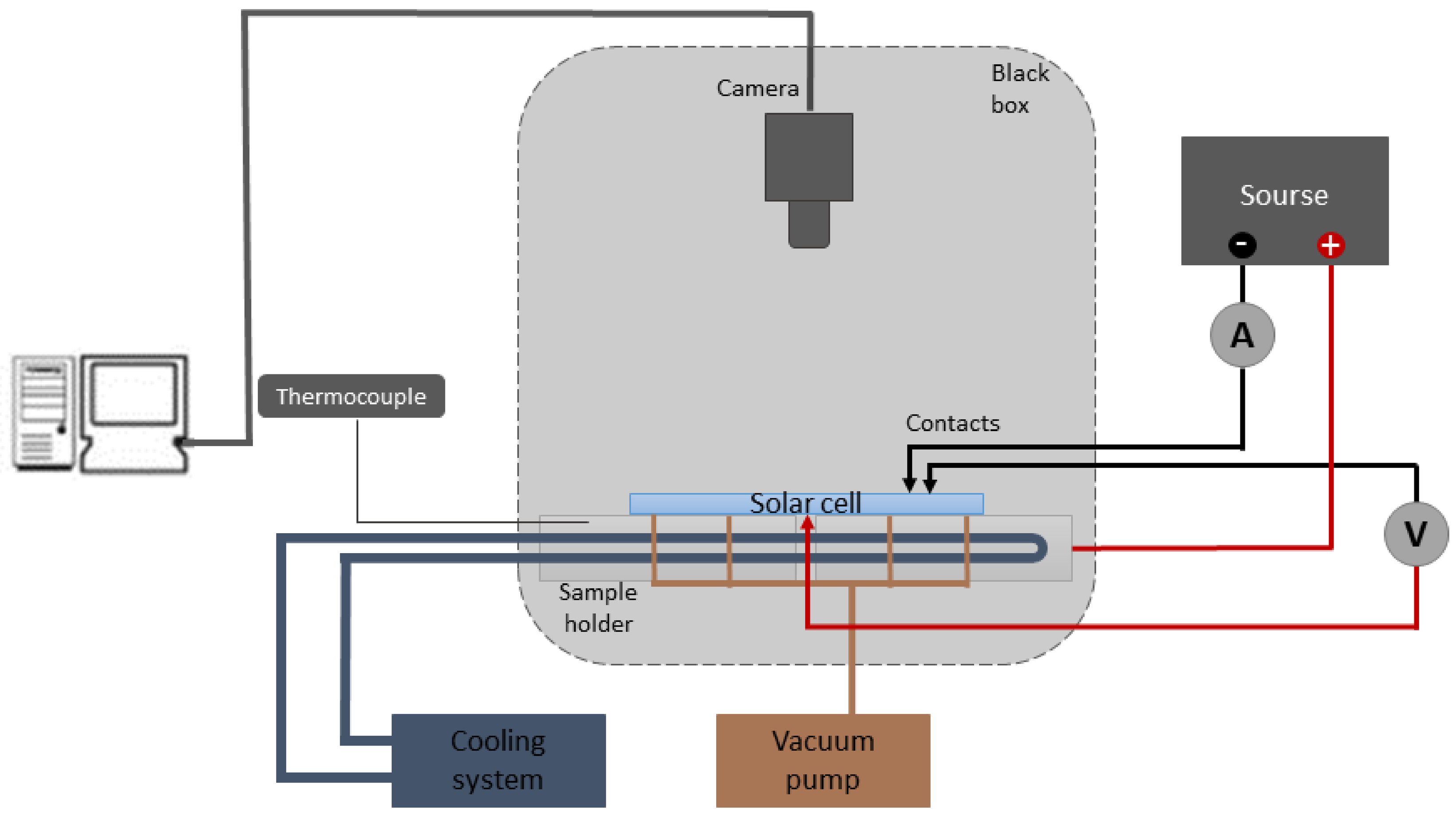
Electroluminescence (EL) and Reverse Bias Electroluminescence (ReBEL) are increasingly used to detect defects on silicon solar cells (Si SC). Such techniques are useful tools to be used both on photovoltaic research and teaching laboratories. However the cost of the conventional luminescence systems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

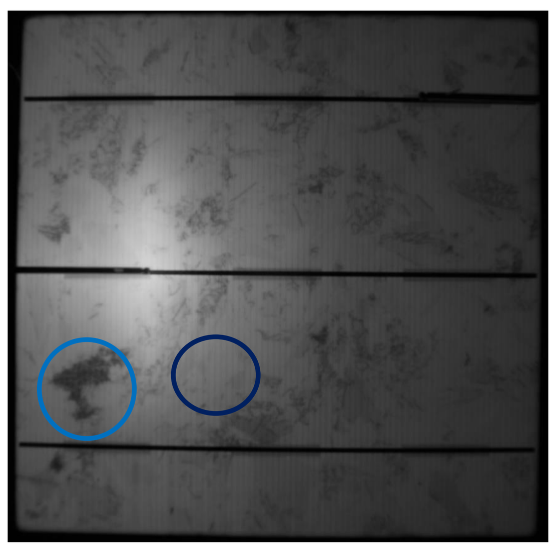
A low cost luminescence system, based on the use of a commercial digital camera, was developed.
The camera uses a silicon CCD sensor.
Its spectral sensitivity is maximal for λ between 500 nm and 800 nm decaying to zero for λ > 1150 nm. The Si-CCD sensor can detect the crystalline silicon solar cells 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

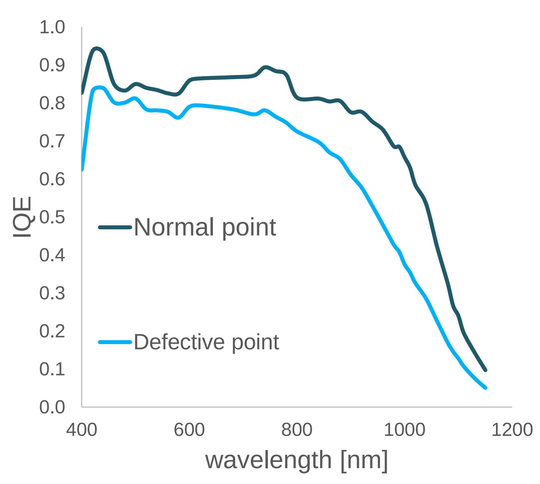


Results

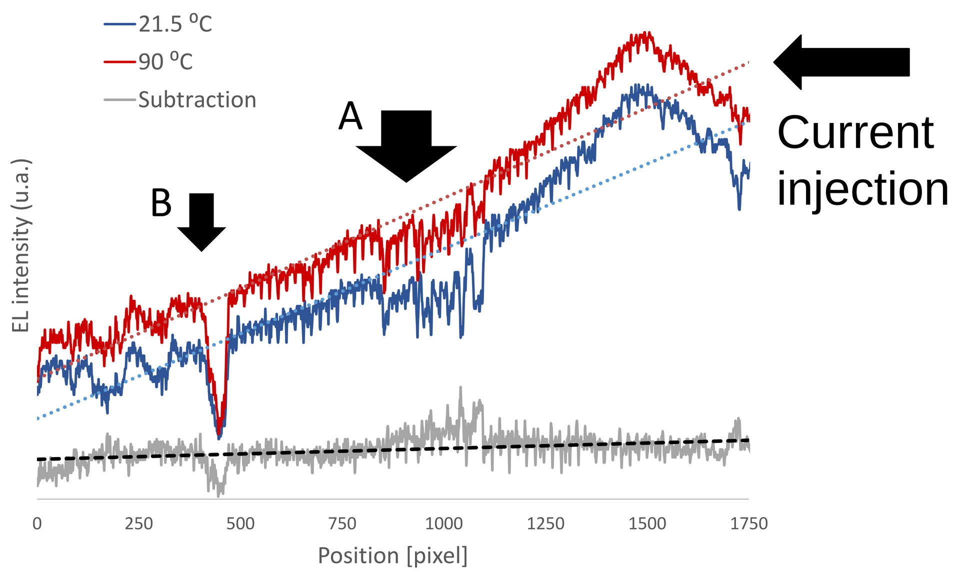
EL multi-Si SC



- A higher recombination region can be observed (dark region on EL).

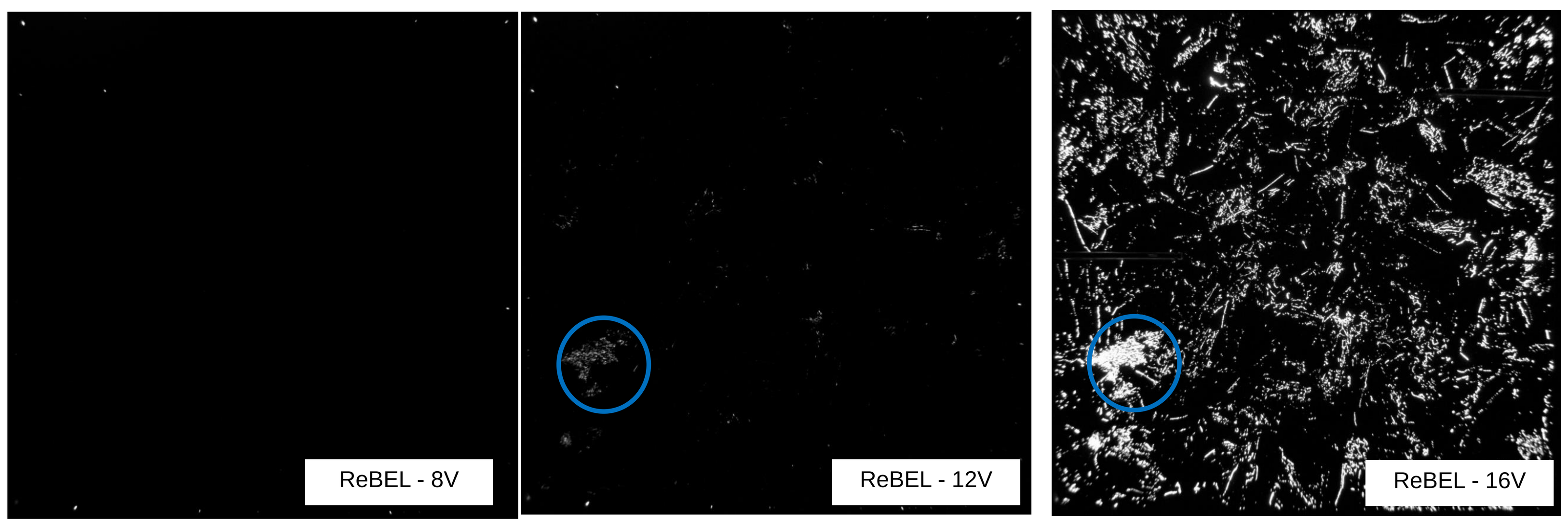


- Local IQE measured on this region confirms its high recombination behavior.



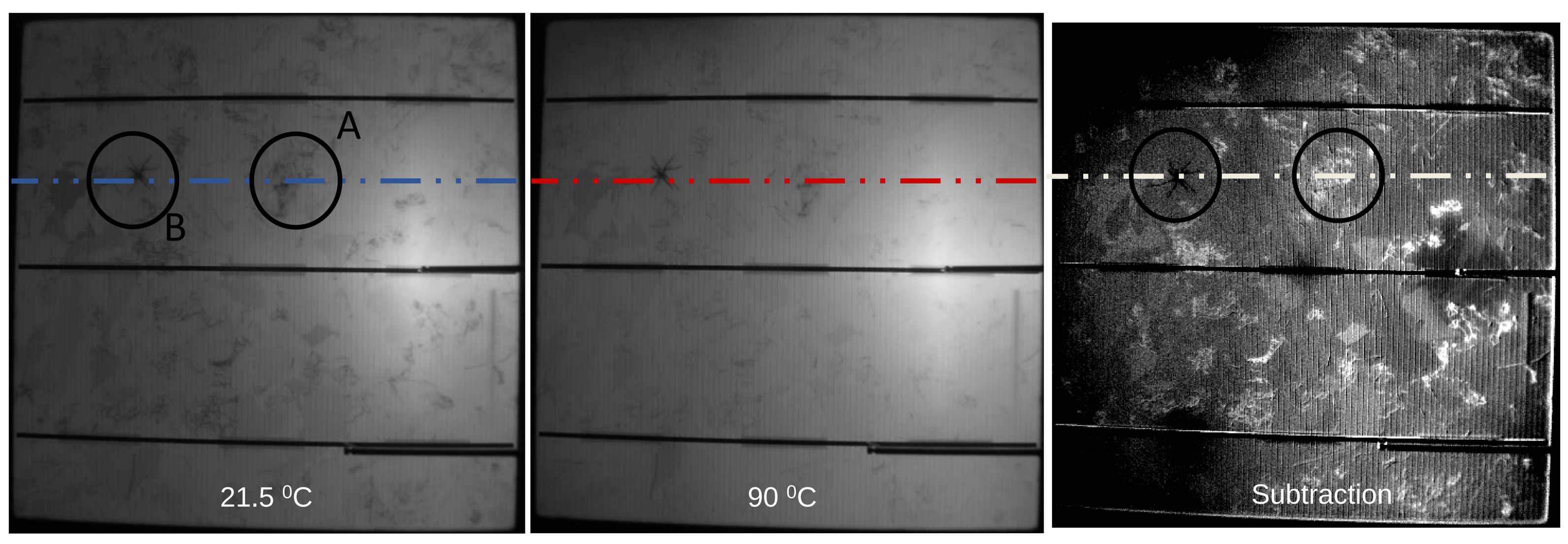
- Current is injected at the right thus the luminescence signal increases from left to right.
- To avoid the lack of homogeneity on EL and ReBEL imaging a multiple contact probe should be introduced.

ReBEL multi-Si SC



- 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.

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).

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.

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