Characterization of silicon thin film solar cells by electroluminescence imaging

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Application Note

Introduction
Over the last 20 years great progress in thin film silicon solar technology has been achieved. Single junction amorphous solar cells reached efficiencies as high as 9.5% [1]. However, to close the gap to crystalline modules higher efficiencies are necessary. Therefore thin film multi junction cells composed of amorphous and microcrystalline silicon have been developed. Here a broader part of the solar spectrum can be utilized due to their different bandgaps. Compared to single junction amorphous silicon cells the yield has been increased by as much as 25%. Cell efficiencies above 12% [2] and module efficiencies of 10% [3] have been realized. Thereby multi-junction cells have been established as a standard in thin film silicon solar cell technology.

As the cells become more complex it is essential to combine multiple characterization techniques to identify possibilities for improvement. One of these techniques is electroluminescence (EL) imaging, which gives information about the radiative recombination in the absorber-material (thin silicon layers). The emission of amorphous and microcrystalline silicon is very weak and is located in the near infrared. Therefore, a detector with a very high sensitivity in the near infrared spectral region is needed.

A thin film silicon solar module consists of an interconnection of single cells. Fig. 1 shows the schematic structure of a thin film solar module. The several thin film layers (transparent conductive oxide (TCO), silicon-absorber, back reflector (TCO or metal)) and the laser patterning for the cell interconnection (Pattern 1-3) are illustrated. The arrows mark the current flow in an unilluminated module.

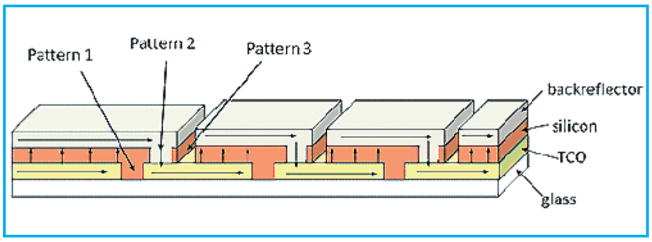

Fig. 1 Interconnection of a thin film solar module [4]

To gain additional information about the investigated solar modules a second characterization method is used: Dark-Lock-In Thermography (DLIT). With this method mid and far infrared radiation is detected. In this way heat development in a module can be visualized. Especially information about ohmic losses in the TCO become available. This is for example important to detect short circuits that dissipate a lot of heat due to high current densities.

By combining the two complementary methods EL and DLIT, the nature of defects can be identified.

Experimental setup
The solar module and the EL camera (CCD detector iKon-M DU934N-BR-DD from Andor Technology) are mounted on a linear unit. The solar module is connected to a power source and operated like a light emitting diode (LED). A voltage of about the respective open circuit voltage (V_{oc}) is applied. With the sensitive Back Illuminated Deep Depletion CCD camera it is possible to image the whole module in high resolution (1024 x 1024 pixels). The time of measurement ranges from seconds to minutes depending on the absorber material, ambient conditions or the camera setup (objective, spacer rings).

Experimental results
Fig. 2 shows EL (left side, red) and DLIT (right side, blue) images of a tandem module with a TCO front and a metal back contact.

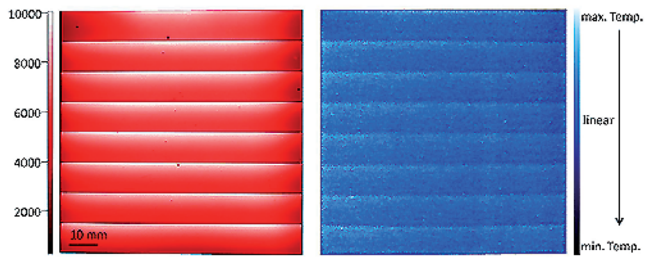

Fig.2 Electroluminescence (left) and thermography (right) images of a tandem solar module (colour coding for a better contrast). The difference between minimum and maximum temperature is a couple of Kelvin [4].

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The upper regions of each cell stripe show a high intensity in both methods. This is caused by the current density profile in the cells. In regions of high current density the luminescence intensity is increased (bright areas) while for low current densities the intensity is small (darker areas). The high current density leads also to the characteristic heat distribution in the DLIT images.

In inactive (dark) areas no electron hole recombination takes place. They are caused by mechanical defects and shunts (short circuit between the front and the back contact). Also the dark areas between the single cells, caused by laser scribing, can easily be identified. In this region a very small signal is observed in EL as well as in DLIT.

Further small dark spots can be seen in the EL image which cannot be detected by thermal imaging due to the high resolution of the iKon-M. The lack of signal in the thermal image indicates that the reason for these spots is not a shunt. This would appear as bright spots in DLIT due to strong heat dissipation. Rather, there must be a mechanical defect.

Fig. 3 shows an EL (left side) and DLIT (right side) image of a similar module as shown in Fig. 2.

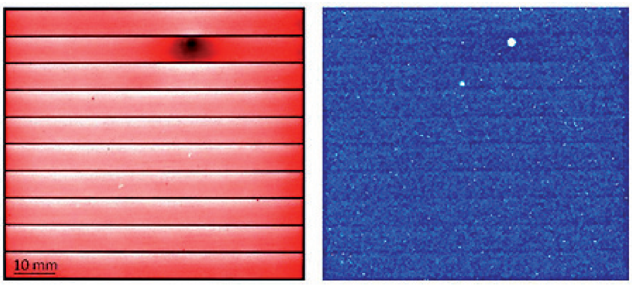

Fig. 3 EL (left) and thermal (right) images of a tandem solar module with a shunt in the second uppermost cell

There is a dominant shunt in the second uppermost cell as can be seen in both methods. On the one hand a shunt leads to ohmic losses, so that heat development occurs, which leads to a strong signal in DLIT. On the other hand in the EL a dark spot can be seen. The current flows almost exclusively through the shunt and not through the silicon surrounding. No radiative recombination of electrons and holes takes place.

In Fig. 4 a module with both, shunts (right side) and mechanical defects (encircled), is shown. The mechanical defect is enlarged in Fig. 5 (left) together with a photomicrograph (right).

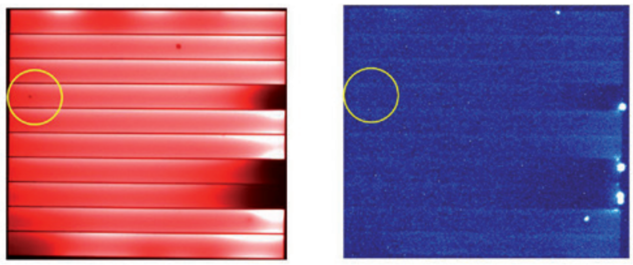

Fig. 4 EL (left) and thermal (right) images of a tandem solar module with shunts and mechanical defects of which one is marked.

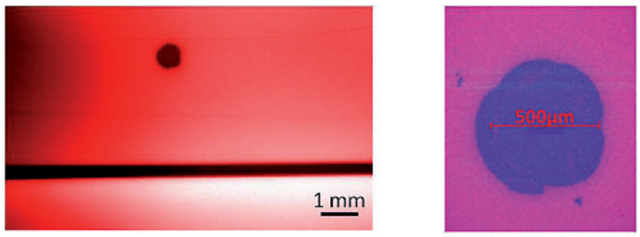

Fig. 5 EL image (left) and photomicrograph (right) of a mechanical defect

Comparing both images reveals the accuracy of the EL imaging. The shape and other features like the defined edges visible in the photomicrograph are well reproduced in the EL image. Thus the resolution of the iKon-M CCD detector is sufficient to analyze even the shape of defects.

Obviously the mechanical defect does not effect its environment. Only the defect location appears dark, while the surrounding is as bright as the rest of the cell.

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Conclusion

EL imaging is a usefull charcterization method for thin film silicon solar cells. Especially in combination with other characterization techniques like thermography or photomicrography, it is well suited to identify defects and their nature. It enables to differentiate between shunts and mechanical defects. Using optical filters (not shown in the examples above) offers an easy possibility to obtain spectral information about the electroluminescence and thereby about the electronic band structure. By its versatility EL imaging is applicable in quality control as well as fundamental research.

References

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