PROPERTIES OF SOLAR CELLS/MODULES WITH SELECTIVE EMITTER ON MULTI-CRYSTALLINE SILICON

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1. Introduction

In recent years, some suitable solutions to produce solar cells with selective emitter have been established. One of the simplest but also most advanced methods is laser-doping of PSG (Hahn, 2010). The process will result in an increase in efficiency for mono- as well as for multi-crystalline cells (Köhler et al., 2009). A detailed analysis of industrially produced multi-crystalline silicon solar cells with selective emitter is given here. The function of these cells in the module in comparison to standard cells is shown. Advantages and disadvantages of this technology in industrial applications are investigated.

2. Experimental

Groups of cells with different laser-doping have been produced and characterized. The best diffusion parameters were determined on mono-crystalline wafes. These parameters were used to produce multi-crystalline cells with selective emitter at an industrial scale.
Based on the same silicon material two groups have been built, to produce cells with standard process with an emitter at 80 ohm/sq as a reference and with selective emitter at 115 ohm/sq. First, the material was homogenized, so that adjacent wafers were included in both groups, thus eliminating the risk of different behavior of the base material in both groups. Electrical parameters have been compared and analyzed. Modules were assembled and the power loss from cell to module was analyzed.

3. Results and Discussion

Key electrical parameters of a solar cell, such as open circuit voltage (U_{OC}), short circuit current density (J_{SC}), efficiency (ETA), filling-factor (FF), serial resistance (R_{SER}) and parallel resistance (R_{SHUNT}) have been compared between reference group and selective emitter group. As a first result an ETA gain of 0.26 % in multi-crystalline cells was found with selective emitter (Fig.1a).

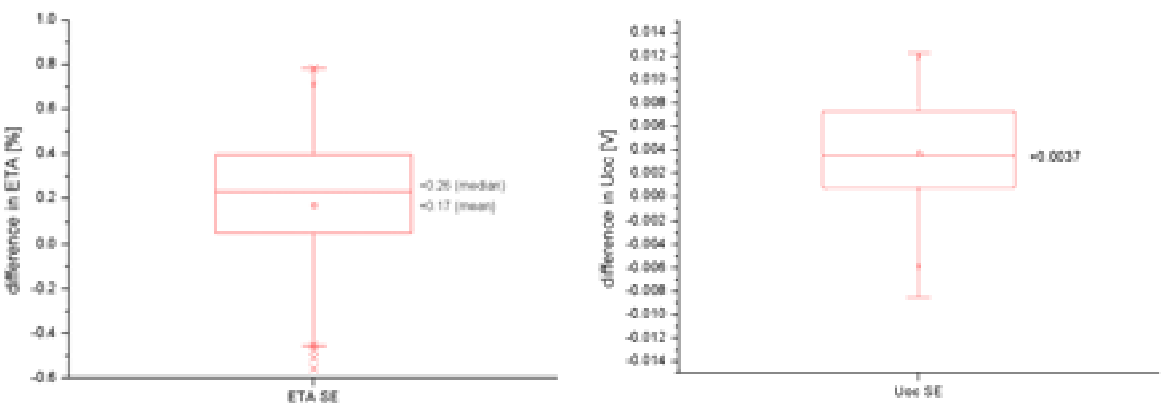

Fig.1: a) Difference in ETA and b) Uoc (mean) between reference group and selective emitter group

This gain is caused by strongly higher J_{SC} and U_{OC}. Cells with selective emitter profit from a higher emitter resistance. A high-ohmic emitter shows a lower recombination activity, so that the emitter saturation current is decreasing and voltage rises (Fig.1b). Parallel to this effect the lower Auger-recombination leads to a higher current density in the blue spectral range. An increase in the J_{sc} is the result (Fig. 2a). As a drawback the FF is reduced by 0.43 % (Fig.2b).

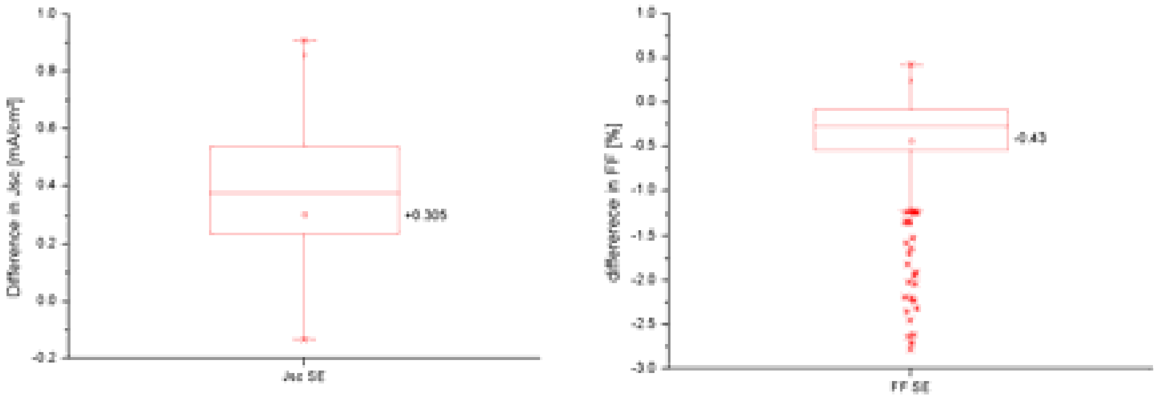

Fig.2: a) Difference in Jsc and b) FF between reference group and selective emitter group

The reason for the lower FF is a higher R_{SER} (Fig. 3a). For both, the reference group as well as the selective emitter group, the same grid design was used. With the high-ohmic emitter, the selective emitter cells show worse transverse conductivity. This is the reason for the higher R_{SER} in the selective emitter group.

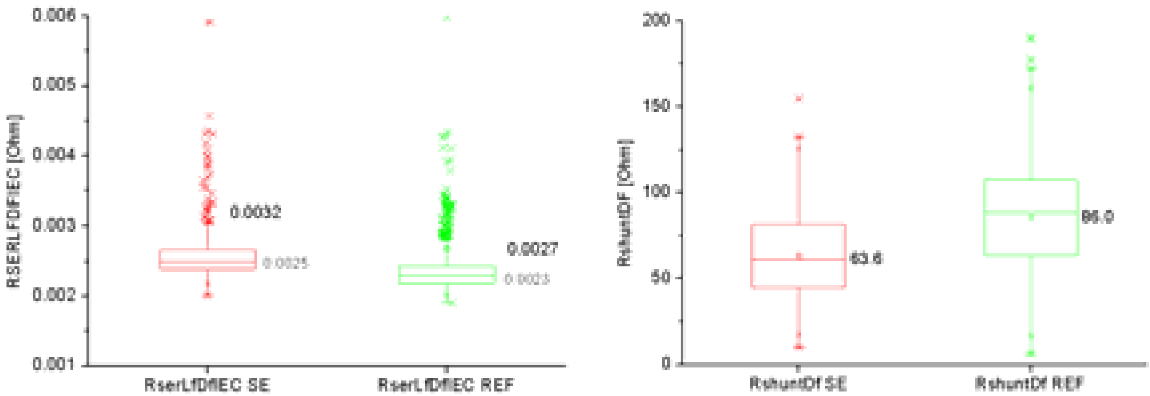

Fig.3: a) Difference in R_{SER} and b) R_{SHUNT} between reference group and selective emitter group

The selective emitter group can also be distinguished by a lower R_{SHUNT} (Fig.3b). In general, there are two types of shunts, which are characterized by linear and nonlinear behavior. The majority of linear shunts is process-induced (e.g. by bad laser edge-isolation), whereas nonlinear shunts are often caused by impurities in the space charge region (Breitenstein 2007).

Another important parameter is I_{REV2} (reverse current on dark field measurement at -10V). This parameter is an indicator for hot spot problems in solar cells. A high I_{REV2} indicates nonlinear shunts.

It was shown, that cells with selective emitter have a significant deviation in reverse current on dark field measurement (Fig.4a, b). This nonlinear breakdown behavior was no shown by mono-crystalline silicon (Fig.4a).

Cells, made from neighboring wafers of multi-crystalline silicon with a standard emitter, have a higher breakdown threshold in comparison to cells with high-ohmic selective emitter (Fig.4b). The initially suspected influence of laser-doping on the I_{REV2} could be excluded through thermography measurements.

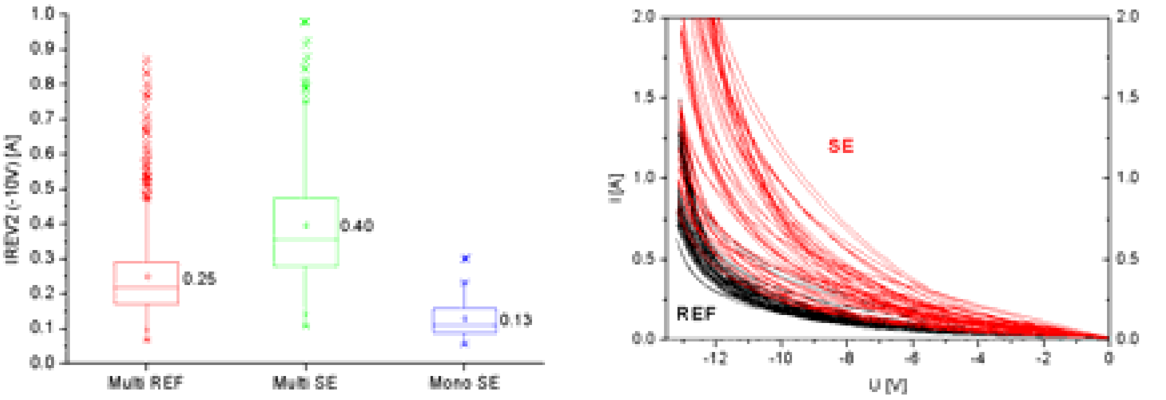

Fig.4: a) Difference in I_{REV2} between multi-crystalline silicon solar cells with standard emitter, selective emitter and mono-crystalline cells with selective emitter; b) cells from neighboring wafers (comparable material): differences in reverse current of standard cells and selective emitter cells

By further investigation, linear and nonlinear shunts were separated (compare Fig. 5a-d). On neighboring cells, the breakdown area was exactly at the same position. Analysis of electroluminescence images indicated, that the breakdown area contains strong dislocation networks (compare Fig. 5d and 5e). Standard cells also show a breakdown at strong dislocations, but the breakdown threshold is higher.

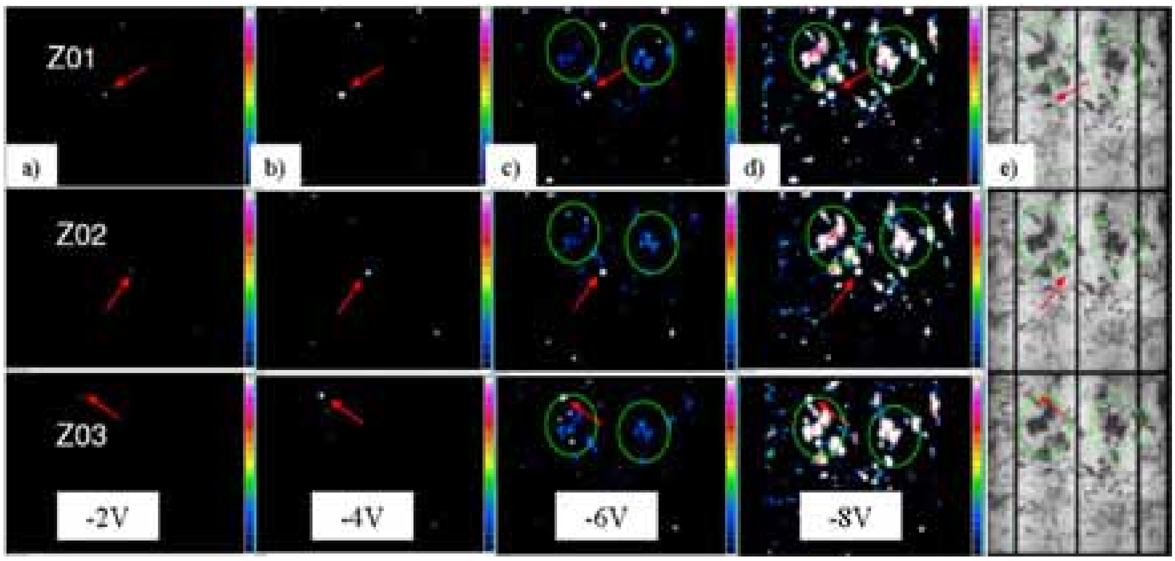

Fig.5: linear shunt: red arrow; nonlinear shunt: green circle; a) cell 1-3: thermography at -2V reverse current; weak linear shunts visible; b) cell 1-3: thermography at -4V reverse current; just linear shunts visible; c) cell 1-3: thermography at -6V reverse current; nonlinear breakdown begins at dislocations; d) cell 1-3: thermography at -8V reverse current; strong nonlinear breakdown at dislocations; e) electroluminescence measurements

Breakdown behavior is influenced only by the high-ohmic emitter. Changes of the temperature profile at the diffusion furnace (inline spray diffusion) aiming at an even more high-ohmic emitter seem to lead to a worse reverse current behavior and thereby to a lower breakdown threshold.

In the Conergy process cells with I_{REV2} above an internal limit are not used to build up modules to avoid hot spots. For the selective emitter, studies show, that I_{REV2} is higher compared to standard solar cells and that yield loss, due to the internal I_{REV2} limit, will be slightly higher. The reason seems to be a combination of material parameters and the thin, high impedance emitter, created by inline diffusion (Schieferdecker et. al.; Germershausen et. al.). There are not more outliers of I_{REV2} in the selective emitter group compared to the reference group, but the all values are shifted by a constant factor (Fig. 6).

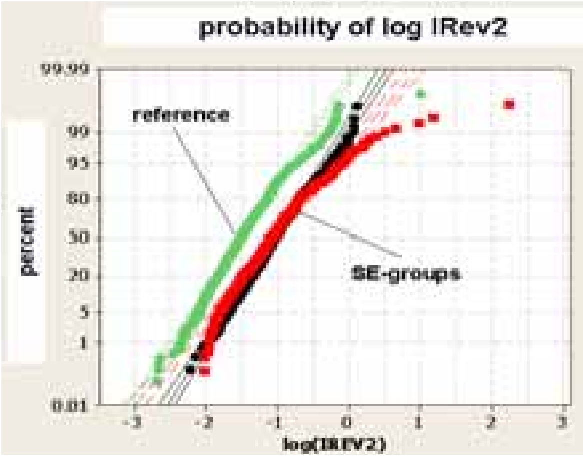

Fig.6: probability net plot of I_{REV2} of cells with selective emitter and cells of a reference group with standard emitter at 80 Ohm/sq

To investigate the influence of cells with high I_{REV2} in more detail, modules have been built up with bad cells. To simulate the shading case, both, normal cells and cells with a low threshold for break-through were partially shaded (real-life test). It was found that normal cells have become less hot and that their temperature has risen homogeneously. Cells with high I_{REV2} above the Conergy internal limit show especially in the field of the dislocation networks strong hotspots (Fig.7). This can have a rather negative effect on the reliability of the module in the field under real-life conditions.

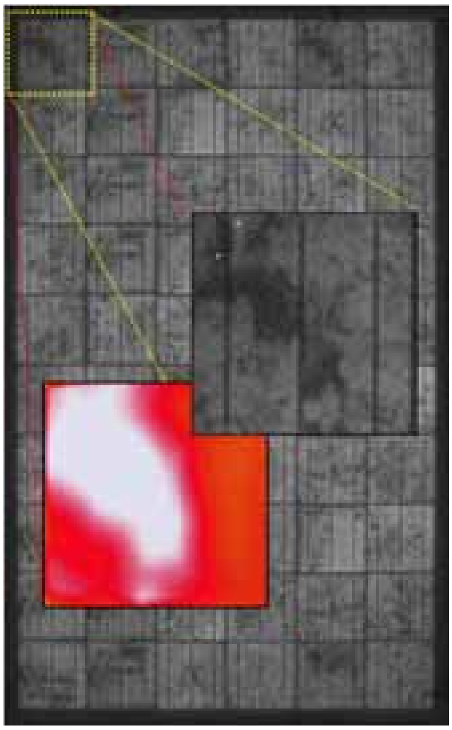

Fig.7: electroluminescence image of a multi-crystalline solar module: cells with a low breakdown threshold are getting hotter in the area with high dislocation density (part of the cell is shaded, so that this cell is not power generator but a power consumer)

To study the performance loss from cell to module between selective emitter group and reference group several modules were built up. Parameter, such as P_{MPP} (power at maximum power point), FF (filling factor), U_{OC} (open circuit voltage) and I_{SC} (short circuit voltage) were measured to determine the performance (Fig.8).

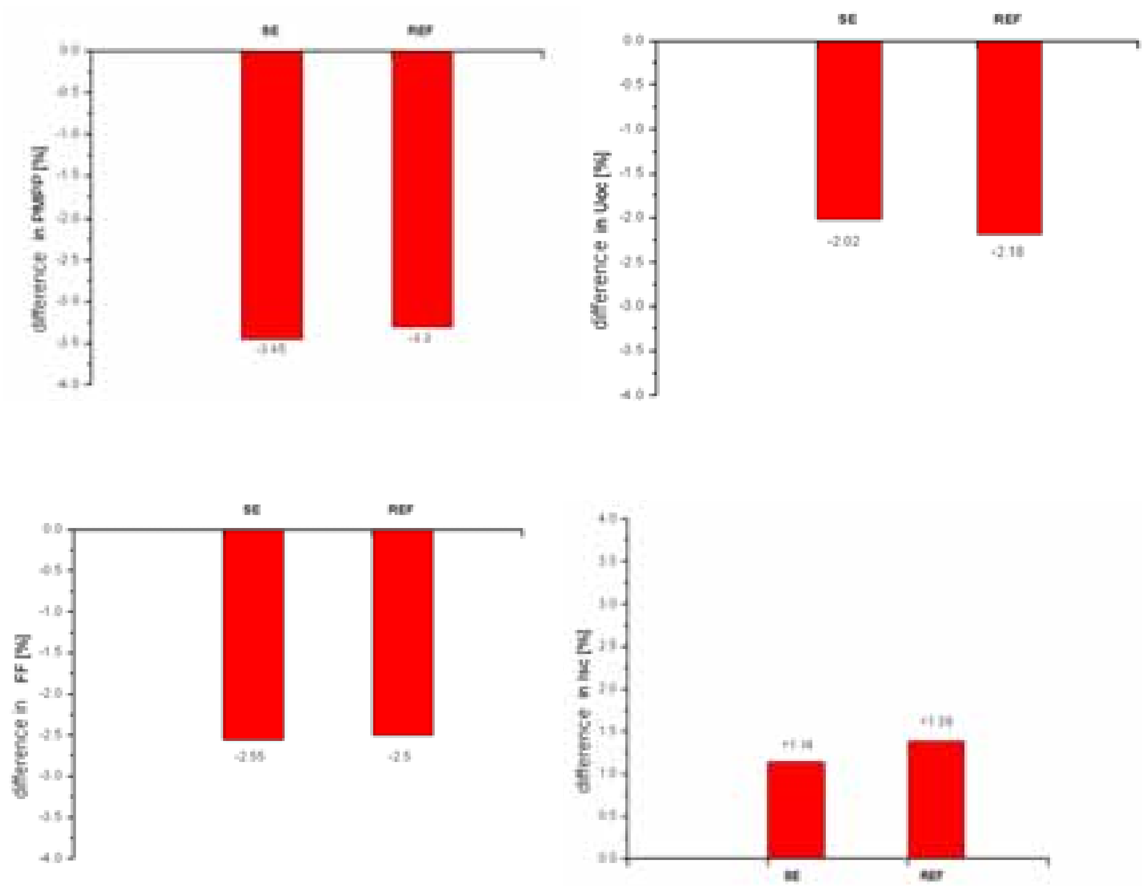

Fig.8: performance loss from cell to module: a) P_{MPP}, b) U_{OC}, c) FF and d) I_{SC}

The modules assembled of cells out of the selective emitter group have not shown any significant higher power losses from cell to module compared to modules assembled of cells out of the reference group (Fig.8a). The same applies to U_{OC} and FF (Fig.8b, c). Only the coupling gain of I_{SC} for the selective emitter is slightly lower (Fig.8d). That could be due to the fact that cells with selective emitter have shown better internal quantum efficiency in the blue spectral range (Küsters et. al. 2010). The EVA foil absorbed a part of the incident light in this spectral region. As a consequence a part of the initial current of the selective emitter cells could not be transferred into the module. However, these losses seem marginally, the total output loss (from cell to module) between selective emitter and reference process is comparable.

4. Conclusion

The experiments show a gain of ETA, U_{OC} and J_{SC} and a draw back in FF due to higher serial resistance. The higher serial resistance can be reduced by optimized grid design. To reduce the parameter yield loss, caused by higher I_{REV2} in selective emitter cells, there are two options: Only material with a small amount of grain boundaries and dislocations should be used and the formation of a deeper and more homogenous emitter should be established. The behavior of selective emitter cells in the module is comparable to conventional cells.

5. References

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