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Light beam induced current of light-induced degradation in high-performance multicrystalline Al-BSF cells

Jeanette Lindroos[a,]*, Kai Petter[b], Kai Sporleder[c], Marko Turek[c], Paolo Pacho[a], Markus Rinio[a]

[a]Department of Engineering and Physics, Karlstad University, Universitetsgatan 2, 65188 Karlstad, Sweden
[b]Hanwha Q CELLS GmbH, Sonnenallee 17-21, 06766 Bitterfeld-Wolfen, Germany
[c]Fraunhofer Center for Silicon Photovoltaics CSP, Otto-Eissfeld-Str. 12, 06120 Halle (Saale), Germany

Abstract

Multicrystalline silicon solar cells are plagued by different types of light-induced degradation (LID), including Sponge-LID. Sponge-LID decreases the Al-BSF cell efficiency by up to 10 %rel. and is only partially recoverable at 200°C. This contribution shows that Sponge-LID occurs at and near most grain boundaries, but only in the centre of the affected cell. Furthermore, Sponge-LID is not the only type of LID in the silicon bulk. High-resolution Light Beam Induced Current mapping reveals local internal quantum efficiency losses of up to 8 %rel. at dislocation clusters and small angle grain boundaries, which recover (nearly) fully at 200°C. Nevertheless, this dislocation-related LID appears to reduce the Al-BSF efficiency by less than 1 %rel.

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1. Introduction

In addition to boron-oxygen LID (BO-LID), industrial high-performance multicrystalline (hpmc) silicon solar cells can suffer from light- and elevated temperature-induced degradation (LeTID) [1,2] or Sponge-LID [3,4]. LeTID forms in Al-BSF and PERC cells as homogenous grain degradation [5,6], which worsens with increasing

* Corresponding author. Tel.: +49 7531 88 2081
E-mail address: jeanette.lindroos@alumni.aalto.fi

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temperature and/or injection level [1,2]. Sponge-LID is a non-uniform type of bulk LID [4] in Al-BSF cells from the lowest third of the ingot, which appear strongest (up to 10 %rel.) near the grain boundaries [3,4]. Increasing the intensity or temperature makes Sponge-LID form faster, but no increase is observed in the defect density [4]. The 200°C anneal that reverses BO-LID has been shown to recover only some two thirds of Sponge-LID [3]. The involvement of interstitial iron has been excluded, as Sponge-LID occurs over days of illumination and does not change after dark storage [3].

Previously, Sponge-LID has been characterized with fast but low-resolution photo- (PL) or electroluminescence (EL) [3], and medium-resolution Light Beam Induced Current (LBIC) [4]. Nevertheless, the non-uniform distribution of Sponge-LID requires analysis at higher spatial resolutions, in order to identify the responsible defect. As the short-circuit current (I_{SC}) is very sensitive to Sponge-LID [4], this contribution presents internal quantum efficiency (IQE) maps measured down to 12.5-µm spatial resolution. After illumination and 200°C recovery annealing, we conclude that Sponge-LID is not the only non-uniform LID effect in the hpmc-Si Al-BSF cells.

2. Experimental details

Boron-doped wafers from the bottom (~5 cm height) and the middle (~10 cm height) of two hpmc-Si ingots were processed into two different types of Al-BSF cells at Hanhwa Q Cells GmbH. The bottom cell subjected to process A was expected to suffer from Sponge-LID, while process B had been shown to eliminate the effect [3]. The IQE was mapped with LBIC at spatial resolutions of 12.5, 50, and 250 µm. The spatial resolution refers to the step size and the matching beam width. At the incident wavelength of 826 nm, the IQE is dominated by the bulk minority carrier recombination lifetime but also affected by back-surface recombination. The laser power was kept at 1.7 µW to induce low injection (10^{12}-10^{13} cm^{-3}) [7]. The cells were illuminated by a 1-sun halogen lamp for up to 110.5 h at 40±5°C, and dark annealed at 210±10°C for 2 min. Before each LBIC measurement, the cells were stored overnight in the dark to allow the formation of FeB. At each step, the I-V response was measured independently at standard testing conditions.

Next, the cells were laser cut into samples of 25 mm x 25 mm, and subjected to grinding and polishing. The samples were then Secco etched for 1 min, after which the surface grain structure was imaged automatically by an optical OLYMPUS microscope at 20x magnification. After manual removal of scratches, surface contamination spots, and grain boundaries from the images, ImageJ was used to extract properties of the etch pits. Finally, the etch pit density map was calculated averaging over a radius equal to the assumed average diffusion length of 645 µm, using a modified Bessel function as weighting function [8].

3. Results and discussion

3.1. Sponge-LID

Figures 1a and b show the IQE maps before and after 99h 33 min of illumination of the bottom Al-BSF cell from process A, which is expected to suffer from Sponge-LID. Figure 1d depicts an average IQE decrease of 3.4 %rel., with local IQE losses of up to 15 %rel. I-V measurements after dark storage (Degraded) in Fig. 2a confirm an j_{SC} loss of 2.1 %rel. and an open-circuit voltage (V_{OC}) decrease of 0.6 %rel., respectively. After dark annealing, Fig. 1c shows partial IQE recovery next to the grain boundaries, but interestingly Fig. 1e reveals that particular areas of the cell recover fully.

In order to better characterize Sponge-LID and determine why certain areas recover fully, the IQE changes in region 1 are displayed at high resolution in Figs. 3a-c. Figure 3d depicts the grain structure of region 2 on top of map 3a, and Fig. 3f shows the grain structure on top of the calculated etch pit density map. Together the images reveal that the fully recoverable area A1 contains grains with high dislocation densities and several small-angle grain boundaries (SAGBs), formed by dislocations. Inside A1, the highest IQE losses of up to 8 %rel. occur at some of the dislocation clusters and SAGBs in Fig. 3d and f. Full recovery at 200°C is usually associated with boron-oxygen LID. However, the homogenous distribution of boron and impurity oxygen cannot explain the non-uniform LID observed at dislocation clusters and SAGBs. Since this recoverable non-uniform LID has also been measured with