Study of Changes in PL Spectrum from Defects in PERC Solar Cells with Respect to LeTID

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Abstract. Illumination at elevated temperature may cause an efficiency loss of more than 10 $\%_{rel.}$ in mc-PERC cells. In this study, we have looked for changes in the photoluminescence spectrum of mc-PERC cells before and after light and elevated temperature induced degradation and, subsequently, after a following regeneration has commenced. We found that combined light and temperature treatment gave different responses depending on if the trap level state in the band gap was deep or shallow.

INTRODUCTION

The purpose of this study was to investigate the light and elevated temperature induced degradation (LeTID) [1] effect in multi-crystalline Passivated Emitter and Rear Contact (mc-PERC) solar cells with hyperspectral photoluminescence imaging [2]. LeTID may cause an efficiency loss of more than 10 $\%_{rel.}$ in mc-PERC cells [1]. It has earlier been shown that when a solar cell is degraded with respect to LeTID, the band-to-band photoluminescence (PL) signal, at 1.10 eV, will be weaker and during regeneration the PL signal will be stronger again [3]. However, little is known about the changes in the defect related luminescence (DRL) spectrum, and if the defects do follow the same pattern as the band-to-band signal.

In our work, we wanted to investigate if all DRL follow the same pattern as the band-to-band (BB) signal, and if not, characterize the differences. We subsequently questioned if the dislocation lines D1-D4 [4] follow different paths.

With the use of hyperspectral PL imaging, changes in the BB and the DRL spectrum in the interval 0.49 – 1.33 eV, have been mapped and analyzed; between initial, degraded and regenerated cells with respect to LeTID.

MATERIALS AND METHODS

Samples investigated in this study were industrially produced mc-PERC solar cells. Several batches of neighboring cells were prepared. Each batch contained cells where one kept as is, one being degraded and one degraded and regenerated. One batch also contained one sample being degraded for only one minute.

The two batches of neighboring cells shown in this paper, batch 5x and 7x, went through slightly different degradation and regeneration treatments. Before degradation, light soaking pre-treatment at 25°C and 1 sun for 24 h was done. This to eliminate light induced degradation with respect to the iron-boron pairs (FeB-LID) [5] and the boron-oxygen-defect (BO-LID) [6].

For batch 5x the degradation was done at 75 °C and 1 sun for 112 h. The regeneration was done at 100°C and 1 sun for 105 h (degraded and regenerated in one go). In addition, batch 5x contained one cell, referred to as Initial, which had not undergone any treatment and one cell which was only degraded for 1 minute. For batch 7x the degradation was also done at 75 °C and 1 sun, but only for 2.5 h. The regeneration was done at 115°C and low injection ($\Delta n = 0.73 \cdot 10^{14} cm^3$) for 158 h. Also in batch 7x, one cell had no treatment and is referred to as Initial.

IV, EQE and LBIC measurements were performed by the cell analysis system LOANA. V_{oc} was measured in-situ during degradation and regeneration.

Hyperspectral photoluminescence imaging was carried out on all the samples using a short wavelength infrared (SWIR) hyperspectral pushbroom camera (Specim, Finland). The output of this technology is a three dimensional data set where a full spectrum is obtained in each pixel of the image. The HgCdTe detector is covering the wavelength range 929 – 2531 nm (1.33 – 0.49 eV) with a spectral resolution of 6 nm. The spatial resolution used in this study was 26µm. As excitation source, an 808 nm line laser was used. The samples were cooled to 90 K.

To separate the different radiative defects, the data were analyzed by multivariate curve resolution (MCR) [7] using MATLAB as platform. MCR is a mathematical method in multivariate statistics for deconvoluting complex, convoluted signals composed of several discrete, simultaneously occurring signals.

RESULTS AND DISCUSSION

For batch 5x, at maximum degradation, the efficiency was reduced by 14.6%$_{rel.}$. For the sample, which went through regeneration, the efficiency was down 5.3 %$_{rel.}$ after regeneration. During regeneration, at maximum degradation, the efficiency was down 17.6%$_{rel.}$. For the degraded sample in batch 7x, at maximum degradation, the efficiency was reduced by 10%$_{rel.}$. For the regenerated sample, after regeneration, the efficiency was down 4.6 %$_{rel.}$. During regeneration, at maximum degradation, the efficiency was down 18 %$_{rel.}$.

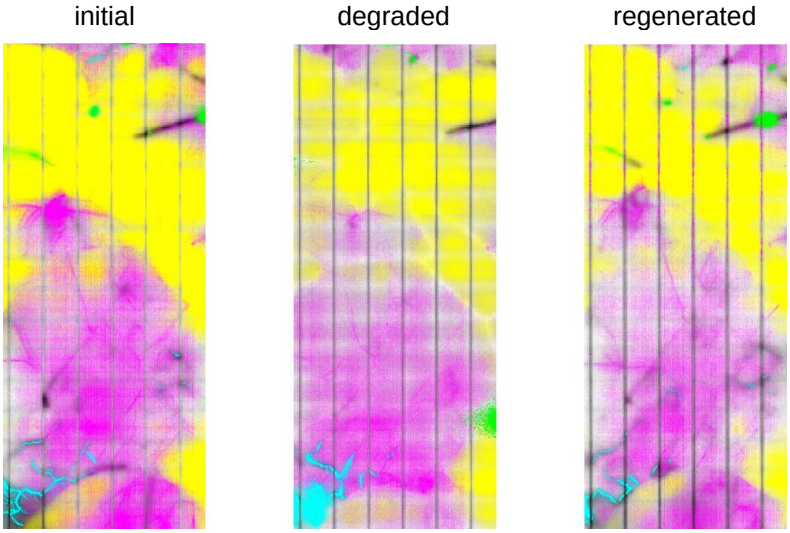

FIGURE 1. MCR analysis of hyperspectral images of initial, degraded and regenerated cell in combination with IQE images. Areas with BB PL shown in yellow, D3/D4 in magenta, D1 in cyan and D07 in green.

MCR analysis of the spatial distribution of different photoluminescence signals in the initial untreated cell, the degraded and the regenerated cell is shown in Fig. 1. The signal from D1 (0.81 eV), D3/D4 (0.93/1.00 eV) and D07(0.72 eV) [8] can be seen in addition to the band-to-band 1.1 eV signal. In combination with IQE images, the D07 and D1 seem to correlate with grain or sub-grain boundaries, while D3/D4 is found in the intra-grain areas.

The changes in the spectrum relative to the initial untreated cell, sample 59, are shown in Fig. 2. For sample 58, which has been exposed to the degradation treatment for only 1 minute in addition to the light soaking pre-treatment, the changes in spectrum can be related to FeB-LID and/or BO-LID. The intensity of the DRL signal below 0.9 eV becomes stronger, while above 0.9 eV it becomes weaker.

For the complete degraded sample, the intensity of the DRL signal below 0.9 eV is on par with sample 58, while above 0.9 eV it becomes even weaker. Throughout the whole spectrum, the intensity is stronger after the regeneration process relative to the degraded state. Below 0.9 eV the signal is stronger than the initial, untreated cell, and weaker for energy levels above 0.9 eV.

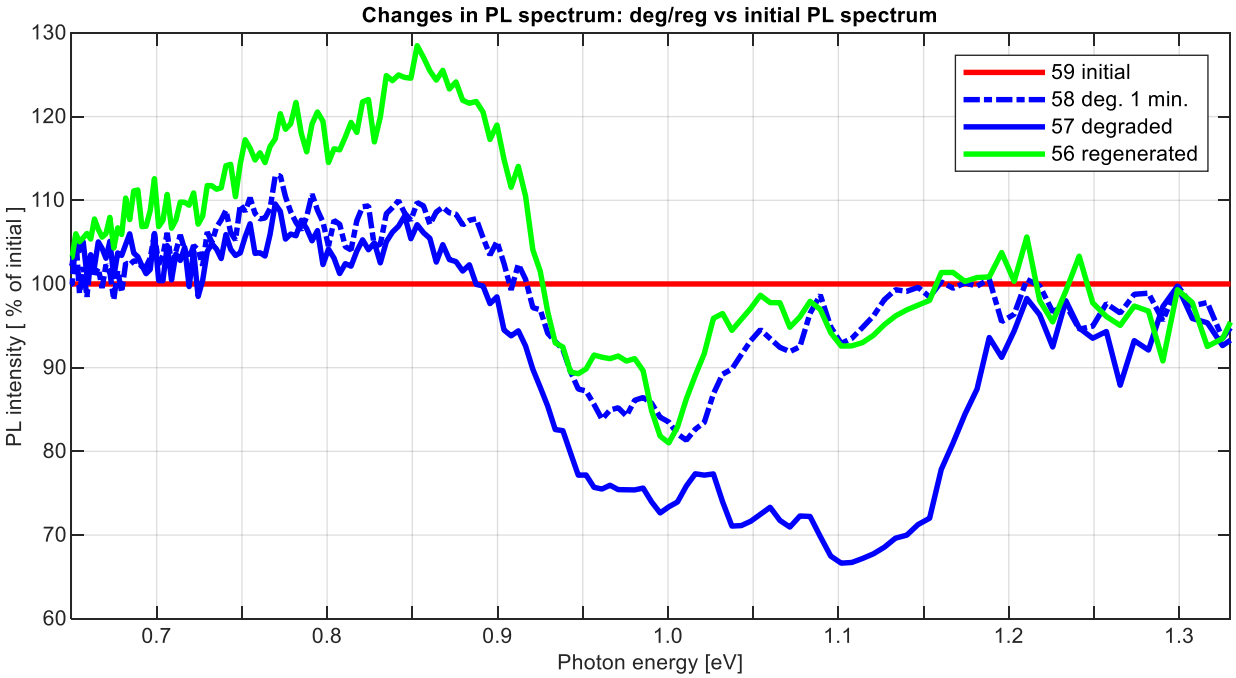

FIGURE 2. Relative changes in PL spectra intensity in percentage from initial (red) of light soaked and one minute of degradation treatment (dotted blue), complete degraded (blue) and regenerated (green).

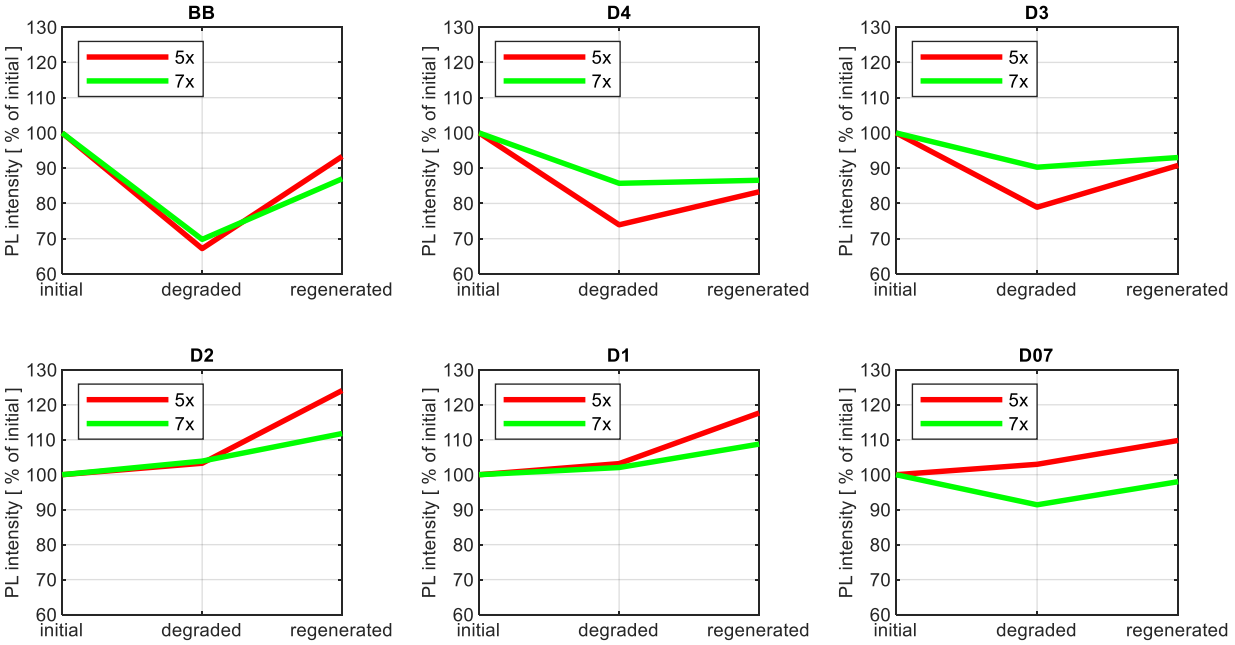

FIGURE 3. Relative changes in PL intensity from initial to degraded and regenerated cell for BB and different DRL. Batch 5x in red and 7x in green.

In Fig. 3, changes in PL spectra intensity from initial to degraded and regenerated cell are shown for two batches, 5x and 7x. The relative changes in intensity of the BB PL signals when degraded and regenerated, compared to its initial value, are higher than for the different DRL. The D3 and D4 DRL follow the same trend, though not as degraded as BB. The D1 and D2 DRL are found to be slightly stronger after the degradation process. As mentioned

before, this can be due to FeB-LID and BO-LID effect during the pre-treatment. After a regeneration process the D1 and D2 DRL are significantly more intense. The D07 signal is also getting stronger after the regeneration, but the degradation process gives different results between the two batches.

D07, D1 and D2 are mostly found in grain and sub-grain boundaries, while BB, D3 and D4 are mostly in intra-grain. This correspond well with the results from Luka et al. [9] which showed a reduced degradation in the grain boundaries. It also appears that regeneration happens all over; regardless of if it is in a grain or at a grain boundary.

CONCLUSION

In this study, we have looked for changes in the photoluminescence spectrum of mc-PERC cells before and after light and elevated temperature induced degradation and, subsequently, after a following regeneration has commenced. Effects of the LeTID have been observed in defect related luminescence. The DRL signals respond differently to LeTID than the band-to-band PL. Thus, it seems that LeTID has a degradation effect in the grains but not in the grain boundaries with respect to the defects.

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