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Different Extent and Behaviour of LeTID in the Past and Current PERC Silicon Solar Cells

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Abstract: The extent and behaviour of light- and elevated-temperature induced degradation (LeTID) varies significantly from manufacturer to manufacturer and from year to year. This paper compares the extent and behaviour of LeTID observed on past and current p-type multicrystalline silicon passivated emitter and rear cells (PERC). We demonstrate that there is high LeTID extent in the old PERC cells, the loss in efficiency is up to $10\%_{rel,}$ the strong degradation is mainly observed in the high lifetime areas (intra-grain regions). On the other hand, only $\sim 2.5\%_{rel}$ efficiency loss is seen on the current PERC cells, and the degradation is highly localised within the high recombination areas (dislocation clusters). This result highlights that now, the extent of LeTID likely depends on the amount of dislocation clusters within the material and mitigation of the degradation from this area requires further optimization.

Introduction: LeTID causes silicon solar cells to degrade in performance; this effect is most pronounced for the PERC structure [1–3]. LeTID has been observed to affect all types of silicon materials including, Ga-doped, float zone (FZ), Czochralski (Cz), n-type, cast-mono, and multi-crystalline silicon (mc-Si), although the extent of LeTID in p-type mc-Si is reported to be much more significant than that of other materials [1,4–7]. From 2012 to 2015, it was reported that LeTID caused performance losses up to $\sim 16\%_{rel}$, depending on the bulk material, position in the ingot and the solar cell processing [1,2,8–10]. However, recently, it has been shown that the extent of LeTID has been reduced to 1-2$\%_{rel}$ [11,12]. Therefore, this work aims to provide a further understanding of the different behaviours of LeTID in the past and the current p-type mc-Si PERC cells from two different manufacturers.

Experimental details and results: In this study, p-type mc-Si PERC solar cells with a resistivity of ~1.1 Ω·cm, were sourced from two different industrial production lines (A and B). For manufacturer A, old (produced in 2015), and new (produced in 2019) p-type mc-Si PERC cells were used, while for the manufacturer B, only new PERC cells were available. All samples were subjected to a stability test at 75 ± 5 °C and 1 sun under a halogen light source. Figure 1 shows a flow diagram of the experiment process sequence. For all samples, the IV measurements were performed using STC at the initial state, and after incremental steps during stability test. The photoluminescence (PL) images were taken using BTi (LIS-R3) luminescence imaging system at the initial state, and at the most degraded point (~200 - 400 hours). To better visualize the localized changes before and after degradation, PL image ratio maps were created by comparing the image at the initial state and after maximum degradation.

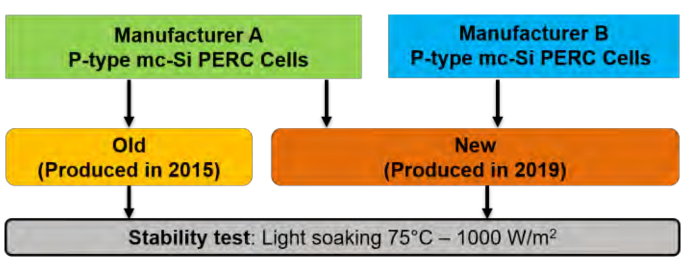

Figure 1. Experimental flow diagram.

Results and discussion

Figure 2 (i) presents the evolution of efficiency (η) and open-circuit voltage (V_{OC}) of all cells after light soaking. It is clear that both η and V_{OC} of old PERC cells from manufacturer A decrease substantially after 200 ~ 300 hours of light soaking, where the η loss is up to 10%$_{rel}$ and V_{OC} is ~ 4%$_{rel}$. However, only <1%$_{rel}$ and ~2.5%$_{rel}$ loss of V_{OC} and η, respectively are seen on new PERC cells from both manufacturers. Note that the kinetics of the current cell from manufacturer B is slightly slower than that of the cells from manufacturer A. This may likely due to different processing used by each manufacturer, and some possible non-uniformity of the ambient temperature during the light soaking. The involvement of hydrogen in LeTID has now been suggested demonstrated by many research institutions [13–16]. The reduction in extent of LeTID may, therefore, be attributed to the optimisation of production lines to limit the excess flow of hydrogen into the wafer bulk, for example, tuning of the SiN_x:H layer [17], a reduction in firing temperature [18,19] made it possible through improved metal pastes and the application of pre- and post-process mitigation strategies to clear out excess hydrogen from the bulk [20,21].

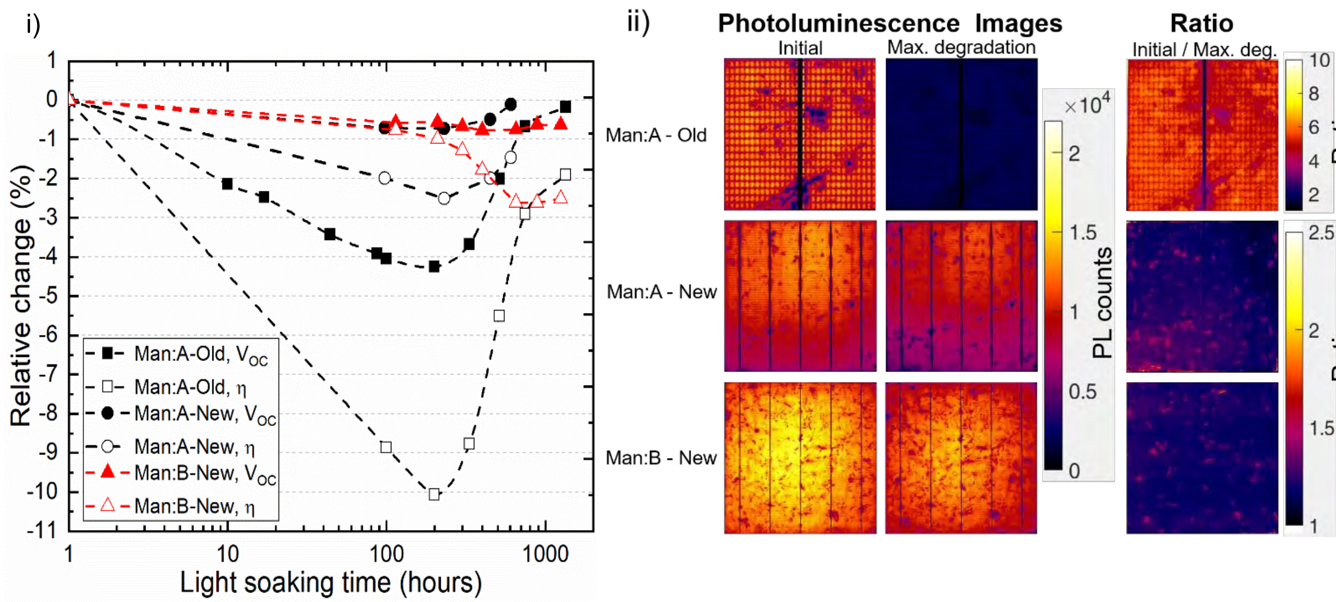

Figure 2. Changes in i) V_{OC} and η relative to the initial value, ii) PL images at initial and maximum degradation (200 ~ 400 hours of light soaking) and PL ratio of samples from Man:A-old) manufacturer A, old PERC cell (Size: 40 m × 40 mm), Man:A-New) manufacturer A, current PERC cell (Size: 156 mm × 156 mm), and Man:B-New) manufacturer B (Size: 156 mm × 156 mm), current PERC cells. The stability testing condition was 75 ± 5 °C with an illumination intensity of 1000 W/m^2.

To better visualise the degradation behaviour of all cells, PL images and PL ratio mapping is shown in Figure 2 (ii). The old PERC cells from manufacturer A exhibited a significant drop in the PL counts after illumination. The reduction was more pronounced on the good area, and the maximum reduction was up to a factor of 10, which was much more severe than the current PERC cells from both manufacturers. The relative loss of PL counts is within a factor of ~2.5, and this degradation is more significant at the dislocation cluster sites. This behaviour is very similar to our recent work [22], where only the dislocation clusters were observed to degrade on the LeTID treated wafers. We hypothesise that this is due to the LeTID treatments clearing out excess hydrogen in the bulk that would otherwise lead to LeTID, preferentially migrating out of the areas where it is weakly bound (intra-grain areas) compared to the areas where hydrogen is more strongly bound to the defects (dislocation clusters). Therefore, only the dislocation clusters, where significant hydrogen concentrations remain, are observed to degrade. This result implies that both manufacturers have applied some approaches to mitigate LeTID in their current cells; however, it appears that approaches to mitigate LeTID in the high recombination-active areas still requires further optimisation. It also suggests that the extent of LeTID may now depend somewhat on the percentage of the dislocations within the material.

Conclusion: This work explores the behaviour of LeTID in the past and the current p-type mc-Si PERC cells from two different manufacturers. The old PERC cells degrade significantly during illumination at 75 °C. At the most degraded pointed, old PERC cell suffers from ŋ losses of ~10 $\%_{rel}$ whiles only ~2.5$\%_{rel}$ was observed on that of the new PERC cells from both manufacturers. PL ratio mapping shows that old PERC cell degrade strongly in good grain but less in the high defect regions. On the other hand, the good grains of the current PERC cells from both manufacturers show hardly change after illumination, and the degradation less at the good grain area while more significant at the dislocation clusters.

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References:

[1] K. Ramspeck, S. Zimmermann, H. Nagel, A. Metz, Y. Gassenbauer, B. Birkmann, A. Seidl, S.S. Ag, S. Solar, W. Gmbh, Proc. 27th Eur. Photovolt. Sol. Conf. Exhib. Frankfurt, Ger. (2012) 861–865.

[2] F. Fertig, K. Krauß, S. Rein, Phys. Status Solidi - Rapid Res. Lett. 9 (2015) 41–46. http://dx.doi:10.1002/pssr.201409424.

[3] F. Kersten, P. Engelhart, H.C. Ploigt, A. Stekolnikov, T. Lindner, F. Stenzel, M. Bartzsch, A. Szpeth, K. Petter, J. Heitmann, J.W. Muller, 2015 IEEE 42nd Photovolt. Spec. Conf. PVSC 2015. (2015). http://dx.doi:10.1109/PVSC.2015.7355684.

[4] D. Chen, M. Kim, B. V. Stefani, B.J. Hallam, M.D. Abbott, C.E. Chan, R. Chen, D.N.R. Payne, N. Nampalli, A. Ciesla, T.H. Fung, K. Kim, S.R. Wenham, Sol. Energy Mater. Sol. Cells. 172 (2017) 293–300. http://dx.doi:10.1016/j.solmat.2017.08.003.

[5] J.M. Fritz, A. Zuschlag, D. Skorka, A. Schmid, G. Hahn, Energy Procedia. 124 (2017) 718–725. http://dx.doi:10.1016/j.egypro.2017.09.085.

[6] H.C. Sio, H. Wang, Q. Wang, C. Sun, W. Chen, H. Jin, D. Macdonald, Sol. Energy Mater. Sol. Cells. 182 (2018) 98–104. http://dx.doi:10.1016/j.solmat.2018.03.002.

[7] F. Fertig, R. Lantzsch, A. Mohr, M. Schaper, M. Bartzsch, D. Wissen, F. Kersten, A. Mette, S. Peters, A. Eidner, J. Cieslak, K. Duncker, M. Junghänel, E. Jarzembowski, M. Kauert, B. Faulwetter-Quandt, D. Meißner, B. Reiche, S. Geißler, S. Hörnlein, C. Klenke, L. Niebergall, A. Schönmann, A. Weihrauch, F. Stenzel, A. Hofmann, T. Rudolph, A. Schwabedissen, M. Gundermann, M. Fischer, J.W. Müller, D.J.W. Jeong, Energy Procedia. 124 (2017) 338–345. http://dx.doi:10.1016/j.egypro.2017.09.308.

[8] F. Kersten, P. Engelhart, H.C. Ploigt, A. Stekolnikov, T. Lindner, F. Stenzel, M. Bartzsch, A. Szpeth, K. Petter, J. Heitmann, J.W. Müller, Sol. Energy Mater. Sol. Cells. 142 (2015) 83–86. http://dx.doi:10.1016/j.solmat.2015.06.015.

[9] A. Zuschlag, D. Skorka, G. Hahn, Prog. Photovoltaics Res. Appl. 25 (2017) 545–552. http://dx.doi:10.1002/pip.2832.

[10] K. Petter, K. Hubener, F. Kersten, M. Bartzsch, F. Fertig, B. Kloter, J. Muller, 9th Int. Work. Cryst. Silicon Sol. Cells. (2016) 1–17.

[11] REC Group, Combatting LeTID in multi and monocrystalline solar panels : (2019). available: https://www.recgroup.com/sites/default/files/documents/wp_-_letid_resistance_of_rec_modules_web.pdf.

[12] PV Magazine, Let's mitigate LID and LeTID, PV Mag. (2018). available: https://www.pv-magazine- india.com/2018/03/17/lets-mitigate-lid-letid/.

[13] D. Chen, P.G. Hamer, M. Kim, T.H. Fung, G. Bourret-Sicotte, S. Liu, A. Chan, Catherine E., Ciesla, R. Chen, M.D. A, Abbott, B. Hallam, S.R. Wenham, Sol. Energy Mater. Sol. Cells. 185 (2018) 174–182. http://dx.doi:10.1016/j.solmat.2018.05.034.

[14] M.A. Jensen, A. Zuschlag, S. Wieghold, D. Skorka, A.E. Morishige, G. Hahn, T. Buonassisi, J. Appl. Phys. 124 (2018). http://dx.doi:10.1063/1.5041756.

[15] T. Niewelt, F. Schindler, W. Kwapil, R. Eberle, J. Schön, M.C. Schubert, Prog. Photovoltaics Res. Appl. (2017) 1–10. http://dx.doi:10.1002/pip.2954.

[16] D. Bredemeier, D.C. Walter, J. Schmidt, AIP Conf. Proc. 1999 (2018). http://dx.doi:10.1063/1.5049320.

[17] F. Kersten, J. Heitmann, J. Muller, 32nd Eur. Photovolt. Sol. Energy Conf. Exhib. 92 (2016) 507–509.

http://dx.doi:10.4229/EUPVSEC20162016-2DO.2.6.

[18] C.E. Chan, D.N.R. Payne, B.J. Hallam, M.D. Abbott, T.H. Fung, A.M. Wenham, B.S. Tjahjono, S.R. Wenham, IEEE J. Photovoltaics. 6 (2016) 1473–1479. http://dx.doi:10.1109/JPHOTOV.2016.2606704.

[19] K. Nakayashiki, J. Hofstetter, A.E. Morishige, T.T.A. Li, D.B. Needleman, M.A. Jensen, T. Buonassisi, IEEE J. Photovoltaics. 6 (2016) 860–868. http://dx.doi:10.1109/JPHOTOV.2016.2556981.

[20] B.J. Hallam, C.E. Chan, R. Chen, S. Wang, J. Ji, L. Mai, M.D. Abbott, D.N.R. Payne, M. Kim, D. Chen, C. Chong, S.R. Wenham, Jpn. J. Appl. Phys. 56 (2017) 08MB13.

[21] C. Sen, C. Chan, P. Hamer, M. Wright, U. Varshney, S. Liu, D. Chen, A. Samadi, A. Ciesla, C.M. Chong, B. Hallam, M. Abbott, Sol. Energy Mater. Sol. Cells. 200 (2019). http://dx.doi:10.1016/j.solmat.2019.109938.

[22] C. Sen, C. Chan, U. Varshney, S. Liu, D. Chen, A. Ciesla, C. Chong, B. Hallam, M. Abbott, Sol. Energy Mater. Sol. Cells. 200 (2019) 1000. http://dx.doi:10.1016/j.solmat.2019.109938.