A short time and low temperature bias annealing process to suppress LeTID on cast-mono p-type PERC solar cells

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Abstract

P-type cast-mono PERC silicon solar cells can be susceptible to strong light-and elevated temperature-induced degradation (LeTID). Various approaches have been investigated to suppress LeTID, such as annealing under high-intensity illumination or annealing with current injection, the latter process generally taking several hours. In this work, a proof-of-concept rapid, low temperature biased annealing process has been developed to suppress LeTID in small-area cast-mono PERC cells. Using this process, the relative efficiency drop is reduced from 5% to 2% during light soaking. By varying the cooling conditions, an efficiency increase of 1.2% relative was obtained after the treatment, however this result was not stable under light soaking. Thus there appears to be a trade-off between efficiency improvement and stability. Ongoing work aims to optimise this process to achieve efficiency improvement as well as stabilisation for 6-inch cast-mono PERC cells.

Introduction

Without treatment, multi-crystalline silicon (mc-Si) passivated emitter and rear cells (PERC) can suffer from severe light- and elevated temperature-induced degradation (LeTID) [1], with detrimental impact on cell efficiency. Various approaches have been studied to suppress degradation, including illuminated annealing, annealing with current injection, and modified thermal processes [2-6]. In addition, LeTID behaviour has been observed in p-type cast-mono Si cells [7] with the degradation appearing to be most severe in regions surrounding crystal defects. While the root cause of the degradation is still under investigation, the degradation has been concluded to be related to hydrogen [9]. Various approaches have been utilised to suppress LeTID on cast-mono Si solar cells. Zhou et al. [10] has used heating (200 °C) with high illumination (7 Suns) to effectively reduce the LeTID. They also managed to improve the cell efficiency by a rapid thermal process (RTP) but did not obtain stabilized results. Recently, Wang et al. [11] employed two iterations of a current injection annealing process (4860s for each process) to realise a 1.17% relative efficiency improvement after the treatment and a 1.13% relative efficiency drop after light soak compared to the initial efficiency before any treatment.

In this abstract, we will present preliminary results as a proof-of-concept to demonstrate that a low temperature and short time bias annealing process has limited the efficiency degradation to less than 2% (relative) after the standard light soak of up to 1000 hours at 1 kW/m^2 and 75 °C. Despite the reduced degradation compared to a non-treated cell, a small degradation in performance is seen immediately after treatment. The biased annealing process with a modified cooling condition leads to a relative efficiency increase of 1.2% after treatment, although the efficiency could not be stabilised during the light soak. The optimisation and application of this biased annealing process to the 6-inch cast-mono PERC cells are ongoing, and results will be presented in the final paper.

Experiment

A batch of 6-inch adjacent cast-mono Si wafers were chosen from the middle section of a central brick of a p-type mc-Si ingot provided by an industrial supplier, and then fabricated into PERC solar cells at UNSW. Each cell was cleaved into 10 identical sized tokens, as shown in Figure. 1, sister small cells from the right bottom region of the full cells were treated by different biased annealing processes, since this region contained a comparable amount of both crystallographic defects and “mono” looking regions. The biased annealing system consisted of a hot plate to heat the samples, an aluminium stage with vacuum to provide better thermal uniformity, sprung contact probes, and a voltage source to apply bias across the cells. The system was placed in a light-tight enclosure to ensure a dark annealing process. Cleaved samples were dark annealed at approximately 260 °C, for 5 to 15 minutes as shown in Figure 1. One sister sample was used as a control cell which was not treated but only light soaked. The temperature of the samples during treatment was measured using a thermocouple that adhered to a similar cell of the same size using ceramic paste. During the dark annealing, a reverse bias of 5V was applied. After the specified dark annealing time, the hotplate was adjusted to 220 °C and samples were left on the hotplate to cool. The reverse bias of 5V was maintained until samples cooled to 220 °C at which point the bias was switched to 1V forward bias for the remainder of the cooling to 95 °C. This was done to avoid the reduction in FF that occurs at higher temperatures in the absence of a reverse bias [12]. The whole process including the cooling with bias is referred to in this work as the “biased annealing process”. The biased annealing process was followed by light soaking under halogen lamps (1 kW/m^2, 75 °C) for approximately 1000 hours. The photoluminescence (PL) and IV of the cells were measured on a BT Imaging R3 tool both before and after the biased annealing treatment, and at various points during light soaking.

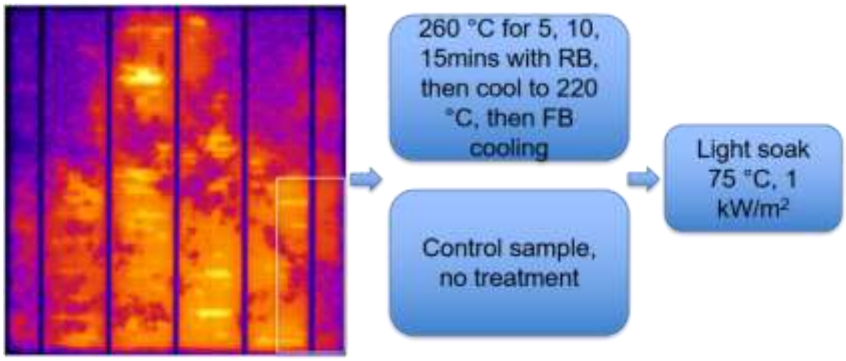

Figure 1 Diagram of experiment flow for the biased annealing process for treated and control samples

Results

- Different biased annealing time

The relative change in PL counts of the cells treated for different times are shown in Figure 2(a). After biased annealing treatment, all cells degraded in PL counts. The cell treated for 5 mins showed the largest decrease in PL counts (~20%). The PL counts of the cells treated for 10 and 15 mins decreased by ~10%. During the light soak, PL counts were quite steady regardless of the time of the treatment, whereas the PL counts of the control cell dropped rapidly during the first 200 hours and then stabilized. The relative change in efficiency for each cell is shown in Figure 2 (b), the sample annealed for 10 mins showed the least degradation of up to approximately 2% relative, and also regenerated more rapidly after 500 hours light soaking, although there was a relative 1.2% efficiency decrease after the treatment. By contrast, 5 mins treatment caused more efficiency degradation, and the control cell without biased annealing treatment degraded up to 5% relative (Repeat experiments are underway to confirm the efficiency evolution during the light soak, since these were preliminary results.)

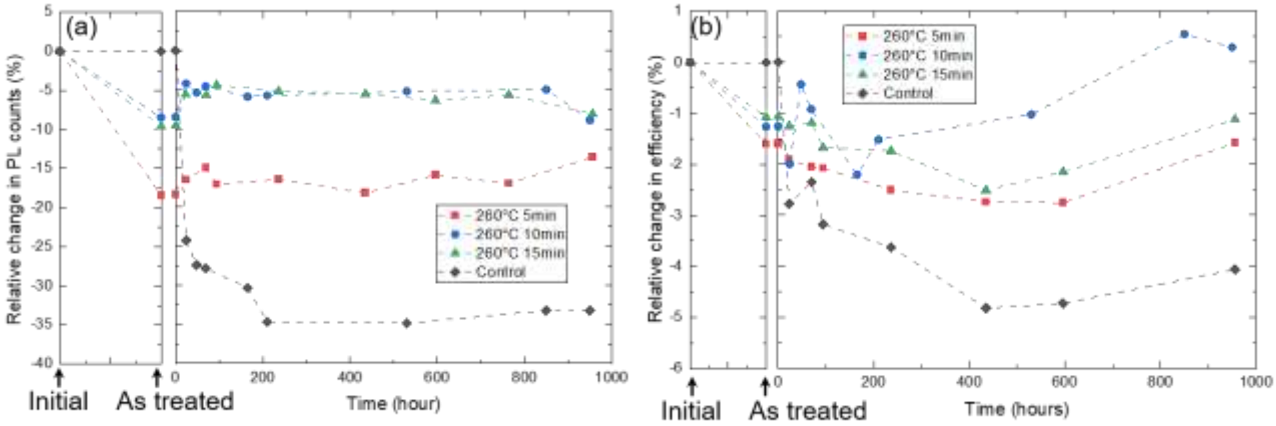

Figure 2. Relative change in (a) PL and (b) efficiency after treatment and during the light soak process for samples bias annealed at 260 °C for 5, 10 and 15 mins and no treatment (control)

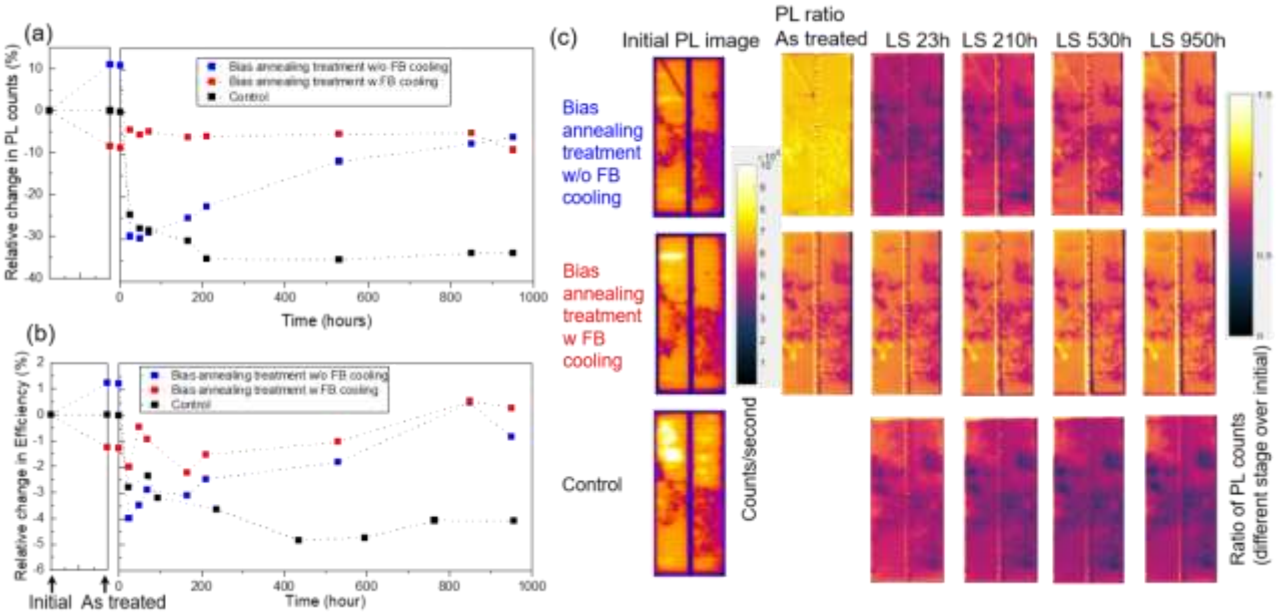

Figure 3 Relative change in (a) PL counts and (b) in efficiency, and (C) initial PL images and PL image ratios of treated sample and control sample at different stage over initial value

- Cooling with forward bias

The step of cooling with forward bias (FB) has been seen to be key for fully suppressing LeTID on mc-Si PERC cells in our research team. This allows the injection of carriers during cool down which accelerates the formation and recovery of any remaining LeTID-related defects after the dark anneal, in a similar way to how stabilisation is achieved from an illuminated annealing process [13]. In order to demonstrate the effectiveness of this FB cooling on the cast-mono cells in this work, another sister cell was treated using the best recipe of the bias annealing process (260 °C for 10 mins followed by cooling to 220 °C, all with 5V reverse bias), but instead of continuing FB cooling to 95 °C, the sample was taken off the stage directly after removing the bias voltage. As shown in Figure 3 (a), without FB cooling, the PL was increased just after the treatment, but decreased dramatically after 23 hours light soak. This was followed by a gradual regeneration and the relative change of the PL counts reached almost the same as that with FB cooling after 800 hours light soak. PL counts for the control sample only showed rapid degradation and then stabilization without any regeneration. Efficiency evolution (Figure 3 (b)) of these samples also showed similar trend to the PL counts. The initial PL images and PL ratio at different stages over initial value for these three samples are presented in Figure 3 (c), which provided clear evolution of PL counts. It is worth noting that the regions with crystallographic defects degraded faster than the “mono” looking regions. With FB cooling step, the degradation has been effectively suppressed in both regions.

Conclusion

To summarise, a proof-of-concept biased annealing process has been developed to suppress the LeTID of small cast-mono PERC cells, although this treatment has caused a relative 1.2% decrease in cell performance. Without FB cooling step, the efficiency increased by 1.2% relative after the treatment, however, it could not be stabilised during the light soak. Future work will optimise this process to achieve efficiency improvement as well as stabilisation.

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