

Influence of Dielectric Layers and Thermal Load on LeTID

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Abstract. Light and elevated temperature induced degradation (LeTID) is observed for multicrystalline (mc) Si passivated emitter and rear cell (PERC) solar cells, strongly limiting solar cell parameters under operation conditions. In this contribution, we investigate the effect of surface passivation layer being present during the firing step based on lifetime samples. The LeTID effect is only observed if the surface passivation layer is present during the firing step. Samples without firing step show no LeTID. A re-passivation of the surface significantly changes the LeTID effect, showing that the whole sample treatment, temperature load and hydrogen content of a sample has to be taken into account investigating and evaluating LeTID.

INTRODUCTION

LeTID affects the performance of mc-Si PERC solar cells [1]. The underlying effect or mechanism of LeTID is still unknown. The effect can also be observed on lifetime samples [2, 3]. It is known that firing conditions like peak temperature and cool-down ramp affect the LeTID strength [4, 5]. Additionally, an influence of different surface passivation layers has been shown [6, 7]. The chosen surface passivation layer and the firing conditions determine the amount of hydrogen in the bulk of the sample, therefore the influence of hydrogen on LeTID is currently under discussion [8].

EXPERIMENT

For the experiment 5x5 cm² high quality mc-Si wafers adjacent in ingot height (sister samples) with B-doping (~1 Ωcm) were used. By using sister wafers, a comparable material quality as well as very similar grain and defect structure can be achieved. A floatzone (FZ) reference wafer (~1 Ωcm) was also processed to ensure the high quality of the final surface passivation. All samples were chemically etched to remove saw damage. To compare samples with and without a P-gettering step, some samples received a POCl₃ diffusion step (55 Ω/□), followed by a variation in surface passivation and firing as shown in Fig. 1. The 75 nm thick SiN_x:H layer, deposited on both sides, was realized by a direct PECVD (plasma-enhanced chemical vapour deposition) system from centrotherm, while a FlexAL system from Oxford Instruments was used for ALD (atomic layer deposition) of Al₂O₃ layers (30 nm, both sides) followed by annealing at 420°C for 20 min in a quartz tube furnace in nitrogen atmosphere. A firing step was performed in an industrial belt furnace (c.FIRE from centrotherm) at 800°C set peak temperature.

To compare LeTID on the differently processed samples, samples were etched back and received an ALD Al₂O₃ passivation (if not already present) (see Fig. 1). An illumination of 1 sun using halogen lamps on a hotplate at 225°C was used to investigate degradation and regeneration behavior in a relatively short time frame. Effective minority charge carrier lifetime (τ_{eff}) measurements of the samples were performed repetitively using TR-PLI (time resolved photoluminescence imaging) [9] at room temperature.

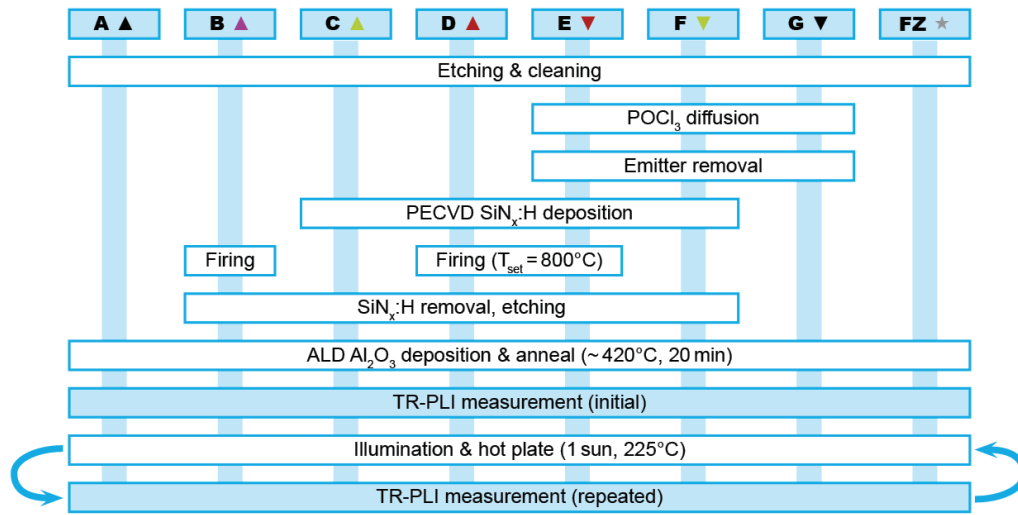


FIGURE 1. Processing steps of mc-Si sister wafers (A-G) and FZ reference.

RESULTS

The process sequence of sample E involved both gettering and hydrogen passivation, similar to the steps used in the production of a solar cell. The average initial τ_{eff} of approximately 540 μs demonstrates the very high quality of the chosen mc-Si material, locally τ_{eff} is reaching up to 1 ms (see Fig. 2(a)).

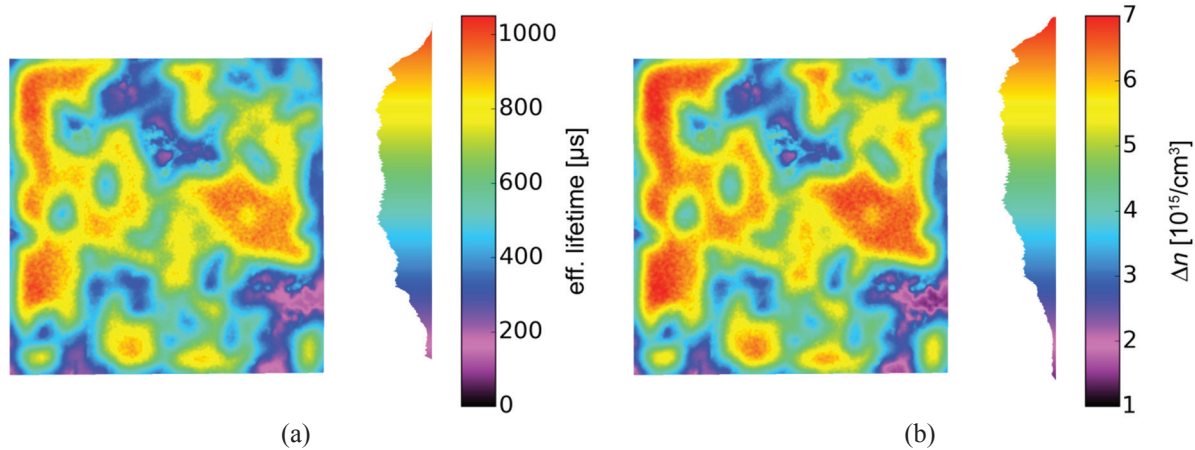


FIGURE 2. (a) Map of the initial lifetime for sample E, locally reaching up to 1 ms. (b) Map of the corresponding injection level Δn . During the TR-PLI measurement process the sample is repetitively illuminated using an LED array ($\lambda=630$ nm) with a photon flux corresponding to 1 sun.

Figure 3 shows the harmonic average τ_{eff} of the samples A-G and FZ. Only samples with a SiN_x:H layer present during firing (samples D and E) showed a pronounced LeTID and regeneration effect within the first hour. Note that LeTID is less pronounced at higher degradation temperatures chosen in this experiment as shown in [10]. The influence of the P-gettering step on the harmonic average τ_{eff} during LeTID and regeneration is negligible which can be seen by comparing the ungettered sample D and the gettered sample E. This can be explained by the already very high material quality of the chosen mc-Si, in contrast to [2, 3]. Sample C without firing step showed a comparable

initial τ_{eff} to samples D and E but no LeTID effect was observed, leading to the assumption that the $\text{SiN}_x\text{:H}$ layer has to be present during firing to activate LeTID. The same can be seen on sample F though on a lower lifetime level.

As a first result, sample B shows the absence of LeTID due to a missing passivation layer during firing. Instead, a slight improvement of its lifetime during the initial hours of degradation treatment is visible, also seen in [11]. The firing of sample B was performed as a “sandwich”, using cleaned mc-Si dummies on upper and lower side to avoid contaminations during the firing process. Due to this variation the result should be double-checked regarding possibly different firing temperatures and contaminations. Besides the different thermal load of the fired and unfired samples, the amount of hydrogen in the sample is also different, depending on the chosen combination of surface passivation layer and firing conditions. After approximately one day τ_{eff} of all samples dropped down, probably due to a decrease in surface passivation quality as can be also observed on the reference FZ sample. A study by Sperber *et al.* on different surface passivation layers showed that all exhibit an increasing surface recombination after many hours of exposure to illumination and elevated temperature [12].

Samples A and G showed no LeTID, too. The harmonic average τ_{eff} remained relatively stable over 24 h. The slight decrease in τ_{eff} can be explained by scratches on the surface due to repeated sample handling, visible in the spatially resolved TR-PLI maps. After 24 h the samples also suffered from changes in the surface passivation quality as described above.

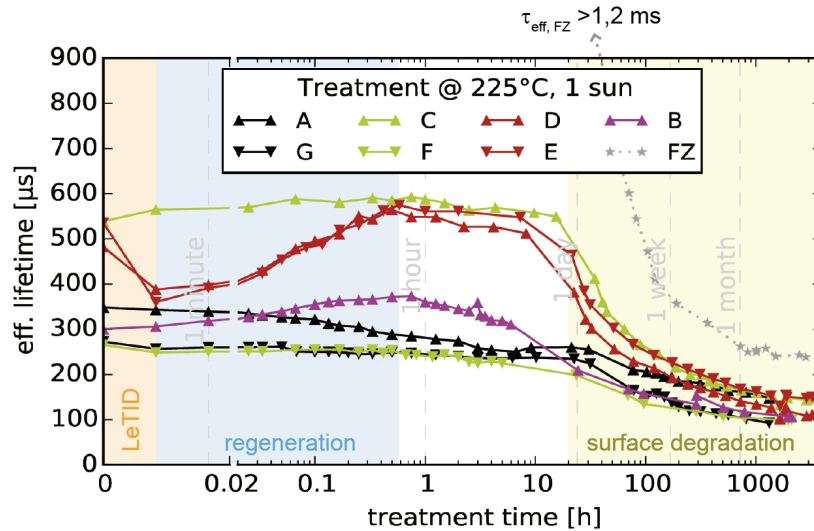


FIGURE 3. Harmonic average τ_{eff} of differently processed samples. Only samples with a fired $\text{SiN}_x\text{:H}$ layer (samples D and E) show the expected LeTID and regeneration effect within the first hour. Decreases in τ_{eff} after 20 h are due to changes in surface passivation quality. Lines serve as guide to the eye only.

It has to be stated that the whole thermal budget of a sample has an influence on LeTID and regeneration. Therefore, Fig. 4 shows the effect of a re-passivation, based on so-called “rainbow” plots as introduced in [2, 3]. For these plots the TR-PLI lifetime maps of each sample over time are aligned and an array of 2,500 areas ($150 \times 150 \mu\text{m}^2$) is distributed over the lifetime maps of the mc-Si sample at fixed positions. Average τ_{eff} values within each area are extracted and plotted against treatment time. The colored lines represent τ_{eff} over time of one area, while the color-coding is defined by the initial τ_{eff} value at the beginning of illumination. The advantage of this approach compared to simply using the harmonic mean of τ_{eff} over the whole sample area is that it is possible to track changes of τ_{eff} of different sample areas and display this spatially resolved information over time. Figure 4(a) shows a P-gettered sample with a fired $\text{SiN}_x\text{:H}$ layer as surface passivation (not shown in Fig. 1). In contrast to the samples described above, this layer was not etched back. Instead the sample was illuminated at elevated temperature with the $\text{SiN}_x\text{:H}$ layer present. τ_{eff} of different sample areas, indicated by the color code, show the expected LeTID and regeneration behavior, including the exceeding of the initial τ_{eff} value for long treatment times, also observed in, *e.g.* [10]. Figure 4(b) shows sample E, where the fired $\text{SiN}_x\text{:H}$ layer was removed and the sample was re-passivated by an ALD Al_2O_3 layer (as shown in Fig. 1). Regarding the initial τ_{eff} , the Al_2O_3 passivated sample showed higher lifetimes than the one with $\text{SiN}_x\text{:H}$ passivation also due to limitations of the latter. The LeTID effect was much less pronounced and the

regeneration dominates earlier which might be an effect of the different surface passivation and the additional thermal budget during Al₂O₃ deposition and activation (420°C, 20 min), leading to a partial annealing of the underlying LeTID defect. Again, the τ_{eff} decrease after 24 h is due to changes in the surface passivation quality.

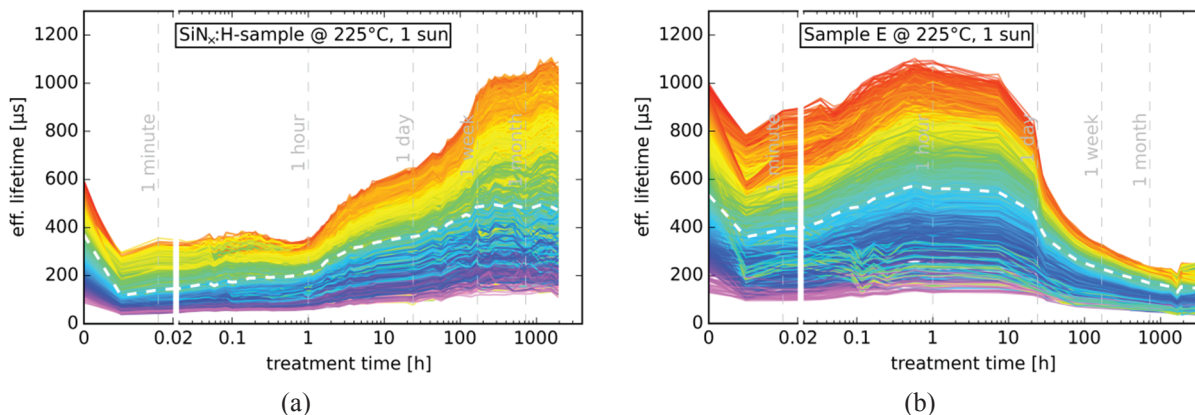


FIGURE 4. “Rainbow” plots represent τ_{eff} of 2,500 sample areas indicated by the color code over degradation and regeneration treatment. Left: P-gettered sample with fired SiN_x:H layer as surface passivation. Right: same sample treatment as for the sample shown on the left, but passivation layer removed and sample re-passivated by ALD Al₂O₃ (sample E in Fig. 1) resulting in a different LeTID and regeneration behavior.

The described results point out that the complete sample treatment has to be taken into account evaluating LeTID experiments. Changes in the passivation layer or the thermal budget influence LeTID. Additionally, LeTID experiments are influenced by changes in the surface passivation quality. The approach of the same passivation for samples with and without firing steps lead to the result that LeTID is only observed for samples with SiN_x:H layer present during firing (Fig. 3). But the comparison in Fig. 4 shows that the strength and the kinetics of LeTID change due to the re-passivation of the sample.

CONCLUSION

High quality p-type mc-Si can reach local lifetimes of 1 ms when fired with standard PECVD SiN_x:H and then re-passivated with annealed ALD Al₂O₃. Firing of a mc-Si sample without dielectric layers in between dummy wafers does not cause a dramatic decrease in material quality.

LeTID occurs if a sample with PECVD SiN_x:H dielectric passivation layer is fired. It does not occur if the sample is not fired, or is fired without a dielectric passivation layer. Removal of the SiN_x:H layer after firing and re-passivation with annealed ALD Al₂O₃ does not fundamentally change the LeTID behavior. Gettering is not always able to significantly suppress degradation.

The surface passivation quality of annealed ALD Al₂O₃ decreases after prolonged (>20 h) treatment at 225°C and 1 sun illumination on both mc and FZ silicon material.

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