IMPACT OF AL2O3 AND SINx PASSIVATION LAYERS ON LeTID

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ABSTRACT: In this work the carrier lifetime evolution of different passivation layers under illumination and at elevated temperatures are investigated. Multicrystalline silicon lifetime samples were treated by implementing typical industrial processing steps. The degradation was found to depend strongly on surface passivation type, but is independent of the surface doping and oxide charge. The influence of the passivation layer on the silicon bulk lifetime degradation is investigated. After reaching a degradation maximum, the lifetime samples feature a regeneration phase. Long-time degradation measurements without excess carrier injection at elevated temperatures show that the carrier lifetime degrades also in darkness. Capacitance-voltage measurements show that the oxide charge is not influenced by the degradation, but a high decrease in carrier lifetime were measured. Firing experiments show that lifetime samples passivated after firing procedure are not prone to degrade.
Keywords: Multicrystalline Silicon, Degradation, Passivation.

1 INTRODUCTION

Multicrystalline silicon (mc-Si) solar cells and modules with PERC (Passivated Emitter and Rear Cell) concept can show unexpected strong light induced degradation levels at elevated temperatures. A new light and elevated temperature induced degradation effect (LeTID) has been detected, which cannot be explained by the activation of boron-oxygen (B-O) complexes or the division of iron-boron (FeB) pairs [1-3]. The degradation mechanism called LeTID, can cause a module power degradation level of above 10% [3] and might be a potential obstacle for the industrial realization of the PERC technology. Hanwha Q CELLS has shown that their Q.ANTUM technology is a unique technology differentiating from mc-Si PERC and is not effected by LeTID [3]. Currently, there is no physical understanding about the degradation effect and it is still unclear if only the rear side of the solar cell [2] or the Si bulk material [3] is affected. In addition, an interaction of surface passivation layer and bulk material could be the root cause of degradation under LeTID conditions. In this work the impact of different passivation layers and surface doping types are investigated to gain a better understanding of the specific root cause of the degradation effect.

2 EXPERIMENTAL

Neighboring LeTID-sensitive block cast boron-doped (1-2 Ω cm) mc-Si wafers (5×5 cm²) with comparable grain and defect structure are processed to lifetime samples by implementing typical industrial processing steps (see Fig. 1). After a wet chemical saw damage removal a phosphor diffusion is performed resulting in n^+-layers on both wafer surfaces. To analyze the influence of the doping at the wafer surface two process flows were implemented. At one half of the samples the emitter was chemically removed (w/o emitter) and the other half keeps its n^+-doping region (w/ emitter). After phosphor glass removal the samples get a symmetrically passivation and receive a final firing step. Two different passivation types, deposited in two different tools, are used. Al2O3/SiNx stacks were deposited in tool A only. The two kind of SiNx passivated samples were produced in two different deposition tools (tool A & B).

To gain a better understanding of the interaction of
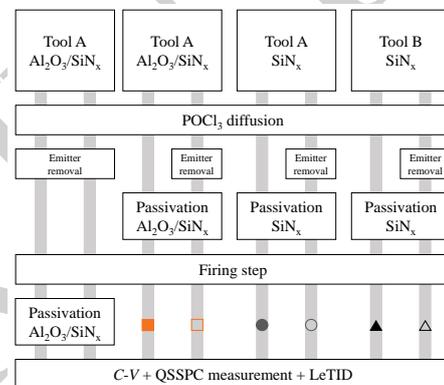
Figure 1: Process sequence of the investigated lifetime samples. The symbols in the last row are standing for the used symbols in Fig. 3-4.

passivation layer and bulk material additional lifetime samples were processed. The samples undergo the POCl3 diffusion, chemical emitter removal, firing step and in this case the passivation layer deposition after firing procedure.

The LeTID treatments are carried out at elevated temperature of 75°C and an excess carrier injection is provided by LED illumination at 300 W m^-2. Quasi steady state photo conductance decay (QSSPC) measurements were used to characterize the carrier lifetime τ_{eff} during time expired degradation. τ_{eff} values are carried out at $\Delta n = 10^{14}$ cm^-3. The long-time degradation behavior of SiNx-passivated samples w/ emitter at elevated temperatures are also investigated without excess carrier injection.

To determine the evolution of fixed charge density Q_f before and after 24 h LeTID treatment capacitance-voltage (C-V) experiments were carried out using a metal-oxide semiconductor model as described in [4].

In Table 1 all passivation layers and their surface properties are collected. τ_{eff} values were measured before (t = 0 h) and after 1000 h of LeTID treatment.

3 LeTID CHARACTERISTICS AND OBSERVATION ON LIFETIME SAMPLES

The results of the lifetime measurements in Fig. 2

Table 1: Passivation layers and their surface properties. τ_{eff} was extracted at $\Delta n = 10^{14}\,\text{cm}^{-3}$.

| Lifetime sample	Symbol	Deposition tool	Emitter	τ_{eff} before LeTID [µs]	τ_{eff} after ~ 1000 h LeTID [µs]
Al_2O_3/SiN_x	□ & ■	A	w/o & w/	76 & 74	5 & 7
SiN_x	○ & ●	A	w/o & w/	63 & 72	7 & 7
SiN_x	Δ & ▲	B	w/o & w/	30 & 57	2 & 7
SiN_x (dark at 75°C)	▼	B	w/	56	34

show that only the samples, which are passivated before firing, degrade severe during the first 24 h degradation procedure ($70 \rightarrow 9$ µs). Samples with a passivation layer deposited after the firing step are not prone to degrade.

In Fig. 3 the long-time τ_{eff} measurement are plotted for different surface passivation types (deposition tool A & B) w/o and w/ emitter. Similar degradation rates were determined for all samples with n^+-doped emitter as well as for samples with passivation layers deposited by using deposition tool A ($\sim 70 \rightarrow 7$ µs). In comparison to the n^+-doped samples and tool A samples the SiN_x-passivated samples deposited in tool B w/o emitter show a slightly higher defect generation. In this sample τ_{eff} degrades from 30 µs up to 2 µs after 1000 h. The degradation of the SiN_x sample w/ emitter in darkness is obviously slower but shows also a decrease of $\tau_{\text{eff}} = 34$ µs after 1000 h (τ_{eff} measurement not presented here).
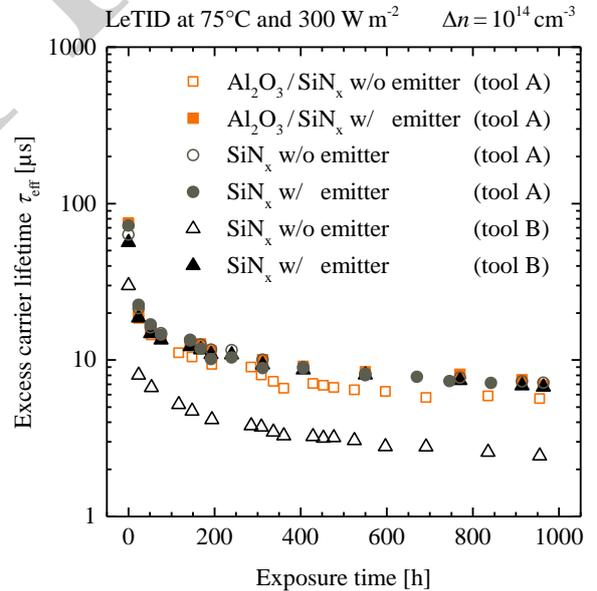
Fig. 4 shows the extended long-time degradation (expansion of Fig. 3) and regeneration behavior of all passivation layers w/o emitter. After reaching a degradation maximum all investigated samples feature a regeneration phase.
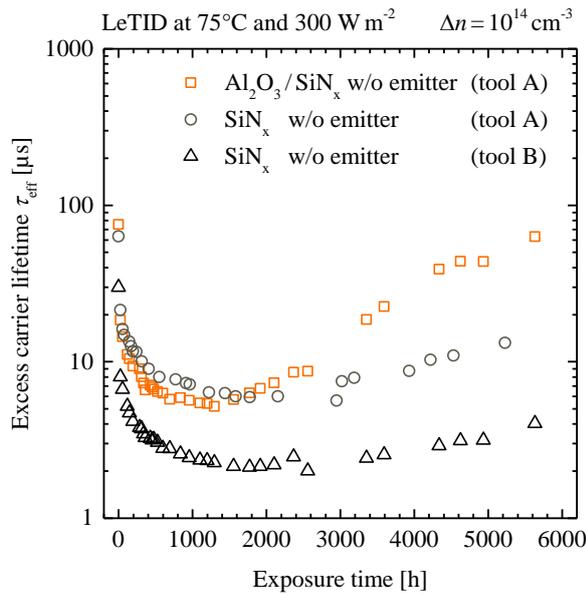
In Fig. 5 the Q_f results of C-V measurement for passivation layers present during firing procedure before and after 24 h LeTID treatment are presented. LeTID sensitive Al_2O_3/SiN_x stack w/o emitter samples exhibit the same degradation behavior as results shown in Fig. 4. There is only a slightly decrease in negative Q_f after 24 h LeTID treatment, but a high decrease in τ_{eff}. Furthermore, Q_f and τ_{eff} were determined for a LeTID controlled lifetime sample with defect engineered process sequence [3]. No decrease of Q_f could be recognized. It was impossible to measure the interface trap density D_{it} of the mc-Si lifetime samples, because of high trapping of accumulation capacitance during conductance measurement.
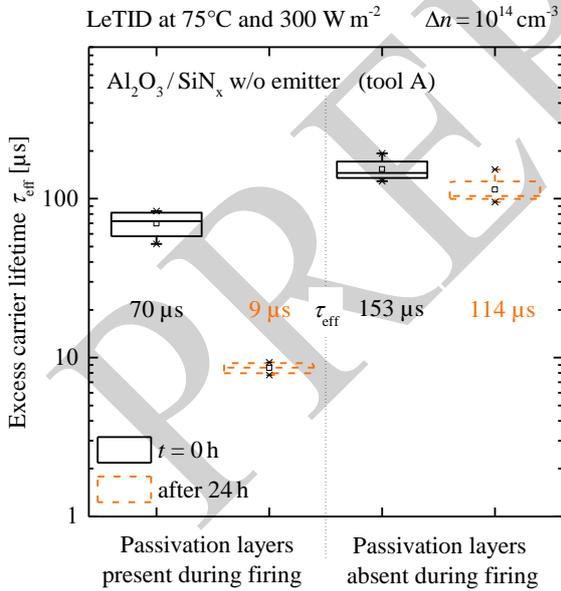
Figure 2: τ_{eff} before and after LeTID treatment of passivation layers, which are present or absent during firing.
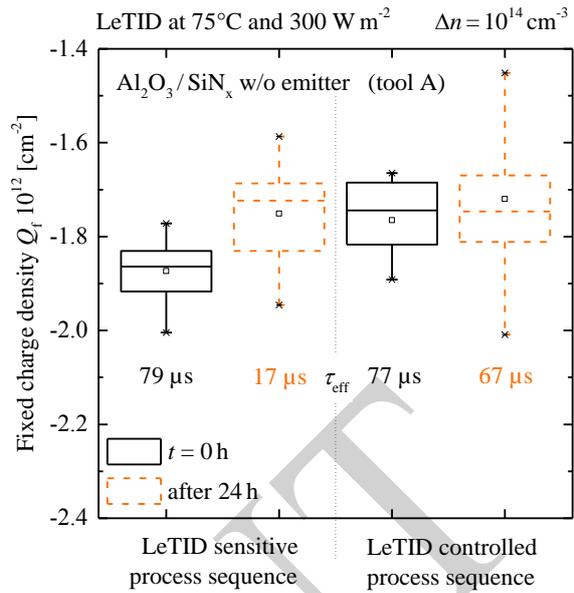

Figure 3: Long-time degradation behavior of different passivation layers with and without n^+-doped emitter.

Figure 4: Extended long-time degradation and regeneration behavior of different passivation layers.

Figure 5: Q_f before and after LeTID treatment of a sensitive sample and LeTID controlled sample.

4 CONCLUSION

All investigated surface passivation layers, which are present during firing step, show a different time-dependent lifetime degradation. The observed severe lifetime degradation strongly depends on the type of surface passivation, but is independent of surface doping and oxide charge. Same degradation behavior for SiN$_x$ (positive surface charge) or Al$_2$O$_3$/SiN$_x$ stack (negative surface charge) were determined. After reaching a degradation maximum, the lifetime samples feature a regeneration phase. On extended time scale the Al$_2$O$_3$/SiN$_x$ stack almost recovered to initial lifetime value. Degradation also occurs without illumination at elevated temperatures. The degradation rate is obviously slower and up to now it is unclear if it is the same degradation effect as with enhanced excess carrier densities. *C-V* measurements show no significant decrease of fixed charge density, but carrier lifetime are prone to degrade. Furthermore, a correlation with the silicon bulk material is observed. Strong degradation for samples with passivation layers present during firing step were determined. Only slight degradation of τ_{eff} with passivation layers absent during firing step and final passivation were observed. The slightly degradation of τ_{eff} is related to B-O degradation in mc-Si [5]. This represents an interaction of passivation layer with mc-Si bulk material during firing step. However, this avoidance of degradation is unfeasible for industrial production, because it is impossible to passivated solar cell rear side after metallization and firing step. Up to now there is no physical explanation for the degradation mechanism and further work is ongoing in order to create a deeper understanding of the LeTID effect on mc-Si lifetime samples and solar cells.

5 ACKNOWLEDGEMENTS

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