Preprint to be published in the proceedings of the
32nd European Photovoltaic Solar Energy Conference, 20-24 June 2016, Munich, Germany

EVALUATION OF SPATIAL ALD OF AL_2O_3 FOR REAR SURFACE PASSIVATION OF MC-SI PERC SOLAR CELLS

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ABSTRACT: In this work the evaluation results on industrial *p*-type mc-Si PERC cells using spatial atomic layer deposition for aluminum oxide from SoLayTec are shown. By optimizing the process flow and integrating a post-deposition anneal into the SiN_x capping process we achieve 0.15% higher cell efficiency compared to remote microwave plasma-enhanced chemical vapor deposition. Furthermore, it is shown that the improved passivation quality resulting in V_{oc} gain remains constant during light and elevated temperature induced degradation measurements.
Keywords: Multicrystalline Silicon, Passivation, Degradation.

1 INTRODUCTION

Deposition of aluminum oxide (Al_2O_3) by an atomic layer deposition (ALD) process has been evaluated on a high throughput deposition tool from SoLayTec ("InPassion ALD"). The key features of this new deposition technology are high flexibility in layer thickness, high throughput due to a deposition rate of up to 1 nm/s with excellent uniformity and single sided deposition on standard 6" solar wafers while maintaining proven superior surface passivation known from batch ALD.

We evaluate the InPassion ultrafast spatial ALD tool from SoLayTec for industrial production of mc-Si solar cells based on Hanwha Q CELLS Q.ANTUM technology [4]. Only the rear side passivation layer was varied by using spatial ALD for Al_2O_3 deposition in comparison to remote microwave plasma-enhanced chemical vapor deposition (MW-PECVD) of AlOx.

Based on recently published severe light-induced degradations levels of mc-Si PERC cells [1-3] the long-time performance stability of these ALD passivated mc-Si PERC cells during light and elevated temperature (LeTID) was investigated.

2 EXPERIMENTAL

The in-line spatial ALD Al_2O_3 system from SoLayTec works with a gas mixture comprising of trimethylaluminium (TMAl) and water (H_2O) vapor. The two process gases are separated by nitrogen (N_2) gas curtains. In a high throughput ALD process both half-reactions are spatially separated, as shown by the sketch in Fig. 1. The wafers move contactless on nitrogen gas bearings and pass TMAl and H_2O vapor inlets sealed off by a flow of pressurized N_2, forming isolated reaction zones. The wafers move back and forth underneath the reactor head, each passage under the injector head results in two complete ALD cycles. The deposition rate is determined by the cycle rate of the wafer in the reactor, enabling deposition rates of up to 1 nm/s. In a conventional ALD reactor operating under vacuum conditions, pump and vent times can severely limit the wafer throughput. As the spatial ALD concept works under atmospheric pressure, any pump or vent times are avoided [5].

Subsequently to the Al_2O_3 deposition a post-deposition anneal (PDA) integrated into the deposition of the SiN_x capping layer in a conventional tube furnace direct plasma PECVD was used.

For performance stability measurements highly LeTID susceptible mc-Si wafer material was processed to 6" PERC solar cells. Part of the cells were passivated with MW-PECVD Al_2O_3 as reference batch. The other cells were passivated with SoLayTec InPassion ALD. The layer thickness was varied between 4.7, 10 and 20 nm ALD Al_2O_3. All cells were processed with a LeTID susceptible process flow. Only the PECVD batches and the 4.7 nm ALD Al_2O_3 cells were additional processed by using the LeTID controlled solar cell process sequence of Hanwha Q CELLS [3]. The LeTID treatments are carried out in V_{oc} mode at 75°C. The excess carriers are injected by illumination at 1000 W/m^2. After 800 h exposure time all cells were regenerated without illumination at 200°C for 10 min in muffle furnace.

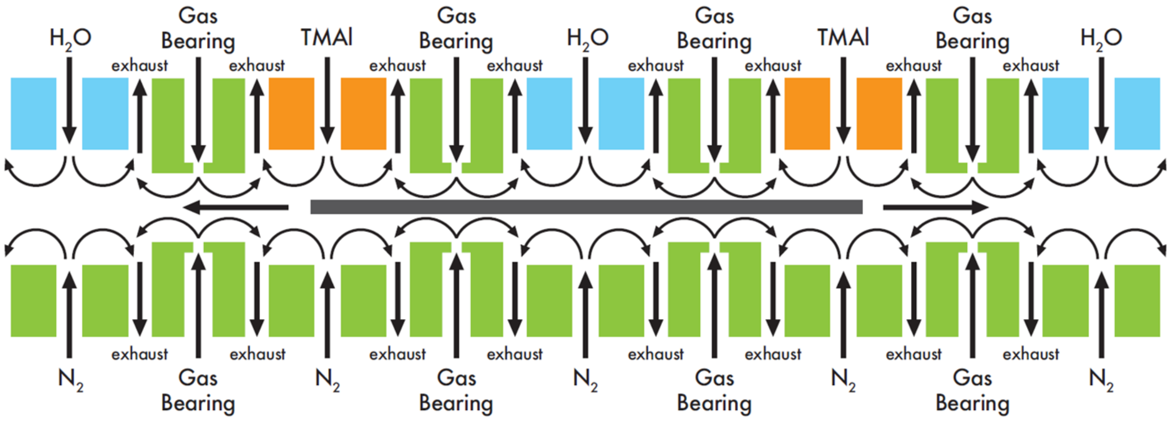
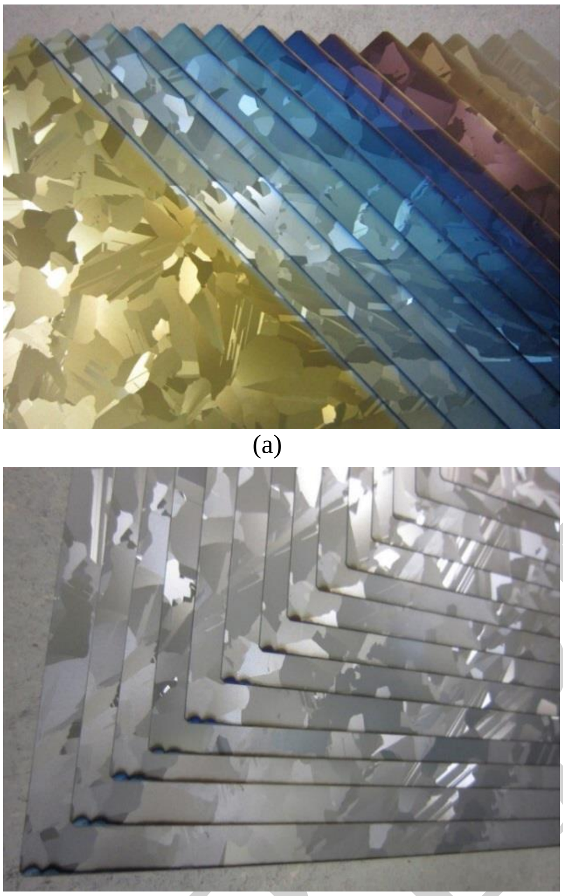


Figure 1: Sketch of in-line spatial ALD concept [6]. The TMAl and H_2O half-reaction zones are separated by N_2 curtains. Contactless transport of the wafer is facilitated by N_2 gas bearings below the wafer.

3 RESULTS

The extent of uncoated and wrap-around borders due to the ALD gas inlet design are shown in Fig. 2. ALD Al_2O_3 single sided deposition in steps of 10 nm up to 180 nm shows a stripe of less thickness at the top and bottom wafer of less than edge < 1 mm (Fig. 2 a) and average wraparound of 0.3 mm and maximum of 1 mm (Fig. 2 b).



(a)

(b)

Figure 2: Wafers with Al_2O_3 single sided deposition in steps of 10 nm up to 180 nm (a) front side and (b) rear side.

3.1 Evaluation of the InPassion ALD tool from SoLayTec

In the upper part of Fig. 3 an efficiency gain of ~ 0.15% of spatial ALD passivation versus MW-PECVD during different calendar weeks is shown. This efficiency gain was reached by depositing only 4.7 nm Al_2O_3 and using an integrated PDA into the deposition of the SiN_x capping layer in a conventional tube furnace direct plasma PECVD. During the evaluation period, the amount of solar cells produced varied between 300 and 700 wafers per week this results in throughput of 1000 w/h. The electrical data for ΔV_{oc}, ΔJ_{sc} and ΔFF are shown in the lower graph of Fig. 3. The good layer uniformity in spite of low layer thickness results in V_{oc} improvement of ≥ 3 mV. The *FF* of the ALD cells was not optimized yet. If the *FF* would be improved for ALD PERC cells, than this cells can reach 0.25% efficiency gain with respect to MW-PECVD.

As shown in Fig. 4 when leaving out the PDA we achieved the same eta as the reference process which clearly shows that spatial ALD needs proper PDA treatment for achieving best passivation properties. Without the PDA a throughput of 1800 w/h was reached in the tube furnace PECVD. In order to achieve the best passivation properties the spatial ALD Al_2O_3 needs proper PDA treatment which is implemented in a direct plasma PECVD capping layer.

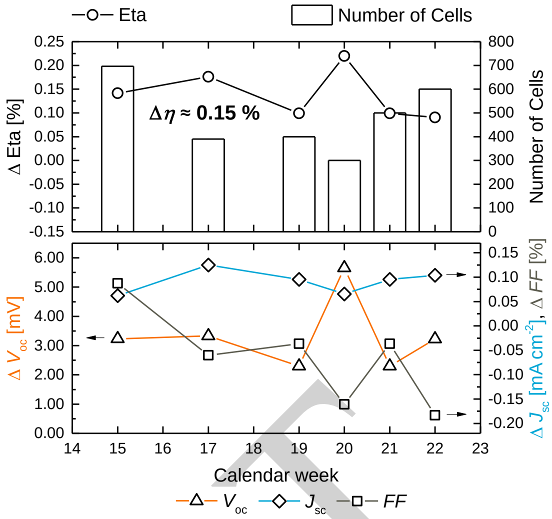


Figure 3: Efficiency gain, amount of solar cells and electrical data delta of ALD versus MW-PECVD.

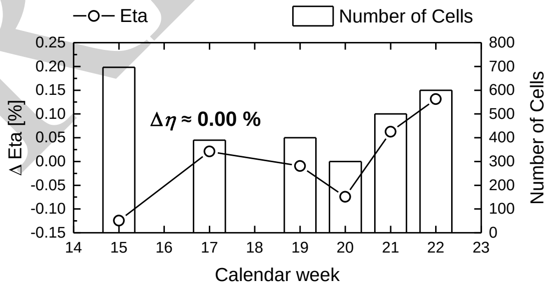


Figure 4: Efficiency gain and amount of solar cells of ALD versus MW-PECVD without PDA.

3.2 Long-time performance stability

The relative cell efficiency degradation for MW-PECVD and ALD Al_2O_3 passivated mc-Si PERC cells with susceptible (w/ LeTID) and LeTID controlled (w/o LeTID) process sequence are shown in Fig. 5. The degradation behavior is independent of Al_2O_3 layer thickness. All ALD passivated mc-PERC cells degrade up to ~ 3% after 400 h exposure time. The ALD cells processed with the LeTID controlled process sequence show a slightly lower degradation level, but also higher than the MW-PECVD cells with defect optimized process sequence. Fig. 5 shows only the relative loss in cell efficiency. It should be noted that there are significant losses in *FF* during degradation, handling and measurement procedure. This results in a higher eta degradation in Fig. 5. The real open-circuit voltage measurement are shown in Fig. 6. A V_{oc} improvement of 5 mV were determined for LeTID controlled ALD cells with an Al_2O_3 layer thickness of 4.7 nm. The V_{oc} gain is constant during the whole degradation measurement. After regeneration occurring at 800 h exposure time, all cells nearly recover to their initial V_{oc} value.

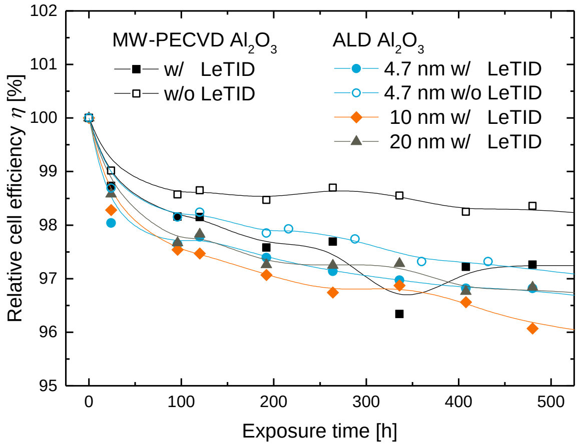


Figure 5: Relative cell efficiency degradation for MW-PECVD and ALD Al_2O_3 passivated mc-Si PERC cells with susceptible (w/ LeTID) and LeTID controlled (w/o LeTID) process sequence.

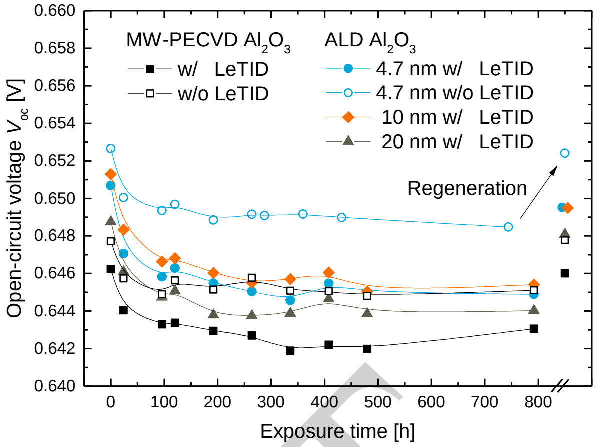


Figure 6: Real open-circuit voltage measurement during degradation for MW-PECVD and ALD Al_2O_3 passivated mc-Si PERC cells with susceptible (w/ LeTID) and LeTID controlled (w/o LeTID) process sequence.

4 CONCLUSION

In this work we show an efficiency gain of spatial ALD Al_2O_3 for the passivation of mc-Si PERC cells compared to MW-PECVD. The biggest advantages of the ALD tool compared to MW-PECVD are a better step coverage, a good layer uniformity and a layer thickness requirement of only 4.7 nm ALD Al_2O_3. An integrated PDA in the SiN_x capping process is needed for improved solar cell performance. By using the LeTID controlled solar cell process sequence of Hanwha Q CELLS [3] the V_{oc} values are continuously higher than for remote MW-PECVD passivated cells during the whole degradation measurements, which shows a better passivation performance for ALD Al_2O_3 compared to MW-PECVD also during degradation. We conclude that spatial ALD provides a promising tool for the integration of Al_2O_3 passivation layers into industrial solar cells.

5 ACKNOWLEDGEMENTS

The authors would like to thank Xavier Gay, Floor Souren, Roger Görtzen from SoLayTec and the entire team of Reiner Lemoine Research Center and pilot line at Hanwha Q CELLS for their contribution to that work.

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