

SPATIAL ALD Al_2O_3 FILM INTEGRATED IN LOW-COST, HIGH-PERFORMANCE BIFACIAL SOLAR CELLS

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ABSTRACT: ALD Al_2O_3 films have been integrated in an open rear-side p-PASHA (Passivated All Sides and H-pattern) type solar cell. The manufacturing of this cell is cost-effective as it uses a single dielectric Al_2O_3 layer (i.e. no SiN_x capping layer), partial (30-50%) coverage of metal paste on the rear side, no laser opening or laser firing required, and co-firing of the Ag and Al pastes. The spatial ALD deposition is carried out in the Levitrack system which is characterized by a high throughput (up to 3600 wafers/hr) and strict separation of H_2O and TMA compounds in the system. The Al_2O_3 film was thin enough to allow effective firing through, while avoiding the formation of defects (blisters) upon high-temperature firing.

On p-type Cz and multi-crystalline material, the p-PASHA cell was superior to the reference full-BSF cell in $J_{sc} \times V_{oc}$ by 1% and 2.5% respectively. Local IQE mapping indicates that the Al_2O_3 passivation performance is maintained after firing.

Keywords: c-Si, Passivation, Solar Cell, Lifetime, ALD, Al_2O_3

1 INTRODUCTION

Although ALD Al_2O_3 films have demonstrated excellent passivation capabilities [1] in various types of solar cells, the integration of this type of film needs more attention than initially anticipated. The most straightforward and cost effective way to contact the underlying silicon substrate is to fire through the film after screen-printing a suitably chosen conducting paste, see figure 1, 'Fire Through Paste'. However, this approach turned out not to be trivial for the rear side of cells, in which the Al contact should also provide local passivation [2]. Low firing temperatures result in good Al_2O_3 surface passivation but poor formation of local BSF, whereas higher firing temperatures provide good quality local BSF, but deteriorates the surface passivation of the dielectric layer.

The second option is to screen print the metal paste and fire through the films though very localized local heating with a laser, a so called Laser Fired Contact approach see figure 1, 'LFC'. In this latter scenario the substrate is not heated much outside the contact areas, which leaves the passivation of the dielectric intact.

The downside with both options is that the addition of the laser process and a capping layer adds costs to the overall process flow. In contrast, a bifacial cell configuration with open rear print reduces paste cost. For that reason ECN and Levitech are researching the possibilities to optimize the Al_2O_3 deposition parameters, type of paste, pre-clean, etc. such that firing through the Al_2O_3 film is possible, while keeping the passivation performance largely intact.

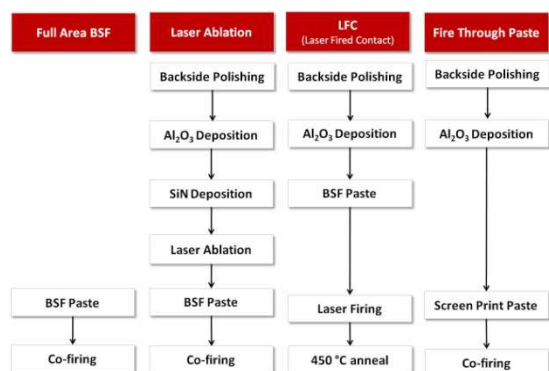


Figure 1. Various cell process flow options; only the differences in rear side processing are shown. The cell that was studied in this paper is the p-PASHA cell, the process flow in the right column

Alternative ways were implemented to circumvent this problem: one option is to open the dielectric film (Al_2O_3 or a stack of $\text{Al}_2\text{O}_3/\text{SiN}_x$) after deposition, and make contact with the now exposed silicon, see figure 1 'Laser Ablation'. As this process can be carried out using a lower firing temperature, the Al_2O_3 passivation performance is largely preserved.

2 EXPERIMENTAL

2.2 Levitrack system

The Levitrack system [3] is a high throughput spatial ALD system for Al_2O_3 deposition on solar cells. In the Levitrack, wafers are floating in a linear gas track at distances of 0.15 mm from the heated top and bottom walls of the track, see figure 2. Gases are injected through a multitude of narrow channels from the top wall down, and from the bottom wall up towards the wafer. The narrow gap results in strong forces that are exerted to the wafer ensuring a stable and contactless movement. After introduction of the wafers, they are heated conductively to process temperature in a few seconds. In the cross section it can be seen that the wafers pass regions in which the bottom side of the wafer surface is successively exposed to TMA, N_2 , H_2O and N_2 . In this arrangement the flow of precursors is constant in time; the wafers being the only objects in the track that move. A typical cell length (TMA, N_2 , H_2O , N_2) is 10-14 cm. Deposition of Al_2O_3 on the track walls is prevented by making sure that the TMA and H_2O do not mix while flowing outwards towards the exhausts. Deposition takes place on only one side of the wafer.

The system is designed to operate in a temperature

window of 150-250°C and to process wafers with a throughput up to 1 wafer/s (3600 wafers/hr).

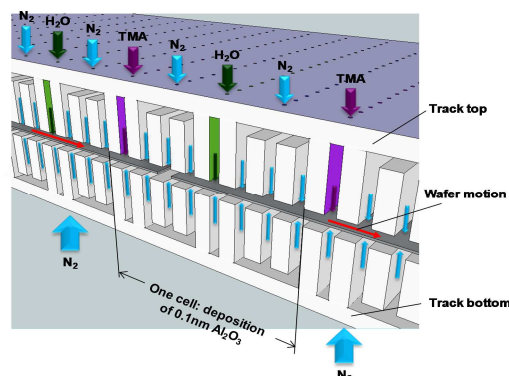


Figure 2. Schematic cross-section of the Levitrack ALD system.

Currently, uniformities in the range of 2-3% are realized. In figure 3 a typical deposition thickness plot is shown. The slight stripes that are visible are related to the gas injection hole pattern; these features will be designed out in the near future. The wafer-to-wafer repeatability of the process is within 1%, and thin films can be deposited in increments of ~1nm.

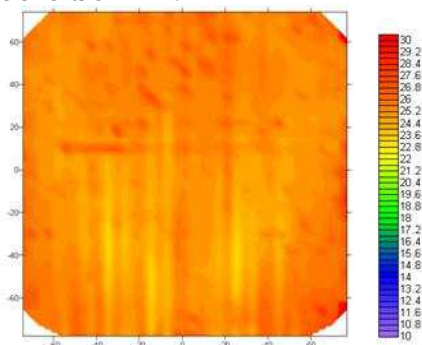


Figure 3. Typical uniformity plot of an Al_2O_3 Film (2.3%, 1σ)

2.2 Process flow and structure p-PASHA cell

The research is done on cells based on the p-PASHA concept, see figure 4. This cell has the following characteristics [4]: Ag and Al metal grids on front and rear sides, respectively, single dielectric Al_2O_3 layer (i.e. no SiN_x capping layer), and reflection of IR light from the back sheet foil (internal reflection coefficient as fitted with PC1D > 95%). The (cost) advantages of this cell are: single rear dielectric layer (Al_2O_3), partial (30-50%) coverage of metal paste on the rear side, no laser opening or laser firing required, and co-firing of the Ag and Al pastes.

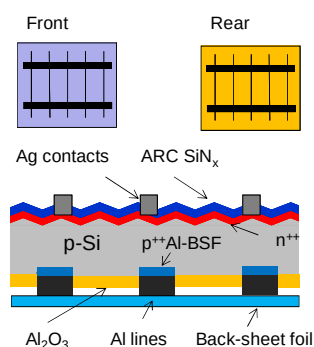


Figure 4. Layout of the p-PASHA cell

The cells received a 75 ohm/sq emitter (tube furnace using POCl_3), followed by an isolation step. Before the ARC layer deposition (SiN_x PECVD), all groups received the same thorough clean steps to ensure the same blue response. The wafers were shipped to Levitech for the deposition of an Al_2O_3 coating on the rear using the Levitrack. The deposition condition compared to our previous report have been further optimized for the p-PASHA cell. Subsequently they were printed and fired using a newly developed Al firing-through paste. These cells had a rear metal fraction of 30%. The fired wafers were shipped back to ECN for optoelectrical characterization (IV and LBIC). The complete process flow is shown in figure 5.

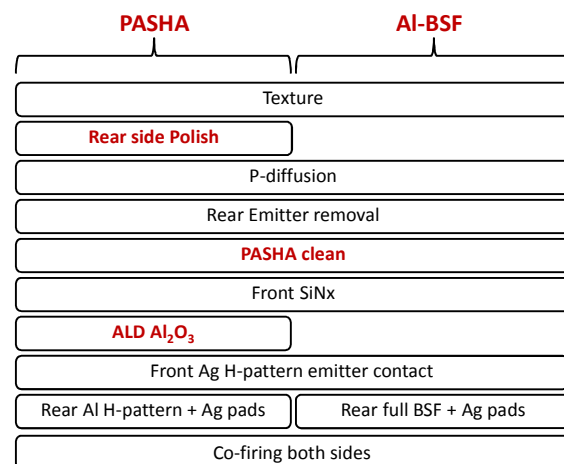


Figure 5. Process flow of Al-BSF reference (black) with in red the additional steps that are specifically used for the Al_2O_3 passivated p-PASHA cells. The p-PASHA clean is used as a thorough clean procedure that affects both the front and rear side [5,6].

3 Al_2O_3 PASSIVATION AND LOCAL BSF FORMATION

The objective of the study was to achieve an optimized passivation with thin Al_2O_3 films. With thin Al_2O_3 films defect (blister) formation is avoided. Extensive studies on blister formation were done [7], resulting in the conclusion that blisters can be avoided with Al_2O_3 films thinner than ~12nm, see figure 6.

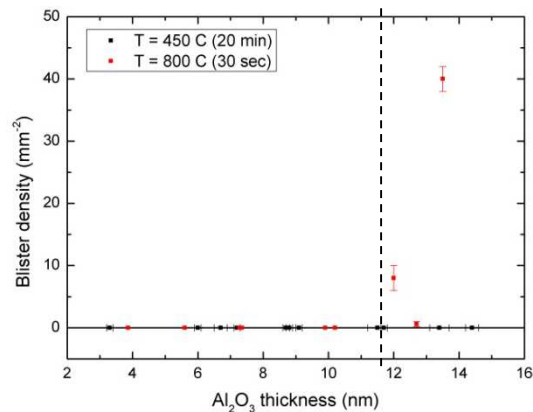


Figure 6. Blister density as a function of film thickness and annealing (firing) temperature. The films were integrated in p-PASHA cells, and a comparison was made with conventional full-Al BSF cells, see figure 5.

The major improvement of this work compared to our previous report [8] is that the passivation quality of the Al_2O_3 is maintained after firing while a BSF is formed at the aluminum rear fingers. The passivation quality at the rear fingers is compared to the dielectric layer by LBIC measurement at 976 nm as illustrated in Figure 7 and 8. It is clear that in parts of the rear surface the passivation layer with IQE values up to 94% performs better than the metal fingers with a maximum IQE of 92% as illustrated by the histograms of Figure 7 and 8. The difference in passivation is presented in more detail in a high-resolution LBIC mapping of a test structure, consisting of Al lines of different width, separated by Al_2O_3 passivated areas, as shown in Figure 8 c. A horizontal line scan through the different areas clearly illustrates the superior passivation of the Al_2O_3 over the local Al-BSF, which is maintained after firing. It also becomes clear that the passivation of the Al fingers is limited by a decreased passivation at the edge. On cell level the gain in $J_{sc} \times V_{oc}$ of Cz and mc based bi-facial solar cells was 1% and 2.5% respectively compared to the corresponding Cz and mc full Al-BSF reference. The gain in Jsc is clearly related to a gain in rear reflection as the IQE of the p-Pasha cell between 1000 and 1200 nm was several tens of percent points higher than the reference.

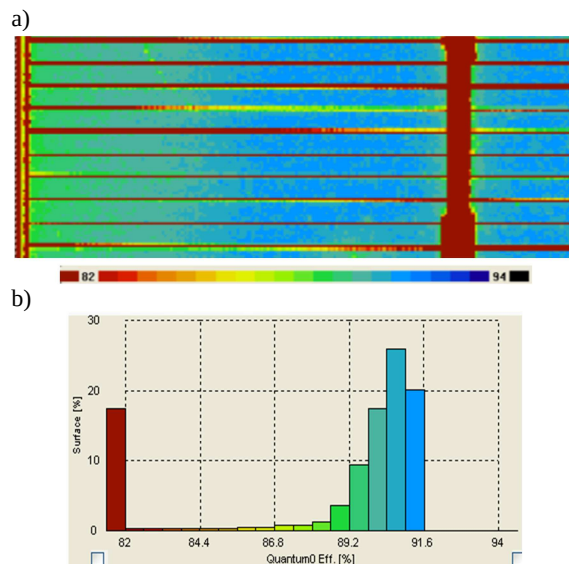


Figure 7 a, b. Laser beam-induced current IQE mapping at 976 nm of the Al BSF reference cell

From the LBIC mapping it becomes apparent that the recombination in the p-PASHA cell would benefit from a smaller finger edge area. Increasing the finger width at constant contact area, results in a larger spacing between the fingers. This in turn results in a larger resistance loss in the base causing the FF to decrease. We expect that optimization of the pitch and finger width will improve the cell efficiency of the p-PASHA cell.

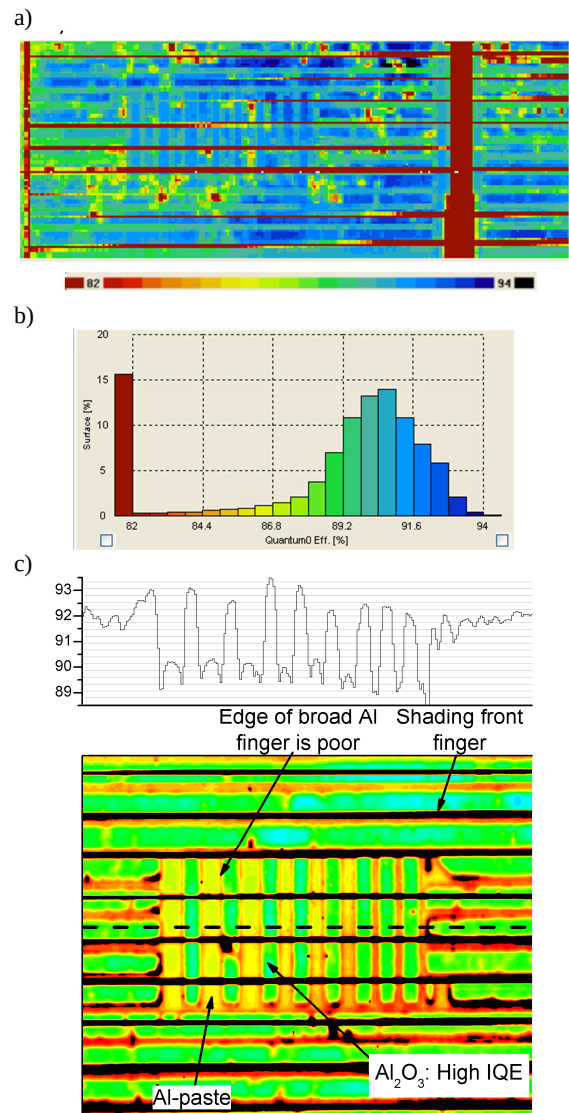


Figure 8 a, b, c. Laser beam-induced current IQE mapping at 976 nm of the p-PASHA cell with open rear side. Dashed line marks path 2D profile. Illumination is done through the emitter.

CONCLUSION

The p-PASHA concept is an attractive concept to improve the cell efficiency of standard full area Al-BSF solar cells by replacing the rear side with a passivated surface and an open aluminum grid. The rear contacts are

fired-through and in an ideal process flow, the only additional process step is the ultra-fast spatial Al_2O_3 ALD tool such as the Levitrack. Improved firing stability of the Al_2O_3 could be demonstrated and the results appear to be limited to the edge of the Al-BSF fingers. Optimization of the metal pattern should limit this problem. Climate testing results suggest that a module consisting of Al_2O_3 passivated p-PASHA cells would pass the full IEC 61215 test which is an important milestone for future industrialization.

ACKNOWLEDGEMENT

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