Causing an inline revolution

Schmid introduces inline single side wet processes along with Atmospheric Pressure Chemical Vapor Deposition doped glass layers.

IBC (interdigitated back contact) solar cells have metal on the non-illuminated side, to maximize the absorption of incident light on the front[1]. Other advantages of the IBC architecture include lower series resistance due to higher metal fraction, an increase in the total area efficiency of modules due to higher packing density, easy module integration and aesthetic module appearance for building integrated photovoltaics (BIPV)[2].

The more complex processing sequence and thus higher production costs are the main reasons why IBC cell technologies are still considered as a niche market: need for patterning the rear side using photolithography, inkjet patterning or laser processing followed by multiple wet bench processing and cleaning steps.

Furthermore, since all charge carriers need to be collected at the rear side, the wafer should have a high minority carrier lifetime. The fabrication of three different doped regions, the front surface field (FSF), the back surface field (BSF) and the emitter require multiple high temperature steps that increase the thermal budget and thus process complexity. Finally, passivation of IBC cells is complex as p- and n-doped areas are located on the rear side and hence require a universal passivation stack for both polarities.

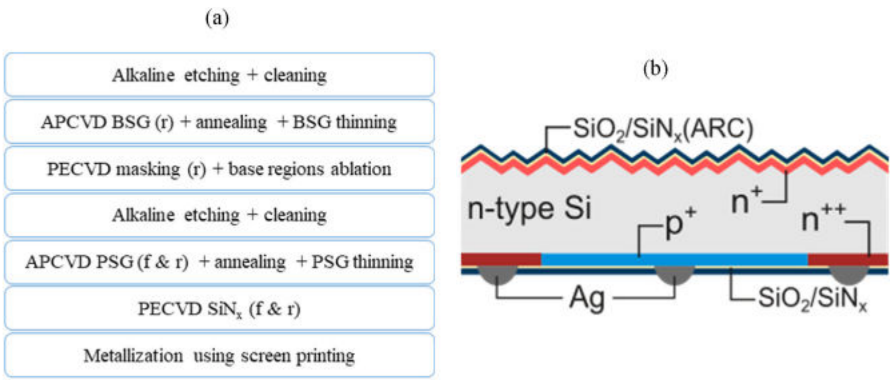


Figure 1: Main process steps (a) for the production of APCVD IBC solar cell (b) [4]. By changing the polarities of the APCVD doping layers, the cell concept can easily be adapted to p-type wafers

The use of Atmospheric Pressure Chemical Vapor Deposition (APCVD)[3] doped glass layers instead of conventional gas tube diffusion decreases the process complexity of IBC solar cells. Additionally, APCVD dopant glass layers are deposited prior to diffusion, thus little or no spacing of wafers in the tube is required during diffusion, which significantly increases throughput.

Furthermore, the deposition is decoupled from the diffusion step, allowing laser processing steps before high-temperature steps or co-annealing to reduce the overall thermal budget. Also, APCVD processing includes lower operational costs and high throughput.

Schmid investigated the effect of varying APCVD dopant concentrations on electric layer properties after high-temperature annealing, optimized for the drive in of dopants, the prevention of the formation of a boron-rich layer (BRL) for p+ doped Si, and growth of an in-situ SiO_2 layer at the interface between glass and Si for passivation and as an etching barrier for the controlled etch back of APCVD borosilicate glass (BSG) and phosphosilicate glass (PSG) layers with varying dopant concentrations in a single wet bench HF glass removal step.

Based on the electrical properties after annealing (Figure 2) individual APCVD glass layers enabling a 250 Ω/sq emitter, a 100 Ω/sq BSF and a 680 Ω/sq FSF were used for

1 M.D. Lammert, R.J. Schwartz, The interdigitated back contact solar cell: a silicon solar cell for use in concentrated sunlight, IEEE Trans. Electron. Dev. 24 (4) (1977) 337–342

2 P. Verlinden, F. Van de Wiele, G. Stehelin, J.P. David, An interdigitated back contact solar cell with high efficiency under concentrated sunlight, in: In Seventh E.C. Photovoltaic Solar Energy Conference, Springer, Dordrecht, 1987, pp. 885–889.

3 P. Rothhardt, C. Demberger, A. Wolf, D. Biro, Co-diffusion from APCVD BSG and POCl3 for industrial n-type solar cells, Energy Proc. 38 (2013) 305–311.

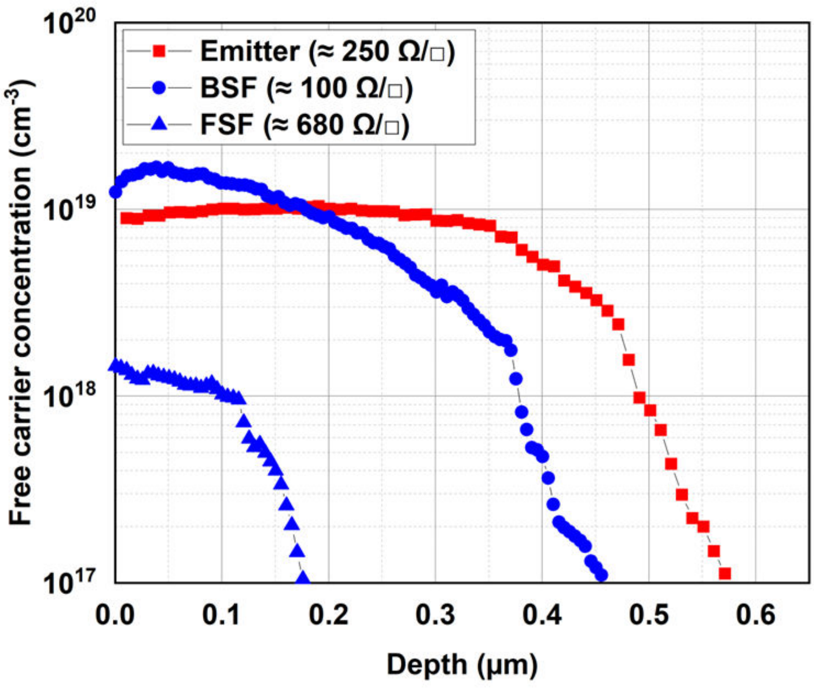


Figure 2: Carrier concentration profiles of the p+ doped emitter layer, lightly doped n+ FSF layer and heavily doped n++ BSF layer after high temperature annealing of the APCVD layers

the fabrication of full APCVD IBC solar cells. The in-situ grown thermal SiO_2 formed during the annealing in a partial O_2 environment was used as a buffer layer to etch back partially or entirely the APCVD PSG or BSG in a single HF wet bench step. The remaining oxide capped with PECVD SiN_x shows excellent surface passivation on both p+ and n+ regions.

On full APCVD solar cell precursors, that is without metallization, iV_{oc} of 714 mV and J_0 of 17 fA/cm² was measured which are outstanding values for diffused junctions. Large area IBC solar cells showed efficiencies approaching 23% (Jsc 41.3 mA/cm², Voc 696 mV, FF 79.3%, eta 22.8%) for a process entirely based on APCVD doping glasses[4]. As both polarities can be easily realized by APCVD doping layers, the cell concept shown in Figure 1 is suitable for n- and p-type wafers alike.

The next step in boosting the efficiency of APCVD IBC solar cells to the 25% range is the transition to passivated contacts and passivated emitters. First experiments using APCVD layers were already performed.

The sample structure for APCVD based doped polySi structures suitable for passivated emitter / back contact IBC solar cells shown in Figure 3 was realized with a patterning of the rear side using selective Laser ablation of an intrinsic poly-Si capping layer[5] and showed excellent passivation quality for the n+ polySi region with iVoc 741 mV and J0e 1.35 fA/cm² and for the p+ polySi region with iV_{oc} 720 mV and J_{0e} 17.4 fA/cm², respectively.

The success of such high performing IBC solar cell concepts strongly depends on the passivation quality of the wafer surfaces, especially on the back surface, as both, emitter and the BSF are located there. The passivation is realized by a TOPCon structure (passivated contacts) consisting of a thin tunnel oxide in combination with highly doped polySi layers.

Since recombination occurs preferentially in the adjacent regions of both polarities, it is necessary to generate a very smooth polished rear side and an excellent single-sided texture on the front side. These wet chemical steps are crucial for an IBC Solar cell concept.

The results for alkaline polishing have shown that the surface roughness of as-cut Wafer can be reduced to less than Ra < 10 nm by using alkaline etch solutions. The exact roughness depends on the concentration, the etch removal and the temperature of the alkaline solution at which the polishing process takes place.

Because the polishing step is already the first step in the IBC cell process and thus the saw damage is already removed, a single-sided texture is required here. SCHMID has developed a novel texturing technique specifically targeting the production of IBC solar cells.

Etching the surface with an alkaline solution mixed with specialized additives results in the formation of pyramids on the surface with sizes of 600-900 nm. These pyramids improve photon absorption and reduce reflection, leading to increased efficiency of the solar cell. The size and density of the pyramids can be controlled through the choice of solution, the concentration and the duration of the etching process, allowing the texture to be tailored to the specific requirements of an IBC solar cell.

Another advantage of the single-sided inline alkaline texturing is that it can be performed in a single process step, making the process cost-effective and streamlining the manufacturing of solar cells. Additionally, single-sided inline alkaline texturing can be combined with other process steps for example poly Si etching techniques to achieve the optimal performance for a particular solar cell.

More results have shown that single-sided inline alkaline texturing results in increased

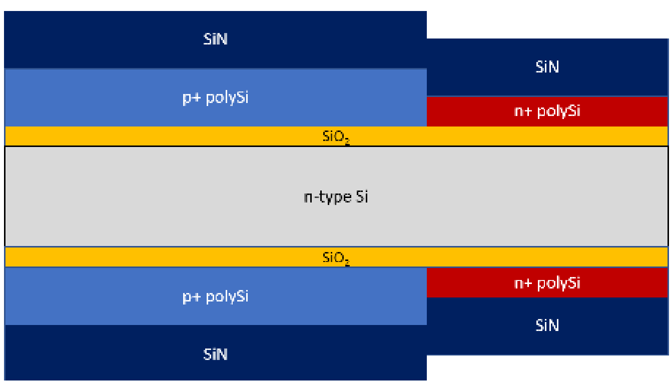
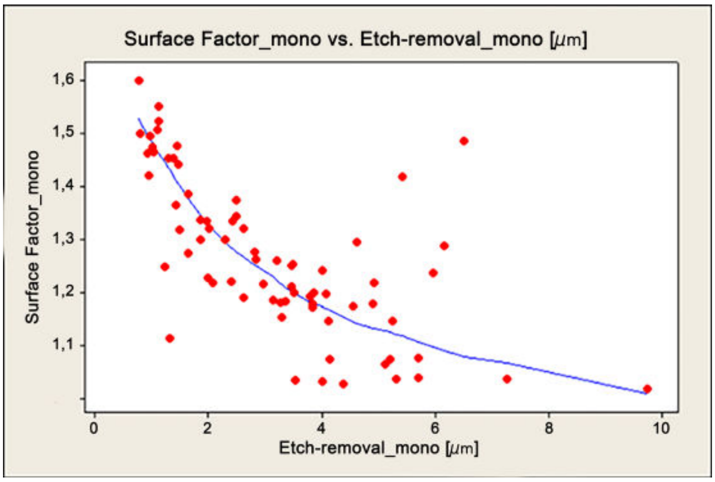


Figure 3: Schematic of symmetric lifetime samples with APCVD doped p+ and n+ polySi layers

4 Vaibhav V. Kuruganti, Daniel Wurmbrand, Thomas Buck, Sven Seren, Miro Zeman, Olindo Isabella, Fabian Geml, Heiko Plagwitz, Barbara Terheiden, Valentin D. Mihailetchi, Industrially viable diffused IBC Solar Cells using APCVD Dopant Glass Layers, SOLMAT Volume 251, 112111, 2023.

5 Vaibhav V. Kuruganti, Radovan Kopecek, Sven Seren, Olindo Isabella, Valentin D. Mihailetchi, Investigation on the passivation quality of ex-situ doped p+ and n+ poly-Si layers for IBC solar cells, Proc. 8th WCPEC, Milan, Italy, 2022.

The use of inline cleaning, specialized rollers, and nozzle technology helps to enhance the surface quality and further improve the efficiency of IBC solar cells.



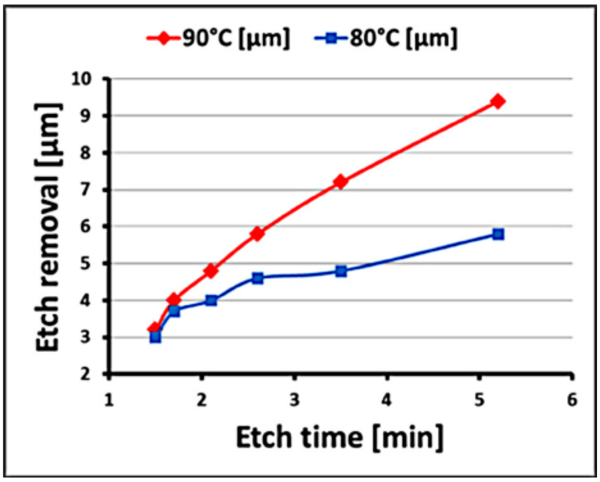


Figure 4: (a) Surface factor vs. etch removal (surface factor = 3-dimensional surface divided by flat area (values around 1 for perfectly polished surface; (b) Fast increase in etch removal depends on higher temperature, high process temperature enables short process module length

photon absorption and reduced reflection, leading to higher conversion efficiency in IBC solar cells. However, the surface quality of the silicon wafer can be impacted by impurities and contaminants. Inline cleaning, specialized rollers, and nozzle technology are used to improve surface quality during the texturing process. Inline cleaning removes impurities and contaminants from the surface of the wafer, specialized rollers ensure consistent texturing, and nozzle technology enhances the uniformity and precision of the etching process.

In conclusion, single-sided inline alkaline texturing and inline alkaline polishing is a cost-effective and efficient method with very high throughput for improving the surface of IBC solar cells. The use of inline cleaning, specialized rollers, and nozzle technology helps to enhance the surface quality and further improve the efficiency of IBC solar cells.

Along with the APCVD the wet process solution from SCHMID offers a very efficient, lean and lowest cost of ownership path towards hybrid passivated IBC cells. All equipment, along with the processes have been proven in mass manufacturing for many years already and are even proven in IBC production.

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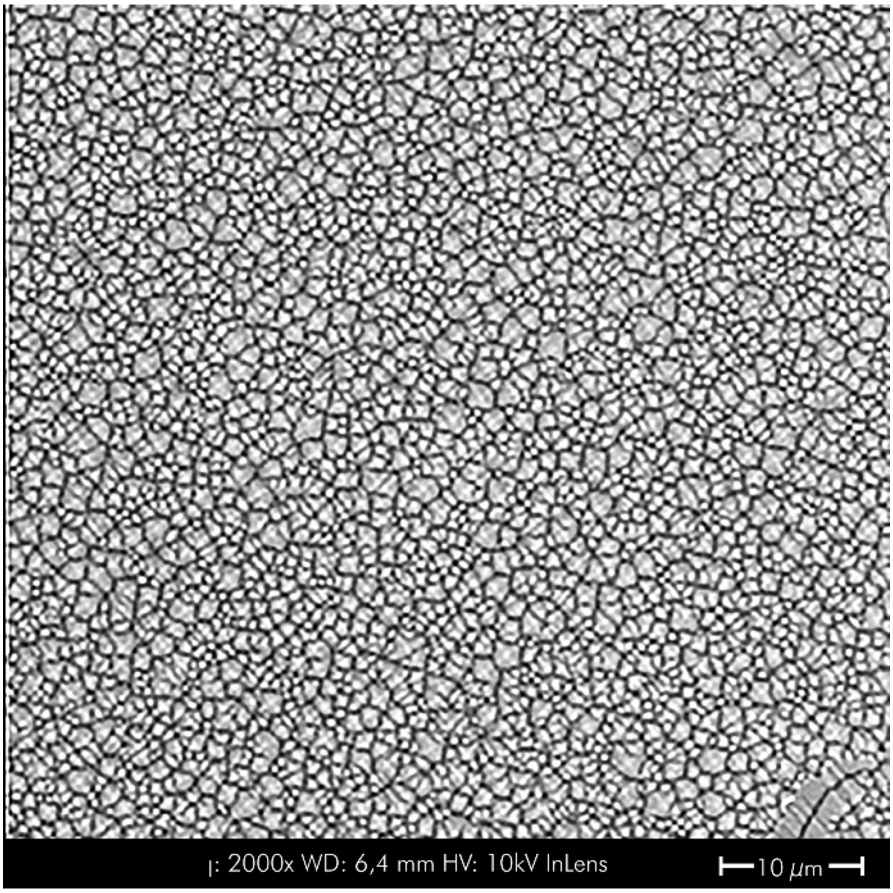

Figure 5: SEM surface from small pyramid texture with very reduced reflection