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TECHNOLOGY ROUTE TOWARDS INDUSTRIAL APPLICATION OF REAR PASSIVATED SILICON SOLAR CELLS

J. Rentsch, O. Schultz, A. Grohe, D. Biro, R. Preu, G. P. Willeke
Fraunhofer Institute for Solar Energy Systems, Heidenhofstr. 2, D-79110 Freiburg, Germany
Phone: +49 761 4588 5199, email: jochen.rentsch@ise.fraunhofer.de

ABSTRACT

Going beyond the standard industrial screen-printed Al-BSF rear side, this paper reports about process technologies for an industrial implementation of a rear passivated, locally contacted multicrystalline (mc) silicon solar cell. The solar cells rear side features a passivation stack system and an evaporated and LFC contacted Al layer. Due to the need of processing thinner wafers, a technology survey focuses on the adaptation of mainly inline based technologies for the realization of an industrial process scheme. New inline process technologies are introduced and compared with standard technologies. Up to date, large area mc-Si solar cells (156 x 156 mm²) fabricated completely with these inline technologies reach fill factors up to 76 %, on reference cells (125 x 125 mm²) an efficiency of 16 % is reached with an untextured front surface.

INTRODUCTION

Presently most solar cells manufactured feature a full area screen-printed or by means of other deposition methods applied aluminium rear contact. The p^+ back surface field (Al-BSF) created underneath the surface lowers the rear side recombination but also creates mechanical stress and leads to a poor optical performance. These disadvantages may limit a future high yield manufacturing of especially thinner wafers. The Laser-Fired Contact technology (LFC) as a concept with a dielectrically passivated rear side and local contacts has proven to overcome these drawbacks in the past. Cell efficiencies well above 20% were reached with a high efficiency cell process using photolithography technology [1,2]. Several process schemes have been proposed so far, downscaling this high efficiency process towards industrial application [3]. In this work we present the comparison of different batch and inline based technologies fulfilling industrial throughput requirements for the fabrication of large area (> 100 cm²) multicrystalline silicon solar cells with rear side passivation. Due to the demand of processing especially thin wafers, more emphasis has been put on the integration of inline technologies to reduce wafer handling steps and therefore the mechanical stress.

SOLAR CELL STRUCTURE

In contrast to earlier studies we are now focussing on a rear passivation scheme based on a stack layer system consisting of a thin thermally grown silicon oxide, a SiN_x and a PECVD silicon oxide layer. The overall cell structure and the impact of each layer to the final solar cell characteristic is described in more detail elsewhere [4]. The thin thermally grown silicon oxide passivates the rear and the emitter on the front side simultaneously and avoids shunting by inversion layers often observed for silicon nitride passivation layers. Since it is only about 15 nm thick the optical properties of the front remain virtually unchanged when the thickness of the antireflection coating is adjusted accordingly. Furthermore the stack system has some benefits especially for multicrystalline silicon of medium material quality:

- Emitter diffusion can be applied on both sides and improves the gettering of impurities.
- The silicon nitride on the rear enables an additional hydrogenation of the multicrystalline silicon bulk during the firing of the screen-printed front metallisation.

The overall solar cell structure is shown in Figure 1. Besides the passivation stack, the cell structure features screen printed front contacts and a Laser Fired Contacts (LFC) back electrode.

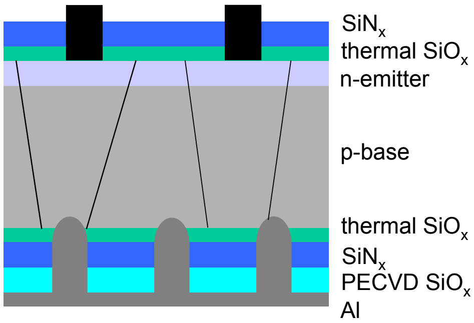

Figure 1. Solar cell structure with stack layer system for rear surface passivation. Front contacts are screen-printed, the back contact is formed by LFC.

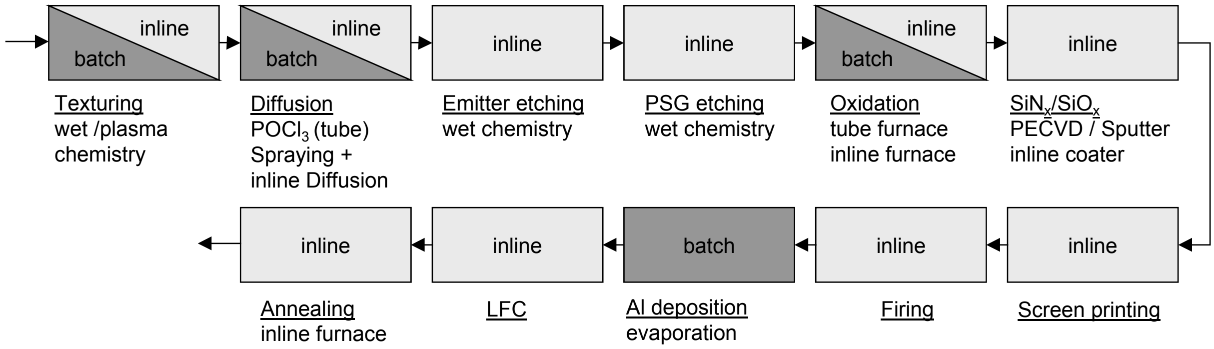

Figure 2. Technology roadmap for the industrial implementation of a silicon solar cell structure with a passivated rear surface and Laser Fired Contacts (LFC). For each process step, technology alternatives are listed and tested.

PRODUCTION CONCEPT

The industrial realization of a solar cell structure with a stack layer system for rear side passivation and local point contacts requires several novel process steps, as can be seen in Figure 2. Compared to standard cell technologies, these are the single-side etch back of the emitter layer on the rear side, a dry oxidation, the aluminum deposition and the annealing after laser contacting. Single-side etching has been done in an inline wet etching system from Gebr. Schmid GmbH, guiding the wafers over wetted rolls. The one-sidedness of the etch is guaranteed by a strong air flow directed to the top surface of the wafer.

With the dry oxidation step, a thin thermally grown silicon oxide (in the range of 10 nm) is build up on both sides of the wafers, simultaneously passivating the p-type rear and the emitter on the front. The layers are thin enough to ensure excellent antireflection properties in combination with the SiN_x antireflection at the front side. On the rear side the thin layer needs to be protected from the metallization by the SiN_x and the PECVD SiO_2. Due to the short process time, the dry oxidation does not need to be done in a tube furnace, but is also possible in an inline furnace very similar to the corresponding diffusion process technologies.

Another novel process step to be included is the deposition of a thin Al layer on the rear side either done by inline sputtering or evaporation. An overview of the different metallization techniques for the back side and their impact as well as details on the optimum annealing conditions gives [5] at this conference. Other already existing process technologies for texturing multicrystalline silicon (wet and plasma chemistry based), for emitter diffusion ($POCl_3$ tube and inline diffusion) as well as passivation layer deposition (Sputtering or PECVD) have been partially compared and process results have been characterized.

The technology survey and the direct comparison of the different technologies has been carried out on 156x156 mm² large neighboring multicrystalline silicon wafers with a thickness 270 µm and a resistivity range of 0.8 – 2 Ωcm.

TEXTURING

For texturing multicrystalline silicon grain independent, isotropic etching technologies have to be applied. In this work, acidic wet and plasma based inline texturing technologies have been compared. Acidic texturing was performed in an inline wet bench using $HF / HNO_3 / H_2O$ as etching solution. Plasma texturing for comparison was carried out in an inline plasma system using SF_6 / O_2 as etching gases [6]. Reflectance measurements of the different etching methods are shown in Figure 3. Directly after texturization, plasma etching reaches weighted reflectance (R_w) values of around 16 % compared to 21 % with the acidic texture (the measured reflectance values are weighted with the solar spectrum and the IQE of an industrial mc-Si solar cell). After SiN_x AR coating the difference disappears giving a R_w in both cases of around 6 %. Compared to a saw damage etched neighboring mc-Si wafer with R_w = 9 %, the texturing results in an overall reflection loss gain of around 3 % which may increase the short-circuit current of the final solar cells.

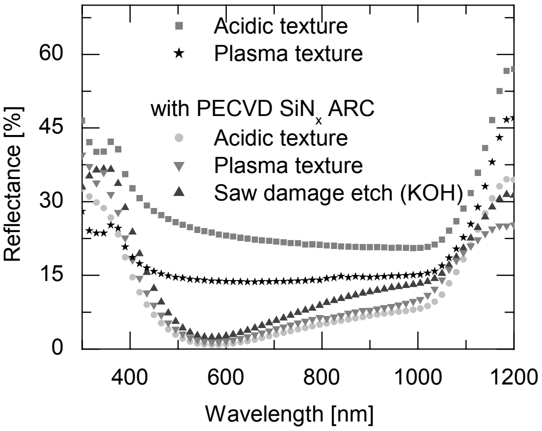

Figure 3. Comparison of dry and wet chemical texturing technologies after etching and after SiN_x antireflection coating.

EMITTER DIFFUSION

For n-type emitter formation a $POCl_3$ tube diffusion as the most common diffusion technology in solar cell manufacturing has been compared with an inline diffusion system. In the latter case, the wafers are first coated with a thin phosphorous-containing layer and then transported through the inline furnace, where the wafers are heated up to temperatures of 850 to 900°C. For coating, the spraying equipment used in this work consists of an ultrasonic nozzle, a spray-shaping device, an exhausted enclosure, a conveyor system and a liquid delivery system [7].

Sheet resistance distributions of both processes are shown in Figure 4 on subsequent multicrystalline silicon wafers. The distribution is slightly sharper in case of $POCl_3$ diffusion, but the differences are marginal.

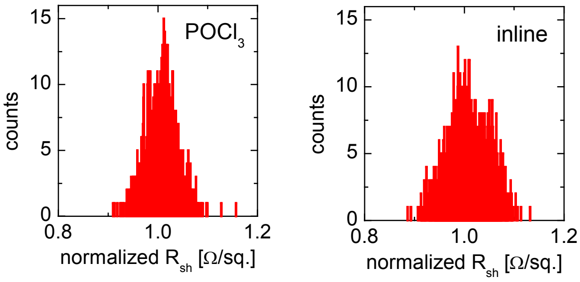

Figure 4. Sheet resistance distribution of mc-Si wafers with $POCl_3$ tube diffusion (left) and inline diffusion (right).

Final sheet resistance values could be fixed to 45 Ω/sq. in both cases, depending on the diffusion time and temperature.

PASSIVATION STACK

After diffusion, rear side emitter removal and PSG etching, the passivation stack system on the front and back side of the wafers can be build up.

Compared to standard cell technology, dry oxidation represents the most challenging process step in our technology route. Requirements concerning the cleanliness of the wafer before oxidation are high and well known from high efficiency processing to maintain a high passivation quality [8]. Two different technologies are compared, oxidation in a tube and in an inline furnace similar to the corresponding diffusion systems. In case of the inline furnace, the oxidation takes place under Air / O_2 ambient for several minutes growing a thermal oxide of around 10 nm. The oxide thickness in case of the tube oxidation has been measured to around 30 µm, which is slightly to thick for an optimum adjustment of the front side antireflection coating. µ-PCD mappings have been performed on neighboring acidic textured and inline diffused mc-Si wafers directly after oxidation (see Figure 5, upper diagrams) in case of tube furnace and inline furnace oxidation. Average lifetimes reached in both cases are similar and in the range of 8 µs, mainly limited by the high emitter doping concentration (~45 Ω/sq.). The distribution in case of inline oxidation is wider, giving slightly higher lifetimes above 20 µs in areas of good material quality. The situation changes, when applying the PECVD SiNx layer on both sides as well as the PECVD SiO_x layer on the rear. The samples were also fired at a typical contact sintering temperature of 800°C. Lifetimes are now shifted towards higher values, in case of tube oxidation the mean value is increased to 10 µs, whereas the inline oxidized wafer only kept his lifetime performance. The increase in lifetime can be attributed to a hydrogen release from the SiN_x layer during firing, the temperature stability of the thin thermal oxide layer also seems to be higher in case of tube oxidation.

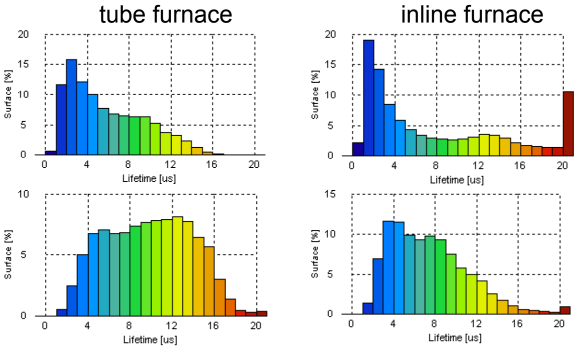

Figure 5. Distribution of carrier lifetimes measured by µ-PCD of neighboring acidic textured mc-Si wafers (156x156 mm²) after oxidation in a tube furnace and in an inline furnace (upper diagrams) and after passivation stack deposition and firing (lower diagrams).

Remaining lifetime limitations are visible by QSSPC measurements of the same mc-Si wafers (Figure 6) [9]. Significant trapping occurs in case of acidic textured and inline diffused wafers independent of the oxidation

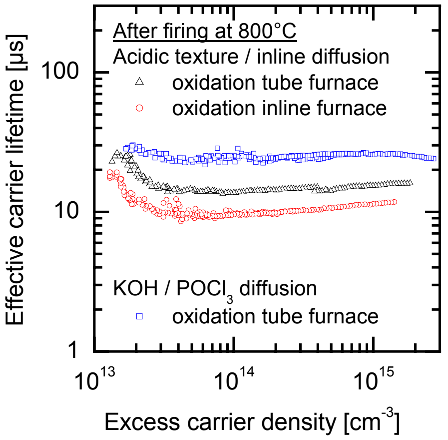

Figure 6. Effective carrier lifetime measured by QSSPC after oxidation and firing for the different oxidation technologies (tube/inline) on mc-Si wafers with acidic textured surface and saw damage etched surface.

method. This trapping may be ascribed to the acidic textured front and back surface, because in case of a saw damage etched surface, an increase in effective lifetime for low excess carrier densities is not as distinctive [10].

SOLAR CELL RESULTS

The current status of fill factor optimization of completely with inline processed (diffusion, oxidation) large area mc-Si solar cells is shown in Figure 7. Due to some mismatches during processing (SiN_x coating on front side too thick, sheet resistance of inline emitter diffusion only around 40 Ω/sq.) V_{oc} and j_{sc} and therefore the efficiency of these cells have to be further optimized.

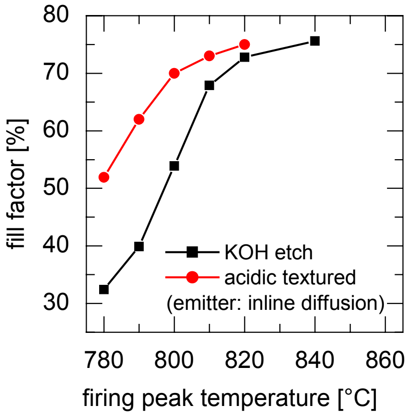

Figure 7. Peak firing temperature optimization for large area (243 cm²) mc-Si solar cells with saw damage etched and acidic texured front surface.

The potential of the passivation stack system with local rear contacts (LFC) is shown in Table 1. An overall increase in V_{oc} of 2 % relative and 4 % relative in j_{sc} is reached on large area mc-Si wafers compared to a standard Al-BSF cell structure. These progressions can be directly attributed to the excellent surface passivation quality as well as the improved internal reflection of the passivation stack layer system on the rear side.

Table 1. Best results for large area (156 cm²) mc-Si solar cells with standard Al-BSF and LFC passivation stack on the rear side.

	V_{oc} [mV]	j_{sc} [mA/cm²]	FF [%]	η [%]
Al-BSF				
Best cell	611	31.2	75.9	14.5
LFC with passivation stack				
Best cell	621	32.5	78.5	15.8

This conclusions are underlined by the spectral response measurement of the two cells in Figure 8. The benefit of the rear passivated solar cell can be clearly attributed to an improved electrical and optical performance of the wafers rear side.

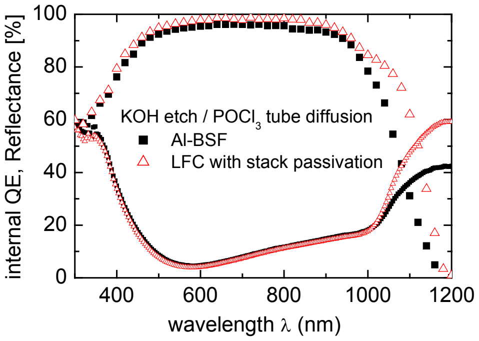

Figure 8. Spectral response of a mc-Si solar cell with passivation stack layer on the rear side compared to a reference cell with a full aluminum BSF.

CONCLUSION

A technology route for the industrial implementation of a rear passivated silicon solar cell structure is presented. The cell features a passivation stack system on the rear assuring high electrical and optical performance. The impact of completely novel as well as more inline based process steps on the material quality of mc-Si wafers have been analyzed and compared with standard process technology. It has been shown that both inline and tube diffusion and oxidation processes can be used in industrial manufacturing of rear passivated silicon solar cells. The potential of these cells has been proven with a relative increase for V_{oc} of 2 % and J_{sc} of 4 % compared to standard mc-Si solar cells featuring an Al-BSF on the rear.

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