INFLUENCE OF REAR SIDE COATING ON EMITTER FORMATION DURING POCl₃ DIFFUSION PROCESS

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ABSTRACT: The influence of a SiN_x coating of a Si wafer on sheet resistance (R_{Sh}) of a neighbouring wafer during POCl₃ diffusion process is investigated. Wafers facing the SiN_x layer of the neighboring wafer in the next slot of the quartz boat show a lower R_{Sh} compared to those facing a bare Si wafer, e.g. a reduction from 61 Ω/sq to 52 Ω/sq and a thicker PSG layer are determined. The active doping profile, measured by ECV, shows a deeper plateau region while the tail region is unchanged. Accordingly, the emitter saturation current density rises from 130 fA cm⁻² to 193 fA cm⁻². We propose that the thicker PSG layer originates from a lower consumption of the reactive gases (POCl₃-N₂ and O₂) at the SiN_x coated surface and thus a higher availability of them at the bare Si surface. On the other hand, we also investigate the influence of the thickness of the SiN_x rear coating on the emitter at the non-coated Si surface. Already a very thin layer of 20 nm SiN_x causes a significant change in R_{Sh} and the emitter profile, while there was no difference observed for the SiN_x thickness in the range from 20 nm to 160 nm. Facing a rear coated neighbor wafer during diffusion seems to improve the uniformity of R_{Sh} on 6-inch large area wafers.
Keywords: POCl₃, Diffusion, Emitter, PSG, PERC, Coating, Passivation

1 INTRODUCTION

Most commonly, a homogenous n-type emitter is fabricated via POCl₃ diffusion. Thereby the emitter is usually formed on both sides of the wafer and has to be removed chemically on the rear side for PERC (Passivated Emitter and Rear Cell) or at least an edge isolation is necessary for Al-BSF (Back Surface Field) solar cells. In order to avoid this process step, it is possible to coat the rear side before diffusion with a silicon nitride (SiN_x) capping layer, which acts as diffusion barrier. The capping layer could be already used for a texturing step before, and edge isolation after diffusion is not necessary anymore. For the manufacturing of PERC solar cells a temperature stable passivation under the SiN_x coating could be applied, which just has to be locally opened after diffusion.

During the diffusion process POCl₃-N₂ and O₂ forms phosphorus pentoxide (P_2O_5), which reacts with silicon to silica and the diffusing atomic phosphorus as dopant:

$$4POCl_3 + 3O_2 \rightarrow 2P_2O_5 + 6Cl_2 \qquad (1)$$
$$2P_2O_5 + 5Si \rightarrow 5SiO_2 + 4P \qquad (2)$$
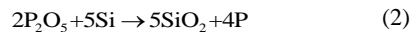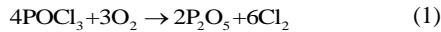
SiO_2 and P_2O_5 forms the doping source, the PhosphoSilicate Glass (PSG) layer, which is possibly a multilayer system [1]:

$$SiO_2 + P_2O_5 \rightarrow P_2O_5 \cdot SiO_2 \qquad (3)$$
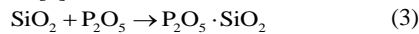
In case of using rear coated wafers during diffusion, we observe a significant change in the emitter formation on the front side of the wafer facing the SiN_x coating in comparison to the emitter of an uncoated wafer. In the following, we show a detailed analysis of this effect.

2 EXPERIMENTAL SET-UP

The standard base material is p-type, 6-inch Cz silicon wafer with a bulk resistivity (R_B) of 2.7 Ωcm and 160 μm thickness. Half of the wafers received a rear side coating with SiN_x of different thicknesses (range 20 to 160 nm). After wet-chemical cleaning, a POCl₃ diffusion leading to a sheet resistance of 60 Ω/sq was performed in a commercial open tube diffusion furnace from Centrotherm. The wafers are arranged in the diffusion quartz boat as indicated in Fig. 1. The first and last 5 slots are used for dummy wafers. The wafers in slot 7 and 8 (as well as 34 and 35) with rear coating are arranged in back-to-back configuration. The neighboring uncoated wafers are used to characterize the emitter. On the other hand, rear coated wafers with different SiN_x layer thicknesses (indicated in Fig. 1) are arranged in the same direction (slot 10 to 21) with an uncoated wafer in between each pair. To balance small variations of R_{Sh} due to the length of the diffusion boat, the experiment is
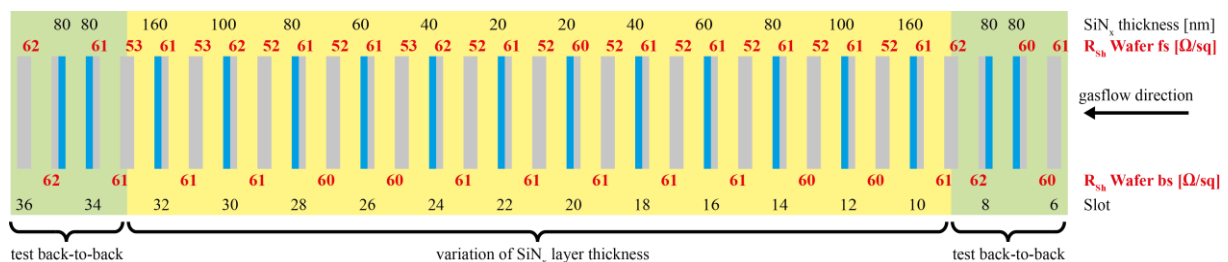

Figure 1: Wafer slot position (black bottom numbers) in the diffusion boat and resulting R_{Sh} on the wafers' front side (fs, red top numbers) and backside (bs, red bottom numbers). Some wafers have a rear coating (indicated as a blue layer) with different SiN_x layer thicknesses (black top numbers). R_{Sh} is the average value of a mapping with 25 measurements.

performed symmetrically using the slots 22 to 36.

Additionally, FZ-Si wafers with 150 mm diameter, p-type, R_B of 200 Ωcm and 250 µm thickness are placed in slots 39 and 42 (not shown in Fig. 1) for further emitter characterization. One FZ-Si wafer has uncoated neighbor wafers on both sides to create symmetrical samples, while the other FZ-Si wafer has coated neighbor wafers with SiN_x layer of 100 nm thickness. Both FZ-Si wafers are halved after diffusion. One half of each FZ-Si wafer is passivated on both sides with SiN_x by PECVD after PSG removal and co-fired in a commercial belt furnace to determine the emitter saturation current density (j_{0E}) by QSSPC [2]. After diffusion, R_{Sh} is measured on each wafer (mapping: 25 measuring points) with a Four-Point-Prober for all wafers tracking the slot position in the diffusion boat. The active doping profile of the wafers is measured by Electrochemical Capacitance Voltage (ECV). Furthermore, we determined the PSG thickness by spectroscopic ellipsometry [3].

3   RESULTS

Fig. 1 shows the measured R_{Sh} on the wafers' front side (red top numbers) in dependence of the slot position in the diffusion boat. First of all, the significant change of R_{Sh} from 61 to 52 Ω/sq on some uncoated wafers can be observed (compare slot 9 and 11). Due to the arrangement of coated and bare wafers in the diffusion boat one can also realize the reason of the change in R_{Sh}. If the coated wafers are arranged back-to-back, then there is no change in R_{Sh} (61 Ω/sq) on the bare neighbor wafers (e.g., slot 9 and 36). On the other hand, if the rear coated wafers are arranged facing one direction, R_{Sh} on the front side of the bare neighbor wafers changes to 52 Ω/sq (e.g., slot 11 and 13). So the change of R_{Sh} is caused by the opposed rear coated backside of the neighboring wafer in the next slot of the boat, independent of its own coating.
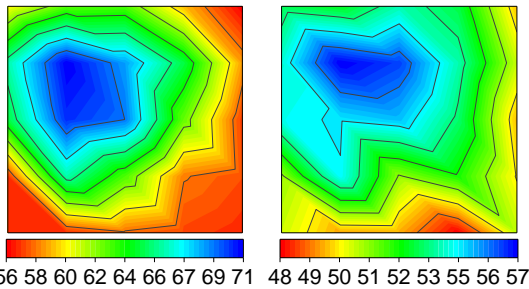

56 58 60 62 64 66 67 69 71   48 49 50 51 52 53 55 56 57

Figure 2: R_{Sh} mapping (25 measurements) of the wafers front side with uncoated neighbor wafer (left, Fig. 1 slot 9) and 20 nm SiN_x coated neighbor wafer (right, Fig. 1 slot 21) in the diffusion boat. The colored scale is in the range from minimum to maximum R_{Sh} of each wafer in the unit Ω/sq.

In Fig. 2 one can see the mapping measurement of R_{Sh} for coated and uncoated neighbor wafers. The change of R_{Sh} is also confirmed by ECV measurements, which are shown for the FZ-Si wafers (Fig. 3) and the Cz-Si wafers (Fig. 5).

The plateau depth of the emitter increases significantly by 6 nm (comparing depth values at a defined P concentration of 10^{20} cm^{-3}), while the emitter tail region is unchanged. This is a similar effect as

compared to increasing the $POCl_3$-N_2 gas flow during diffusion [3].
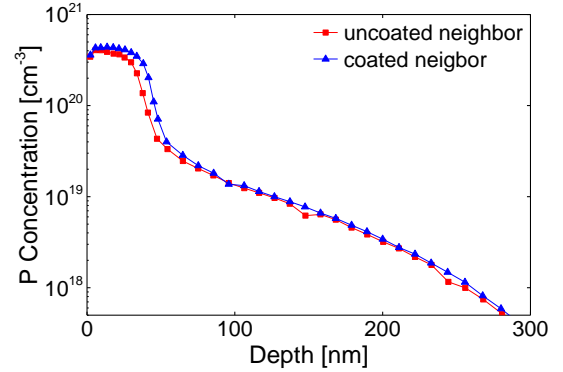

Figure 3: Emitter profiles in dependence of rear coating of neighboring wafer in the diffusion boat, measured with ECV using FZ samples. The measurement was performed in the middle of the wafer.

Furthermore, we show in Figure 4 the change in j_{0E}. If the FZ-Si wafer has uncoated neighbor wafers, j_{0E} is in average 130 fA cm^{-2} while j_{0E} rises up to 193 fA cm^{-2} for the FZ-Si wafers with coated neighbors. On the other hand, we also observe a change in thickness of the doping source, the PSG layer: The PSG thickness measured by ellipsometry changes significantly from 29 nm to 32 nm due to a coated neighbor wafer for the FZ-Si wafers (also 3 nm difference measured on the Cz-Si samples).
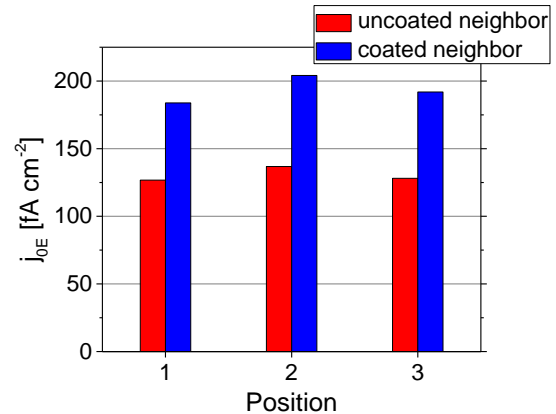

Figure 4: Emitter saturation current density measured by QSSPC. The one sample has uncoated neighbor wafers (in red), while the other one has coated neighbor wafers (in blue). Both FZ were halved after diffusion and then after PSG removal passivated by SiN_x symmetrically and co-fired. The measurement is performed in the middle (1), left (2) and right (3) position of the half 150 mm diameter FZ wafer.

We also investigated the influence of the thickness of the rear coating on the emitter properties of the neighboring wafers. As one can see in Fig. 1, there is no significant influence of the thickness in the range from 20 nm to 160 nm on R_{Sh}. Furthermore, in Fig. 5 the ECV measurements for different SiN_x thicknesses are shown. There is significant change between uncoated and 20 nm coating, but no significance for increasing the SiN_x thickness. The PSG thickness is also independent of the SiN_x thickness for the range from 20 to 160 nm.
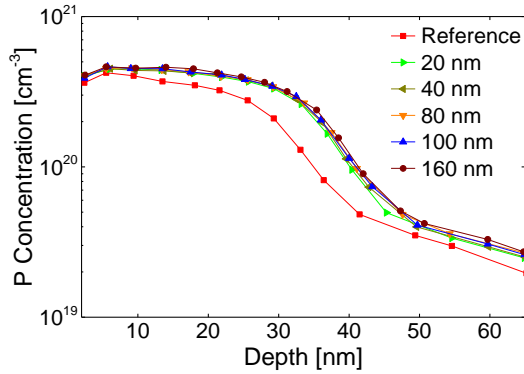
Figure 5: Emitter profiles in dependence of the SiN_x rear coating thickness of a neighboring wafer in the diffusion boat, measured with ECV. The reference sample (slot 9 in diffusion boat, see Fig. 1) has only an uncoated neighbor wafer to its front side (slot 8). The other samples have the slot position 11 (facing 160 nm SiN_x coating), 13, 15, 17, 19 and 21 in the diffusion boat. The measurement was performed in the middle of the wafer.

In addition, we show the effect for lowly doped emitters (see Tab. I) on 6-inch textured rear passivated wafers. Half of the wafers in the first part of the diffusion boat has a back-to-back orientation, while the other half of the wafers is orientated in the same direction (rear passivated backside shows in gasflow direction). For diffusion B, the rear passivated wafers with a back-to-back orientation have a sheet resistance of 108 Ω/sq (which corresponds to R_{Sh} on uncoated wafers), while the rear passivated wafers with no back-to-back orientation have a lower R_{Sh} of 88 Ω/sq. For diffusion C, R_{Sh} of the rear passivated wafers with a back-to-back orientation corresponds to 91 Ω/sq while R_{Sh} for the not back-to-back orientation decrease to 68 Ω/sq. Facing a rear coated neighbor wafer during diffusion seems to improve the uniformity of R_{Sh} on large area wafers. As one can see in Tab. I, for diffusion A, back-to-back orientation, the uniformity is the same as for diffusion B in a non back-to-back configuration, while R_{Sh} is much higher for the former.

Table I: Three diffusions, using always the same textured wafers with a SiO_2/SiN_x rear passivation. The rear passivated wafers are orientated back-to-back (b2b) or in same direction (not b2b) in the diffusion boat, which causes a dramatic change in R_{Sh} and uniformity (U).

Diffusion	Orientation	R_{Sh} [Ω/sq]	U [%]
A	b2b	63 ± 5	16
	not b2b	54 ± 3	11
B	b2b	108 ± 17	25
	not b2b	88 ± 9	16
C	b2b	91 ± 13	25
	not b2b	68 ± 5	15

4   CONCLUSIONS AND OUTLOOK

We observe a significant change in the emitter (R_{Sh}, j_{0E}, active doping profile) and the PSG thickness when the wafer side is facing a neighboring wafer in the diffusion boat which is rear coated with SiN_x. We propose that the thicker PSG originates from a lower

consumption of the reactive gases ($POCl_3$-N_2 and O_2) at the SiN_x coated surface and thus a higher availability of them at the bare Si surface. Since one cannot expect an infinite doping source while increasing the $POCl_3$-N_2 gas flow [4], the change in PSG growth also changes the emitter formation.

On the other hand, we also investigated the influence of the thickness of the SiN_x rear coating. Already a very thin layer of 20 nm SiN_x causes a significant change of the emitter in R_{Sh} and the plateau depth of the emitter profile, while there was no change for increasing the SiN_x thickness up to 160 nm. In further experiments, a SiN_x layer of 10 nm and below would be of great interest to determine the minimum SiN_x thickness for a significant change in R_{Sh}.

In addition, we demonstrated the effect for highly doped emitters. Thereby one can expect a higher uniformity of R_{Sh} on 6-inch large area wafers by facing rear coated wafers. As we showed by Four-Point-Probe mapping, the highest R_{Sh} is in the middle of the wafer, where the least reactive gas molecules can be expected. Due to the SiN_x coated surface, the lower consumption of the reactive gases would be most effective in the middle of the wafer.

One has to be careful to expect always the same emitter properties, independent of a rear coating during diffusion. This is, e.g., very important for manufacturing of j_{0E} samples, which have to be symmetrical [2]. Furthermore, this systematic investigation of the rear coating during diffusion can help to transfer the emitter of a standard Al-BSF solar cell to a modern rear passivated solar cell.

5   ACKNOWLEDGEMENTS

6   REFERENCES

[1] R.N. Ghoshtagore: *Phosphorus diffusion processes in SiO₂ films*, Thin Solid Films 25(2) (1975) 501.

[2] D.E. Kane, R.M. Swanson, *Measurement of the emitter saturation current by a contactless photoconductivity decay method*, Proc. 18th IEEE PVSC, Las Vegas 1985, pp. 578-583.

[3] M. Steyer, A. Dastgheib-Shirazi, H. Wagner, G. Micard, P.P. Altermatt, G. Hahn: *A study of various methods for the analysis of the phosphosilicate glass layer*, Proc. 27th EU PVSEC, Frankfurt 2012, pp. 1325-1328.

[4] A. Dastgheib-Shirazi, M. Steyer, G. Micard, H. Wagner, P. P. Altermatt, G. Hahn: *Effects of process conditions for the n⁺-emitter formation in crystalline silicon*, Proc. 38th IEEE PVSC, Austin 2012, pp. 1584-1589.