GETTERING EFFICACY OF APCVD PSG AND BSG LAYERS IN MC-SI

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ABSTRACT: APCVD (atmospheric pressure chemical vapor deposition) offers promising improvements for the PERT (passivated emitter rear totally diffused) solar cell concept. One-sided diffusion of P as well as B allows reduced processing steps. In this work the gettering efficacy of P- and B-doped layers deposited by APCVD on mc (multicrystalline) Si (silicon) material is evaluated by minority charge carrier lifetime measurements.
Comparison with the influence of thermal load showed that P-gettering resulted in significant lifetime increase, whereas temperature treatment without PSG (phosphor silicate glass) induced the opposed effect. Close to the crucible wall, the local defect structure in the wafer leads in ungettered samples to negative effects that can be strongly reduced by P-gettering. In addition, the APCVD PSG layers showed at least comparable gettering efficacy to standard $POCl_3$-gettering via diffusion in a quartz tube furnace. Finally, co-diffusion of APCVD PSG and BSG layers was tested for a PERT concept.
Keywords: Gettering, Multicrystalline Silicon, Lifetime, APCVD

1 INTRODUCTION

Most industrial crystalline Si solar cell concepts use open tube diffusions for fabrication of doped layers. The most prominent example is P-diffusion, which normally is carried out in an open quartz tube furnace using, *e.g.*, $POCl_3$ as precursor. For emitter fabrication in n- or p-type PERT solar cells, normally a BBr_3-based open tube diffusion is used. Due to the slower diffusion of B in Si, B-diffusion is usually applied at higher temperatures compared to P-diffusion.

For the PERT solar cell concept, a one-sided diffusion of P as well as B would be beneficial to reduce processing steps (masking or etching). Therefore, CVD(chemical vapor deposition)-based doping layers are of high interest for industrial processing of PERT solar cells, as they can be deposited on one side only and allow for a following single co-diffusion step for both doping types. Compared to PE(plasma-enhanced)CVD, AP(atmospheric pressure) CVD [1] could be even more beneficial as it does not involve vacuum processing and allows for a high throughput. In addition, the temperature load on the material is different to standard diffusion processes. When applying the PERT solar cell concept to mc-Si, care has to be taken that effective minority charge carrier lifetime τ_{eff} is not negatively influenced by the higher temperatures normally needed for B-diffusion.

Standard P-diffusion is known to have a gettering effect on lifetime limiting impurities, especially in defect-rich mc-Si. But also B-diffusion can have a positive gettering effect. Gettering efficacy of $POCl_3$- and BBr_3-based open quartz tube diffusions have been studied for mc-Si (*e.g.* [2]) and dependence of gettering efficacy on the material quality has been shown (*e.g.* [3]). However, to our knowledge the gettering efficacy of doped APCVD SiO_2 layers (phosphor-silicate glass (PSG) and boro-silicate glass (BSG)) on mc-Si has not been studied so far.

Therefore, in this contribution the gettering efficacy of P- and B-doped APCVD layers in standard mc-Si is investigated. It is compared to wafers with same temperature load, but without doping glasses. In addition, the gettering efficacy is studied depending on wafer position in the ingot because distance to crucible walls is a critical parameter for contaminations and defects. The gettering efficacy of a standard $POCl_3$-based layer is compared to the APCVD-based processes.

2 EXPERIMENTAL

156x156 mm² B-doped industrial standard mc-Si wafers (~1 Ωcm) from one standard ingot were obtained with known position and defined orientation of each wafer in the block. Hence gettering efficacy can be studied in dependence of vertical and horizontal distance to the crucible walls. If not specified, gettering efficacy on samples from mid ingot height with about 10 cm in horizontal distance to the crucible wall are discussed. Sister wafers shown here origin from a relatively small range in height resulting in a very similar defect structure.

5x5 cm² samples were laser cut out of the 156x156 mm² wafers. After saw damage etch, wafer surfaces were cleaned. A reference (A) wafer was not further processed and only a surface passivation was realized by firing of a remote PECVD SiN_x:H layer. For samples B, C, D, E, and F different gettering sequences were applied. The doping glasses for those samples are deposited by APCVD. APCVD allows depositing BSG- and PSG-layers on one side of the wafer without capping the other side. An overview of the experiment with the applied APCVD process sequences is given in Fig. 1.

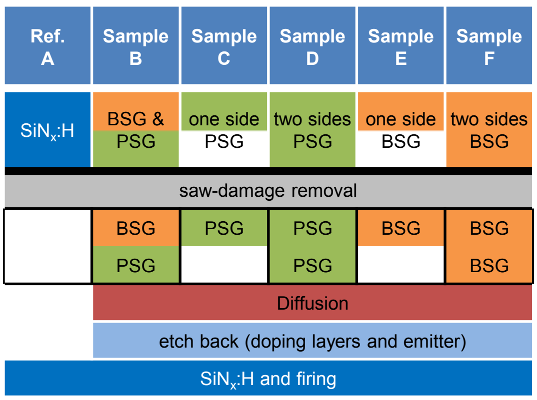

Figure 1: Overview of process steps and APCVD layers.

Sample C received a one-sided and sample D a two-sided PSG. Sample B received PSG on one side and BSG on the other. Sample E features a one-sided BSG and sample F a two-sided BSG. To separate temperature induced effects from P-gettering, for sample C and D sister wafers received the same thermal load but without any deposition (process steps not shown in Fig. 1). After deposition, respectively temperature treatment, the dopants were driven into wafers in a standard open quartz tube diffusion furnace at same temperature and duration for all samples in the same process. This resulted in a 60 Ω/□ P-diffusion and a 110 Ω/□ B-diffusion. Afterwards, PSG and BSG and the diffused layers were removed by wet chemical etching and PECVD SiN_x:H was deposited on both sides and fired in a belt furnace at 800°C peak firing wafer temperature.

To determine gettering efficacy in areas close to the crucible wall, two sister wafers with one side showing the effect of the nearby crucible wall were additionally processed analogous to the reference sample A and sample D. For comparison of two-sided APCVD P-gettering with $POCl_3$-gettering, two sister wafers from top ingot height were used as wafers from top height show elevated concentrations of contaminations. $POCl_3$ diffusion was performed in an open quartz tube furnace with parameters in accordance to achieve similar sheet resistance (R_{sh}) as the APCVD samples. Due to process requirements, the $POCl_3$ sample received a different SiN_x:H from a direct plasma process. Therefore, SiN_x:H was removed after firing from the sister wafers with $POCl_3$- and APCVD P-gettering and a wet chemical surface passivation was applied for comparison.

Afterwards, τ_{eff} of the samples was measured by self-calibrated time resolved photoluminescence imaging (TR-PLI [4]) and the harmonic mean of τ_{eff} is calculated.

3 RESULTS AND DISCUSSION

3.1 APCVD gettering efficacy

Fig. 2 shows selected spatially resolved τ_{eff} data for the samples described above. Comparing the reference sample A (Fig. 2A, harmonic mean: 66 µs) with the single-sided P-gettered one (sample C, Fig. 2C, 111 µs), a pronounced P-gettering effect can be seen. This effect is further improved for the two-sided P-gettered sample (sample D, Fig. 2D, 129 µs). From literature it is known that having P-gettering layers present on both wafer sides results in a more pronounced gettering effect in mc-Si (*e.g.* [5]). This seems to be true for APCVD-based PSG layers as well.

On the other hand, a sample with the same temperature load as the one-sided P-gettered sample C shows a decrease in τ_{eff} in most sample areas (Fig. 3a, 44 µs). Therefore, we conclude that for the pronounced positive gettering effect the presence of a PSG layer and/or the diffused P-profile are needed. The sample that received the same thermal load as the two-sided PSG sample D shows an even more decreased τ_{eff} (Fig. 3b, 35 µs). This could be caused by the second run through the APCVD reactor and the additional temperature load involved therein, or by additional in-diffusion of impurities, as no masking layer is present for the second run in contrast to the two-sided PSG sample D where the other side is protected by the PSG deposited in the first run through the machine.

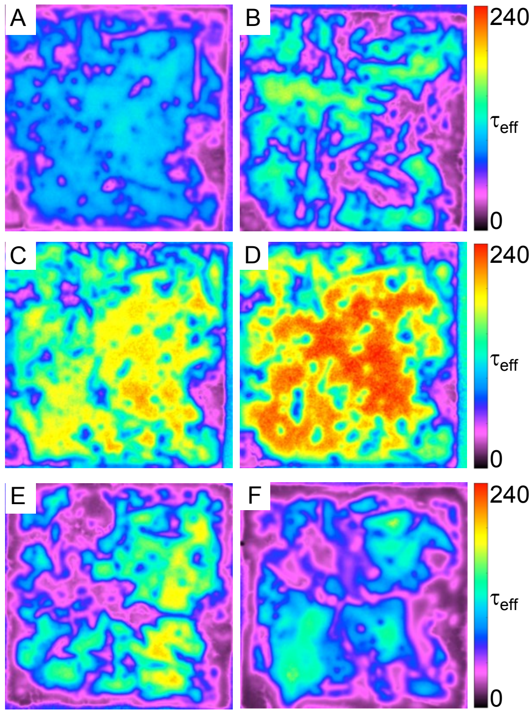

Figure 2: τ_{eff} maps of the 5x5 cm² samples processed according to Fig. 1 from mid ingot position. A) reference sample, B) co-gettered with BSG and PSG, C) one-side P-gettered, D) two-sides P-gettered, E) one-side B-gettered, F) two-sides B-gettered sample.

The one-sided B-gettered sample E (Fig. 2E, 58 µs) shows in some regions a positive gettering effect, too, but significantly less effective than the one-sided P-gettering (Fig. 2C). Standard B-gettering is usually less effective than P-gettering, but the efficacy seems to depend more critically on the applied gettering parameters [2]. Especially as the two-sided B-gettered sample F shows an overall decrease of τ_{eff} (Fig. 2F, 47 µs). Nevertheless, it demonstrates that also a B-diffusion from an APCVD-sourced BSG layer can have a positive gettering effect.

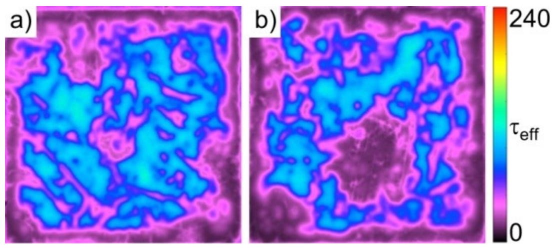

Figure 3: τ_{eff} maps of the 5x5 cm² samples from mid ingot position. a) same temperature load as one-side P-gettered sample C, b) same temperature load as two-sides P-gettered sample D.

Sample B with APCVD PSG on one side and APCVD BSG on the other (Fig. 2B, 63 µs) shows a mixed behavior. In some areas a significant improvement can be detected, while other areas do not respond well to the gettering layers or show even decreased τ_{eff} values. The reason for this behavior is still unclear. But it is expected that the local defect structure in combination with the applied temperatures may play a crucial role. In addition, unintentional contamination during processing might play a role and should be avoided.

3.2 Influence of crucible wall

All samples discussed so far resulted from a column of mid ingot position far away from the crucible walls. Samples from a position close to the crucible wall were also included in this study. As the gettering efficacy should be strongly influenced by the local concentration of impurities as well as their interaction with extended defects, a more complete picture is expected when investigating samples with varying concentration of impurities. It can be stated that in samples close to the crucible wall, an area of strong decrease in τ_{eff} is visible in the reference sample (red zone effect, Fig. 4a, 18 µs), which can be almost completely removed after APCVD-PSG-based P-gettering (Fig. 4b, 108 µs).

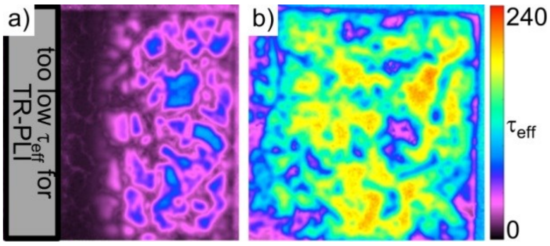

Figure 4: τ_{eff} maps of the 5x5 cm^2 samples from mid ingot position close to the crucible wall. a) sample processed according to reference sample A, b) two-sides P-gettered sample according to sample D.

3.3 Comparison of APCVD PSG and $POCl_3$ gettering

In addition to the described APCVD-based gettering schemes, also $POCl_3$-based standard gettering steps are carried out and provide reference gettering scenarios with similar R_{sh}. Due to process requirements, the $POCl_3$-gettered sample received a different SiN_x:H passivation. Hence for comparing both samples with a surface passivation of same quality, SiN_x:H layers were removed after firing from both samples and surface passivation was realized with wet chemical passivation. With comparable surface passivation the APCVD P-gettered sample (Fig. 5b, 329 µs) shows slightly higher τ_{eff} than the $POCl_3$-gettered one (Fig. 5a, 277 µs). In addition, both samples show similar τ_{eff} in low quality areas.

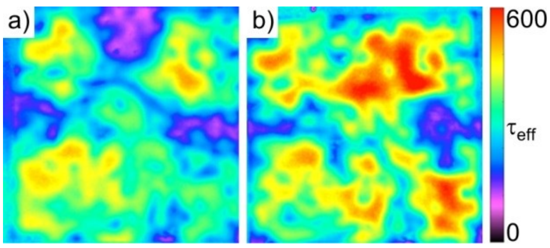

Figure 5: τ_{eff} maps of the 5x5 cm^2 samples from top ingot position with wet chemical surface passivation. a) $POCl_3$-gettered, b) two-sides APCVD P-gettered sample.

4 SUMMARY AND OUTLOOK

Deposition of PSG and BSG layers using APCVD is a very promising alternative to $POCl_3$- and BBr_3-based standard diffusion as it offers the possibility of higher throughput, less process complexity and lower cost. It offers a very attractive processing scheme especially for PERT-type solar cell architecture as PSG and BSG can be deposited on each side of the wafer, and emitter as well as back surface field can be formed in only one co-diffusion step.

Especially for mc-Si, gettering efficacy plays an important role and is a key point for reaching high efficiencies. Therefore, the gettering efficacy of APCVD PSG and BSG layers has been investigated. Results on samples from mid ingot position point out that one-side P-gettering is less effective than two-sides gettering, and B-gettering is less effective than P-gettering at the same diffusion temperature. Spatially resolved measurement of τ_{eff} allows for investigation of the influence of local defect structure on gettering efficacy.

As expected, gettering efficacy is strongly affected by the local defect structure. Especially wafers from a position close to the crucible wall with higher density of extended defects and higher transition metal concentration benefit from P-gettering steps. Regarding the contamination level this holds true also for wafers of the top ingot height.

Comparison of $POCl_3$-based diffusion gettering as the state-of-the-art reference gettering scheme in today's industrial production with APCVD P-gettering has shown comparable τ_{eff}.

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