MINORITY CARRIER LIFETIME MONITORING IN A BURIED CONTACT SOLAR CELL PROCESS USING MC-SI

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ABSTRACT: The buried contact solar cell is produced in industry using monocrystalline silicon. The low shading losses and the selective emitter design can lead to high efficiencies. The buried contact solar cell process features two diffusion steps, one of them is a high temperature step at 950°C. Compared to a standard screen print process the hydrogen passivation scheme also differs. In this paper we investigate the evolution of minority carrier lifetime of several multicrystalline silicon materials during processing and compare the final lifetime after the buried contact process to the final lifetime of a neighboring wafer after a standard screen print process. Solar grade feedstock (Elkem SoG) from a metallurgical process route produced by Elkem Solar AS has the potential for a reduction of costs per watt-peak in photovoltaics and is therefore in the focus of our investigation. The solar grade reference material “A” shows high lifetimes after a standard screen print process. In the buried contact process, lifetime drops after the high temperature $POCl_3$ diffusion and can be recovered partly by hydrogenation. In Elkem SoG silicon wafers, the phosphorous gettering continues even in the high temperature $POCl_3$ diffusion, resulting in high lifetimes also after the buried contact solar cell process.

Keywords: Metallurgical-Grade, Lifetime, Buried Contacts

1 INTRODUCTION

Upgraded metallurgical silicon has the potential for reduction of costs per watt-peak in photovoltaics since the energy intensive “Siemens procedure” to clean the silicon can be omitted. Silicon wafers obtained by a metallurgical process route may behave different in terms of minority carrier lifetime in the solar cell process compared to typical solar-grade silicon wafers. The change in lifetime depends on many parameters like different kinds of impurity concentrations in grains, grain boundaries, dislocations and the interactions between them. The applied solar cell process influences the lifetime by phosphorous gettering, redistribution of impurities in high temperature steps, aluminum gettering and hydrogen passivation.

We investigate the influence of two solar cell processes (buried contact and base-line screen print) in the lifetime of Elkem SoG-Si obtained by the metallurgical process route and two reference multicrystalline silicon materials. The base-line screen print process contains usually only beneficial process steps in regard of minority carrier lifetime. The standard phosphorous diffusion is able to getter impurities effectively. The screen printed aluminum my also getter impurities in the co-firing step. The co-firing step also releases hydrogen from the SiN_x antireflective coating into the bulk silicon, leading to the passivation of recombination active areas.

High efficiency solar cell processes like the buried contact solar cell process have a different process scheme that often contains a high temperature process step. Especially the high temperature process step and the different hydrogen passivation are studied in our experiments. A similar investigation was presented before [1] with the focus on process dependent hydrogenation of String Ribbon silicon, since String Ribbon is known to be sensitive on hydrogenation. This paper treats block casted mc-Si with a focus an Elkem SoG silicon.

2 BURIED CONTACT PROCESS

The buried contact solar cell features a selective emitter structure on the front side as can be seen in Fig. 1 on the left hand side. The high sheet resistance emitter of about 100 Ω/sq emitter has low recombination losses and the heavy 10 Ω/sq diffusion underneath the contact grid allows a low contact resistance. The grooves can be made by a laser or a dicing saw. The groove width is 20 µm when using a dicing saw with a 15 µm thick blade. This contact design has lower shading losses than screen printed cells (100 to 150 µm with Ag paste), see Fig. 1 on the right hand side. The typical sheet resistance of a standard screen printed cell is about 50 Ω/sq to form a good ohmic contact during the co-firing step.

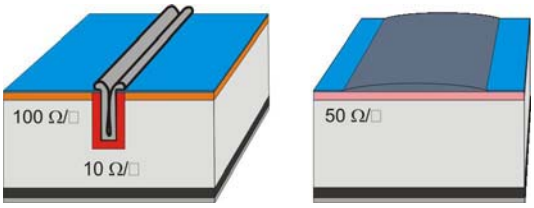

Figure 1: Schematic drawing of a buried contact cell on the left side, on the right a screen printed cell.

The process sequence of the buried contact process can be seen in Fig. 2. After the 100 Ω/sq emitter diffusion a LPCVD (Low Pressure Chemical Vapor Deposition) SiN_x deposition follows. The LPCVD SiN_x has a low pinhole density and prevents metal plating in the holes in the last process step. The LPCVD SiN_x serves as antireflective coating, surface passivation and masking layer for the second diffusion. Wafers are placed back to back in a quartz boat to ensure a single side deposition. The deposition temperature is 780°C for about 40 min, and there is only a negligible amount of hydrogen inside the LPCVD layer due to the high deposition temperature. After the groove formation, the 10 Ω/sq $POCl_3$ diffusion follows. This is a high temperature process of 950°C, 30 min. The rear side passivation is performed by screen printing and firing of aluminium paste. The excess aluminium is removed in HCl and 2 µm aluminium can be evaporated on the rear side as an aid for nickel and copper plating. Before metallization an optional hydrogen passivation step can be carried out by MIRHP (Microwave Induced Remote Hydrogen Plasma) passivation.

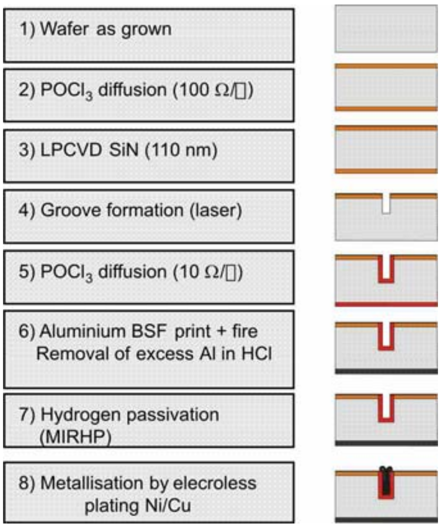

Figure 2: Buried contact solar cell process sequence .

The essential process steps that differ from a baseline screen print process are the heavy 10 Ω/sq $POCl_3$ diffusion and the missing hydrogen passivation by PECVD SiN_x deposition and firing which is replaced by MIRHP passivation.

3 EXPERIMENT

Neighboring 5x5 cm^2 wafers from Elkem SoG silicon, solar grade reference material “A” and reference material “B” obtained from high purity feedstock, were used. Only the essential buried contact process steps that are able to change the bulk lifetime were applied, therefore no groove formation and metallization was carried out. The metallization for solar cells would be done by electroless plating of nickel and copper and there is no thermal treatment like nickel sintering in our process scheme.

Beginning with an as grown wafer, every further neighboring wafer is processed with a further buried contact process step. After MIRHP treatment, the final bulk lifetime is reached, A neighboring wafer to this last one was processed with a standard screen print process. The standard screen print process includes a $POCl_3$ diffusion, PE(Plasma-Enhanced)CVD-SiN_x deposition and a screen printed Al BSF. The positive effect of phosphorous gettering and hydrogen passivation by firing PECVD-SiN_x for multicrystalline Si materials is well known. The screen printed wafer serves as a reference for the final bulk lifetime after the buried contact process.

The processed wafers with Al-BSF on the rear were etched in HCl to remove the excess aluminium. All wafers were etched in HF (10%) to remove the silicon nitride layer. Finally, 30 µm of silicon per side were removed with CP6 solution. The surfaces were passivated by iodine/ethanol. The iodine/ethanol passivation was chosen in favor of SiN_x surface passivation, since the SiN_x deposition may also change the bulk lifetime [1-4]. Lifetime measurement was carried out by µ-PCD (Microwave Photo Conductance Decay).

4 RESULTS

4.1 Lifetime maps

In Fig. 3 the lifetime maps of the reference “A” and Elkem material can be seen. Average initial lifetime is about 20 µs of the reference material “A” (sample 1a). The 100 Ω/sq phosphorous diffusion improves the lifetime by gettering (2a). There was no change in bulk lifetime after the following LPCVD SiN_x deposition (3a). A strong degradation occurred after the heavy $POCl_3$ diffusion (4a). The high temperature of 950°C probably redistributes impurities over the whole wafer. Screen printing aluminum on the rear side and firing led only to a very small improvement (5a). The hydrogenation by MIRHP recovered the bulk lifetime to about the same value as the initial lifetime of about 20 µs. A neighboring wafer processed with a baseline screen print process showed high lifetime values up to 150 µs on some grains. Screen printed solar cells of this material have typically efficiencies of 15.0 to 16.0%.

The initial lifetime of the Elkem material is comparable to the reference “A” material in the good part of the wafer. The wafer was cut out of an edge column, this can be seen at the low lifetimes on the left and bottom of the wafer (sample 1b). There is a large improvement in lifetime by the 100 Ω/sq $POCl_3$ diffusion, especially the former low lifetime edges can be gettered effectively (2b). The LPCVD SiN_x deposition led to a small improvement in lifetime (3b). The 100 Ω/sq $POCl_3$ emitter is still existent on this sample and impurity gettering continues during SiN_x deposition (780°C, 40 min). The 10 Ω/sq $POCl_3$ diffusion at 950°C still improves the bulk lifetime, especially the edges on the left and bottom have now equivalent lifetimes to the centre area (4b). The region on the right wafer side may suffer from an imperfect iodine/ethanol surface passivation. Screen printing and firing aluminium on the rear side had a small effect (5b), whereas no significant effect on hydrogenation can be seen with the MIRHP parameters used in this study (450°C, 1 h). The neighboring wafer has also high lifetimes after the screen print process (7b). Differences can be seen between the final bulk lifetime of the buried contact and screen print process at the left and bottom edge and at some grain boundaries. The mentioned edge region could be gettered more effectively in the buried contact process, since the screen print process contains only a 50 Ω/sq diffusion carried out at moderate diffusion temperatures. The buried contact process left some recombination active grain boundaries compared to the screen print process. It is known that grain boundaries can be passivated by hydrogen. The effectiveness of hydrogen passivation by PECVD SiN_x deposition and firing is reported to be high [5], whereas hydrogenation via MIRHP can be less effective [6].

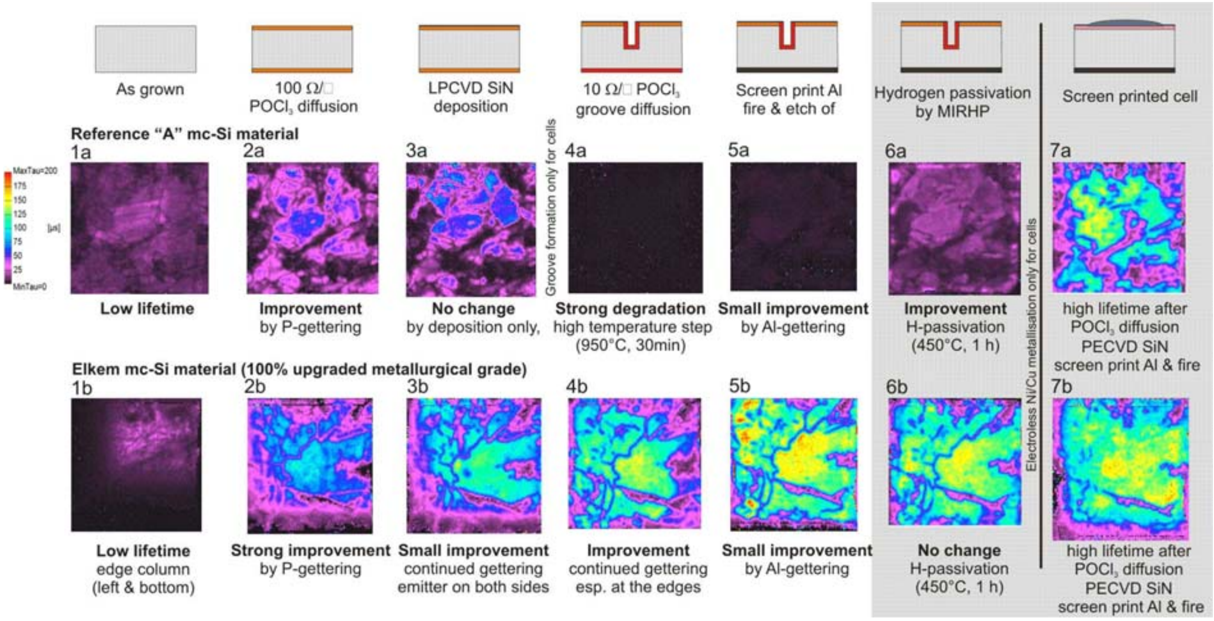

Figure 3: Lifetime maps of the reference "A" and Elkem material wafers. The reference "A" showed a strong degradation after the heavy 10 Ω/sq diffusion (4a). The lifetime can be partly recovered by hydrogen passivation (6a). The neighboring wafer after a screen print process reached high lifetimes (7a). The Elkem material monotonically improves with every process step, especially during the high temperature diffusion (4b) and Al-gettering (5b). Lifetimes are on a high level after the buried contact and the screen print process.

4.3 Grain boundary passivation by hydrogenation

Wafers from references material "B" were processed in the same way as the Elkem and reference "A" material. Material "B" was crystallized from high purity feedstock. The effect of different MIRHP parameters was investigated on this material. MIRHP duration was 1 h as used before and in addition a 3 h MIRHP treatment was applied. The result can be seen in Fig. 4. The 3 h was more effective than the 1 h MIRHP treatment especially with regard to grain boundary passivation. High quality grains show even higher lifetimes (up to 200 µs) after the buried contact process than after the screen print process.

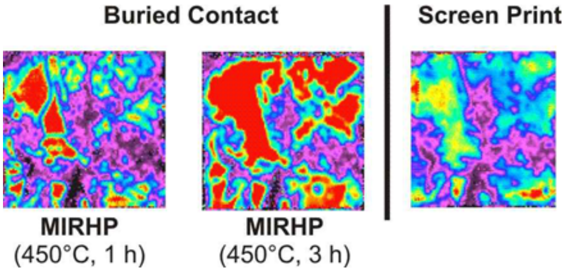

Figure 4: Reference "B" material. Two different MIRHP treatment times were applied. The 3 h MIRHP can better passivate grain boundaries. Higher lifetimes were observed after the buried contact process compared to the screen print process.

5 SUMMARY

We investigated the bulk lifetime propagation in a buried contact solar cell process of several mc-Si materials and compared the final lifetime to the final one of a neighboring wafer processed with a base-line screen print process. The reference material "A" showed a strong degradation after the heavy phosphorous diffusion applied at a temperature of 950°C. Bulk lifetime could be partly recovered by hydrogen passivation. Nevertheless, the bulk lifetime of a neighboring wafer after a screen print process is significantly higher. This leads to the conclusion that using the reference "A" material in a screen print process can lead to good efficiencies, whereas the material is not compatible with the buried contact solar cell process.

Elkem SoG wafers showed a monotonical improvement in bulk lifetime during the buried contact process. The phosphorous diffusions have a positive effect, especially on the initially low lifetime wafer edges (wafers were cut from an edge column). The 950°C high temperature $POCl_3$ diffusion still improves the material whereas the reference material "A" showed a strong degradation. The Elkem material reached high lifetimes up to 150 µs after both processes, the buried contact and the screen print process. Differences can be seen in the recombination activity of some grain boundaries. This is supposed to be an effect of the efficiency of hydrogen passivation as seen before by M. Rinio et al. [5].

The possibility for an efficient hydrogen passivation of grain boundaries by MIRHP was shown on reference "B" mc-Si material obtained by high purity silicon feedstock. A 3 h MIRHP treatment could passivate grain boundaries to a similar level as a neighboring wafer fabricated by the screen print process, where hydrogen passivation occurs via PECVD SiN_x deposition and firing. The final bulk lifetimes of the high quality grains where higher (up to 200 µs) after the buried contact process than the final lifetimes after the screen print process.

The microscopic reasons for the different behavior of multicrystalline silicon materials especially during high temperature steps should be further investigated. The levels and kinds of impurities that can be tolerated or may even be useful and their interactions also with grain boundaries results in a big set of parameters one can look into. It is noteworthy that the wafers crystallized from Elkem SoG feedstock obtained by a metallurgical process route showed high bulk lifetimes also after a high temperature phosphorous diffusions.

6 AKNOWLEDGEMENTS

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