LIFETIME MONITORING AND HYDROGEN PASSIVATION IN A BURIED CONTACT CELL PROCESS USING STRING RIBBON SILICON

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ABSTRACT: The buried contact cell design has a higher efficiency potential than the widely used screen print cell concept due to its selective emitter design and low shading losses. In industry only Cz-Si is used. Hydrogen bulk passivation and thermal load of the wafers are different in the buried contact process and can be key issues to reach high efficiencies with multi-crystalline silicon. Adjacent String Ribbon wafers are used to monitor the change of bulk lifetime during a buried contact process. Bulk lifetime was measured 2-dimensionally resolved with μ-PCD. An improvement of PECVD-SiN deposition without a firing step was measured. The heavy 10 Ohm/sq diffusion leads to a degradation due to effusion of hydrogen. Bulk lifetime after hydrogen passivation by MIRHP in a buried contact solar cell process is similar to an adjacent wafer after a screen print process, therefore higher efficiencies of buried contact cells are expected.

Keywords: ribbon silicon, buried contacts, passivation

1 INTRODUCTION

To reduce silicon costs per W_p, Evergreen Solar's String Ribbon technology is a promising alternative to ingot grown multicrystalline silicon wafers. There are no kerf losses and sawing costs are avoided. Cast ingots also have contaminated parts near the edges and cannot be used for cell production due to very low bulk lifetimes. String Ribbon wafers are advantageous concerning the amount of silicon per used W_p, this is especially important because of the current shortage of silicon feedstock.

The buried contact cell design has a higher efficiency potential than the widely used screen print cell concept. The buried contact cell has an emitter with a high sheet resistance (100 Ω/sq) for a good blue response and a low sheet resistance underneath the fingers (10 Ω/sq) for low contact resistance. Buried contact cells are currently commercially produced by BP Solar. Only Cz-Si is used in production. The buried contact process includes a heavy groove diffusion (high T-step). Bulk hydrogen passivation can be carried out by MIRHP (Microwave Induced Remote Hydrogen Passivation) and is different to a screen print process where hydrogen diffuses from the SiN layer into the bulk during the firing step. Thermal load and hydrogen passivation can be key issues to reach high efficiencies with multicrystalline silicon. The current record efficiency for large area mc-Si cells of 18.1% is reached with a buried contact process [1].

This work investigates the change of bulk lifetime during a buried contact process using String Ribbon material. Ribbon silicon is known to be sensitive to hydrogen passivation [2] and therefore interesting in combination with the buried contact cell concept.

2 BURIED CONTACT PROCESS

A schematic of a buried contact cell is shown in figure 1 on the left hand side, on the right side is a screen printed cell.

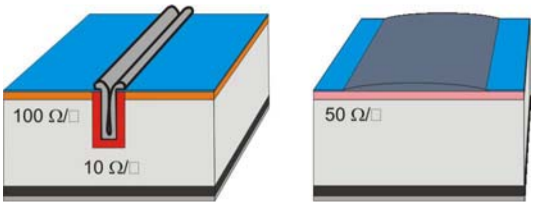

Figure 1: Schematic drawing of a buried contact cell on the left side, on the right a screen printed cell.

Several issues have to be taken into account by applying the buried contact process to ribbon silicon. The suggested process sequence is shown in figure 2.

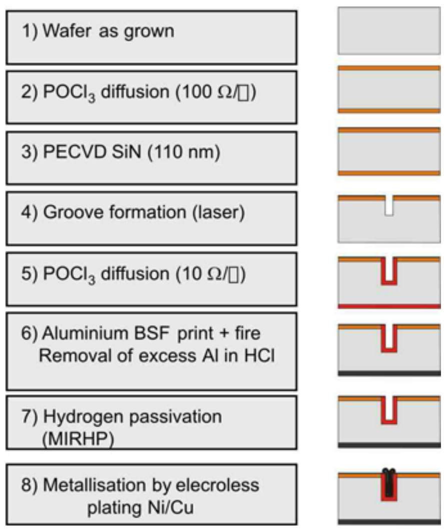

Figure 2: Buried contact process sequence with String Ribbon silicon.

After the 100 Ω/sq $POCl_3$ diffusion a silicon nitride layer is deposited on the top. It acts as a capping layer and protects the high efficiency emitter from the later followed heavy groove diffusion. Usually low pressure silicon nitride (LPCVD) is used. To avoid the deposition on both wafer sides, wafers are arranged 'back to back' in the boat. Ribbon material tends to be uneven and silicon nitride would creep around the edges during the

LPCVD-SiN deposition. So, the LPCVD-SiN has to be replaced with PECVD-SiN to assure a single side SiN layer. Groove formation must be carried out with a laser system. The achievable finger width is about 40 µm. The back surface field is formed by screen printing aluminium paste on the rear side, firing the wafer in a belt furnace and etching off the excess aluminium with HCl. Hydrogen passivation is performed by MIRHP, it is an important step as it will be shown in the results. The metallisation is carried out by electroless plating nickel and copper.

3 EXPERIMENT

Adjacent 5x5 cm^2 String Ribbon wafers were used. Lifetimes can be compared between the same grains on adjacent wafers (see figure 3). The buried contact process in figure 2 was applied. Because only lifetime measurements were performed, groove formation and metallisation was not carried out.

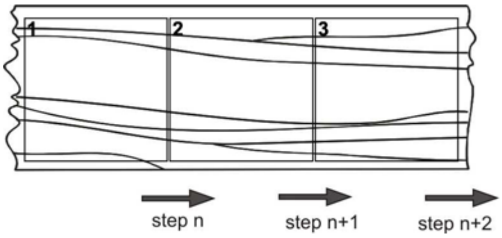

Figure 3: Lifetimes of the same grains on adjacent String Ribbon wafers can be compared.

Beginning with an as grown wafer, every further adjacent wafer is processed with a further buried contact process step. After MIRHP treatment, the final bulk lifetime is reached, because the following metallization to finish the solar cells is done by electroless plating of nickel and copper and there is no thermal treatment in our process scheme. An adjacent wafer to this last one was processed with a standard screen print process. The standard screen print process includes a $POCl_3$ diffusion, PECVD-SiN deposition and a screen printed Al BSF. The positive effect of P-gettering and hydrogen passivation by firing PECVD-SiN 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 silicon per side was removed with CP6 solution. The surfaces were passivated by Iodine/ethanol. Lifetime measurement was carried out by µ-PCD (Microwave Photo Conductance Decay). The two dimensional measurements allow to compare bulk lifetime of the same grains on adjacent wafers.

4 RESULTS

4.1 Lifetime evolution during buried contact process

Figure 4 shows the bulk lifetime map of the as grown wafer on the left. The adjacent wafer underwent a 100 Ohm/sq $POCl_3$ diffusion. The improvement in lifetime after P-gettering is clearly visible on the wafer on the right. The colour code is the same for all lifetime maps. Purple is in the order of magnitude 0.1 µs, blue 1 µs, green 10 µs and red 100 µs.

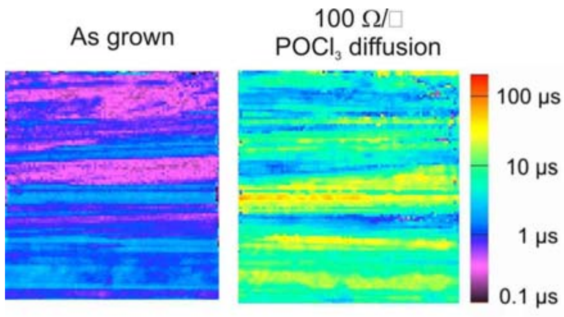

Figure 4: Lifetime map of as grown wafer on the left. Improvement after 100 Ω/sq $POCl_3$ diffusion (P-gettering).

On the right side in Figure 5 the lifetime map of an adjacent after the following deposition of 110 nm thick PECVD SiN is shown. The silicon nitride is thicker than in a screen print process, because thickness will be reduced to 75 nm in a following heavy $POCl_3$ diffusion. The grains with an already good lifetime became even better after the SiN deposition. No firing step or other thermal treatment was applied.

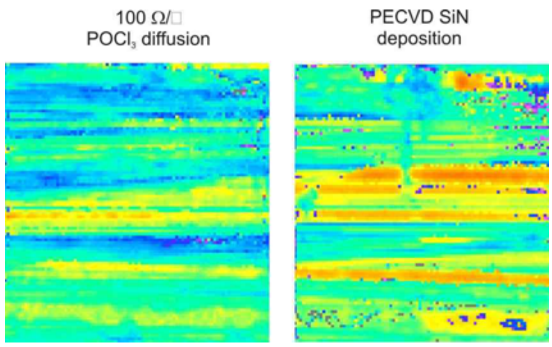

Figure 5: Improvement by PECVD-SiN deposition only. No firing step was applied.

The heavy 10 Ohm/sq $POCl_3$ diffusion led to a degradation of lifetime as can be seen figure 6. Effusion of hydrogen occurs during the 30 min long and 950°C hot process step [3].

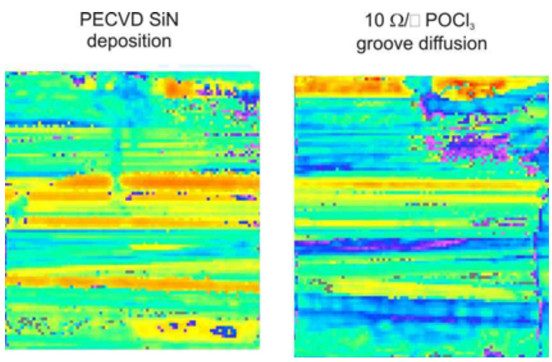

Figure 6: Degradation after heavy diffusion. Effusion of hydrogen.

The positive effect of Al-gettering can be seen in figure 7. The screen printed and fired aluminium on the rear improves especially the already good regions.

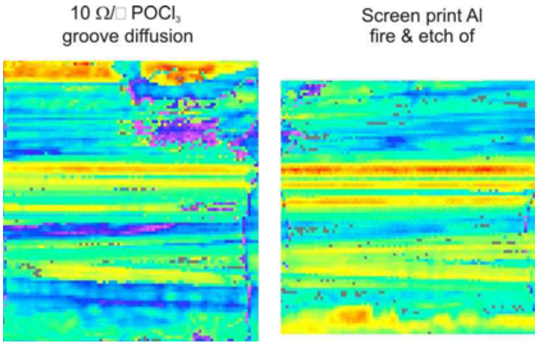

Figure 7: Improvement after Al-BSF fomation (Al-gettering).

The most significant improvement in bulk lifetime was reached by the MIRHP treatment. Low lifetime and high lifetime regions were improved. The good regions have bulk lifetimes above 100 µs (red colour, see figure 8).

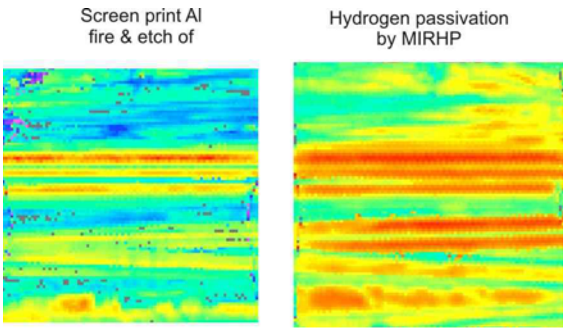

Figure 8: Improvement of hydrogen passivation by MIRHP.

4.2 Comparison of buried contact and screen printed wafers

The bulk lifetime after the buried contact process was compared to bulk lifetime of an adjacent screen printed wafer. In Figure 9 both lifetime maps are shown. Lifetimes are similar and on a high level. Higher efficiencies are expected with the buried contact compared to the screen print concept.

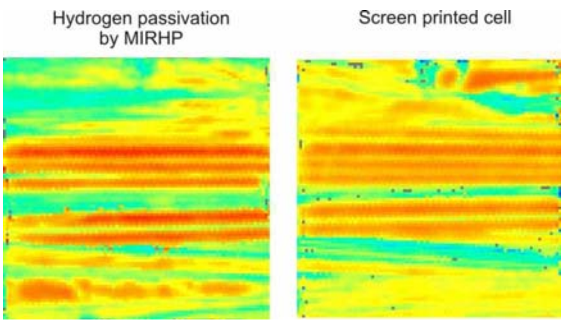

Figure 9: Comparison of lifetime maps. Buried contact process (left) to screen printing process (right).

4.3 Alternative hydrogen passivation

An adjacent wafer to the screen printed one was again processed with the buried contact concept, except for the MIRHP treatment. As an alternative to the MIRHP hydrogen bulk passivation, PECVD silicon nitride was deposited on the rear and fired in a belt furnace. The so realized hydrogen passivation is again effective. Lifetime maps are shown in figure 10. This indicates that the String Ribbon material can withstand the high temperature step used in the buried contact process and shows again the importance of an effective hydrogen passivation.

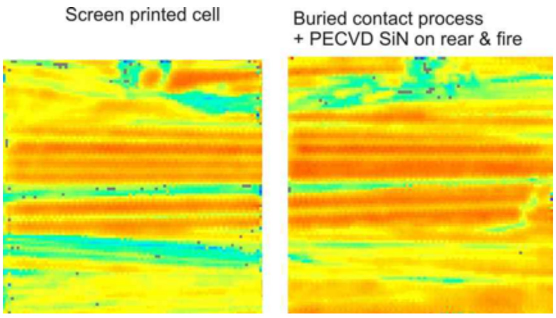

Figure 10: Alternativ hydrogen passivation.

To use the hydrogen from the deposited SiN layer at the rear side in a solar cell structure, a local rear contact scheme must be used. With regard to rear surface recombination velocity, different rear layer stacks (e.g. SiO_2/SiN) may be needed [4].

5 SUMMARY

Bulk lifetime maps of String Ribbon were measured of adjacent wafers in a buried contact process. An improvement in bulk lifetime by deposition of PECVD SiN only was observed. Therefore one has to be aware, that the often used surface passivation with PECVD SiN on both sides to measure bulk lifetime may lead to higher lifetimes. In this investigation the surfaces were passivated with Iodine/ethanol.

In the buried contact process, hydrogen bulk passivation is realized with a MIRHP reactor. The hydrogen from the PECVD SiN antireflection layer cannot be used, since there is an effusion during the long and hot groove diffusion. An alternative hydrogen bulk passivation was performed by depositing a SiN layer on the rear and firing the wafer in a belt furnace. Bulk lifetimes were as high as for the reference wafer after a screen printing process. This indicates that the high temperature step used in a buried contact process is not detrimental to String Ribbon silicon. Bulk lifetimes after the buried contact process with MIRHP hydrogen passivation and screen printing process were similar, thus higher efficiencies of buried contact cells are expected.

6 REFERENCES

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