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# REAR PASSIVATION SCHEMES FOR INDUSTRIAL SILICON SOLAR CELLS

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**ABSTRACT:** This article deals with the problem of the contact between dielectric layers and aluminium on the rear side of solar cells and its impact on the passivation effect. Several dielectric layers and stacks of PECVD silicon nitride and silicon oxide have been deposited on monocrystalline and multicrystalline wafers to study their passivation behaviours. Solar cells were also elaborated with a dielectric/aluminium structure on the back side and a set of wafers was used to highlight the influence of aluminium capping dielectric layers on passivation. Although it is reported that all structures give similar passivations when composed of one layer of silicon nitride at least, capping them with aluminium degrades the passivation below the standard aluminium BSF except for the SiNr/SiN stacks which is only slightly degraded. Consequently, solar cells are not as good as full aluminium coverage cells and it is found that the minority carrier lifetime and the internal quantum efficiency results are in contradiction with the I (V) results. This fact entails the need of performing complete solar cells to study the rear passivation by dielectric layers.

**Keywords:** Rear side passivation, PECVD, Silicon Nitride

## 1 INTRODUCTION

During the past few years, the impressive growth of the photovoltaic industry has caused a general silicon shortage. Many solutions are brought by research laboratories and manufacturers, like the development of thin films solar cells or the reduction of thickness in standard silicon solar cells [1]. With the last solution, several problems appear, dealing particularly with the possible presence of aluminium on the rear side. In order to solve this problem, some photovoltaic laboratories developed new structures to limit the two major problems due to aluminium: low surface passivation and high bowing of the cell [1-5].

The common point in all these new structures is the need of a good passivation layer on the rear side to keep the efficiency similar or better to standard cells. To fulfil this aspect, deposited dielectric layers from common CVD reactor is the most promising solution, as it is already performed on the front side of industrial solar cells by PECVD for the  $\text{SiN}_x$ :H antireflection coating. Unfortunately, except on bifacial solar cells [5-6], a single layer of  $\text{SiN}_x$ :H does not work very well and alternative dielectric structures have to be developed [7-8].

In this paper, we concentrated on studying rear structures containing  $\text{SiO}_x$ :H ( $\text{SiO}$ ) and  $\text{SiN}_x$ :H ( $\text{SiN}$ ) with different stoichiometries (nitrogen or silicon-rich) to investigate their passivation behaviours with and without capping aluminium. All these layers have been elaborated by Low Frequency Plasma Enhanced Chemical Vapour Deposition with ammonia ( $\text{NH}_3$ ), silane ( $\text{SiH}_4$ ) and nitrogen protoxide ( $\text{N}_2\text{O}$ ) as precursor gases.

## 2 EXPERIMENTAL

In order to separate the surface and the bulk influences, three sorts of substrates have been used.

- One set of FZ-monocrystalline silicon.
- One set of multicrystalline silicon, textured with NaOH.

- One set of multicrystalline silicon which has undergone a phosphorous diffusion followed by emitter etching.

Resistivity and thickness are given in Table I.

In order to study the influence of passivation layers with aluminium, we have also carried out five sets of six multicrystalline silicon solar cells of  $156 \text{ cm}^2$  area with five different rear structures.

**Table I:** Characteristics of samples used in this study.

Properties	Monocrystalline	Multicrystalline
Size	2 inches	$62.5 \times 62.5 \text{ mm}^2$
Type	P	P
Resistivity	4-7 ohm.cm	1 ohm.cm
Thickness	280 $\mu\text{m}$	300 $\mu\text{m}$

For our structures, we have chosen single, double and triple layers based and on previous tests and on the literature. Three PECVD dielectric layers have been used:  $\text{SiO}$ ,  $\text{SiN}$  and silicon-rich  $\text{SiN}$  (noted  $\text{SiNr}$  afterwards). Nine different stacks were processed, and three simple layers act as reference. Table II summarizes these rear passivation schemes.

**Table II:** Rear structures tested.

Single	Double	Triple
SiN	SiNr/SiN	SiO/SiN/SiO
SiNr	SiNr/SiO	SiO/SiNr/SiO
SiO	SiO/SiN	
	SiO/SiNr	

The total thickness of deposited layers is contained between 100 and 130nm with roughly 20 – 25 nm for the first layer and 85 – 105 nm for the total of the other layers in the case of multilayer stacks. These values have been confirmed after the deposition with spectroscopic ellipsometry. All the depositions have been made on both sides of the samples to allow the measurement of the minority carrier lifetime (MCL) by the photoconductance decay method. MCL measurements were performed in transient and quasi steady state mode. All results are given for an injection level of  $7.10^{14} \text{ cm}^{-3}$ .

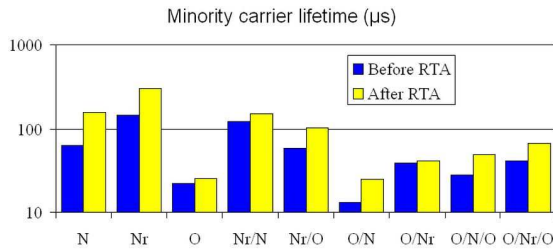
Finally, after the measurement, all the samples have been annealed during several seconds (RTA) at 800°C in a lamp furnace to simulate the contact-firing step and then MCL measurements were carried out again.

### 3 RESULTS FOR SILICON WAFERS

To discuss minority carrier lifetime results, we first consider the results for the monocrystalline samples and then for the multicrystalline samples to discriminate surface and bulk passivation.

#### 3.1 Monocrystalline samples

Float zone samples lead directly to the surface passivation because of their high bulk lifetime (superior to 2ms with iodine methanol surface passivation [10]).



**Figure I:** Minority carrier lifetime on monocrystalline samples of the nine rear passivation schemes tested. N, Nr and O stand for SiN, SiNr and SiO.

Concerning single layers, SiN and SiNr have a better passivation effect than SiO. SiNr leads to the best passivation results among these layers with or without the rapid thermal anneal (RTA). For double layers, the best results are obtained with SiNr as the first layer and show comparable values to the silicon nitride single layer. The other stacks with SiO as first layer have intermediate results between SiN and SiO alone. As observed for single layers, the RTA is still beneficial for the passivation quality for all stacks. Finally, the triple layers show the same trend than the double layers with a slightly better result for the structure containing SiNr.

PECVD hydrogenated silicon nitride is well known to be a great passivation layer, contrary to PECVD silicon oxide. Moreover, the better passivation of SiNr has been already demonstrated by a lot of authors [11-13].

The field effect created by the SiN layer is always strong whatever the stoichiometry of the film is (Qf in the layer is reported to be higher than  $10^{12} \text{ cm}^{-2}$ , sufficient to put the silicon surface in weak inversion) [13]. Thus, the better passivation must come from a smaller interface states density at the SiNr/Si interface due to higher Si-H bonds than in N-rich SiN. In fact these bonds are strongly correlated to the passivation quality and can be used as surface passivation indicators [14]. We can also expect fewer constraints and consequently fewer defects, at the interface between a Si-rich SiN layer and a silicon substrate [15].

Lastly, the RTA gives the opportunity for the SiN layers to free a part of their atomic hydrogen which can bond to some remaining interface defects. But this release does not happen necessarily in the same way for both layers. In the case of SiNr, the hydrogen will be released in high quantity due to the high number of easily break-

able Si-H bonds. However, the low density of the film will allow more  $\text{H}_2$  molecules to form and might be destructive for the layer itself if these molecules accumulate and pierce the film (also called blistering effect [9]).

Concerning the SiO single layer, the passivation remains weak. Moreover, contrary to our previous work on hydrogenated silicon oxynitride [16], the RTA does not improve the minority carrier lifetime. This fact leads us to conclude that the RTA profile (different from [16]) is a critical parameter for the passivation effect of deposited SiO.

The excellent surface passivation of the double SiNr/SiN layer is explained by what we have developed for single layer: the high surface passivation by SiNr and the high hydrogenation during the layers deposition and the RTA which results in a passivation as good as SiN single layer. The SiNr/SiO layers bring a reasonable MCL with only 20nm of SiNr that appears to be sufficient for surface passivation.

For the two stacks layers with SiO as first layer (SiO/SiN and SiO/SiNr), the passivation effect comes mainly from the diffused hydrogen of the SiN layer during the deposition and during the annealing [1,8]. Thus, a large improvement with the RTA is expected but it is not clearly evident on Figure I. The low MCL value of SiO/SiN might suggest a problem during the wafer's cleaning before the deposition. Although we can observe an improvement after the RTA, the final passivation remains low. Conversely, in the case of SiO/SiNr, MCL of the as-deposited layer is quite high but stays constant after the RTA. These results would suggest no more surface hydrogenation during the RTA due probably to the hydrogen exodiffusion.

Finally, both triple layers confirm the tendency observed on the double layers with slightly higher passivation results. This time, the MCL results seem to confirm a better hydrogenation of the interface during the deposition of SiNr layer and more atomic hydrogen diffusion from the SiN layer through the SiO layer during anneal. The capping of the silicon nitride layers by SiO seems to improve slightly the surface passivation probably by limiting the hydrogen exodiffusion out of the layer.

In a nutshell, the double and the triple layers are less efficient than the single silicon nitride layer for surface passivation. But the situation becomes more complex on the multicrystalline samples with the necessity of improving the bulk passivation by hydrogen diffusion. This passivation is also completed by the gettering effect during the phosphorous diffusion step. We have thus to discriminate both contributions in our experiments by studying samples with and without gettering.

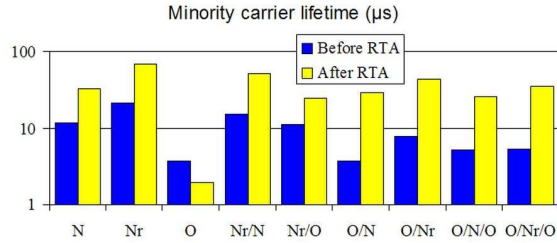
#### 3.2 Multicrystalline samples

The comparisons and discussions between the samples with and without gettering have to be made carefully because of they are not neighbouring wafers.

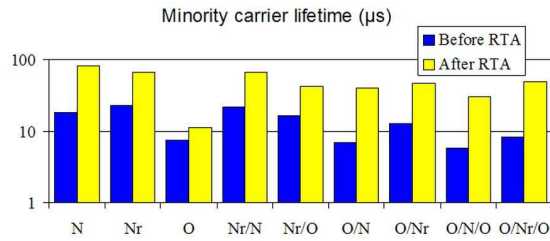
The minority carrier lifetime results are inferior to the monocrystalline samples but the differences between the various passivation schemes tested remain the same before RTA. On the other hand, the impact of the annealing step is a major benefit for the multicrystalline samples especially when the first layer is SiO. Thus, except the SiO single layer, the other structures show good passiva-

tions after RTA with slightly superior results for the all silicon nitride stacks.

For the samples with gettering the tendency is globally the same. The gettering effect seems to be independent of the hydrogenation effect except, maybe, for the SiNr layer. After annealing, the improvement is in the same order as samples without gettering.



**Figure II:** Minority carrier lifetime on multicrystalline samples without gettering of the nine rear passivation schemes tested.



**Figure III:** Minority carrier lifetime on multicrystalline samples with gettering of the nine rear passivation schemes tested.

The slightly identical behaviour before annealing can be explained in the same way as for the monocrystalline wafers. After deposition, the surface passivation enhancement seems to be the main contribution to the effective MCL: the structures with silicon nitride at the interface exhibit the best results.

The strong MCL improvement after the RTA points out an effective bulk passivation due to the hydrogen diffusion from SiN (or SiNr) layers into the bulk. The rear passivation structure needs only one layer of silicon nitride for the bulk hydrogenation to happen. This fact is highlighted with SiO/SiN: a poor MCL before annealing (bad surface passivation) but similar results as the other structures after the RTA (bulk enhancement).

Identical tendency between the samples with and without gettering were expected. The hydrogen will essentially help to fill dangling bonds or lattice dislocations whereas the gettering will contribute to reduce recombinations created by metallic impurities [17]. Thus, both treatments have complementary actions.

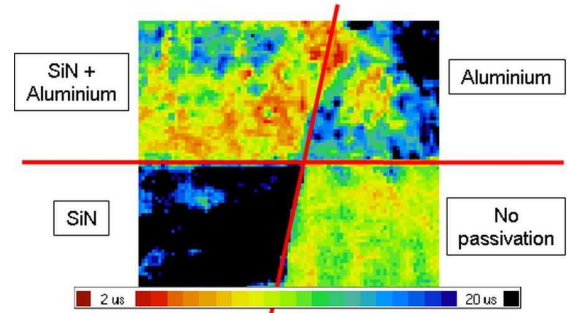
To sum up, it seems that for the multicrystalline samples, all studied stacks give less contrasted minority carrier lifetime results (except SiO) due to a predominant bulk passivation by hydrogen. Thus, it may be better to choose a structure in order to optimise another parameter of the back side (reflection for example).

To complete these results, we have studied the influence of the aluminium deposition on these structures to look for the degradation problem due to the formed Metal-Insulator-Semiconductor (MIS) structure.

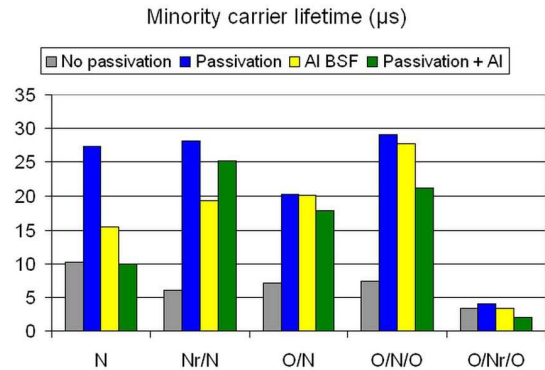
#### 4 RESULTS FOR MIS STRUCTURES

Several sets of  $156 \text{ cm}^2$  multicrystalline silicon substrates with no emitter were used for minority carrier lifetime purpose. This time, dielectric layers and screen printed aluminium were applied on different half on the back side as shown in Figure IV for the case of the SiN layer. The same dielectric layers were also deposited on the front side. Next, all these structures have been annealed in a belt furnace from Photowatt. The temperature profile for this annealing step differs from the one used at INL. Finally MCL were performed using  $\mu\text{PCD}$ .

Solar cells with dielectric stacks passivation were also elaborated for spectral response and  $I(V)$  measurements purpose. A set of cells with a full aluminium coverage stand as references with also a thick SiO/SiN structure which has already given good solar cells results [18]. The passivation results and the normalized internal quantum efficiency (IQE) are plotted in Figure V and Figure VI.



**Figure IV:** Cartography of minority carrier lifetime for rear passivation with a single SiN layer.



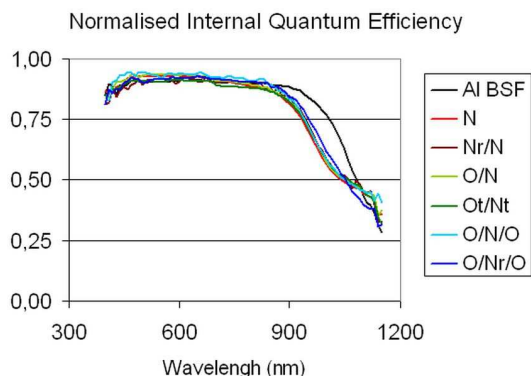
**Figure V:** Minority carrier lifetime for different rear passivation state.

The dielectric layers without aluminium achieve the best passivation in all structures compared to the aluminium back surface field (BSF). After aluminium capping, all MCL decrease and become inferior to the aluminium BSF except for the SiNr/SiN stacks. The SiNr/SiN structure gives also the best passivation and stays unaffected, contrary to the triple layers where SiNr has been degraded by the RTA. It is probably due to a thinner SiNr layer and a thicker capping layer in the SiNr/SiN structure.

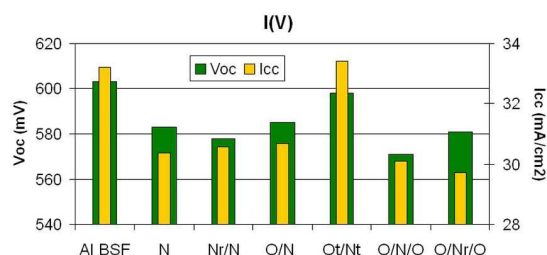
As it was already mentioned by IMEC [19], capping the dielectric layer by aluminium creates a MIS structure and consequently might affect the SRH recombination by inducing a weak inversion at the surface of the substrate.

Although this explanation might work, it is insufficient to explain why SiNr/SiN is so good compared to SiN with aluminium coverage (Figure V).

Moreover, if we consider the IQE results (Figure VI) we can see that, surprisingly, every passivation schemes give clearly worse results than standard full-coverage aluminium even for the SiNr/SiN stacks.



**Figure VI:** Normalized IQE for the five rear passivation schemes, for the standard aluminium BSF and for a thick O/N passivation stacks (Ot/Nt). The normalization has been made with the calibration sample of the quantum efficiency device.



**Figure VII:** The  $I_{cc}$  and The  $V_{oc}$  of the final cells performed with a dielectric rear side passivation.

To settle the argument,  $I(V)$  measurements have been performed on final cells. As shown in Figure VII the short-circuit current  $I_{cc}$  and the open circuit voltage  $V_{oc}$  remain strongly below the two references with full-coverage aluminium and thick dielectric stacks. Thus they are in agreement with the poor rear side passivation indicated by the IQE except for the stacks with thick SiO/SiN layers. In fact this structure gives a  $I_{cc}$  and a  $V_{oc}$  nearly as good as aluminium BSF, but leads to poor IQE results. This contradiction remains hard to explain; it might be caused by the measurements done at different injection levels in each case. In any case these characterizations seem unable to give correct information about the final solar cells behaviours. Thus, these results point out the necessity of processing complete solar cells to perform any passivation comparison.

Moreover, as it was already mentioned, we can conclude that the aluminium seems to play an important role in the efficiencies degradations by creating a MIS structure. The interaction between the MIS and the density of positive dielectric charges are probably other factors which have to be taken into consideration to explain correctly the  $I(V)$  results.

## 5 SUMMARY

In the present article, we have studied different rear passivation schemes on monocrystalline and multicrystalline substrates in order to choose the most promising structures. Although the all silicon nitride layers give slightly best results, capping them with aluminium entails inferior results than standard aluminium BSF, except for the SiNr/SiN stacks which is only slightly affected by the aluminium. The contradictions between the MCL results, the IQE and the  $I(V)$  measurements lead to the need of studying the rear structure using complete solar cells.

Lastly, the most promising structure on the final solar cell seems to be a combination of thick layers as it was already mentioned by the IMEC.

## 6 ACKNOWLEDGEMENTS

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## 7 REFERENCES

- [1] G. Agostinelli et al., 17<sup>th</sup> NREL Workshop on Crystalline Silicon Technology (2007)
- [2] A. Schneider et al., 29<sup>th</sup> IEEE Photovoltaic Specialists Conference, New Orleans (2002) 336-339
- [3] E. Schneiderlöchner et al., Progress in Photovoltaic: Research and Applications 10 (2002) 29 – 34
- [4] G. Agostinelli, et al., 20<sup>th</sup> EUPVSEC, Barcelona, Spain (2005) 647
- [5] L. Janßen et al., Progress in Photovoltaic: Research and Applications 15 (2007) 469-475
- [6] I. Romijn et al., 22<sup>nd</sup> EUPVSEC, Milan, Italy (2007) 1043
- [7] B. Rémiat et al., 22<sup>nd</sup> EUPVSEC, Milan, Italy (2007) 1755
- [8] M. Hofmann et al., 22<sup>nd</sup> EUPVSEC, Milan, Italy (2007) 1030
- [9] E. Fourmond et al., 2CV.5.13, this conference.
- [10] A. Schönecker et al., 14<sup>th</sup> EUPVSEC, Barcelona, Spain (1997) 666
- [11] A.G. Aberle, Solar Energy Materials & Solar Cells 65 (2001) 239 – 248
- [12] H. Charifi et al., 21<sup>st</sup> EUPVSEC, Dresden, Germany (2006) 846
- [13] J.F. Lelièvre et al., 15<sup>th</sup> IPSEC, Shanghai, China (2005) 124
- [14] H. Mäkel et al., Journal of Applied Physics 92 (2002) 2602-2609
- [15] J.F. Lelièvre, PhD Thesis (2007), INSA de Lyon, Villeurbanne, France
- [16] J. Dupuis et al., Thin Solid Films 516 (2008) 6954-6958
- [17] J. Tan et al., Progress in Photovoltaic: Research and Applications 16 (2008) 129-134
- [18] G. Agostinelli et al., 21<sup>st</sup> EUPVSEC, Dresden, Germany (2006) 601
- [19] G. Agostinelli et al., 4<sup>th</sup> IEEE WCPEC, Waikoloa, Hawaii (2006) 1004