COMPARISON OF REMOTE AND DIRECT PLASMA SILICON NITRIDE

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ABSTRACT

SiN (silicon nitride) deposited by a PECVD (plasma enhanced chemical vapor deposition) system is a more and more common method to combine ARC (antireflection coating) with surface and bulk passivation. At this moment two types of commercial industrial PECVD systems are most common: a direct plasma parallel plate reactor and a remote plasma system. For the latter the plasma activation is located remote from the wafers to avoid a possible surface damage. For mc Si the hydrogen passivation is of great importance whereas on CZ wafers this effect is negligible. Therefore we used both materials and performed a preliminary comparison of these systems. On 5” mc wafers mean efficiencies of 15.3 % and on alkaline textured 5” pseudo square CZ wafers 16.9 % were reached using a standard screen printing process. Together with the other characterisation methods (dark IV, SR-LBIC, reflectivity) the IV data reveal that remote and direct plasma SiN lead to comparable results.

INTRODUCTION

Silicon nitride from plasma-enhanced chemical vapor deposition is widely used in PV industry as an antireflection coating [1], [2]. In addition the large amount of hydrogen (of up to 25 at%) [3] incorporated in the SiN layer can be driven into the solar cell during deposition and more important during the contact firing step, which leads to an excellent bulk passivation for mc-Si solar cells as demonstrated by several research institutes during the last decade [4]. As a third advantage the SiN layer acts as surface passivation. Depending on the Si material and the type of solar cell the different functions of the SiN layer play a different important role. It has already been shown, that on industrial type emitters the surface passivation quality is of minor importance. We have shown, that on CZ wafers with an 40 Ohm/sq emitter no difference in lifetime could be observed after different deposition conditions, whereas on wafers with removed emitter there was a dependence between deposition parameters and effective lifetime [5].

The share of mc Si is continuously increasing and has reached 50 % of the complete PV industry in 2001 [6], therefore the bulk passivation properties of the SiN layers become more and more important. Due to the reduced recombination in the bulk and space charge region of the fired PECVD-SiN, a large improvement in open circuit voltage, short circuit current density and fill factor is observed, compared to solar cells without bulk passivation.

Due to the different deposition conditions between direct and remote PECVD SiN there might be a difference in the ability of the SiN layers to perform surface and bulk passivation. The optical parameters aren’t independent of the above mentioned properties, therefore all 3 values have to be checked.

Using mc Si material the ability of bulk passivation due to incorporated hydrogen can be verified. On CZ wafers bulk passivation is less important therefore the surface passivation quality is of more influence.

EXPERIMENTS

Different types of silicon were used. 5” pseudo square CZ wafers of two different lots and 5” mc Si wafers of two different vendors (called mc 1 and mc 2). From mc 1 we used wafers from 3 different heights of the ingot (bottom, middle and top) to check the influence of the different SiN on the quality of the silicon. In table 1 the number of wafers in each group is shown. Altogether 128 wafers were used. Wafers of group CZ 1 and CZ 2 lead to nearly equivalent results, therefore they are summarized in the following.

Table 1. Numbers of wafers in each group.

	mc 1	**mc 2**			**CZ**	
		Bottom	Middle	Top	CZ 1	CZ 2
Direct	18	9	9	9	10	9
Remote	18	9	9	9	10	9
Total	**36**	**18**	**18**	**18**	**20**	**18**

After mixing and marking of the wafers the following standard sequence was performed:

1. Removal of the saw damage in NaOH on mc and alkaline texture etch on CZ
2. Cleaning in HCl and HF
3. $POCl_3$ diffusion leading to 45 Ω/sq
4. Plasma etching for edge isolation
5. HF dip
6. Direct/remote plasma PECVD SiN deposition
7. Screen printing of the front and back contacts
8. Co firing
9. Characterization: IV (illuminated and dark), Reflection, SR-LBIC (spectrally resolved laser beam induced current)

The direct plasma SiN deposition was performed in a commercial available system of Centrotherm, Germany. The remote plasma deposition was carried out in a prototype pilot production system from Roth & Rau, Germany located at ECN, the Netherlands [7]. At the time of the deposition (Oct. 2001) there were still problems concerning the homogeneity of the remote plasma SiN. There was a thickness variation up to 10 % from wafer to wafer in one batch of 25 wafers and on single wafers (see Fig 2) . This problem has been solved recently by using two microwave sources instead of one. Nevertheless the influence of a too thin SiN layers ranging from gold to a purple appearance on one wafer on J_{sc} is very small, therefore this was mainly an esthetical problem.

Both SiN deposition processes were not completely optimized for the used cell processing. This means that the SiN process parameters were not optimized for the used emitter processing and firing of the metallisation. Therefore the results must be interpreted very carefully.

SOLAR CELL RESULTS

Due to the variety of used Si material each illuminated cell parameter is drawn in one graph. In this way the influence of the deposition method on the different materials becomes more clear.

For good quality material with a high open circuit voltage V_{oc} the direct plasma SiN layer leads to better results (see Fig. 1, CZ and mc 2 middle and top). The gain lies in the range of the standard deviation, but it is observable for every 3 groups.

For the short current density J_{sc} no clear correlation can be seen. There is a small increase for direct plasma in combination with mc 2, but with mc 1 which is on the same level than mc 2 bottom it is just opposite (see Fig. 2). In addition the differences lie in the range of 0.1 mA/cm² which is very small.

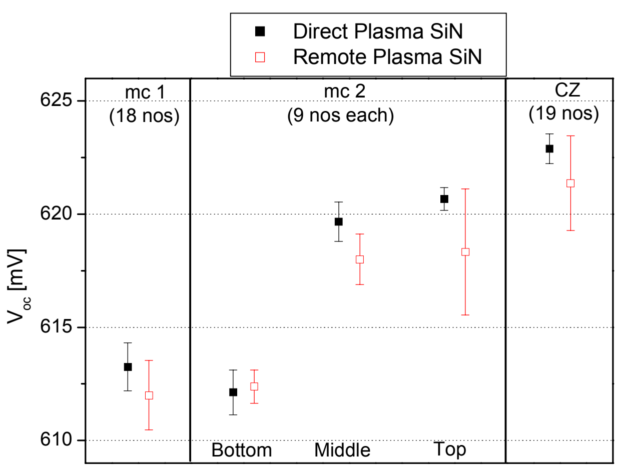

Fig. 1 Mean values and deviation of open circuit voltage V_{oc} of solar cells with direct/remote PECVD SiN. On good quality material with high V_{oc} the direct plasma SiN is superior.

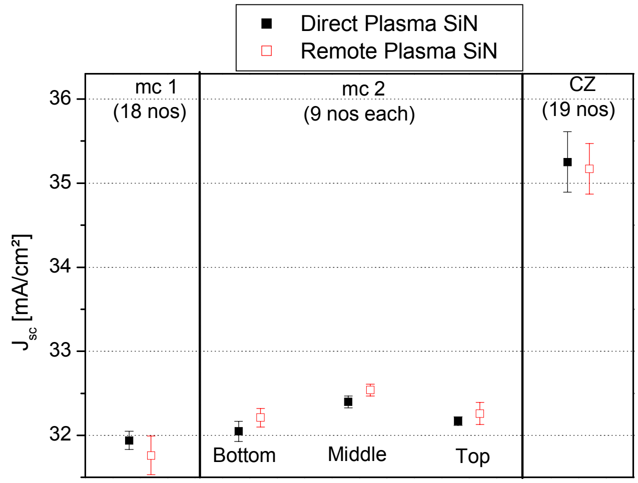

Fig. 2 Mean values and deviation of short circuit density J_{sc} of solar cells with direct/remote PECVD SiN.

For all materials and both deposition methods the fill factor FF lies in the range of 76 % and the differences between the groups are not significant (Fig. 3). The resulting efficiencies are also very similar, because the little variations in V_{oc} and J_{sc} nullify mutual. Only in the case of CZ Si the direct plasma SiN is superior. Here a mean efficiency of 16.86 % is reached compared to 16.62 % with remote plasma SiN (see Fig. 4). A possible explanation for the lower fill factor of the CZ wafer with remote plasma SiN may be the varying thickness, because of this the firing of the solar cells may not have been optimal. This could also lead to the lower V_{oc}.

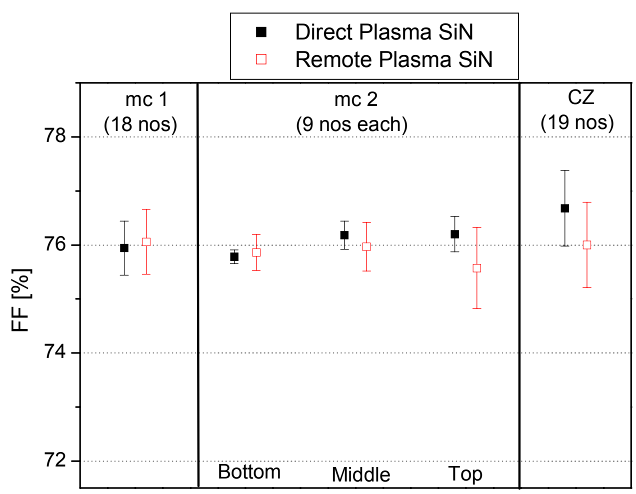

Fig. 3 Mean values and deviation of fill factor FF of solar cells with direct/remote PECVD SiN. No significant difference can be seen.

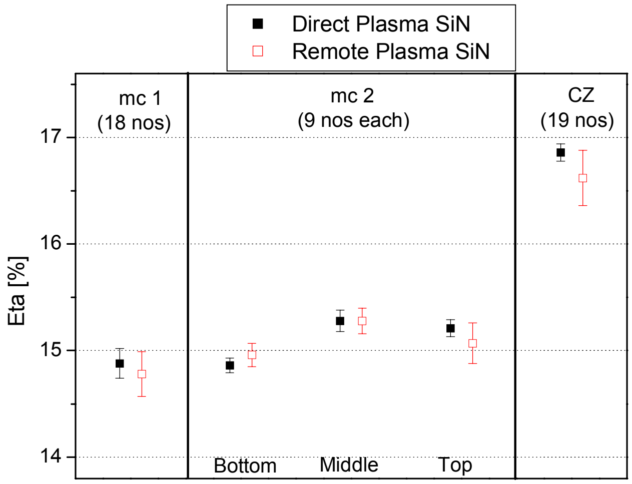

Fig. 4 Mean values and deviation of efficiency of solar cells with direct/remote PECVD SiN. Only on CZ Si direct plasma SiN leads to better results.

As already mentioned the homogeneity of the remote plasma SiN layer was unsatisfying at the time of deposition. To quantify this reflection measurements of the processed solar cells were carried out (see Fig. 5). On solar cell R09, which is an extreme example the appearance of the SiN layer differs from gold to purple. Therefore two measurements of this wafer are shown. The neighboring solar cell D10, which is homogeneously deposited with direct plasma SiN a gain in J_{sc} of 0.5 mA/cm² can be seen. For the cells which have the right thickness of the SiN layer also the reflection for both types of SiN is identical (see R10, D09 and D10).

The alkaline textured CZ solar cells show a very low reflection compared to the mc solar cells not only because of the texturisation but also due to the fact that the screen printed fingers are more narrow (~120 µm compared to ~150 µm on mc Si). This lead to a shadowing of these cells of only 5.8 % and a J_{sc} of up to 35.7 mA/cm².

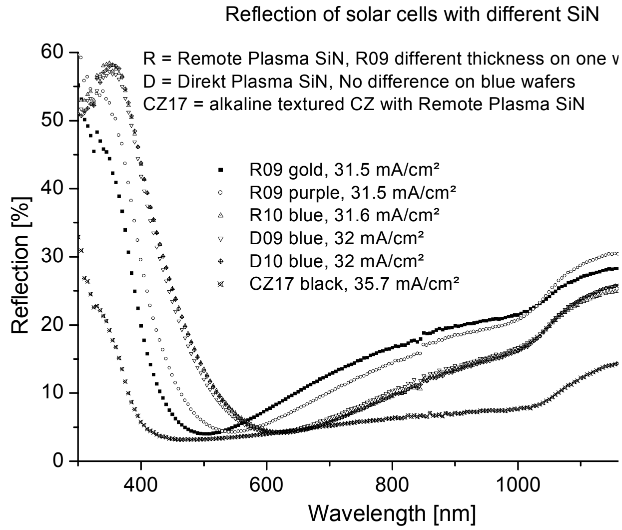

Fig. 5. Reflection of 4 mc and 1 alkaline textured CZ solar cell. Despite the fact that on cell R09 with remote plasma SiN the layer thickness is too thin and the appearance varies from gold to purple there is only a moderate loss in J_{SC}.

Using the data of the SR-LBIC at 833, 910 and 980 nm L_{eff} was calculated with the Basore fit. On the mappings in Fig. 6 a little higher level of L_{eff} for the direct plasma can be observed (less dark areas), but this was an extreme example of neighboring cells. In most cases the difference wasn't that high.

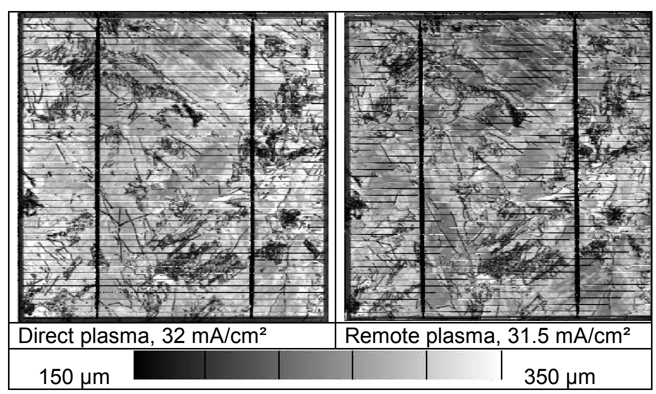

Fig. 6. L_{eff} mapping of 2 neighbouring wafers with direct/remote PECVD SiN. LBIC mappings with 833, 910 and 980 nm wavelength were used to calculate L_{eff}.

SUMMARY

PECVD SiN deposited by remote and direct plasma have been compared. The direct plasma SiN was performed in a prototype system and the direct plasma SiN in a commercial available system. CZ and mc Si of different quality was used and the group size varied from 9 to 19 wafers. Applying a simple screen printing process mean efficiencies of 15.3 % for mc Si and 16.9 % for alkaline textured CZ Si have been reached. The differences for direct and remote PECVD SiN lie mostly in the range of the standard deviation. Only in the case of CZ Si a gain for direct plasma SiN of 0.26 % absolute in efficiency was observed. Despite this was a preliminary investigation and the deposition parameters weren't totally optimised for all the used Si material it can be concluded, that both types of SiN may lead to excellent results lying on comparable levels.

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