

Passivating Mc-Si Solar Cells Using SiN_x:H: How to Tune to Maximum Efficiencies

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Abstract: In this study we determine the structural properties of SiN_x:H layers and relate these to both the deposition parameters and its passivating qualities for solar cells. We show that Si-N bond density is an important parameter governing both the bulk and surface passivation of the SiN_x:H layers. The best bulk and surface passivating layers have a relatively low hydrogen diffusion coefficient due to a high Si-N bond density. We find optimum bulk and surface passivation for Si-N bond densities of $1.3 \times 10^{23} \text{ cm}^{-3}$, regardless of nitrogen containing precursor gases used and regardless of the wafer quality.

Key Words: Antireflection Coating, Silicon-Nitride, Passivation.

1 Introduction

Hydrogenated amorphous silicon nitride (a-SiN_x:H) layers have become a very important part of modern silicon PV technology. They act as an anti-reflection coating and provide bulk and surface passivation, important means for the optimizing of mc-Si solar cells and reaching high efficiencies for those cells.

Passivating SiN_x:H layers can be deposited using Plasma Enhanced Chemical Vapor Deposition (PECVD) techniques using nitrogen and silicon containing precursor gasses. One of the key issues of our research is to combine excellent bulk and surface passivation on low cost material with easy to handle gasses. Relations between structural properties and the bulk and surface passivating quality need to be known for fast optimization with different gases and equipment, and thus saving time and effort.

In recent publications, Weeber et al. [1,2] presented a systematic investigation on the bulk and surface passivating properties and related these to the structural properties of the SiN_x:H deposited with SiH₄ and N₂. This first study is now extended to the use of NH₃. The use of both N₂ and NH₃ nitrides on solar cells reveals the structural properties of the SiN_x:H layers that govern its inherent passivating qualities independent of the deposition mechanisms.

2 Experiment

SiN_x:H layers were deposited using the in-line MW RPECVD system at ECN. This system was developed in close cooperation with Roth&Rau and is described in more detail in a previous paper [3]. The PECVD process parameters that were varied were: pressure, different precursor gasses, gas flow ratio and total gas flow.

We determined the bond densities within the nitride layers using Fourier Transform Infrared (FTIR) spectroscopy [4]. The bond densities are calculated by integrating the different absorption peaks over the frequency. In hydrogenated silicon nitride layers, usually three different bonds are investigated: the Si-N, Si-H and N-H bond density.

SiN_x:H layers with different compositions were deposited on solar cells and tested for passivating qualities by measuring IV characteristics and the IQE spectrum. The solar cells were made in an industrial in-line process, using screen printing metallization and firing through the silicon nitride.

3 Results and Discussion

3.1 SiN_x:H structural properties related to the deposition parameters

In previous studies it was found that the mass density of the SiN_x:H layers is related to the Si-N bond density ([Si-N]): layers containing more Si-N bonds have a higher mass density ρ , while those with relatively more Si-Si bonds are less dense and have a more porous structure [5,6].

In Fig.1 and 2 the Si-N bond density for nitrides deposited with NH₃ or N₂ as precursor gasses are shown as a function of the N/Si gas flow ratio, and for different deposition pressures. For all nitrides [Si-N] increases for increasing N/Si flow ratio, and is higher for lower deposition pressures. The refraction index n increases with decreasing [Si-N] and decreasing N/Si flow ratio, which is shown qualitatively by the arrow in the graphs.

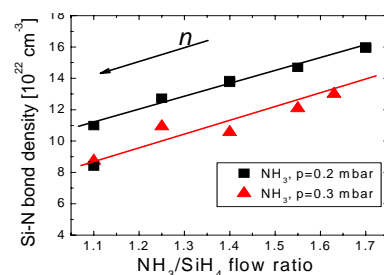


Fig.1 Si-N bond density versus the N/Si flow ratio for nitrides deposited with NH₃ and SiH₄

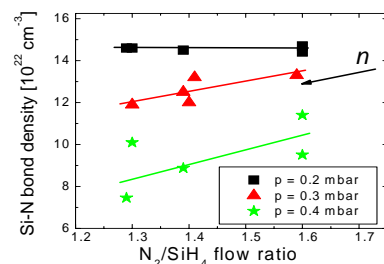


Fig.2 Si-N bond density versus the N/Si flow ratio for nitrides deposited with N₂ and SiH₄

At higher N/Si flow ratios relatively more reactive N-containing species are available; this will favor the formation

of Si-N and N-H bond over that of Si-Si and Si-H. The decrease of Si-N bond density for increasing pressures, seen in all nitrides, is due to properties of our remote MW PECVD. In the system, the nitrogen containing gas is fed in near the plasma source [7]. Higher pressures will confine the nitrogen plasma closer to the plasma source, and less reactive N-containing species will reach the substrate, decreasing the Si-N and N-H bond densities.

The different flow and pressure dependence for both types of nitrides is caused by the difference in dissociation energy for N-N (9.81 eV) and H-NH₂ (4.65 eV) [8]. At low pressures, the degree of N₂ depletion will saturate for a certain microwave power, rendering the plasma independent on further increasing the N₂/SiH₄ flow ratio. Due to the lower ionization energy this saturation is not reached for NH₃. Although the deposition mechanisms are not the same, similar [Si-N] can be reached for both N₂ and NH₃ nitrides.

3.2 Bulk and surface passivation as a function of Si-N bond density

In previous publications we show that the Si-N bond density is a key parameter for bulk passivation [1,2]. Fig.3 shows the V_{oc} of cells made with SiN_x:H layers deposited with N₂ or NH₃. Wafers of average quality (A) and wafers of higher quality (B) were used.

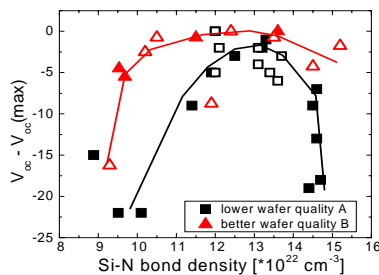


Fig.3 V_{oc}-V_{oc}(max) of mc-Si solar cells versus the [Si-N]. Closed symbols: N₂ nitrides; Open symbols: NH₃ nitrides

From the figure it can be seen that:

The Voc for cells with SiN_x:H layers deposited with N₂ or NH₃ have the same dependence of the Si-N bond density.

The maximum Voc for both material qualities is found at the same [Si-N], viz. 1.3 × 10²³ cm⁻³. The difference is that for the better quality higher Voc values are found for a broader range of [Si-N].

Voc is determined by both the bulk and surface passivation. To investigate the dependence of [Si-N] on the bulk passivation the IQE at 1000 nm is shown in Fig.4.

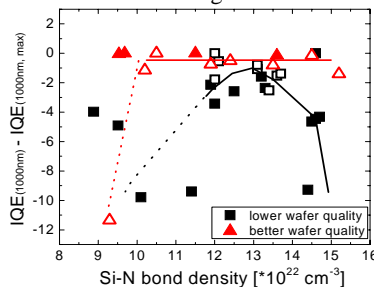


Fig.4 IQE-IQE(max) at 1000 nm for the different mc-Si solar cells versus [Si-N]. Closed symbols: N₂ nitrides; Open symbols: NH₃ nitrides

When the wafer quality is lower (squares), V_{oc} follows the

IQE at 1000 nm indicating V_{oc} is mainly influenced by the bulk properties of the solar cell. In the case of better wafer quality (triangles) however, the bulk properties (IQE) remain constant and smaller changes in V_{oc} (< 5mV) are caused by differences in surface passivation; Indeed around [Si-N] = 1.3 × 10²³ cm⁻³ we find the most stable surface passivation [2]. At the lowest bond densities, the drop in IQE reflects a drastic reduction in bulk passivation; this results in an additional loss in Voc of about 10 mV.

3.3 Discussion

Bulk, or defect, passivation of solar cells is achieved by driving hydrogen from the SiN_x:H layers into the mc-Si solar cells by a short thermal anneal [1]. In earlier publications on SiN_x:H layers deposited with N₂, the amount of hydrogen diffusion was shown to depend on the Si-N bond density [1,2].

Although the N₂ and NH₃ nitrides are formed with different deposition mechanisms, we showed that the bulk passivating properties of the two layers depend in the same way on [Si-N]. This fact can be explained by the similar H diffusion from the SiN_x:H layer into the mc-silicon due to the same Si-N bond density in the layers.

Layers with low [Si-N] are porous, enabling large hydrogen diffusion coefficients. During the anneal step the hydrogen will effuse into the ambient in molecular form and will not contribute to the passivation. Dense layers on the other hand, with high Si-N bond densities have very low diffusion coefficients. For too high Si-N bond densities the diffusion of the atomic hydrogen in the SiN_x:H layers will be too slow, resulting in less passivation during short anneals.

The Si-N bond density is found to be an important parameter for the bulk passivation of solar cells, regardless of the type of SiN_x:H and regardless of the wafer quality used.

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