Improved Homogeneous Emitter Solar Cells with Double Layer Anti-reflection Coatings

Z. Li*, G. Xu, Y. Chen, Y. Yang, Z. Bian, Z. Feng, Q. Huang

*State Key Lab of PV Science and Technology, Trina Solar Limited Company, No.2 Trina Road, Trina PV Park, Xinbei District, Changzhou, 213031, China
b Institute for Solar Energy Systems, Sun Yat-sen University, Guangzhou, 510275, China

Abstract

A double layer SiNx stack shows a better performance compared to conventional single layer SiNx ARC on monocrystalline silicon cells. The double layer SiNx ARC shows a lower reflectivity in the wavelength range of 350-500nm than single layer SiNx, which is quite beneficial to the high sheet resistance emitters featuring good blue spectrum response. In this experiment, the solar cells have a traditional structure with optimized homogenous emitters (HE) having a sheet resistance of 75 Ω/sq. Well controlled screen-printing and firing conditions have led to a fill factor up to 79.0% and efficiency up to 18.9% on monocrystalline solar cells, and demonstrated a 0.5% efficiency gain compared to baseline solar cells with single layer SiNx ARC. In comparison to the single layer ARC, there is an increase of 2.8 mV in V_{oc} and 0.4 mA/cm² in J_{sc}. Furthermore, the fill factor is improved due to the fact that the screen-printed fingers show a better profile on the double layer ARC's cells.

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1. Introduction

The antireflection coatings play an important role in solar cells’ performance. Good ARCs not only reduce the reflectivity, but also provide a good passivation on the surface of the solar cells, improving of the cell efficiency. Researchers have been using double or multi-layer antireflection coatings for years [1], [2]. For example, with a SiNx/SiNx/SiOxNy multilayers stack, M. Junghanel achieved a 0.24%
efficiency improvement on multicrystalline silicon solar cells [3]. For mass-production, the manufacturers need to balance the cost and the benefits of adding more layers.

On the other hand, it’s well known that high sheet-resistance emitters with shallower surface doping result in better blue response compared to conventional emitters. It’s reported that 100Ω/sq emitter showed a noticeable improvement of about 0.5% in absolute efficiency over conventional co-fired 45Ω/sq emitter on HE cells [4]. In this work, we combined these two aspects by using 75Ω/sq relatively high sheet resistance and homogeneous emitters, and double layers SiNx ARC, while maintaining a good ohmic contact with screen-printed industrial silver paste. The single layer SiNx was deposited by an inline PECVD equipment, while the double layer SiNx deposited using a tube PECVD system. The reflectivity and refractive index were measured with a spectrophotometer and an ellipsometer, respectively. The screen-printed Ag finger profiles were characterized by a 3D microscope.

2. Experiment

The 125 × 125 mm² solar cells were fabricated on 180μm-thick 1-1.5 Ω.cm p-type boron-doped Cz-silicon wafers. The cell structure is shown in Fig. 1. Potassium hydroxide-based saw-damage etching is followed by a dielectric protective coating deposited on the rear side. This process made the single side texturing structure possible (rear side polished). Then the protective coating was removed by hydrofluoric acid etching and the wafers were cleaned with a standard RCA procedure. Homogeneous emitters with 75 Ω/□ sheet resistance were formed by phosphorus diffusion using POCl₃. Then the rear and edge junction were removed by HNO₃/HF solution, and the phosphosilicate glass (PSG) was removed with a diluted HF solution. Afterwards, the wafers were split into two groups. For group A (20 pcs), the front side of the wafers were coated with a conventional single layer SiNx, with a refractive index around 2.05. For group B (20 pcs), the front side was coated with a double layer SiNx/SiNy, with refractive indexes of 2.30 and 1.92, respectively. The single-layer SiNx coating was deposited by a SINA Roth & Rau PECVD, while a Centrotherm PECVD system was used for the double layer SiNx/SiNy. The rear and front contacts were screen printed with Al and Ag pastes, respectively. After co-firing process, the cells were measured under standard testing conditions.

3. Results and discussions

Table 1 shows the current-voltage parameters of the solar cells. The best cell with the double layer SiNx stack demonstrated an efficiency of 18.9%, which is 0.5% higher than the traditional single layer SiNx cells.

The refractive index (n) of SiNx is adjustable from 1.80-3.40 in theory [3]. But actually what we could obtain was a refractive index comprised between 1.92 and 2.30 due to the limitation of the equipment. In
general, the passivation quality is improved when the refractive index $n$ increases, but higher $n$ also means higher Si content which rapidly increases the absorption in SiNx. So neither the refractive index nor the thickness should go too large.

Table 1. Solar cell parameters measured under standard testing conditions

<table>
<thead>
<tr>
<th>Cell type</th>
<th>$V_{oc}$ (mV)</th>
<th>$J_{sc}$ (mA/cm²)</th>
<th>FF (%)</th>
<th>$\eta$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double layer SiNx best</td>
<td>634.4±1.5</td>
<td>37.7±0.6</td>
<td>79.0±0.5</td>
<td>18.9±0.3</td>
</tr>
<tr>
<td>Double layer SiNx average</td>
<td>633.8±1.5</td>
<td>37.5±0.6</td>
<td>78.8±0.5</td>
<td>18.7±0.3</td>
</tr>
<tr>
<td>Single layer SiNx average</td>
<td>631.6±1.5</td>
<td>37.3±0.6</td>
<td>77.9±0.5</td>
<td>18.4±0.3</td>
</tr>
</tbody>
</table>

It is easy to calculate the reflective index and corresponding thickness of the two layers using geometrical optics formulas [5]. But this method takes neither the absorption of the ARC nor the surface structure of the wafer into account. Sentaurus simulation tools provide the possibility of adjusting a large range of parameters to approach the properties of both the ARC and the wafer. We use the Sentaurus TCAD ray tracing to simulate the reflectivity of both single and double layer ARCs on pyramidal surface.

Fig. 2 shows the optimized reflectivity curves of textured solar cells with single and double layer ARCs. The simulations fit the measured reflectivity of both ARC structures. With a similar structure, a 0.3-0.4% efficiency gain was previously obtained in the literature [1], which is lower than we have achieved, so far. This is probably due to a relatively low sheet-resistance emitter compared to what was used in this experiment. As the major beneficial wavelength range is from 350nm-500nm, which falls into the robust response range of the wafer. Compared to single layer structure, the total reflectivity from 350nm-1050nm is reduced from 3.5% to 3.0%. But this cannot lead to a 0.5% efficiency improvement alone. Another benefit is obtained from better passivation effects introduced by the bottom SiNx layer with higher refractive index [6]. This aspect could be observed from the 2.8mV of $V_{oc}$ gain.

![Graph of reflectivity curves](image)

Fig. 2. measured and simulated reflectivity curves of different ARC structures

It should be noted that the screen printing parameters have also been optimized for group B (double layer SiNx), which generated higher finger aspect ratio, as shown in Fig.3. The variations of the fill factors of these two groups were mainly due to the screen printing process. Fig. 3 shows that, for group B, the double layer SiNx cells, have an average finger width of 87 μm and an average height of 18 μm, which results in an aspect ratio of 0.20. While for group A, the single layer SiNx cells, yield an aspect ratio of 0.17.
4. Conclusion

Both optical and passivation properties of front side ARCs play important roles in solar cell efficiency improvement. With the successful application of double layer SiNx ARCs on homogeneous high sheet resistance emitter solar cells, a best efficiency of 18.9% was achieved. The improvement of \( V_{oc} \) was due to the better passivation effect of the bottom SiNx layer with a higher refractive index. The double-layer ARC reduced the reflectivity in the range of 350-500nm wavelength, which enhanced the blue response of the cell, thus led to the \( J_{sc} \) gain of 0.4 mA/cm\(^2\). The better finger aspect ratio on the double-layer ARC cells contributed to the higher FF, as well.

References