PERFORMANCE OF SUPERSTRATE MULTIJUNCTION AMORPHOUS SILICON BASED SOLAR CELLS USING OPTICAL LAYERS FOR CURRENT MANAGEMENT

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ABSTRACT

The performance of multijunction amorphous silicon based thin film solar cells has been reported using thin layers of TiO2 and SiOx acting as refractive index matching optical layers for different interfaces of the superstrate device structure. Under precise current management of the sub cells, an increase of short-circuit current (4.5%) from a-Si top cell is obtained and consequent improvement of the device performance leads to an efficiency of 11.7% so far in this work.

1. INTRODUCTION

The initial efficiency of a-Si based thin film solar cells has reached 15% in the recent years following the multijunction structure in device fabrication [1]. The most successful device configurations being double [a-Si/μc-Si] and triple [(a-Si/a-SiGe/μc-Si) or (a-Si/μc-Si/a-Si)] junction cells. The main contribution in the improvement of the efficiency could be attributed to the increase in the short-circuit current (Jsc) from the individual sub cells. Being concerned with the light induced degradation of the a-Si based solar cells an important task is to sort out one novel approach which could provide a way to increase the ‘stabilised’ efficiency of the a-Si based solar cells. In case of a glass superstrate based device structure, an optical loss occurs due to refractive index (n) mismatch between the transparent conducting oxide viz. ZnO (n~1.9) and Si (n~3.5) layers. A layer of TiO2 (n~2.5) at ZnO and silicon interface has shown to have potential to act as an anti-reflection layer (ARL) for improvement of the optical loss due to refractive index mismatch [2]. Very recently it has been demonstrated that an increase of Jsc is possible from multijunction a-Si based solar cells using TiO2 as a refractive index matching layer [2]. Again by the same time, another approach demonstrated a control over the distribution of currents from the sub cells of a multijunction cell using a PECVD grown SiOx as intermediate reflector layer (IRL) and this IRL could preferentially illuminate the a-Si top cell which is prone to light induced degradation compared to the bottom microcrystalline cell in a multijunction structure [3]. In the present work, these two approaches with optical layers, namely TiO2 as ARL and SiOx as IRL have been constructively combined to gain Jsc from a multijunction a-Si based solar cell through precise current management. The performance of the multijunction solar cells using ARL and IRL has been demonstrated in this paper. The gain in efficiency combining ARL and IRL over the standard cell design could entirely be contributed to the ‘stabilized’ efficiency of the a-Si based multijunction solar cell, since no modification in the silicon layers has been done for this improvement compared to the standard one.

2. EXPERIMENTAL

2.1 TiO2 Thin Films

The TiO2 thin films have been developed by rf-magnetron sputtering of TiO2 target using Ar and O2 gas mixture environment. The detail of experimental process and the optimization of the TiO2 film properties with electrical and optical characterizations are described elsewhere [2].

2.2 SiOx Thin Films

The SiOx films have been grown by PECVD technique using H2, SiH4, PH3 and CO2 gas mixtures and the films are n-type in nature. A substrate temperature below 200°C has been used for the deposition of SiOx thin films. The film used for the application in the solar cells has a refractive index, n~2 with a thickness between 50 nm to 100 nm. Further information regarding the deposition conditions and the layer properties of SiOx could be found elsewhere [3].

2.3 Silicon Thin Films

The silicon thin films have been deposited by either RF (13.56 MHz) or VHF (95 MHz) PECVD. Both the 10x10 cm² and 30x30 cm² substrate area compatible PECVD systems have been used for the thin film deposition process where low (<1 Torr) and high (3-10 Torr) pressure regimes in the deposition process have been used.

2.4 Solar Cells

The glass substrate is used in superstrate configuration for the fabrication of p-i-n solar cells. The standard solar cells are deposited on ZnO coated glass,
where the ZnO is texture-etched with HCl. In case of the solar cells with ARL, the TiO\textsubscript{2} layer has been deposited on the texture-etched ZnO and covered with a very thin film of ZnO (10nm) to protect it from H\textsubscript{2} plasma reduction process during exposure to PECVD silicon deposition. In case of the solar cells with IRL, the SiO\textsubscript{x} layer has been deposited at the n/p junction of two consecutive p-i-n subcells. The back contact of the solar cells has been fabricated with ZnO-Ag. The cells have been measured under 1 sun, AM 1.5 illumination. The quantum efficiency (QE) and thereby the integrated $J_{sc}$ have been calculated for the solar cells.

3. RESULTS and DISCUSSIONS

In the first step, the performance of the multijunction solar cell has been demonstrated with application of ARL following the device design: glass/ZnO(texture-etched)/TiO\textsubscript{2}/ZnO(10nm)/a-Si(p-i-n)/μc-Si(p-i-n)/ZnO-Ag. In Table I, the performance with ARL is compared with a standard cell. The increase (8.8\%) in current is due to improvement of quantum efficiency (not shown here) in the wavelength region between 500 nm to 850 nm from both the sub cells with ARL.

### Table I: Performance of a-Si/μc-Si double junction cells for standard and with ARL

<table>
<thead>
<tr>
<th></th>
<th>$V_{oc}$/V</th>
<th>FF</th>
<th>$J_{sc}$/mA/cm\textsuperscript{2}</th>
<th>η/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>1.37</td>
<td>0.70</td>
<td>10.54</td>
<td>10.1</td>
</tr>
<tr>
<td>ARL</td>
<td>1.40</td>
<td>0.70</td>
<td>11.47</td>
<td>11.3</td>
</tr>
</tbody>
</table>

Again with incorporation of IRL, following a design a-Si(p-i-n)/n-SiO\textsubscript{x}/μc-Si(p-i-n), compared to the standard one a preferential control of $J_{sc}$ from the sub cells has been demonstrated. In Table II, the performance with IRL is compared with a standard cell.

### Table II: Performance of a-Si/μc-Si double junction cells for standard and with IRL, showing sub cell $J_{sc}$ obtained from QE measurements

<table>
<thead>
<tr>
<th></th>
<th>$V_{oc}$/V</th>
<th>FF</th>
<th>$J_{sc}$/mA/cm\textsuperscript{2}</th>
<th>η/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>1.36</td>
<td>0.73</td>
<td>9.98</td>
<td>12.6</td>
</tr>
<tr>
<td>Bottom</td>
<td>1.37</td>
<td>0.75</td>
<td>11.24</td>
<td>11.5</td>
</tr>
</tbody>
</table>

Thus IRL plays an important role to control the $J_{sc}$ from top and bottom sub cells. However, the increase (12.6\%) in $J_{sc}$ from the top cell is counterpoised with a successive decrease (12.0\%) in the bottom cell.

In the next step, both the ARL and IRL have been incorporated in the device design and the performance of the solar cells has been demonstrated in Table III.

### Table III: Performance of a-Si/μc-Si double junction cells for standard and with ARL and IRL, showing sub cell $J_{sc}$ obtained from QE measurements

<table>
<thead>
<tr>
<th></th>
<th>$V_{oc}$/V</th>
<th>FF</th>
<th>$J_{sc}$/mA/cm\textsuperscript{2}</th>
<th>η/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>1.42</td>
<td>0.74</td>
<td>11.48</td>
<td>11.5</td>
</tr>
<tr>
<td>Bottom</td>
<td>1.41</td>
<td>0.74</td>
<td>11.36</td>
<td>11.4</td>
</tr>
</tbody>
</table>

Therefore, using both ARL and IRL, an increase (4.5\%) of $J_{sc}$ from the top cell is achieved and the decrease in $J_{sc}$ from bottom cell due to application of IRL is recovered (1.9\%). This increase corresponds to an improvement of efficiency (2.6\%) in the solar cell.

4. CONCLUSIONS

- The TiO\textsubscript{2} as ARL and SiO\textsubscript{x} as IRL have been developed and incorporated successfully into the multijunction a-Si based solar cell design.
- The application of the ARL and IRL has been demonstrated to improve the efficiency of the solar cell with precise current management of the sub cells. An efficiency of 11.7\% has been achieved in this program of work. Further investigations on this topic are underway and the results will be discussed in the conference.

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