Technology CAD for Anti-reflecting Coating Engineering on Silicon Solar Cells

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ABSTRACT
This paper reports the I-V curves and optical characteristics of solar cell using Si3N4, TiO2, and MgF2 as Anti reflecting coating (ARC) in front of c-Si solar cell. It is found that the current produced by using Si3N4 as an anti-reflective coating is more than TiO2 by order 10 and is comparable to the current produced by MgF2. According to the results, Si3N4 is proven to be suitable as anti-reflective coating material with a Maximum Power Point (MPP) value of $3.8 \times 10^{-8}$ W/µm where current is $6 \times 10^{-8}$ A/µm.

Keywords— Anti reflecting coating (ARC), Si3N4, TiO2, MgF2, Reflectance spectra, Transmittance spectra, Transfer Matrix, Generation rate, Solar cell

1. INTRODUCTION
The search for alternative energy sources has been making continuous advancement for the development of solar cell technology. The present inventions relate in general to photovoltaic cell having an anti reflecting coating (ARC) in the front (light reflecting surface of the cell). Anti reflecting coating of solar cell increase the concentration of light that will be absorbed by the cell rather reflected away. As a result, the conversion efficiency of cells with an AR coating increases overall efficiency of solar cells.

In this paper the focus is to have a comparative study of the I-V curves, optical device characteristics (reflectance spectra and transmittance spectra) of planar solar cells using Si3N4, TiO2 and MgF2 as anti-reflective coating to determine which material is apt in fabricating a single layer ARC.

Light striking a solar cell is partially reflected at the interfaces of different materials before reaching the photo-active layers. The following phenomenon reduces the current generated by the solar cell and therefore has to be minimized. Refractive indices of materials acting as ARC play important role in photo-electrical conversion in a solar cell. The material chosen for the comparative study have the following refractive indices Si3N4 (n=2.3), TiO2 (n=2.2) and MgF2 (n=1.35). A material with a suitable refractive index increases the efficiency of solar cells by reducing the reflectivity loss. Hence Anti Reflecting Coatings have become a vital feature of high efficiency solar cell.

2. SOLAR CELL SIMULATION

![Fig.1. Structure of solar cell and its doping profile.](image)

The Fig.1 depicts 2-D structure of Solar cell made up of silicon (15 µm), an anti reflective coating (0.07515 µm) and contacts. The Structure has been made by using Sentaurus Structure Editor.

3. RESULTS AND DISCUSSION

Transfer Matrix Method is used to calculate the rate of optical carrier generation for different wavelengths of the incident radiation, which is subsequently used in Inspect to calculate the photo generated current and to deduce the efficiency of the device. Transfer Matrix Method uses:

$$G_{opt}^C = \alpha \eta \frac{l(d)}{h_{abs}}$$

Where $G_{opt}^C$ is the rate of generated electron-hole pairs is, $\alpha$ is the absorption coefficient given by $4\pi Z_n/\lambda$, Quantum yield, $\eta$ is the number of carrier pairs generated by one photon [1-2].

The Quantum yield is given by:

$$\eta = \frac{G_{opt}^C}{G_{inc}}$$
\[ \eta = \begin{cases} 1 + 33.5(0.45 \mu m - \lambda(\mu m))^2, & \text{for } \lambda < 0.450 \mu m \\ 1, & \text{else} \end{cases} \]

\( TiO_2 \) Being an efficient UV absorber gives us scope for implementing drift-diffusion equation on generated electron-hole pairs during photo-electric conversion (assuming UV radiation are being completely absorbed by \( TiO_2 \)). Considering the accuracy and optical properties of \( Si_3N_4 \) and \( MgF_2 \) during UV excitation the concentration of generated electron-hole pairs (UV excited) is neglected unless the pairs are thermalized. During cooling the pairs diffuse from location of generation. This is being made possible by spreading the generation rate \( G_{opt} \) with two weight functions.

The Stepwise constant function:

\[ c(x) = \begin{cases} \frac{1}{2\lambda_{sp}}, & -\lambda_{sp} \leq 0 \leq \lambda_{sp} \\ 0, & \text{Otherwise} \end{cases} \]

And the Gaussian Function:

\[ g(x) = \frac{1}{\lambda_{sp}\sqrt{\pi}} e^{-\left(\frac{x}{\lambda_{sp}}\right)^2} \]

Here the characteristic length \( \lambda_{sp} \) is calculated by using random walk model [3]

\[ \lambda_{sp} = \frac{2}{3} N_{ph} \lambda_{ph} \]

Where \( \lambda_{ph} = 5.5 \) is the average mean free path for phonon scattering and \( N_{ph} \) is the number of phonons generated during thermalization.

Assuming optical phonon scattering and impact ionization are the determining mechanism in thermalization process, the number of phonons generated during this process is given by:

\[ N_{ph} = \frac{1}{2} \frac{\hbar \omega - E_{gap} - (\eta - 1)(E_{imp})}{(E_{ph})} \]

Where \( E_{gap} \) is the band gap, \( E_{imp} = 1.5 \text{ eV} \) and \( E_{ph} = 0.054 \text{ eV} \) are the average impact ionization and phonon energies respectively [4].

The \( I-V \) and the power curves of the illuminated solar cell with different Anti-reflective coating are being shown below. Initially photo current under the influence of low applied voltage is independent (applied voltage) but solar cell power grows linearly. As the voltage is increased after the Maximum Power Point is reached the contribution of the photo current to the total current is negligible and total current attains a negative value.

Basing upon the TMM model the dark current characteristics of the specified solar cell is as follows.
Above Figures show us clearly that the current produced by using Si₃N₄ as an anti-reflective coating is more than TiO₂ by order 10 and is comparable to the current produced by MgF₂ (anti-reflective Coating)

TABLE I and TABLE II depicts an explicit comparison of the different types of anti-reflecting coating being used on solar cells. The values of current and power produced by respective solar cells are depicted.

TABLE I

<table>
<thead>
<tr>
<th>ARC’s used</th>
<th>Initial Value</th>
<th>Value at MPP</th>
<th>Final Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si₃N₄</td>
<td>6.34 × 10⁻⁸</td>
<td>6 × 10⁻⁶</td>
<td>-1.435 × 10⁻⁵</td>
</tr>
<tr>
<td>MgF₂</td>
<td>2.32 × 10⁻⁸</td>
<td>2.3 × 10⁻⁸</td>
<td>-1.437 × 10⁻⁵</td>
</tr>
<tr>
<td>TiO₂</td>
<td>2.57 × 10⁻⁹</td>
<td>2.45 × 10⁻⁹</td>
<td>-1.438 × 10⁻⁵</td>
</tr>
</tbody>
</table>

It should be pointed out that the values of current and power to some extent depend upon the type of anti reflective coating being used. According to the results, Si₃N₄ is proven to be suitable anti reflective coating material with a Maximum Power Point (MPP) value of current as 6 × 10⁻⁶ A/µm.

TABLE II

<table>
<thead>
<tr>
<th>ARC’s used</th>
<th>Initial Value</th>
<th>Value at MPP</th>
<th>Final Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si₃N₄</td>
<td>0</td>
<td>3.8 × 10⁻⁸</td>
<td>-1.14 × 10⁻⁵</td>
</tr>
<tr>
<td>MgF₂</td>
<td>0</td>
<td>1.4 × 10⁻⁸</td>
<td>-1.150 × 10⁻⁵</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0</td>
<td>1.3 × 10⁻⁹</td>
<td>-1.151 × 10⁻⁵</td>
</tr>
</tbody>
</table>

Whereas the maximum power value at Maximum Power Point (MPP) is for Si₃N₄ (3.8 × 10⁻⁶ W/µm) and minimum is for TiO₂ (1.3 × 10⁻⁹ W/µm).

Basing upon the parameters of current under illumination and power Si₃N₄ is being considered as an optimized anti-reflecting coating material.
It is interesting to observe in Fig.5 that the optical radiation is not transmitted for wavelength less than 0.6 μm on the contrary in Fig.6 and Fig.7, there is no threshold required for the transmission of optical radiation. In Fig.5, beyond this wavelength (0.6μm) transmittance grows and multiple reflections becomes prominent whereas in Fig.6, transmittance is seen to increase gradually and reflectance decreases but in Fig.7, transmittance and reflectance maintain a constant value beyond 0.63 μm with nearly periodic oscillations. Hence, an occurrence of interference is being predicted in the fast oscillations of reflectance and transmittance spectra.

4. ACKNOWLEDGMENT
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5. REFERENCES