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 Si_3N_4 ,TiO_2 and MgF_2 as Anti reflecting coating (ARC) in front of c-Si solar cell. It is found that the current produced by using Si_3N_4 as an anti-reflective coating is more than TiO_2 by order 10 and is comparable to the current produced by MgF_2 .According to the results, Si_3N_4 is proven to be suitable as anti reflective coating material with a Maximum Power Point (MPP) value of $3.8 \times 10^{-8}\ W/\mu m$ where current is $.6 \times 10^{-8}\ A/\mu m$

Keywords—
Anti reflecting coating (ARC), Si_3N_4 , TiO_2 , MgF_2 , 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 relates 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 Si_3N_4,TiO_2 and MgF_2 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 Si_3N_4(n=2.3), TiO_2 (n=2.2) and MgF_2(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

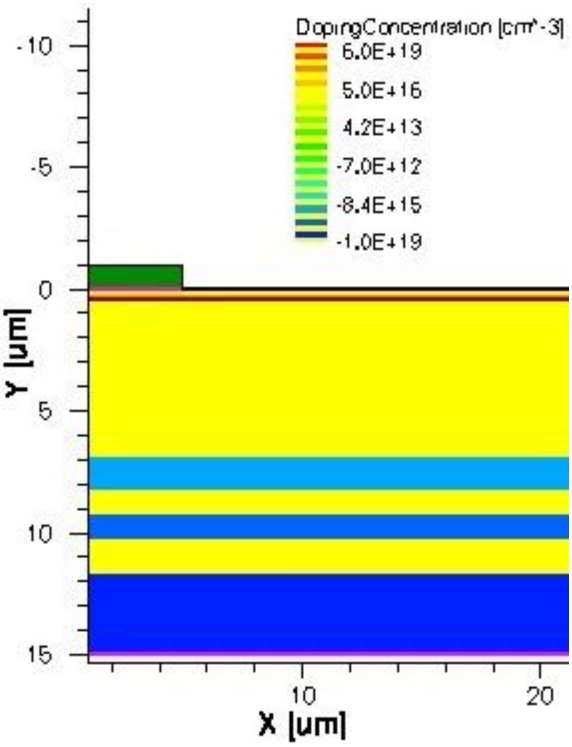

Fig.1. Structure of solar cell and its doping profile.

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.

$$G_0^{opt} = \alpha\, \eta\, \frac{I(d)}{\hbar\omega}$$

Where G_0^{opt} the rate of generated electron-hole pairs is, α is the absorption coefficient given by $4\pi\ Z_{Si}/\lambda$. Quantum yield, η is the number of carrier pairs generated by one photon [1-2].

The Quantum yield is given by:

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

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_0^{opt} with two weight functions.

The Stepwise constant function:

$$c(x) = \begin{cases} \dfrac{1}{2\lambda_{sp}}, & -\lambda_{sp} \le 0 \le \lambda_{sp} \\ 0, & \text{Otherwise} \end{cases}$$

And the Gaussian Function: $g(x) = \frac{1}{\lambda_{sp}\sqrt{\pi}} e^{\left[-\left(\frac{x}{\lambda_{sp}}\right)^2\right]}$

Here the characteristic length λ_{sp} is calculated by using random walk model [3]

$$\lambda_{sp} = \sqrt{\frac{2}{3} N_{ph} \lambda_{ph}}$$

Where λ_{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:

$$N_{ph} = \frac{1}{2} \frac{\hbar\omega - E_{gap} - (\eta - 1)\langle E_{imp} \rangle}{\langle E_{ph} \rangle}$$

Where E_{gap} is the band gap, $\langle E_{imp} \rangle = 1.5$ eV and $\langle E_{ph} \rangle$ = 0.054 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.

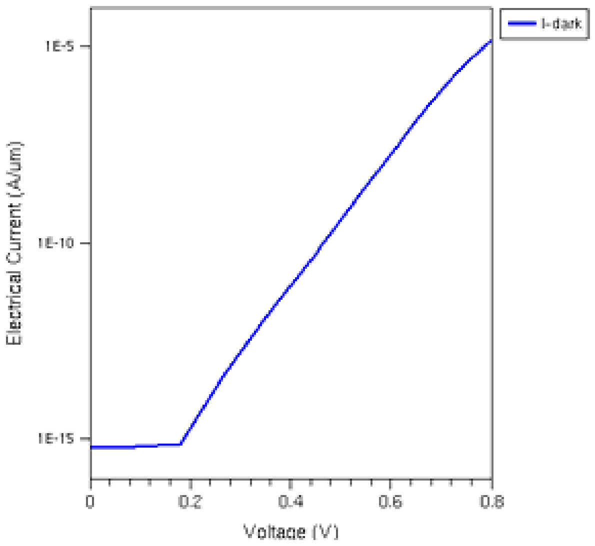

Fig. 2 I-V Curve of the solar cell without illumination

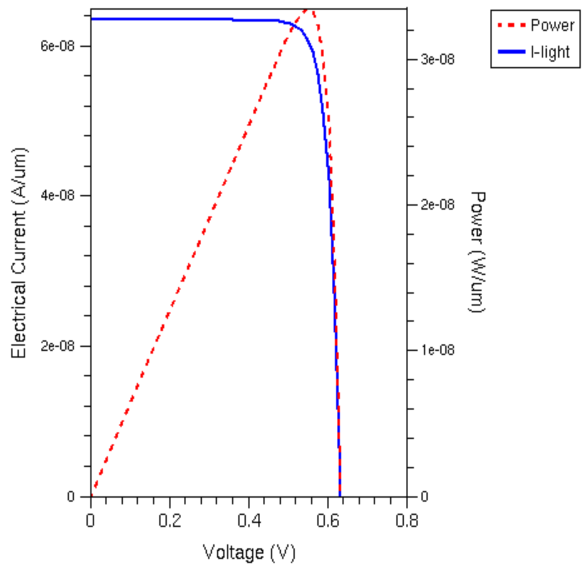

Fig.3. Power and current with illumination versus bias voltage for Si_3N_4 as an Anti-Reflective Coating

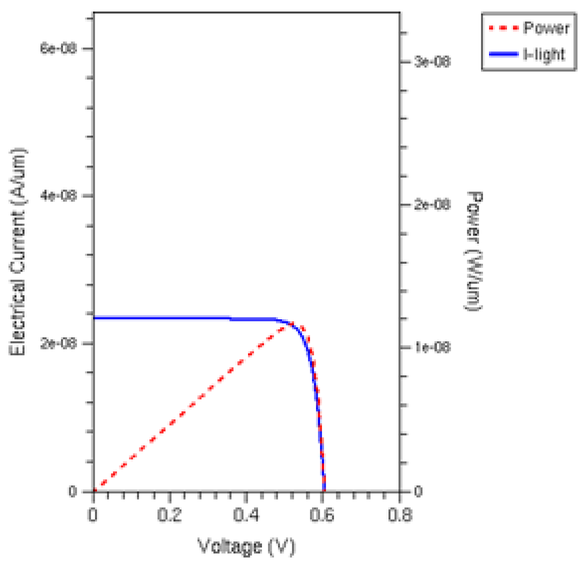

Fig.4. Power and current with illumination versus bias voltage for MgF_2 as an Anti-Reflective Coating.

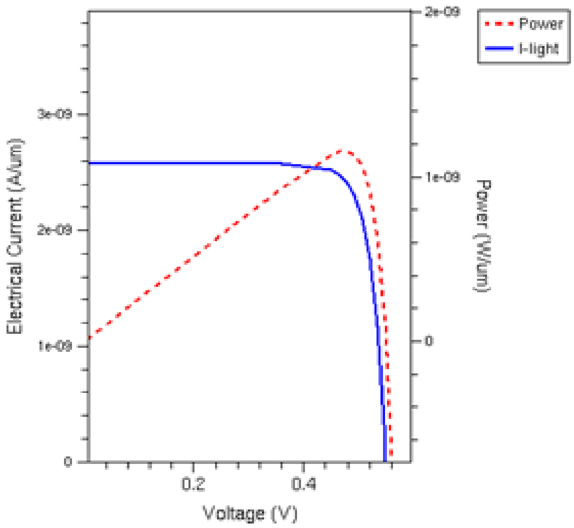

Fig.5. Power and current with illumination versus bias voltage for TiO_2 as an Anti-Reflective Coating.

Above Figures show us clearly that the current produced by using Si_3N_4 as an anti-reflective coating is more than TiO_2 by order 10 and is comparable to the current produced by MgF_2 (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
Comparison of current (A/μm) with illumination for different ARC's

ARC's used	Initial Value	Value at MPP	Final Value
Si_3N_4	6.34×10^{-8}	6×10^{-8}	-1.435×10^{-5}
MgF_2	2.32×10^{-8}	2.3×10^{-8}	-1.437×10^{-5}
TiO_2	2.57×10^{-9}	2.45×10^{-9}	-1.438×10^{-5}

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, Si_3N_4 is proven to be suitable anti reflective coating material with a Maximum Power Point (MPP) value of current as 6×10^{-8} A/μm.

TABLE II
Comparison of power ($W/\mu m$) for different ARC's

ARC's used	Initial Value	Value at MPP	Final Value
Si_3N_4	0	3.8×10^{-8}	-1.14×10^{-5}
MgF_2	0	1.4×10^{-8}	-1.150×10^{-5}
TiO_2	0	1.3×10^{-9}	-1.151×10^{-5}

Whereas the maximum power value at Maximum Power Point (MPP) is for Si_3N_4 ($3.8\times 10^{-8}\ W/\mu m$) and minimum is for TiO_2 ($1.3\times 10^{-9}\ W/\mu m$).

Basing upon the parameters of current under illumination and power Si_3N_4 is being considered as an optimized anti-reflecting coating material.

It is interesting to investigate the Reflectance and Transmittance parameters which shows the behavior of the ARC's when subjected to different wavelength of light.

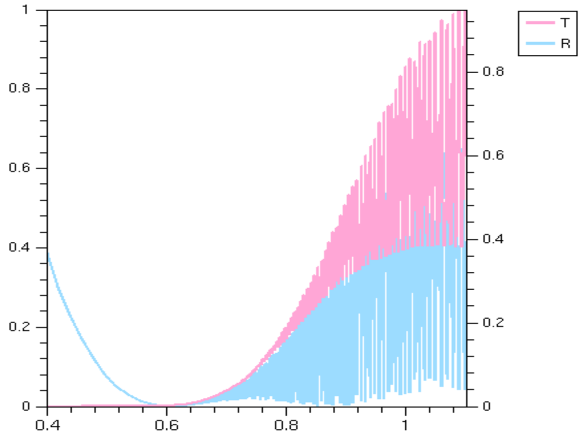

Fig.6. Reflectance and Transmittance versus wavelength for Si_3N_4 as an Anti-Reflective Coating.

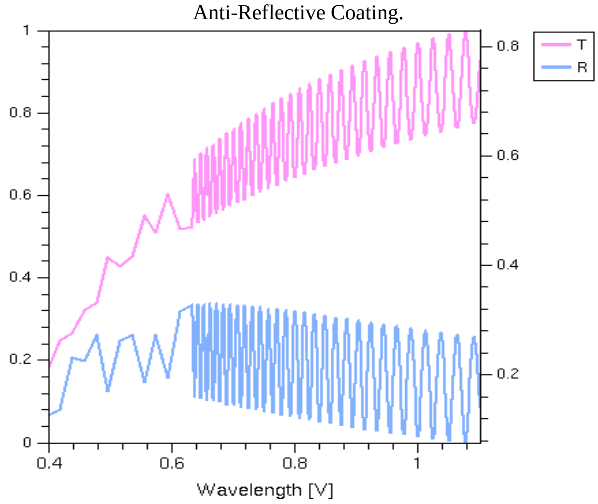

Fig.7. Reflectance and Transmittance versus wavelength for MgF_2 as an Anti-Reflective Coating.

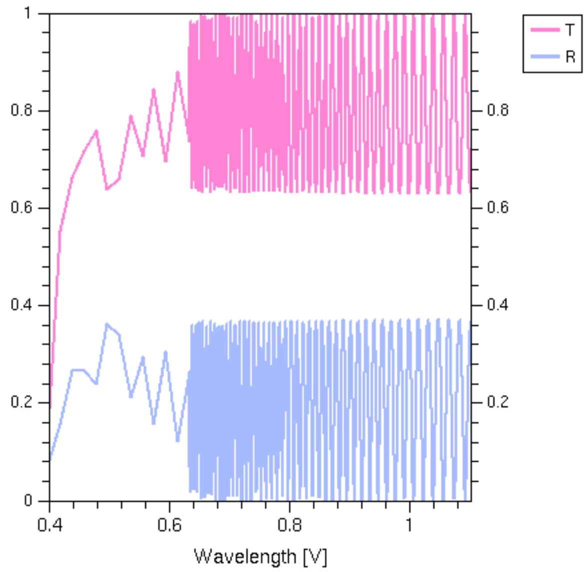

Fig.8. Reflectance and Transmittance versus wavelength TiO_2 as an Anti-Reflective Coating.

It is interesting to observe in Fig.5.that the optical radiation is not transmitted for wave length 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

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