

Efficiency enhancement of Solar Cell by introduction of Cerium Oxide along with Silicon Nitride

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Abstract: In this paper we have carried out the comparative simulations study of n type c-Si Solar Cell with SiN_x and SiN_x+CeO₂ layers separately by PC1D simulation software. The motivation of this paper is to determine the optimum condition when Solar Cell yields more efficiency by using SiN_x+CeO₂ layer rather than only SiN_x layer respectively on the front side of the Solar Cell. For these purpose the simulations have been done by changing the thickness and refractive index of CeO₂ layer. By the observation of simulation's data i.e. reflectance versus wavelength, Quantum Efficiency versus wavelength, and current density versus voltage curves, it has been endeavored to determine the optimum condition when the Solar Cell with SiN_x+CeO₂ layer yield the maximum possible efficiency. In this paper the efficiency of Si+SiN_x+CeO₂ combination has been found as 17.34% whereas the Si+SiN_x combination gives the efficiency about 16.91%.

Keywords: PC1D; Anti reflection coating(ARC); Quantum Efficiency; Short Circuit Current Density; open circuit voltage

1. Introduction

During the last decade, the Photovoltaic industry has demonstrated an annual growth rate of 87% [1]. With the escalating demands of power supply, and increase in tariff of electricity generation on a per unit basis, there has been an ineluctable need of designing the solar modules in a way that the maximum efficiency is obtained, with the concurrent minimization of the various losses that occur in a photovoltaic cell. The losses that primarily hamper efficiency of a solar cell are optical losses, recombination losses and resistivity losses [2,3].

It has already been reported that bare Silicon gives 40% reflectance for which we find a low efficiency [4]. To reduce this reflectance an antireflection coating (ARC) coating is being used. Generally in industrial production line SiN_x is extensively used as ARC for p type Solar Cell [5] because it produces fixed positive charge density of 10¹² at the emitter surface of the p type Solar Cell [4]. But in this paper n type solar cell is being used. Due to the detrimental effect of application of SiN_x film on n type silicon Solar Cell [4] a suitable ARC is necessitated on the front surface of Si which can produce a fixed negative charge on the

emitter surface of n type solar cell.

Generally CeO₂ and Al₂O₃ are used to overcome the above drawbacks [6,7]. In this paper CeO₂ has been used. It has already been reported that CeO₂ acts as a good antireflection coating and has many superior properties like high dielectric constant, large bandgap (~ 6eV), good thermal stability, a very small lattice mismatch ($\Delta a=0.35\%$) and can induces negative charge at the emitter surface of n type Silicon Solar Cell [8].

Through a number of simulations we have attempted to compare and contrast the scenario when efficiency plots for SiN_x layer and SiN_x+CeO₂ layer are juxtaposed.

2. Simulation and Results

We have carried out all simulation by PC1D simulator in order to determine how the variations between short circuit current and open circuit voltage, reflectance and wavelength, quantum efficiency and wavelength occur by changing of the parameters like refractive index, thickness etc of CeO₂ and SiN_x layer. An ideal p-n-n+ Solar Cell have been taken with area 100 cm². The doping density of base material is 10¹⁶ cm⁻³ with thickness is 200 μ m. The p type emitter has a peak density of 10¹⁹cm⁻³ with thickness 0.5

um and the n+ rear junction has a peak density of 10^{19}cm^{-3} with thickness 0.8 um. The all over simulation has been carried out for AM 1.5 Global Solar spectrum [4]. The typical n type c-Si Solar Cell used for the simulation purpose is shown in fig.1

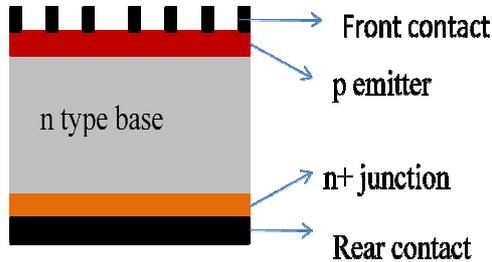


Figure 1. c-Si Solar cell structure used for simulation.

2.1. With Only Silicon Nitride Upon Silicon Substrate

In the first stage of our simulation, we have considered only Silicon Nitride at the front surface of silicon substrate [fig.2] as a antireflection coating. Under some specified conditions viz, with SiNx thickness= 65 nm, SiNx refractive index (r.i.) = 2.00 we find an efficiency of 16.91%.The characteristic table for the required simulation is shown below. The performance parameter obtained by simulation of the Solar Cell is shown in table 1.

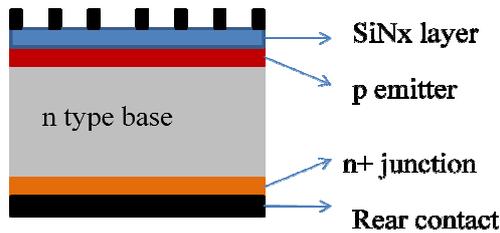


Figure 2. Arrangement of SiNx layer on Si solar cell.

Table 1. Simulated Parameters for crystalline silicon structured with Si+SiNx combination.

SiNx thickness (nm)	SiNx r.i.	Voc (V)	Isc (A)	Efficiency (%)
65	2.00	0.607	3.36	16.91

2.1.1. Variation of Short Circuit Current Density Versus Open Circuit Voltage

The plot between current density and voltage has been drawn, by keeping the refractive index of SiNx at 2.0, and thickness of SiNx layer= 65 nm. Open circuit voltage is found to be 0.607V. The corresponding short circuit current is 3.36A. It is found that the efficiency in this case is 16.91% [Fig 3].

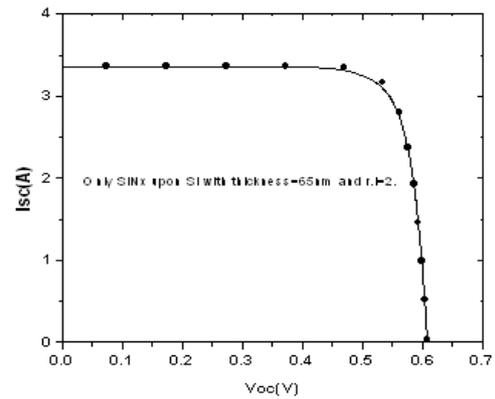


Figure 3. Variation of short circuit current density versus open circuit voltage.

2.1.2. Variation of Quantum Efficiency Versus Wavelength

Fig.4 as depicted below is a plot between quantum efficiency and wavelength of Si with SiNx as antireflection layer, where the refractive index of Silicon Nitride layer has been kept at 2.0, and the thickness of layer has been maintained as 65 nm.

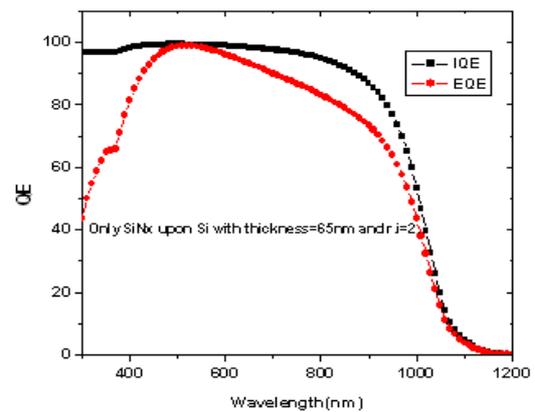


Figure 4. Variation of quantum efficiency versus wavelength with Si+SiNx layer, under stated conditions.

Prior to a detailed elucidation of the quantum efficiency-wavelength curve, an illustration of the terms – external and internal quantum efficiency are necessary.

Quantum efficiency is basically a measure of the percentage of photons striking the photo-reactive surface of a device, and consequently produces charge carriers. It is again of two types-

1. Internal Quantum Efficiency
2. External Quantum Efficiency

Internal quantum efficiency is the ratio of the number of charge carriers collected by the solar cell to the number of photons that shine on the solar cell from outside and are absorbed by the cell. Again, external quantum efficiency is defined as the ratio of the number of charge carriers collected by the solar cell to the number of photons of a given energy shining on the solar cell from outside [4]. Both in-

ternal and external quantum efficiencies have been plotted against wavelength in the range of 300 to 1200 nm. We observe that the curve for Internal Quantum Efficiency has maintained a relatively flat nature in the wavelength range of 300-980 nm, and has retained an efficiency value of about 98%. But, it is also to be noticed, that the External Quantum Efficiency curve has started off with an efficiency value of 40%, and then it is advanced to a peak, where the efficiency value is same as the highest efficiency value attained by the IQE curve, i.e 98%. But it again descends steadily up to an efficiency value of 70%. From the point where wavelength is 950 nm, the EQE curve starts declining abruptly, and ends in attaining a zero value of quantum efficiency, at a wavelength of 1200 nm.

2.1.3. Variation of Reflectance Versus Wavelength

As the reflectance of a coated film decreases, the transmission consequently increases. Hence the absorption of photon into the base material rises if and only if the absorption of the coated material is too low. Henceforth, more number of electron-hole pairs are generated at the junction, thereby increasing the generation rate of base material manifold. Therefore, the short circuit current density increases. This is followed by an increase in the efficiency. In this case, an efficiency value of 16.91% is obtained. At the first place, we are going to take up the reflectance versus wavelength plot, when only SiN_x is used along with the Si substrate. Fig.5 shows that in the UV region, we are not getting a good response for the transmission through the film. The reason behind this is, that SiN_x does not exhibit appreciable response in the Ultra Violet region. [6] A minimum reflectance is procured at about 500 nm wavelength. It is to be noted, that in order to improve the transmission to a desirable value, the average reflection has to be brought down to a minimum possible value. This necessitates the introduction of a material that will enable us to accomplish the same. We have thus incorporated Cerium Oxide, a new material, with which we have performed several simulations and have obtained some desirable nature of the curves.

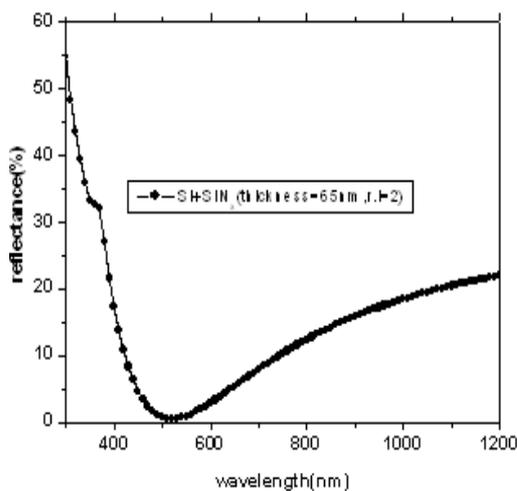


Figure 5. Plot of reflectance versus wavelength for Si+SiN_x layer.

2.2. With Silicon Nitride and Cerium Oxide on Silicon Substrate

Henceforth, we shall head for the application of cerium oxide along with the single layer of silicon nitride on the the front side of silicon Solar Cell [fig 6].

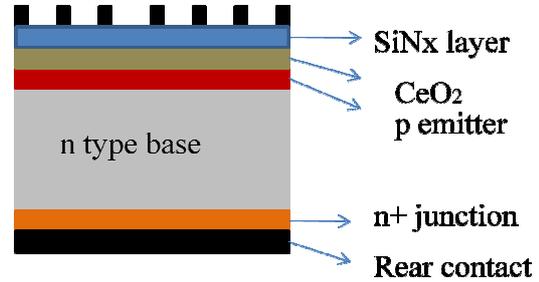


Figure 6. Arrangement of CeO₂+SiN_x layer on Si substrate

As the dielectric constant of CeO₂ is higher than SiN_x layer so we have to use this CeO₂ layer in between the SiN_x and the emitter surface of c-Si Solar Cell. After the introduction of CeO₂ in the Solar Cell it has been found that the efficiency rises than the previous condition i.e the efficiency of Si+SiN_x combination..The characteristic table after introducing CeO₂ is shown in table 2.

Table2. Simulated parameters for crystalline silicon structured with Si+CeO₂+SiN_x layers.

CeO ₂ thickness (nm)	SiNx thickness (nm)	CeO ₂ r.i	SiNx r.i	Voc (V)	I _{sc} (A)	Efficiency (%)
5	75	2.352	2	0.617	3.37	17.30
5	60	2.352	2	0.617	3.34	17.17
10	65	2.352	2	0.617	3.38	17.34
10	65	2.78	2	0.617	3.37	17.31

2.2.1. Variation of Short Circuit Current Density Versus Open Circuit Voltage

Fig.7 shows the relevant plots of short circuit current density versus open circuit voltage of the specified layer of solar cell material, while varying the thickness of CeO₂ from 5-10 nm and that of SiN_x from 60-75nm, and the CeO₂ refractive index (r.i) between 2.352-2.78.

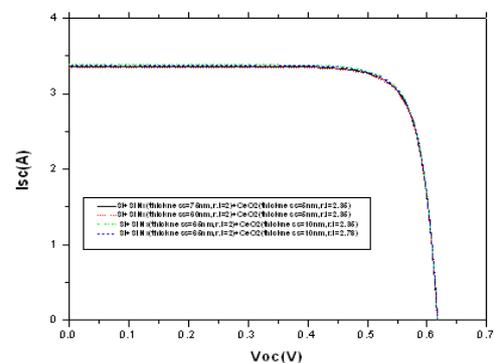


Figure 7. Variation of short circuit current density versus open circuit voltage.

From the curve we have seen that at CeO_2 thickness 10 nm with r.i 2.352 and SiN_x thickness 65 nm with r.i 2 the maximum efficiency have been found which is 17.34%.

2.2.2. Variation of Quantum Efficiency Versus Wavelength

In the next plot, quantum efficiency is made to vary with a spectrum of wavelength values, keeping the same conditions, i.e, CeO_2 thickness varying from 5 to 10 nm, CeO_2 r.i varying from 2.352 to 2.78 nm, SiN_x thickness varying from 60 to 75 nm, and lastly , SiN_x r.i being kept constant at 2.00 [Fig.8].

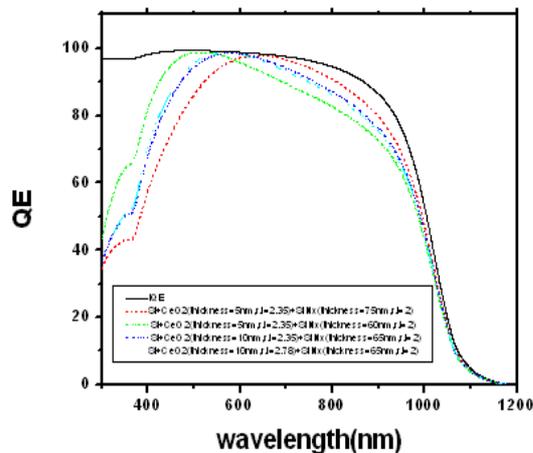


Figure 8. Variation of quantum efficiency versus wavelength under specified conditions

From the different EQE curves that have been obtained under the varying conditions, the one which has maintained the desirable flat topography to some extent has been considered. This is provided by the curve under the condition $\text{Si}+\text{SiN}_x$ thickness= 65 nm, CeO_2 thickness= 10 nm, and CeO_2 r.i= 2.352. For this curve, the difference between IQE and EQE values is the minimum.

It is to be observed over here, that the EQE for the curve we have chosen as optimum has maintained the desirable value throughout. This is possible if and only if, recombination losses have been reduced to a state, which has been impossible to achieve through the combination of $\text{Si}+\text{SiN}_x$ only [11]. Thus it is inferred that for this optimum condition, more number of incident photons are trapped, and therefore, the generation rate is also higher.

2.2.3. Variation of Reflectance Versus Wavelength

Fig.9 shows the plot between reflectance and wavelength of the $\text{Si}+\text{SiN}_x+\text{CeO}_2$ layer. At first it should be mentioned that for all the simulations performed with $\text{Si}+\text{SiN}_x+\text{CeO}_2$, the CeO_2 layer thickness is varied from 5 to 10 nm, CeO_2 r.i from 2.352 to 2.78, SiN_x thickness from 60-75 nm, and SiN_x refractive index fixed at 2.00.

For each of the above curves, we have found that they attain a minimum value of reflectance at some point. Now, due to the presence of CeO_2 , the absorption becomes favorably reduced. Thus the average transmission value is high. Hence more amount of the incident solar radiation is able

to penetrate the $\text{SiN}_x+\text{CeO}_2$ layer and reach the Si substrate. Consequently, more number of electron-hole pairs is generated at the junction, thereby increasing the generation rate of Si itself. Hence, it is concluded, that highest efficiency (nearly = 17.34% in this case) is attained at lowest reflectance.

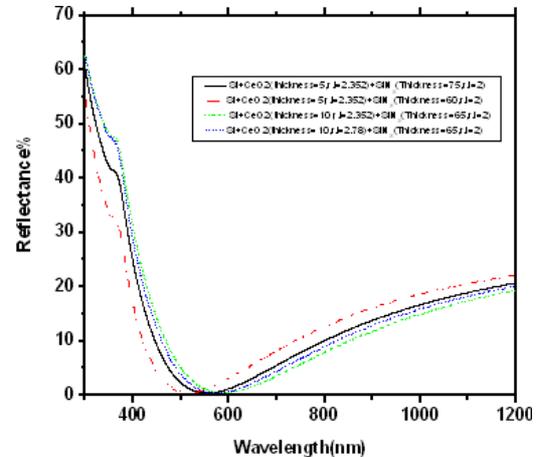


Figure 9. Variation between reflectance and wavelength of $\text{Si}+\text{SiN}_x+\text{CeO}_2$ layer.

3. Conclusion

Through the simulation works it has been established that some inevitable benefits are obviated when CeO_2 is introduced along with Silicon Nitride. The reflectance curves are allowed to have a range of wavelength values where they can attain minimum reflectance. By using $\text{SiN}_x+\text{CeO}_2$ layer, we have obtained reflectance curves which individually attain minimum values at certain points, thereby enabling us to obtain an average value of reflectance, for which desirable transmission will take place.

The quantum efficiency curves pave way for selecting the most appropriate curve where the desirable topography of EQE and IQE curves are maintained. In case of the plots taken for only SiN_x layer, we find that the deviations between EQE and IQE curves are quite high, which is not desirable. But in case of the plots taken for $\text{SiN}_x+\text{CeO}_2$, it is found that for a particular condition, i.e, $\text{Si}+\text{SiN}_x$ thickness=65 nm, SiN_x r.i.= 2, CeO_2 thickness= 10 nm, and CeO_2 r.i=2.35, the EQE curve has maintained a minimum deviation from the IQE curve.

Here an ideal Solar cell has been taken for the simulation purpose. But to actuate an as high value of efficiency for a practical solar cell, we must take adequate measures by the proper utilization of dielectrics like CeO_2 , so that the reflectance losses can be reduced to some feasible extent of the Solar Cell.

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