Modeling And Simulation of Anti Reflecting Coating For Efficiency Improvement of Solar Photovoltaic System

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Abstract- *Efficiency improvement of the solar photovoltaic system has been achieved using modeling and simulation of anti-reflecting coating. Anti-Reflecting coating helps in deploying new geometries shape for the evaluation of different methods to provide for light trapping in all directions and enables full space utilization when bringing together into device arrays. Here we have studied simulated single layer Anti-Reflective Coating (ARC) on silicon solar cells that are based on the refractive index limit of silicon dioxide (SiO2), zinc oxide (ZnO), and zinc sulphide (ZnS) are presented. Two simulations of ZnO and ZnS coating were simulated to compare with SiO2 ARC on silicon solar cell surface. When the refractive index value is high, the available photocurrent also can be high in wide range wavelength and more reducing the refractivity. In ARC analysis, the ZnS coating could perform more efficiently on a wide range of wavelengths compared to SiO2 and ZnO ARC.*

Keywords- Anti Reflecting Coating, Simulation, Solar cell

I. INTRODUCTION

The conversion of solar energy to electrical energy (photovoltaic power) has various advantages such as safe, simple, easy installation, longer life utilization and also not harmful to the environment. Renewable energy source accomplishes the demands of world energy problems. Among various renewable energy resources, photovoltaic (PV) power generation systems are expected to play a key role as eco-friendly electrical power generation resources. It is necessary to improve its efficiency and develop the reliability of the photovoltaic power generation system. PV system consists of photovoltaic cells which are connected in series and parallel to form a PV module. In general individual cells are connected in series to get desired voltage of the module which encapsulates the cells and protects them from dust, water and other damages. Modules are connected to form a PV array. To obtain more voltage individual cells are connected in series and to get more current the cells are connected in parallel. Matching of the cells and modules and structure of the array is important in the overall performance of the array.

Energy storage devices like batteries and AC and DC converters are also integral with the PV system to store and distribute the power generated through a photovoltaic module or PV array. Solar cell is the important element that absorbs the sun's energy and converts it directly into electricity. It consists of a p-n junction fabricated in a thin wafer of semiconductor material usually silicon as vast data is available for silicon wafer technology from the semiconductor industry.
Silicon is a semiconductor optical material with a relatively high refractive index. It is an ideal material for solar cells nowadays. Not only is silicon non-toxic, but it is also the second most abundant element in the Earth’s crust (after oxygen) posing minimal environmental or resource depletion issues if used on a large scale. Silicon solar cells have attracted considerable attention as low-cost and high-efficiency solar cells. The material of pure silicon is shiny. When the light hits the silicon wafer, it can reflect up to 35% of the sunlight. To reduce the amount of sunlight lost, an Anti-Reflective Coating (ARC) is put on the silicon wafer. The most commonly used coatings are titanium dioxide (TiO_2) and silicon oxide (SiO), though others are used. This case studied of zinc oxide (ZnO) and zinc sulphide (ZnS) material as an ARC and to be compared to silicon dioxide coating, SiO_2. A good ARC is vital for solar cell performance as it ensures a high photocurrent by minimizing reflectance. Unlike many other optoelectronic devices, solar cells operate at a range of wavelengths, from 300-1200 nm, which means they need a broadband ARC. To enhance the short circuit current density (J_{sc}) of solar cells, an ARC is fabricated on the surface of the solar cells. Si and Si-related materials (such as SiO_2) are of interest for solar cell work because they can be used as a surface passivating ARC or as the top cell in an all-silicon tandem solar cell (. Zinc oxide (ZnO) has recently received growing attention, as this material can be produced with superior electrical conductivity and optical transparency. Meanwhile, zinc sulfide (ZnS) is a wide bandgap semiconductor with a high refractive index and hence a

promising material for ARC over commercial silicon solar cells.

II. MATERIALS AND METHODS

Silvaco ATLAS is a physically-based device simulator that predicts the electrical characteristics that are associated with specified physical design and bias conditions. Physically-based simulation is very different from analytical modeling that provides efficient approximation and interpolation but does not provide insight, or predictive capabilities, or encapsulation of the theoretical knowledge.

Modeling Solar Cell Structure:

The solar cell that has been chosen for the test is made in the usual method in VLSI. An orientation silicon wafer of <111> with 50 µm thickness and 1x1014 atom cm-2 boron concentration was chosen. The 1 µm p-n junction was developed by the implant of phosphorus with 1x1015 atom cm-2 and energy is 110 ev. The diffuse time 300 min and the temperature 900 °C are constant. The ATHENA software is used to design the solar cell structure with the area 50×50 µm2.

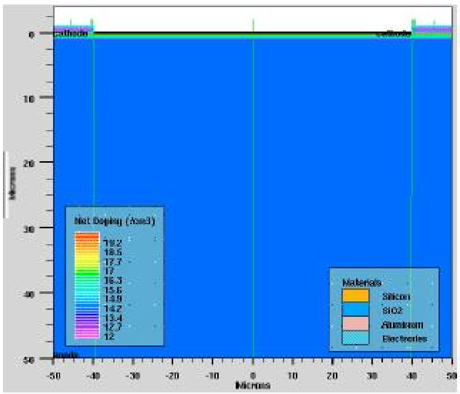

Fig. 1: Silicon solar cell structure with SiO_2 coating when applying 90° incident light

Table 1: The input data of ARC was used in the ATLAS simulator

Coating	Refractive index (n)	Thickness (d) (nm)
Silicon oxide (SiO_2)	1.46	50, 60, 70, 80
Zinc oxide (ZnO)	2.02	50, 60, 70, 80
Zinc sulphide (ZnS)	2.36	50, 60, 70, 80

The next process is applying voltage by using the ATLAS simulator to compute open-circuit voltage, Voc and short circuit current density, Jsc. Then the 90° incident light angle is applying on the top of the silicon solar cell to trace the reflectance in silicon wafer. The complete virtual solar cell structure shows in Fig. 1.

Simulation of anti-reflective coating: The second step is to simulate the spectral response of variable coating thickness by using the ATLAS simulator. The mesh of solar cell has been created to 50x50 µm2, then the substrate material is setting up to silicon. The doping concentration of boron is fixed to 1x1014 atom cm-2 of p-type. In this analysis, the beam is fixed to 90° angle and the ARC layer is setting up to variable thickness (50 to 80 nm) to plot the spectral response graph. Table 1 shows the input data used for ARC analysis simulated by ATLAS simulator. Only using ATLAS simulator can do the ARC simulation by producing a spectral response graph to calculate the quantum efficiency of each ARC.

III. RESULTS AND DISCUSSION

Electrical properties of silicon solar cell: It is described earlier, the solar cell 2D devices have been modeled to compare the electrical properties between silicon solar cells with no SiO2 and 0.05 µm SiO2 coating. Figure 1 shows the basic structure of silicon solar cell deposited 0.05 µm SiO2 layer when applying 90° incident light.

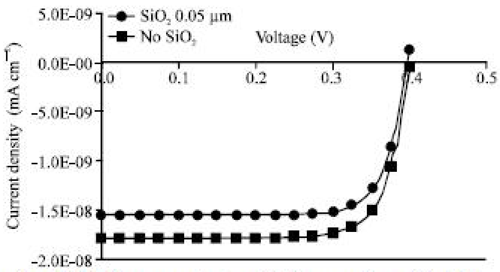

Fig. 2: Graph of J-V characteristics of silicon solar cell with 0.05 µm SiO2 and no SiO2 coating

Table 2: The electrical properties of virtual silicon solar cell

Properties	No SiO_2	0.05 µm SiO_2
V_{oc} (mV)	400.990	397.670
J_{sc} (mA cm^{-2})	17.962	15.634
FF	0.758	0.758
η (%)	5.460	4.720

Figure 1 shows the direction of incident light go straight into the substrate without reflecting because the surface structure is even or flat, but it does not mean all the photons were fully absorbed. If the surface structure is a textured or different angle of incident light before entering the substrate, the direction of light might be reflected.

For the solar cell simulation, the J-V characteristic is shown in Fig. 2. As for the result of Voc and Jsc for silicon solar cell structure with SiO2 and no SiO2 coating, it is shown in Table 2. Table 2 shows the Voc from both is 0.05 µm SiO2 and no SiO2 coating too small referred to the best

Voc of silicon solar cell, Voc = 0.706 V, possibility the area of the structure is small, which is 50x50 µm2. It shows the values of Voc and Isc for silicon substrate are higher than 0.05 µm SiO2 coating and the efficiency of the virtual cell is decreasesby about 13.6% when the deposited 0.05 µm SiO2 coating. This might happen the refractive indexof SiO2 is lower than 2.0. Figure 2 shows the result computed from solar cell simulation analysis.

Anti-reflective coating simulation result: In this study, the ARC analysis has been used four variables thickness of single-layer coating with the p-n junction of 1 µm could be simulated. The ARC simulation result is shown in Fig. 3-5, which shows the photocurrent effects of the wavelength on silicon solar cells. The pink line on the top shows the photocurrent from the source and the other lines are the available photocurrent can be absorbed by variable ARC thickness. Fig. 3 shows there has a space or gap between the available photocurrent and source photocurrent lines of SiO2 ARC and this situation might cause the SiO2 refractive indexto be lower than 2.0.

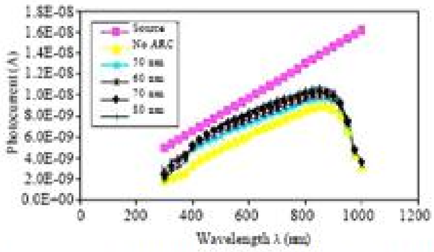

Fig. 3: Graph of spectral response of variable thickness SiO_2 ARC (d = 50 ~ 80 nm)

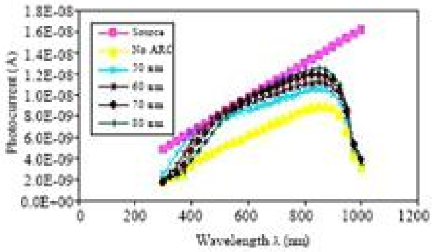

Fig. 4: Graph of the spectral response of variable thickness ZnO ARC (d = 50 ~ 80 nm)

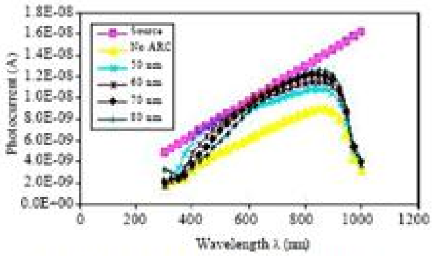

Fig. 5: Graph of the spectral response of variable thickness ZnS ARC (d = 50 ~ 80 nm)

When the **refractive index**value is higher, the available photocurrent can be higher in wide range wavelength and more reducing the refractivity. The spectral response of ZnO and ZnS coating is capable of reducing the refractivity over a wide range of wavelengths increase around 600 and 700 nm, respectively (Fig. 4, 5).

The Quantum Efficiency (QE) measurement is one of the most significant characterization tools for solar cells. The source photocurrent is the amount of current generated by the light source (ATLASUser's Manual, 1998).

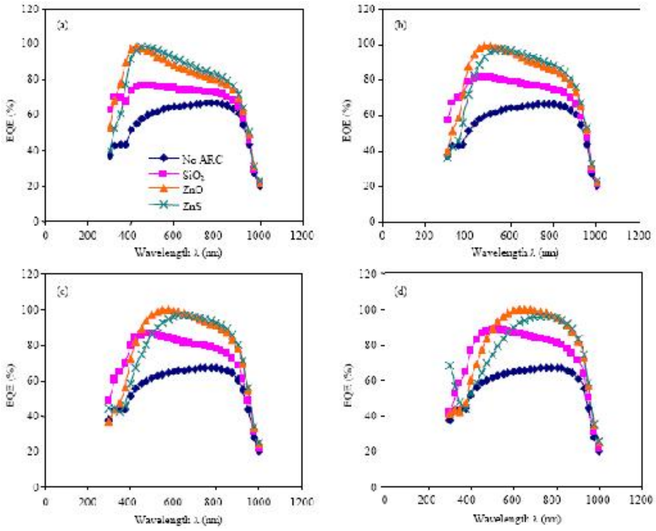

Fig. 6: Graph of External Quantum Efficiency (EQE) for single-layer ARC with variable thickness (a) 50, (b) 60 (c) 70 and (d) 80 nm, respectively on silicon solar cell

Available photocurrent is the amount of current absorbed by the semiconductor. Differences between these two photocurrents are due to reflection, transmission or absorption in non-semiconductor materials. The ratio of available and source photocurrents is often known as external quantum efficiency. Figure 6a-d shows the graph of External Quantum Efficiency (EQE) for single-layer ARC with variable thickness (50, 60, 70 and 80, respectively) on silicon solar cells. Overall, the graph shows the SiO2 is the lowest EQE line compared to ZnO and ZnS coating. The EQE of ZnO is high increase around 400-700 nm wavelength. Meanwhile, the EQE of ZnS is increasing higher in a wide range of wavelength, which is around 600-800 nm wavelength. And this means the ZnS coating could perform more efficiently on a wide range of wavelengths. This can be concluded the ZnO layer is optimum to be a first layer for fabricating multilayer coating solar cell. From the results obtained, it is found that the maximum percentage of EQE, which nearly 99.99% is on 60-80 nm thickness ZnO coating.

IV. CONCLUSION

A theoretical study of the ARC on silicon solar cells is made. This study presented a simulation of single layer ARC on silicon solar cells, based on silicon dioxide (SiO_2), zinc oxide (ZnO) and zinc sulphide (ZnS) coatings by using an ATLAS simulator. The ability of the ATLAS device simulator to accurately model solar cell characteristics has been shown. The detailed outputs available to the solar cell designer allow for efficient and effective simulation and optimization of even the most advanced solar cell designs. Using these tools, the basic silicon solar cell structure was designed by using the ATHENA device simulator, meanwhile, the J-V characteristics and spectral response for ARC analysis were showing by the ATLAS simulator. From the solar cell analysis, it is found the V_{oc} is 397.69 mV and J_{sc} is 15.646 mA cm^{-2}, meanwhile, the FF and solar cell efficiency is 0.758 and 4.72%, respectively, from 0.05 μm SiO_2 coating. In ARC simulation, the ZnO and ZnS ARC are capable to reduce the refractivity because the available photocurrent is increase around 600 and 700 nm for ZnO and ZnS, respectively. And this can be concluded when the **refractive index** value becomeshigher, the available photocurrent also can be higher in wide range wavelength and capable of reducing more refractivity on the solar cell. For the ARC analysis, the spectral response graph was plotted to evaluate the external quantum efficiency. The percentage of EQE is calculated to compare the differences between coatings thickness. From the results obtained the maximum percentage of EQE, which nearly 99.99% is on 60-80 nm thickness ZnO coating. Meanwhile, the EQE of ZnS is increasing around 600-800 nm of broad range wavelength. Solar cell simulation could be useful for time-saving and cost consumption. This method also cheaper and faster compared to the experimental. So, the simulation has some advantages over physical experimental to decided to fabricate a solar cell.

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