# Optimization of Multilayer Antireflection Coating For Solar Cells

Norhuda Binti Hamzah

Faculty of Electrical Engineering, Universiti Teknologi MARA, Malaysia (UiTM)
Email: norhuda_hamzah9485@yahoo.com.my

**ABSTRACT**

This paper presents the effects of Silicon dioxide ($SiO_2$) and Silicon nitride (SiN) used as an antireflection (AR) coating for solar cell. The ATLAS simulator of Silvaco TCAD tools was used to simulate the photovoltaic cells. Basically, this paper describes the simulation of highest conversion efficiency for solar cell with double layer $SiO_2$-SiN antireflection coating. The same parameter will be investigated for triple AR coating as well. For photovoltaic applications, the refractive index, and thickness are chosen in order to minimize the reflection. In this project, the refractive index used is 1.46 for $SiO_2$ and 2.05 for SiN and the thickness of SiN is fixed as 0.05um and varies the $SiO_2$. When thickness of $SiO_2$ is 0.09um, the external quantum efficiency measurements showed that the double layer $SiO_2$-SiN is more efficient than three layers $SiO_2$-SiN-SiN with 97.8% efficiency.

Key word: Antireflection coating, silicon dioxide, silicon nitride, thickness, reference wavelength, external quantum efficiency.

## 1.0 INTRODUCTION

Solar cell or photovoltaic is best known as a method for generating solar power by using solar cells packaged in photovoltaic modules, often electrically connected in multiples as solar photovoltaic arrays to convert energy from the sun into electricity. To explain the photovoltaic solar panel more simply, photons from sunlight knock electrons into a higher state of energy, creating electricity as shown in Figure 1.

The term photovoltaic denotes the unbiased operating mode of a photodiode in which current through the device is entirely due to the transduced light energy. Virtually all photovoltaic devices are some type of photodiode.

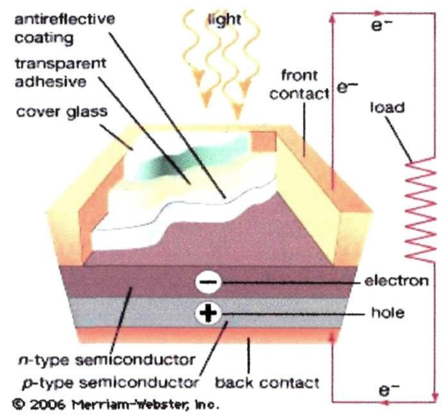


Figure 1: Photovoltaic effect

Solar cells produce direct current electricity from light, which can be used to power equipment or to recharge a battery [1]. As light passes through an uncoated glass substrate, approximately 4% will be reflected at each surface. This results in a total transmission of only 92% of the incident light. Applying an AR coating on each surface will increase the throughput of the system and reduce hazards caused by reflections traveling backwards through the system (ghost images). Anti-reflection coatings are especially important if the system contains many transmitting optical elements. Many low-light systems incorporate AR coated optics to allow for efficient use of light.

It is a popular strategy to place anti-reflective (AR) coatings on light detecting devices to improve device quantum efficiency. Such coatings rely on coherence effects to reduce the reflection coefficient between the detecting device and the ambient (i.e., air or vacuum) in the direction of the light source. Typically, these

AR coatings are composed of one or more layers of insulating materials that are one quarter optical wavelength thick and optically transparent to the wavelength in question.

## 2.0 ATLAS SIMULATOR

ATLAS device simulator by Silvaco International was introduced for used as a tool in modeling solar cell. The ATLAS software tool was developed by Silvaco to be used for the design of solid state microelectronic devices. This ATLAS simulator extracts the electrical characteristics of a solar cell based on virtual fabrication of its physical structure, allowing for direct manipulation of materials, dimensions and dopings.

This project shows how anti-reflection coating can be simulated in ATLAS. This simulator will demonstrate the construction of silicon region, specification of normally incident light beam, definition of anti-reflective layer using the INTERFACE statement and the simulation of spectral response [2].

A good anti-reflection coating (ARC) is vital for solar cell performance as it ensures a high photocurrent by minimizing reflectance. Double layer ARCs can be designed to minimize reflection over a broader wavelength range than single layer ARCs by creating minima and keeping the interconnection maxima as low as possible [3]. It is shown that sequential plasma enhanced chemical vapor deposition (PECVD) of SiN and $SiO_2$ can produce a very effective double-layer antireflection (AR) coating by measuring the external quantum efficiency that carried out in this paper. Figure 2 shows the physical structure of antireflection coating in silicon solar cell, where R refers to light reflected back into the ambient, while the A refers to the light absorbed by the layers and the T is the light which reaches the substrate.

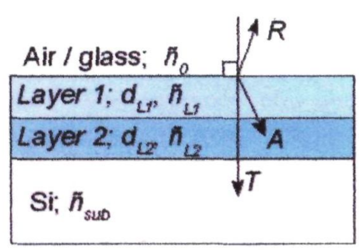


Figure 2: Physical structure of antireflection coating in silicon solar cell

Figure 3 shows the types of information that flow in and out of ATLAS. Most ATLAS simulations use two inputs: a text file that contains commands for ATLAS to execute, and a structure file that defines the structure that will be simulated.

ATLAS produces three outputs. The run-time output provides a guide to the progress of simulations running where error messages and warning messages appear. Log files store all terminal voltages and currents from the device analysis, and solution files store two- and three-dimensional data relating to the values of solution variables within the device for a single bias point [2].

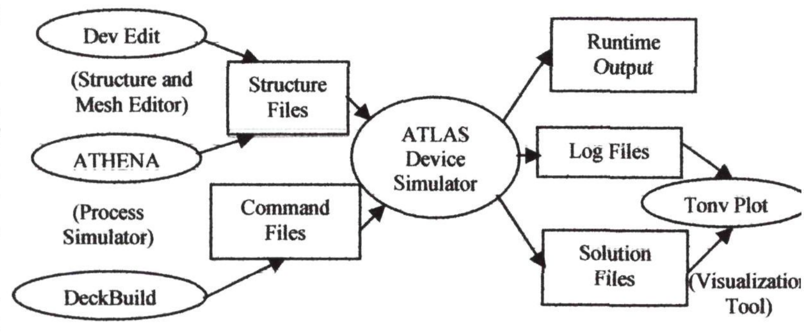


Figure 3: ATLAS Inputs and Outputs

## 3.0 SIMULATION

By using the Atlas simulator of Silvaco TCAD tools, the final plot compares the spectral response of the cases with and without the ARC. A two layer coating is capable of reducing the reflectivity over a wide range of wavelengths. In this simulation the terminal current is not important since we consider a one terminal device with no applied bias. The source photocurrent is the amount of current generated by the light source and the available photocurrent is the amount of current absorbed by the semiconductor. Differences between these two are due to reflection, transmission or absorption in non-semiconductor materials. The ratio of available/source photocurrents is often known as external quantum efficiency given in Equation 1. This quantity can be plotted using the functions in Tonyplot [2].

$$ExternalQuantumEfficiency = \frac{AvailablePhotocurrent}{SourcePhotocurrent} \quad (1)$$

Recent studies have shown that the application of PECVD SiN thin film can be very helpful in improving the efficiency of polysilicon solar cells. It not only acts as an antireflection coating layer with a suitable refractive index, but can also improve the performance of photovoltaic devices by defect/surface passivation. This is because a large amount of atomic hydrogen is produced during PECVD process.

In addition, PECVD is a low temperature process (about 300°C), compared to other CVD processes (LPVCD or APCVD), and has high throughput, good uniformity, better thickness control (< 5%), and excellent reproducibility, compared to the physical evaporation techniques. These entire advantages make PECVD SiN film very attractive for solar cells [4]. The refractive index limits for SiN and $SiO_2$ are 1.8-3.2 and 1.46-2.05 respectively [3]. In this project, the refractive index used at 300K is 1.46 for $SiO_2$ and 2.05 for SiN [5]. Approximately 10% of the solar energy lies in a wavelength between 320 and 420 nm. In most solar cells this light is absorbed quickly. However, it is typically absorbed in support structures and/or too near to the front surface of a solar cell to produce electric power. Significantly more power is lost at longer wavelengths. But approximately 50% of the solar energy lies between wavelengths of 720 nm (the longest wavelength light a thin amorphous silicon solar cell can absorb in one or two passes). This wavelength was used in this project as a reference lambda or wavelength.

## 4.0 RESULTS/ DISCUSSION

In this project, the ATLAS device simulator by Silvaco International was used to simulate and optimize $SiO_2$-SiN and $SiO_2$-SiN-SiN multilayer antireflection (AR) coatings and show their efficiency. Atlas simulator of Silvaco TCAD tools also used to compare the plot of spectral spectrum of the cases with and without AR coating. The efficiency was obtained at reference wavelength, 720nm. This is because this wavelength is the longest wavelength light a thin amorphous silicon solar cell can absorb in one or two passes. The external quantum efficiency with thickness of $SiO_2$ are 0.03um, 0.06um, 0.09um, 0.12um, 0.15um, 0.18um and 0.21um were measured.

### 4.1.1: Case 1: Thickness of $SiO_2$ is 0.03um

Figure 4 (a) and (b) show the spectral response and efficiency of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.03um.

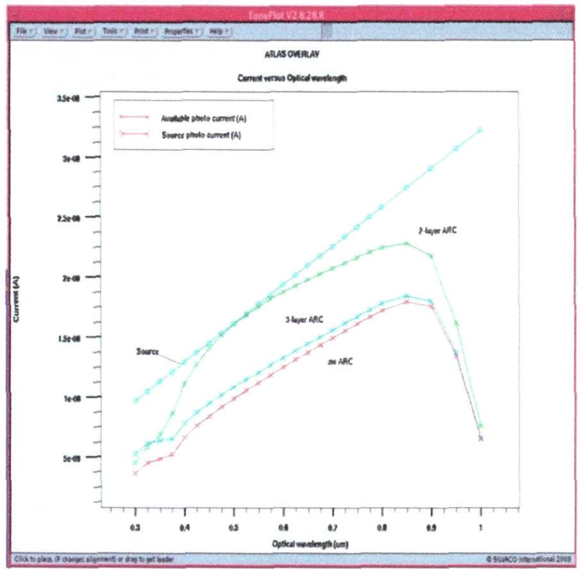


Figure 4 (a): Spectral response of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.03um

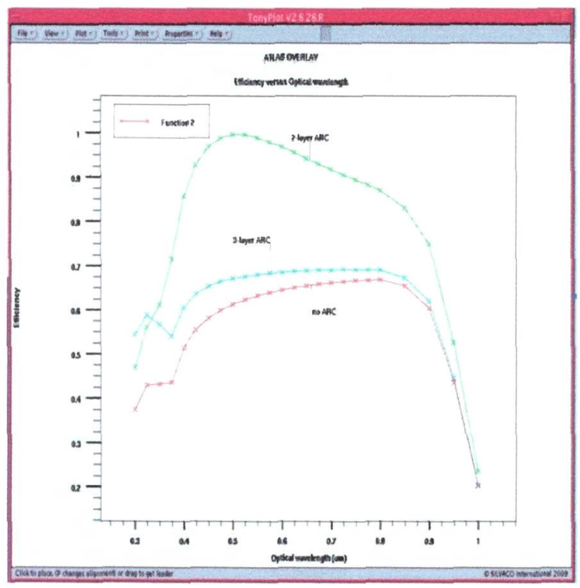


Figure 4 (b): Efficiency of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.03um

Figure 4(b) shows the efficiency of no ARC, 2layer ARC and 3layer ARC for 0.03um thickness of $SiO_2$, where the thickness of SiN is fixed to 0.05um.

### 4.1.2: Case 2: Thickness of $SiO_2$ is 0.06um

Figure 5 (a) and (b) show the spectral response and efficiency of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.06um.

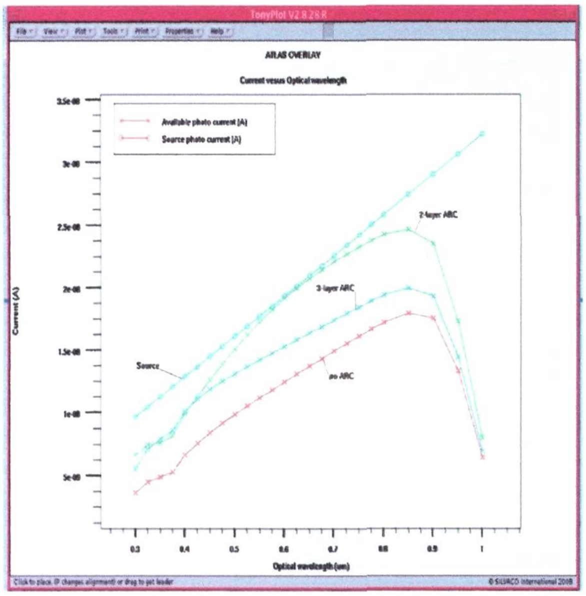


Figure 5 (a): Spectral response of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.06um

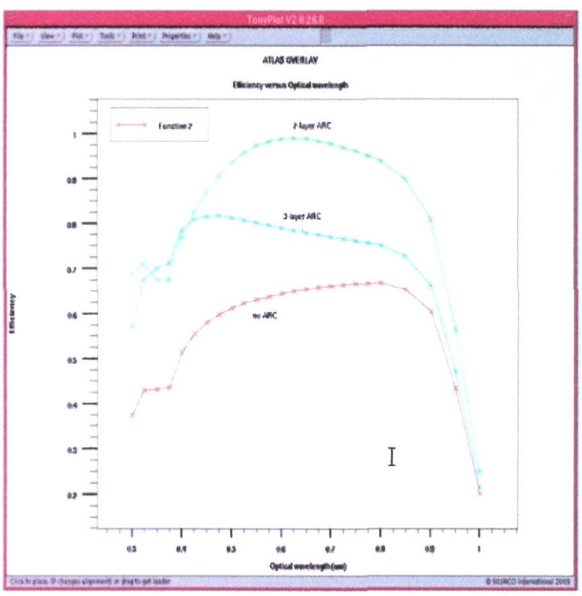


Figure 5 (b): Efficiency of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.06um

### 4.1.3: Case 3: Thickness of $SiO_2$ is 0.09um

Figure 6 (a) and (b) show the spectral response and efficiency of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.09um.

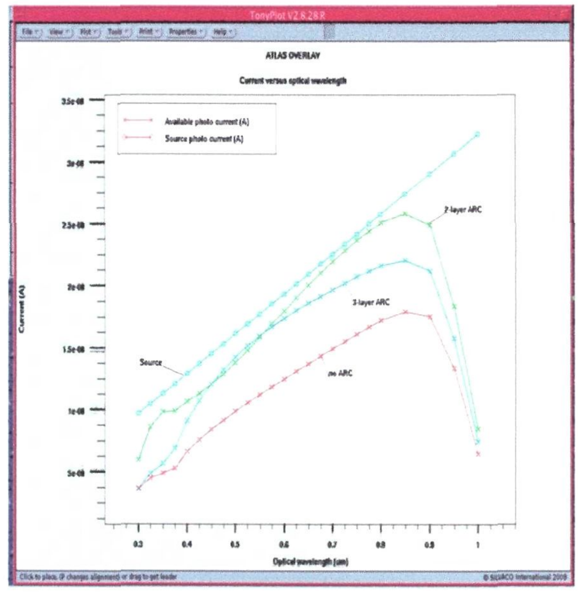


Figure 6 (a): Spectral response of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.09um

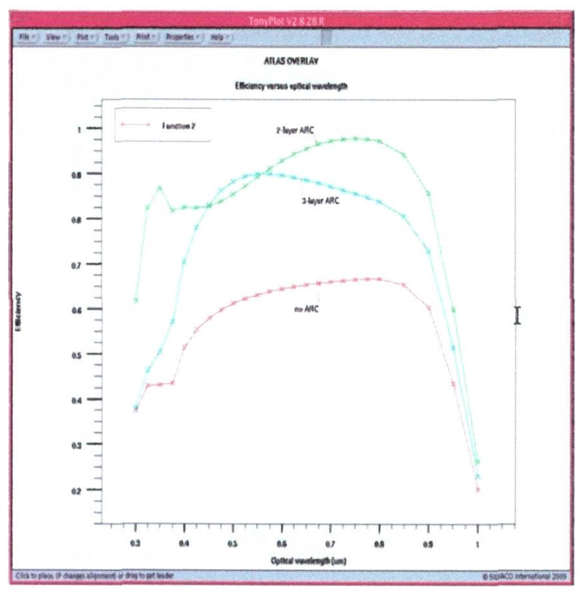


Figure 6 (b): Efficiency of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.09um

### 4.1.4: Case 4: Thickness of $SiO_2$ is 0.12um

Figure 7 (a) and (b) show the spectral response and efficiency of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.12um.

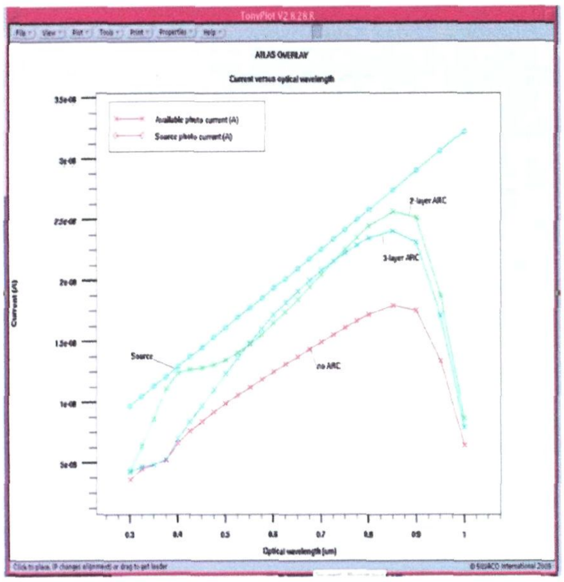


Figure 7 (a): Spectral response of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.12um

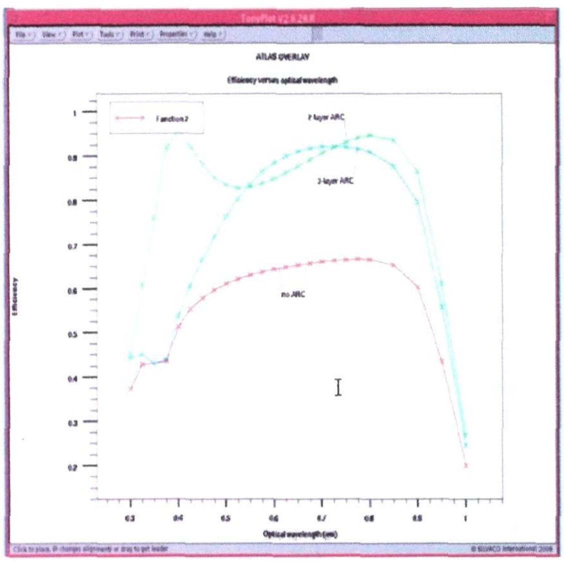


Figure 7 (b): Efficiency of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.12um

### 4.1.5: Case 5: Thickness of $SiO_2$ is 0.15um

Figure 8 (a) and (b) show the spectral response and efficiency of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.15um.

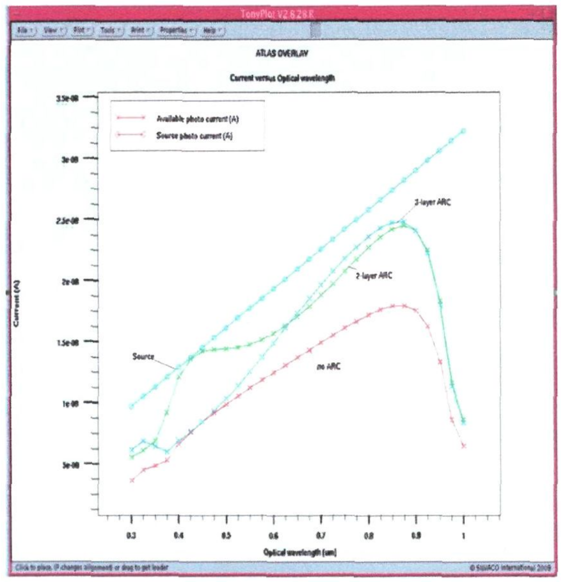


Figure 8 (a): Spectral response of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.15um

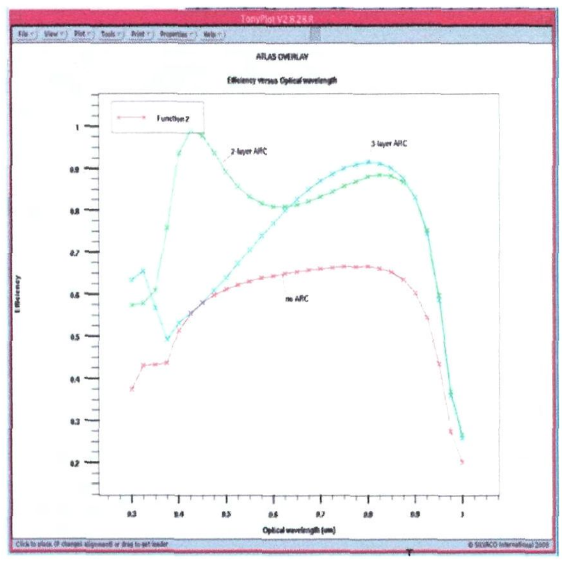


Figure 8 (b): Efficiency of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.15um

### 4.1.6: Case 6: Thickness of $SiO_2$ is 0.18um

Figure 9 (a) and (b) show the spectral response and efficiency of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.18um.

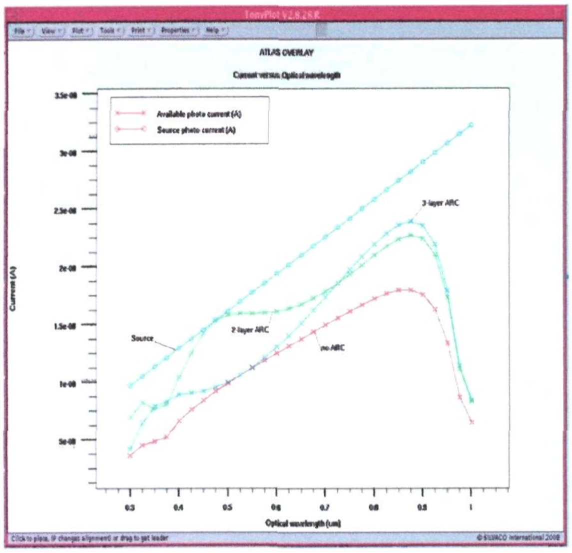


Figure 9 (a): Spectral response of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.18um

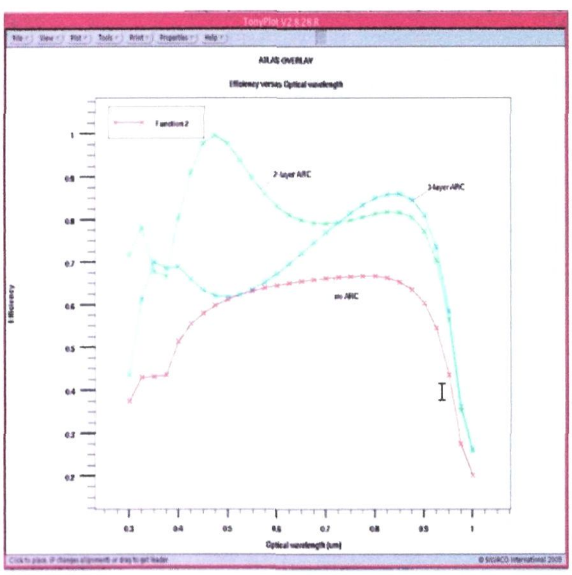


Figure 9 (b): Efficiency of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.18um

### 4.1.7: Case 7: Thickness of $SiO_2$ is 0.21um

Figure 10 (a) and (b) show the spectral response, efficiency of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.21um.

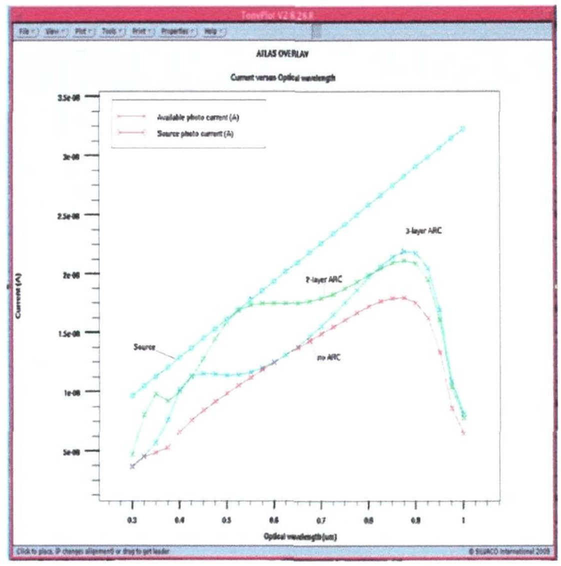


Figure 10 (a): Spectral response of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.21um

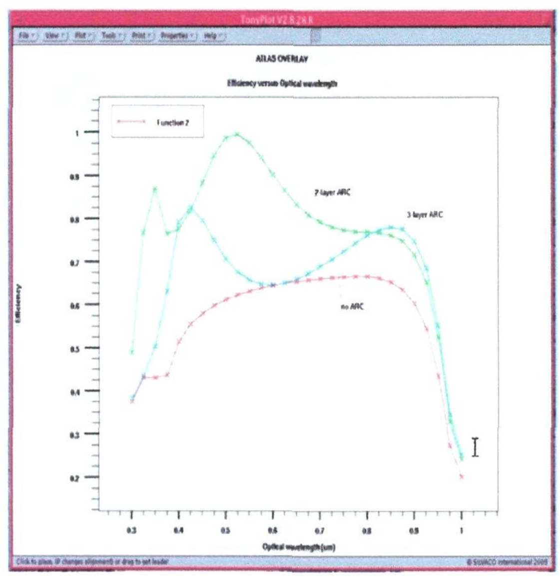


Figure 10 (b): Efficiency of no ARC, 2layer ARC and 3layer ARC when thickness of $SiO_2$ is 0.21um

The efficiencies of multilayer antireflection (AR) coatings for solar cell with different thickness of $SiO_2$ at reference wavelength (720nm) were summarized in Table 1 below:

Table 1: The efficiencies of double layers $SiO_2$-SiN, three layers $SiO_2$-SiN-SiN and without layer for solar cell with different thickness of $SiO_2$ at reference wavelength

| Thickness of $SiO_2$ (µm) | Efficiency for 2layers | Efficiency for 3layers | Efficiency without layer |
|---|---|---|---|
| 0.03 | 0.908 | 0.692 | 0.665 |
| 0.06 | 0.973 | 0.765 | 0.665 |
| 0.09 | 0.978 | 0.865 | 0.665 |
| 0.12 | 0.919 | 0.926 | 0.665 |
| 0.15 | 0.844 | 0.885 | 0.665 |
| 0.18 | 0.793 | 0.794 | 0.665 |
| 0.21 | 0.786 | 0.704 | 0.665 |

Based on the Table 1, it shows that the thickness gives an effect on solar cell efficiency. When thickness of $SiO_2$ is 0.09um, the external quantum efficiency measurements showed that the double layer $SiO_2$-SiN is more efficient than three layers $SiO_2$-SiN-SiN with 97.8% efficiency. This is the highest external quantum efficiency for this project. While when the thickness measured at 0.12um, 3layer become more efficient than 2layer ARC until 0.18um. Then at thickness of $SiO_2$ is 0.21um, the 2layer ARC is more efficient than 3layer ARC. The table above shows that for 2layers ARC the external quantum efficiency was reduced starting from the thickness of $SiO_2$ is 0.12um at reference wavelength (720nm). Starting from the thickness of $SiO_2$ is 0.15um at reference wavelength the external quantum efficiency for 3layer ARC also decreases. This is because significantly more power is lost at longer wavelengths.

## 5.0 CONCLUSION

Silvaco Atlas device simulator was used to design the solar cell. In the designing, it involves both single junction solar cell and multi junction solar cell.

Solar cells that use anti-reflective coating (AR coating) improved their efficiency. Anti-reflective coatings are important in order to reduce the reflection of light so that more light can be absorbed by the solar cells. The material used for AR coating also important to give the lowest reflection in improving the efficiency. The ratio of available/source photocurrents is often known as external quantum efficiency. The source photocurrent is the amount of current generated by the light source and the available photocurrent is the amount of current absorbed by the semiconductor.

The thickness gives an effect on solar cell efficiency. By compared the plot of spectral spectrum of the cases with and without AR coating, solar cell with ARC is more efficient. When thickness of $SiO_2$ is 0.09um, the external quantum efficiency measurements showed that the double layer $SiO_2$-SiN is more efficient than three layers $SiO_2$-SiN-SiN with 97.8% efficiency. For 2layers ARC the external quantum efficiency was reduced starting from the thickness of $SiO_2$ is 0.12um at reference wavelength (720nm) and for 3layer ARC starting from the thickness of $SiO_2$ is 0.15um, the external quantum efficiency also decreases. This is because significantly more power is lost at longer wavelengths.

## 6.0 FUTURE DEVELOPMENT

Solar cells become popular nowadays because of their ability to provide nearly permanent, uninterrupted power. However in providing the power, they have low power per unit area of sunlight which causes the low efficiencies. Its performance is dependent upon the intensity of the sunlight and also the material used for the solar cell device.

In the improvement of their efficiency better than obtained in this project, n-type silicon wafers is recommended. This is because they are more tolerant to chemical and crystallographic defects, and as such, they have exceptional potential as a wafer for high-efficiency commercial silicon solar cells.

Besides that, n-type silicon wafers offer a significant opportunity for commercial high-efficiency silicon solar cells. Recombination and device characteristics have been proven to be stable under illumination. High lifetimes have been reported in multicrystalline, Czochralski, and float-zoned wafers, and high efficiency solar cells are now being reported in solar cells made on n-type wafers. As for feedstock considerations, the growing list of defects that exhibit high hole lifetime and low electron lifetime, and the impact that the associated a-SRH recombination has on the terminal characteristics of solar cells, suggests that n-type silicon wafers are better suited for high-efficiency commercial silicon solar cells [6].

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