Modeling and Analysis of GaAs Solar Cells for Conversion Efficiency Improvement by Reducing Reflection Losses

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***Abstract*— Finite difference time-domain (FDTD) method is used to design, simulate and calculate the light trapping properties of nano-gratings over the GaAs substrate. The simulation results show that the light reflection loss reduces ~27% using the nano-grating structure when compared with a conventional or flat type solar cells.**

***Index terms*— Conversion efficiency, FDTD simulation, GaAs substrate, Light reflection, Nano-grating structure, Solar Cells.**

I. INTRODUCTION

As an alternative of fossil fuel energy, solar cells can provide an efficient and environmental friendly solution for green earth. Solar cells were discovered in the 19^{th} century, which has attracted to different scientists around the world to conduct research in this area to improve the conversion efficiency and also in an aim to attain minimized CO_2 reduction. In general, solar panel emits 16~21g/kWh of CO_2 for roof and ground-mounted CdTe PV panels with solar irradiance of 1700kWh/m2 /yr in Southern Europe [1]. My Queensland Government survey reported that electricity generation is the largest source of CO_2 emission [2]. Reduction of CO_2 emissions can be achieved gradually by utilizing the renewable energy sources, such as solar or PV and wind power systems. The conversion efficiency of solar cells are affected by different types of losses. However, the light reflection loss has significant impact to reduce the conversion efficiency of solar cells. They have a very significant appeal over light absorption property of a solar cell. In-order to overcome this issue, thin film anti-reflective (AR) coating is used to minimize the reflection losses but the AR coating can work for certain wavelengths only. However, there are some drawbacks on using the AR coating, such as it might have thermal and adhesive mismatch with the substrates. Hence, subwavelength grating (SWG) structures have been identified as promising candidate for realising high conversion efficiency in solar cells due to their low reflection losses. If the pitch (or period) of a single grating structure is less than the wavelength of the incident light, it behaves like a homogeneous medium with an effective refractive index [3]. Therefore, the SWG structures provide gradual changes in refractive index that ensure an excellent antireflective and light trapping properties compared to a planar or flat type thin film [3-4]. Finite-difference time domain (FDTD) simulation tool is used to design, simulate and analyze the data associated with properties of light transmission, reflection and absorption in the nano-grating structure [5]. For simulations, we have considered triangular, trapezoidal, and rectangular nano-grating shapes. All the nano-grating shapes height is varied during the simulation process in-order to find the best possible result that can capture more incident lights into the GaAs substrate for high conversion efficiency of the solar cells [6].

II. DESIGN OF NANO-GRATING STRUCTURE

In this section, we discuss the nano-gratings shape design and modeling of nano-structured gratings (i.e., SWG structures). The nano-grating shapes are: (i) rectangular, (ii) trapezoidal with different aspect ratios (i.e., 0.1 ~ 0.9), and (iii) triangular. Here, we discussed only the triangular shaped nano-gratings as shown in Fig. 1. For triangular-shaped nano-gratings, the aspect ratio is '0' (i.e., the top length of the trapezoid is zero compared to the base length of the trapezoid). This shape is used for the simulation and analyzed the results for light reflection, transmission and absorption for the SWG structures.

In Fig. 1, there are two lines above the nano-grating structures, such as red and green lines, they represent the incident and reflected lights, respectively. However, in the substrate there are two lines which represent the transmission line 1 and 2. The triangular shaped nano-structured gratings are designed on top of the GaAs substrate.

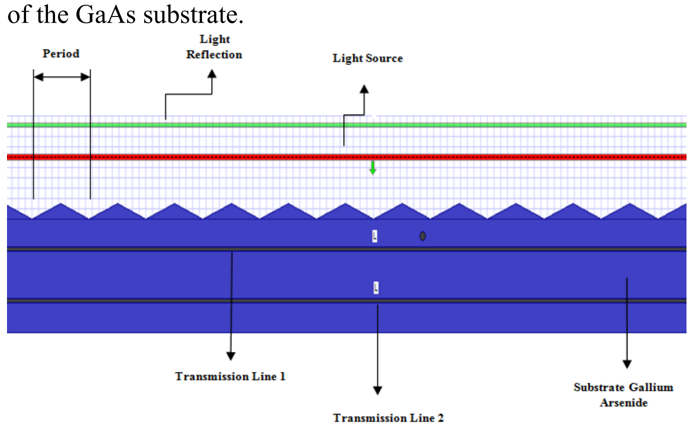

Fig. 1. Schematic diagram of a triangular shaped nano-gratings on top of the semiconductor (GaAs) substrates.

The material Gallium Arsenide (GaAs) is used for the substrate and the nano-grating structure. The incident light directly hits on top of the nano-structure. A major portion of light is absorbed by the nano-grating zone due to the gradual change of refractive index in the nano-grating zone, some portion of the light is reflected and the remaining portion of the light is transmitted through the GaAs substrate. Since the light absorption rate of this nano-grating is high, it provides a steady change in the refractive index and ensuring a phenomenal AR medium alongside a light trapping capacity in comparison to other films. The refractive index change can be calculated using following equation,

$$\frac{n_1}{n_2} = Sin\left(\frac{\theta_2}{\theta_1}\right) = \frac{\lambda_2}{\lambda_1} \qquad (1)$$

where, n_1 and n_2 represents the medium of refractive index. θ_1 and θ_2 represents the angle of incidence and angle of refraction. λ_1 and λ_2 represents the wavelength of incident medium V_1 and refracted medium V_2, respectively. Fig. 2 shows the relationship between the angle of incidence and angle of refraction using Snell's law.

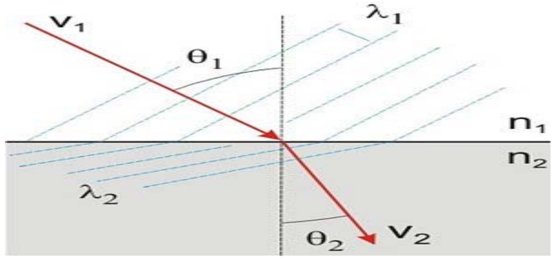

Fig. 2. Relationship between the incidence angle and refraction angle.

III. Simulation Results and Discussion

Fig. 3 shows the light reflection losses spectra for several nano-grating heights (i.e, 100 nm ~ 400 nm) with the period of 830 nm. For this simulation, the incident light wavelength is kept constant at 830 nm. The simulated results show that when the nano-gratings height increases then the light reflection reduces and reaches to the saturation of light reflection at 300 ~ 350 nm. These results show that the nano-grating height is ~300 nm gives minimum light reflection. It has also confirmed that the light refelection for 300 nm and 350 nm grating height is very close. This nano-grating height for light reflection is minimum and it reaches to the saturation, which has the similar tendency as reported [5]. When the nano-grating height decreases further, such as 100 nm, the ligth reflection increases.

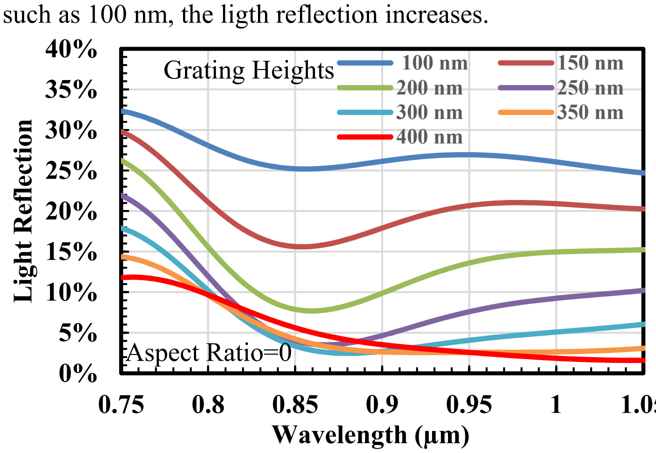

Fig. 3. Light reflection spectra for triangular shaped nano-grating structure with the grating pitch 830 nm.

Fig. 4 shows the light absorption spectra for different nano-grating heights, such as 100 nm to 400 nm. The simulated results show that with the increase of nano-grating heights the light absorption rate increases and reaches the saturation at 300 ~ 400 nm. It also observed that light absorption rate for 300 and 350 nm is very close, at the wavelength 830 nm. As the nano-grating height decreases, the capacity of light absorption also decreases gradually.

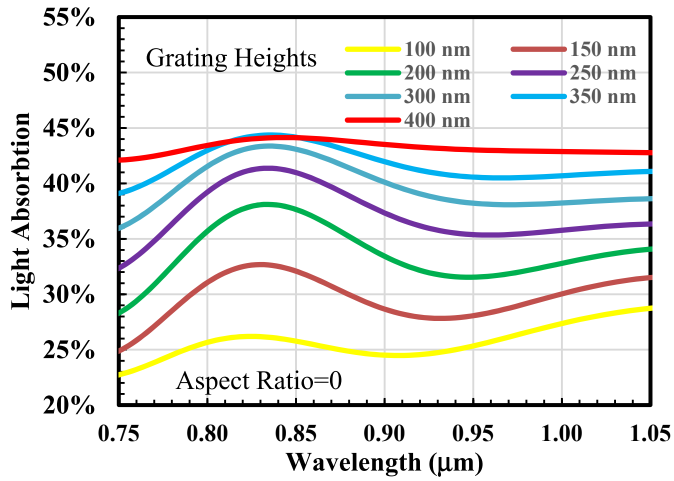

Fig. 4. Light absorption spectra for triangular shaped nano-grating structure with the grating pitch 830 nm.

IV. Conclusion

We have modeled and analyzed the light capturing properties of nano-grating structures with different shapes. For this simulation, FDTD method is used to obtain the results for light transmission, reflection and absorption on GaAs solar cells. It is clear from the simulated results that the triangular shaped nano-gratings absorb more light into the GaAs substrate. This simulation results confirm that the use of nano-grating structure has ~ 27% higher light absorption capacity than the conventional solar cells, hence increase the conversion efficiency of GaAs solar cells. The simulated results are useful for the design and development of high conversion efficiency of GaAs solar cells for a sustainable green earth.

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