Simulation and Optimization of Nano-structured Gratings Alternative of Thin-film Anti-Reflectors for GaAs Solar Cells Conversion Efficiency Improvement

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***Abstract*— Modern civilization demands energy, and the energy demand is increasing almost every day all over the world. The dependency on conventional energy resources including fossil fuel, oil, gas, coal etc. are not in favor of having sustainable global earth. For this reason, renewable or clean energy is one only option while acquiring energy from the abundant sunlight is the best and cost-effective choice. Photovoltaic (PV) panels are widely employed as clean and environmentally acceptable energy sources. However, due to restrictions in PV cells, the sun's full energy cannot be turned into electricity. In this paper, we discuss how to improve the conversion efficiency of GaAs solar cells by optimizing the design and performance of nano-structured gratings. We design, simulate, and analyze the performance of three alternative arrangements of periodic nanostructures with varied pitches and heights using the finite difference time domain (FDTD) approach. Different geometries of nanostructures behave differently towards impinging the light, as the simulation results.**

Keywords*— *Light absorption, Nano-structured grating, Reflection loss, Solar cells, Subwavelength; Aspect Ratio, Conversion Efficiency, FDTD Simulation.

I. Introduction

Alternative green energy sources have become necessary as a result of rising energy demand and the reduction in traditional energy sources, such as fossil fuels. The pollution caused by fossil fuels has increased the value of renewable energy. Photovoltaic (PV) cells have become a proven renewable energy source for generating electricity directly from sun light. The PV cells have various advantages, including being ecologically benign, pollution-free, compact, and noise-free. Despite the growing usage of solar technology in power generation, traditional solar cells have two fundamental drawbacks: poor output efficiencies and high manufacturing costs. Solar panels have a modest efficiency of around 20 ~ 22%. Many recent research studies have focused on increasing the efficiency of solar cells [1-4]. Using solar panels with concentrated PV (CPV) cells is a common way to improve the cell conversion efficiency. The CPV principle focuses on the exceptionally high-efficiency solar cell [5]. The CPV panels are mentioned to have a 46% efficiency, which is more than double that of standard panels. Due to the high cost of CPV panels, ongoing research into alternate materials is being conducted in order to reduce costs while maintaining high efficiency.

However, improving efficiency with the methods described above has little effect on the cost of solar panels. The efficiency and cost of solar cells can both be enhanced by utilising nano-structured gratings. Due to their low reflection losses, subwavelength grating (SWG) structures have recently been the aim for achieving high conversion efficiency in PV solar cells [6]. This study mainly focuses on employing nanostructured gratings to improve solar cell conversion efficiency and reduce light reflection losses. To build, configure, and optimize nano-grating structures that can help in the absorption of higher amounts of light for higher energy conversion efficiency, the Finite-Difference Time-Domain (FDTD) method is used.

II. Background and Motivation

Several elements, including as structural defects and shading resistance, influence the performance of solar cells (primarily conversion efficiency), prompting scientists and researchers around the world to conduct study in this area in order to develop various types of solar cells [1-7]. One of the important qualities that scientists are working to improve for all types of solar cells is light reflection loss. Distinct types of solar cells absorb different light spectrum, resulting in differences in performance and conversion efficiency. However, light reflection losses from the front surface of the panel affect all types of solar cells differently. As a result, several thin-film anti-reflective (AR) coatings have been reported to be utilised to reduce reflection losses, although these AR coatings have limitations in terms of absorbing a certain light spectrum. Furthermore, there are some drawbacks to applying the AR coating, such as thermal and adhesive incompatibility with the substrates, which necessitates a specific material and geometry selection. When compared to a planar or flat type thin film, subwavelength grating (SWG) structures give superior AR and light trapping qualities due to their ability to deliver progressive variations in the refractive index [7-9].

A. Different Types of Nano-grating Structures

Due to nano-grating structures ability to reduce losses caused by light reflection off the front facet of solar cells, the nano-structured grating has been known as an effective technique of improving low efficiency in solar cells. Light reflection loss is the primary issue in decreasing solar

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efficiency [4]. However, there are four types of nano-grating shapes are found in the literature to be used to trap more incident lights inside the substrate to improve the conversion efficiency [8]. By taking control over the light reflection of a solar cell, the control over the efficiency of a solar cell can be achieved.

B. *Method for Nano-Structure Simulations*

The FDTD algorithm, which was first developed in 1966 by K.S. Yee [9] that is at the origin/ heart of the Opti-wave FDTD (Opti-FDTD) simulation software. To solve the partial differential wave equations, the Opti-FDTD software employs second-order numerical accuracy and the most advanced boundary conditions – Uniaxial Perfectly Matched Layer (UPML). Figure 1 shows the optimization workflow and the TF/SF (total field/ scattering field) technique for the incident plane.

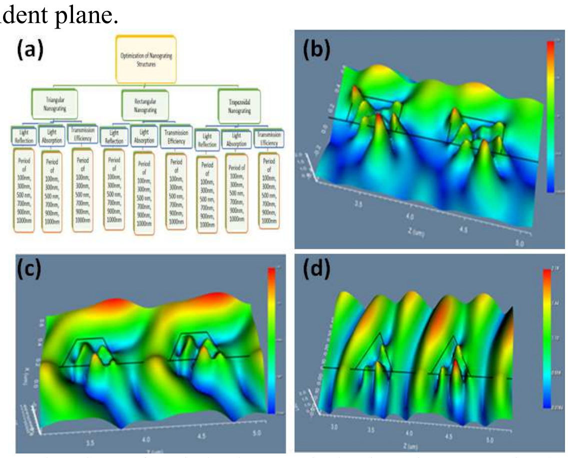

Fig. 1. Flowchart of optimization to obtain the relevant results (a), and images of observation area analysis of different nano-structure gratings (b-d).

III. Results and Observation

Different nano-grating structures, such as triangular, trapezoidal, and rectangular forms, were used in the Opti-wave FDTD simulation. During the simulation procedure, the height and aspect ratio of the nano-gratings are varied to determine the ideal conditions for absorbing maximum incident light into the GaAs substrate for high conversion efficiency solar cells.

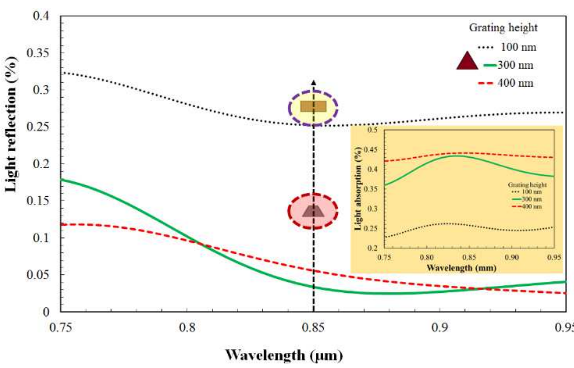

Fig. 2. In comparison to data points acquired in trapezoidal and rectangular shaped nano-grating structures, the best obtained light reflection spectra for triangle shaped nano-grating structures with a grating pitch of 830 nm are provided. The light absorption spectra for a triangle shaped nano-grating structure are shown in the inset.

Fig. 2 shows the best obtained light spectra (i.e., both the reflection and absorption) for the triangular-shaped nano-gratings in the range of wavelengths from 0.75 µm to 0.95 µm. The relationship between nano-grating height and light reflection is confirmed, and this tendency holds for all nano-grating heights, while the amount of reflection saturates in the region of 300 nm to 350 nm. The simulation results reveal that when the nano-grating height is around 300 nm to 400 nm, the light reflection loss is minimal, and when the height is around 300 nm to 400 nm, the absorption rate increases and achieves saturation. From the FDTD simulation performance, it can be concluded that the nano-grating parameters, especially the grating height and width (i.e., period) influence to manipulate the incident light after hitting the solar cell surface, however it is up to a certain limit depending on the nano-grating shapes.

IV. Conclusion

In conclusion, the design, simulation, and analysis of the light catching properties of nano-gratings with various geometrical and form parameters have been proven. When compared to other grating designs, triangular-shaped nano-grating structures can absorb more light into the GaAs substrate than other nano-grating structures. The nano-grating structures played a substantial effect on the light absorption properties as shown in the presented data. Furthermore, nano-grating structures boosted light absorption capacity by 27% over conventional/ traditional solar cells, indicating that GaAs solar cells can improve conversion efficiency as projected. As a result, triangular (i.e., conical or perfect cone)-shaped nano-grating structures have been proven as an excellent alternative antireflective (AR) coating for reducing the light reflection losses and improving the conversion efficiency in GaAs solar cells for a sustainable green future.

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