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Effects of Indium-Phosphide-Oxide on Photon Absorption of Multi-junction Photovoltaic Cells

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Abstract. The objective of the anti-reflective coating on the solar cell has been to reduce the photon reflectance and increase the photon absorption. This increase in light trapping ability of the solar cell increases the maximum photocurrent of the incident solar spectrum. This increase of photon absorption of the cell increases the efficiency of the solar cell. In this paper we have worked on multi-junction solar cell and has shown how the photon absorption changes when we have an anti-reflective coating on top of the cell. The effect of using an anti-reflective coating on the photon absorption of multi-junction photovoltaic cell has been shown with simulation results. Our result shows that with the inclusion of an anti-reflective coating, Indium-Phosphide-Oxide, the photon absorption of the photovoltaic cell increases in the range of 528nm – 710nm of solar spectrum over other current high efficient solar cell.

Keywords: photovoltaic, single-junction, multi-junction, anti-reflective coating, indium-phosphide-oxide.

1. Introduction

A good anti-reflective coating (ARC) is crucial for photovoltaic cell performance since it ensures a high photocurrent by minimizing photon reflectance. Photovoltaic (PV) solar cell operates at a range of wavelengths from 300 – 1100 nm, which means to cover this wide range of wavelengths photovoltaic cell needs a broadband ARC. This ARC reduces photon reflection dramatically compared to bare photovoltaic cell surfaces. Using ARC, the high refractive indices of semiconductors and high reflection losses can be minimized [1] for both Si [2, 3] and multi-junction [4, 5] solar cells. Thus photon absorption would increase greatly enhancing the solar cell efficiency. It is, therefore, essential to optically match the PV cell to the incident medium in which it operates. This necessarily requires the addition of one or more interfaces between the solar cell and the incident medium in the form of ARC [6]. The design of a good ARC must not be based solely on reducing the light reflectance but somewhat make the most of the external quantum efficiency or diminishing the loss of short circuit current due to reflection. In this work, we have shown the effects of using ARC on a multi-junction (MJ) photovoltaic (PV) cell. We have compared the results of the photon absorption, transmission and reflection of the current high efficient MJ PV cell with ARC. We simulated the performance of the cell with an online simulator, PhotnicsRT. After comparing the results of the simulations, we see a dramatic improvement of photon absorption in the range of 528nm – 710nm of solar spectrum of the PV cell InPO/InGaAs/InGaSb. The research carried out by Simon Y. Foo and Indranil Bhattacharya of Florida State University on MJ PV cell showed that the PV cell based on InP/InGaAs/InGaSb has best photon absorption in the range of 598nm-800nm of the solar spectrum [7]. On the other hand, our research shows that the photon absorption is increased significantly when InPO is added replacing InP layer from the cell InP/InGaAs/InGaSb. Thus, reducing the large optical reflection by using a well-designed ARC we increase the photon absorption significantly.

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2. Multi-Junction Solar Cell

MJ solar cells consist of single-junction solar cells piled upon each other so that the band gap of each layer increases from the lowest to the highest layer. Consequently, it absorbs a larger range of photon energies more efficiently over a variety of semiconductor materials. The semiconductor materials convert the photons that have energies greater than band gap of that layer [8]. Thus using multiband-gap system and splitting the solar spectrum towards matched spectral sensitivity we can get higher efficiency of solar cell. There are *N* sub-cells in multi-junction solar cells, each of which is a pn junction electrically connected in series to adjacent sub-cells via tunnel junctions. The efficiency improvement of the multi-junction solar cell rests on the improved use of the wide wavelength of sunlight. Each cell having unlike band gap captivates light at decreasing photon energy from highest to lowest of the cell. With more sub cells extreme efficiency can be obtained. However, this improvement would be carried out with the expense of spectral sensitivity and added complexity due to the requirement for *N-1* tunnel junctions [6].

3. Anti-Reflective Coating

It is important to have a minimum reflection in PV cell over the entire visible spectrum (300 - 1100 nm). A dielectric thin film called ARC is applied to an optical surface to reduce the optical reflectivity of that surface [9]. The coating for a single layer ARC is designed for normal incidence consists of a single quarter-wave layer of a material, also the refractive index of which is close to the geometric mean value of the refractive indices of the two adjacent media [9]. At the time of this situation the two reflections of equal magnitude arise at the two interfaces, and these reflections cancel each other by destructive interference [9]. Since chemical oxides are readily grown on III-V semiconductor materials, the technique of using the grown oxide layer to both passivize the surface as well as serve as the first of a multilayer ARC should work well for essentially all III-V compound-based solar cells [8].

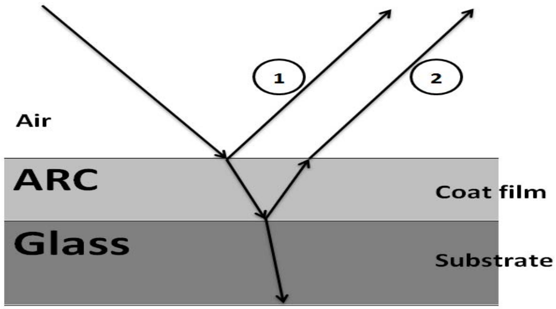

Fig. 1: Single-layer ARC on glass substrate.

According to the procedures for phase change upon reflection, both rays 1 and rays 2 undergo 180° shifts equal to $\lambda_0 / 2$, in the meantime both reflections occur at interfaces separating lower-to-higher refractive indexes. As a result the difference in phase between rays 1 and 2 comes from only the optical path difference due to the coating thickness *t*. Now, if the thickness *t* of ray 2 falls behind ray 1 by $\lambda_{coat} / 2$, the two rays interfere destructively consequently minimizing the reflected light. At near-normal incidence this requires that the distance 2*t*, down and back, equal $\lambda_{coat} / 2$ [10]. The mathematical condition for anti-reflection is then given by

$$2t = \frac{\lambda_{coat}}{2}$$

$$\text{Since, } \lambda_{coat} = \frac{\lambda_{air}}{nf}$$

Thus $t = \frac{\lambda_{air}}{4nf}$, where n_f is the refractive index of the anti-reflective coating.

4. Multi-Junction PV Cell Based on Indium-Phosphide-Oxide/Indium-Gallium-Arsenide/Indium-Gallium-Antimonide

MJ cell based on InPO/InGaAs/InGaSb has shown better photon absorption due to the introduction of ARC. Indium Phosphide Oxide, an anti-reflective was given on top of InGaAs\InGaSb cell. It is known that low bandgap semiconductor materials have better photon absorption. The multi-junction solar cell, InPO/InGaAs/InGaSb having 0.75eV and 0.5eV creates perfect combination of bandgaps. Thus this ideal combination results in better photon absorption of sunlight, therefore, enhance the efficiency of the photovoltaic cell. The inclusion of InPO as the top layer on the InGaAs/InGaSb has shown the best photon absorption in the range of 528nm – 710nm wavelength InPO/InP/InGaAs/InGaSb cell is shown in figure 2.

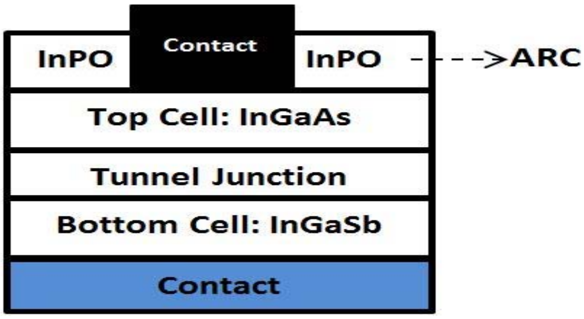

Fig. 2: InPO/InGaAs/InGaSb based three layer multi-junction solar cell designs.

5. Simulation and Results

To analyze the result of the photon absorption, photon reflection and photon transmission of the cell we performed simulations with Real Time Photonic Simulator [11]. The thickness of the ARC was taken to be 100nm Also the thickness of the other layers of the PV cell was taken to be 100nm as well. The cell was exposed in radiation at an angle of 45°. The PV cell based on InPO/InGaAs/InGaSb is exposed in solar radiation of wavelength 400nm – 775nm. After the light passes through the cell the incident light will get reflected, absorbed and transmitted. The aim of our work is to show the effects of the ARC on the photon absorption. We are concerned about the maximum photon absorption and reduced photon reflection. Since higher photon absorption would enable the creation of greater number of mobile holes and electrons. The design of any ARC can be simply characterized by the irradiance, emittance and absorptance of the sources and media in which the ARC will operate.

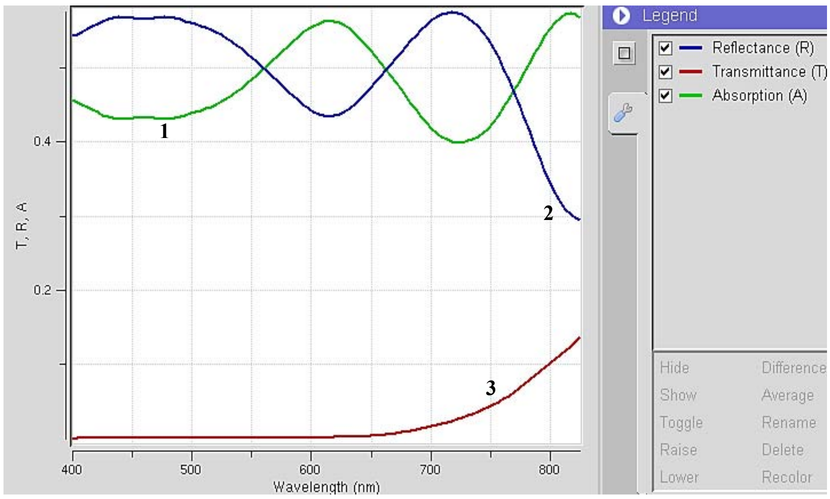

Fig. 3: Reflectance, Transmittance and Absorption of InGaAs/InGaSb at 45° incidence.

In figure 3, the curve 1 represents absorption, curve 2 reflectance and curve 3 transmittance of InGaAs/InGaSb having band gap of 1.1eV and 0.5eV respectively. We examined that the absorption is 45.7%, 43.8%, 55.6%, 56.4% at 400nm, 500nm, 600nm, and 700 nm respectively.

Now, after the application of the anti-reflective coatings on InGaAs/InGaSb cell we examined an impressive improvement of photon absorption. The result of the findings is shown in figure 4.

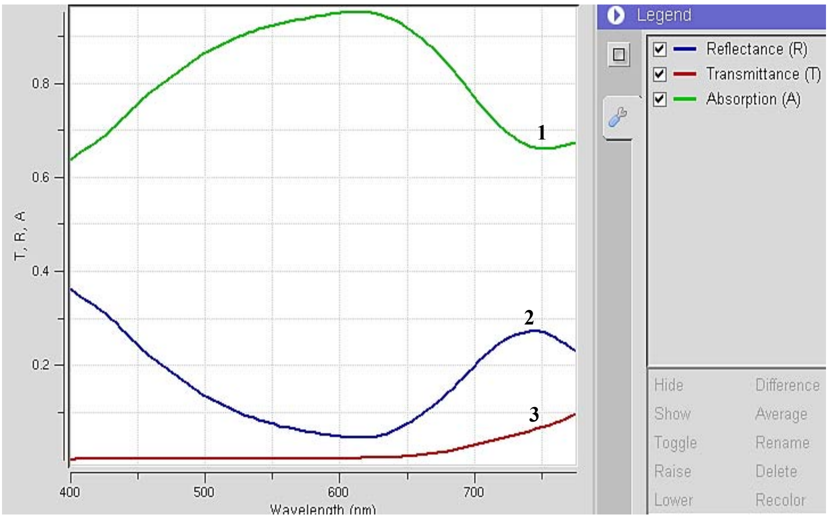

Fig. 4: Reflectance, Transmittance and Absorption of InPO/InGaAs/InGaSb at 45° incidence.

In figure 4, the curve 1 represents photon absorption, curve 2 photon reflectance and curve 3 photon transmittance. InPO/InGaAs/InGaSb having band gap of 1.1eV and 0.5eV respectively accomplishes very high photon absorption. We examined that the absorption is 63%, 86.8%, 94.9%, 75.9% at 400nm, 500nm, 600nm, and 700 nm respectively.

The result of the cell, InP/InGaAs/InGaSb designed by the researchers of Florida State University shows that at 400 nm the photon absorption is 69%, at 500nm 81%, 600 nm 80.2% and at 700 nm 71% [7]. The result of the simulation is shown in figure 5.

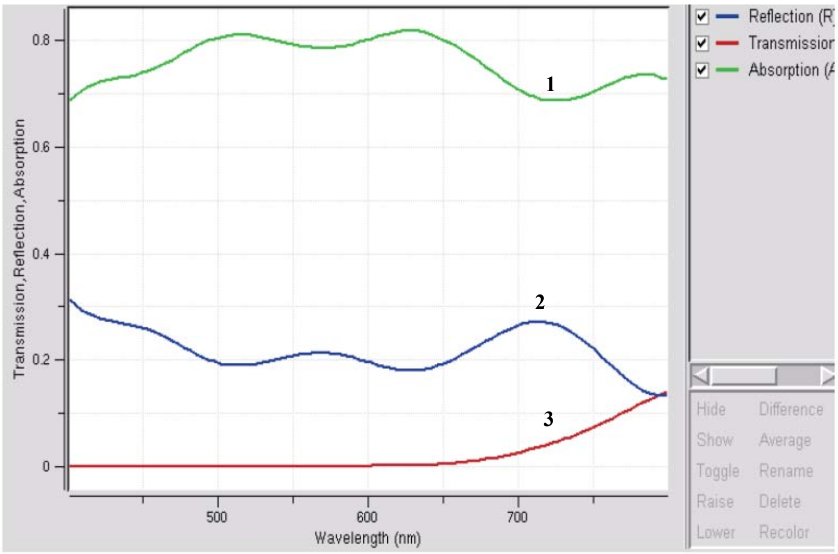

Fig. 5: Reflectance, Transmittance and Absorption of InP/InGaAs/InGaSb at 45° incidence [7].

Analysing the results of all the simulations of different multi-junction cell with and without the ARC we see the cell with ARC, InPO/InGaAs/InGaSb has much better photon absorption. Comparing the photon absorption results of the cell InP/InGaAs/InGaSb with our InPO/InGaAs/InGaSb cell, we see that our cell has best photon absorption in the range of 528nm – 710nm against the cell InP/InGaAs/InGaSb. Thus it shows that the addition of ARC has significantly improved the photon absorption of the MJ PV cell. With this significant improvement of the photon absorption we see the PV cell based on InPO/InGaAs/InGaSb performs well in solar photon absorption thus increasing photocurrent hence efficiency.

6. Conclusion

The use of an ARC, Indium-Phosphide-Oxide, on the MJ cell has shown to increase the photon absorption. The minimization of the optical loss contributes to higher cell efficiency. The triple junction cell designed by the researchers at Florida State University showed the best photon absorption in the range of 598nm – 800nm of the solar spectrum. However, with the application of ARC the photon absorption can be increased further contributing to much higher solar cell efficiency. The photon absorption of our three layer InPO/InGaAs/InGaSb shows 63%, 86.8%, 94.9%, 75.9% at 400nm, 500nm, 600nm, and 700 nm which is better in comparing to the cell InP/InGaAs/InGaSb. The MJ PV cell based on InPO/InGaAs/InGaSb has much better photon absorption in the range of 528nm – 710nm of the solar spectrum. Thus, in this paper we have shown how the photon absorption changes with the application of ARC on MJ PV cell.

7. References

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