Numerical simulation of high-efficiency InGaP/GaAs/InGaAs triple-junction solar cells grown on GaAs substrate

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Abstract

The structure parameters and illumination condition for InGaP/GaAs/InGaAs triple-junction solar cells grown on GaAs substrate have been numerically studied to search the optimal point of device performance. The dependences of conversion efficiency, I-V curves, and band diagram on the structure parameters and illumination condition have been investigated. Our work shows that the performances are largely dependent on the geometric design of device and the optimal parameters are extracted

I. Introduction

Multi-junction solar cell based on group III-V semi-conductor material system use multiple subcell band gaps to divide the broad solar spectrum into smaller sections, each of which can be converted to electricity more efficiently. And it is a promising photovoltaic device to utilize solar energy not only because of its high conversion efficiency, but also it can be applied under cheaper concentrated sunlight optical system to achieve higher efficiency and reduce the cost per unit area at the same time[1].

In this paper, the InGaP/GaAs/InGaAs triple-junction solar cells on GaAs substrate are numerically investigated. The electrics characteristics such as I-V curves, efficiency and physical quantities like band diagram are analyzed under different illumination condition.

II. Simulation models

The basic Poisson equation and drift-diffusion current continuity equations for electrons and holes are included in the simulator to calculate the electrical characteristics of the device. The ray-tracing model and optical generation-recombination term in the continuity equations are used for optical simulation[2]. Meanwhile, the flexible carrier mobility model and advanced Zener type tunneling model are introduced to simulate the behavior of the device for more accurate results compared to reality.

The structure discussed in this study is composed of three junctions, as shown in Figure 1. Each junction is consist of an n-type emitter layer and a p-type base (absorber) layer between the passivating window layer and back surface field layer (BSF, and the bottom junction has no BSF). Two tunnel junctions, which are all high doped and only 20 nm thick, are connecting the junctions for better current transferred. The transparent InGaP grading layer is used for lattice match.

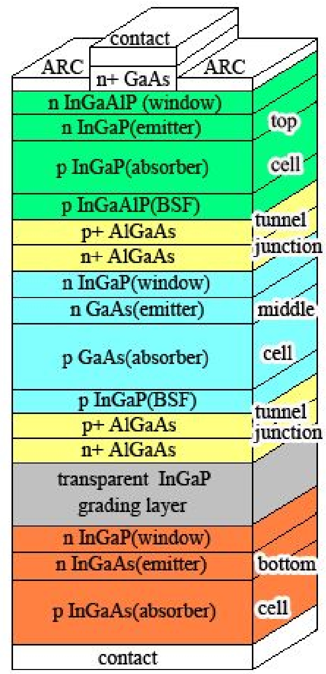

Figure 1. Schematic of InGaP/GaAs/InGaAs triple-junction solar cells

The thickness and doping of each layer is referred to Ref[3]. During the simulation, some crucial parameters, such as the thickness and doping of absorber layer are varied with illumination condition. Then the photoresponse curve and some other properties of the solar cells are calculated to study the performance of the device and find the optimal parameters for operating.

III. Result And Discussion

Figure 2 shows that the conversion efficiency changes with the thickness of p-type InGaAs(bottom cell) absorber and different illumination. The efficiency rapidly grows as the thickness of p-type InGaAs absorber increases at first. Then the efficiency stays at almost the same level regardless of the

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change of thickness. The result of p-type GaAs absorber (not listed here) shows a similar trend. Meanwhile, before the concentration level reaches about 200 suns, more light power is provided to the device, more conversion efficiency is acquired. The reason of this phenomenon is that when the absorber layer is thick enough to absorb the incident light, the efficiency can reach its maximum values.

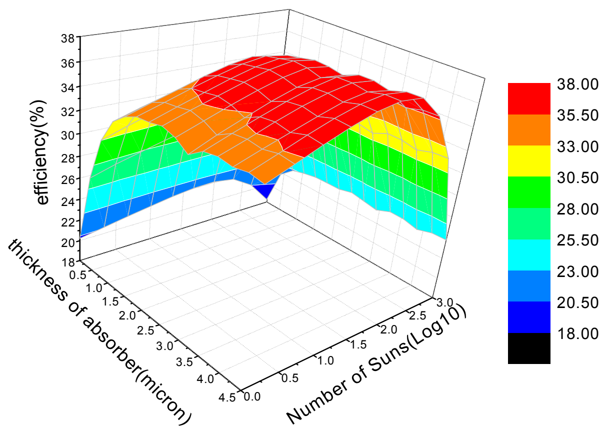

Figure 2 Conversion efficiency with the p-InGaAs absorber thickness changing from 0.1 to 4.5µm and concentrated condition from 1 sun to 1000suns (AM1.5G).

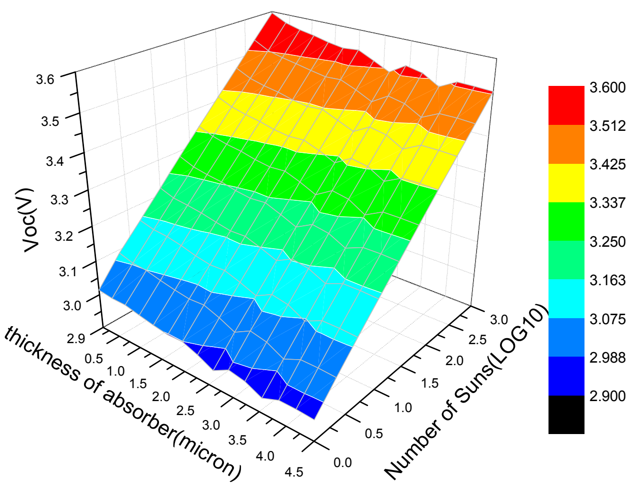

Figure 3 Open-circuit voltages with the p-GaAs absorber thickness changing from 0.1 to 4.5µm and concentrated condition from 1 sun to 1000 suns (AM1.5G).

Figure 3 shows that the open-circuit voltage goes down slightly with the augment of the thickness of middle cell p-type GaAs absorber and increases logarithmically with concentration. Similar results can be obtained with the different thicknesses of bottom cell p-type InGaAs or top cell p-type InGaP.

The whole open-circuit voltage is the sum of the individual values of each junction, which is the interval of quasi-Fermi levels for electron and hole respectively[4]. So the thickness of absorber layer has little effects on the electrical value reflects that the band diagram is not observably changed with the geometric structure. As the concentrated sunlight enhances, the generation rate in the junction increases and the interval of quasi-Fermi levels for electron and hole is widened. As a result, the open-circuit voltage grows logarithmically.

IV. Conclusion

The photoresponse and performance on the geometric design of device and illumination condition have been numerically simulated with the APSYS simulator from Crosslight Software Inc. The simulation results show that the thickness of absorber layer of each junction and concentrated sunlight have an important effect on both photoresponse and performance of the solar cells. In order to achieve the highest conversion efficiency, a illumination condition of 200~500 suns is optimal since higher concentration does not bring better performance. The p-type absorber layer is the most crucial part of each junction of the solar cell. Considering the process and cost of fabrications, the thicknesses of 2.7, 2.2, and 0.9µm for bottom, middle, and top junctions is thick enough to utilize the solar energy and no more materials are necessary.

Acknowledgements

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