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Improvement of Quantum Efficiency and Reflectance of GaAs Solar Cell

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Abstract—In this work authors presented improvement performance of GaAs solar cell of antireflection coating and texturing using PC1D simulation. About 32.58% light reflect from a bare GaAs surface and giving external quantum efficiency about 67.32%.This paper presented the improvement of external quantum efficiency (EQE) of GaAs solar cell about 14.23% using antifriction coating (ARC) of Silicon-di-Oxide (SiO2) with refractive index 1.55 at thickness 121 nm and about 14.77% using ARC of and Indium Tin Oxide (ITO) with refractive index 1.92 at 100 nm. The structure of SiO2/GaAs is showing reflectance about 4.370% and the structure of ITO/GaAs is showing reflectance about 0.0087% based on AM1.5 photon flux from 300-1200nm. Further EQE can be improved about 1.62% using SiO2 ARC and 2.56% using ITO ARC with deposition of 5-10 nm front surfaces texturing over ARC by texturing angle of 54.740. Combination of ARC and texture improve the reflectance about 4.36%.

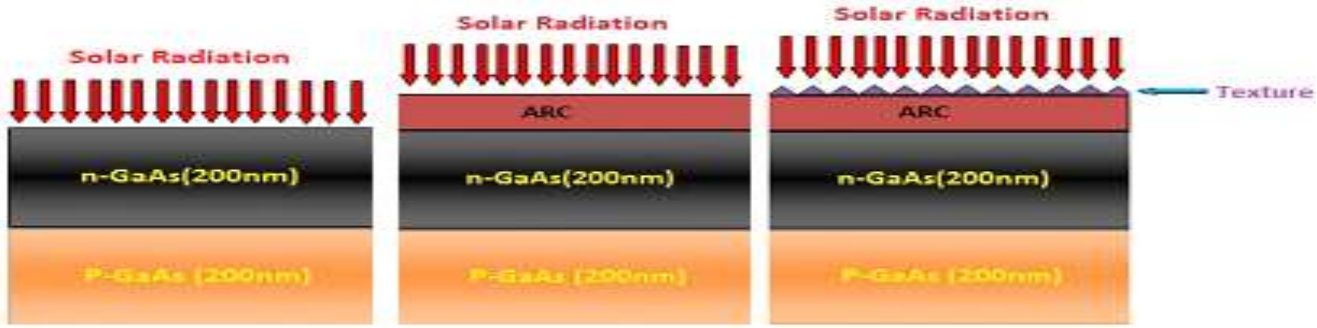
Keywords—Solar cell; ARC; PC1D; ITO; Texture; Reflectance; Efficiency; SiO2; Refractive Index.

INTRODUCTION

One of the main barriers of solar cell efficiency is reflection of light from front of its surface. A bare silicon surface reflects the light about 30% and GaAs reflect the light about 32.58% light from their front surface. GaAs-based solar cells have attracted much interest because of their high conversion efficiencies of ~29.1%-40% under one sun illumination [5,6,7]. However, they are too expensive for terrestrial large-area applications because of the high device fabrication cost and the availability of relatively rare elements (In, Ga) [4]. The reflection of light from GaAs surface is over 32% due to its high refractive index. The reflectivity, R, between air and *GaAs* surface is determined by Fresnel reflection using equation.1. One of the main barriers of solar cell efficiency is reflection of light from front of its surface. A bare silicon surface reflects the light about 30% and GaAs reflect the light about 32.58% light from their front surface. GaAs-based solar cells have attracted much interest because of their high conversion efficiencies of ~29.1%-40% under one sun illumination [5,6,7]. However, they are too expensive for terrestrial large-area applications because of the high device fabrication cost and the availability of relatively rare elements (In, Ga) [4]. The reflection of light from GaAs surface is over 32% due to its high refractive index. The reflectivity, R, between air and GaAs surface is determined by Fresnel reflection using equation.1.

DEVICE STRUCTURE

In this paper we have simulated texturing and ARC layer structure consisting of SiO_2, ITO and GaAs p-n junction. SiO_2 is an excellent material which transmits light about 97% in visible spectrum range is achieved for few nm thin films [1,17]. Indium tin oxide (ITO) film has been widely used as transparent conducting material in many electronic and optoelectronic devices such as flat panel display, anti-reflection coating, solar cell and heat mirror for its high transmission in visible light range and high conductivity property[9,13,14]. By iteratively varying the thicknesses of the ARC layers, we were able to establish an optimized structure with respect to the total reflectance. Hence we estimated the obtainable short circuit current (Jsc) and EQE of GaAs solar cell. Solar cell structure of GaAs with bare surface, with ARC and with ARC/texture is shown in Fig. 1.



Solar cell structure of bare surface, with ARC and with ARC/texture

In this study, a GaAs solar cell based on PC1D simulations has been carried out. The structure of simple p-n junction was selected for all simulations. This choice was made due to the excellent results obtained from this structure. This structure is the simplest structure, most widely used method, is highly accurate and can be adapted for all types of solar cells. PC1D has been chosen as a simulation tool for this research regarding its user-friendly system. PC1D is the most common and perhaps simplest simulation software. The process parameters can be adjusted by choosing the appropriate layers in the schematic diagram of the device.PC1D is usually used for solving the one-dimensional semiconductor equations based on Shockley–Read Hall recombination statistics (Shui-Yang *et al.* 2009). Based on these considerations, PC1D was chosen to describe GaAs solar cell of antireflection coating and texturing in this study [15].

SIMULATION

In this work a homo-junction of GaAs has chosen to simulate ARCs and texture structures and calculate their reflectance spectra and External Quantum Efficiency (EQE). The ARCs structures were simulated on 5-125 nm thin films of SiO_2 and ITO. The texturing depth was simulated on 5-10 nm. List of the parameters used in simulation are given in TABLE I.

We have considered that there is no surface recombination, no surface charge, no internal shunt element for simplicity [3]. The solar structure without ARCs, with ARCs and texturing are shown in the Fig.1.

LIST OF PARAMETERS USED IN SIMULATION.

Parameters	Value
Device area	100 cm2
Thickness of p- GaAs	200 nm
Thickness of n- GaAs	200 nm
p- type background doping	1×1018 cm-3
n- type background doping	1×1018 cm-3
Others parameters	From internal model of PC1D
Excitation mode	Transient
Temperature	25˚c
Primary light source	AM1.5D spectrum
Wavelength range	300-1200 nm

ARC MATERIAL WITH THEIR THICKNESS AND REFRACTIVE INDEX

ARC	Thickness	Refractive Index
SiO2	5-125 nm	1.55
ITO	5-125 nm	1.92

RESULTS AND DISCUSSION

When n-GaAs/p-GaAs simulated without any ARC and texturing with 0% front surface reflection, the results are showing that EQE is about 99.85% in violet and blue range and decrease exponentially to invisible range, because most of the light of 300-500 nm wavelength are absorbed and penetrate deeper into the semiconductor in this range of wavelength. When we assume that reflection is about 32.58%, EQE decreases about 32% in the same range, because of few photon energy absorbed by the semiconductor. Electric field increases rapidly from 185 nm of depth about 53kv/cm, because of carrier extraction of photon energy and higher charge density near the depletion region and electric field decreases linearly from 216 nm. Total current density increases at depletion region as electron current density increases. By using the parameters listed in TABLE I and TABLE II with 32.58% reflection, the simulation results have been shown in the following Figures. The Fig.2., Fig.3. and Fig.4. are showing the energy band diagram, electric field and charge density of GaAs solar cell respectively. Fig.5. and Fig.6. are showing current density and base current & power without any ARC and texturing.

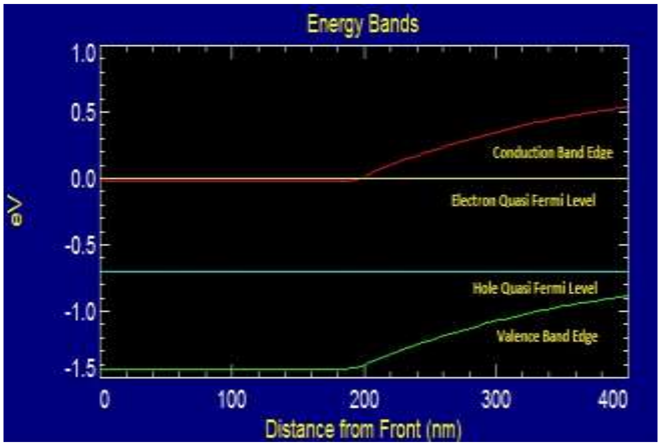


Fig.2 Energy band diagram of GaAs solar cell without any ARC and texture.

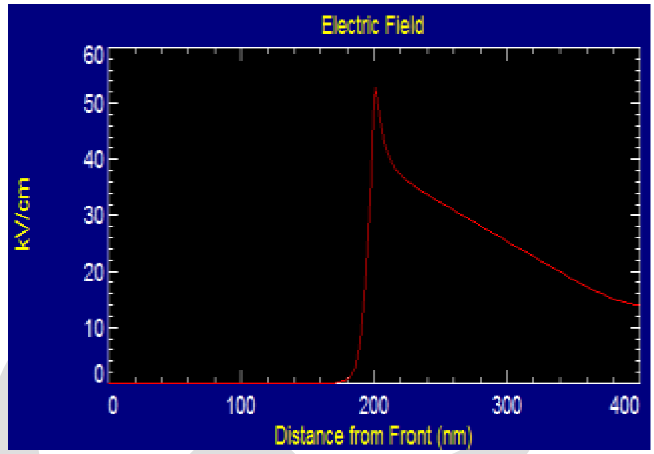


Fig. 3 Electric field of GaAs solar cell without any ARC and texture

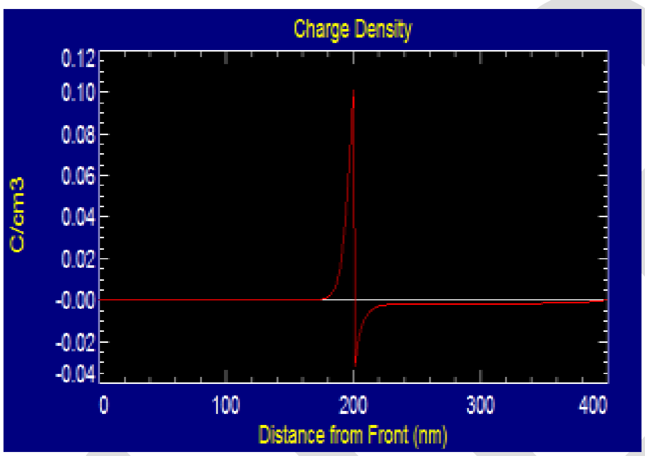


Fig. 4 Charge density of GaAs solar cell without any ARC and texture.

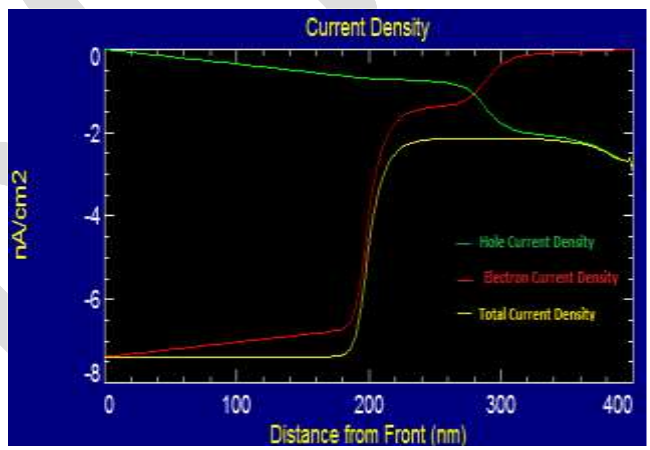


Fig. 5 Current density of GaAs solar cell without any ARC and texture.

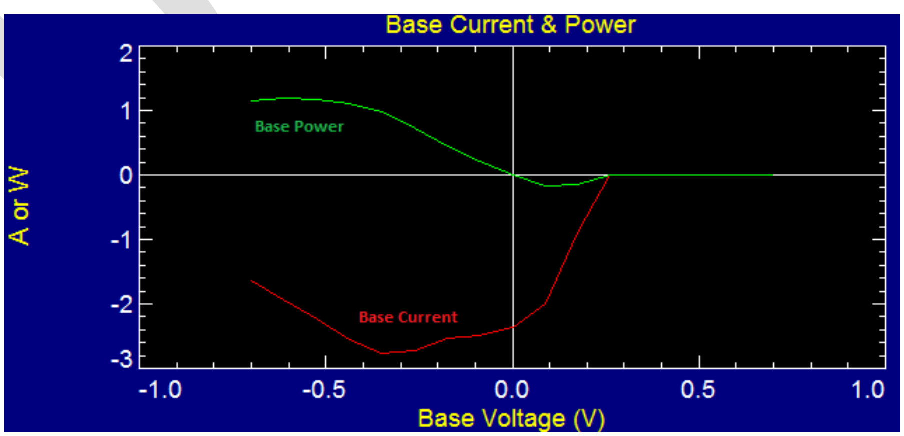


Fig. 6 Base current & power of GaAs solar cell without any ARC and texture.

SiO_2 ARC and SiO_2 ARC /texture

Deposition of SiO_2 ARC on top of surface, initially current density increases linearly from 5 nm to 121 nm thickness of SiO_2 and after that current density get saturated. Further increasing the thickness of SiO_2 above of 123nm, current density again starts to decrease linearly. The thickness of SiO_2 ARC between 121-123 nm shows the best solar cell structure which gives EQE about 81%.Further deposition of 5 nm texturing over the SiO_2 ARC increases the EQE about 2%.The reflection of light without any ARC and the reflection of light after deposition of SiO_2 have been shown in Fig.6. EQE of GaAs solar cell of 32.58% reflection, EQE of SiO_2 ARC structure and EQE of SiO_2 ARC/texture structure are shown in Fig.8.

Initially reflection increases in the middle of violet range and after that reflection decreases rapidly upto red range. The reflection of light again starts to increase in higher wavelength range. The reflectivity of SiO2 ARC has shown in Fig.7.

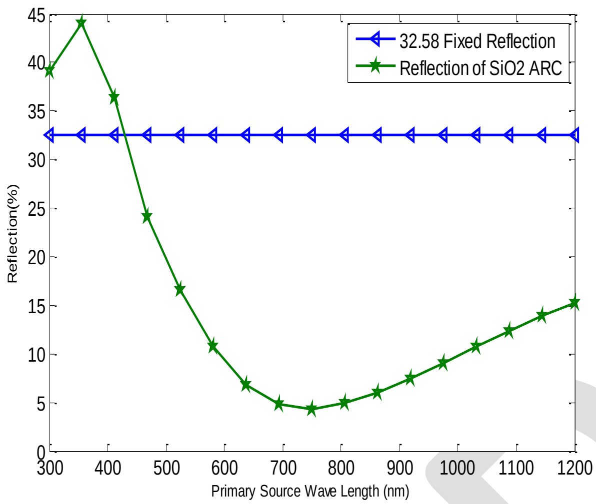


Fig.7. Reflectivity of SiO2 ARC

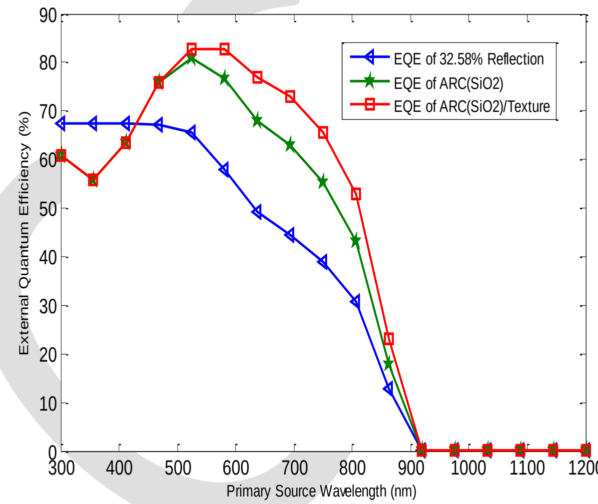


Fig.8. EQE of 32.58% reflection, EQE of SiO_2 ARC and EQE of SiO_2 ARC/texture

ITO ARC and ITO ARC /Texture

The simulation of GaAs solar cell with deposition of ITO ARC structure on the top of the surface shows that initially most of the light below of the violet range reflected by ITO surface and the pri-surface total reflection reaches to 44.84%. After violet range of light reflectivity decreases linearly and reflectivity can be decreased about 0.008135% at red range. The best structure of ITO ARC obtained at 100 nm thickness and gives the EQE about 82.09%. Further, deposition of 5 nm depth of texture over ITO ARC increases the EQE about 2.56% at yellow range. Reflectivity of ITO ARC compared to 32.58% reflection has shown in Fig.9. The EQE of GaAs solar cell of 32.58% reflection, EQE of ITO ARC structure and EQE of ARC/texture structure are shown in Fig.10.

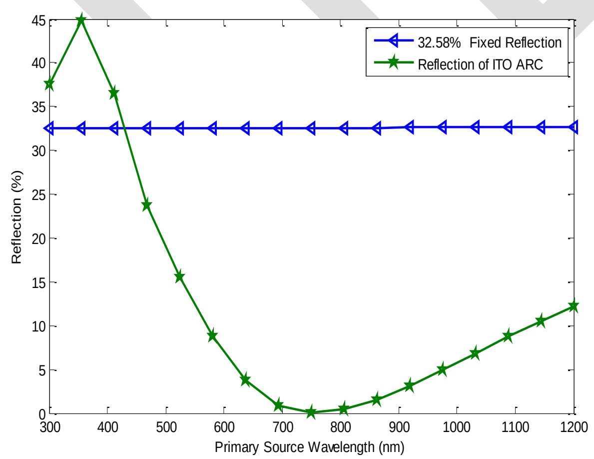


Fig.9. Reflectivity of ITO ARC

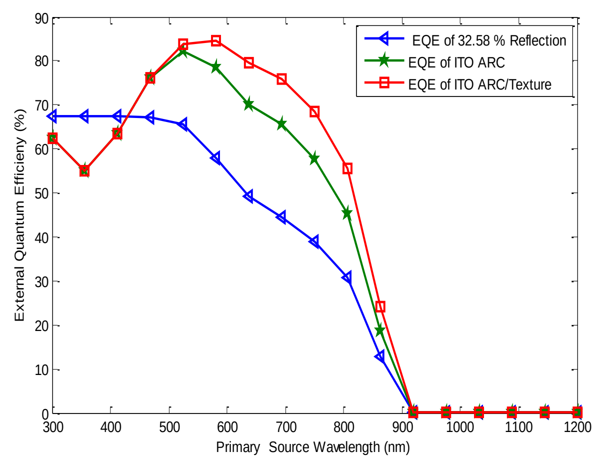


Fig.10. EQE of 32.58% reflection, EQE of ITO ARC and EQE of ITO ARC/texture.

In the both cases of ARC, the short circuit current (Jsc) increases due constructive interference property of light. Constructive interference properties of light shows that different waves of light added to each other and increase the amplitude of resultant light wave which in turns increases the short circuit current (Jsc) in solar cell. Similarly short circuit current (Jsc) may be decreased due to destructive interference property of different light waves [16]. The best structures of GaAs solar cell of our simulation have shown in table III.

THE BEST STRUCTURE OF SIO2 ARC AND ITO ARC.

Material	Thickness of ARC	Maximum EQE without Texture	Jsc(A) without texture	Maximum EQE with Texturing of 5 nm depth	Jsc(A) with texturing of 5nm depth
SiO_2	121 nm	81%	3.340	83%	3.962
ITO	100 nm	82.09%	3.491	84.65%	4.142

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CONCLUSION

In this paper, Authors presented a fundamental optical analysis framework for designing light reflection schemes of thin film SiO_2 and ITO ARC structures for a GaAs solar cell. The improvement of External Quantum Efficiency (EQE) of GaAs solar cell was calculated for both cases of ARCs. The reflectivity of SiO_2 and ITO of different thickness give the idea about the properties of these two materials in the presence of light. The EQE gives the idea about the designing of GaAs solar cell by antireflection coating on the top of the surface. Quantum efficiency of solar cell depends on photon absorption co-efficient of solar cell materials. Result shows that transmission of photon energy through SiO_2 ARC increases from 5nm and 121 nm. Most of the incident light energy passes through SiO_2 layer and absorbed by GaAs solar cell. Only 4.370% light reflected back from the surface. Therefore an optimized structure of SiO_2 ARC was obtained at 121 nm thickness for 81% EQE. Similarly, an optimized ITO ARC can be obtained at 100 nm thickness for 82.09% EQE. Almost all of the incident light energy passes through ITO and absorbed by GaAs solar cell. Therefore, it was observed that ITO shows higher transparency property than a SiO_2 ARC which was expected. Further improvement of EQE of GaAs solar cell was also calculated after deposition of texturing over the surface. The deposition of ARC and texturing on top of the surface are showing very encouraging results about GaAs solar cell. Further, an optimization of presented result is needed to improve the perfomance of GaAs solar cell, though the simulation results are showing a higher improvement in the performance of GaAs solar cell.

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