Available online at www.sciencedirect.com

ScienceDirect

Materials Today: Proceedings 3 (2016) 2463–2467

materialstoday: PROCEEDINGS

www.materialstoday.com/proceedings

Recent Advances In Nano Science And Technology 2015 (RAINSAT2015)

Design and analysis of GaAs thin film solar cell using an efficient light trapping bottom structure

S. Saravanan[a], T. Krishna Teja[a], R. S. Dubey[a,*], S. Kalainathan[b]

[a]*Advanced Research Laboratory for Nanomaterials and Devices, Department of Nanotechnology, Swarnandhra College of Engineering and Technology, Seetharampuram, Narsapur-534280 (A.P.), India*
[b]*School of Advanced Sciences, VIT University, Vellore-632014, (T. N.) , India*

Abstract

Due to reduced thickness of absorbing region, thin film solar cells have weak absorption of incident light and hence, low conversion efficiency. In this scenario, light trapping mechanism is demanded which includes textured top layer, distributed Bragg reflector, metal based nanoparticles/thin films, diffraction grating etc. Presently, GaAs thin film solar cells has limited absorption in an infrared region and so needs attention to address this issue. In this work, we propose a design of GaAs thin film solar cell of thickness 500 nm with silver nano grating which is integrated at the bottom. The designed solar cell showed strong field due to supported plasmonic effect. An enhancement in short-circuit current density i.e. 24.79 mA/cm^2 and 27.15 mA/cm^2 has been obtained for TE and TM polarizations.

*Keywords:*Solar cell; Light trapping; Plasmonic; Diffraction; Grating;Absorptions

* Corresponding author. Tel.:+91-970-156-8383; fax: +91-881-424-0443.
*E-mail address:*rag_pcw@yahoo.co.in

1. Introduction

In recent years, solar cells have become thrust area of research and development due to their reduced active layer thickness. As thin absorbing layer provides poor absorption and hence, novel optical engineering scheme has been demanded which includes patterned structures, metal nanoparticles, diffraction grating, distributed Bragg reflector (DBR) at the bottom of silicon solar cell etc. These techniques are centre of attention because of their effective scattering and coupling of incident light into fundamental layers.The metallic/dielectric grating structure based solar cells provide significant enhanced absorption because of the coupling of plasmonic or photonic guided mode resonance in absorber region [1]. An anti-reflection coating layer is one of easiest way to prevent the incident photons in solar cells. In semiconductor materials, GaAs have been used for optoelectronic device applications in photo detectors, image sensor, lasers, solar cells etc. This material is promising one or solar cell application due to their reduced reflection losses and high performance.

Wang et al. have proposed an ultrathin planer absorber structure with plasmonic resonance absorption enhancement and compared the optical absorption of TE and TM polarization modes. In TM polarization mode ~90 % enhanced absorption at normal incident wavelength was observed [2]. Munday et al. have reported a modeling of ultrathin solar cell structure with various combinations of grating structures and explored the analysis of wave guiding, dispersion and localized plasmonic effect. The optimized solar cell design could yield enhanced absorption due to the localized resonance mode [3]. Callahan et al. have reported a design of solar cell structure and investigated the local density of optical states (LDOS) as a key criterion which exceeded the ray optic light trapping limit [4]. An efficient light trapping structure could contribute in the enhancement light absorption. In this paper, we propose a solar cell design which is composed of an anti-reflection coating (ARC) layer of Si_3N_4, a active layer of GaAs and a grating structure of silver (Ag). Due to plasmonic effect, we have noticed enhanced light absorption in longer wavelength of solar spectrum. Section 2 presents the design and simulation approach and results & discussion is summarized in section 3. Finally, section 4 concludes the paper.

2. Design and Simulation Approach

The proposed design of GaAs solar cell structure is shown in figure 1. The optical modeling is performed by using finite difference time domain (FDTD) method which is widely used to solve complicated optical equations In this method space and times are divided into a grid levels (individual) and simulated time evaluate in electromagnetic fields. To perform simulation, perfect match layer (PML) condition was applied in z-direction while periodic boundary condition (PBC) was performed in x and y- directions.

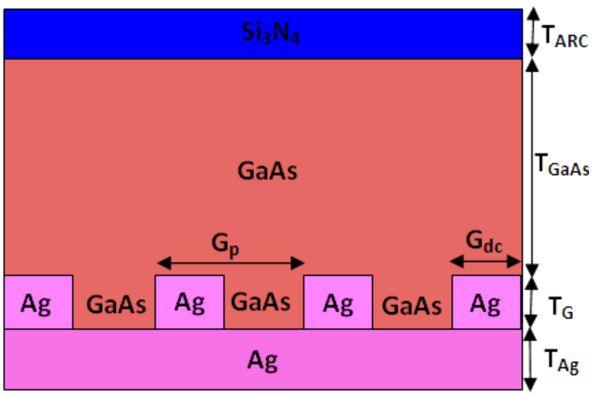

Fig. **1.** Schematic diagram of the GaAs solar cell structure.

As shown in above schematic diagram, GaAs solar cell consists of thin layer of anti-reflection coating with thickness 70 nm, a GaAs active layer of thickness 500 nm as absorbing region, silver grating with thickness 160 nm and width 150 nm and a bottom Ag layer of 335 nm.

3. Results and Discussions

Figure 2 shows the variation in short-circuit current density as a function of anti-reflection coating layer thickness from 0 to 100 nm. The purpose of the optimization of ARC layer was to analyze the reflection behavior of incident light through it, which is also a primary concern for any solar cell.

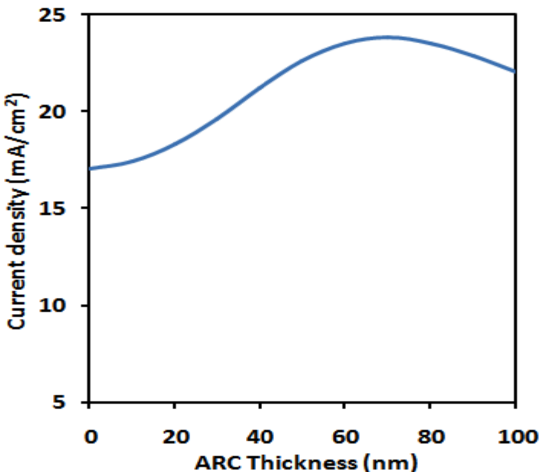

Fig. 2.Short-circuit current density (Jsc) as a function of ARC thickness under AM 1.5G condition

An exponential increment of short-circuit current density can be noticed in accordance to ARC layer thickness. The maximum obtained short-circuit current density ~ 24 mA/cm^2 at 70 nm ARC layer thickness was observed which further found to be reduced beyond 70 nm.

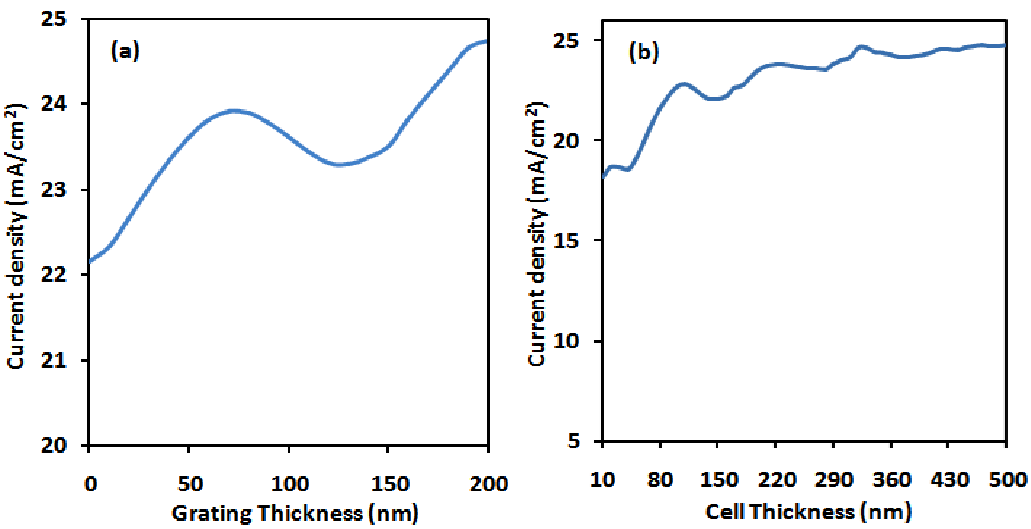

Fig. 3.Short-circuit current density (Jsc) in accordance to (a) grating thickness. and (b) cell thickness

Figure 3 depicts short-circuit current density as a function of grating thickness and cell thickness. The maximum short-circuit current density ~25mA/cm^2 can be observed at grating thickness 200 nm as shown in figure 3(a). Figure 3(b) shows short-circuit current density variation in accordance to cell thickness from 0 to 500 nm. As the cell thickness increased the short-circuit current density was also increased gradually. To validate the assumed value of ARC and cell thicknesses, we have plotted figure 3(a) and 3(b) and observed better performance at ARC thickness 70 nm and at 500 nm cell thickness. This indicates the assumed value of ARC and cell thicknesses were appropriate.

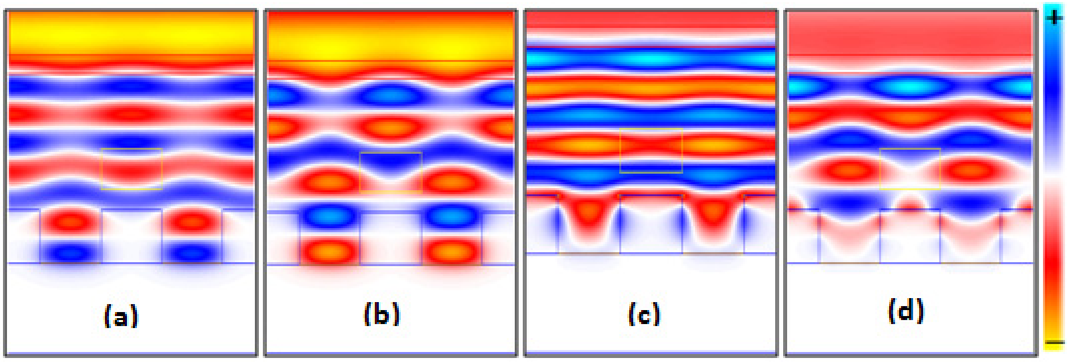

Fig. 4. Electric and Magnetic field profile of GaAs thin film solar cell at respective wavelength

Figure 4 depicts the electric and magnetic profile of GaAs solar cell at different wavelength. The field profile is in cyan, blue, white, red and yellow colors represent electric field interaction with in the solar cell device. Cyan and blue colors are representing high electric field intensity, bright white color represents the guiding mode resonance (GMR) and yellow color shows the low interaction field. At wavelength 799 nm enhanced electric field with guided wave can be observed in figure 4(b) however, it is less as shown in figure 4(a). Figure 4(c) and 4(d) depicts magnetic field profile at 740 and 799 nm wavelengths respectively.

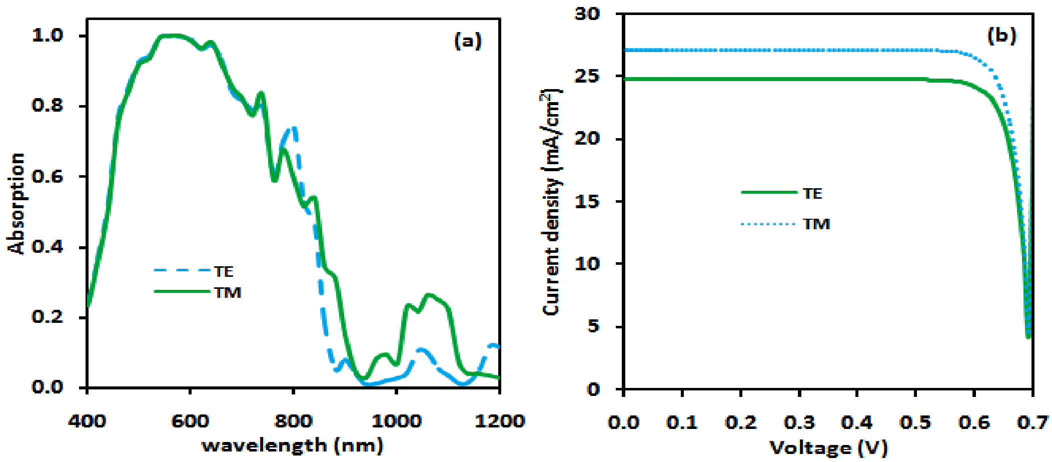

Fig. 5. Absorption spectra of.(a) and J-V curve fig.(b) GaAs solar cell for both TE and TM polarizations.

We can observe intense field at the top of the Ag grating which represents Fabry-Perot (FP) like resonance. FP like resonance can be seen within metal grating regions with cyan and blue colors which shows the plasmonic effect.

At the edge of Ag grating, plasmonic effect is clearly visible as shown in figure 4(b) plotted in wavelength 799 nm. In general, the absorbed photons generate an electron-hole pair and get surface guiding mode resonances (GMR). To improve the light absorption in active region an efficient trapping and coupling of light is required. The use of metal (Ag) gratings at bottom can effectively enhance the light absorption due to scattering and coupling of photons. By this way surface plasmon and surface plasmon excitation can be generated which helps to increase photon path length and residing time. Figure 5(a) shows absorption spectrum for TE and TM waves. The absorption studied here is limited to the active (semiconductor) region only. The absorption peaks of TM waves observed at various wavelengths is attributed to the FP like resonance. As comparison to TE case, TM curve shows an enhancement in light absorption in longer (IR) spectrum of light. Figure 5(b) shows the short-circuit current densityversus voltagefor TE and TM polarizations. The remarkable enhanced performance can be observed for transverse magnetic field. The optimized design of GaAs solar cell could produce high performance due to use of an efficient light trapping structure which is integrated at the bottom.

4. Conclusions

We have demonstrated a design of GaAs solar cell with an efficient light trapping structure. The absorption in 500 nm thick GaAs layer was remarkably found to be improved for both transverse electric and magnetic polarizations. The validation of assumed values of ARC and grating thickness were performed and found appropriate. Overall, the optical performance of GaAs solar cell was enhanced in longer wavelength ((IR) of solar spectrum. The obtained cell efficiency and short-circuit current density were found to be 16.3 % & 17.85 % and 24.79 mA/cm^2& 27.15 mA/m^2 for TE and TM polarizations respectively. Finally, the presented designing approach would be helpful to achieve light weight and low cost GaAs solar cell.

Acknowledgments

The financial support provided by Defence Research and Development Organisation (DRDO), New Delhi, INDIA is highly acknowledged.

References

[1] R.S. Dubey, S. Saravanan, S. Kalainathan, M. A. More and D. K. Gautam “Design and Optimization of Ultrathin Crystalline Silicon Solar cells using an Efficient Back Reflector” AIP Adv., 5, 057160-1-9 (2015).

[2] Zhu Wang, Thomas P. White, and Kylie R. Catchpole “Plasmonic Near-Field Enhancement for Planar Ultra-Thin Photovoltaics” IEEE, 5 (5), 8400608 (2013).

[3] Jeremy N. Munday and Harry A. Atwater “Large Integrated Absorption Enhancement in Plasmonic Solar Cells Combining Metallic Gratings and Antireflection Coatings” Nano Lett. 2195-2201 (2010).

[4] Dennis M. Callahan, Jeremy N. Munday, and Harry A. Atwater “Solar Cell Light Trapping beyond the Ray Optic Limit” Nano Lett.214-218 (2012).