Absorption Enhancement of GaAs Thin Film Solar Cell using Hemisphere Core-shell Nanoparticles

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Abstract— **A novel design of GaAs solar cell (SC) is proposed and analyzed. Hemisphere core shell structures are placed over the surface of the SC to harvest more energy and increase the solar cell efficiency. The GaAs and GaSb are used as core/shell materials to increase the wavelength coupling between the dual cores of the proposed structure. Moreover, the reflection is reduced which enhances the light absorption through the GaAs planar layer. This is due to the difference in the bandgaps between GaAs and GaSb The geometrical parameters of the proposed SC are studied by three dimensional finite difference time domain (3D FDTD) via Lumerical software package to achieve higher optical characteristics. The reported SC has an ultimate efficiency and short circuit current of 26% and 21.8 mA/cm^2 compared to 16.8% and 13.7 mA/cm^2 of planar GaAs SC without hemisphere design**

***Index Terms— Core-shell*, Solar cells, Hemisphere, Ultimate efficiency.**

Recently, there is a highly need for the use of clean renewable energy resources. In this context, photovoltaic (PV) devices have attracted major attention in research due to their ability of light-trapping, collection and transportation of carriers. However, finding efficient strategies to improve the light absorption with reduced cost is a strong desire. So, the use of thin-film solar cell (TF- SC) has been presented[1-4]. Additionally, materials with low quality can be utilized to decrease the cost of PV products. However, the efficiency of TF-SC is low due to the short optical path in the active material. To enhance the TFSC absorption efficiency, different designs have been utilized based on nanotechnologies. In this regard, antireflection coatings[5], nanowires[6-9], nanoholes[10,11], and core-shell nanostructures[12] have been presented at the back and/or front sides of the active layer.

Due to the superior properties of the GaAs and GaSb, they are excellent candidates for SC design[13,14]. The GaAs and GaSb have been identified as essential materials for optoelectronic devices due to carrier accumulation at the interface of the core–shell and high carrier concentration can be obtained without the required doping[15-17]. Till now, most of the research has been concentrated mostly on GaAs-GaSb axial heterostructures, while there is a lack of the core-shell representation.

In this work, a novel design of GaAs SC is suggested and analyzed. Hemisphere core-shell based on GaAs-GaSb is also added on the top surface to increase the light absorption in the active material. The optical characteristics are studied using finite difference time domain via Lumerical software package [18]. The schematic diagram of the suggested SC unit cell is shown in Fig. 1. The GaAs TF thickness (h) is fixed at 500 nm. Further, periodic hemisphere structure is used with periodicity of Λ= 250 nm and the hemisphere core-shell have radius of r_c =60 nm and r_s =100 nm as shown in Fig. 1. In order to decrease the computational time, one unit cell is simulated with periodic boundary conditions. Further, perfectly matched layer (PML) are used in the z-direction. The incident light irradiates the structure from the top with a wavelength range from 300 nm to 900 nm. The refractive indices of the materials are obtained from pervious published work[11,19]. The absorption can be calculated through the reflection and transmission monitors as:

$$A(\lambda) = 1 - R(\lambda) - T(\lambda) \quad (1)$$

The ultimate efficiency η can also be calculated from[20]:

$$\eta = \frac{\int_{300}^{900} F_s(\lambda)\ \ A(\lambda)\frac{\lambda}{900}\ \ d\lambda}{\int_{300}^{4000} F_s(\lambda)\ \ d\lambda}$$

where $F_s(\lambda)$ is the photon flux density.

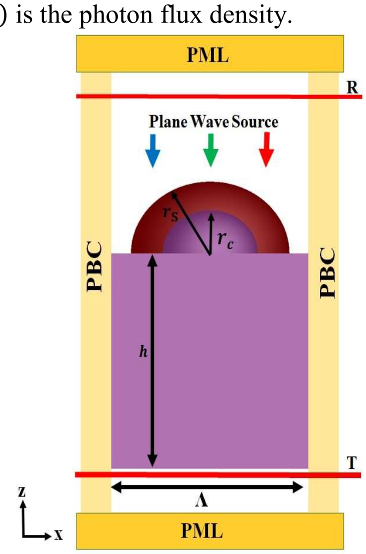

Fig. 1. x-z Cross section of the unit cell of the proposed SC.

Figure 2 shows the absorption spectra of the conventional planar GaAS SC, and the proposed structure with hemisphere core-shell. It may be seen that the reported SC offers higher absorption across the region of the entire wavelength than the other studied design. Furthermore, the presence of the core-shell can induce many resonant modes that are concentrated and coupled well inside the GaAs layer[21]. Consequently, the absorption and the ultimate efficiency are greatly improved. Several mechanisms such as the resonance of Mie scattering and the core-shell refractive indices are responsible for the absorption and ultimate efficiency enhancement. On the other hand, the absorption of the planar SC is decreased with the wavelength increase. This is due to a large amount of the photons cannot be totally guided into the active layer where the structures cannot support several guided resonant modes efficiently.

Further, high reflectance occurs for the incident photons from the top surface and the absorption is incomplete inside the active material because of the loss of light trapping features. Further, more power is reflected from the planar air/GaAs interface. However, our core-shell structure can repress those losses effectively with a much concentrated field trapped inside the active layer. The reported SC with absorption enhancement offers η of 26 % compared to 16.8 % of the planar GaAs SC.

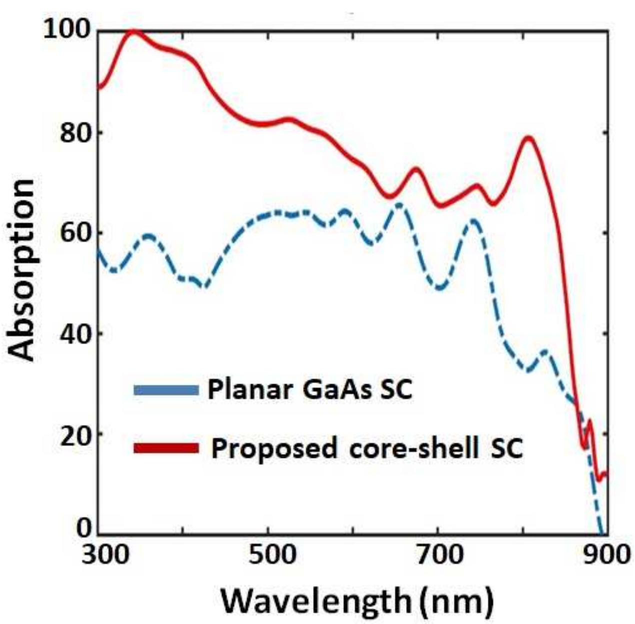

Fig. 2. Optical absorption of planar GaAs SC, and the suggested design with GaAs-GaSb hemispheres core-shell.

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