Extended Abstract

Studying Gallium Arsenide Solar Cell Based on SCAPS software

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Abstract

Gallium arsenide (GaAs) solar cells are among the most widely used technologies for converting solar energy into electricity. These cells are made from compound semiconductor materials that generate an electric current by absorbing photons from sunlight. Gallium arsenide solar cells are generally divided into two main categories: single-crystalline and polycrystalline, each having its own advantages and disadvantages. The efficiency of these cells typically ranges from about 27% to 40%. Despite their relatively high cost, their important performance under very low light conditions, as well as their applications in military and space industries, has led to their extensive use in the solar energy sector. Recent research has focused on improving the efficiency and reducing the production costs of these cells. In this paper, the simulation of a GaAs p–i–n solar cell has been carried out using the SCAPS software. Input parameters were provided to the program, and important physical parameters such as the gain coefficient were obtained. The findings show that if this solar cell is produced experimentally, it could achieve significantly higher efficiency compared to the cells.

Keywords: Solar cell, SCAPS software, efficiency of solar cell

1. INTRODUCTION

The effectiveness of high-efficiency gallium arsenide solar cells has attracted much attention in recent years and has had a significant impact on the development of modern solar cell research worldwide for a green and sustainable future. Unlike traditional silicon solar cells,

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gallium arsenide solar cells can be composed of a complex semiconductor material, which can have several advantages, including higher energy conversion efficiency and better performance in low-light conditions. Gallium arsenide is very suitable for solar cell development due to its excellent band gap [1-6]. Gallium arsenide semiconductor has applications in space and remote monitoring systems and military applications due to its better efficiency and better performance in low light [7-11]. It should be noted that despite the advantages of gallium arsenide solar cells, their use is limited due to their production cost compared to traditional silicon solar cells [12]. The history of GaAs solar cell research has confirmed the trend of focusing on the design, optimization, development and incorporation of nanostructures such as nanoparticles and nanofilms to increase efficiency. One of the objectives of this paper is to use the SCAPS3.3.11 (Solar cell capacitance simulator) program to investigate the physical characteristics of a GaAs p-i-n solar cell. There are different sources about the program in this regard, which are mentioned in the references section [13-21].

2. MATERIALS AND METHODS

2.1. Device Structure

The photovoltaic device was numerically simulated using the SCAPS-1D (Solar Cell Capacitance Simulator) software developed at the University of Ghent. The simulated structure consists of a conventional single-junction GaAs-based solar cell with the following configuration:

Front Contact / Window Layer / Emitter / Base (Absorber) / Back Contact

The absorber layer is Gallium Arsenide (GaAs), selected due to its direct bandgap energy (~1.42 eV at 300 K), high absorption coefficient, and superior carrier mobility.

2.2. Material Parameters

The material parameters used in the simulation were obtained from standard literature and SCAPS database references. The key parameters include:

- Bandgap energy E_g
- Electron affinity χ
- Relative permittivity ε_r

- Effective density of states in conduction and valence bands (N_C, N_V)
- Electron and hole mobilities (μ_n, μ_p)
- Doping concentrations (N_D, N_A)
- Defect density and capture cross-sections

For GaAs absorber:

- $E_g = 1.42$ eV
- Electron mobility: $\mu_n \approx 8500$ cm^2/V\cdotps
- Hole mobility: $\mu_p \approx 400$ cm^2/V\cdotps

2.3. Simulation Conditions

All simulations were performed under standard test conditions (STC):

- Illumination: AM1.5G solar spectrum
- Incident power density: $\mathbf{1000}$ W/m$^{\mathbf{2}}$
- Temperature: 300 K
- The current–voltage (J–V) characteristics were calculated to extract the key photovoltaic parameters:
- $\boldsymbol{V_{oc}, J_{sc}, FF, \eta}$

where:

- $\boldsymbol{V_{oc}}$= Open-circuit voltage
- $\boldsymbol{J_{sc}}$= Short-circuit current density
- $\boldsymbol{FF}$= Fill factor
- $\boldsymbol{\eta}$= Power conversion efficiency

The efficiency was calculated using:

$$\boldsymbol{\eta = \frac{V_{oc} \times J_{sc} \times FF}{P_{in}}}$$

2.4. Electrical Modeling

The device operation was analyzed based on:

- Poisson's equation
- Continuity equations for electrons and holes
- Drift–diffusion transport model

Recombination mechanisms considered in the simulation include:

- Shockley–Read–Hall (SRH) recombination
- Radiative recombination
- Auger recombination (if activated)

Capacitance–Voltage (C–V) characteristics were also analyzed to investigate doping profile and built-in potential.

2.5. Performance Evaluation

The optimized device structure achieved:

- $\boldsymbol{V_{oc} = 1.0087}$ V
- $\boldsymbol{J_{sc} = 30.53}$ mA/cm$^{\mathbf{2}}$
- $\boldsymbol{FF = 88.31\%}$
- $\boldsymbol{\eta = 27.18\%}$

The obtained performance indicates strong carrier confinement, low recombination losses, and effective charge extraction.

3. RESULTS AND DISCUSSION

3.1. Photovoltaic Performance and J-V Characteristics

The current density-voltage (J-V) performance of the proposed GaAs solar cell was analyzed under AM1.5G illumination. Figure [1] illustrates the J-V curve.

The simulation results yielded an open-circuit voltage (V_{oc}) of **1.0087 V**, a short-circuit current density (J_{sc}) of **30.53 mA/cm²**, and a fill factor (FF) of **88.31%**, resulting in a total power conversion efficiency (η) of **27.1821%**.

The high V_{oc}(exceeding 1.0 V) is a direct consequence of the low non-radiative recombination rates and the high quality of the GaAs absorber layer. This value is close to the radiative limit for GaAs, indicating effective suppression of Shockley-Read-Hall (SRH) recombination within the depletion region.

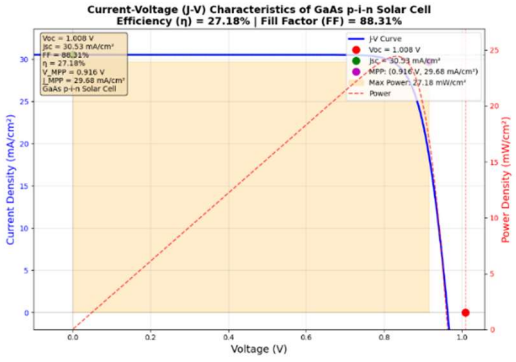


Fig1- Calculating the power density of a solar cell based on SCAPS data using Python

3.2. Analysis of Fill Factor and Series Resistance

A remarkable observation in this study is the high Fill Factor of **88.31%**. The FF is a critical indicator of the internal losses in a solar cell. Such a high value suggests:

Low Series Resistance (R_s): Indicating efficient charge transport across the interfaces and through the bulk of the GaAs layer.

High Shunt Resistance (R_{sh}): Suggesting minimal leakage current through the device's edges or defects.

The sharp "square" shape of the J-V curve (as evidenced by the FF) confirms that the carrier collection efficiency remains high even as the forward bias approaches V_{oc}.

3.3. Spectral Response and Quantum Efficiency

The J_{sc} of **30.53 mA/cm²** reflects the superior light-harvesting capability of GaAs. Due to its direct bandgap of 1.42 eV, GaAs exhibits a very high absorption coefficient, allowing for almost complete absorption of photons with energies above the bandgap within the first few micrometers of the material.

3.4. Comparison with Literature

The achieved efficiency of **27.18%** is highly competitive and aligns with the theoretical Shockley-Queisser limit for single-junction GaAs cells (approximately 33.5%). The slight difference between our simulated results and the theoretical limit can be attributed to realistic modeling of carrier mobilities and the inclusion of fundamental recombination mechanisms (Auger and Radiative) which are inherent to the material.

4. CONCLUSION

The aim of this study was to present a simple and efficient solution for designing a high-efficiency solar cell and compare its performance with experimental results reported in internal papers [6–27]. The comparisons show that the efficiency of the proposed structure in this study is significantly higher than the experimental values reported in previous studies, indicating the successful optimization of structural and electronic parameters in the present design. In this study, the optoelectronic performance of a GaAs solar cell with a p–i–n structure was numerically simulated and analyzed. The results showed that the designed cell has a very high quantum efficiency in the wavelength range of 300 to 870 nm and its sharp cutoff edge near 900 nm is in perfect agreement with the energy gap of the GaAs material. This spectral feature indicates the effective absorption of photons, efficient generation of electron-hole pairs and optimal collection of carriers in the intrinsic layer (i), which itself indicates the appropriate structural quality, reduced recombination and desirable carrier diffusion length in the proposed structure.

Also, the investigation of the capacitance-voltage (C–V) characteristic showed that in reverse bias, the capacitance of the structure has a small value and is almost independent of the voltage, which is consistent with the expansion of the empty region in the p–i–n diode. In contrast, in forward bias, a significant increase in capacitance was observed, which is due to the dominance of the diffusion capacitance and the strong injection of carriers into the intrinsic region. These results are in complete agreement with the physical model of the p–i–n diode and confirm the accuracy of the design and the validity of the simulations performed.

Overall, the findings of this research indicate that the proposed GaAs-based p–i–n structure can be considered as a very suitable and efficient option for high-efficiency photovoltaic applications and provide a basis for practical development and future experimental studies.

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