



Original research article

Theoretical design and performance of $\text{In}_x\text{Ga}_{1-x}\text{N}$ single junction solar cellY. Marouf^a, L. Dehimi^{a,b}, F. Bouzid^{c,*}, F. Pezzimenti^d, F.G. Della Corte^d^a Laboratory of Metallic and Semiconductor Materials, University of Biskra, P.B. 145, Biskra 07000, Algeria^b Faculty of Science, University of Batna, Batna 05000, Algeria^c Thin Films Development and Applications Unit UDCMA, Setif/Research Center in Industrial Technologies CRTI, P.O. Box 64, Cheraga 16014, Algiers, Algeria^d DIIES – University of Reggio Calabria, Loc. Feo di Vito, Reggio Calabria I-89100, Italy

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ABSTRACT

The insertion of optimized Window and a back surface field (BSF) layers on an $\text{In}_x\text{Ga}_{1-x}\text{N}$ p-n basic single junction (BSJ) solar cell is the chief reason behind the reduction of front and back recombination. In this context, this work is focused on the selection of the suitable parameters including the indium (*In*) content, thickness and doping concentration for the $\text{In}_x\text{Ga}_{1-x}\text{N}$ inserted layers, that gives the best photovoltaic performances. At this aim, numerical simulations were performed using the computational numerical modeling TCAD *Silvaco-Atlas* to design, optimize the $\text{In}_x\text{Ga}_{1-x}\text{N}$ BSJ and extract the above Window and BSF parameters that enhance the BSJ performances. A short circuit current density (J_{sc}) of 26.15 mA/cm², an open circuit voltage (V_{oc}) value of 0.904 V and a fill factor (*FF*) value of 79.67 % are obtained under AM1.5G illumination, exhibiting a maximum conversion efficiency (η) of 19.62 %. Other parameters like the external quantum efficiency (EQE), electric field developed, the current density-voltage (*J-V*) and the power density-voltage (*P-V*) characteristics are also calculated and plotted for the designed solar cell.

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1. Introduction

As the demand of energy and emphasis on environmental protection increase, solar energy is expected to become the major energy source [1]. Solar cells still remain the best way yet determined to harness energy from the sun, which is literally the unlimited source of renewable and clean energy [2]. To attain the expected breakthrough of photovoltaic technology as a competitive energy source against fossil fuels, the cell higher conversion efficiency, low cost and stability are the main factors [3]. Several materials were utilized to perform solar cells, the most common material used for the production of photovoltaic cells is silicon which is now approaching his theoretical maximum efficiency [4,5].

III-V group materials have been widely used for tandem solar cells for the space application, such as *GaAs* stacked with *InGaP* and *Ge*. The toxicity of arsenic in *GaAs*, the *InGaP* low resistance against irradiation damage and the indirect bandgap of the *Ge* are the biggest barriers of these materials [3]. *InGaN* is an alternative photovoltaic material, it has become a promising candidate for high-efficiency solar cells due to its attractive features. Among these, the following are of most interesting: First, the direct band gap lying from 0.7 eV (*InN*, in the near IR) to 3.4 eV (*GaN*, in the mid-UV), which can absorb the full

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Window: $p^+ (x_{win}, d_{win}, N_{win})$

Emitter: $p (x, d_E, N_a)$

Base: $n (x, d_B, N_d)$

BSF: $n^+ (x_{BSF}, d_{BSF}, N_{BSF})$

Fig. 1. $In_xGa_{1-x}N$ BSJ device structure. The parameter x represents the In concentration, d is the layer thickness, N is the doping concentration.

solar spectrum by a single material $InGaN$ with different indium contents [6]. In addition, $InGaN$ alloys exhibit a much higher resistance to high-energy (2 MeV) photon irradiation than currently used PV materials such as $GaAs$ and $GaNP$ and, therefore, offer great potential for a radiation-hard high-efficiency solar cell for space applications. Furthermore, $InGaN$ alloys have the advantages of high carrier mobility, high drift velocity, high thermal conductivity, and high temperature resistance [7]. Finally, $InGaN$ alloys display high absorption coefficients ($\sim 10^5 \text{ cm}^{-1}$) [8,9]. Thus, only a few hundred nanometers of $InGaN$ material are required to absorb most of the incident light, thereby rendering moderately expensive indium more cost effective [5].

Abdoulwahab Adaine et al. [10] have numerically studied an $InGaN$ p-n junction solar cell using the Atlas device simulation software from the *Silvaco* suite, an optimum efficiency of 17.8% was obtained.

In this paper, we conduct numerical simulations using same simulation environment to investigate the effect of the back surface field (BSF) and window layers on the performance of $InGaN$ -based solar cells and calculate the physical properties of the p-n junction such as the short circuit current density (J_{sc}), open circuit voltage (V_{oc}), fill factor (FF) and conversion efficiency (η) by varying the indium content, the thickness and doping densities of each layer.

2. Modeling and simulations

2.1. Software and device structure

The device structure as designed in this work, represented schematically in Fig. 1, is an $In_xGa_{1-x}N$ p-n basic single junction (BSJ) solar cell, in which we have introduced two $In_xGa_{1-x}N$ layers, one acting as a back surface field at the bottom and the other as a window at the top.

This device is simulated under AM1.5G spectrum and a temperature of 300 K by using the Atlas device simulation software, a physically-based device simulator from the *Silvaco* suite, in which we implemented our physical models. It predicts the electrical characteristics that are associated with specified physical structures and bias conditions. This is achieved by approximating the operation of a device onto a two dimensional grid, consisting of a number of grid points called nodes. By applying a set of differential equations, derived from Maxwell's laws and solved by the Newton coupled and Gummel decoupled methods onto this grid, the transport of carriers (including the Poisson and continuity equations on electrons and holes) can be simulated through a structure [11].

2.2. Physical modeling

Although the Poisson and continuity equations represent the fundamental laws governing the operation of a semiconductor device, additional models are often necessary to properly account for the dynamic nature of electrons and holes and to elaborate on the rich theory of device physics. These models supplement the Poisson and continuity equations by determining or modifying the variables contained in those laws. Among these:

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