Study of design the ($In_{0.04}Ga_{0.96}N$/SiC) solar cells

W. J. AZIZ*, K. IBRAHIM
Nano-Optoelectronics Research Technology Laboratory, School of Physics, Universiti Sains Malaysia, 11800 Penang, Malaysia

In this study, the performance of the ($In_{0.04}Ga_{0.96}N$/SiC) solar cells was theoretically designed and investigated. The design and performance evaluated by developing simulation models that are included in our simulator (ISE TCD). The limitation of the current versus voltage and efficiency values will be discuss and analyze. The calculation of current and voltage has been done under AM 1.5 with doping concentration levels $5x10^{18}cm^{-3}$ of n-type and $2x10^{18}$ cm^{-3} for p-type. The effects of some parameters likes V_{oc}, I_{sc}, fill factor, efficiency were carried out and investigated in this study. Our results indicate that the ($In_{0.04}Ga_{0.96}N$/SiC) alloy have interesting performance for tandem cells application, practically, there is a very little range of materials that could be used to make these cells.

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1. Introduction

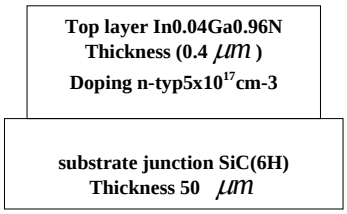
Because the limitations in the ability of a one-junction solar cells to utilize efficiently the photons of the broad solar spectrum, multi-junction solar cells have been the focus of much theoretical and experimental work in the past few decades [1]. The most successful efforts to date have concentrated on using well-known semiconductors such as SiC and various III-V alloys to construct such cells, achieving energy conversion efficiencies of over 30% for two-junction cells [2]. And over 40% for three-junction cells combined with solar concentrators [3].

Recent advances in the growth and doping of InGaN alloys may provide an alternative to traditional III-V materials. The band gap of InGaN can be varied from 0.77 to 3.4 eV, making it suitable for a wide range of multi-junction solar cell designs. These cells would be able to utilize high energy photons with more efficiency than those made from traditional III-V alloys.

Thus, a two junction $In_{0.04}Ga_{0.96}N$/SiC tandem solar cell where the InGaN has an alloy fraction to x=0.04 be grown without heavy doping of the interface between the materials, as is required in multi-junction cells constructed from traditional III-V materials. As a bonus, the band gaps of such a cell would be 3.01eV SiC and 3.17 eV ($In_{0.04}Ga_{0.96}N$), close to the band gap combination predicted to give the maximum energy conversion efficiency for solar cells [4,5].

In this paper, we calculate the characteristics of series connected, monolithic, two-junction $In_{0.04}Ga_{0.96}N$/SiC solar cells carried out and investigated under conditions AM 1.5 solar spectrum. We also briefly discuss results regarding a two layers cells and investigate the high performance and the high efficiency solar cells design numerically using ISE- TCAD simulator, we calculated manually the mole fraction (x) with the band gap (E_g), lattice constant(a), electron affinity (χ), dielectric constants (ε) and refractive index (n), to got its values and adjusted to be optimum with other parameters.

The equations were calculated it as following [6].



Design (1) $In_{0.04}Ga_{0.96}N$/SiC

(i) Band gap

$$E_{g(InxGa1-xN)} = xE_{g(InN)}+(1 - x)E_{g(GaN)}- bx (1 - x) \quad (1)$$

Where:
$E_{g(InN)}$=band gap for InN and equal 0.8 eV
$E_{g(GaN)}$=band gap for GaN and equal 3.4 eV
x=mole fraction
b=bowing parameter and it given by

$$b(x)= (1-x)(11.4–19.4x) \text{ eV} \quad (2)$$

but in our calculations we consider this constant and given by

$$b=1.43 \text{ eV}$$

as many researchers took this parameter b as constant equal to 1.43 ev.

(ii)Refractive index [7].

$$n_{(InxGa1-xN)} = x\, n_{(InN)}+(1 - x)\, n_{(GaN)}- bx (1 - x) \quad (3)$$

where
n(InN)= refractive index for InN and equal 2.9

n(GaN)= refractive index for GaN and equal 2.3
(iii)The Dielectric constants [8].

$$\varepsilon_{InGaN}(x) = 4.33x + 10.28 \quad (4)$$

(iv) Lattice constant [9].

$$a_{(InxGa1-xN)} = x\, a_{(InN)} + (1 - x)\, a_{(GaN)} \quad (5)$$

where
$a_{(InN)}$= lattice constant for InN and equal 3.548 A
$a_{(GaN)}$= lattice constant for GaN and equal 3.189 A

(v) And the electron affinity [10].

$$\chi_{(InxGa1-xN)} = x\, \chi_{(InN)} + (1 - x)\, \chi_{(GaN)} \quad (6)$$

where
$\chi_{(InN)}$ = electron affinity for InN and equal 5.8 eV
$\chi_{(GaN)}$ = electron affinity for GaN and equal 4.1 eV

2. The properties of iii-v nitrides and SiC materials

The group III-V nitrides such indium nitride (InN), gallium nitride (GaN) and their alloys have been actively investigated for the last three decades or so for its promising semiconductor device applications in the electronics as well as optoelectronics operating in the blue and ultraviolet (UV) region of the light spectrum. The wavelength range of these continuous alloy system formed by the nitrides with direct band gaps start from 0.77 eV for InN to 3.4 eV for GaN, thus covering the technologically important UV and visible spectral ranges [11]. The GaN and InN are considerably the most intensely studied among the III-V nitride semiconductors. GaN a direct and wide band gap semiconductor when compared to the more widely known Si and GaAs. With its superior radiation hardness and chemical stability, together with its large band gap characteristic, these properties have made InN and GaN a suitable semiconductor material for device applications in the high-temperature and caustic environment as well as in space applications. GaN is also an attractive candidate for protective coatings due to its radiation hardness, wide band gap make it go to intrinsic concentration at a much higher temperature than materials like Ge, Si and GaAs, i.e. the intrinsic carrier concentration at any given temperature decreases exponentially with band gap, and therefore GaN and similar wide band gap materials are attractive for high temperature applications. Moreover, the InN and GaN have many attractive features like densities, higher mobilities and higher breakdown voltages, also a potential candidate for the application in electronic devices such as high temperature, high power and high frequency transistors [12,13 ,14].

There has been increasing interest in silicon carbide (SiC) due to its favorable electronic properties, anomalous charge transfer, and extreme elastic and thermal properties [15]. The technological realization of self-aggregating wires [16,17] and quantized homo structures [18]. Make it one of the most promising materials for nano-devices, microelectronics, sensors, and high power, high-temperature devices. An understanding of the SiC/substrate interface is important for the growth of high quality SiC films. Furthermore, SiC is a promising substrate material for the growth of GaN or AlN semiconductors since GaN, InN and AlN are well lattice-matched to SiC. Previous studies on the interfaces between SiC and nitrides have revealed the favorable bonding configuration.

3. Simulation results and discution

For a practical analysis of solar cell performance the dark and light I–V characteristics shown in Fig. 1 are investigated.

Prominent parameters of the illuminated I–V characteristics include the open-circuit voltage V_{oc}, the short-circuit current density I_{sc}, the maximum power voltage V_{mp} and the current density for maximum power I_{mp}. The maximum power P_{mp} is given by the product V_{mp} Imp. The efficiency of the cell at the maximum power point is the ratio of output power P_{mp} to the incident solar power P_{in}.

$$\eta = \frac{P_{mp}}{P_{in}} = \frac{V_{mp} I_{mp}}{P_{in}} = \frac{V_{oc} I_{sc} \eta_{fill}}{P_{in}} \quad (7)$$

Where η_{fill} is the fill factor

$$\eta_{fill} = \frac{I_{mp} V_{mp}}{I_{sc} V_{oc}} \quad (8)$$

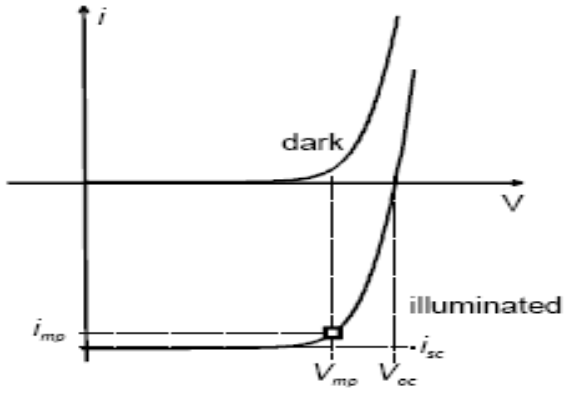


Fig. 1. Typical dark and illuminated solar cell from I–Vcurve show the maximum power point.

The our result for I-V curves shows below.

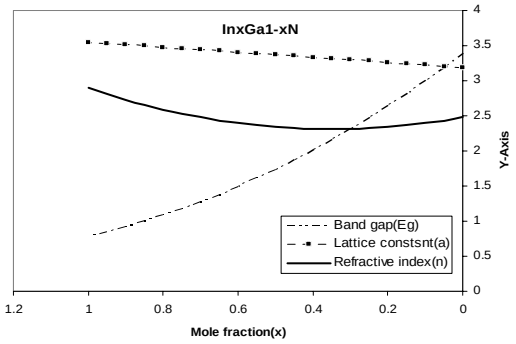


Fig. 2. Mole fraction vs. band gap (eV),Lattice constant (A) and refractive index(n).

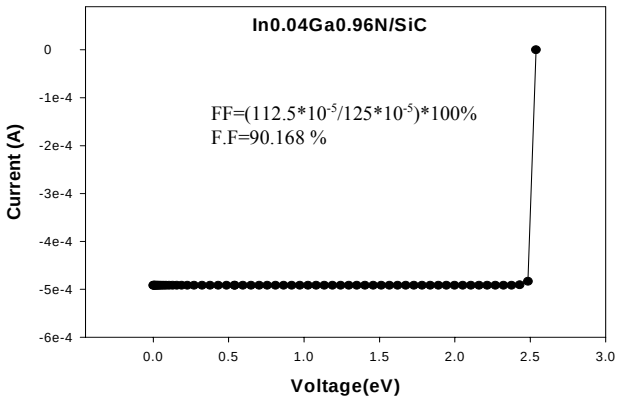


Fig. 3. The I-V characteristics as a function of thickness.

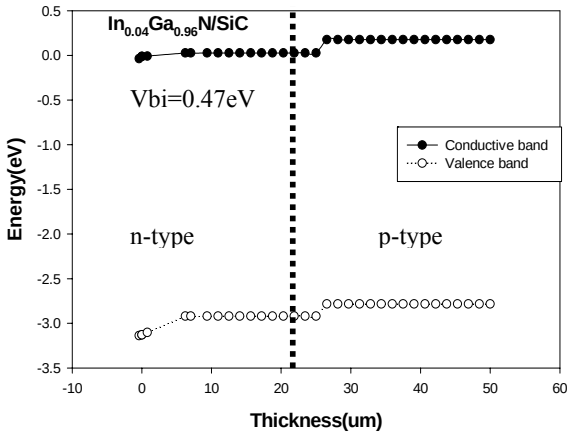


Fig. 4. Thickness(um) vs. Conductive and valence band energy (eV).

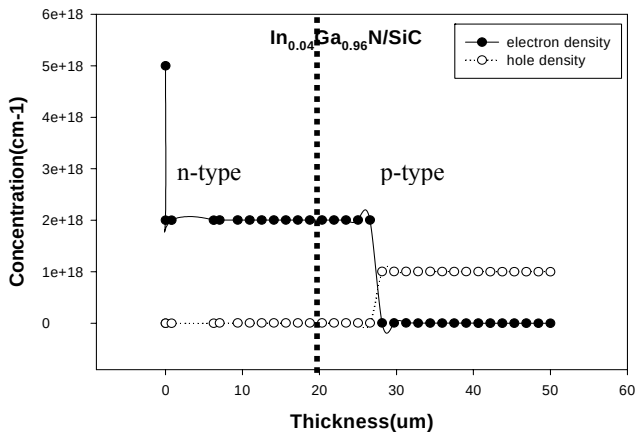


Fig. 5. Thickness(um) vs. electron and hole density(cm^{-3}).

In Fig. 2 We investigated the relationship of mole fraction(x) with the band gap(Eg), lattice constant(a) and refractive index(n) according to equations above.

In Fig. 3 the I-V characteristics are depending on V_{oc} and I_{sc} in order to obtain the filling factor (FF) and efficiency (η) values so the results for these parameters shows below.

P_{in}(mw)	V_m(eV)	I_m(mA)	V_{oc}(eV)	I_{sc}(mA)	FF	Efficiency(η)
2.4	2.5	$45x10^{-2}$	2.538	$49x10^{-2}$	90.46%	46.96%

In Fig. 4 we see the conductive and valence energy band with deep of design, it observe the built in voltage equal (0.47 eV) and the behavior the conductive and valence band is very clear.

Fig. 5 the concentration of electrons start with 5×10^{-18} cm^{-3} in $In_{0.04}Ga_{0.96}N$ layer and after that decrease to become 2×10^{-18} cm^{-3} in n-type SiC and become zero in p-type SiC, so for the holes concentration start with 1×10^{-18} cm^{-3} in SiC layer and after that decrease to become zero in (SiC and $In_{0.04}Ga_{0.96}N$) n-type.

4. Conclusion

The theoretical design and performance of InxGa1-xN solar cells for high efficiency have been studied by developing a simulation model. The simulation result shows that the $In_xGa_{1-x}N$ alloys have interesting performances for tandem cells applications.

In this study, the design of high performance ($In_{0.04}Ga_{0.96}N$/SiC) solar cells was carried out and we found the mole fraction which enter in the calculation effect on the many parameters.

I-V curve show the increase in the solar cell performance is ascribe to the increase in the open circuit

voltage (V_{oc} = 2.538) of the solar cell so it seem good value to voltage, the reason for this come from inserted SiC material in our design which have purely electronic ones as a result of its high thermal conductivity, high electron mobility (1000 cm^2 V^{-1} s^{-1}), high saturated drift velocity $>10^7$ cm s^{-1}) and high breakdown field [19], without significant loss in the short circuit current (I_{sc}), so we got good efficiency η (46.96%) for this reason, furthermore, the chosen mole fraction (x=0.04) give benefit by reduce InN to reduce the dislocation in $In_xGa_{1-x}N$. All these results suggest that the $In_xGa_{1-x}N$ alloy is an excellent candidate for high performance solar cells.

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*Corresponding author: Wisam_jafer@ yahoo.com, kamarul@usm.my