TCAD Based Simulation and Performance Optimization of InxGa(1-X)N based Solar Cell

Deepak Kumar Mangal[1], A. D. D. Dwivedi[2], Md. Asif Iqbal[3] and Surender Kumar Sharma[4]

[1] Poornima University Jaipur

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Abstract

Solar cells are a promising renewable and carbon-free electric energy resource to address the fossil-fuel shortage and global warming. Various studies on solar cells using IIInitrides semiconductors in the photovoltaic applications have been done. Among them the InGaN alloy is a promising candidate for the photovoltaic applications because it exhibits attractive photovoltaic properties such as high tolerance to radiation, high mobility, and large absorption coefficient allowing thinner layers of material to absorb most of the solar spectrum.Indium Gallium Nitride (InGaN) solar cells might yield high bene fits concerning efficiency and reliability, because its bandgap can be tuned through the Indium composition(from 0.7 eV to 3.42 eV) and It's energy range covering approximately the total solar spectrum [1].

Index terms— indium gallium nitrite (InGaN), energy band gap (EG), efficiency, fill factor (FF), opencircuit voltage, short-circuit current density, iii-nitride.

1 I. INTRODUCTION

roup III-V nitride are now a widely studied class of semiconductor materials. In x Ga (1-x) N, with small x, are very ef ficient light emitters, even in samples with relatively high densities of structural defects are used as component layers in a wide range of optoelectronic devices. Its high light absorption and its Indium-composition-tuned band gap, the Indium Gallium Nitride (InGaN) ternary alloy is a good candidate for high-efficiency-high-reliability solar cells able to operate in harsh environments.

Moreover, the most important advantage of InGaN alloy might be the direct band gap energy which can be adjusted according to the indium composition.

Thus, the InGaN's energy band gap can be tuned from 0.7 eV to 3.42 eV, covering approximately the total solar spectrum **??**1]. In this paper, we present simulation of InGaN based p-n homo junction solar cell at different Indium composition . The layers of InGaN solar cell can be deposited using the cost-effective techniques, such as Metal Organic Chemical Vapor Deposition (MOCVD), Metal Organic Vapor Phase Epitaxy (MOVPE), and Molecular Beam Epitaxy (MBE) **??**2]. Whatever the deposition technique used, higher growth rates (~1.0 Angstrom/second) and lower temperature(~550 °C) characterize the InGaN growth

2 (

)InN GaN g x g g 1-x In Ga N =x.E +(1-x).E -b.x.(1-x) E (1)

where the band gap energy of InN denoted as ?? ð ??"ð ??" ?????? and band gap energy of GaN denoted as ?? ð ??"ð ??" ?????? is 0.7eV and 3.42eV, respectively, x is the indium content and ?? is the bowing parameter (?? = 1.43) **??**5] **??**6].

The other modeling parameters of the In??Ga (1-??)N alloy were calculated using the following equations-Electron Affinity [7][8][9]: -( ) ( ) 1 4.1 0.7(3.4) x g x In Ga N E ? ? = + ? (2)

Relative permittivity[6]: -( ) ( )**1**

15.3 8.9(1) **??**) 18 1 (0.9 2.3(1)).10x x In Ga N x x ? ? = + ? (3)C x x N In Ga N x x ? = + ? (4)

Effective density of valence band [8][9]: -( ) ( )**19 1**

(5.3 1.8(1)).10 V x x N In Ga N x x ? = + ? (5)

3 b) Physical & Optical Perameters

The energy band gap of In x Ga (1-x) N is depended on concentration of Indium (x) and energy band gap of In x Ga (1-x) N is given by following formula **??**)(GaN) 1 (524* x) n x n x U In Ga N U ? = +**(11) ( ) ( )**h(GaN) 1 (6.5* x) h x x U In Ga N U ? = +**(12)**

Where the U n(GaN) is 1000 & U h(GaN) is 170.

For the In??Ga 1-?? N alloys, Adachi's wavelengthdependent refractive index model is given by the following equation **??**6,12]:2 E E E (E) 2 1 1 B E E E ph ph ph g g g n A ? = ? + ? ? + ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ....(**13**)

Where Eph is photon Energy A & B is coefficient dependent on material composition that equation giving by following equation. This real part of refractive index is approximate same 2.32 Its slightly worry for InGaN alloy with different composition of x from 2.30 to 2.34.

The InGaN alloys absorption coefficient ?? is given by equation (**??**6) [13] ( )

4 (

) Mobility [11]: -5 2 1 10 (E E) D(E E) x ph g ph g x In Ga N C ? ? = ? + ? ???????????????????(B B i i B U U T U N T U ? ? ? ? = + ? ? ? ? + ????????????????????(10)( ) . . % SC OC in I V FF P ? =**(9)**

Where I SC is short circuit current, V OC is open circuit voltage, P in is incident optical power and FF is fill factor of the solar cell. [10] ( ) ( ) 1 0.17 1.0(1) Intrinsic carrier concentration: -h x x m In Ga N x x ? = + ? (7)2 g B E K T i C V N N e n ? =**(8)**

Where K B is Boltzmann constant and T is lattice temperature Efficiency: -Velocity of electron & hole (S n,h) [cm/s] 10 3

5 Recombination time of electron & hole (? n,h)[sec.] 1ns

For the case studied, the initial physical and geometrical parameter values used for In x Ga (1-x) N single p-n junction solar cell are presented in table 6. After modeling & simulation get results with the help of above work following results are tabulates **??**)5 1 1.24 2.2*10 E x g x In Ga N ? ? ? = ? ????.(**19**)

Where ? is photon wavelength

For the In??Ga 1-?? N alloys, wavelength-dependent imaginary part of refractive index is given by the following equation4 K ?? = ? ??????????????(20)

Where pie (?) is 3.14. Following Fig. **??** Spectral response with respect to wavelength has been shown above in Fig. 5. Source photo current is maximum possible total current due to incident photons, available photo current is current due to total generated electron-hole pair and cathode current is total current collected at terminals. Among these three, source current is always greater than other two. Total photons incident losses due to reflection, transmission, thermalization etc. Further there is loss of some of the generated electron-hole pairs due to recombination and hence collected cathode current is less than or equal available photo current. After getting all results we gets maximum efficiency is 19.36% at In 0.50 Ga 0.50 N single p-n junction solar cell. This above table 9 shows simulation results of fill factor and efficiency at different composition of x for single p-n junction solar cell. In this paper we report the TCAD simulation and performance optimization of In x Ga (1-x) N based solar cell. Evaluation of the performance of the device has been performed for various values of mole fraction x of In in InGaN. Extracted performance parameters such as current, voltage, power, fill factor and efficiency from the proposed structure are: open circuit voltage (V oc) of 1.08 V, Short circuit current (I sc) is 0.027A, Fill Factor (FF) is 88.58%, Maximum voltage (V max) is 0.99 V, Maximum current (I max) is 0.26A and overall efficiency is 19.36%. IV.

6 Conclusion

[1]

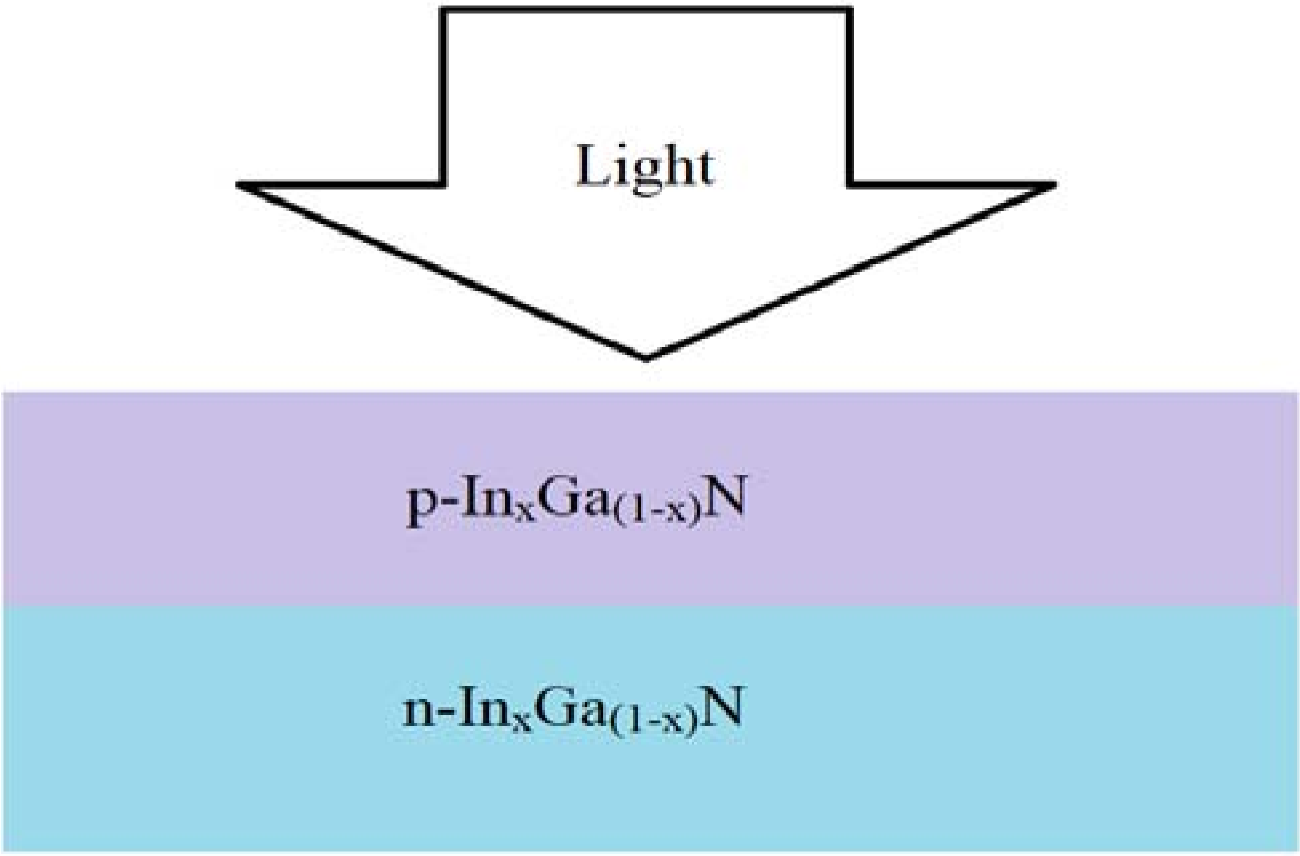
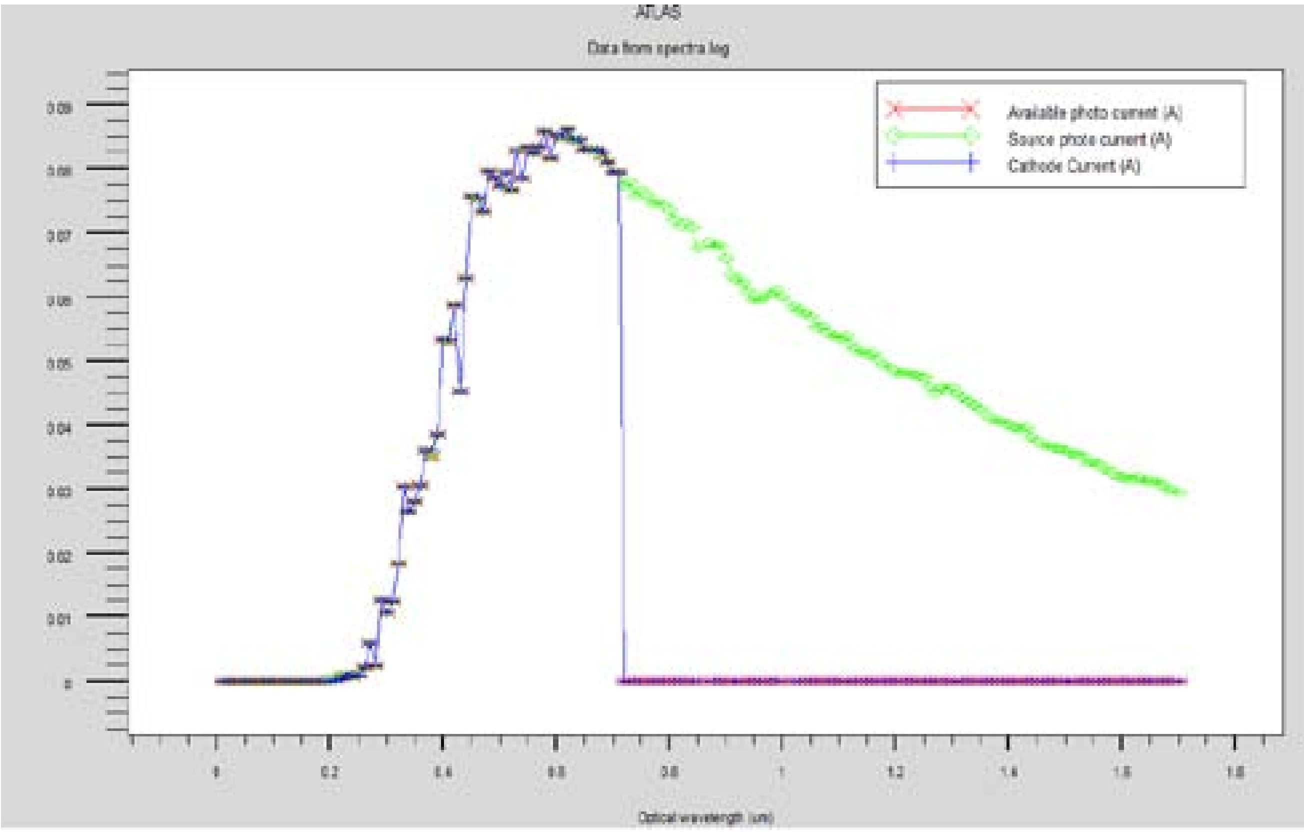


Figure 1:



1

Figure 2: Fig. 1 :

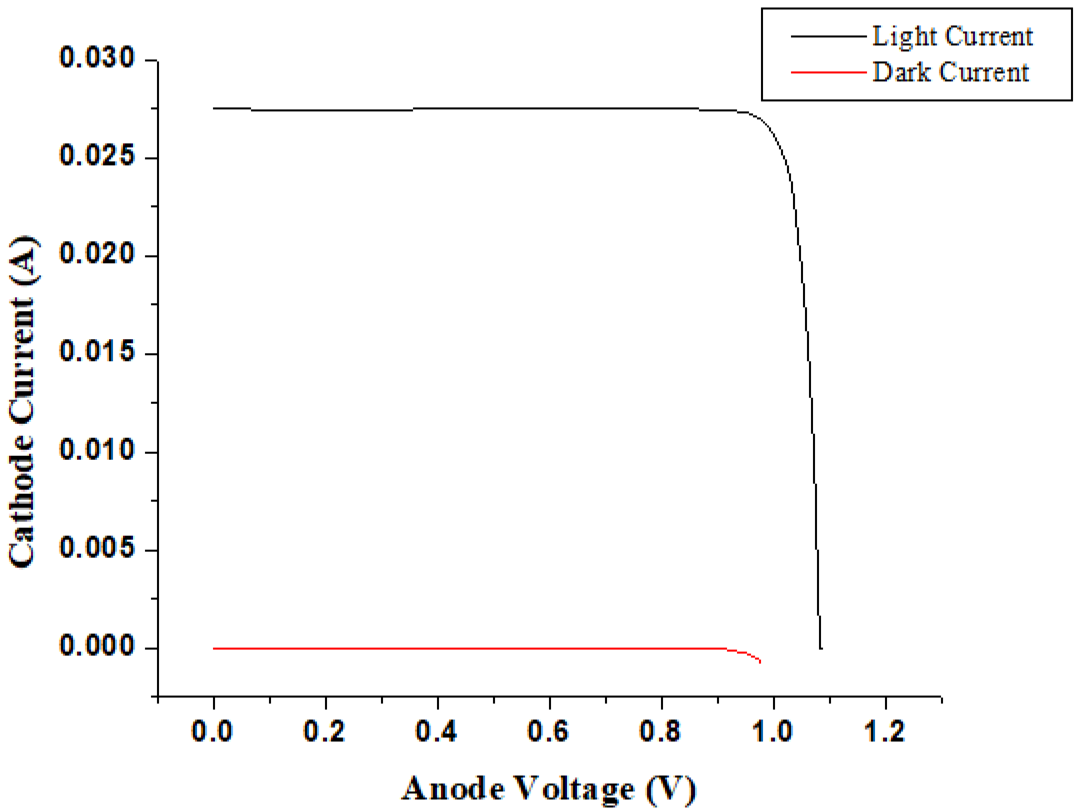


Figure 3:

2

of electron affinity and relative permittivity of In x Ga (1-x) N at different value of x

Material In x Ga (1-x) N	Electron Affinity(X)	Relative permittivity(E)
GaN	4.092	8.9
In 0.20 Ga 0.80 N	4.3955	10.18
In 0.35 Ga 0.65 N	4.5931	11.14
In 0.50 Ga 0.50 N	4.765	12.1
In 0.62 Ga 0.38 N	4.884	12.868
In 0.78 Ga 0.22 N	5.017	13.892
In 0.90 Ga 0.10 N	5.0975	14.66
InN	5.152	15.3

[Note: ( )]

Figure 4: Table 2 :

3

Energy Band Gap of In x Ga (1-x) N at x

Material In x Ga (1-x) N	Energy band gap (Eg)
GaN	3.42
In 0.20 Ga 0.80 N	2.6612
In 0.35 Ga 0.65 N	2.1672
In 0.50 Ga 0.50 N	1.7375
In 0.62 Ga 0.38 N	1.4401
In 0.78 Ga 0.22 N	1.1076
In 0.90 Ga 0.10 N	0.9063
InN	0.77

Figure 5: Table 3 :

1

Material In x Ga (1-x) N	Effective density of Conduction band (Nc) (1×10 18)	Effective density of Valance Band(Nv) (1×10 20)
GaN	0	0
In 0.20 Ga 0.80 N	1.8	1.06
In 0.35 Ga 0.65 N	3.15	1.855
In 0.50 Ga 0.50 N	4.5	2.65
In 0.62 Ga 0.38 N	5.58	3.286
In 0.78 Ga 0.22 N	7.02	4.134
In 0.90 Ga 0.10 N	8.1	4.77
InN	9	5.3
Effective mass of electron[7]		

Figure 6: Table 1 :

5

Material In x Ga (1-x) N	Mobility of Electron (MUN or Un)	Mobility of Hole (MUP or Uh)
GaN	1000	170
In 0.20 Ga 0.80 N	1104.8	171.3
In 0.35 Ga 0.65 N	1183.4	172.275
In 0.50 Ga 0.50 N	1262	173.25
In 0.62 Ga 0.38 N	1324.9	174.03
In 0.78 Ga 0.22 N	1408.7	175.07
In 0.90 Ga 0.10 N	1471.6	175.85
InN	1524	176.5

Figure 7: Table 5 :

4

Material In x Ga (1-x) N	Effective Mass of Electron (Mn)	Effective Mass of Hole (Mh)
GaN	0.2	1
In 0.20 Ga 0.80 N	0.184	0.834
In 0.35 Ga 0.65 N	0.172	0.7095
In 0.50 Ga 0.50 N	0.16	0.585
In 0.62 Ga 0.38 N	0.1504	0.4854
In 0.78 Ga 0.22 N	0.1376	0.3526
In 0.90 Ga 0.10 N	0.128	0.253
InN	0.12	0.17

Figure 8: Table 4 :

7

Material In x Ga (1-x) N	Isc (mA/cm^2)	Voc (V)
In 0.20 Ga 0.80 N	0.00813315	1.9963
In 0.35 Ga 0.65 N	0.0158621	1.51555
In 0.50 Ga 0.50 N	0.0274789	1.08184
In 0.62 Ga 0.38 N	0.0385468	0.781803
In 0.78 Ga 0.22 N	0.0539032	0.446001
In 0.90 Ga 0.10 N	0.0654447	0.242227

Figure 9: Table 7 :

6

( ) 1 x D In Ga N (x ?) 0.665 3.616 2.460 x = ? + ? x

Following equation is simplified expression of absorption coefficient ?? (19)

Imaginary Part of Refractive Index(K) 0 2000 4000 6000 8000 10000 12000

0 0.2 0.4

Fig. 2: Graph of wavelength vs imaginary part of refrective index at differ

Some initial parame

Parameter Used	Value
Thickness of n-InGaN layer	0.015 micron
Thickness of p-InGaN layer	0.63 micron
n-type doping [cm -3]	2e18

[Note: ( )]

Figure 10: Table 6 :

TCAD Based Simulation and Performance Optimization of In x ga (1-X) N Based Solar Cell

( ) 1 x C In Ga N (x ?) 3.525 18.29 40.22 x = ? + x 2 ? 37.52 x 3 + 12.77 x 4 ?????

III. RESULT & DISCUSSION

Figure 11:

8

Material In x Ga (1-x) N	Im (mA/cm^2)	Vm (V)
In 0.20 Ga 0.80 N	0.00798644	1.88
In 0.35 Ga 0.65 N	0.01556	1.41
In 0.50 Ga 0.50 N	0.0265989	0.99
In 0.62 Ga 0.38 N	0.0372977	0.69
In 0.78 Ga 0.22 N	0.0507992	0.369998
In 0.90 Ga 0.10 N	0.0563837	0.19

Figure 12: Table 8 :

9

Material In x Ga (1-x) N	Fill Factor	Efficiency
In 0.20 Ga 0.80 N	92.4754	11.0401
In 0.35 Ga 0.65 N	91.2636	16.1321
In 0.50 Ga 0.50 N	88.5801	19.3624
In 0.62 Ga 0.38 N	85.3975	18.9231
In 0.78 Ga 0.22 N	78.1818	13.8203
In 0.90 Ga 0.10 N	67.5787	7.87713

Figure 13: Table 9 :

Efficiency

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Fig. 7:

Figure 14:

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