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By Nezam Uddin, Atiqul Islam, Md. Nasmus Sakib Khan Shabbir, Aparajita Adhikary Poonam & Md. Samiul Zahid

Bangladesh University of Business & Technology (BUBT), Bangladesh

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Nezam Uddin [α], Atiqul Islam [σ], Md. Nasmus Sakib Khan Shabbir [ρ], Aparajita Adhikary Poonam [Ѡ] & Md. Samiul Zahid [¥]

Abstract- Increasing the efficiency of solar cell is the prime concern in the field of photovoltaic technology as solar cell has become the promising source of renewable energy in recent years. This paper presents $In_xGa_{1-x}N$ based multi quantum well solar cell for higher efficiency. In this paper the performance of the solar cell i.e., open circuit voltage, short circuit current and efficiency are justified with the variation of band gap difference and donor and acceptor doping concentration. The maximum efficiency is found when the baseline cell is designed at 1.424eV and the maximum efficiency is 30.17% and 31.94% for a band gap difference of 0.3eV and donor doping concentration of $5*10^{18}$ cm^{-3} respectively.

Keywords: PV Technology, MQW, baseline cell, donor concentration , acceptor concentration.

I. Introduction

Solar energy represents a clean, renewable energy. As solar light is at our disposal, it represents a primary source of abundant clean energy. The internal quantum efficiency close to 100% in bulk hetero junction Solar Cells (SCs) makes SCs promising candidates among renewable energy sources [1]. But the cost per KWH is high due to low efficiency of the conventional solar cell. In conventional solar cell (Si p-n solar cell) maximum 18%-20% energy conversion can be possible [2]. To be competitive with the conventional energy source the efficiency of solar cell must be improved. There are many approaches to increase the efficiency, such as MJ solar cells, multiple spectrum solar cells; multiple absorption path solar cells, multiple energy level solar cells, multiple temperature solar cells, p-i-n and Multi quantum well solar cell. Among these approaches MJ solar cell is being studied widely all over the world during last few decades. But this approach has some limitations. Practically, there is a very little range of materials that could be used to make these cells. The primary requirements for the materials used for MJ solar cells are band gap matching with the solar spectrum, highmotilities and lifetimes of charge carriers, thermal and lattice matching etc. The currently used conventional materials for MJ solar cells are not suitable according to the requirements. Formation of series resistance is another problem when several cells are placed in tandem. The fabrication of MJ solar cell requires highly sophisticated technology which results in higher fabrication cost. But in case of p-i-n and quantum well solar cell there are no such problems. So, the fabrication cost may be lower in these approaches.

A multiple-energy gap structure, similar to tandem solar cells, can also be achieved using the Quantum-Well Solar Cell (QWSC) structure was proposed by Keith Barnham's group in 1991 [2][3].The Multi-Quantum Well solar cell tries to overcome the single band gap limitations by combining more than one band gap, into an intrinsic region between the p and n regions, one or normally more quantum wells are added [4]. Carriers can be absorbed at energies below the band gap of most of the cell, giving more current that of a wide band gap cell alone. Well depth of the quantum well should be carefully considered to get a reasonable open circuit voltage. The AlGaAs MQW solar cell developed by Joanna Prazmowska &, Ryszard Korburowicz was able to provide maximum efficiency of 27.4% on air mass AM1.5 [2]. Although the efficiency is greater than convention one, it can be increased more by other approaches. R. Dahal B. Pantha, worked on $In_xGa_{1-x}N$ MQW solar cell's wave length dependence and found that a maximum efficiency can be obtained at 420nm wavelength [5]. J. Li. K. Aryal developed a model of $In_xGa_{1-x}N$ MQW solar cell for x=0.3 and discussed about the effect of the concentrator [6]. Omkar Jani in his research developed p-i-n solar cell and showed that a maximum efficiency is found to be 27% [7], which can also be increased by other approaches.

In this research we intend to develop a model for $In_xGa_{1-x}N$ MQW solar cell where x=.4. Different parameters such as quantum well width, depth, doping concentration, intrinsic layer length, no. of well will be varied to get the optimized model, so that an efficiency

Author α: Lecturer, Department of Electrical & Electronic Engineering, National Institute of Textile Engineering and Research.
Author ¥: Lecturer, Department of Electrical & Electronic Engineering, Northern University Bangladesh.
e-mail: samiulzahid@hotmail.com
Author σ ρ Ѡ: Lecturer, Department of Electrical & Electronic Engineering, Bangladesh University of Business & Technology (BUBT). e-mails: atiqulislam.atiq@gmail.com, eng.sakib@gmail.com, 0703043@gmail.com

more than the existing can be found. In this model we intend to use air mass AM 1.5[8]. In order to design the solar cell Sim windows software is to use. Collecting the data from the software MATLAB coding is to use to analysis the performance of the designed MQW solar cell and consequently determine the optimized condition.

II. Modeling of $In_xGa_{1-x}N$ MQW Solar Cell

MQW's are made by inserting quantum wells, which are very thin layers of lower band gap material, within the intrinsic region of a p-i-n solar cell. In this proposed model InGaN is used as high band gap material (barrier) and GaN as low band gap material (channel).

The band gap energy Eg of solar cell material is the minimum for which an electron in the valance band can be excited into conduction band in order to produce electricity. Here approximate calculations were performed in order to identify the band gap energy, Eg, of $In_xGa_{1-x}N$ alloys that are used for MQW solar cell.

$$E_{g_{InGaN}}(x) = (1-x)\,E_{g_{GaN}} + x\,E_{g_{InN}} - bx(1-x) \qquad (2)$$

Where energy gap $E_{g_{GaN}}$ and $E_{g_{InN}}$ are equal to 3.4eV and 0.7eV, respectively and bowing parameter b=2.5eV ($In_xGa_{1-x}N$). The compositional dependence of the band gap energy in $In_xGa_{1-x}N$ material is shown Fig. 1

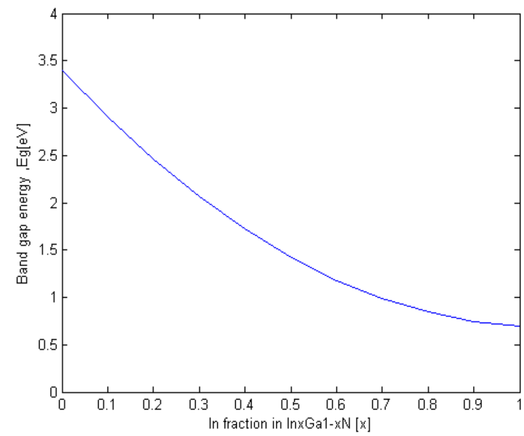


Figure 1 : Calculated band gap energy of semiconductor as a function of Indium fraction x

For this model some simplifying assumptions e.g. Depletion Approximation, Radiative Limit, Quasi-Equilibrium, Infinite Mobility Limit, Symmetry have been considered [2].

The band gap difference (ΔE) at which quantum well recombination becomes important can be found by calculating the point at which $r_G\,\beta = 1$ for ΔE , which yields:-

$$\Delta E = \frac{kT}{q}\ln\left(\frac{1-\beta(1-f_W)}{\beta f_W\,\gamma_B\,\gamma_{DOS}^2}\right) \qquad (2)$$

The J-V equations for the multy quantum well solar cells are

$$J_{MQW}(V) = J_0(1+r_R\beta)\left[\exp\left(\frac{qV}{kT}\right)-1\right] + (J_1 r_{NR} + J_s)\times\left[\exp\left(\frac{qV}{2kT}\right)-1\right] - qW\phi \qquad (3)$$

III. Proposed Model

The schematic arrangement of a InGaN/GaN MQW consists of a InGaN/GaN MQW with p-GaN and n-GaN on both side respectively [5]

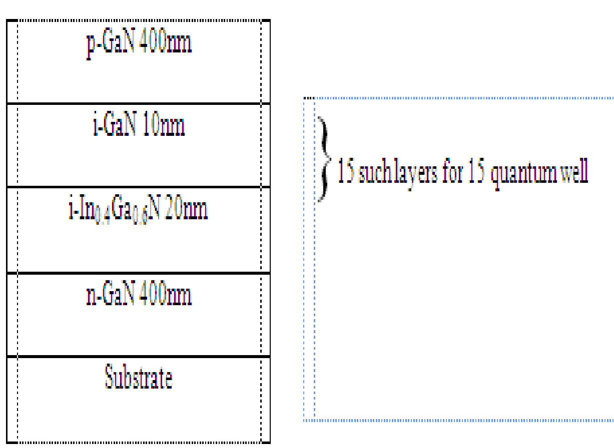


Figure 2 : Proposed model of MQWsolar cell

IV. Result and Discussion

a) Effect Band gap difference

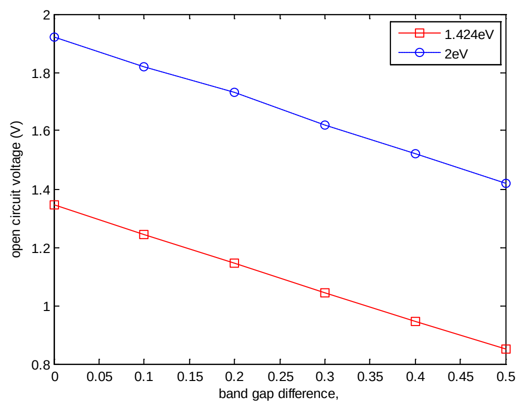
At baseline cell band gap of 1.424eV and 2eV parameters like J_{sc} , Voc and η% have been calculated at various, ΔE.

Table 1 : Variation of Voc, J_{sc} scand η% of MQW solar cell with band gap difference when baseline cell band-gap is 1.424eV

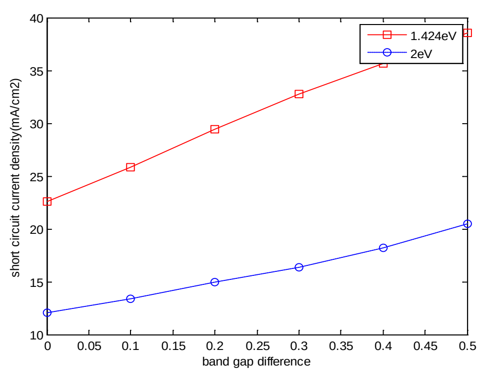
Band gap difference ΔE(eV)	Open circuit voltage V_{oc} (V)	Short circuit current density J_{sc} (mA/cm^2)	Efficiency η(%)
0.0	1.345	22.56	26.76
0.1	1.245	25.79	28.32
0.2	1.145	29.46	29.75
0.3	1.045	32.73	30.17
0.4	0.9449	35.63	29.69
0.5	0.85	38.57	28.74

Table 2 : Variation of Voc, J_{sc} and η% of MQW solar cell with band gap difference when baseline cell band-gap is 2.0eV

Band gap difference ΔE(eV)	Open circuit voltage V_{oc} (V)	Short circuit current density J_{sc} (mA/cm^2)	Efficiency η(%)
0.0	1.92	12.05	20.4
0.1	1.82	13.4	21.5
0.2	1.73	14.94	22.8
0.3	1.62	16.39	23.42
0.4	1.52	18.16	24.35
0.5	1.42	20.46	25.6



(a)



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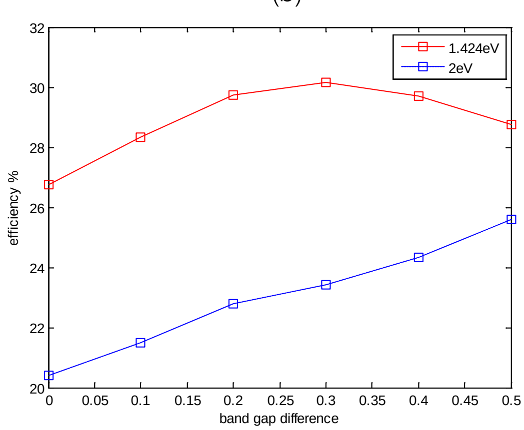


(c)

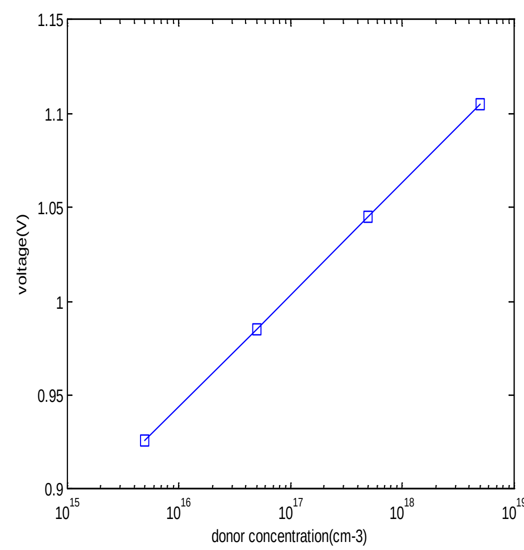
Figure 3 : Variation of (a) Voc (b) J_{sc} and (c) η% with ΔE

The fig.3 (a) implies that at every baseline band gap as the ΔE increases, the V_{oc} decreases. For example, in case of baseline cell of 1.424eV band gap as the ΔE increases from 0.1eV to 0.2eV the V_{oc} decreases from 1.82V to 1.73V. When there is an increase of ΔE, it puts an impact on the r_R which is exponentially depends on the ΔE and is the parameter giving rise to the reduced open circuit voltage in the quantum well cell. As the ΔE increases the recombination of carriers at the well increases which results in the reduced open circuit voltage. Fig 3(c) shows the variation of efficiency at various ΔE for baseline cell band gap of 1.424eV and 2eV. The maximum efficiency is found when the baseline cell is designed at 1.424eV with ΔE =0.3eV and the maximum efficiency is 30.17%.

b) Effect of doping concentration

Table 3 : Variation of Voc, J_{sc} and η% of MQW solar cell With donor doping concentration(Nd) when acceptor concentration(Na) is kept 5*10^{17} (cm^{-3}) and well depth is 0.3 eV (Baseline band-gap is 1.424 eV)

Donor doping concentration Nd(cm^{-3})	Open circuit voltage V_{oc} (V)	Short circuit current density J_{sc} (mA/cm^2)	Efficiency η(%)
5*10^{15}	0.926	32.02	26.15
5*10^{16}	0.985	32.31	28.07
5*10^{17}	1.045	32.73	30.17
5*10^{18}	1.105	31.94	31.94



(a)

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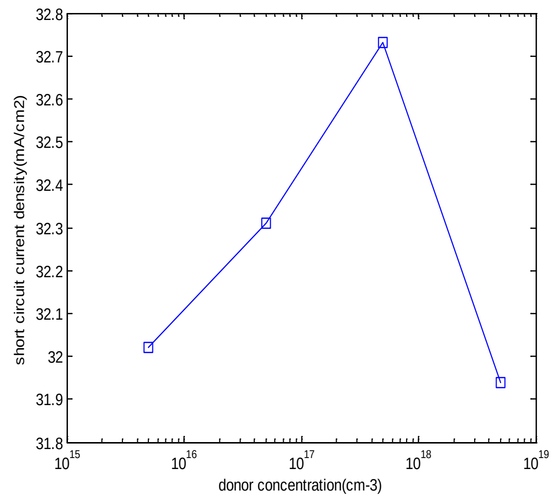

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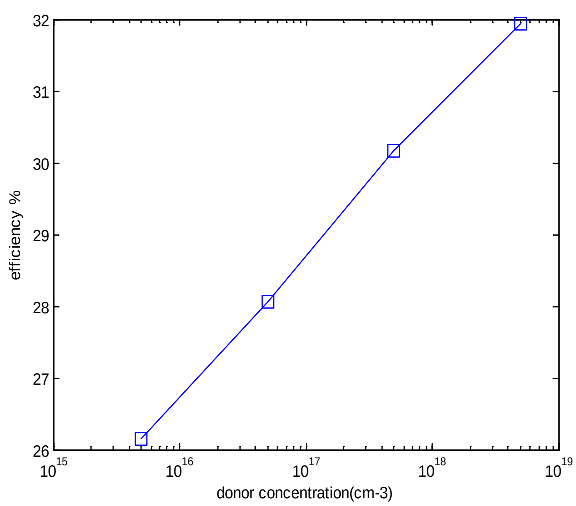


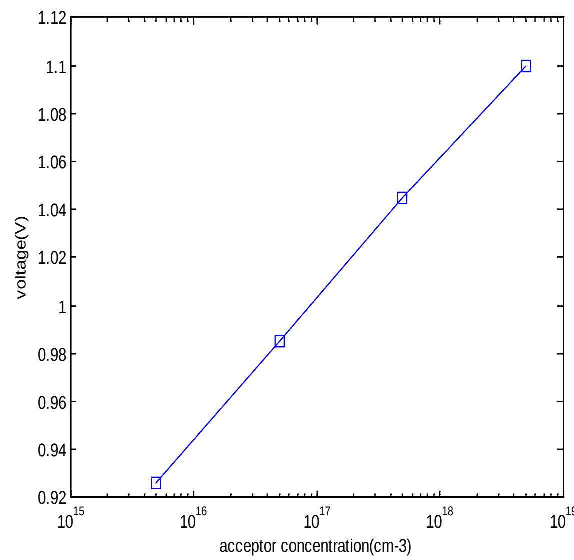
(c)

Figure 4 : Variation of (a) Voc (b) J_{sc} and (c) η% with Nd when Na=$5*10^{17}$ cm^{-3}

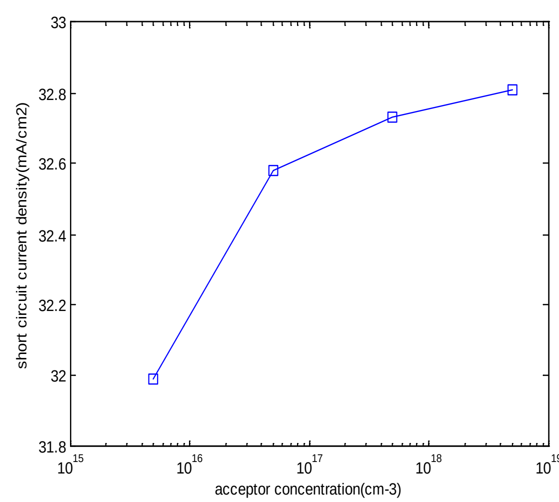
The doping density plays an important role on efficiency. It is well known that radioactive lifetime decreases with increasing doping level. Consequently, radioactive recombination becomes dominant compared to non radioactive recombination. The variation of efficiency with donor doping concentrations is shown in Fig.4(c) where the efficiency is found to increase with increasing carrier concentration. If the doping concentration is increased the, open circuit voltage Voc also increases (fig. 4(a)). It is well established that if the doping concentration is increased the reverse saturation current is decreased. As a result efficiency is increased due to increase of Voc as shown in fig 4(c).

Table 4 : Variation of Voc, J_{sc} and η% of MQW solar cell With acceptor doping concentration(Na) when donor concentration (Nd) is kept $5*10^{17}$ (cm^{-3}) and well depth is 0.3 eV (Baseline band-gap is 1.424 eV)

Acceptor doping concentration Na (cm^{-3})	Open circuit voltage V_{oc} (V)	Short circuit current density J_{sc} (mA/cm^2)	Efficiency η(%)
$5*10^{15}$	0.926	31.99	26.13
$5*10^{16}$	0.985	32.58	28.3
$5*10^{17}$	1.045	32.73	30.3
$5*10^{18}$	1.1	32.81	31.8



(a)



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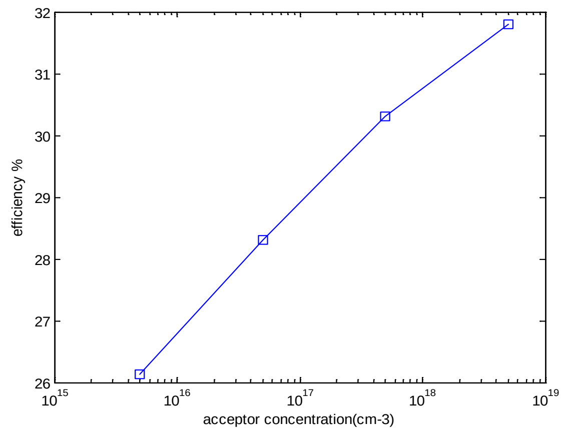

(c)

Figure 5 : Variation of (a) Voc (b) J_{sc} and (c) η% with Na when Nd=5*10^{17} cm^{-3}

The acceptor concentration is varied keeping Nd=5*10^{17} cm^{-3} constant. The variation of efficiency is shown in figure 5(c), where the efficiency increases with the increase of acceptor concentration .This is because, the open circuit voltage also increases shown in fig.5 (a).

V. Conclusion

In the proposed model InGaN is used because, InGaN has low effective mass of electron. As a result it has greater mobility, high peak and saturation velocities, high absorption coefficients and radiation tolerance [11].

InGaN also has an apparent insensitivity to high dislocation densities as the polarization and piezoelectric properties [9][10] of the material introduce electric fields and surface diploes that may counter the effect of dislocations. With the incorporation of MQW structure in the i-region, the conversion efficiency exceed the efficiency limit of a conventional homojunction single-gap solar cell. The overall result is that, InGaN solar cell attains greater short circuit current density consequently the efficiency of InGaN MQW solar cell is higher than the AlGaAs MQW solar cell.

VI. Future Work

In future the optimization of the geometry and composition of all layers of the structure should be more improver in order to achieve the enhancement of the quantum well solar cell structure performance. The lattice mismatch could be minimized by selecting materials of appropriate band gap.

References Références Referencias

1. Magdalena Lidia Ciurea, Ana-Maria Lepadatu, Ionel Stavarache,"Quantum Well Solar Cells: Physics, Materials and Technology", DOI: 10.4018/978-1-4666-1927-2.ch003J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.
2. Turid Worren Reenaas, "Modeling of intermediate band solar cell", Trondheim , June19,2009.K. Elissa, "Title of paper if known," unpublished.
3. Barnham, K.W.J. , Braun, B. ,Nelson, J," Short-circuit current and energy efficiency enhancement in a low-dimensional structure photovoltaic device", Appl. Phys. Lett., vol. 59, p. 135, 1991.
4. JOANNA PRAZMOWSKA, RYSZARD KORBUTOWICZ, "Optimization of multi quantum well solar cell", Optica Applicata,Vol xxxv,No. 3, 2005.
5. R. Dahal, B. Pantha, J. Li,"InGaN/GaN multiple quantum well solar cells with long operating wavelengths" Appl. Phys. Lett. **94**, 063505 (2009).
6. R. Dahal, J. Li, K. Aryal, J. Y. Lin, and H. X. Jiang," InGaN/GaN multiple quantum well concentrator solar cells", Appl. Phys. Lett. **97**, 073115 (2010).
7. Jani, O; Honsberg, C.; Asghar, Ali; Nicol, D.," Characterization and analysis of InGaN photovoltaic devices", Photovoltaic Specialists Conference, 2005, Pages:37 – 42.
8. P. H. Fu, G. J. Lin, C. H. Ho," Efficiency enhancement of InGaN multi-quantum-well solar cells via light-harvesting SiO_2 nano-honeycombs", Appl. Phys. Lett. **100**, 013105 (2012).
9. R. D. Schaller and V. I. Klimov, "High Efficiency Carrier Multiplication in PbSe Nanocrystals: Implications for Solar Energy Conversion", Phys. Rev. Lett., vol. 92, p. 186601, 2001.
10. T. V. Shubina, A. Vasson,H. Amano,"Mie Resonances, Infrared Emission, and the Band Gap of InN", Phys. Rev. Lett. 92, 117407 (2004).
11. Y. Nanishi, Y. Saito and T. Yamaguchi, "R-F Molecular Beam Epitaxy Growth and Properties of InN and Related Alloys", Jpn. J. Appl. Phys., vol. 42, 5A, p. 2549-25.

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