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Performance Analysis and Efficiency Improvement of Graded p-i-n Solar Cell

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Abstract: The graded bandgap cell is designed to produce a significant photocurrent at relatively higher voltage. The graded device provides an effective field which enhances the collection of electrons and holes. The GaInAsP quaternary system was selected for actual device fabrication and characterization. However, studies were carried out which clearly indicated that the structures with graded bandgap were characterized by an enhanced photo response. The results suggest that once high quality GaInAsP films can be designed and fabricated considering minimum recombination via defect energy levels with grading the material composition in such a way that the lattice constant remains same. A significant effort of analysis of current –voltage characteristics and deep level spectroscopy was made to the development of high efficiency GaInAsP solar cells. Such effort resulted in the fabrication of multi-junctional GaInAsP which increased the efficiency of solar cells.

Keywords: ***GaInAsP films,*** **solar cells, Bandgap, Efficiency, Fabrication**

1. INTRODUCTION

A solar cell is formed by a light sensitive p-n junction semiconductor where the photons of the sunlight are absorbed. Every photon has its own energy. If the energy of the photon is greater than or equal to the energy needed to transfer electron from the valance band to the conduction band, it will contribute to the output of the solar cell. After generating the free electrons, a path is found towards the p-type semiconductor (As the rule goes "unlike charges attract each other"), through an external path. If an external path is not available there, the process of generating free electrons stops. The probability of releasing electrons by the photons depends on the amount of light absorbed by the cell's surface. More absorption implies more electron release, and hence more electricity will generate [1]. Solar cells are used for converting the photon energy to electrical energy. When sunlight falls on the solar cell, the materials absorb the photons (if

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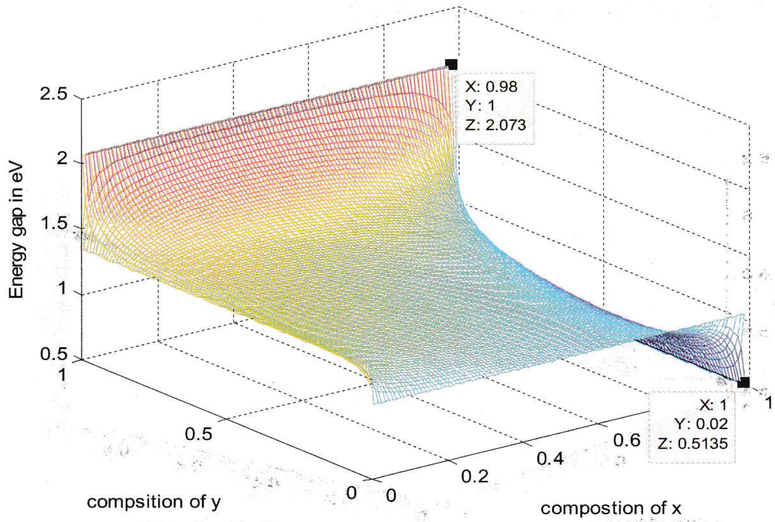
the photon's energy is equal or greater than the energy gap of that material) and produce electricity [2]. The efficiency of solar cell achieves dramatic improvements when the focus is shifted from Si towards GaAs and III-V semiconductor compound system. In 1980 several types of III-V solar cells had been tested and by 1984, first GaAs solar cell was developed [3-8]. After that by using the concentrator on solar cell, we can get maximum conversion of around **37%** of absorbing sunlight to electrical energy. The researchers move toward to hetero-junction solar cell. Hetero-junction solar cells consist of two different types of materials. Hetero-junction is a contact point between two layers of different crystalline semiconductors. Hetero-junction is different from homo-junction semiconductor materials due to its unequal band gaps. In hetero-junction solar cells, we use two different types of semiconductor materials and those materials have unique band gap, and these type of solar cell can absorb two different energized photons [8]. In this research work, Quaternary GaInAsP semiconductor material has been used to control the lattice parameter and band gap of such material. The method adopted to increase the efficiency of Graded p-i-n solar cell is presented and discussed.

2. EXPERIMENTAL PROCEDURE

One of the approaches being pursued for fabricating high efficiency solar cells involves the use of two or more cells having different bandgaps. By utilizing more than one bandgap, a photovoltaic system can be coupled to the solar spectrum in a more optimum manner than that achieved with a single homo-junction cell. The most common approach is to construct a multiple cell system which involves arranging devices in tandem, in order of the bandgaps and with the largest bandgap cell receiving the incident photons. 50% efficiency is possible for graded bandgap cells. As a result, the graded bandgap cell is worthy of investigation. The basic concept of modeling a graded p-i-n solar cell can be fabricated by graded bandgap cells based on the multi-junction semiconductor solar cell concept. We have to choose the semiconductor materials according to the characteristics and potentiality. Then we measure and analyze the electro-optical properties of the devices and interpret results in terms of appropriate models and developed the approaches to modeling calculations for graded bandgap cells. The approaches for Graded Band gap solar system are firstly to reach the maximum value of photocurrent by grading the bandgap to optimize coupling between solar spectrum and photo response and secondly, to increase the efficiency of optical absorbers and anti-reflection coating system. Then the current –voltage characteristics and deep level spectroscopy are analyzed. After that the electro-optical characteristics in terms of theory is interrupted. According to the analysis and spectroscopy uses advanced materials technology of layer arrangement for penetration depth management with the consideration of reducing band to band recombination by minimizing low band gap region. Finally, the recombination via defect energy levels by grading the material composition is minimized in such a way that the lattice constant remains same.



3. RESULTS AND DISCUSSION

This study has emphasized investigations of graded bandgap p-i-n junction solar cells in order to improve efficiency by causing absorption of wider spectrum of sunlight. The main purpose of graded band gap is to ensure more efficient absorption of photons. We use quaternary semiconductor material GaInAsP in which bandgap can be easily changed without changing the lattice constant and this bandgap change over a wide region is made by changing their composition. By varying the composition of x and y (called mole fractions) from 0 to 1 of GaInAsP, we get a maximum energy gap of 2.0731eV and minimum band gap is 0.5135 eV respectively as depicted in Fig.1.

Fig.1. Band gap vs. composition

The above mentioned band gap absorbs large portion of sunlight's spectrum that means the efficiency of our solar cell is increased. The formula for finding the bandgap of quaternary materials in terms of the bandgaps of ternary semiconductor materials is given in equation (1) [9].

$$Q_{xy} = \frac{[x(1-x)[yT_{ABC}(x) + (1-y)T_{ABD}(x)] + y(1-y)[xT_{ACD}(y) + (1-x)T_{BCD}(y)]]}{x(1-x) + y(1-y)}$$

(1)

Alternatively the band gap can be calculated by equation (2) [10].

$Q=1.35 + 0.668x - 1.068y + 0.758x^2 + 0.078y^2 - 0.069xy - 0.332x^2y + 0.03xy^2$eV. (2)

The lattice constant of our quaternary semiconductor material (GaInAsP) should be matched with the substrate material (InP). By varying the compositions of mole fractions, we find the maximum and minimum lattice constants are of 6.042 A and 5.452 A which are shown in Fig.2.

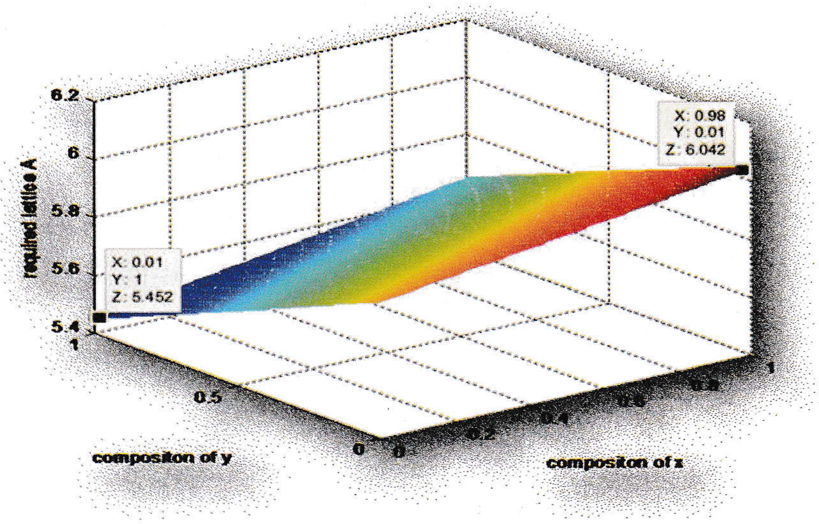


Fig.2. Lattice constant vs. composition.

The lattice constant of quaternary semiconductor can be calculated by equation (3) [11].

Lattice constant = 5.87+0.18x-0.42y+0.02xy .

(3)

Now, we can observed that at maximum band gap, the lattice constant and composition are 5.8658A, x=0.0100 and y=0. At minimum band gap, Lattice constant and composition are 5.8980A, x=0.3800 and y=1. These restricted values of the compositions and band gaps are used to design the graded p-i-n solar cell. For modeling p-i-n solar cell, we put the material at the top which have higher bandgap and at the bottom which have lower bandgap, because the penetration depth for high frequency is low and for low frequency is high. For the maximum and minimum band gaps are 1.3763 eV, 0.5135 eV and the corresponding wave lengths are 901nm, 2416 nm respectively .Fig.3 and Fig.4 shows the calculation of penetration depth for those photons which have maximum and minimum bandgaps and get the amount of solar radiation of those solar cells can be absorbed.

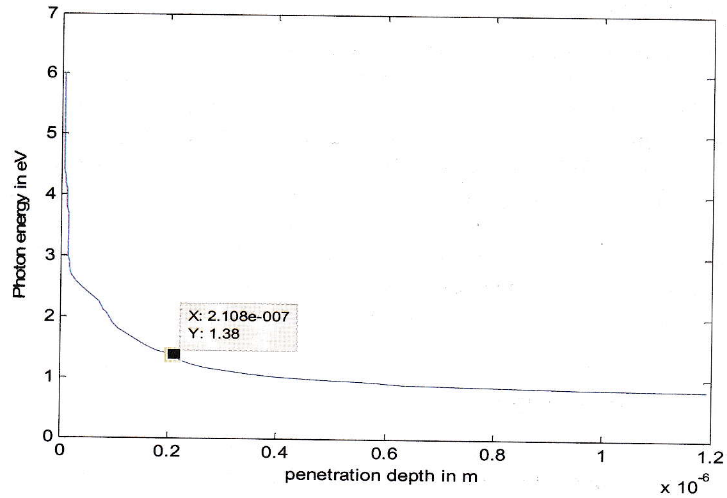


Fig.3. Penetration depth vs. Photon energy for 1.3763 eV.

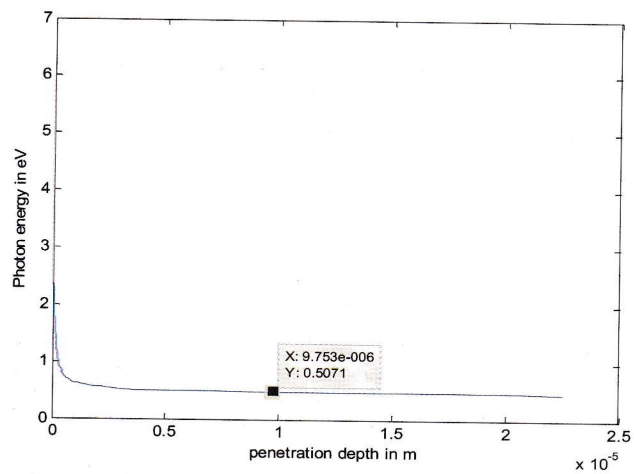


Fig.4. Penetration depth vs. Energy for 0.5135 eV

Besides, anti-reflective glass coating of Brisbane Materials solar panels capture more light and therefore boost up their efficiency. While Hyper Solar intends to produce a thin, flat, clear solar concentrator that could boost up the amount of sunlight reaching solar cells by up to 400 %. Solen Sphere is working to commercialize their patented hybrid solar concentrator, which is claimed to be able to capture 72% of the sun's energy falling on it by focusing the sunlight on PV cells engineered to use concentrated light, as well as being able to capture solar thermal energy within the device.

5. CONCLUSIONS

A simple graded p-i-n solar cell model is developed by using GaInAsP semiconductor material. For this purpose we choose GaInAsP as active semiconductor material of solar cell and InP as substrate, because its lattice constant are pretty close with GaInAsP. We have analyzed energy gap and lattice parameter of GaInAsP. From the analysis, it is cleared that our graded p-i-n solar cell would cover wider spectrum of sunlight without effective change in the lattice constant. Finally we have analyzed the efficiency and observed that if we could able to integrate the composition of GaInAsP on InP substate graded p- i-n solar cell with the efficiency improvement technique then it would be an unbelievable matter of up to 72% efficient solar cell.

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REFERENCES

[1] H Palaniappan (2000), *Solar cells.*

[2] A Goetzberger, V. U. Hoffmann (2005). Springer-Varlag Berlin Heidelberg, *Photovoltaic Solar Energy Generation*, Germany, p. 2.

[3] S Russell,O hl, N.J Little Silver (1941). Bell Telephone Laboratories, *Light-sensitive electronic device*, New York, U.S. Patent 2,402,662.

[4] Om Prakash Pahuja (2005). Laxmi Publications LTD, *Solid State Physics*, New Delhi, p. 308

[5] T. M. L. Wigley, and David Steven Schimel (2000). Cambridge University Press, *The Carbon Cycle*, New York, p. 58.

[6] A Donald, Neamann (2003). The McGraw-Hill Companies, Inc, *Semiconductor Devices and Physics*, New York, p 601.

[7] I. Ravi Kumar, N. Bala Saraswathi (2001). Laxmi Publications, *Principal of Optical Communication and Opto Electronics*, New Delhi, p. 198.

[8] Antonio Luque and Steven Hegedu (2005). John Wiley & Sons Ltd, *Handbook of Photovolatic Science and Engineering*, England, p. 426.

[9] JoachimPiprek (2005). Springer Science Business Media, Inc. *Semiconductor Optoelectronic Devices: Introduction to Physics and Simulation*, New York, USA, pp. 43-45.

[10] http://www.ioffe.ru/SVA/NSM/Semicond, *Basic Parameters*

[11] R.L.Moon, G. A. Antypas, L.W. James (1973). Varrianlabrotaries, Palo Alto, *Bandgap and lattice constant of GaInAsP as a function of alloy composition*, California,p . 635.