IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 1 Issue 09, November 2014
www.ijiset.com
ISSN 2348 – 7968

A Simulation Study of Composite Direct Band Semiconductors as Solar material

Rajni Seth,
Department of Physics, Dyal Singh College, Karnal, India

ABSTRACT

PC1D (Photo-conductance one dimensional) software, which was developed by the University of New South Wales, has been used to simulate photovoltaic properties of crystalline semiconductor devices. Silicon an indirect band gap material has been most widely used solar material. The probability of light absorption is less in indirect band gap semiconductor, as it requires two particles (a photon and a phonon) to excite an electron from the valence band to the conduction band, as a result, a thicker layer is required to absorb complete solar spectrum. The need of the hour is to replace silicon with other direct wide band gap semiconductor materials. Here, the important parameters like open circuit voltage, short circuit current, fill factor, efficiency for the alternate direct band materials like InP, GaAs, and AlGaAs are obtained by simulation. The simulation of AlGaAs solar cell is carried out by setting up key parameter like front surface reflection, highlighting the importance of use of antireflection layer on the front surface.

1. Introduction

Photovoltaic solar energy provides humanity with a powerful tool to foster a sustainable, prosperous, and eco-friendly global society. The photovoltaic source of energy i.e. solar irradiation has the advantage of being widely distributed over the entire world. Among the various renewable energies, solar energy is considered as the most promising for its versatility, since solar energy does not pose location restrictions nor does it require special geographical features. It is stated that nearly 1367W/m^2 of solar power is delivered by sun into atmosphere [1]. The conversion process of this solar energy directly into electricity using the optical and electronic properties of suitable materials appears to be an elegant energy conversion process and an ideal alternative to conventional energy sources. World's power requirement can be easily met by absorption of $1.8x10^{11}$ MW of solar energy globally[2]

Solar cells are considered a major candidate for obtaining energy from the sun since they can convert sunlight directly to electricity. They at present furnish the most important long duration power supply for satellites and space vehicles. Solar cells have also been successfully employed in small scale terrestrial applications. Solar cells work on the principle of photovoltaic effect i.e. the process of conversion of sun light into electricity which was initially discovered by Alexandre Edmond Becequerel in 1839[3].

2. Theoretical Background

Sunlight is composed of photons or packets of energy which contain different amount of energy corresponding to the different wavelengths of light. When these photons strike on a P-N junction device (solar cell), some of them gets reflected, some of them absorbed within the device and the rest are transmitted. Photons entering into the semiconductor material interact with its atoms. Only those photons having energy more than or equal to

ISSN 2348 – 7968

the band gap energy of the semiconducting absorber material causes excitation of an electron from the valence band to the conduction band, resulting in the generation of the electron hole pairs[4]. The whole process of electric current generation using solar cell is actually composed of the following important steps:

- Sunlight absorption by the semiconducting absorber layer
- Generation of electron-hole pair
- Transportation of charges thus produced: due to the built-in electric field at the PN junction, the newly generated electron-hole pairs are separated. Electrons are pushed towards the n-type side of the cell, while holes are pushed towards the p-type side.
- Flow of Electrons: The separated electrons are collected by metal contacts on the surface of the cell, forming an electric current. This current can be harnessed for external use.
- External Load: When an external electrical load (such as a light bulb or a battery) is connected to the PV cell, the flow of electrons through the load generates electrical power, which can be used to power various devices or may charge batteries for later use.
- Recombination of charge carriers: ultimately restoring the absorber layer to ground state

The intensity of light (number of photons per unit area) reduces as it travels deeper in the absorber material. The decrease in the intensity I of a monochromatic light of wavelength λ and frequency υ as a function of depth x is given as[5]:

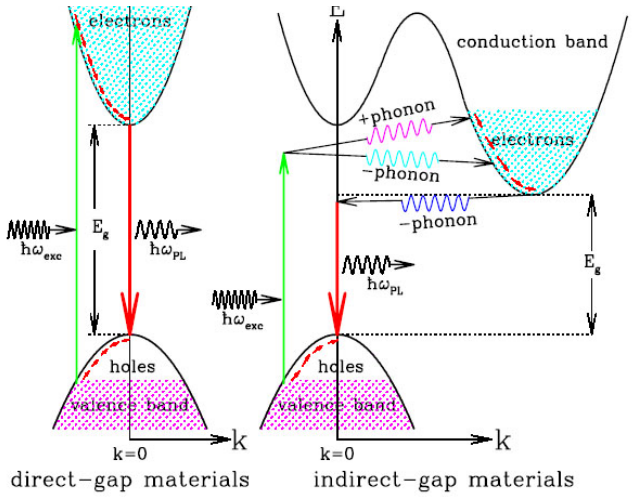
$$I=I_o\, e^{-\alpha x}$$

Where I_o is the light intensity at the surface of the semiconductor and α is the absorption coefficient. The absorption coefficient reflects how strongly a particular photon gets absorbed in a material. Its value depends upon the nature of the material as well as on the wavelength of the incident light. Absorption coefficient is a very important material parameter from the view point of the efficiency of the solar cell. Its higher value results in the decrease in the thickness of the material required to absorb most of the radiations falling on it. Absorption length L_α is defined as inverse of absorption coefficient.

$$L_\alpha = 1/\alpha$$

Absorption coefficient is also found to depend upon the type of band gap material. For direct band gap semiconductor material (such as GaAs and CdTe) for most of the wavelengths of solar spectrum, the absorption coefficient is high ($>10^4$ cm^{-1} and corresponding $L_\alpha < 1\mu m$). The high value of α for direct band gap semiconductor represents high absorption probability because the valence band maxima E_v and conduction band minima E_c exist at the same value of k. This suggests that in order to excite an electron from the valence to the conduction band only a photon of energy $E_c - E_v = h\upsilon$ is required. Photon is considered as a particle of high energy and low momentum; therefore, the electronic transition in the direct band gap semiconductor is almost vertical in the E-K diagram as shown in the following diagram[6].

ISSN 2348 – 7968



In the indirect band gap semiconductor, the conduction band minima does not exist exactly below the valence band maxima in the E-K as shown in the above diagram. Since K axis represents electron momentum, excitation of an electron from the valence band to the conduction band requires not only absorption of a photon but also absorption of another particle called phonon. A phonon is thought of as a particle of low energy and high momentum and is related to lattice vibration. Phonon absorption is required to conserve momentum. Since in indirect band gap semiconductor like silicon, instead of one particle (photon), two particles (photon and phonon) are involved in the generation and recombination of E-H-P pair, so the absorption coefficient has smaller value as compared to direct band gap semiconductor. As a result large thickness of material is required to absorb radiations, which in turn results in the larger cost of the solar cell though depending on the grain size, efficiencies of over 16% have been demonstrated in thin film solar cell [7]. Its recent emergence as a cost-effective electricity source is rooted in a straightforward optoelectronic technology: the crystalline silicon solar cell. While the development of this device progressed at a modest pace in the past, advancements have rapidly gained momentum in recent years, bringing both fresh challenges and exciting possibilities.

In order to bring down the cost and make the solar energy more popular we need to replace Si, with the materials with direct band gap[8] like indium phosphide [9], Gallium arsenide[10], aluminum gallium arsenide, cadmium telluride etc. Such solar cells are known as compound semi-conductor based solar cells. The special electrical characteristics of compound semi-conductor materials, which are made up of two or more elements from different periodic table groups, make them suitable for photovoltaic applications. These semiconducting compound materials are deposited on different substrates like glass, polymer sheets or metallic sheets as layers [11]. Thin polycrystalline films can be prepared by different methods such as sputtering [12] spray pyrolysis[13], sol-gel[14] pulsed laser deposition[15], chemical bath deposition (CBD)[16], physical vapor deposition[17] etc. The role of material science in fast growing PV technology has been discussed by asim et al[18]. This review explores the critical contributions of

ISSN 2348 – 7968

material science in improving the efficiency, cost-effectiveness, and performance of solar cells, addressing both established and emerging PV technologies. The material parameters of various solar materials have been given in the table (1).

Table 1: Material parameters of various solar materials[19]

Material	Band Gap(eV)	Dielectric Constant	Refractive Index	Lattice constant(Å)
Silicon	1.124	11.9	3.58	5.43095 (Diamond)
InP	1.35	12.1	3.1	5.8687 (ZincBlend)
GaAs	1.424	13.18	3.66	5.65325 (ZincBlend)
AlGaAs	1.817	12.24	3.81	5.6533 (ZincBlend)

3. Simulation Experimental Design

The structure of the solar cell used for the solar cell is such that the light enters the solar cell through front window which has front surface texture depth of 3 μm, fixed exterior front reflectance of 10% with internal optical reflectance enabled. The total device thickness being 300 μm and illuminated with an intensity $0.1 W/m^2$.
The I-V, P-V characteristics curves have been obtained for four materials namely Silicon, InP, GaAs, and AlGaAs for P-N junction solar cell, using the PC1D simulator program. The objective of the present study is to calculate the important parameters using different materials so that we are able to find suitable material for fabricating efficient solar cells. Moreover the importance of anti reflection coating is also studied.

4. Result and discussion

In order to find various solar cell parameters like short circuit current, open circuit voltage, fill factor, and efficiency, the characteristics curves were obtained from the simulator program and these observations were used to justify the use of new direct band gap semiconductor binary or ternary materials for solar cell applications.

Table-1: Parameters of solar cell fabricated using different materials [20]

Material	V_{oc}(V)	I_{sc}(A)	V_m(V)	I_m(A)	P_{max}(w)	FF	Efficiency
Si	0.592	3.17	0.48	2.76	1.361	0.715	13.24%
InP	0.91	2.16	0.810	1.87	1.5	0.763	15.20%
GaAs	0.985	1.770	0.847	1.47	1.245	0.714	12.44%
AlGaAs	1.34	1.215	1.139	0.894	1.019	0.625	10.17%

ISSN 2348 – 7968

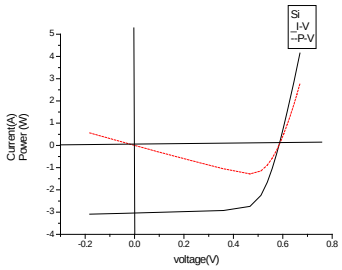


Figure 1(a)

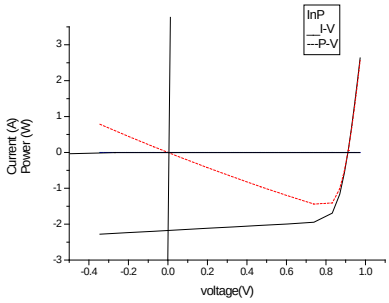


Figure 1(b)

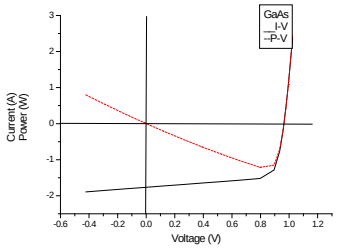


Figure 1(c)

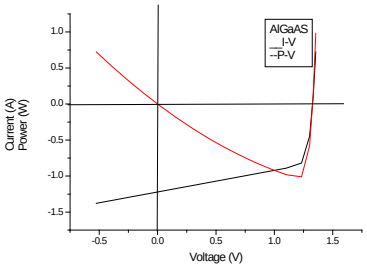


Figure 1(d)

Figure 2: Characteristics curves of P-N junction solar cell fabricated using different materials [21]

Figure 2 shows the effect of material on the simulated current-voltage and power-voltage characteristics of P-N junction solar cell. From the table (2) and figure (2) we find that the direct band gap semiconductors give higher open circuit voltage. Indium phospide has the highest efficiency among the materials tested. AlGaAs is found to give the highest open circuit voltage. To further improve the efficiency, the front surface of the solar cell has been coated with anti reflection coating, which is a thin layer of a dielectric material deposited on the surface of a solar cell. It should not absorb any light and should reduce the reflection losses. The reduction in the reflection is based on destructive interference between the light reflected from air-ARC interface and ARC- semiconductor interface. So the thickness of the ARC should be quarter of the wavelength. The effect of reflection on the open circuit voltage, short circuit current and maximum power for AlGaAs is given below in the table (3).

Table 3: Effect of ACR on the solar cell parameters

Reflection(%)	V_{oc} (V)	I_{sc}(A)	P_{max}(mw)
10%	1.340	1.215	1.340
20%	1.337	1.087	0.863
30%	1.333	0.959	0.701

ISSN 2348 – 7968

5. Conclusion

Simulation studies were carried out using PC1D simulator program. InP is found to give maximum efficiency, where as AlGaAs gives highest open circuit voltage. As silicon is an indirect band gap semiconductor, as a result its absorption coefficient is low. Hence it may be replaced with direct band gap semiconductor materials like InP or AlGaAs or GaAs.

References

1. Liu,L.“Commenton‘recent progress in thermodynamics of radiation-exergy of radiation,effective temperature of photon and entropy constant of photon,’(Jun.).Sci. China, Ser. E: Technol. Sci. 2009;52 (6): 1809–1810.
2. Shah,A.S.B.M.,Yokoyama,H.,Kakimoto,N.,High-precision fore casting model of solar irradiance based on grid point value data analysis for an efficient photovoltaic system (Apr.). IEEE Trans. Sustain Energy.2015;6 (2): 474–481.
3. Fonash,StephenJ. Solar Cell Device Physics. 2010; Elsevier,
4. Parnis, J.M., Oldham, K.B.Beyond the beer–lambert law: the dependence ofabsorbance on time in photochemistry (Sep.). J. Photochem. Photobio. A Chem. 2013;267: 6–10.
5. Hecht, E. *Optics* (5th Edition). 2017;Pearson Education
6. Kasap, S.O. "Principles of Electronic Materials and Devices," 3rd Edition, 2005;McGraw-Hill Education
7. Bergmann, R.B. and Werner, J.H., “ The future of crystalline Si thin Films on Foreign Substrate”, Thin Solid Films. 2002;403-404: 162-169
8. Masafumi Yamaguchi , Tatsuya Takamoto , Kenji Araki , Nicholas Ekins-Daukes “Multi-junction III–V solar cells: current status and future potential” Solar Energy 2005;79: 78–85
9. Keavney CJ, Haven VE, Vernon SM. “Emitter structures in MOCVD InP solar cells”. Conference Record, 21st IEEE Photovoltaic Specialists Conference, Kissimimee; 141–144 (May 1990)
10. Bauhuis GJ, Mulder P, Schermer JJ, HaverKamp EJ, vanDeelen J, Larsen PK. “High efficiency thin film GaAs solar cells with improved radiation hardness.” 20th European Photovoltaic Solar Energy Conference, Barcelona;June, 2005: 468–471 ,
11. Moutinho, H.R., Hasoon, F.S., Abulfotuh, F., Kazmerski, L.L., “Investigation of polycrystalline CdTe thin films deposited by physical vapor deposition, close-spaced sublimation, and sputtering” J. Vac. Sci. Technol. A. 1995;13 (6): 2877–2883
12. Dang W L, Fu Y Q, Luo J K, Flewitt A J, Milne W I. “Deposition and characterization of sputtered ZnO films. Superlattices and microstructures”, 2007 July-Dec;42(1-6):89-93.

ISSN 2348 – 7968

13. Lehraki N, Aida M S, Abed S, Attal N, Attaf A, Poulain M, “ZnO thin films deposition by spray pyrolysis: Influence of precursor solution properties”. Current Applied Physics,2012 ;12(5):1283-1287.
14. Linhua X U, Xiagyin L, Yulin C, Fei X, “Structural and optical properties of ZnO thin films prepared by sol–gel method with different thickness Applied Surface Science”, 2011Dec;257(9): 4031-4037
15. Tsoutsouva MG, Panagopoulos CN, Papadimitriou D, Fasaki I, Kompitsas M. “ZnO thin films prepared by pulsed laser deposition”. Materials Science and Engineering: B. 2011 Apr; 176(6):480-483.
16. Mane R S, Lokhande C D "Chemical Deposition Method for Metal Chalcogenide Thin Films”. Journal of Materials Chemistry and Physics, 2000;65:1-31.
17. Fouad OA, Ismail AA, Zaki ZI, Mohamed RM. “Zinc oxide thin films prepared by thermal evaporation deposition and its photocatalytic activity”. Applied Catalysis B: Environmental. 2006 January; 62(1-2): 144-149
18. Asim, N., Sopian, K., Ahmadi, S., Saeedfar, K., Alghoul, M. A., Saadatian, O., et al. **“**A review on the role of materials science in solar cells”. Renewable and Sustainable Energy Reviews, 2012; 16(8): 5834-5847.
19. solanki, C.S. “Solar Photovoltaics Fundamentals, Technologies and Applications” PHI Learning Private Ltd., New Delhi(2011)
20. Green M.A. “Solar cells: Operating Principles ,Technology and System applications”, Prentice Hall Inc., Englewood Clffs, N.J., USA,(1982)
21. Sze, S.M. “Physics of Semiconductor Devices” 1981. John Willey & Sons, Newyork