Research Article
Open Access

Simulation design of multi-junction solar cell

Volume 3 Issue 1 - 2019

Shoaib Rauf, Ali Raza Kalair, Nasrullah Khan
Department of Electrical Engineering, Comsats Institute of Information Technology, Pakistan

Correspondence: Shoaib Rauf, Department of Electrical Engineering, Comsats Institute of Information Technology, Park Road, Tarlai Kalan, Islamabad 45550, Pakistan, Email engr.shoab@uog.edu.pk, 13030@students.au.edu.pk, nasrulahk@yahoo.com

Received: January 23, 2019 | **Published:** March 19, 2019

Abstract

This paper presents the idea of increasing the efficiency of solar cells by considering efficient junction structure and using different spectrums of light. Under ideal conditions for sun irradiation, three cases of simulation for triple junction and seven junctions is carried out at ideality factor of diode at 25°C. In this research, the solar cells are prepared using different semiconductor materials by adjusting their bandgap energies and their efficiencies are calculated. InGaN/AlInP/AlGaAs triple junction, solar cell was investigated for visible spectrum, and efficiency for a seven junction cell is also evaluated. Another simulation for ultraviolet, visible and infrared light (100-1000nm) is presented. Efficiencies of these cells are evaluated to be 37.2%, 21.95% and 62.6% for seven junction solar cell. We observed expected increase in efficiency with increase in number of junctions. Characteristics curves of solar cells are also presented in this work.

Keywords: Renewable energy, multi junction solar cell, pv system, fill factor, bandgap energy, open circuit voltage, short circuit current

Introduction

The major focus of recent energy policies is to increase the energy production while decreasing the consumption of primary power sources. As a consequence, development and research tends to increase the efficiency of energy systems and incorporate renewable power sources in energy production.[1] Solar power is an abundant and free source of energy. The power from solar cell is clean and environment friendly. In the last few years, the production of photovoltaic (PV) cells has exponentially increased and the cost of these cells has decreased. Top countries leading in solar power generation are China, Germany, Japan, USA and Italy.[2,3] After the oil crisis in 1970s, solar cells emerged as an effective alternate for the power source. Solar cells are advantageous because of their carbon-free nature and hence decreasing the global warming.

The only problem is the low conversion efficiency of solar cells; hence there is requirement for developing high efficiency solar cells. The reason of low conversion efficiency is the loss in solar cells due to fundamental or technological reasons. The basic losses include transmission, thermalization, and voltage and fill factor losses. These losses cannot be avoided or minimized beyond their fundamental limits. Technological losses in solar cells may be optical or electrical. Optical loss is basically the loss of photons, which are required for electron-hole pair generation. While the electrical loss belongs to the loss of photons, which are absorbed in solar cells and due to recombination or ohmic losses, cannot contribute to cell output. Optical losses reduce solar radiation by the phenomenon of reflection and shadowing of light while electrical losses have detrimental effects on both voltage and current of cell. These losses have higher percentage in case of single junction solar cell. Design problem of solar cells requires the reduction of these losses and hence increasing the absorption efficiency. Recently, a number of approaches are under consideration focusing on the reduction of losses and improved efficiency. Multi-junction solar cell technology is a suitable proposed approach.[4,5]

The ratio of power generated in solar cell and power (irradiance) received by solar cell is expressed in efficiency (η). The efficiency of single-junction solar cell at standard test condition (STC) is 22 %. The efficiency of single-junction solar cell is low and most of the photons penetrate and are dissipated into heat.[6] To increase efficiency of solar cell multiple PN junctions of different materials are used. These multiple semiconductor materials are stacked over in such a manner that the material of higher bandgap energy is placed on top, while material of lower bandgap is placed at the bottom of cell. Each material's p-n junction will produce electric current in response to different wavelengths of light, so more energy can be captured. Efficiency of triple junction solar cell, achieved practically in laboratory at STC is about 37.9%, for four to five junction the efficiency is nearly 46%. Efficiency for infinite PN junctions, calculated theoretically is about 86% at air mass AM0 and at temperature 25 ^{0}C.[7]

Methodology

In this research simulation for various cells are performed using different spectrum of light. The cell InGaN/AlInP/AlGaAs was used for visible spectrum. Their Bandgap Energies (E_g) are adjusted so that the photons in the spectrum are efficiently used. The bandgap energy of semiconductor materials is adjusted by using different composition ratio in order to achieve maximum efficiency for same lattice constant and can be varied by using different composition of x. The bandgap energy in multi-junction solar cell must be selected so that each junction receives equal power and generates equal current.[8] The calculated bandgap energy is then used to find out the wavelength which in turn is used for calculating input power and short circuit current for each cell. Leakage current and open circuit voltage are also calculated. Output power and efficiency are determined for each cell. Similarly visible spectrum of light (400-700nm) is used for seven junction solar cells, efficiency and other parameters are calculated. Another spectrum (100-1000nm) of light is used for finding triple junction solar cell characteristics. Simulation for triple junction cell is carried out for UV, Visible and IR light spectrum to find efficiency of cell InGaN/AlGaAs/InGaAs. The efficency for this cell is calculated to be 21.95% . Also, the efficiency calculated for a triple junction cell for visible light spectrum is 37.2%. Figure 1 shows schematics of triple and seven junction cells, their bandgap energies and cell compostion.

The current density voltage (IV) characteristics of cell devices were investigated by using equivalent model of solar cell. The model requires various parameters V_{oc}, J_{sc}, and E_g. These values are formulated from simulation and placed in simulink model of solar cell.

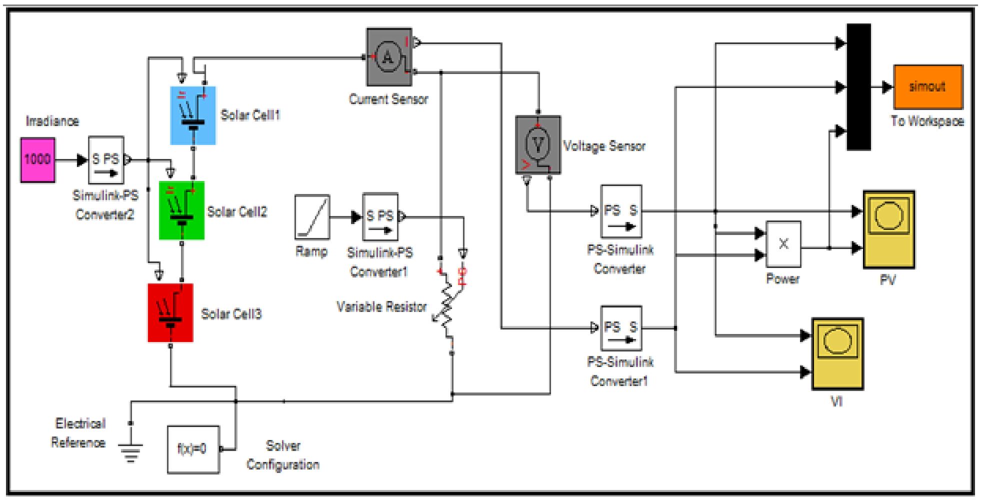

Figure 1 (a) Equivalent circuit for triple junction solar cell for visible spectrum.

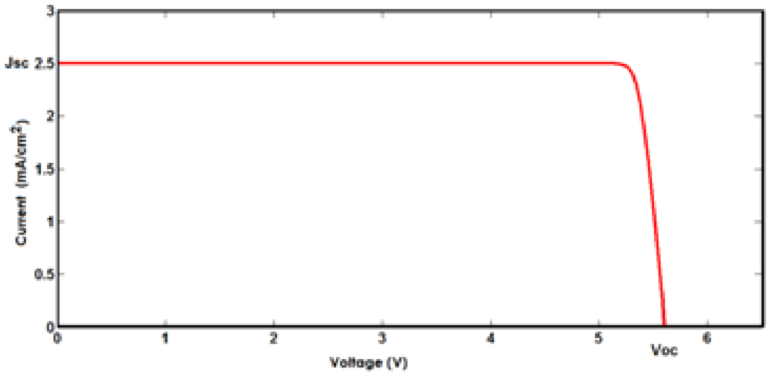

Figure 1(b) IV curve plotted for triple junction solar cell for visible spectrum.

The VI and PV characteristics curves are plotted using the following equations.[9]

$$J=Jsc-Jo[\exp\frac{(V+J.Rs)}{Vt}-1]-\left(\frac{V+J.Rs}{Rsh}\right) \qquad (1)$$

When output terminal become short circuited the voltage drops to zero, the load current $J=Jsc$. The Rs is series resistance and the value of this resistance is so small, and can be neglected.

$$V=Vt.\ln\left(\frac{Jsc-J+Jo}{Jo}\right)-J.Rs \qquad (2)$$

At open circuit voltage, current is minimum or zero, so the voltage V=Voc

$$Voc=Vt.\ln\left(\frac{Jsc}{Jo}+1\right) \text{ for } J=0 \qquad (3)$$

$$J= Jsc+[ki(Tc-Tref).\frac{G}{Gref} \qquad (4)$$

The current (J) flowing in external load resistance (R) due to voltage (J=V/R), this current also depends on irradiance (G) and temperature (T).[10]

The reverse leakage current is $Jo=A.\exp(\frac{-q.Eg}{k.T})$ (5)

A variable load is connected to solar cell and is varied from minimum to maximum via a ramp signal.

The load resistance should be such that maximum power is dissipated in the load and at this point $V= V_{max}$, $J=J_{max}$ and $P=P_{max}$.

Simulation and results

From simulation various parameters have been calculated mentioned in Table 1. Minimum short circuit current and total open circuit voltage are used to calculate output power of a solar cell. Efficiency for a triple junction solar cell for visible light spectrum is 37.2%. Efficiency for triple junction cell InGaN/AlGaAs/InGaAs is low (21.95%) because no suitable materials are yet found for UV, IR and visible spectrum. More materials should be investigated so that entire solar spectrum can be efficiently used. In MJSC, all cells are connected in series, but minimum current flows through each cell, for this reason it is desirable that each junction produces same current.

$$P_{out}= V_{oc}(t).J_{sc}(\min) \qquad (6)$$

P_{out}=0.01381W/cm^2

$$\eta(\%) = \frac{P_{out}}{P_{in}}(100) \qquad (7)$$

η=0.01381/0.0371=0.372 or 37.2 %

Table 1

η= 0.01857/0.0844=0.2195

Total P_{in} = 49mW/cm^2, J_{sc} min is 2.53mA/cm^2

P_{out}=2.53mA/cm^2 x 12.12V=30.66 mW/cm^2

η = 30.66mW/cm^2/49mW/cm^2= 0.626 or 62.6 %

Citation: Rauf S, Kalair AR, Khan N. Simulation design of multi-junction solar cell. *MOJ Solar Photoen Sys.* 2019;3(1):24–28. DOI: 10.15406/mojsp.2019.03.00031

The detailed cell characteristics consisting of bandgap energy, input power (P_{in}) short circuit current (J_{sc}) and open circuit voltage (V_{oc}) are summarized in Table 1. Output power and efficiency are calculated.

$$P_{out} = V_{oc}(t)J_{sc}(\min) = 13.18 \text{ mW/cm}^2$$

The value of maximum power P_{max} can be shown in workspace of the Matlab, which is 12.8mW/cm^2.

$$F.F = \frac{P_{max}}{V_{oc} \cdot J_{sc}} = 12.8/13.18 = 93\ \%$$

Figure 2 and Figure 3 show the measured IV and PV characteristics of InGaN/AlInP/AlGaAs triple junction solar cell in visible spectrum.

Figure 4 shows the measured IV characteristics of InGaN/AlInP/AlGaAs triple junction solar cell in UV, Visible and IR.

$P_{out} = V_{oc}(t)J_{sc}(\min)$ =4.795x 3.873 =0.01857W/cm^2 or 18.57mW/cm^2

The value of maximum power P_{max} can be shown in workspace of the Matlab, which is 16.74mW/cm^2. So the Fill factor $F.F = \frac{P_{max}}{V_{oc} \cdot J_{sc}}$ = 16.74/18.57= 90 %

$P_{out} = V_{oc}(t)J_{sc}(\min)$ = 2.53mA/m^2 x 12.12V= 30.66mW/m^2

The value of maximum power P_{max} can be shown in workspace of the Matlab, which is 28.93mW/cm^2. So the Fill factor $F.F = \frac{P_{max}}{V_{oc} \cdot J_{sc}}$ = 30.66 /28.93= 94.3 %

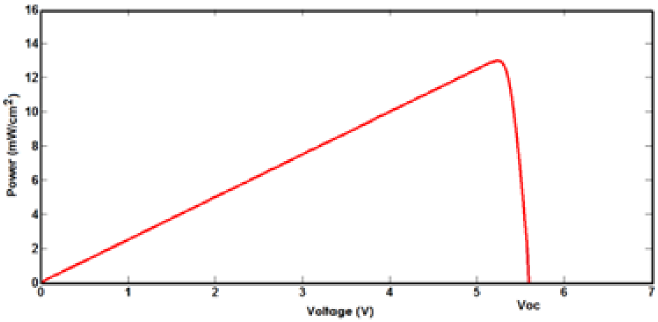

Figure 2 PV curve plotted for triple junction solar cell for visible spectrum.

The IV characterization curve in Figure 5 for seven junction solar cell at standard 1.5AM provides reliable results to compare cell performance.

Table 1 Seven junction solar cell parameters

Junction Materials	E.g	Wavelength (nm)	Power (Pin) mWt/cm²	Jsc mA/cm²	Voc V
In0.2Ga0.8N	2.85	380-435	7.5	2.53	2.386
In0.31Ga0.69N	2.56	435-485	7.4	2.852	2.105
Al0.9In0.1P	2.34	485-530	7.2	2.888	1.822
Al0.74In0.26P	2.16	530-575	6.9	3.075	1.706
Al0.79Ga0.21As	2.0	575-620	6.8	3.168	1.551
Al0.58Ga0.42As	1.85	620-670	6.7	3.533	1.339
Al0.41Ga0.59As	1.73	670-720	6.5	3.482	1.214
Total	-	-	49	-	12.12

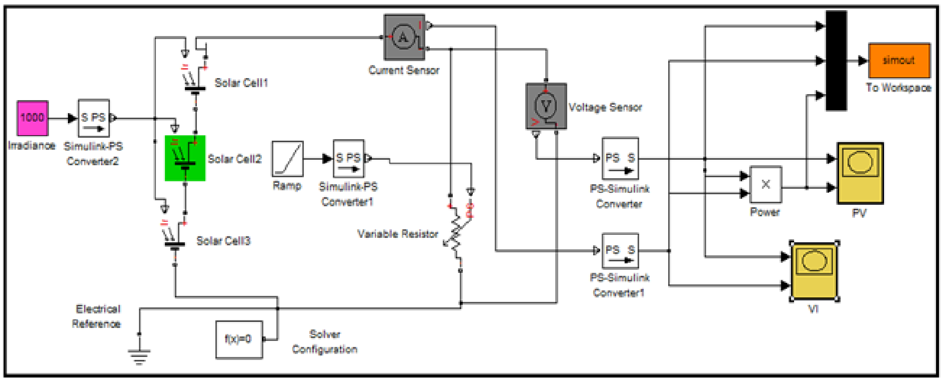

Figure 3 (a) Equivalent circuits for triple junction solar cell light spectrum of UV,Visible and IR.

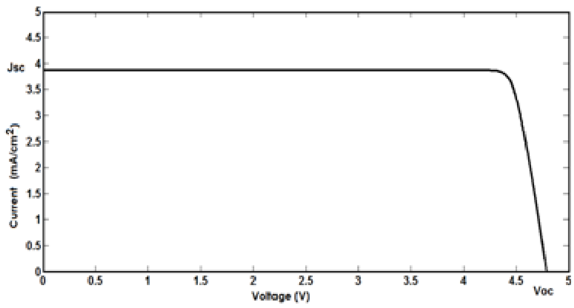

Figure 3 (b) IV curve plotted for triple junction solar cell light spectrum of UV,Visible and IR.

Citation: Rauf S, Kalair AR, Khan N. Simulation design of multi-junction solar cell. *MOJ Solar Photoen Sys.* 2019;3(1):24–28. DOI: 10.15406/mojsp.2019.03.00031

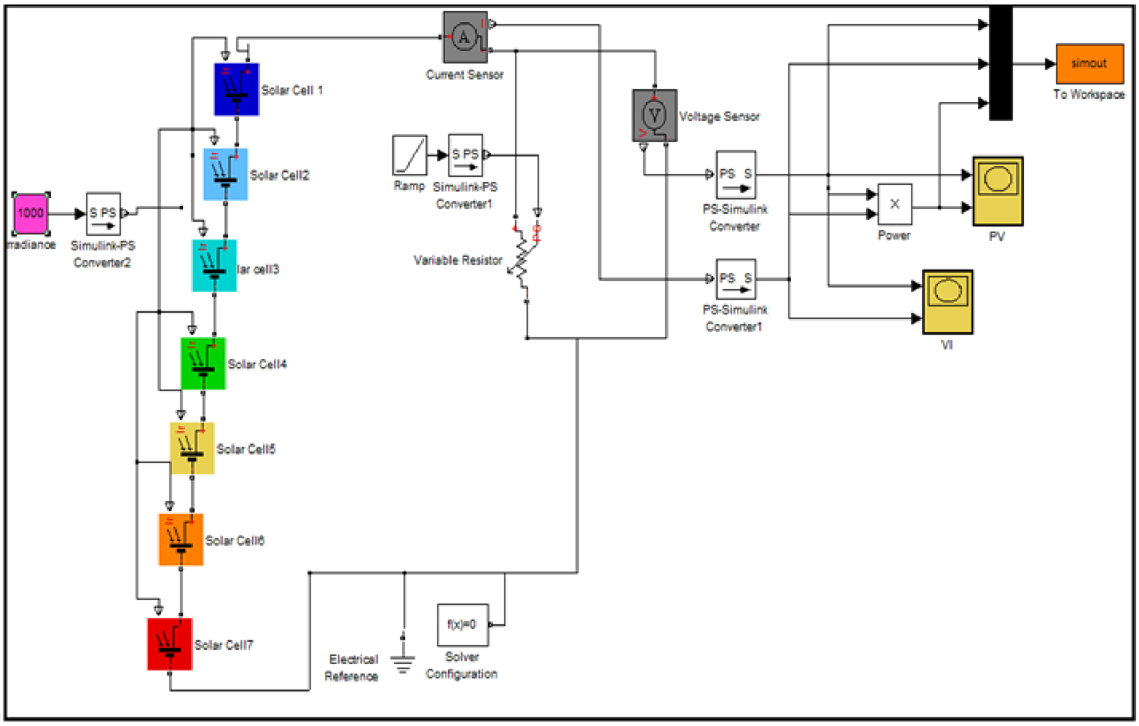

Figure 4 (a) Equivalent circuits for seven Junction solar cell visible light spectrum.

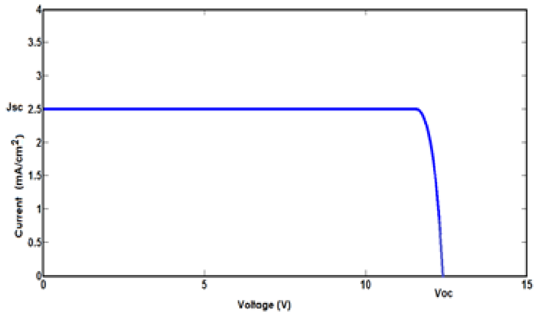

Figure 4 (b) IV curve plotted for seven junction solar cell for visible spectrum.

From the simulations performed above, following results have been extracted. As seen from the Table 2, efficiency of triple junction solar cell is greater than efficiency of seven junction cell. Seven junction cell designs allows finer division of incident spectrum allowing all sub cells to be current matched to the low current producing sub cell. Thermalization loss and I^2R losses are also reduced. Hence by increasing the number of junctions efficiency of cell also increases. Efficiency for triple junction cell InGaN/AlGaAs/InGaAs is low because no suitable materials are yet found for UV, IR and visible spectrum. More materials should be investigated so that entire solar spectrum can be efficiently used.

Table 2 Comparison of different solar cell efficiencies

Number of Junctions at STC	% efficiency
Single junction silicon solar cell	22
Triple junction InGaN/AlInP/AlGaAs for visible spectrum	37.2
Triple junction InGaN/AlGaAs/InGaAs for UV,IR and visible spectrum	21.9
Seven junction solar cell for Visible Spectrum	62.6

Conclusion

In this research, simulation for three different solar cells are performed. Visible spectrum of light (400-700nm) is used for triple and seven junction solar cells, efficiency and other parameters have been calculated. Another spectrum (100-1000nm) of light is used for finding triple junction solar cell characteristics. The spectrum is divided into ultraviolet, visible and infrared light. The efficiency of this cell is found low (22%). It is observed that the efficiency of a multi-junction solar cell can be increased by increasing number of cell junctions, equalizing short circuit current in each sub cell, decreasing cell temperature and increasing light concentration. If efficiency of a multi-junction solar cell is low, all parameters V_{oc}, J_{sc}, J_o, P_{in} of each cell are checked. The generated photo current should be the same in each cell. A semiconductor material of desired bandgap energy is selected. Bandgap energy is adjusted to match the generated photo current and the lattice constant of all cell. In this simulation, efficiency can be increased by current matching in each cell. Also, with increase in voltage and light concentration efficiency of cell can be increased.

Acknowledgments

None.

Conflicts of interest

The author declares that there is no conflict of interest.

References

1. Mastny P, Matousek A, Machacek J. Renewable energy sources in combined systems - On-line system for measuring and collecting data. *WSEAS Trans Environ Dev*. 20008;4(1):6–11.
2. Global Market Outlook for Solar Power. 2015−2019.
3. IEA PVPS: 177 GW of PV installed worldwide. *pv magazine International*. 2017.

4. Shivaganaik H, Jangamshetti SH. Modeling and Analysis of Multi-junction Solar Cells. 2011 International Conference on Emerging Trends in Electrical and Computer Technology. 2011;174–179.

5. McMahon WE, Friedman DJ, Geisz JF. Multijunction solar cell design revisited: disruption of current matching by atmospheric absorption bands. *Prog. Photovoltaics Res*. 2017;25(10):850−860.

6. Blakers A, Zin N, McIntosh KR, et al. High Efficiency Silicon Solar Cells. *Energy Procedia*. 2013;33:1–10.

7. King RR, Symko-davies M, Posey-eddy F, et al. Raising the Efficiency Ceiling in Multijunction Solar Cells Acknowledgments. 2009;14–16.

8. Das N, Al Ghadeer A, Islam S. Modelling and analysis of multi-junction solar cells to improve the conversion efficiency of photovoltaic systems. 2014 Australasian Universities Power Engineering Conference (AUPEC). 2014:1–5.

9. Shukla A, Khare M, Shukla KN. Modeling and Simulation of Solar PV Moduleon MATLAB/Simulink. *Int J Innov Res Sci Eng*. *Technol*. 1970;4(1):1−12.

10. Park J, Kim H, Cho Y, et al. Simple Modeling and Simulation of Photovoltaic Panels Using Matlab/Simulink. *Modeling of Photovoltaic Module*. 2014;73:147–15514.