

Theoretical Study of Multiple Solar Cells System as a Function of Temperature

Hassane Ben Slimane*, Ben Moussa Dennai, and Helmaoui Abderrachid

Laboratory of Semiconductors Devices Physics,
Physics Department, University of Bechar, P.O. Box 417
Bechar, Algeria

*Corresponding author, e-mail: hassane_ben@yahoo.fr

Abstract

A simulation model has been performed on materials as Ge, Si, GaAs, AlGaAs and the values of gaps E_{gk} of hypothetical materials, the calculation of the corresponding maximum efficiency was carried out for multigap solar cells systems coupled in splitting mode. The effects of an optical coupling by a dichroic mirror between independent solar cells, and solar cells coupled in series have been analysed. One particular result of our study is that the coupling by a dichroic mirror between an independent cell gives an interesting efficiency.

Keywords: multiple solar cells, Dichroic system, multijunction, Tandem solar cells

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1. Introduction

The analysis of single-junction solar cell performance shows that two major losses are due to weak photons and excess photon energy [1]. The weak photons are not absorbed by the cell because their energy is lower than the energy band gap that do not create more than one electron-hole pair. This excess photon energy is dissipated in the form of heat.

The multijunction approach requires that incident photons be directed on to the junction that is tuned to the photon's energy. In general the solar spectrum can be split by using a dichroic mirror (filter and reflector) system, if the subcells are electrically independent, so they need the external load circuit (case of fig 1.a). However, if the subcells are connected in series, the total photocurrent can be no larger than the smallest photocurrent of any of the subcells.

The aim of our work is a comprehensive study of the multiple solar cells system in two main parts: The first is to compare using a theoretical model between the two systems (independent and series connected systems). For the second part we study the factors that limit performance for solar cells dichroic mode with a simple system of two cells. To collect the characteristics of photovoltaic component, and determine its behavior, we must study the following parameters: Short-circuit current; the open circuit voltage; the efficiency photovoltaics

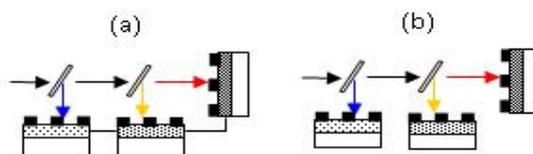


Figure 1. Multijunction Solar Cells:
(a) Series connected dichroic system, (b) Independent dichroic system

2. Conversion Efficiency Of Single Solar Cell

Under illumination, the cell may be represented by an equivalent circuit based on the single-diode model, as shown in Figure 2. The cell is described as a current source in parallel with the junction as:

$$I = I_{ph} - I_d - I_{Sh} \tag{1}$$

whith: $I_d = I_0 \left(\exp \left[\frac{q}{nkT} (V + IR_S) \right] - 1 \right)$

$$I_{Sh} = \frac{V + IR_S}{R_{sh}}$$

Where I_{ph} represent the photocurrent, I_d current flowing through cell without illumination I_0 is the saturation current; R_S and R_{Sh} are respectively series resistance and shunt resistance, n is the ideality factor, q is elementary electron charge, k is the Boltzmann constant, and T is the absolute temperature.

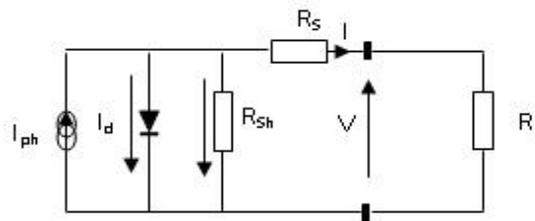


Figure 2. Equivalent Circuit of Solar Cells

The dark saturation current can be described by:

$$I_0 = K_e^{-E_g/kT} \tag{2}$$

Where $K_e = q \cdot N_c \cdot N_v \times \left[\frac{1}{N_A} \cdot \left(\frac{D_n}{\tau_n} \right)^{1/2} + \frac{1}{N_D} \cdot \left(\frac{D_p}{\tau_p} \right)^{1/2} \right]$

If every photon having an energy $h\nu > E_g$ contributed one minority carrier to the short circuit current. The photocurrent can be related to incoming light as follows:

$$I_{ph} = Qq \int_{E_g}^{\infty} N_{ph}(E_{ph}) dE_{ph} \tag{3}$$

Q is overall cell quantum efficiency, E_g is the band gap of the cell and N_{ph} is number of photons which have energies in the rang (E_{ph}, dE_{ph}) .

The maximum output power of the illuminated solar cell corresponds to the point on the current–voltage curve where product of voltage and current reaches maximum value which means that first derivative $d(IV)/dV$, must be equal to zero, i.e.:

$$\left. \frac{dP}{dV} \right|_{V=V_m} = \left. \frac{d(I.V)}{dV} \right|_{V=V_m} = \left. \frac{d \left[\left(I_{ph} - I_0 \left(\exp \left[\frac{q}{nkT} (V + IR_S) \right] - 1 \right) - \frac{V + IR_S}{R_{sh}} \right) V \right]}{dV} \right|_{V=V_m} \tag{4}$$

Solving Equation (4) gives an implicit relation from which value of voltage V_m corresponding to maximum power point may be derived:

$$\frac{I_{ph}}{I_0} + 1 = \exp\left[\frac{q}{nkT}(V_m + IR_S)\right] \left(\frac{q}{nkT} V_m + 1\right) \quad (5)$$

The current at maximum power I_{mp} is easily calculated from the relation (1) $I_m(V_m)$, the cell parameters are calculated from the same equation as follows:

a) For $V = V_{OC}$ and $I = 0$ (V_{OC} : the open-circuit voltage)

$$0 = I_{ph} - I_0 \left(\exp\left[\frac{q}{nkT}(V_{OC} + IR_S)\right] - 1 \right) - \frac{V_{OC} + IR_S}{R_{sh}} \quad (6)$$

b) For $I = I_{sh}$ and $V=0$ (I_{sh} : the short-circuit current)

$$I_{sh} = I_{ph} - I_0 \left(\exp\left[\frac{q}{nkT}(I_{sh} R_S)\right] - 1 \right) - \frac{I_{sh} R_S}{R_{sh}} \quad (7)$$

Using definition of the solar cell conversion efficiency it may be written:

$$\eta = \frac{P_m}{G} \quad (8)$$

Where P_m is maximum power of the cell and G_0 is the value of the total power global irradiance of the incident photon flux (AM1.5) given by [3].

3. Conversion Efficiency of Multiple-Cell Photovoltaic System

3.1. Subcells Electrically Independent

In the case of subcells electrically independent the conversion efficiency of the system is calculated as a simple sum of the efficiencies corresponding to particular cells.

$$\eta_T = \sum_i^n \eta_i \quad (9)$$

3.2. Series-connected Subcells

For any set of n series-connected subcells (or, indeed, any sort of two-terminal element or device) whose individual current–voltage ($J - V$) curves are described by $V_i(J)$ for the i th device, the $J - V$ curve for the series-connected set is simply:

$$V(J) = \sum_i^n V_i(J) \quad (10)$$

That is, the voltage at a given current is equal to the sum of the subcell voltages at that current. Each individual subcell will have its own maximum-power point (V_{mi}, J_{mi}) which maximizes $J.V_i(J)$. However, in the series-connected multiple cells, the currents through each of the subcells are constrained to have the same value, and therefore each subcell will be able to operate at its maximum-power point only if J_{mi} is the same for all the subcells, that is,

$J_{m1} = J_{m2} = \dots = J_{mn}$. If this is the case, then the maximum power output of the combined multiple-cells is the sum of the maximum power outputs ($V_{mi} \cdot J_{mi}$) of the subcells. On the other hand, if the subcells do not all have the same value for J_{mi} , then in their series-connected multiple-cells combination, some of the subcells must necessarily operate away from their maximum-power points, so the total current can be no larger than the smallest current of any of the subcells and the maximum generated power is calculated as:

$$P_{mT} = J \cdot \sum_i^n V_{mi}(J) \quad (11)$$

The efficiency of the multiple cell photovoltaic system therefore:

$$\eta_T = \frac{P_{mT}}{G} \quad (12)$$

The variation of band gaps with temperature can be expressed approximately by a universal function.

$$E_g(T) = E_g(0) - \frac{\alpha T^2}{T + \beta} \quad (13)$$

Where α and β are constants specific to each semiconductor. It is clear that as the temperature increases, the intrinsic concentration increases, and thus recombination increases, and cell performance is impaired. Band gap narrowing, referred to earlier, is a reduction in band gap due to high doping and also serves to increase n_i and impair solar cell performance.

4. Results

In this section we consider associations with particular materials such as Ge, Si, and GaAs for the dichroic mode of two cells and three cells, then we will calculate the efficiency for the independent system and the system connected in series.

The efficiency of a solar cell can be increased substantially by using dichroic multijunction solar cells. The theoretical limit to the AM1.5 efficiency of a low band gap cell is about 56% [4]. The current-voltage of two solar cells is obtained from the Equation (1). Figure 3 show how two solar cells with different energy gaps E_g (AlGaAs) and E_g (Si) divide the incident energy current of the AM1.5 spectrum.

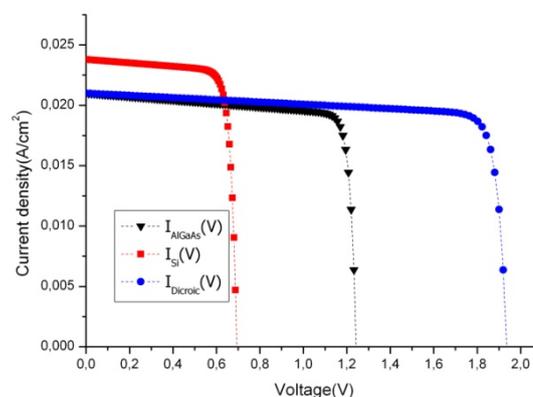


Figure 3. J-V Characteristics of Series Connected Solar Cells AlGaAs/Si

The energy current first falls on the cell with the greater energy gap $E_g(\text{AlGaAs})$, which $h\nu \geq E_g(\text{AlGaAs})$ absorbs all photons with $h\nu < E_g(\text{AlGaAs})$ and transmits all photons with the cell behind, with the lower energy gap, then absorbs the photons with $E_g(\text{Si}) \leq h\nu < E_g(\text{AlGaAs})$. The Table 1 lists the efficiency for the independent system and the system connected in series. Energy gap, simulated efficiency of each cell in two junction dichroic system.

Table 1. Efficiency of the tow multiple solar cell system for different cases

Dichroic system	2.086eV/GaAs	1.798eV/Si	1.495eV/Ge	GaAs/Ge
Independent system	$\eta=32.10\%$	$\eta=35.93\%$	$\eta=28.72\%$	$\eta=31.93\%$
System connected in series	$\eta=27.34\%$	$\eta=33.19\%$	$\eta=27.26\%$	$\eta=25.52\%$

The Figure 4 show that the voltage at the open circuit voltage decrease with increasing temperature, while the current density J is relatively independent of temperature. Solar cells are sensitive to temperature. Increases in temperature reduce the band gap of a semiconductor (Equation (13)) In a solar cell, the parameter most affected by an increase in temperature is the open-circuit voltage and the conversion efficiency.

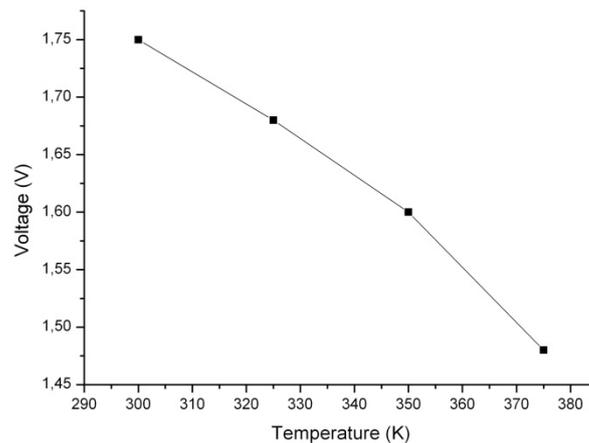


Figure 4. Open Circuit Voltage at Different Temperatures

The Table 2 lists the efficiency at the maximum power point decrease with increasing temperature, while the efficiency of independent systems is relatively decrease more than the system connected in series (Relations 8 and 12).

Table 2. Efficiency as a Function of Temperature in the Tow Multiple Solar Cell System

Temperature	Independent system	System connected in series
T=300K	31.81%	26.35%
T=310K	31.13%	25.13%
T=320K	30.19%	23.6%
T=325K	29.87%	22.96%

5. Conclusion

The internal power losses causing heating of the cells in the tow-cell system based on AlGaAs/GaAs-Si is reduced to approximately half of corresponding single-cell systems for the same illumination. This reduction is favorable to the design requirement of cell cooling needed to keep the cell temperature stable and low. In the electric coupling of two different types of solar cells, the I(V) characteristic, which has the more important current is modified.

The calculations described in this paper were conducted for the AM1.5, the results shows that the efficiency of independent coupled cells is interested.

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