COMPARATIVE STUDY BETWEEN COUPLING SYSTEMS OF MULTI JUNCTION PHOTOVOLTAIC CELLS

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This research work aims at studying systems of multi junction photocells mixed-mode (tandem and diachroic) where we take into consideration associations of particular materials, namely for a device of five cells coupled 1 by 2 by 2 by a diachroic mirror. We carried out a comparative study between two systems (the independent system and the electrical coupling system) in order to obtain better performances (photo-currents and cells efficiencies).

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1. Introduction

Energy excess and photons non-absorption are the most important losses responsible of photocells low efficiency. Using simultaneously many photocells of different materials enables to limit somewhat these losses and get better efficiencies. Cells could be coupled one behind the other on the optical path as this is done in tandem systems [1] or via diachroic mirrors which emit on each cell a well-defined part of the solar spectrum like the diachroic system [2]. Hence, different cells are placed on the optical beam and coupled electrically like the tandem system.

Prior theoretical studies emphasized possible efficiency increases of independent cells systems coupled in tandem or diachroic modes. However, it is to be noted that mixed groupings with combinations of the two known coupling modes: tandem and diachroic.

In the present work, we analyze this problem where optical coupling between cells is not only carried out by one mode or the other, tandem or diachroic, but also by combining these two modes.

Added to that, we considered the case where cells are put in electric series using a simple conducting wire linking initially independent photocells between each other. This study's aim is to make evidence of differences existing between the two modes, diachroic and tandem, electrically coupled and taken independently.

We studied five and four cells made by hypothetical materials with a band gap wide of respectively Eg1, Eg2, Eg3, Eg4, Eg5 where always $Eg_1>Eg_2$; Eg2 $>Eg_3$; $Eg_3>Eg_4$; $Eg_4>Eg_5$; we give Egk optimal values and maximal efficiency values of our systems.

To have photovoltaic component characteristics and determine its behavior we had to study the following parameters:

-short-circuit current Icc.

-Open circuit tension Voc.

-Photovoltaic efficiency η.

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2. The studied structure

Cells are put in layers in decreasing order of induced band Eg height values; the device with the highest value is put on the top and receives all radiations [3], for a given solar spectrum and a finite material number. Values of Eg that are imposed yield maximum efficiency for the system [5].

For example, the optimal coupling for five cells with AM1.5 spectrum could be obtained for Eg values which correspond substantially to .

For this, we have chosen Eg1=2.4eV, Eg2=1.84eV, Eg3=1.43eV, Eg4=1.12eV, Eg5=0.74eV, under the spectrum AM1.5.

2.1. GaAs System

The structure of GaAs direct band gives it interesting electronic features. Electrons effective mass is very weak in the central valley Γ. Consequently, the electronic mobility is higher. The band gap height is increased (1,424 eV to 300K). For the sake of comparison, the corresponding values in Silicon and Germanium are of 1,12 eV and 0,6 eV respectively.

In the weak field, electrons mobility is very important in GaAs than in Silicon even at a strong doping level, added to that, the effect of over speed in GaAs which enables transit time reduction in the basis and contact resistance.

2.2. GaInP System

GaInP could be obtained as a ternary compound from two binary semiconductors InP and GaP. Its gap band energy equals 1,87 eV. This material is used to manufacture photovoltaic cells transmitters. Electrons effective mass is weaker in GaInP which enables stronger electronic mobility: 1,6 times higher than in GaAs and 9 times than in Silicon, hence a very low basis resistance. Surface recombination velocity in GaInP is inferior

Than in GaAs, which enables current increase. GaInP has higher substrate heat conductivity than GaAs's. Figure. 1 shows the studied structure with a five-cell system, dependent or electrically independent. [6]

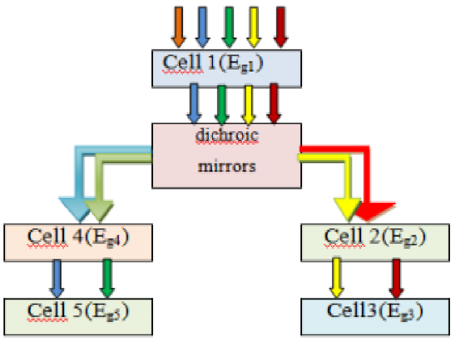

Fig.1.Five independent cells with diachroic mirror.

3.Solar cell modeling

3.1.Efficiency Calculus for Multi-Spectral Solar Cell

For convenience reasons, especially those pertaining to well-known and universal use, the solar spectrum we chose to use in our calculations is based on AMI.5 with solar constant of 1000W/m^2. Cells are conducted with a diode in case of solar cells. Fig.2.

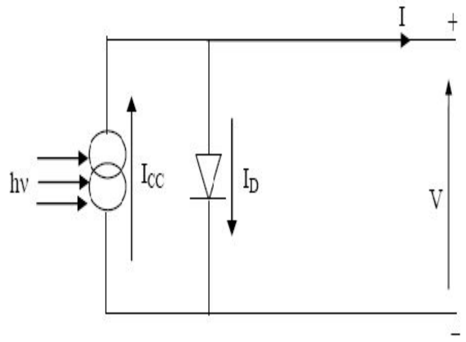

Fig.2. Electric Diagram of an Ideal Solar Cell.

We used measures of [ASTM G173-03 Reference Spectra Derived from SMARTS v. 2.9.2 (AM1.5)] which gave the solar spectrum division AM1.5 in 2000 intervals on an energy scale ranging from 4.42 to 0.3 eV. Such a great number of intervals enabled us to have higher precision as we covered all E_{gk}. [7]

3.2. Current Photon

In diachroic mode, the solar spectrum is divided by means of mirrors (supposed perfect mirrors). Each mirror emitting a part of solar spectrum on corresponding cells.

We have taken on one side absorption quantum efficiency and on the other side collection efficiency of minority carriers by p-n junction barrier, both equaling 1.0. We obtained easily a basis table [3] which gives calculated current photon from photons number N ph for energies ranging between hν and semiconductor Eg gap [8].

For the first cell:

$$N_{ph1} = \int_{Eg1}^{h\nu} n_{ph}\,(h\nu)d(h\nu) \qquad (1)$$

For the k th cell:

$$N_{phk} = \int_{h\nu-Egk}^{h\nu-Egk-1} n_{ph}\,(h\nu)d \qquad (2)$$

wherenph(hν) is elementary photons flux at hν energy of the solar spectrum. We have obviously:

For the first cell: $I_{ph1}(E_{g1}) = qN_{ph1}(h\nu)$

For the k th cell: $I_{phk}(E_{gk}) = qN_{phk}(h\nu)$

3.3. Current Characteristics – Tension (tandem-dichroic mode):

A. Short circuit current ICC :

$$I_{cck} = I_{phk} - I_{0k}\cdot\left(e^{\frac{q}{kt}(R_{Sk}\,.I_{cck})} - 1\right) - \frac{R_{sk}\,.I_{cck}}{R_{pk}} \qquad (3)$$

$$I_{CCk} = \frac{I_{phk}}{1 + \frac{R_{Sk}}{R_{Pk}}} \qquad (4)$$

B. Short circuit tension:

It is obtained for a zero-output current from the equation[9]:

$$V_{COk} = \frac{kT}{q} \times Log\left\{1 + \frac{I_{phK}}{I_{0k}}\right\} \quad (5)$$

Maximal power delivered in charge:

$$P_{\max k} = I_{mpk} V_{mpk} \quad (6)$$

With: $$V_{mpk} = V_{COk} - \frac{K.T}{q}.\log\left(1 + \frac{qV_{COk}}{K.T}\right) \quad (7)$$

And $$I_{mpk} = \frac{\left[I_{phk} - I_{0k}\left(e^{\frac{q.V_{mpk}}{K.T}} - 1\right) - \frac{V_{mpk}}{R_{pk}}\right]}{1 + \frac{R_{Sk}}{R_{Pk}}} \quad (8)$$

Efficiency:
k cell efficiency:

$$\eta_{mk} = \frac{P_{\max k}}{P_{in}} = \frac{I_{mk} V_{mk}}{\varphi_k .S_k} \quad (9)$$

Where: Pin is the total incident light power per surface unit.

For the mixed mode (tandem-diachroic), we have two efficiencies to calculate:

If we have independent cells, the efficiency of n solar cells in mixed mode (tandem-diachroic) equals:

$$\eta = \sum_{k=1}^{n} \eta_k \quad (10)$$

When cells are linked between them by conducting wire, we have to note that the same current goes through all cells and the total terminal electric tension and the whole device will be simply the sum of terminal tensions of each cell.

After having determined the operating point I_{mk}, V_{mk} of independent cells, we imposed series current I which equals the smallest current I_{mk} that is $I = \inf(I_{mk})$.

We obtained usage tension V_{mk} and useful tension $P_k = V_{mk}.\inf(I_{mk})$

Global efficiency will be [4]:

$$\eta = \frac{\sum_{k=1}^{n} P_k}{P_{in}} \quad (11)$$

4. Results

4.1 I(V) and P(V) Characteristics of the first system five cells independent with a mirror

In this system, we have five cells optically associated and electrically independent. The Fig. 3 represents I(V) property for the first system. We remarked that the system yields better efficiency. The Fig .4 represents P(V) Characteristic for the first system.

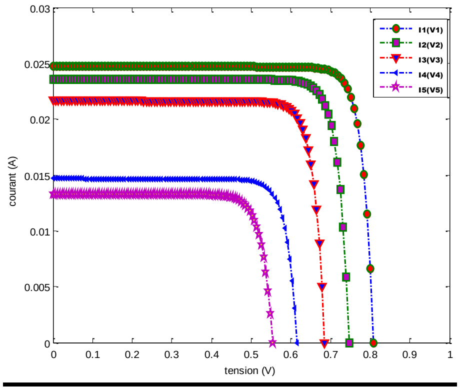

Fig. 3.I(V) Characteristic of the First System.

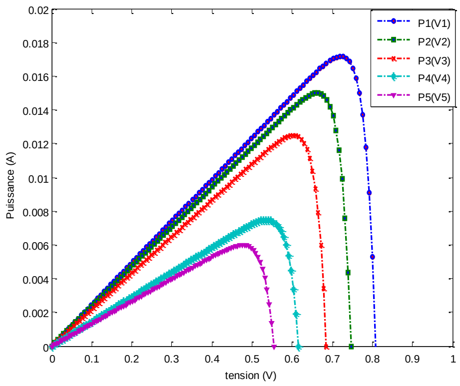

Fig. 4. P (V) Characteristic of the First System.

The Table 1 gives modeling results (short-circuit current Jsc, open circuit tension Voc, conversion efficiency η) of the first circuit, added to that, this same table compares our calculated results to those of [10].

Table 1Photovoltaic Dimensions Of The First System.

Materials	**Eg(eV)**	**Our calculation**			**ref [der]**
		Icc(mA)	**Vco(V)**	η(%)	η(%)
	2.4	24.74	0.808	17.17%	14.72%
GaInP X=0.47/ y=0	1.84	23.58	0.747	14.98%	15.52%
GaAs X=1 y=1	1.43	21.68	0.685	12.49%	13.19%
GaInAsP X=0.47/ y=0.63	1.12	14.67	0.616	7.48%	8.78%
GaInAs X=0.47/ y=1	0.74	13.30	0.554	5.99%	4.93%
The global Efficiency is =				58.11%	57.14%

4.2. I-V and P(V) Characteristics of the Second System 1by2by2 by means of a Mirror:

In this system, five cells electrically associated and independent 1by2by2 by means of a diachroic mirror.

Figs. 5 and 6 represents respectively I(V) and P(V) for the second system.

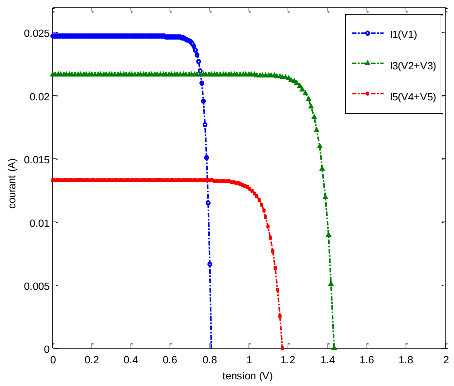

Fig. 5.I(V) Characteristic of the Second System.

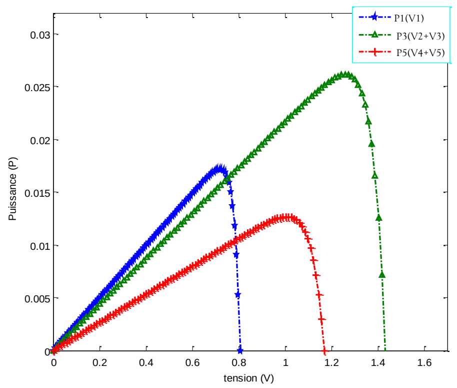

Fig. 6.P(V) Characteristics of the Second System.

Photovoltaic dimensions of the second system are given in the table II.

Table 2.Photovoltaic Dimensions Of The Second System.

Materials		GaInP/ GaAs	GaInAsP/ GaInAs
Eg(eV)	2.4	1.83 1.41	1.12 0.74
$V_{CO}(Volt)$	0.808	1.43	1.17
$I_{CC}(mA)$ inf	24.74	21.68	13.30
Efficiency η(%)	17.17	26.23	12.74

According to this table, we remark that second system efficiency is less than the first system's because the current going through the device is overwhelmed by the cell of the weakest current.

4.3. I-V and P(V) Characteristic of the Third Electric Coupling System with a Mirror:

Five cells connected between each other in series, the current going through the device is overwhelmed by the cell of the weakest current.

Fig. 7 and Fig. 8 represent respectively I(V) and P(V) properties for the five cells in electric series.

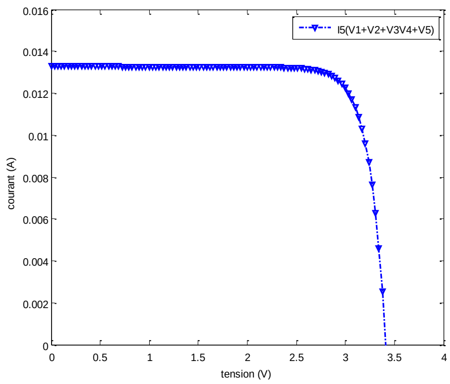

Fig. 7. I(V) Characteristic of the Third System.

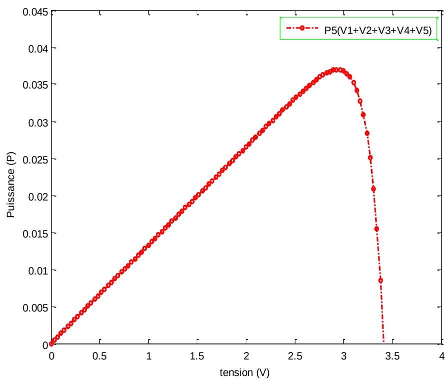

Fig. 8. P(V) Characteristic of the Third System.

According to electric characteristic represented in Figs. 7 and 8: The current going through the device is imposed by the cell of the weakest current; Open circuit tension (Vco) is the sum of tensions in the open circuit of each cell. However, we noticed that the maximal power of this device is not the sum of maximal power of each cell. Hence, this device efficiency is not the sum of efficiencies.

Cell in mixed mode and electric coupling system:

$$V=V_1+V_2+V_3+V_4+V_5$$

$$I_{Ph}=\min(I_{phk})$$

Photovoltaic dimensions of electric coupling system are given in the table III.

Table 3.Photovoltaic Dimensions Of The Third System .

Photovoltaic Dimensions	**Five-Cells Electric Coupling**
$V_{CO}(Volt)$	3.408
$I_{CC}(mA)$ inf	13.30
Efficiency $\eta(\%)$	37.77

4.4. Efficiency of Electric Coupling System with a Mirror:

Using the Table 3, we can calculate the system efficiency.

$$\eta_{c-él}=\frac{\min(I_{\max k})*(V_{\max 1}+V_{\max 2}+V_{\max 3}+V_{\max 4}+V_{\max 5})}{P_{in}}$$

After calculations, we found $\eta_{c-él}=37.77\%$.

6. Conclusions

In this research work, we focused on photovoltaic properties of two systems: one which is independent and the other with electric coupling of solar cell in mixed mode (tandem-diachroic).Moreover, as it is indicated above, we compared our calculated results to certain results of [10].

For the independent system, we obtained the efficiency $\eta_{ind}=58.11\%$ .for electric coupling system, we obtained the efficiency $\eta_{c-él}=37.77\%$ and for five-cell mixed mode, the efficiency $\eta_{ind}=53.44\%$.

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