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Influence of a Semiconductor Gap's Energy on the Electrical Parameters of a Parallel Vertical Junction Photocell

Nfally Dieme

Laboratory of Semiconductors and Solar Energy, Department of Physics, Faculty of Science and Technology, Cheikh Anta Diop University, Dakar, Senegal
Email: nfallydieme@yahoo.fr, fallydieme@gmail.com

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Abstract

The present work is a theoretical study on a parallel vertical junction solar cell under a multispectral illumination in static regime. The density of the minority charge carriers was determined based on the diffusion equation. Photocurrent and photovoltage are deducted from such density. All these parameters are studied taking into account the influence of the gap energy (E_g).

Keywords

Vertical Junction, Energy Gap, Photocurrent Density, Photovoltage

1. Introduction

The operation of solar cells is basically dependent on photon-electron interaction. For an electron to be removed from the valence stripe to the conduction, the minimum value of the photon energy must at least equal E_g. The gap energy (E_g) is determined by the material and fluctuates according to temperature [1].

The aim of this work is to investigate the influence of gap energy (E_g) on electrical parameters such as photocurrent and photovoltage. Knowing the evolution of these two quantities based on the gap energy is a good indicator for us to comment on the performance of solar cells and types of semiconductors for use in the manufacture of solar cells able to run at high temperature.

The density of excess minority carriers, photocurrent and photovoltage will be determined from the diffusion equations. In the second part of this work we present our simulation results.

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2. Theory

This study is based on a parallel vertical junction silicon solar cell [2] presented in **Figure 1**. The solar cell is illuminated along the *z* axis in steady state.

We assume that the following hypotheses are satisfied.

- The contribution of the emitter is neglected.
- Illumination is made with polychromatic light, and is considered to be uniform on the *z* = 0 plane.
- There is no electric field without space charge regions.

2.1. Density of Minority Charge Carriers

When the solar cell is illuminated, there are simultaneously three major phenomena that happen: generation, diffusion and recombination.

These phenomena are described by the diffusion-recombination equation obtained with:

$$\frac{\partial^2 n(x)}{\partial x^2} - \frac{n(x)}{L^2} = -\frac{G(z)}{D} \tag{1}$$

D is the diffusion constant and is related to the operating temperature through the relation [2]

$$D = \mu \cdot \frac{K}{q} \cdot T \tag{2}$$

with *q* as the elementary charge, *k* the Boltzmann constant and *T* temperature.

G(*z*) is the carrier generation rate at the depth *z* in the base and can be written as [2] [3]:

$$G(z) = \sum a_i \mathrm{e}^{-b_i z} \tag{3}$$

a_i and b_i are obtained from the tabulated values of AM1.5 solar illumination spectrum and the dependence of the absorption coefficient of silicon with illumination wavelength.

n(*x*), *L*, *τ*, and *μ* are respectively the density of the excess minority carriers, the diffusion length, lifetime and mobility.

The solution to the Equation (1) is:

$$n(x) = A\sinh\left(\frac{x}{L}\right) + B\cosh\left(\frac{x}{L}\right) + \sum \frac{a_i}{D} L^2 \mathrm{e}^{-b_i z} \tag{4}$$

Coefficients *A* and *B* are determined through the following boundary conditions:
at the junction (*x* = 0):

$$\left.\frac{\partial n(x)}{\partial x}\right|_{x=0} = \frac{S_f}{D} n(0) \tag{5}$$

This boundary condition introduces a parameter S_f which is called recombination velocity at the junction; S_f determines the flow of the charge carriers through the junction and is directly related to the operating point of the solar cell. The higher S_f is, the higher the current density will be.

In the middle of the base (*x* = *W*/2):

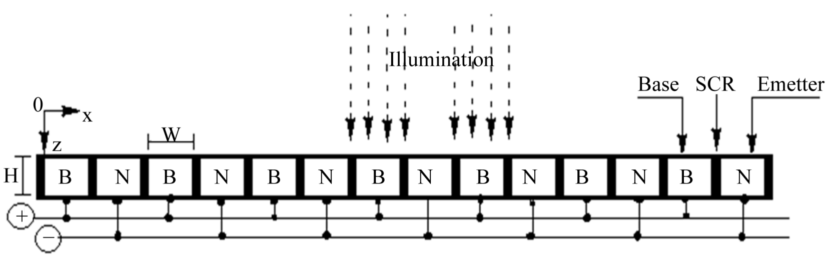

Figure 1. Parallel vertical junction solar cell (*H* = 0.02 cm; *W* = 0.03 cm).

$$\left.\frac{\partial n(x)}{\partial x}\right|_{x=\frac{w}{2}}=0 \tag{6}$$

Equation (8) illustrates the fact that excess carrier concentration reaches its maximum value in the middle of the base due to the presence of junction on both sides of the base along *x* axis (**Figure 1**).

2.2. Photocurrent Density

The photocurrent J_{ph} is obtained from the following relation given that there is no drift current:

$$J_{ph}=qD\left.\frac{\partial n(x)}{\partial x}\right|_{x=0} \tag{7}$$

2.3. Photo-Voltage

The photo-voltage derives from the Boltzmann relation:

$$V_{ph}=\frac{k\cdot T}{q}\cdot\ln\left(N_B\cdot\frac{n(0)}{n_i^2}+1\right) \tag{8}$$

with

$$n_i=A_n\cdot T^{\frac{3}{2}}\cdot\exp\left(\frac{E_g}{2KT}\right) \tag{9}$$

n_i refers to the intrinsic concentration of minority carriers in the base,
A_n is a specific constant of the material ($A_n=3.87\times10^{16}$ for silicon)
N_B is the base doping concentration in impurity atoms
E_g is the energy gap; it is given by [4] [5]:

$$E_g=E_{g_0}-\frac{a\cdot T^2}{b+T} \tag{10}$$

($E_{g_0}=1.170\ \text{eV}$; $a=4.9\times10^{-4}\ \text{eV}\cdot\text{K}^{-2}$; $b=655\ \text{K}$ for silicon).

3. Results and Discussion

In this section of our work, we present the results obtained from simulations.

3.1. Gaps Energy

When the solid temperature tends to absolute zero, two allowed energy bands play a special role. The last completely filled band is called “valence band: E_V”. The allowed energy band is called following the “conduction band: E_C”. It can be empty or partially filled. The energy between the valence band to the conduction band is called the “energy gap: E_q” [6]. **Figure 2** illustrates the band representation.

To have extraction of electrons under the influence of light, incident photon must have an energy greater than or equal to the energy of the gap. $E_g=E_C-E_V$. The gap energy is the energy that electron must absorb to be extracted.

3.2. Photocurrent Density

Figure 3 shows the photocurrent density profile versus junction recombination velocity for various values of energy gap.

It can be seen that photocurrent density quickly increases with the recombination velocity at the S_f junction until short circuit occurs. Given that the recombination velocity at the junction reflects the stream of carriers crossing the junction, an increase in this rate suggests an increase in the photocurrent density. S_f higher values represent a short circuit operation point and lower values are obtained in a situation of open circuit.

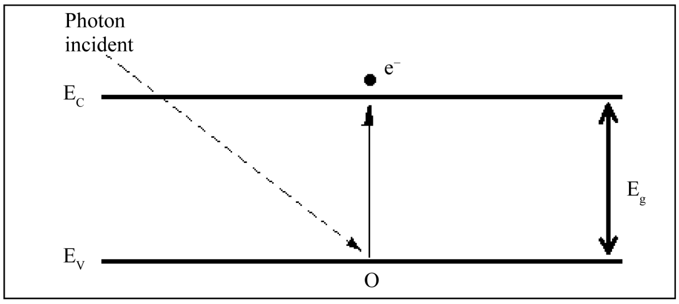

Figure 2. Gap's energy.

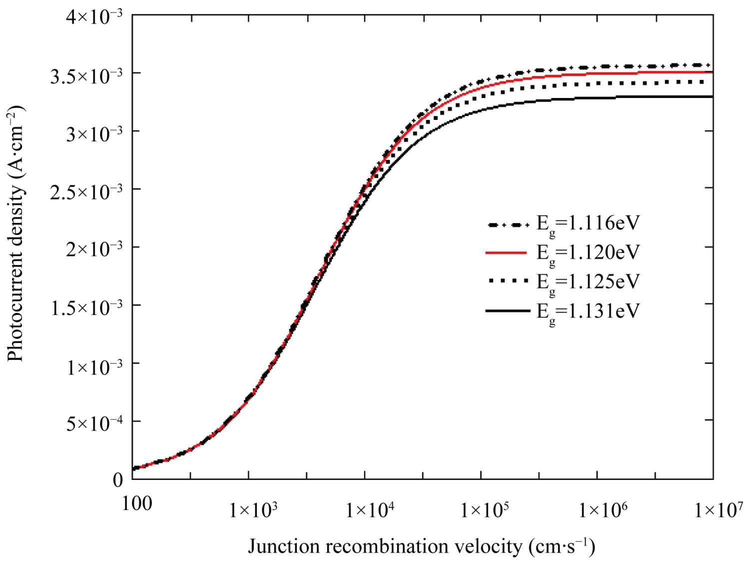

Figure 3. Photocurrent density versus junction recombination velocity ($z = 10^{-2}$ cm).

It can also be seen that the increase in the material's gap energy causes a decrease in the photo-courant density. This variation is much more visible in short circuit situations.

Indeed, photocurrent is produced by a movement of carriers photo-generated through the junction. When the height of the barred band increases, many electrons are extracted with low kinetic energy [7] [8]: this phenolmenon is called the photoelectric effect:

$$E_{\text{cinetik}} = E_{\text{photon}} - E_g .$$

Consequently the diffusion of carriers through the junction weakens as some carriers do not have enough kinetic energy to jump the depletion zone. It is said that photocurrent density decreases as the gag energy (E_g) increases.

3.3. Photo-Voltage

Figure 4 shows the evolution of photo-tension depending on recombination velocity at the junction regarding different values of the material's gap energy E_g.

Figure 4 shows that photovoltage decreases along with S_f junction recombination velocity. When S_f increases, the flow of charge carriers crossing the junction increases. Thus, fewer and fewer carriers are stored, which causes decrease in photovoltage at the junction.

Unlike photocurrent, it can also be seen that photovoltage increases as the gap energy increases. This should not be that surprising. Because the low kinetic energy possessed by some of the electrons and which is due to the growth of E_g, is not sufficient to make the charge carriers jump the depletion zone [9]. So they reach the junction and start piling up, thus increasing the difference in potential at the junction: it is said that photovoltage increases when E_g is high.

3.4. Current-Voltage Characteristics

Figure 5 shows the evolution of photo-courant density for different values of the gap energy and in relation to photo-tension.

Figure 4 shows that when photo-courant is maximized, photo-tension nears the zero level and vice versa. It can be noted that this figure perfectly confirms variation of the two physical quantities (photovoltage and photocurrent) in relation to gap energy. It can also be seen that when there is an increase in E_g of $\Delta E_g = 4\times10^{-3}$ eV, photovoltage increases by almost 10% while photocurrent decreases by about 2%.

4. Conclusion

In the simulation carried out in this work, we have demonstrated that the electric quantities of a solar cell such as photovoltage and photocurrent are very sensitive to the variation of a material's gap energy. Under the influence of temperature, an increase in the gap energy of $\Delta E_g = 4\times10^{-3}$ eV can prompt a growth in photovoltage of

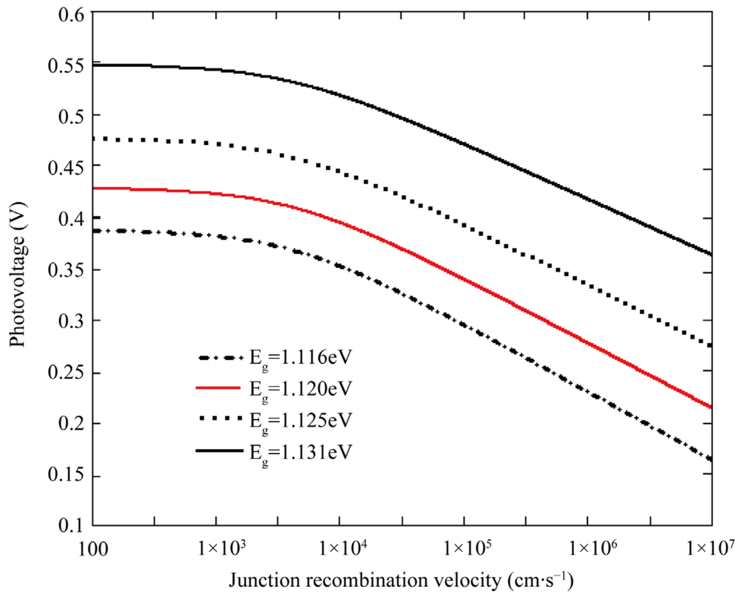

Figure 4. Photo-voltage versus junction recombination velocity ($z = 10^{-2}$ cm).

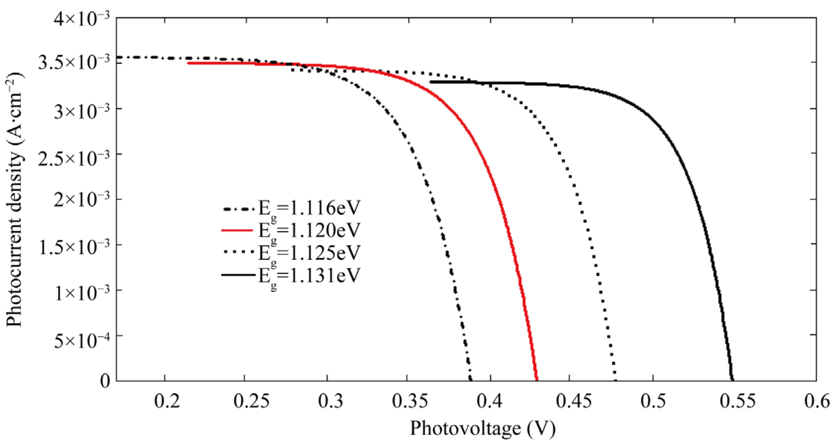

Figure 5. Photocurrent density versus photovoltage, $z = 10^{-2}$ cm.

almost 10% and a decrease in photocurrent of about 2%. We can estimate that according to experience, semiconductors have a great height of the band gap such as GaP, GaN, which are most suitable for high operating temperatures. This theoretical study can be confirmed by a comparative study of the conversion efficiency of semiconductor of different energy gap.

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