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Study of the Transient Voltage of the Silicon Solar Cell with Multi Vertical Junctions Connected in Parallel and Placed in Opened Circuit: Influence of Temperature and Magnetic Field on Transient Decay

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ABSTRACT

This work consists in studying the transient voltage of a silicon solar cell with vertical junctions connected in parallel under polychromatic illumination and under the influence of temperature and magnetic field, in open circuit transient operation. The experimental device of the transient decay who occurs between two operating points in steady state is presented. The effect of the potential difference between two operating points on the voltage amplitude is also studied. Indeed, the influence of the optimum temperature on the transient decay and on the amplitude of the voltage is also studied. This optimum temperature is obtained by determining the optimum thickness from a given magnetic field.

Key words Silicon Solar Cell, Vertical Parallel Junction, Magnetic Field, Temperature, Time Constant, Base Thickness, Transient Voltage

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1. INTRODUCTION

The silicon solar cells being under different technologies [1] have been the subject of several research works. They have undergone many changes in their structures.

The study models and the techniques used are essentially aimed at determining the phenomenological parameters [2, 3, 4], which influence the electrical parameters [5, 6, 7, 28], which are the series and shunt resistances, as well as than the capacity of the space charge area.

New architectures of solar cells have been produced, such as vertical junction solar cells (series or parallel) where the illumination is done parallel (or laterally) to the junction plane [8, 9], monofacial [10, 11] (front or rear face illumination), bifacial [12, 13] where illumination can be performed either from the front and the rear or simultaneously from both sides.

Vertical junction solar cells also called Vertical Multi Junctions (MJV) [14, 15, 16].

These structures are made from materials that are poor in electronic quality. The electronic quality is evaluated from phenomenological parameters [17, 18, 19, 20] which are the lifetime, the diffusion coefficient, the diffusion length and the mobility of the minority charge carriers, in the different regions of the solar cell, more particularly the base. By the surface which limit the various zones, the surface recombination speeds [21, 22, 23, 24, 25, 26] are also parameters which make it possible to evaluate the performance of the solar cell, which can be studied according to the models at one dimension [9, 27] or three dimensions [29,30] of space, under the conditions of operating regimes, which are: the static regime [31, 32], the transient dynamic regime [33, 34, 35, 36, 37] or frequency dynamics [38, 39, 40, 41].

Under these operating regimes, the solar cell may be subject to external conditions, which may be: temperature variations [42, 43], electromagnetic field variations [44, 45, 46, 47, 48], etc…

In regards to transient states, we can note, open circuit voltage decay (OCVD), the most popular technique, photocurrent decay (PCD) method [49], light-induced transient phase measurements photocurrent and voltage (SLIM-PCV), microwave photocurrent decay (MWPCD) [50].

In this work, we are interested in the study of a silicon solar cell (n/p) with vertical junctions connected in parallel, in transient state and placed under the double condition of temperature and magnetic field. This regime occurs between two stable states by operating points depending on two variable resistors. This technique makes it possible to obtain a transient decay at any operating point on the static I-V characteristic between two points close to the open circuit of the solar cell under illumination [51, 52]. We examine the effects of external conditions by variation of the temperature [53, 54], the magnetic field [55, 56] and the optimal thickness [57, 58] on the transient voltage and on the time (to) initiating their exponential decay [60], which delimits the conditions for experimental measurement of the time constant.

2. MATERIALS AND METHODS

2.1 Experimental apparatus

Figure 1 presents the experimental device used to obtain the transient state by variations of the operating point of the solar cell [35, 36, 37].

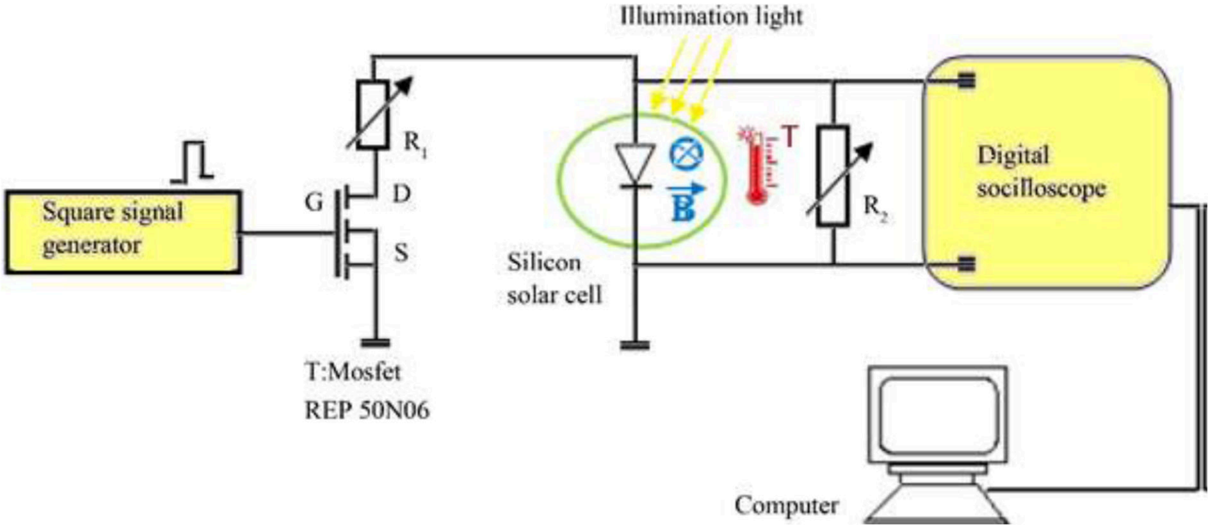

Fig. 1 Experimental device for the characterization of the solar cell

This experimental device includes a BRI8500 square wave generator which drives an RFP50N06 type MOSFET transistor, two adjustable resistors R1 and R2. The silicon solar cell placed under temperature and magnetic field, is subjected to constant multispectral lighting. A digital oscilloscope and a microcomputer are used for signal acquisition and processing. The transient decay occurs according to the following procedure, described below.

At time t<O (figure 1), the solar cell being under constant multi-spectral illumination, the MOSFET transistor is open and the solar cell is closed in series with the resistor R2 alone: this corresponds to the operating point F2 in steady state [51, 52] giving the potential V2. At t=0 (figure 1), the closing of the MOSFET begins and after a very short time the MOSFET is completely closed, then the resistor R1 is in parallel with R2 this corresponds to the operating point F1, therefore the voltage V2 goes to V1.

By varying R1 and R2, the steady state operating points F1 and F2 move over the I-V characteristic (Figure 2), to produce a transient state.

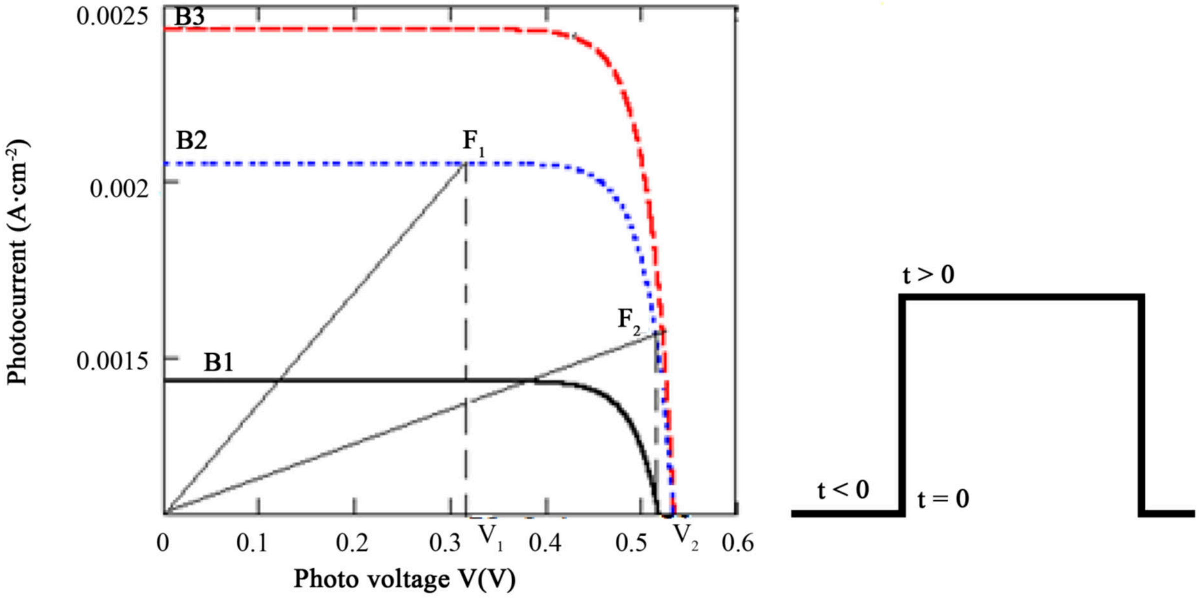

Fig. 2 Illuminated I-V curve under constant magnetic field ($B3 < B2 < B1$) with two specific operating points

In figure 3, the structure of the (n/p) silicon solar cell with vertical junctions connected in parallel under magnetic field and temperature is presented.

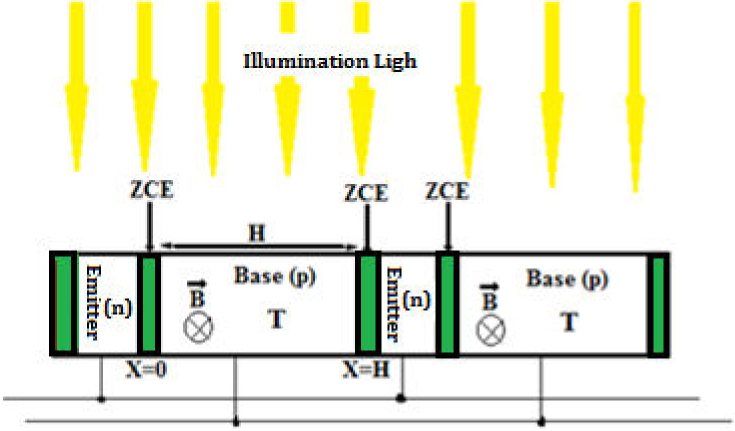

Fig. 3 Structure of (n/p) solar cell with vertical junctions connected in parallel

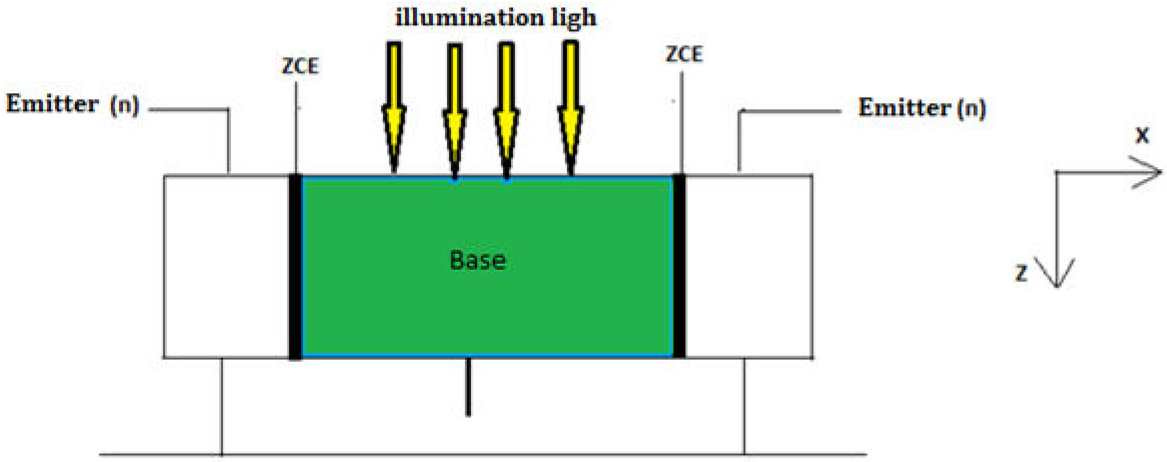

Fig. 4 Structure of a vertical junction (n/p) solar cell

The rate of generation G(z) of excess minority carriers which depends on the depth of absorption z of light in the base is given by the following relationship:

$$G(z)=\sum_{i=1}^{3} a_i \exp(-b_i z) \qquad (1)$$

The coefficients a_i and b_i are obtained through tabulated values of the radiation [64].

During the experiment, the level of illumination remains constant, which implies that the level of injection is not modified with respect to time. We obtain the magneto-transport equation [22, 46] in dynamic regime, relating to the excess of charge carriers δ(x, t) [27], in the base at the temperature (T) [42]:

$$D^*.\frac{\partial^2 \delta(x,t)}{\partial x^2}-\frac{\delta(x,t)}{\tau}=\frac{\partial \delta(x,t)}{\partial t} \qquad (2)$$

The diffusion coefficient D* of the minority carriers in the base under the influence of the temperature T and the applied magnetic field B, is given by the relationship [46, 59]:

$$D^* = D^*(B,T)=\frac{D(T)}{1+[\mu(T)\times B]^2} \qquad (3)$$

τ is the average lifetime of minority carriers in the base.

$$\mu(T)=1{,}43.10^9\, T^{2{,}42} cm^2 V^{-1} S^{-1} \qquad (4)$$

$\mu(T)$ is the mobility of minority carriers in the base [62]

B is the magnetic field in the base.

The diffusion coefficient of the minority carriers of charge in the base, dependent on the temperature D(T) without magnetic field is given by the relation of Einstein-Smoluchowski:

$$D(T)=\mu(T).\frac{K_B.T}{q} \qquad (5)$$

Where Kb is the Boltzmann constant Kb = $1{,}38.10^{-23}$ m^2 kg s^{-2} K^{-1} and q the elementary charge of the electron.

The equation is solved using the following boundary conditions:

- at the junction x=0:

$$D^*.\left.\frac{\partial \delta(x,t)}{\partial x}\right|_{X=0} = S_f \bullet \delta(0,t) \qquad (6)$$

- In the middle of the base:

$$D^*.\left.\frac{\partial \delta(x,t)}{\partial x}\right|_{X=\frac{H}{2}} = 0 \qquad (7)$$

Sf is the recombination velocity of the minority charge carriers at the junction [23, 25, 37] and defines the operating point of the solar cell [15, 51, 52] on its I-V characteristic.

The system of equations (2), (6) and (7) constitutes a problem of Sturm Liouville [63] whose solutions are with separable variables of the type:

$$\delta\,(x,t) = X(x)\cdot T(t) \qquad (8)$$

X(x) represents the spatial part of the minority carrier density and T(t) the temporal part.

X(x) and T(t) take the following forms respectively:

$$X(x)=A_1\cos\left(\frac{\omega.x}{\sqrt{D^*}}\right)+A_2\sin\left(\frac{\omega.x}{\sqrt{D^*}}\right) \qquad (9)$$

$$T(t)=T(0).\exp(-(\omega^2+\frac{1}{\tau})t)\,) \qquad (10)$$

With $\frac{1}{\tau_c} = \frac{1}{\tau} + \omega^2$ (11)

The application of the boundary conditions (6) and (7) give respectively the relations (12) and (13):

$$\frac{\omega.\sqrt{D^*}}{S_f} = \frac{A_1}{A_2} = \gamma \qquad (12)$$

$$\tan\left(\frac{\omega.H}{2\sqrt{D^*}}\right) = \frac{S_f}{\omega\sqrt{D^*}} \qquad (13)$$

Equation (13) is a transcendental equation whose solutions are determined graphically.

With : $\frac{\omega.H}{2\sqrt{D^*}} \in \left[0, \frac{\pi}{2}\right[\cup \left](n-\frac{1}{2})\pi;(n+\frac{1}{2})\pi\right[$ (14)

The first interval $\left[0, \frac{\pi}{2}\right[$ suit for n=0 and the second for n >0.

When n=0, we have the first term $\delta_0(x,t)$ that corresponds to the fundamental state with the eigenvalue. And for n >0, we have the different $\delta_n(x,t)$ harmonics of order n of eigenvalues .

A1 and A2 are calculated using the normalization conditions and the Fourier transformation.

The expression of T_n (0) is calculated using the density of minority carriers in the static regime.

The expression of $\delta(x,t)$ is therefore written:

$$\delta(x,z,t,T,B) = \sum \delta_n(x,z,t,T,B) = \sum X_n(x).T_n(z,T,B,0).\exp\left(-\frac{1}{\tau_{c,n}}t\right) \qquad (15)$$

The density of excess charge minority carriers in the base is given by relation (16).

$$\delta(x,z,t,T,B) = \sum_n \delta_n(x,z,t,T,B) \qquad (16)$$

$\tau_{c,n}$ is called decay time constant, its inverse can be written:

$$\frac{1}{\tau_{c,n}} = \frac{1}{\tau_0} + \omega_n{}^2 \qquad (17)$$

The expression of the voltage collected at the terminals of the solar cell when it submitted to polychromatic illumination is obtained from the Boltzmann relationship; it is expresses in the form:

$$V(t) = q_0 \cdot Fc(\omega_0) \cdot \exp\left(-\frac{t}{\tau_{c,0}}\right) \qquad (18)$$

With $Fc(\omega_0) = \frac{A_0 \cdot T_0(0)}{\delta(0,0)}$

3. RESULTS AND DISCUSSION

3.1 Transient Voltage

The solutions of the transcendental equation as well as the expression for the minority carrier density δ(x, t) allowed us to plot the profiles of the transient voltage in the base using the results of the optimum base thickness (Hopt) [55, 56] for different magnetic fields (B) and values of the optimum temperature, border between normal phenomena and the Umklapp process [59].

The following figures represent the evolution of the transient voltage as a function of (Hopt), of the magnetic field (B) and of (Topt).

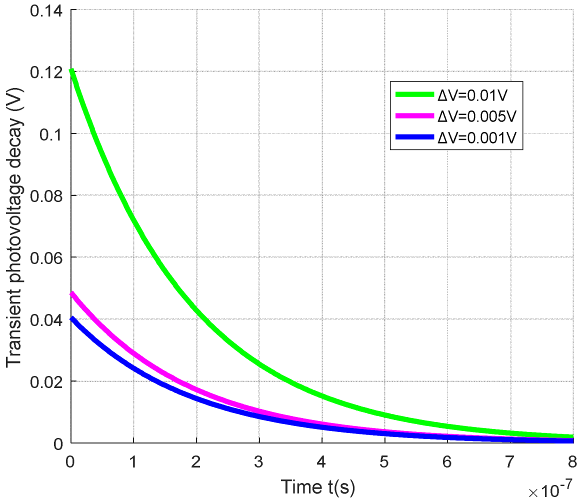

Fig. 5 Transient photo voltage decay versus the time *t*(*s*) for different values of ΔV Sf=10cm/s; Top=254.7K B=0.0003T; Hopt =0.0161cm; z=0.017cm; τ=10 ^{5}s

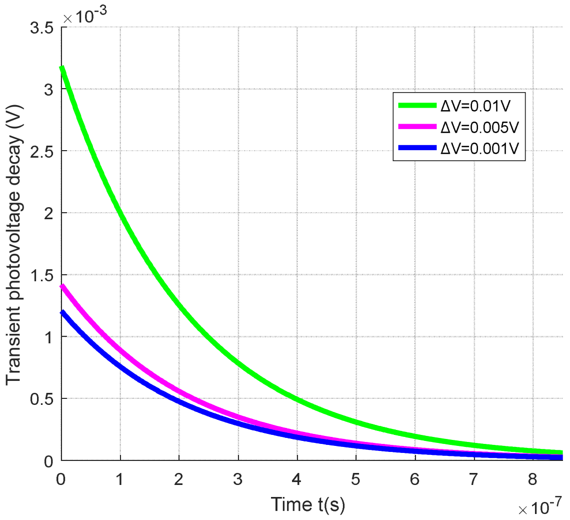

Fig. 6 Transient photo voltage decay versus the time *t*(*s*) for different values of ΔV Sf=10cm/s; Top=286.6K; B=0.0004T; Hopt=0.0156cm; z=0.017cm; τ=10 ^{5}s

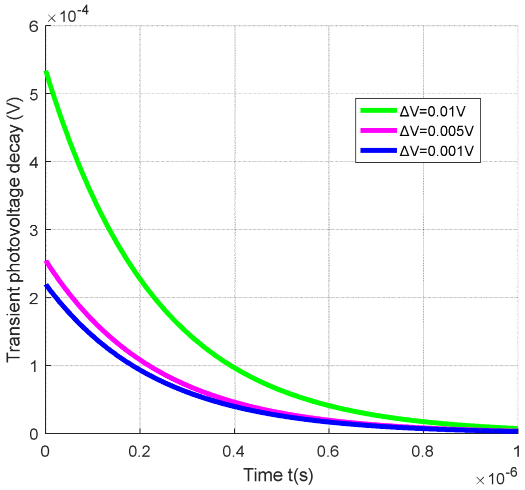

Fig. 7 Transient photovoltage decay versus the time *t*(*s*) for different values of ΔV Sf=10cm/s; Top=336.5K; B=0.0005T; Hopt =0.0153cm; z=0.017cm; τ=10 ^{5}s

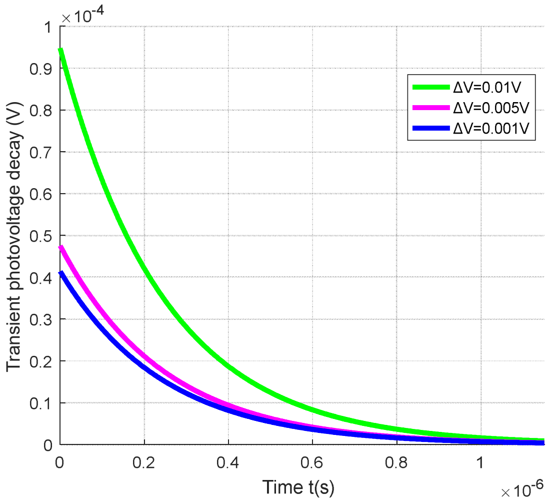

Fig. 8 Transient photovoltage decay versus the time *t*(*s*) for different values of ΔV Sf=10cm/s; Top=336.5K; B=0.0006T; Hopt =0.0149cm; z=0.017cm; τ=10 ^{5}s

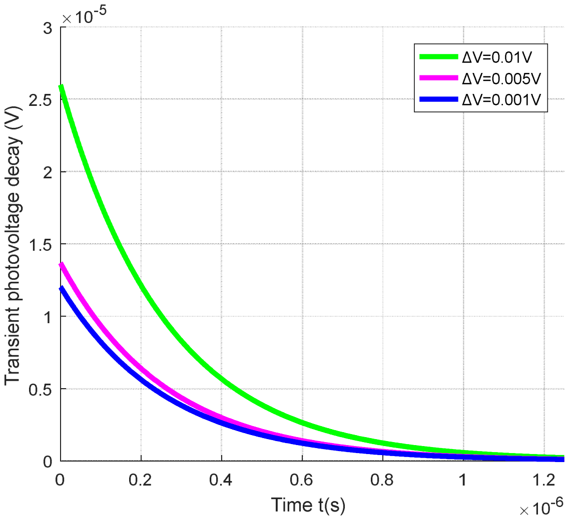

Fig. 9 Transient photovoltage decay versus the time *t*(*s*) for different values of ΔV Sf=10cm/s; Top=361.4K; B=0.0007T; Hopt =0.0147cm; z=0.017cm; τ=10 ^{5}s

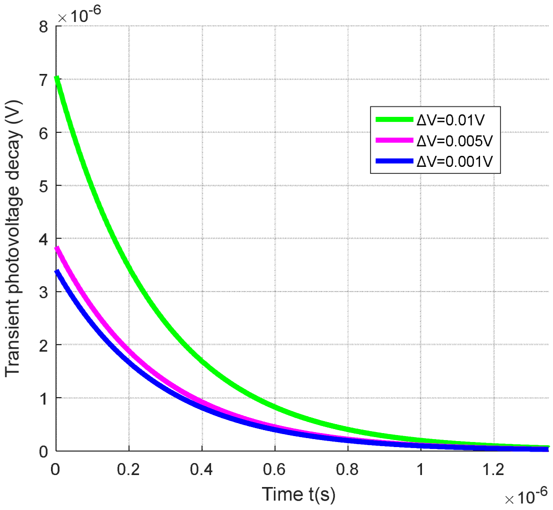

Fig. 10 Transient photo voltage decay versus the time *t*(*s*) for different values of ΔV Sf=10cm/s; Top=381.9K; B=0.0008T; Hopt =0.0146cm; z=0.017cm; τ=10 ^{5}s

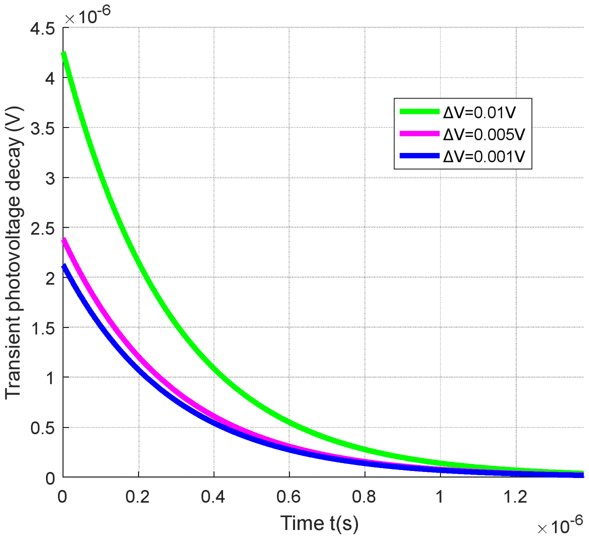

Fig. 11 Transient photo voltage decay versus the time *t*(*s*) for different values of ΔV Sf=10cm/s; Top=410K; B=0.0009T; Hopt =0.01445cm; z=0.017cm; τ=10 ^{5}s

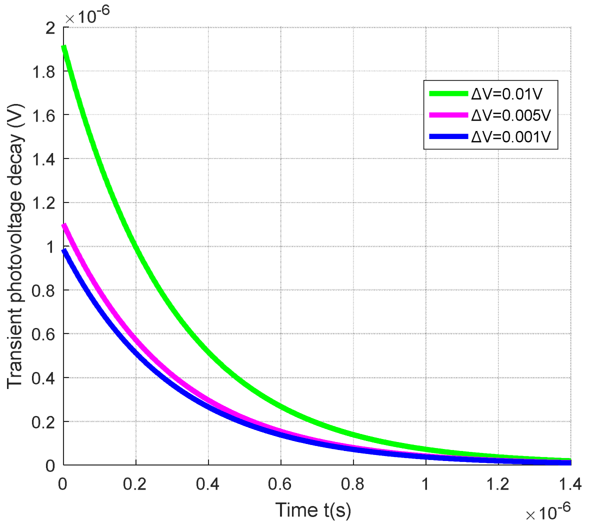

Fig. 12 Transient photo voltage decay versus the time *t*(*s*) for different values of ΔV Sf=10cm/s; Top=418.8K; B=0.001T; Hopt=0.0143cm; z=0.017cm; τ=10 ^{5}s

We observe in figures 5, 6, 7, 8, 9, 10, 11 and 12 a slow decay of the transient photovoltage as the temperature increases. Indeed, when the temperature constantly increases, there will be thermal agitation. As a result, the carriers will take longer to arrive at the final steady state, hence a slow decay with increasing temperature. We also observe a decrease in the amplitude of the transient photovoltage with increasing temperature and magnetic field. In addition, the thermal agitation leads to the increase of the intrinsic density of carriers at the level of the junction, therefore the reduction of the photovoltage and the increase of the transient decay with the increase of the optimal temperature.

Almost all of the carriers stored at the junction will not cross there when Sf tends to zero. We must therefore expect an open circuit voltage greater than that of the short circuit voltage.

4. CONCLUSION

This work allowed us to see the effect of temperature and magnetic field on the transient photovoltage of a parallel vertical junction silicon solar cell. It also allowed us to see the effect of the potential difference on the photovoltage amplitude. After the graphical resolution of the transcendental equation, we could observe that the eigenvalues and the decay time constants obtained are dependent on the optimal temperature. Increasing the thickness of the base results in an acceleration of the decay time.

An increase of the magnetic field leads an increase of the temperature (Umklapp), therefore the same effect of increasing the decay time and a decrease of the amplitude of the photovoltage corresponding to a reduction in the optimum thickness is obtained from the base.

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