EFFECT OF IRRADIATION ON THE TRANSIENT RESPONSE OF A SILICON SOLAR CELL

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Abstract: A theoretical study of a silicon solar cell under multispectral illumination and particles (electrons, protons…) irradiation is presented. The solar cell is placed in a fast switch interrupted circuit and the transient decay is obtained between two steady states. The transient variation of minority carriers’ density is presented and we show how diffusion length, transient photocurrent, transient capacitance depend on the irradiation parameters (energy Φ and damage coefficient KI of particles).

Keywords: Solar cell, Transient variation, Irradiation.

1. INTRODUCTION

Photovoltaic solar energy is the main energy source for satellites and other space stations. Most solar panels are embedded in silicon semiconductor materials. They are subjected to ionizing radiation, which are able to change their electrical behaviour. When there is absorption of a dose of ionizing radiation, the concentration of electrons and holes is modified and the solar cells operation could be strongly modified. The harmful radiation sources for semiconductors are of two sorts: natural phenomena and those related to human activity. The first one is mainly brought due to the space environment: solar flare, solar wind, cosmic radiation and the radiation belts. Phenomena resulting from human activity are similar but the energy and flow of radiation are higher.

Radiative emission is found in civil (nuclear power plants) and military (nuclear explosion, etc ...) applications.

All these phenomena generate emissions of particles and radiation which interact with matter and introduce disturbances in the atomic structures and the electrical balance in the solar cell. Particles that interact are charged particles (ions, electrons, protons etc ...), neutrons and photons [1].

When energetic particles go through the atomic lattice of the material, they transfer their energy to the network through events in which ionizing electrons in the network are temporarily excited to higher energy levels and events in which non-ionizing collisions between the incident particle and the target atoms causes displacement of the atoms in the lattice. It is the permanent displacement produced by non-ionizing events incident (protons and electrons) that degrades the performance of the semiconductor devices [2].

The purpose of this study is to show the influence of the irradiation energy (Φ) and the nature of the radiation KI on silicon solar cell, particularly on the following parameters: minority carriers’ density, transient photovoltage, transient photocurrent density and transient capacitance.

2. DEVICE OPERATION

Figure 1 show the experimental setup used to obtain the transient response of the solar cell.

This setup includes a square wave generator (BRI8500) which drives a RFP50N06 MOSFET type, two adjustable resistors R1 and R2, a silicon solar cell, a digital oscilloscope, a computer and multi-spectral light source [3], [4].

The I-V curve of the solar cell is given in Figure 2 [5].

- At time t < 0 (Figure 1), the solar cell is under constant multispectral illumination, MOSFET T is turned off and the solar cell is loaded only by resistor R2: this correspond to operating point F2 in steady state.
At $t = 0$ (Figure 1), MOSFET T turning on and after a very short time (600-800ns) it is fully turned on so that resistor R2 is in parallel with R1 + Rsan. Rsan is the drain (D) - source (S) resistance. For a sufficient Gate voltage, the value of Rsan is very low (less than one ohm) and can be neglected compared to that of R1 (10 \( \Omega \) to 47 k\( \Omega \)). The solar cell is then at the operating point F1 in steady state (Figure 2).

![Figure 2: I-V curve photovoltage of a silicon solar cell](image)

The transient decay occurs between the operating points F1 and F2. The transient voltage across the solar cell is recorded by a digital oscilloscope (Tektronix), coupled with a computer for processing and analysis. Varying R1 and R2, lead to changing operating points F1 and F2 respectively; this allow us to perform the transient decay at any operating point of the solar cell.

3. THEORY

3.1 Excess minority carrier density

This study is done on a n\(^{+}\)p\(^{+}\) BSF silicon solar cell. Given that the base contribution is more important, our analysis will be conducted only in this region of the solar cell.

The solar cell is under constant multispectral illumination. At time t and at the depth x in the base, the distribution of the minority charge carriers is represented by $n(x,t)$ in transient state.

Let $n(x)$ be the distribution of minority charge carriers in the steady state and $\delta(x,t)$ the excess minority carriers at time t from the final state, we have [6]:

$$\delta(x, t) = n(x,t) - n(x)$$  (1)

Distribution of minority carrier’s $n(x,t)$ at time t satisfies the continuity equation on the charge carriers given by:

$$D \frac{\partial^2 n(x,t)}{\partial x^2} = \frac{g(x,t)}{\tau} = \frac{\delta(x,t)}{\tau}$$  (2)

$D$ is a diffusion constant and $L$ is the diffusion length of the minority carriers.

$G(x)$ is the carrier generation rate at the depth $x$ in the base.

$$G(x) = \frac{3}{2} n \sum_{m=1} a_m e^{-b_m x}$$  (3)

$n$ is the illumination level, $H$ is the thickness of the base, $a_m$ and $b_m$ are coefficients tabulated from overall AM1.5 solar radiation [2].

$L$ is the diffusion length of minority carriers in the base depend on the irradiation energy $\phi$ and the damage coefficient $K_L$ through the following expression [7], [2], [8]:

$$L(K_L, \phi) = \frac{1}{\sqrt{\frac{1}{L_0^2} + K_L \phi}}$$  (4)

$L_0$ is the diffusion length without irradiation.

We present on figure 3 the diffusion length versus particles energy for various damage coefficients.

![Figure 3: Profile of the variation of the diffusion length depending on the irradiation energy](image)
The solutions of these differential equations in \( X(x) \) and \( T(t) \) lead to the following general terms:

\[ X_n(x) = \delta(x) \cos \left( \frac{\sqrt{2}}{2} n x \right) + \sum_{m=0}^{\infty} \frac{B_m}{m!} (\frac{\sqrt{2}}{2} n x)^m \]

And

\[ T_n(t) = T_{n,0} e^{-\frac{t}{\tau_n}} \]

\( \tau_{n,0} \) is the decay time constant and is related to the minority carriers lifetime by the following expression.

\[ \tau_{n,0} = \frac{\tau_{n,0}}{\alpha_{n,0}} \]  

\( \alpha_{n,0} \) is the Eigen value of the transcendental equation below.

We establish the following transcendental equation, taking into account the expression of \( L \)

\[ L \]  

This equation is valid only if:

\[ L^2 \alpha_{n,0} = \tau_{n,0} \bar{S}_n f + \sigma_{S} \bar{S}_n L \]

\( \bar{S}_n \) is determined from the fundamental mode corresponding to \( n=0 \) predominates and is equal to the excess minority carriers \( \delta(x, t) \).

We can write that [11].

\[ \delta(x, t) = \sum_{n=0}^{\infty} X_n(x) T_n(t) (0) \]  

The excess minority carrier’s density versus time is presented on figures 7 and 8 respectively for various damage coefficients.

**Figure 7:** Variation of the carrier density versus time for different values of irradiation energy \( \Phi \)

**Figure 8:** Variation of the carrier density versus time for different values of damage coefficient \( K_I \)

We note in Figures 7 and 8 that the particle irradiation energy affects the transient variation of the carrier density. When the irradiation energy increases, the carrier density decreases, and the variation in time is faster. Thus, for a given value of the energy of radiation, we feel the same effects with the increase in the coefficient of damage. The passage of a charged particle, including an ion through the material generates a region damaged along its path; irradiation creates defects inherent in interactions between charged particles and electrons of silicon. The charged particles lose their energy in the material and the electron density decreases [12], [13].

We present in figure 9 the excess minority carriers density versus irradiation energy for various damage coefficients.

**Figure 6:** Transient decay versus time

This figure show that the different terms of the series expansion decrease very quickly and after a certain amount of time \( t_0 \), the fundamental mode corresponding to \( n=0 \) predominates and is equal to the excess minority carriers \( \delta(x, t) \).

We present on figure 6 the transient decay and also the series expansion of equation (6) limited to one, two, and three terms.
We present in the figure 10 the effect of $\Delta V$ at the transient photovoltage.

**Figure 11:** Profile of the transient voltage for various $\Delta V$

We can observe that Transient voltage increases with the voltage difference $\Delta V$, this means that carriers are increasingly blocked at the junction.

Figures 12 and 13 below present the transient photovoltage for various radiation energies $\Phi$ and damage coefficients $K_l$.

**Figure 12:** Profile of the transient voltage between two operating points for different values of the radiation energy $\Phi$

**Figure 13:** Profile of the transient voltage between two operating points for different values of damage coefficient $K_l$

We note in Figures 12 and 13 that photovoltage decreases in time. The magnitude of the transient voltage remains constant when the irradiation energy increases and also when the damage coefficient increases. This means that irradiation does not affect the carriers trapped at the junction.

### 3.3 Transient Photocurrent

The transient photocurrent is given by the equation below

\[ I(x, t) = \frac{q_0 dU}{dx} \bigg|_{x=0} \]

Figures 14 and 15 below represent the transient photocurrent profiles for various radiation energies $\Phi$ and damage coefficients $K_l$.

**Figure 14:** Profile of the photocurrent density versus time for different values of the radiation energy $\Phi$

**Figure 15:** Profile of the photocurrent density versus time for different values of the damage coefficient $K_l$

The transient photocurrent density decreases when the amplitude level of radiation increases. Irradiation affects the density of the carriers, the carriers passing through the space charge zone decreases, so it is a decrease of the amplitude of the transient photocurrent density and therefore.

### 3.4 Transient capacitance

Transient capacitance is given by the following relation:

\[ C(x) = \frac{d\Phi}{dU} \]

Figures 16 and 17 below present the transient capacitance for various irradiation energy $\Phi$ and damage coefficient $K_l$ respectively.

**Figure 16:** Profile of the transient capacity versus time for different values of the irradiation energy $\Phi$

**Figure 17:** Profile of the transient capacity versus time for different values of the damage coefficient $K_l$
When the irradiation energy increases, ie when the radiation level increases, as the increase in the coefficient of injury, the number of particles interactions increases, and the carrier density is affected which reduces the number of carriers stored on either side of the junction, and there is a widening of the space charge zone. This is what explains the decrease in the amplitude of the transient capacitance with increasing irradiation energy and damage coefficient.

4. CONCLUSION
This study based on a silicon solar cell irradiated by energetic particles shows that the diffusion length depends strongly on the irradiation energy but also on the damage coefficient of these particles. The study also showed that the minority carriers density, transient photovoltage, transient photocurrent density and transient capacitance, are influenced by both the irradiation energy and the damage coefficient. We can also extend this study to a bifacial solar cell.

REFERENCES

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