Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01//21156
DOI URL: http://dx.doi.org/10.21474/IJAR01//21156

ISSN NO. 2320-5407

RESEARCH ARTICLE

STUDY OF THE CAPACITY OF A POLYCRYSTALLINE SILICON SOLAR CELL UNDER MULTISPECTRAL ILLUMINATION IN THE FREQUENCY REGIME: EFFECT OF GRAIN SIZE AND FREQUENCY

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Manuscript Info

Manuscript History
Received: 12 April 2025
Final Accepted: 15 May 2025
Published: June 2025

Key words:-
Multispectral, Capacitance, Solar Cell, Rate of Recombination, Frequency, Semiconductor, Grain Size, Photovoltage

Abstract

In this work, the capacity of polycrystalline silicon solar cells when subjected to multispectral illumination in the frequency regime has been investigated using a numerical resolution method with the aim of making a contribution to this area of research. The focus is on the influence of silicon grain size and illumination frequency on capacitance, in other words on cell performance. Using a numerical resolution method, we have obtained results which show that grain size affects the optical and electrical response of cells when the recombination rate at the junction is less than 10^{4} cm/s. The influence of frequency is also studied, showing that the capacitance is sensitive to the frequency of illumination when the recombination velocity is less than 10^{2} cm/s. The study identified frequencies that enhance charge carrier generation. The results provide valuable insight into how to proceed to optimize solar cell efficiency based on polycrystalline silicon solar cell design, and pave the way for significant improvements in their performance under different illumination conditions. This article is a major contribution to the design of more efficient photovoltaic systems.

Introduction:-

Life on earth would be impossible without energy. Photovoltaic solar energy is a sustainable source and a solution to the world's energy challenges. Research and technology in the field of photovoltaic energy continues to grow and expand. Silicon-based solar cells stand out for their efficiency and competitive cost. However, performance depends on many physical and electrical parameters, such as silicon grain size and irradiance. In this study, we focus on the impact of multispectral illumination and frequency regime on cell capacity. By studying the effect of grain size and illumination frequency, we aim to better understand how illumination frequency and grain size impact solar cell performance. The aim of this research is to help optimize the efficiency of photovoltaic solar cells, opening up prospects for more efficient and sustainable cells [1], [2], [3], [4], [5].

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Theory

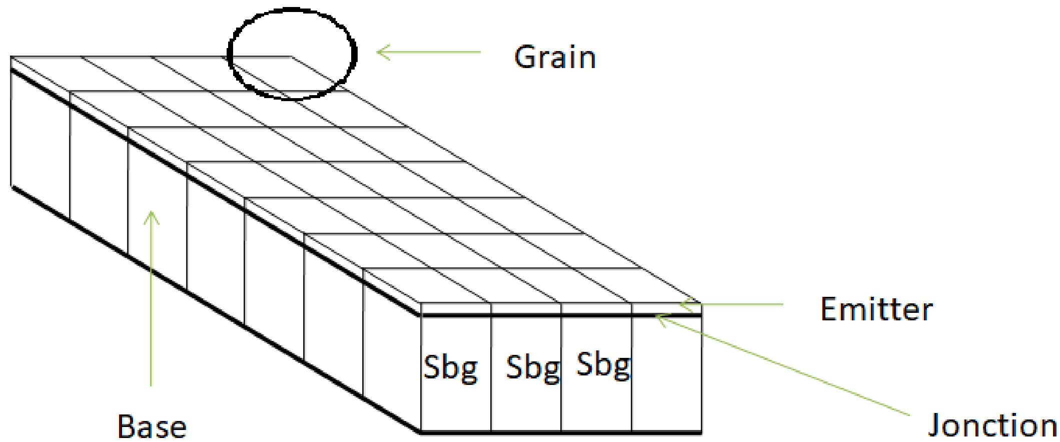

Figure 2.1:- Solar cell components.

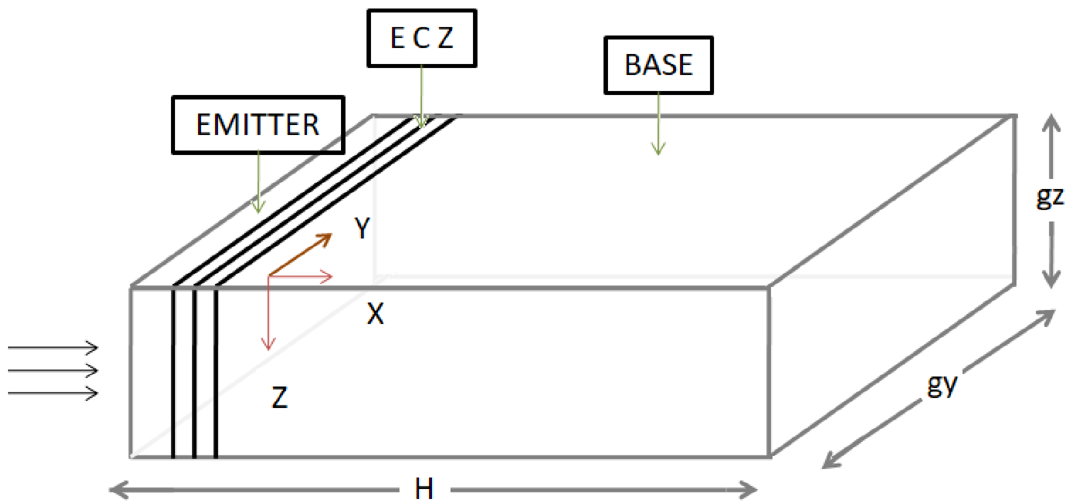

Figure 2.2:- Model of a front-illuminated horizontal junction the solar cell.

The polycrystalline solar cell considered is of the $\boldsymbol{n}+/\boldsymbol{p}/\boldsymbol{n}+$ type, the cell is made up of several silicon grains. The interfaces between the grains, called grain boundaries, are recombination sites. Their qualities can impact cell performance. Figures 2.1 and 2.2 show an illustrative model of the components of a solar cell and the illuminated cell respectively. Based on the general transport equation for the local instantaneous tensor quantity $\boldsymbol{\mathcal{F}_i}$as follows

$$\frac{\partial\,\mathscr{F}_i}{\partial t} + \vec{\nabla}.[J_i(\mathscr{F}_i)] = \Phi(\mathscr{F}_i)(2.1)$$

We have established the charge carrier distribution equation,
with :
$\mathbf{J_i}(\boldsymbol{\mathcal{F}_i})$total flux density of $\boldsymbol{\mathcal{F}_i}$ and $\boldsymbol{\Phi}(\boldsymbol{\mathcal{F}_i})$indicates the existence of a source (creation or destruction) of $\boldsymbol{\mathcal{F}_i}$.

In a semiconductor volume element, the rates of time variation of carrier densities are mainly related to the following four mechanisms :

- Generation rates $\mathbf{G_i}$
- Recombination rates $\mathbf{U_i}$
- Current density $\mathbf{J_i}$
- Diffusion coefficient $\mathbf{D_i}$.

$$\frac{\partial \delta}{\partial t} = -\frac{1}{e}(\vec{\nabla}.\vec{J}\ ) + G \quad - U \quad (2.2)$$

Under the transport-diffusion approximation, the current density $\vec{\mathbf{J}}$ is written :

$$\vec{J} \ = \sigma \ .\vec{\mathscr{E}} - e.D \ .(\vec{\nabla})(2.3)$$

With σ the conductivity defined by: $\sigma \ = -e.p.\mu \quad (2.4)$

Where

- **e** elementary electric charge,
- The field $\vec{\boldsymbol{\mathcal{E}}}$ derives from a potential field **V** solution of the following Poisson equation

$$\nabla^2 V = \ -\frac{p - n + N_0 - N_A}{\varepsilon_s}(2.5)$$

The quantities **μ** and **D** represent respectively the mobility and the diffusion coefficient of the charge carriers and are linked by the following Einstein relation

$$\frac{D}{\mu} = \frac{k.T}{e} = V_T(2.6)$$

By replacing the current density $\vec{\mathbf{J}}$ by its expression given by relation (2.3) in relation (2.2) then we obtain equation (2.7)

$$\frac{\partial \delta}{\partial t} = \vec{\nabla}.\{-\mu \ .(\vec{\nabla}\, V) + D \ .(\vec{\nabla})\} + G \quad + U \quad (2.7)$$

The axis system is:x, y and z

In three dimensions, equation (2.7) is written as follows:

Considering that diffusion phenomena outweigh mobility, each U-rate carrier recombination mechanism is associated with a lifetime τ.

With $\mathbf{U} = \frac{\delta}{\tau}(2.8)$

And considering that the illumination is on the surface only, we have :

$$\frac{\partial \delta(x,y,z,t)}{\partial t} - D\left[\frac{\partial^2 \delta(x,y,z,t)}{\partial x^2} + \frac{\partial^2 \delta(x,y,z,t)}{\partial y^2} + \frac{\partial^2 \delta(x,y,z,t)}{\partial z^2}\right] - \frac{\delta(x,y,z,t)}{\tau} + G(z,t) = 0 \qquad (2.9)$$

Since we are not in a frequency-dynamic regime, we assume :

$$G(x,t) = f(x).g(t) \qquad (2.10)$$

Avec

$f(x) = G_0(1-R).e^{-\alpha x}$ (2.11) et $g(t) = Re(e^{j.w.t})$ (2.12)

Hence, under these conditions, the equation is written :

$$\frac{\partial \delta(x,\ y,\ z,t)}{\partial t} - D.\left[\frac{\partial^2 \delta(x,\ y,\ z,t)}{\partial x^2} + \frac{\partial^2 \delta(x,\ y,\ z,t)}{\partial y^2} + \frac{\partial^2 \delta(x,\ y,\ z,t)}{\partial z^2}\right] - \frac{\delta(x,\ y,\ z,t)}{\tau}$$
$$+G_0(1-R).e^{-\alpha x}.Re(e^{j.w.t}) = 0 \qquad (2.13)$$

To close this equation, initial and boundary conditions must be added.

The choice of conditions depends on the specific problem to be solved and on simplifying assumptions. Initial and boundary conditions ensure a unique solution, which is essential in the analysis of differential equations.

Initial conditions :

At t = 0 we have $\delta = \delta_i(0,y,z,t)$ (2.14)

Boundary conditions

$$D\left[\frac{\partial \delta(x,y,z,t)}{\partial x}\right]_{x=0} = S_f.\delta(0,y,z,t) \qquad (2.15)$$

$$D\left[\frac{\partial \delta(x,y,z,t)}{\partial x}\right]_{x=H} = -S_b.\delta(H,y,z,t) \qquad (2.16)$$

- S_f The rate of recombination at the junction of excess minority charge carriers in the front-illuminated cell.
- S_b The junction recombination velocity of excess minority charge carriers at the back face when the front face is illuminated.
- H Epaisseur de la base de la photopile.

$$D\left[\frac{\partial \delta(x,y,z,t)}{\partial z}\right]_{z=\pm\frac{gz}{2}} = \pm S_g b.\delta(\pm x,y,\frac{gz}{2},t) \qquad (2.17)$$

$$D\left[\frac{\partial\delta(x,y,z,t)}{\partial x}\right]_{y=\pm\frac{gy}{2}} = \pm S_g b.\delta(\pm x, \frac{gy}{2}, z, t) \qquad (2.18)$$

- $S_g b$ recombination velocity at grain boundaries.
- gz grain size
- gy grain length [6], [7]

The capacity of the solar cell under illumination is given by :

$$C = q.\frac{\delta(x=0,y,z,t)}{V_T} + \frac{qn_0^2}{N_b V_T} \qquad (2.19)$$

Under the conditions of the experiment, we have : $C_0 = \frac{qn_0^2}{N_b V_T}$ (2.20)

$$\text{So : } C = q.\frac{\delta(x=0,y,z,t)}{V_T} \qquad (2.21)$$

When the cell is illuminated, a photovoltage V appears at its terminals. From Boltzmann's relation, we express the photovoltage as follows: [8] [9]

$$V = V_T \cdot \mathbf{ln}\left[1 + \frac{Nb}{n_0^2} \cdot \delta(x=0,y,z)\right]_{x=0} \qquad (2.22)$$

With Nb, base doping rate in base acceptor atoms ($Nb = 10^{16}$ cm^{-3}) ;
n_0, Intrinsic density of minority carriers ($n_0 = 10^{10}$ cm^{-3}) ;
V_T = Thermal voltage (V_T = 26 mV)
Thermal stress is defined by the following relationship :

$$V_T = \frac{K\,x\,T}{q} \qquad (2.23)$$

Where K is Boltzmann's constant, q is the electron charge and T is the absolute temperature at thermal equilibrium. (T = 300°K).

At the junction $\delta(x=0,y,z)$, the photovoltage will be a function of the recombination rate S_f. Consequently, we can plot the photovoltage profile V as a function of the recombination rate $S_f$at the junction. [6], [8].

Results:-

Capacity profile

Capacitance profile as a function of recombination velocity at the Sf junction (cm/s) for different frequency values

Figure (3.1) shows the capacitance profile as a function of recombination speed for different frequency values.

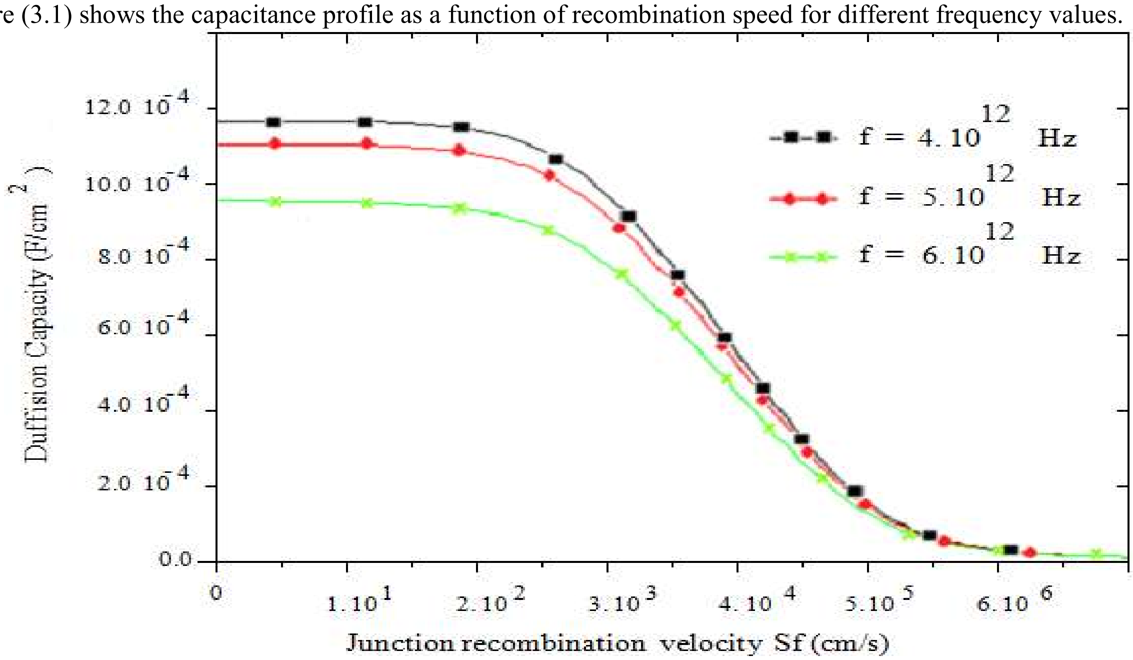

Figure 3.1:- Photovoltaic cell capacity as a function of junction recombination rate for different frequency values.

Capacity profile as a function of recombination velocity at the Sf junction (cm/s) for grain size

Figure (3.2) shows the capacitance profile as a function of recombination speed for different grain size values.

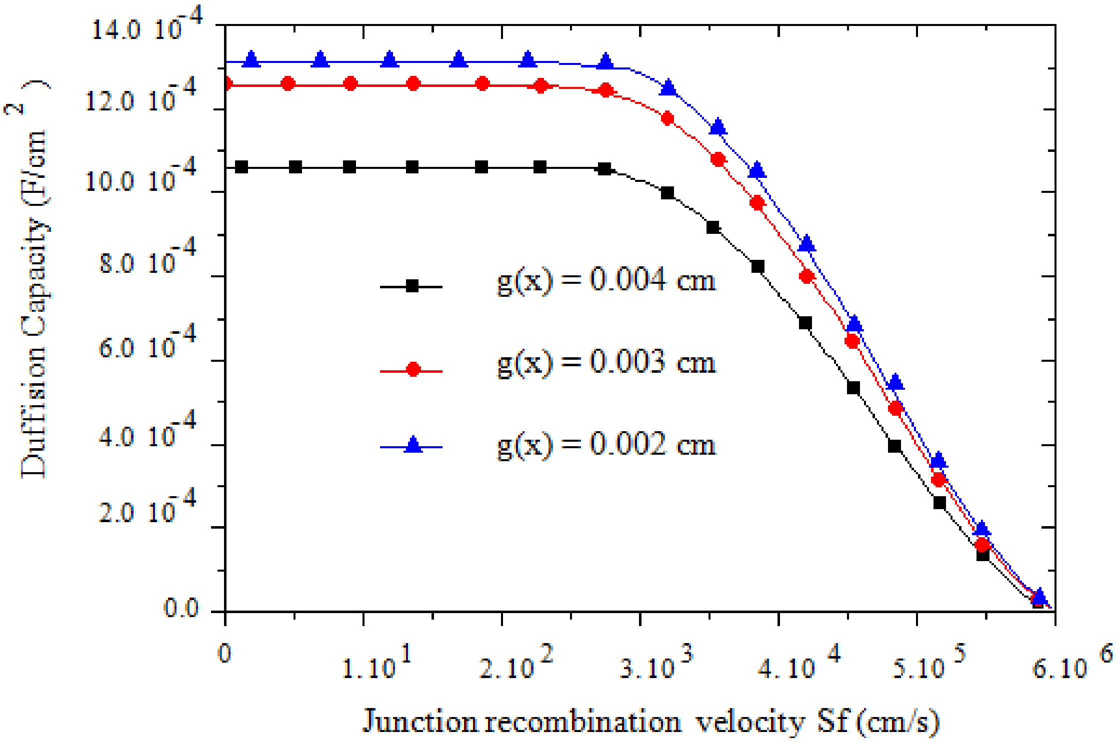

Figure 3.2:- Capacity as a function of recombination rate for different grain size values.

Figures 3.1 and 3.2 show the same benefit. The curves show that the variation in capacitance as a function of recombination speed at the junction decreases until it is cancelled out. We note that for low recombination speeds, below 10 2 cm / s, the capacitance amplitude is maximum and constant. Minority charge carriers are thus blocked and stored at the junction. This maximum capacitance value decreases slightly with increasing illumination frequency and decreasing grain size, corresponding to the short-circuit current. The current is very low for low values of recombination velocity: this is the open circuit, with the space charge zone resembling a planar capacitor of small thickness (X_{CO}) corresponding to high values of C.

The variation of capacity as a function of recombination rate for different grain size values also shows that for recombination rates above 104 cm/s grain size has no influence on capacity, whereas for recombination rates below 10 3 cm/s capacity increases as a function of grain size [10], [11].

For junction recombination rates above 105 cm/s for different grain size values, and for junction recombination rates above 103 cm/s for different frequency values, the capacitance tends towards its minimum value, meaning that the minority charge carriers have crossed the junction. This low value of the capacitance (Ccc) corresponds to a high value of the thickness (Xcc) of the planar capacitor in the space charge zone of the short-circuited solar cell. 4. The study of capacitance as a function of Sf therefore shows an extension of the space charge zone, from open circuit to short-circuit of the photopile [11], [12].

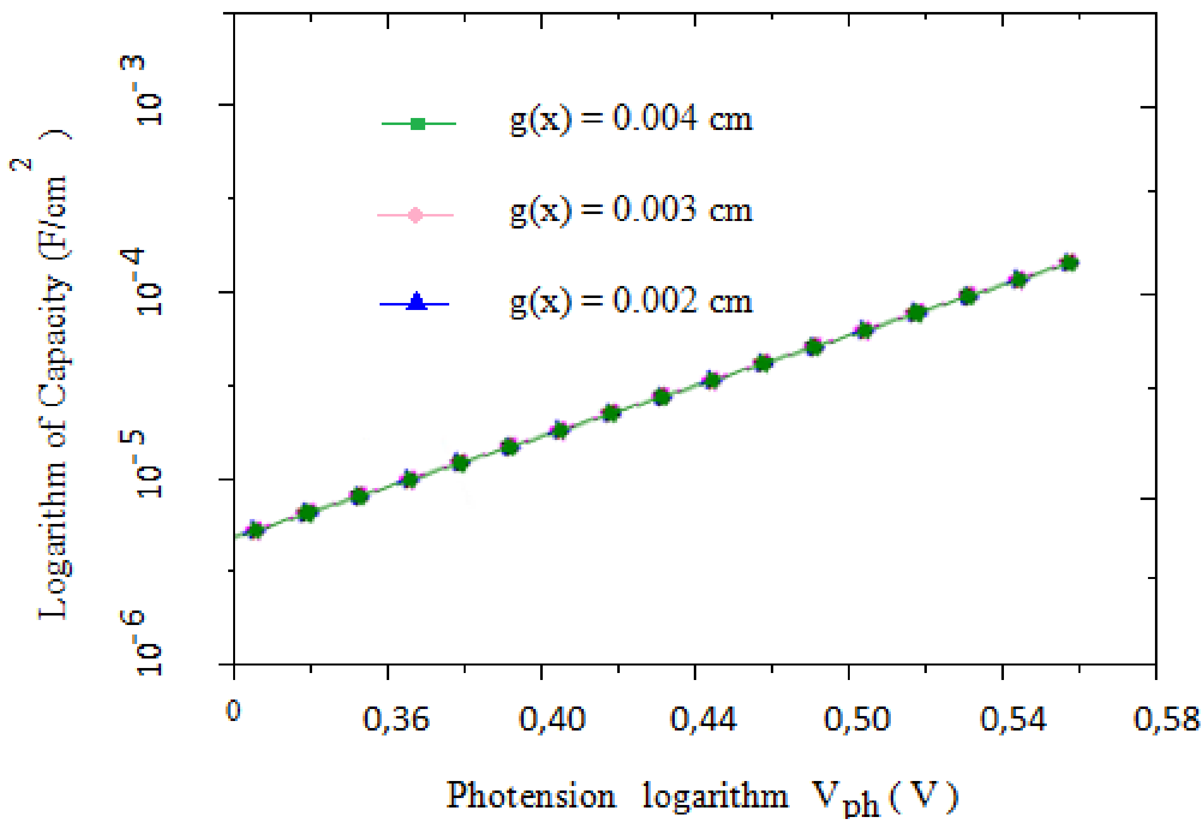

Figure 3.3:-Profile of the logarithm of the photocell capacity versus the logarithm of the photovoltage for different depth values.

The profile of the logarithm of capacitance versus the logarithm of photovoltage is a linear function, meaning that capacitance varies proportionally with photovoltage. Under these operating conditions, the system is energy-optimized. The initial value of capacitance C_0 increases with photovoltage.

Conclusion:-

The study carried out on the capacity of a polycrystalline silicon solar cell under multispectral illumination in the frequency regime highlighted the influence of grain size and illumination frequency on the solar cell's capacity. The results show that grain size has an impact on energy conversion efficiency, affecting both capacity, diffusion and recombination mechanisms, and hence charge carrier density. The smaller the grain size, the better the cell response at low recombination rates. Analysis of the results highlights the importance of multispectral illumination for maximizing absorption and, consequently, carrier generation.

Finally, this study paves the way for future research. The exploration of new materials, an approach based on the control of electron transport phenomena and electrical parameters. It is important to continue research in this field in order to provide solutions for more efficient and sustainable photovoltaic solar cells, in the face of today's energy challenges.

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