

Research Article

# Modeling and Optimization of an $\text{In}_x\text{Ga}_{1-x}\text{N}$ Solar Cell Subjected to a Magnetic Field Under Monochromatic Illumination

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## Abstract

This work focuses on the modeling and optimization of an  $\text{In}_x\text{Ga}_{1-x}\text{N}$  based on photovoltaic cell subjected to a magnetic field under monochromatic illumination. Using a mathematical model adapted to our photovoltaic cell, we solved the continuity equation for excess minority carriers in the base in the presence of the magnetic field. This solution enabled us to determine several fundamental parameters of the photovoltaic cell as a function of the intensity of the applied magnetic field, including: the density of excess minority carriers in the base, the short-circuit current ( $J_{cc}$ ), the open-circuit voltage ( $V_{oc}$ ), the power ( $P$ ), the form factor ( $FF$ ), and the efficiency ( $\eta$ ). We then conducted a numerical simulation to optimize the indium fraction ( $x$ ) as a function of the applied magnetic field and evaluate the impact of the latter on electrical performance, in particular power and efficiency. Analysis of the results shows that low magnetic field values ( $B \leq 10^{-3}$  T) have virtually no effect on the efficiency of the photovoltaic cell. However, efficiency gradually decreases for more intense fields ( $B > 10^{-3}$  T). The best performance of the photovoltaic cell was obtained for an indium fraction  $x = 0.5$  and a base thickness  $H = 0.2 \mu\text{m}$ . These optimal conditions result in a maximum efficiency  $\eta = 28.40\%$ , with a short-circuit current  $J_{cc} = 0.024 \text{ A}\cdot\text{cm}^{-2}$ , an open-circuit voltage  $V_{oc} = 1.3 \text{ V}$ , and a form factor  $FF = 90.2\%$ . This efficacy value obtained is close to the 28.53% value reported by F. B. Pelap et al (2021), suggesting good agreement between studies.

## Keywords

Modeling, Optimization, Magnetic Field, Electrical Parameters, InGaN Solar Cell

## 1. Introduction

Today, the most commonly used material in the manufacture of photovoltaic solar panels is silicon. However, in optoelectronics and fast electronics, the properties of silicon are insufficient, as it has relatively low carrier mobility and an indirect electronic transition [1]. As a result, its conversion

efficiency is low. In order to improve the efficiency of photovoltaic cells and reduce the space required for large-scale installations and to produce cheaper solar cells, it would be worthwhile to focus our research on other types of semiconductor materials that can meet these challenges. Among these

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materials, III-V semiconductors such as indium gallium nitride (InGaN) have interesting properties because they have a wide spectral coverage ranging from near infrared (InN gap = 0.7eV) to ultraviolet (GaN gap = 3.39eV), a direct electronic transition, and a gap energy that can be modulated with the indium fraction, a high absorption rate, and strong interatomic bonds. This makes it a promising material for electronic and photovoltaic applications [1].

These particular physical properties have led to extensive research into different InGaN basis solar cell structures in recent years.

InGaN was first proposed for photovoltaic applications in 2003 by J. Wu et al. [2], highlighting its tunable energy gap and resistance to high-energy radiation.

Several studies have been conducted, including the following:

Bouzzid and Ben Machiche [3] simulated the spectral response and current-voltage characteristics using a simulation program designed in Visual Basic 5. The achievable efficiency can be improved to 34% and 37% for tandems with double and triple junctions respectively, obtained under AM1.5 illumination of 1 sun and at room temperature, using realistic materials.

A. Khetrou et al. [4] conducted a numerical study in 2020 on an InGaN/GaN Schottky photovoltaic cell under AM1.5 illumination, obtaining an optimal efficiency of 21.69% for an optimal indium concentration of 54%; however,  $V_{co}$  and  $I_{cc}$  were not specified.

In 2021, F. B. Pelap [5] examined the best indium fraction ( $x$ ) and critical depth ( $H$ ) through numerical simulation of a single-junction photovoltaic (PV) cell ( $In_xGa_{1-x}N$ ) with the aim of optimizing its electrical efficiency. The best indium fraction and depth of the solar cell at the point of optimal electrical power are  $x = 0.6$  and  $H = 1\mu m$  ( $In_{0.6}Ga_{0.4}N$ ), respectively. Furthermore, under standard irradiation conditions ( $0.1 W.cm^{-2}$ ,  $T=25^\circ C$ ), they found maximum electrical power and efficiency to be approximately  $28.53 mW.cm^{-2}$  and 28.53%, respectively.

With the development of telecommunications, we will see antennas installed in many locations, and these photovoltaic cells are likely to be subjected to magnetic fields that can disrupt their operation.

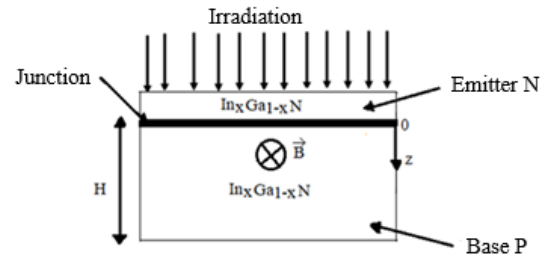
Our contribution focuses on the effect of magnetic fields on: short-circuit current, open-circuit voltage, power, and con-

version efficiency.

## 2. Theoretical Study

### 2.1. Presentation of the Model

The study focuses on a photovoltaic cell, one-dimensional in static conditions under monochromatic illumination. It is illuminated so that the radiation is perpendicular to the plane of the emitter, as shown in Figure 1 below.



**Figure 1.** Presentation of an  $In_x Ga_{1-x} N$  based photovoltaic cell subjected to a magnetic field.

### 2.2. Optical Parameters of the Material

#### Gap energy

The gap energy is modulated according to the fraction of indium denoted  $x$  through equation (1) [6, 7]:

$$E_g = x \cdot E_g^{InN} + (1 - x) \cdot E_g^{GaN} - b \cdot x \cdot (1 - x) \quad (1)$$

With  $E_g^{InN}$  being the band gap energy of the binary alloy InN and  $E_g^{GaN}$  being the band gap energy of the binary alloy GaN. Their values are 0.7 eV and 3.42 eV, respectively. The curvature parameter is denoted by  $b$  and its value is 1.43 eV.

#### Absorption coefficient:

A semi-empirical model is used to evaluate this quantity, adjusting the experimental data according to photon energy and indium content.

The absorption coefficient is expressed as follows [5, 9, 10]:

$$\alpha(\lambda, x) = 10^5 \sqrt{C(x) \cdot (E_{ph} - E_g(x) + D(x) \cdot ((E_{ph} - E_g(x))^2} \quad (2)$$

$$C = 3,525 - 18,29 \cdot x + 40,22 \cdot x^2 - 37,52 \cdot x^3 + 12,77 \cdot x^4 \quad (3)$$

$$D = -0.6651 + 3.616 \cdot x - 2.460 \cdot x^2 \quad (4)$$

$$E_{ph} = \frac{1,24}{\lambda_{photon}} \quad (5)$$

The reflection index:

The refractive index is given by the following formula (6) [4-11]:

$$n(x, \lambda) = \sqrt{\frac{A}{\left(\frac{E_{ph}}{E_g}\right)^2} \cdot \left[ 2 - \sqrt{1 + \frac{E_{ph}}{E_g}} - \sqrt{1 - \frac{E_{ph}}{E_g}} \right] + B} \quad (6)$$

With

$$A = 13,55. x + 9,31. (1 - x) \quad (7)$$

$$B = 2,05. x + 3,03. (1 - x) \quad (8)$$

### 2.3. Electrical Parameters

*Intrinsic concentration:*

It is related to the indium fraction by the following relationship [12]:

$$ni = \sqrt{N_C \cdot N_V} \cdot e^{\frac{-E_g}{2K_B T}} \quad (9)$$

Where  $N_C$  and  $N_V$  are the respective state densities of the conduction band and valence band. They are represented by the following expressions:

$$N_C = ((0,9. x + 2,3. (1 - x)). 10^{18} \quad (10)$$

$$N_V = ((5,3. x + 1,8. (1 - x)). 10^{19} \quad (11)$$

*Effective mass of carriers*

The effective mass of carriers is given by the following relationship: [13]

$$m_n = ((0,12. x + 0,2. (1 - x))m_0 \quad (12)$$

*Diffusion coefficient:*

It is expressed in the presence of a magnetic field as follows [14-16]:

$$D_n^* = \frac{D_n}{1 + (\mu_n \cdot B)^2} \quad (13)$$

Where  $D_n$  is the diffusion coefficient in the absence of a

magnetic field, given by equation (14), and  $\mu_n$  is the mobility of minority carriers in the base.

$$D_n = \frac{K_B \cdot T \cdot \tau_n}{m_n} \quad (14)$$

$\tau_n$  is the lifetime of minority carriers in the base and  $T$  represents the temperature.

*Excess minority carrier density in the base:*

The minority carrier density of the base is obtained by solving the continuity equation according to the mathematical model presented as follows [17, 18]:

$$\frac{\partial^2 \delta n(x, B, Sf, Sb, \lambda, H, z)}{\partial z^2} - \frac{\delta n(x, B, Sf, Sb, \lambda, H, z)}{L^2(x, B)} = -\frac{G(x, z, \lambda)}{D^*(x, B)} \quad (15)$$

Where  $\delta n(x, z, \lambda, B)$  is the minority carrier density of the base,  $L$  is the diffusion length defined by:

$$L = \sqrt{D^*(x, B) \cdot \tau_n} \quad (16)$$

$G(x)$  represents the number of charges created per unit volume for a given irradiation:

It is expressed as:

$$G(x, z, \lambda) = \phi_0(\lambda) \cdot \alpha(\lambda, x) \cdot (1 - R(\lambda, x)) \cdot e^{-\alpha(\lambda, x)z} \quad (17)$$

Where  $\phi_0(\lambda)$  represents the incident photon density per unit wavelength,  $R(\lambda, x)$  represents the reflection coefficient, and its expression is given by [19]:

$$R = \left( \frac{n_1 - n_2}{n_1 + n_2} \right)^2 \quad (18)$$

With  $n_1$  the air index and  $n_2$  the InGaN index

The solution to such an equation takes the form:

$$\delta n(x, B, Sf, Sb, \lambda, H, z) = A \cosh\left(\frac{z}{L(x, B)}\right) + B \sinh\left(\frac{z}{L(x, B)}\right) + K e^{-\alpha(\lambda, x)z} \quad (19)$$

with

$$K = -\frac{\alpha(\lambda, x) \cdot \phi_0(\lambda) \cdot (1 - R(\lambda, x)) \cdot \tau_n}{\alpha(\lambda, x)^2 \cdot L(x, B)^2 - 1} \quad (20)$$

The constants A and B are determined using the boundary conditions [20, 21].

1). At the junction  $z = 0$ , we have:

$$\frac{\partial \delta n(x, B, Sf, Sb, \lambda, H, z)}{\partial z} \Big|_{z=0} = \frac{Sf}{D^*(x, B)} \delta n(x, B, Sf, Sb, \lambda, H, z) \Big|_{z=0} \quad (21)$$

2). At the rear face  $z=H$  we have:

$$\frac{\partial \delta n(x, B, Sf, Sb, \lambda, H, z)}{\partial z} \Big|_{z=H} = \frac{-Sb}{D^*(x, B)} \delta n(x, B, Sf, Sb, \lambda, H, z) \Big|_{z=H} \quad (22)$$

$Sf$  and  $Sb$  are the recombination velocities of minority carriers at the junction and at the rear surface, respectively.

Solving the system formed by the two equations gives:

$$A = K \left[ \frac{\left( \frac{Sb}{D^*(x,B)} - \alpha(\lambda, x) \right) e^{-\alpha(\lambda, x) \cdot H} + \left( \frac{Sf}{D^*(x,B)} + \alpha(\lambda, x) \right) L(x, B) \cdot X}{\frac{Sf \cdot L(x, B) \cdot X}{D^*(x, B)} + Y} \right] \quad (23)$$

$$B = K \left[ \frac{-L(x, B) \cdot Y \left( \frac{Sf}{D^*(x, B)} + \alpha(\lambda, x) \right) + \frac{Sf \cdot L(x, B)}{D^*(x, B)} \left( \frac{Sb}{D^*(x, B)} - \alpha(\lambda, x) \right) e^{-\alpha(\lambda, x) \cdot H}}{\frac{Sf \cdot L(x, B) \cdot X}{D^*(x, B)} + Y} \right] \quad (24)$$

*Photocurrent density:*

This is obtained from the density of excess minority carriers in the base according to the following relationship [22-24]:

$$J_{ph}(x, H, \lambda, B, Sf, Sb) = q \cdot D^*(x, B) \cdot \left. \frac{\partial \delta n(x, H, \lambda, B, Sf, Sb, z)}{\partial z} \right|_{z=0} \quad (25)$$

This allows us to obtain:

$$J_{ph}(x, H, \lambda, B, Sf, Sb) = q \cdot D^*(x, B) \cdot \left( \frac{B}{L(x, B)} - K \cdot \alpha(\lambda, x) \right) \quad (26)$$

*Photovoltage:*

When a photovoltaic cell is illuminated, a voltage appears across its terminals, given by Boltzmann's equation [25-27]:

$$V_{ph}(x, H, \lambda, B, Sf, Sb) = V_T \cdot \ln \left( 1 + \frac{N_b}{ni^2} \cdot \delta n(x, H, \lambda, B, Sf, Sb, z) \right) \Big|_{z=0} \quad (27)$$

Where  $N_b$  is the doping level of the base in impurity atoms:  $N_b = 10^{19} \text{ cm}^{-3}$  [13].

$V_T$  is the thermal voltage:

$$V_T = \frac{K_B T}{q} \quad (28)$$

$q$ : is the elementary charge;

$K_B$ : Boltzmann's constant:  $K_B = 1.38 \cdot 10^{-23} \text{ J/K}$ ;

$T$ : the temperature, which is set at 300K throughout our work

This gives us:

$$V_{ph}(x, H, \lambda, B, Sf, Sb) = \frac{K_B T}{q} \ln \left[ 1 + \frac{N_b}{ni^2} (A - K) \right] \quad (29)$$

*Short-circuit current ( $J_{cc}$ ):*

The short-circuit current is obtained from the photocurrent limit when the recombination velocity at the junction tends towards infinity.

It is therefore defined by the following expression [14]:

$$J_{cc}(x, H, \lambda, B, Sb) = \lim_{Sf \rightarrow \infty} J_{ph}(x, \lambda, B, Sb, H) \quad (30)$$

We then obtain:

$$J_{cc}(x, H, \lambda, B, Sb) = q \cdot D^*(x, B) \cdot K \left[ \frac{\left( \frac{Sb}{D^*(x, B)} - \alpha(x, t) \right) e^{-\alpha(x, \lambda) \cdot H}}{X \cdot L(x, B)} - \frac{Y}{X \cdot L(x, B)} + \alpha(x, \lambda) \right] \quad (31)$$

*Open-circuit voltage ( $V_{oc}$ ):*

This is obtained when the photovoltage limit as a function of the recombination rate at the junction tends toward zero [14]:

$$V_{oc}(x, H, \lambda, B, Sb) = \lim_{S_f \rightarrow 0} V_{ph}(x, H, \lambda, B, Sb, S_f) \quad (32)$$

Which gives us:

$$V_{oc}(x, H, \lambda, B, Sb) = \frac{K_B T}{q} \ln \left[ 1 + \frac{N_b}{n i^2} \varphi \right] \quad (33)$$

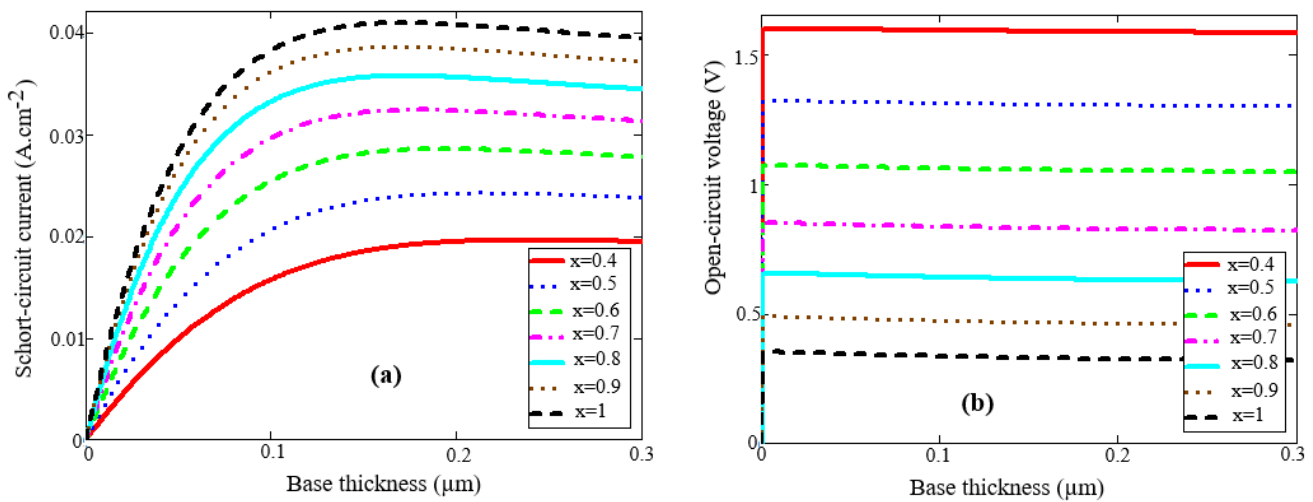
With:

$$\varphi = K \cdot \left[ \frac{X \cdot \ln(x, B) \cdot \alpha(x, \lambda) + \left( \frac{S_b}{D^*(x, B)} - \alpha(x, \lambda) \right) \cdot e^{-\alpha(x, \lambda) \cdot H}}{Y} - 1 \right] \quad (34)$$

### 3. Results and Discussion

#### 3.1. Influence of Indium Concentration on Short-circuit Current and Open Circuit Voltage

Figure 2 show the variation in short-circuit current (a) and open-circuit voltage (b) as a function of base thickness for different values of indium concentration and for fixed values of magnetic field, wavelength, and rear-surface recombination velocity.



**Figure 2.** Short-circuit current (a) and open-circuit photovoltage (b) as a function of base thickness, for different values of indium concentration.  $S_b=2.10^2 \text{ cm.s}^{-1}$ ,  $\lambda=0.48 \mu\text{m}$ ,  $B=0.0001 \text{ T}$ .

We can see in Figure 2(a) that the short-circuit current increases proportionally with the indium concentration. This is because an increase in indium concentration leads to a decrease in the band gap energy, thereby promoting an increase in the flow of minority carriers that can cross the junction.

We can also note that the short-circuit current increases with the thickness of the base up to a limit value for each given indium fraction value.

Increasing the thickness of the base leads to an increase in the minority carriers in the base, which enhances the flow of particles that can cross the space charge region. However, this thickness is limited to a maximum value.

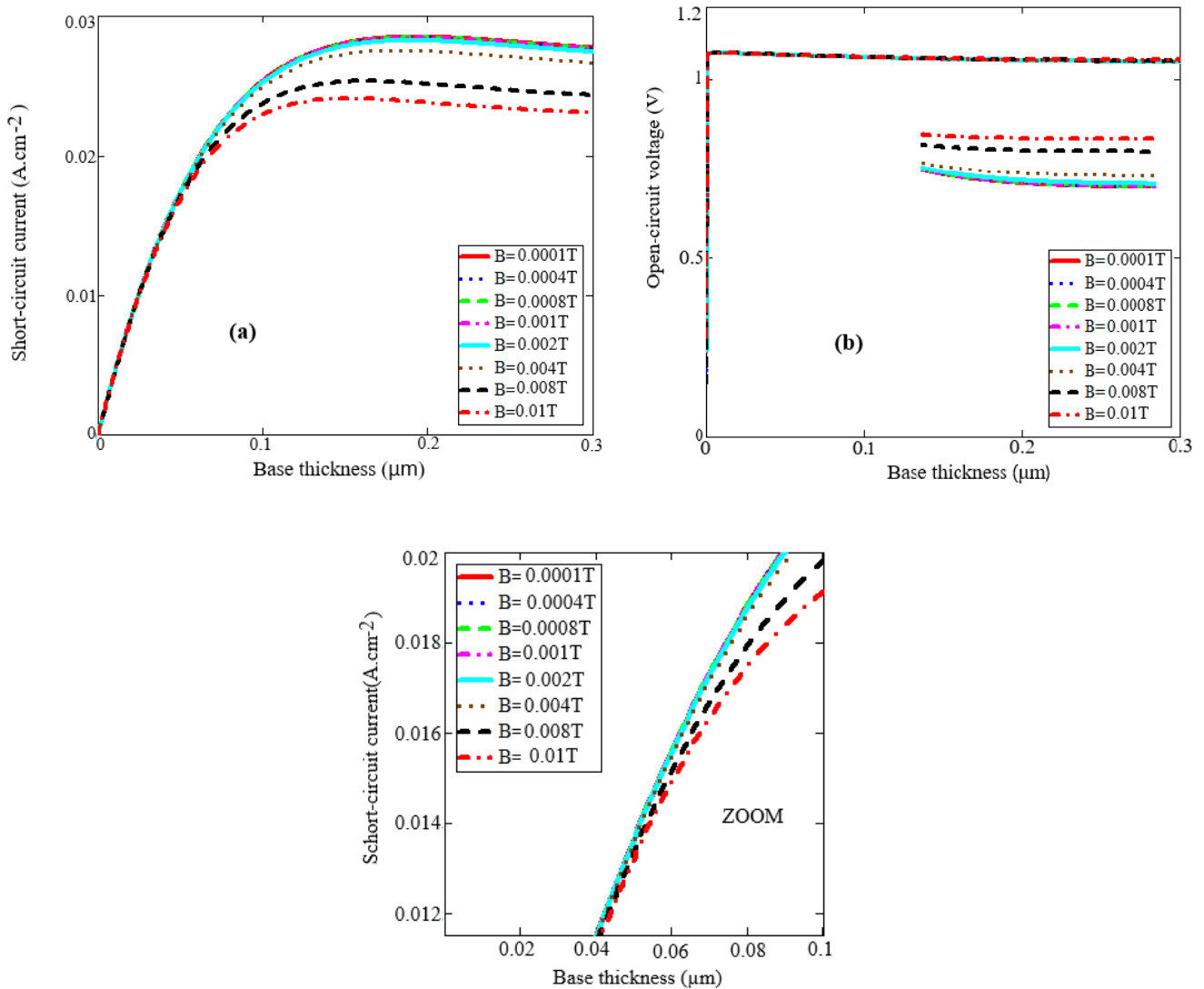
In Figure 2(b), we see that the open-circuit photovoltage decreases inversely to the short-circuit current for different indium fraction values. This is because the energy gap of the

material decreases with increasing indium concentration, so that the higher the indium fraction, the more minority carriers can cross the junction. This leads to a decrease in the number of carriers present at the junction and a drop in the open-circuit photovoltage [5].

#### 3.2. Influence of the Magnetic Field on the Short-circuit Current and the Open Circuit Voltage

Figure 3 shows the variations of the short-circuit current (a) and open-circuit voltage (b) as a function of base thickness for different magnetic field values and for fixed values of indium fraction, minority carrier recombination velocity at the rear

surface, and wavelength.



**Figure 3.** Short-circuit current density (a) and open-circuit photovoltage (b) as a function of base thickness, for different magnetic field values.  $Sb=2.10^2 \text{ cm.s}^{-1}$ ,  $\lambda=0.48\mu\text{m}$ ,  $x=0.6$ .

In Figure 3a., we can see that:

- 1). For a very thin layer of  $0.06 \mu\text{m}$ , the magnetic field has almost no effect on the short-circuit current density. This is because, for layers thinner than this, minority carriers cross the junction without being blocked by the magnetic field.
- 2). Above this thickness, an increase in the magnetic field causes a decrease in the short-circuit current density. This drop is much greater than when the magnetic field value is greater than  $0.002\text{T}$ , which could be due to the deflection of minority carriers before crossing the junction.

In Figure 3b, we can see that the increase in the magnetic field causes a slight rise in the open-circuit photovoltage.

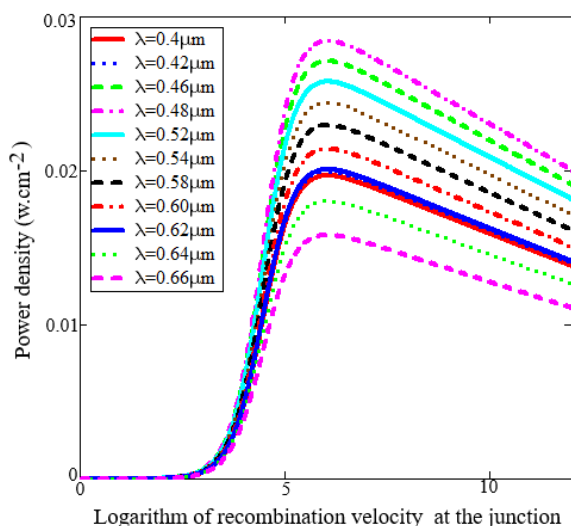
The minority carriers stored at the junction by the effect of

the magnetic field are responsible for the increase in open-circuit photovoltage [28].

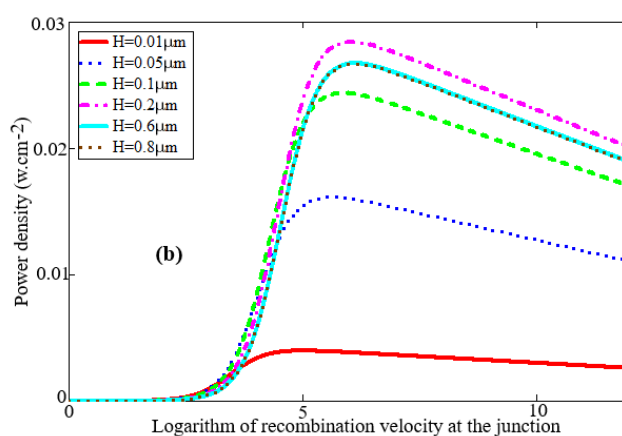
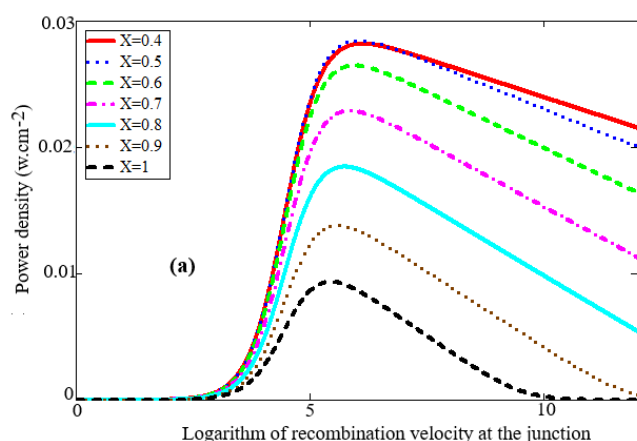
Similar work on silicon was carried out by Zoungana et al. [28] in 2017, Zerbo et al. [29] in 2016, and Diop et al. [14] in 2021, with effects related to the magnetic field similar to ours.

### 3.3. Influence of the Wavelength, the Indium Fraction and the Base Thickness on the Power

Figure 4 shows the influence of wavelength on the power as a function of the recombination velocity at junction of excess minority carriers in the base.



**Figure 4.** Power density as a function of the recombination velocity at junction for different wavelength values.  $S_b=2.10^2 \text{ cm.s}^{-1}$ ,  $H=0.2 \mu\text{m}$ ,  $x=0.5$ .



**Figure 5.** Power density as a function of recombination velocity at the junction for different values of indium concentration with  $H=0.02 \mu\text{m}$  (a) and different values of base thickness (b) for  $x=0.5$ ,  $\lambda=0.48 \mu\text{m}$ ,  $S_b=2.10^2 \text{ cm.s}^{-1}$ ,  $B=0.0001T$ .

In Figure 5a, we see that the power increases with the indium fraction for values of  $x$  between  $[0.4; 0.5]$  and above  $x=0.5$ , the power decreases with the indium concentration, so the best power value was obtained for  $x=0.5$ .

In Figure 5b, the power increases with the thickness of the base up to  $0.2 \mu\text{m}$  and then remains almost constant for the other values of base depth chosen.

The photovoltaic cell was studied at several wavelengths ranging from  $0.4 \mu\text{m}$  to  $0.66 \mu\text{m}$ .

We can see that the maximum power was obtained at a wavelength  $\lambda=0.48 \mu\text{m}$ .

This wavelength, being very close to the peak of the solar spectrum, would result in intense light, thus generating a maximum number of photons and, consequently, maximum power, which justifies the choice of this wavelength for all of our work.

### 3.4. The Impact of the Indium Fraction and Base Thickness on Power

Figure 5 shows the variation in power density as a function of the recombination rate at the junction for different values of indium concentration (a) and for different values of base thickness (b).

These variations in power as a function of indium concentration and base thickness can be confirmed by the work carried out by F. B. Pelap et al. [5] in 2021 based on a photovoltaic cell (InGaN).

Tables 1 and 2 illustrate the influence of indium composition ( $x$ ) and base thickness ( $H$ ) on power performance.

**Table 1.** Maximum power density ( $P_{max}$ ) as a function of indium concentration ( $x$ ).

| $x$                          | 0.4    | 0.5    | 0.6    | 0.7    | 0.8    | 0.9    | 1      |
|------------------------------|--------|--------|--------|--------|--------|--------|--------|
| $P_{max} (\text{W.cm}^{-2})$ | 0.0282 | 0.0284 | 0.0265 | 0.0228 | 0.0184 | 0.0138 | 0.0093 |

**Table 2.** Maximum power density ( $P_{max}$ ) and efficiency  $\eta$  as a function of base thickness ( $H$ ).

| H ( $\mu\text{m}$ )             | 0.01  | 0.05   | 0.1    | 0.2    | 0.6    | 0.8    |
|---------------------------------|-------|--------|--------|--------|--------|--------|
| $P_{max}$ ( $\text{Wcm}^{-2}$ ) | 0.004 | 0.0161 | 0.0243 | 0.0284 | 0.0267 | 0.0267 |
| $\eta$ (%)                      | 4     | 16.1   | 23.3   | 28.4   | 27.6   | 27.6   |

### 3.5. Influence of the Magnetic Field on the Power

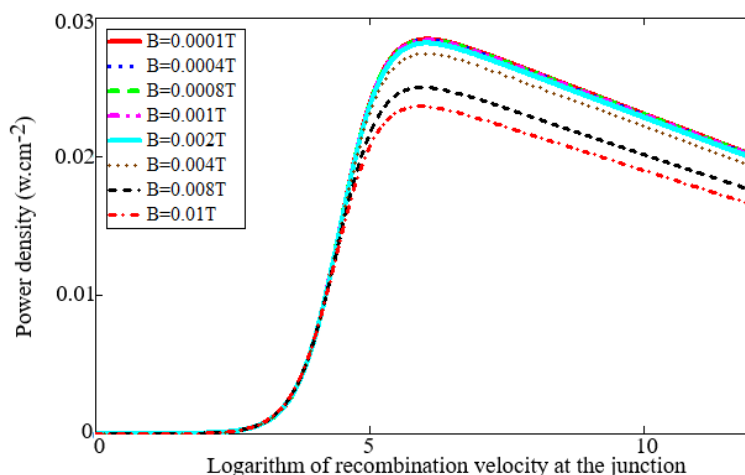
**Figure 6.** Power density as a function of the recombination velocity of minority carriers from the base to the junction for different magnetic field values.  $S_b=2.10^2 \text{ cm.s}^{-1}$ ,  $x=0.5$ ,  $\lambda=0.48\mu\text{m}$ ,  $H=0.2\mu\text{m}$ .

Figure 6 shows the variation in the power density as a function of the recombination velocity at the junction for different magnetic field values.

We can see in the figure above that, for values of the field  $B \geq 10^{-3} \text{ T}$ , increasing the magnetic field applied to the photovoltaic cell reduces its power and therefore its efficiency.

This phenomenon can be explained by the fact that the drop in photocurrent under the influence of the magnetic field is greater than the corresponding increase in the photo voltage generated.

Table 3 illustrates the variation in maximum power under the effect of the applied magnetic field ( $B$ ).

**Table 3.** Maximum power density ( $P_{max}$ ) as a function of the applied magnetic field ( $B$ ).

| B (T)                            | 0.0001 | 0.0004 | 0.0008 | 0.001  | 0.002  | 0.004  | 0.008 | 0.01   |
|----------------------------------|--------|--------|--------|--------|--------|--------|-------|--------|
| $P_{max}$ ( $\text{W.cm}^{-2}$ ) | 0.0284 | 0.0284 | 0.0284 | 0.0284 | 0.0284 | 0.0281 | 0.025 | 0.0236 |

## 4. Conclusion

In this article, we present the modeling of an InGaN-based photovoltaic cell subjected to a magnetic field. Solving the continuity equation allowed us to determine the electrical parameters of the cell, which were then simulated. The study shows the importance of taking into account the effect of the magnetic field when the solar cell is exposed to it and of

choosing the appropriate long pass and indium fraction, parameters that must be considered when designing solar cells for environments where a magnetic field is present.

We draw the following conclusions:

Magnetic field values of less than 0.001T have no effect on the power supplied by the solar cell, whereas for field values greater than 0.001T, the power gradually decreases.

The best performance of the photovoltaic cell is obtained for an indium concentration  $x=0.5$  with an optimal thickness  $H_{op}=0.2\mu\text{m}$ , which corresponds to an efficiency  $\eta$  (%) = 28.4

and a short-circuit current density  $J_{cc}=0.024A.cm^{-2}$ , an open-circuit voltage  $V_{oc}=1.3V$ , a maximum power  $P_m=0.0284W.cm^{-2}$  and a form factor  $FF=90.2\%$ .

This model could prove crucial for the space sector, where photovoltaic solar panels are exposed to radiation and various magnetic fields, by allowing their performance to be optimized and their lifespan to be predicted, thus ensuring the reliability and efficiency of these space missions.

## Abbreviations

|            |                                                      |
|------------|------------------------------------------------------|
| B          | Magnetic Field [mT]                                  |
| H          | Base Thickness [cm]                                  |
| Hop        | Optimum Base Thickness [cm]                          |
| Jsc        | Short-circuit Current Density [ $A.cm^{-2}$ ],       |
| Voc        | Open-circuit Voltage [V],                            |
| $\eta$     | Conversion Efficiency [-]                            |
| $\delta_n$ | Excess Minority Charge Carrier Density [ $cm^{-2}$ ] |
| Jphcc      | Short Circuit Photocurrent Density [ $A.cm^{-2}$ ]   |
| Pmax       | Maximum Power Density [ $W.cm^{-2}$ ]                |
| P          | Power Density [ $W.cm^{-2}$ ]                        |

## Author Contributions

**Ngor Dione:** Formal Analysis, Methodology, Software, Visualization, Writing – original draft

**Moussa Camara:** Formal Analysis, Investigation, Software, Supervision, Visualization, Writing – original draft

**Sada Traore:** Formal Analysis, Investigation, Software, Visualization, Writing – original draft

**Moustapha Thiame:** Conceptualization, Project administration, Supervision, Validation, Writing – review & editing

## Conflicts of Interest

The authors declare no conflicts of interest.

## References

- [1] Marouf, Y., Modeling of InGa<sub>N</sub> solar cells using Silvaco Atlas. Mohamed Khider University – Biskra, June 27, 2013. pp. 4–8.
- [2] Wu, J., Walukiewicz, W., Yu, K. M., Shan, W., Ager, J. W., Haller, E. E., Lu, H., Schaff, W. J., Metzger, W. K., Kurtz S., Superior radiation resistance of alloys: Full-solar-spectrum photovoltaic material system, *J. Appl. Phys.* 94,(10) (2003) 6477-6482; <https://doi.org/10.1063/1.1618353>
- [3] Bouzid, F., and Machiche, S. Ben., Potentials of In<sub>x</sub>Ga<sub>1-x</sub>N photovoltaic tandems, *J. Ren. Energies*, vol. 14, no. 1, pp. 47 – 56, Mar. 2011, <https://doi.org/10.54966/jreen.v14i1.240>
- [4] Khetrou, Abderrahim., Zeydi Imen., Chellali, Mohammed., Arbia, Marwa Ben., Mansouri, Sedik., Helal, Hicham., Hassen Maaref A., Simulation and optimization of InGa<sub>N</sub> Schottky solar cells to enhance the interface quality, *Superlattices Microstruct.*, vol. 142, p. 106539, juin 2020, <https://doi.org/10.1016/j.spmi.2020.106539>
- [5] Pelap, F. B., Tagne, E. Konga., et Kenfack, A. D. Kapim., Numerical Optimization of a Tandem Solar Cell based on In<sub>x</sub>Ga<sub>1-x</sub>N, *J. Renew. Energ.*, vol. 24, n 1, p. 25 – 39, juin 2021, <https://doi.org/10.54966/jreen.v24i1.971>
- [6] Li, Jiangong., Li, Fubin., Lin, Shuo., Zhong, Shuiku., Wei, Yiming., Meng, Xianghai., and Shen, Xiaoming., Theoretical study on In<sub>x</sub>Ga<sub>1-x</sub>N/Si hetero-junction solar cell, *Proc. SPIE 7409, Thin Film Solar Technology*, 740910 (20 August 2009); <https://doi.org/10.1117/12.826088>
- [7] Traore, S., Fickou, B., Thiame, M., Tine, M., Optical Optimization of InGa<sub>N</sub> Solar Cells Via Doping and Thickness Control, *International Journal of Sustainable and Green Energy* 2025, Vol. 14, No. 3, pp. 225-233. <https://doi.org/10.11648/j.ijsge.20251403.19>
- [8] Adaine A., Hamady, S. O. S., et Fressengeas, N., Effects of structural defects and polarization charges in InGa<sub>N</sub>-based double-junction solar cell, *Superlattices Microstruct.*, vol. 107, p. 267-277, juill. 2017, <https://doi.org/10.1016/j.spmi.2017.04.025>
- [9] Adaine, A., Simulation and Optimization of an InGa<sub>N</sub>-based Schottky Solar Cell. University of Lorraine, July 6, 2018. p. 50.
- [10] Mesrane, A., Rahmoune, F., Mahrane, A., et Oulebsir, A., Design and Simulation of InGa<sub>N</sub> p - n Junction Solar Cell, *Int. J. Photoenergy*, vol. 2015, p. 1-9, 2015, <https://doi.org/10.1155/2015/594858>
- [11] Abdelkader, M. A., Simulation and optimization of a solar cell based on InGa<sub>N</sub> material. Saad Dahlab University of Blida, 2021. p. 26.
- [12] Hernandez-Gutierrez, C. A., Morales-Acevedo, A., Cardona, D., Contreras-Puente, G., and Lopez-Lopez M., Analysis of the performance of In<sub>x</sub>Ga<sub>1-x</sub>N based solar cells, *SN Appl. Sci.*, vol. 1, no. 6, p. 628, June 2019, <https://doi.org/10.1007/s42452-019-0650-x>
- [13] Fickou, B., Camara, M., Thiame, M., Faye, I., Diatta, L., and Mamadou, F., Modelling and Optimization of the Electrical Parameters of an In<sub>x</sub>Ga<sub>1-x</sub>N Solar Cell Under Dynamic Frequency Illumination, *InterSol 2024, LNICST 610*, pp. 38–46, 2025. [https://doi.org/10.1007/978-3-031-86493-3\\_4](https://doi.org/10.1007/978-3-031-86493-3_4)
- [14] Diop, G., Fall, M. F. M., Sall, M., Loum K., Diatta, I., Ndiaye, M., Wade, M., and Sissoko, G., Determination de la resistance serie de la photopile au silicium (n+/p/p+) a jonctions verticales series sous champ magnetique, *Int. J. Adv. Res.*, vol. 9, n 10, p. 1204-1217, oct. 2021, <https://doi.org/10.21474/IJAR01/13668>
- [15] Zerbo I., Zougrana, M., Sere, D., Ouedraogo, F., Sam, R., Zouma, B., and Zougmore, F. Influence of an electromagnetic wave on a silicon photovoltaic cell under multispectral illumination in static conditions, *J. Renew. Energ.*, (2023), vol. 14, no. 3, pp. 517–532. <https://doi.org/10.54966/jreen.v14i3.278>
- [16] Sourabie, I., Zerbo, I., Zougrana, M., Combari, D. U. and

- Bathiebo, D. J. Effect of Incidence Angle of Magnetic Field on the Performance of a Polycrystalline Silicon Solar Cell under Multispectral Illumination. *Smart Grid and Renewable Energy*, (2017), 8, 325-335. <https://doi.org/10.4236/sgre.2017.810021>
- [17] Ngom, M. I., Diouf, M. S., Thiam, A., M. A. O. El., et Sissoko, G., Influence of Magnetic Field on the Capacitance of a Vertical Junction Parallel Solar Cell in Static Regime, Under Multispectral Illumination, *Int. J. Pure Appl. Sci. Technol.*, 31(2) (2015), pp. 65-75.
- [18] Kosso, A. M. M., Thiame, M., Traore, Y., Diatta, I., Ndiaye, M., Habiboullah, L., Ly, I., and Sissoko, G., 3D study of a silicon solar cell under constant monochromatic illumination: influence of temperature and magnetic field. *Journal of Scientific and Engineering Research*, (2018), 5, 259-269.
- [19] Gorge, V., Characterization of materials and testing of components of solar cells based on III-V nitride elements. Paris-Sud University 11, May 2, 2012, p. 25.
- [20] Zougrana. M., Zerbo. I., Boubacar, S., Mahamadi, S., Sanna, T., et B. Dieudonné Joseph., The effect of magnetic field on the efficiency of a silicon solar cell under an intense light concentration, *Adv. Sci. Technol. Res. J.*, vol. 11, n 2, p. 133-138, juin 2017, <https://doi.org/10.12913/22998624/69699>
- [21] Faye, D., Gueye, S., Ndiaye, M., Ba, M. L., Diatta, I., Traore, Y., Diop, M. S., Diop, G., Diao, A., Sissoko, G., Lamella Silicon Solar Cell under Both Temperature and Magnetic Field: Width Optimum Determination, *Journal of Electromagnetic Analysis and Applications*, 2020, 12, 43-55  
<https://www.scirp.org/journal/jemaa>
- [22] Ngom, M. I., Cheikh, M. L., Lemrabott, H., Gueye, S., Thiame, M., and Sissoko, G., Determination of the shunt resistance of an irradiated silicon photovoltaic cell (n+/p/p+) placed under a magnetic field and under polychromatic illumination with frequency modulation, *Int. J. Adv. Res.*, vol. 11, no. 06, pp. 783-795, June 2023, <https://doi.org/10.21474/IJAR01/17127>
- [23] Ly, I., Lemrabott, O. H., Dieng, B., Gaye, I., Gueye, S., Diouf, M. S., and Sissoko, G. Techniques de détermination des paramètres de recombinaison et le domaine de leur validité d'une photopile bifaciale au silicium polycristallin sous éclairage multi spectral constant en régime statique, *J. Renew. Energ.* (2012), vol. 15, no. 2, 187–206, Oct. 2023, <https://doi.org/10.54966/jreen.v15i2.311>
- [24] Sall, M., Diarisso, D., Fall, M. F. M., Diop, G., Ndiaye, Mor., Loum, K., Sissoko, G., Study of the Intrinsic Recombination Velocity at the Junction of Silicon Solar under Frequency Modulation and Irradiation, *J. Appl. Math. Phys.*, vol. 03, n 11, p. 1522-1535, 2015, <https://doi.org/10.4236/jamp.2015.311177>
- [25] Sagna, B., Cheikh, M. L., Lemrabott, H., Gueye, S., Thiame, M., and Sissoko, G., Single-sided silicon photovoltaic cell in transient conditions: influence of irradiation on photocurrent density and capacity, *Int. J. Adv. Res.*, vol. 11, no. 12, pp. 234-249, Dec. 2023, <https://doi.org/10.21474/IJAR01/17980>
- [26] El-Adawi, M. K. et Al-Nuaim I. A., A method to determine the solar cell series resistance from a single I–V. Characteristic curve considering its shunt resistance—new approach, *Vacuum*, vol. 64, n 1, p. 33-36, nov. 2001, [https://doi.org/10.1016/S0042-207X\(01\)00370-0](https://doi.org/10.1016/S0042-207X(01)00370-0)
- [27] Niane, M., Ould E. M., Mohamed A., Loum, K., Simpore, R., Diatta, I., Traore, Y., Thiame, M., Gueye, S., and Sissoko, G., Etude d'une photopile (n+/p/p+) au silicium cristallin sous éclairage polychromatique en modulation de fréquence : effet de la vitesse surfacique de recombinaison, de la fréquence et de l'épaisseur sur les paramètres électriques, *Int. J. Adv. Res.*, vol. 12, n 05, p. 276-289, mai 2024, <https://doi.org/10.21474/IJAR01/18715>
- [28] Martial, Z., Issa, Z., Boubacar, S., Mahamadi, S., Sanna, T., and B. Dieudonné Joseph., The effect of magnetic field on the efficiency of a silicon solar cell under an intense light concentration, *Adv. Sci. Technol. Res. J.*, vol. 11, no. 2, pp. 133-138, June 2017, <https://doi.org/10.12913/22998624/69699>
- [29] Zerbo, I., Zougrana, M., Sourabie I., Ouedraogo, A., Zouma, B., et Bathiebo, D. J., External Magnetic Field Effect on Bifacial Silicon Solar Cell's Electrical Parameters, *Energy Power Eng.*, vol. 08, n 03, p. 146-151, 2016, <https://doi.org/10.4236/epe.2016.83013>