# Enhancing Performance of a Nitride-Infused MQWEL PIN Photodiode Device through Optimization

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## 1. Abstract

A new consideration of new devices have prospect for solar and photodiodes applications for various stoichiometric parameters. Because can combine the materials to obtain alloys in various energy gap. Our simulation based SILVACO TCAD [1]. After give a good the stoichiometric parameter that must use to achieve high quantum efficiency injection current and spectral responsivity for different active layers. Following this, in the first part, we create a new structure with different graduate InGaN layers focusing particularly on semiconductor GaN.
In a second step, we will write methods of Simulation with silvaco with variation optic proprieties, stoichiometric proprieties and graduate layers. The results show that the InGaN photodiode has high responsivity compared to literature.
*Keywords: nitride of element III, semiconductors GaN, structure zinc blend, Photodiode, optimization.*



## 2. Introduction

Various materials have prospect for development of photodiode such as II-VI and III-IV materials for example SiC. This material has an indirect band gap.
GaN/AlGaN photodetectors IR have been reported [2,3]. In the room temperature, the responsivity of this GaN/AlGaN is ~10 mA/W [2,4].
Active region with a size of 17 × 17 μm2 detectors exhibit an RC-limited BW–3 dB cut off frequency at 19.7 GHz [5] More recently, Pesach et al. demonstrated if use stoichiometric parameters of IN x=0.095 the InGaN/ (Al)GaN QWIPs [6] Devices consisting of 2.5-nm InGaN and AlGaN superlatices
Displayed photocurrent peaks at 7.5 μm and 9.3 μm, respectively; but the characterisation use low temperature (14 K).
A new consideration of new devices have prospect for solar and photodiodes applications for various stoichiometric parameters. Because can combine the materials to obtain alloys in various energy gap.

## 3. Theoretical Model And The Parameters Used For The Materials

The room temperature band gap Eg of our ternary alloys is calculated from:
For $In_xGa_{1-x}N$

$$E_g = E_g(InN)x + E_g(GaN)(1-x) - bx(1-x) \quad (1)$$

And for $(Al_xGa_{1-x}N)$

$$E_g = E_g(AlN)x + E_g(GaN)(1-x) - bx(1-x) \quad (2)$$

$E_g(AlN) = 6.28\,ev$ , $Eg(GaN) = 3.42\,ev$ *wurtzite structure*

*boeing parametres* $= -0.36ev$ For $(Al_xGa_{1-x}N)$

$$n(\lambda)^2 = 1 + \frac{A_0\lambda^2}{\lambda^2 - \lambda_0^2} \quad (3)$$

### 3.2 Photodiodes Model

The maximum responsivity structure is calculated from:

$$S(\lambda) := \frac{\lambda \cdot q \cdot n_{ext} \cdot e^{-\alpha \cdot \lambda}}{h \cdot c} \quad (4)$$

Where Reflective index:

$$R := \frac{(n_1 - 1)^2}{(n_1 + 1)^2} \quad (5)$$

Quantum efficiency

$$\eta_{int} := \frac{n_{ext}}{(1 - R)}$$



(6)

The maximum detectivity structure is calculated from:

$$D(T) := \frac{\eta \cdot \left(\frac{R \cdot S}{4 \cdot K \cdot T}\right)^{\frac{1}{2}}}{Eg} \quad (7)$$

The position of the Sun is identified by the two angles of azimuth a and height h which are calculated by the following theoretical formulas:

## 4. SILVACO TCAD:

For the simulation of devises, we uses SILVACO TCAD simulation software offers different module like ATLAS DEVEDIT end DECKBUILD. ATLAS is use for electric end electronic simulation methods. DEVEDIT use for creation micro thin and Nano structures
It includes a library of nitrides semiconductor binary, ternary and quaternary. Luminous3D 2D and 3D simulators are designs to model absorption and photo- generation.

## 5. Proposed Structures

### a. photodiode proposed Structure

We use the “DEVEDIT SILVACO” tools for fabrication our photodiode structure (figure.3)

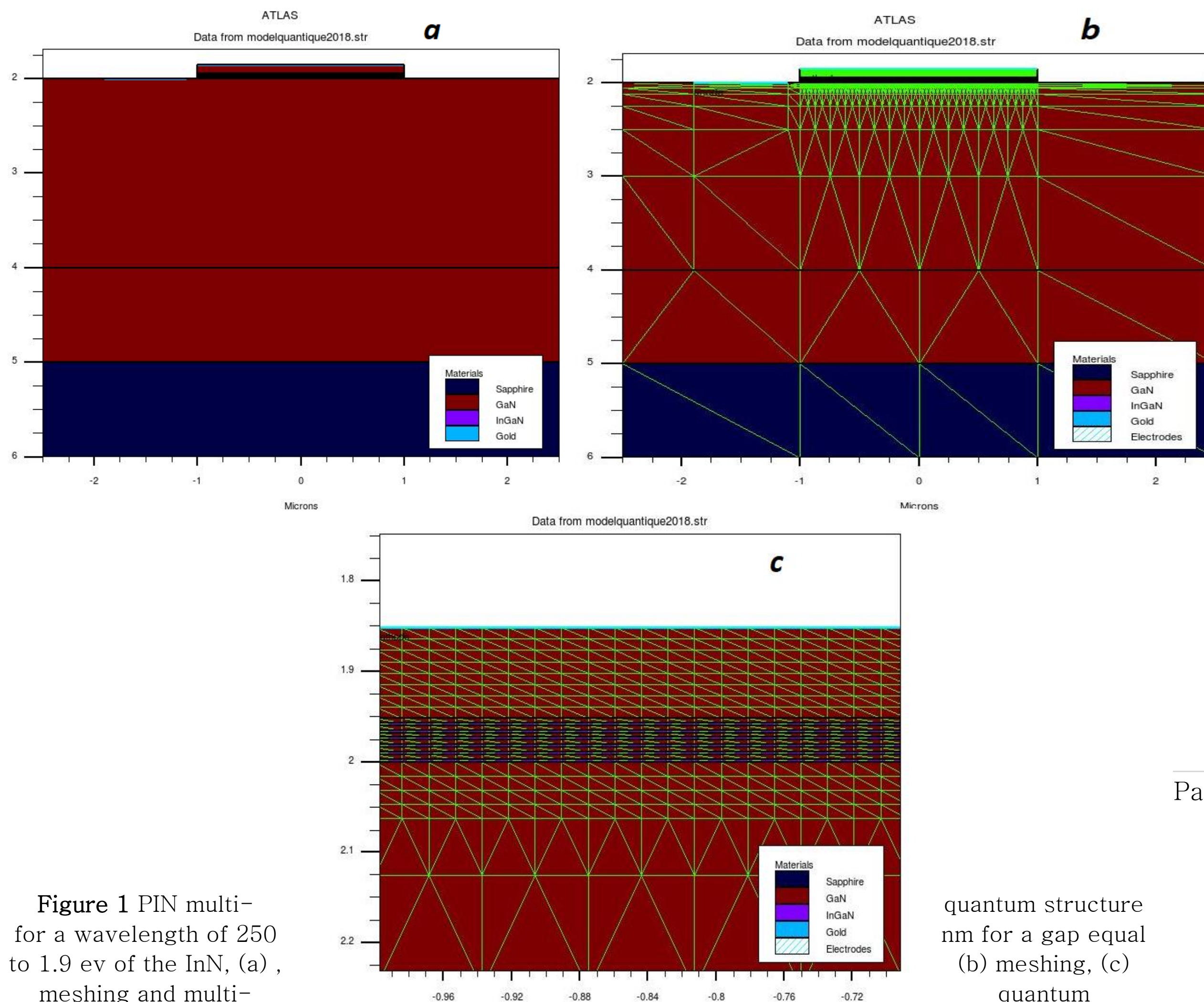


**Figure 1** PIN multi-quantum structure for a wavelength of 250 nm for a gap equal to 1.9 ev of the InN, (a) , (b) meshing, (c) meshing and multi-quantum



In figure 1 conventional photolithography and inductively coupled plasma etching manufacture the layer of InGaN. We introduce 7QWEL of 5nm GaN and 7nm $In_XGa_{1-X}N$ for multiple stoichiometric parameters, with a size of 5.2* 5 um$^2$

## 6. Results and discussion

### a. photodiode based on InGaN

#### i. Conversion efficiency of a photodiode based on InGaN

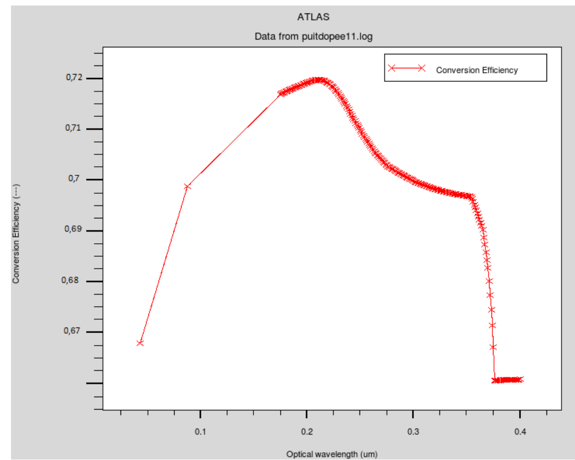


**Figure 2:** conversion efficiency according to the wavelength of the InGaN MQWEL graduate active layers

### ii. Responsivity of a photodiode for different material structures

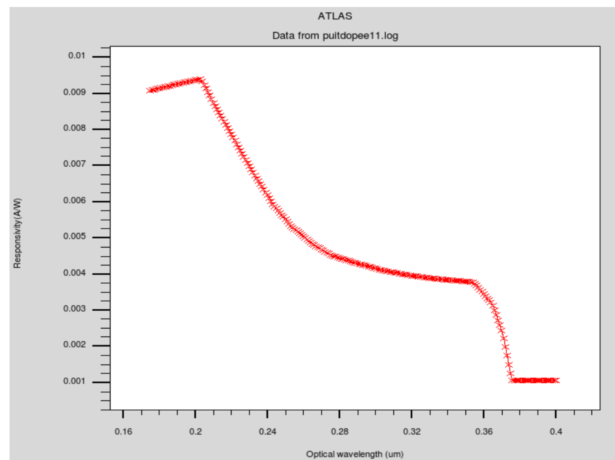


**Figure 3:** Responsivity according to the wavelength of the InGaN, for x= 0.25

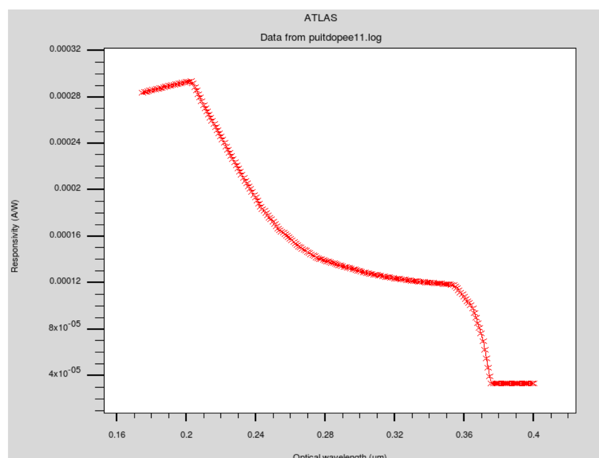


**Figure 4:** Responsivity according to the wavelength of the InGaN, for x= 0.15

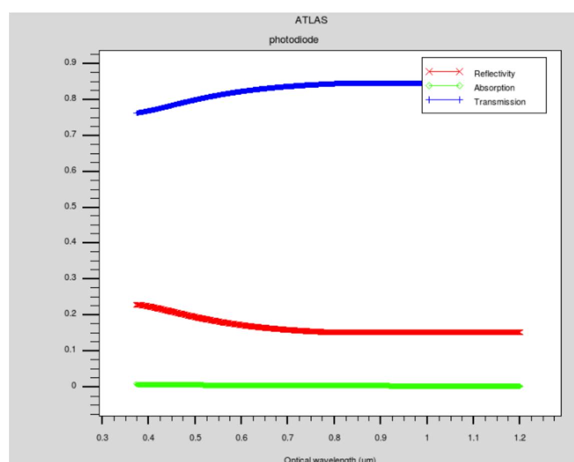


Figure 5: optic propriety of layer

### iii. Current density for a photodiode

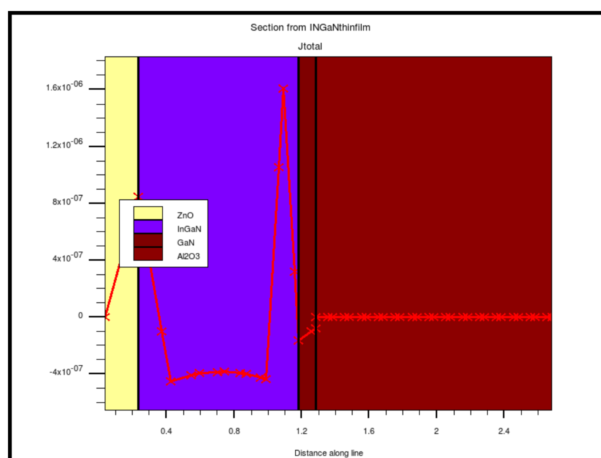


**Figure 6:** current density

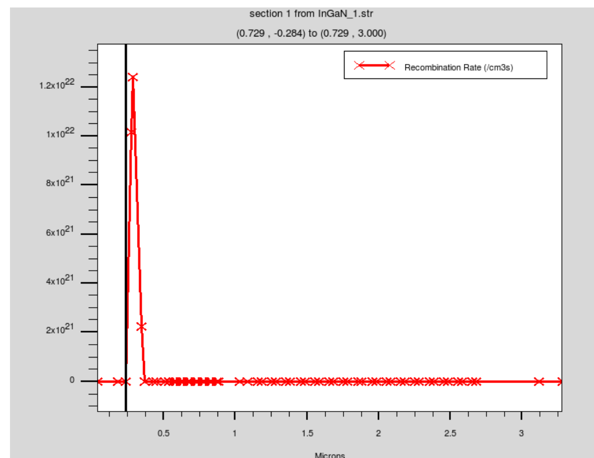


**Figure 7:** Recombination rate of photodiode structures

In this study, we consider the three parameters of the structure, the optimization of stoich iometric parameters, current density and the responsivity. In figure 1c we change the mes hing parameters for a better results.
The major approach is change stoichiometric parameters of the active layers for best spectral and conversion efficiency. I this case a good according wavelength is for x=0.25 to Understand the influence of structure effectiveness. If we look at figure 2 the maximum conversion is in 0.25 to 0.35 um, and the photodiode give a good efficiency in this band length and can be used in UV-ABC, for a good detection.



The adequate width of active lattice of structure is parameter of a good photodiode perfor mance. In order in Figure 6 we represent the evolution of the current density in all struct ure width, we can tell a good performance is in the active layers because the maximum de nsity is in bottom of InGaN graduate layer between this and buffer layer.

Figure 3, 4 illustrates the effect of doping level, and the molar fraction of the active region on the conversion efficiency of the structure we see from the figure that increasing the molar fraction level makes a remarkable improvement in the conversion efficiency of the structure. This improvement is particularly important if the current injection is maximum in active layers. Indeed, with increasing a transmission of window layer (figure 9) conversion responsivity increase and have 0.09 A/w in adequate wavelength.

If the recombination rate increases (figure 7), the lifetime of carriers and mobility deteriorate, this compensates losses carriers recombined in the next grain. This results in a significant decrease in performance due to Auger recombination.
The comparison between data experimental and calculated gives an idea of the conditions necessary for making such a structure, such as growing conditions, temperature, doping, in order to have the issue of the desired wavelength.
We have used Silvaco to analyse the PIN structure in order to determine the region where conversion intensity is maximum.

## 7. Conclusions

In our study, we were interested in the photodiodes based on nitrides, especially PIN / Ga N InGaN photodiodes. This structure can use in the UVA-UVB range. We need simulation to optimize the intrinsic parameters of the structure InxGa1-x N.
First, we optimize the mole fraction to determine a good wavelength. We use silavaco too ls to make our structure and to give different materials parameters in order to determine

precisely the value of the mole fraction, optic parameters and buffer layer parameters.
The results of our simulation show that it is preferable to work with the cubic structure F urthermore; this structure has been the subject of several research projects.
For this, we have different influences the spectral responsivity, the conversion efficiency and the current injection of our structure.
The maximum value of the current injection obtained between active and buffer layer. Th e spectral responsivity obtained is 0.09 A/w at λ = 215nm. The peak width of 150nm at 35 00 nm shows that the material can use in ultra-violet with good responsivity by comparis on with the literature.
In the end, we need to create a new structure with different nanoparticle layers, or in win dow layer, we can use ITO nanoparticle. In addition, we can calculate noises and spectral responsivity with different temperature.

## 8. Reference

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