Study of the GaN Semiconductor Effect as a thin First layer of a Two Layers Solar Cell without Diffusion Doping Technique

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Abstract- The XXI century came with a lot of technological advances, being most of them productive and helpful in the human life, looking for deeply there is a huge problem that the population and the planet inherited from XIX and XX centuries and is called global warming, now in this century that issue is affecting the whole planet in many different ways. One of the solutions to this problem is to eliminate our fossil fuel dependency by changing it for a sustainable and clean way as are the renewable energies, and most of it the solar one, considered as the greatest one. Which through Solar cells, it is possible to capture and converting it into electricity, but nowadays the conversion efficiency is around 15%, lowering its attractiveness and its chances as a way to replace the actual energy sources, that is the reason why different studies have been performed, in order to increase the efficiency, by modifying the physicochemical structure of the semiconductors used or changing some processes like the diffusion doping one, where the main purpose of this process is to modify the carries and the electrical chargers of the semiconductor, which has a significant effect in the behaviour of the whole cell, like in this paper where a deep study of the Gallium nitride (GaN) layer Effect is performed in a Two Layers Solar Cell based on Aluminium gallium arsenide (AlGaAs), Silicon (Si) and Indium phosphide (Inp) semiconductors, with the aim of replacing the diffusion doping process with the proposed scheme of solar cell, which presents different advantages as is going to be observed along this study.

Keywords- Diffusion Doping, Solar Cells, Tandem Cell, PC1D, Gallium Nitride, Energetic Efficiency.

1. Introduction

The current environmental awareness, at global level and different problematic like global warming and climate change have impulse the promotion and supporting of alternatives in order to reduce the greenhouse effect, which have become in the main source of the global warming. One of the most viable way to reduce these effects is implementing clean alternatives to produce energy, like the sun as is described in [1].

According to [2] and [3] solar energy uses, as a method of processing and capturing sunlight, photovoltaic cells based on different semiconductor materials such as Silicon and Germanium. These semiconductors allow to produce energy transforming photon energy in electrical energy by a physic-chemical effect of movement electrons inside of the cell.

In [4] and [5] the concept of tandem cell is to harness the most possible quantity of energy radiated by the sun along its spectre at which is transmitted, to perform this multiple semiconductors are employed in order to use their different band gaps absorbing more sections of the solar spectrum as its band gap allows it.

On the other hand [6] different configurations of Silicon– Germanium Solar cell were studied using PC1D, achieving an efficiency between 18 and 22% depending on the configuration used, this evidenced the use of Silicon as a part of a tandem solar cell, taking in count the commercial efficiency of Silicon which is 15%.

Additionally, in [7] using metal organic chemical vapour deposition (MOCVD) with a graded-junction an Indium phosphide (InP) solar cells have been made, where an improvement in the short-wavelength quantum efficiency and the overall conversion efficiency with 19.1% was observed as a main result.

Furthermore, in [8] the improvements of the AlGaAs/Si tandem solar cell by metal organic chemical vapour deposition have been investigated, where a high efficiency monolithic AlGaAs/Si tandem solar cell under two-terminal and four-terminal configurations is obtained with a conversion efficiency of 19.9% and 20.6% respectively (AM0 and 1 sun at 27 “C).

Beforehand, in [9] a solar cell development based in InGaN/GaN is described using quantum wells, where a conversion efficiency of 40% is obtained in spite of GaN downsides related to a high temperatures and other limitations as explained in [10].

Of all the works studied, the semiconductors selected for this work, have multilayer solar cells developments with important results. That is the reason why in this paper a study of the effects of using Gallium Nitride (GaN) semiconductor as a thin additional layer for different solar cells is studied, where the aim is to observe the option to replace the diffusion doping process in the manufacturing of solar cells for an additional layer of GaN semiconductor.

2. Methodology

As is described in [9] the parameter AM 1.5 in conjunction with AM 0 were defined for the PV industry in conjunction with the American Society for Testing and Materials, government research and development laboratories with the aim of define a standard direct normal spectral irradiance and a standard total spectral irradiance.

According to [10], these parameters includes the solar spectrum, the intensity and the temperature to define the global radiation inside and outside the earth’s atmosphere. In the other hand, this spectres provide a reference point corresponding to a particular set of atmospheric conditions and a specific air mass to test photovoltaic cells and any component related with the solar spectrum [11].

Additionally, there are some others parameters related with the incidence angle of the sun like AM-1 AM 1.5 (Global and Direct) and AM-2. In order to perform an accurate study, this work was based in the Air Mass 1.5 G, a cause of the direct one depends on the earth´s position.

Table 1. Semiconductors properties at 300K

Properties	GaN	Si	AlGaAs	InP
Abundance	18 ppm (Ga) 780900 ppm (N)	267700 ppm	84100 ppm (Al) 18 ppm (Ga) 1 ppm (As)	0.05 ppm (In) 1050 ppm (P)
Thickness	0.1 um	100 um	100 um	100 um
Band gap	3,42 eV	1,124 eV	1,7 eV	1,35 eV
Lattice constant	3.189 A (a) 5.178 A (c)	5.431 A	5.65 A	5.86 A
Absorption range	-	1e17 cm^{-3}	1e17 cm^{-3}	1e17 cm^{-3}
Diffusion Doping	1e20 cm^{-3}	-	-	-
Electron Mobility	440 cm^2/Vs	1417 cm^2/Vs	8569 cm^2/Vs	4730 cm^2/Vs
Hole Mobility	150 cm^2/Vs	470 cm^2/Vs	408 cm^2/Vs	151 cm^2/Vs
Bulk Recombination	7.208 µs	7.208 µs	7.208 µs	7.208 µs
Front Recombination	1000 cm/s	1000 cm/s	1000 cm/s	1000 cm/s
Rear Recombination	1000 cm/s	1000 cm/s	1000 cm/s	1000 cm/s

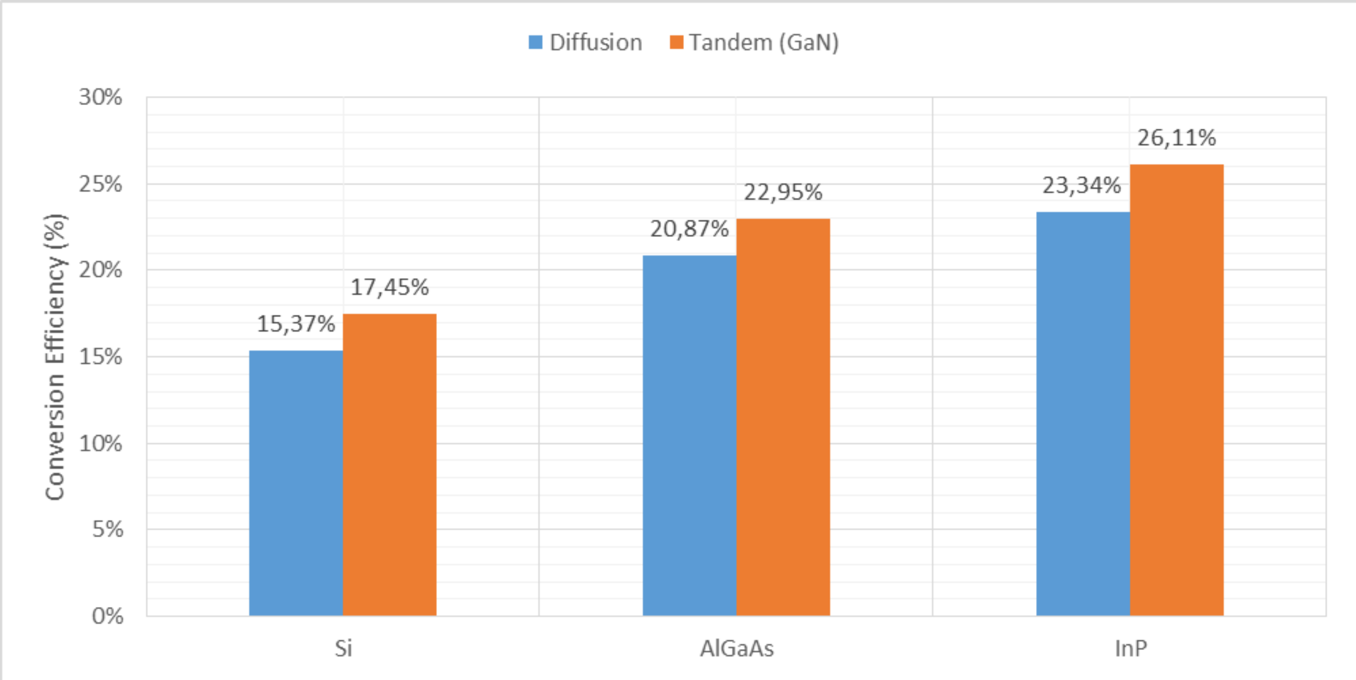

Fig 1. Conversion Efficiency of Solar Cells with and without the effect of a thin GaN layer

The whole study was performed using GaN semiconductor as the essential component of a solar cell to create the photovoltaic effect, replacing by this way the diffusion doping effect. This is possible due to GaN's variable range of band gap as described in [12].

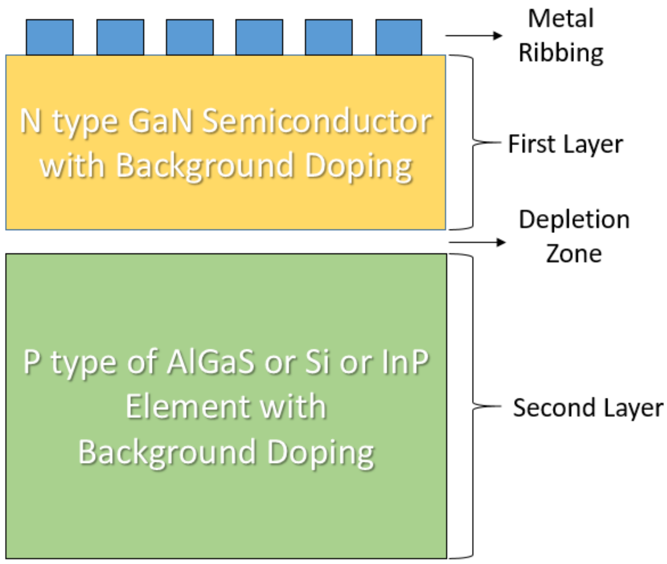

Fig 1. Solar Cell Design in PC1D

This study it's compounded of three different solar cells, using the semiconductors Si, AlGaAs and InP, and it's divided in two comparisons. The first one is using the solar cells with the diffusion doping technique compared with the same solar cells without diffusion but using a thin GaN layer. For the second one the generated power it's compared with the efficiency of each solar cell. All of this, in order to determinate the real effect of adding the GaN layer.

In order to perform all these simulations the PV software PC1D was used, due to its multiple advantages and tools, like its database of the physic-chemical properties of Si, AlGaAs and InP. But for the GaN semiconductor, was necessary to implement them using the data obtained from [13] and [14]. Table 1 shows the most important properties of the semiconductors.

The simulation parameters implemented in PC1D are: a constant radiation of 0.1 W / cm2 under the standard terrestrial solar irradiance AM 1.5 as explained before what means a room temperature (25 ° C), a cell dimension of 100 cm2 and a reflectance factor of 5% with a textured surface of 3 um depth and an inclination angle of 54.74 °.

The solar cell scheme used for this work is shown in Figure 1, where the first layer corresponds to the added GaN semiconductor replacing the diffusion doping method and the second layer is a Si-based, AlGaAs-based and InP-based semiconductors.

The aim of this study is to confirm by using the scheme shown in Figure 1 that the diffusion doping effect can be replaced using a GaN thin layer in the semiconductor which the solar cell is based and for that purpose the Equation 1 defines the calculation of the diffusion dopping procces length.

$$L = \sqrt{D\tau} \qquad (1)$$

Where L is the length of diffusion measured in meters, D is the diffusivity measured in m2/s and τ is the time of life of minority carriers, which is calculated depending on the design to propose.

3. Results

The first simulations performed were of each semiconductor (Si, AlGaAs, InP) using diffusion doping technique, the results obtained are shown in table 2, where the five electrical characteristics studied are the short circuit Current (Isc), the Open circuit Voltage (Voc), the Generated Power (Pg), the fill factor (FF) and Absorbed Power (Pa).

Table 2. Electrical Results of Si, AlGaAs and InP based Solar Cell

Electrical Characteristic	Si	AlGaAs	InP
Isc (Amps)	3,418	2,418	2,942
Voc (Volts)	0,606	1,019	0,956
FF (%)	74,2	84,7	83
Pg (Watts)	1,537	1,745	2,087
Pa (Watts)	6,609	5,4827	6,182

The data obtained from table 2 show the advantages of each semiconductor, starting to Si, which is the cheapest and more abundant semiconductor with the highest value of current, the InP semiconductor has the highest power generation and the AlGaAs semiconductor has the highest value of Voltage and is more stable and abundant than the InP one.

The next step was performing the same simulation with the GaN layer as a replacement of the doping by diffusion for the same three semiconductors, the results are shown in the table 3.

From the data presented in table 3, comparing them with the ones obtained in the table 2, an improvement can be appreciated where depending on the semiconductor studied, the improvement is different, starting in Si in which the most remarkable one was in terms of voltage increasing 59,8 mV followed by the fill factor which increased 2,8%. For AlGaAs and InP the current increased 0,629 Amps and 0.34 Amps, representing an advantage for reducing the number of panels necessary to satisfy an energetic demand.

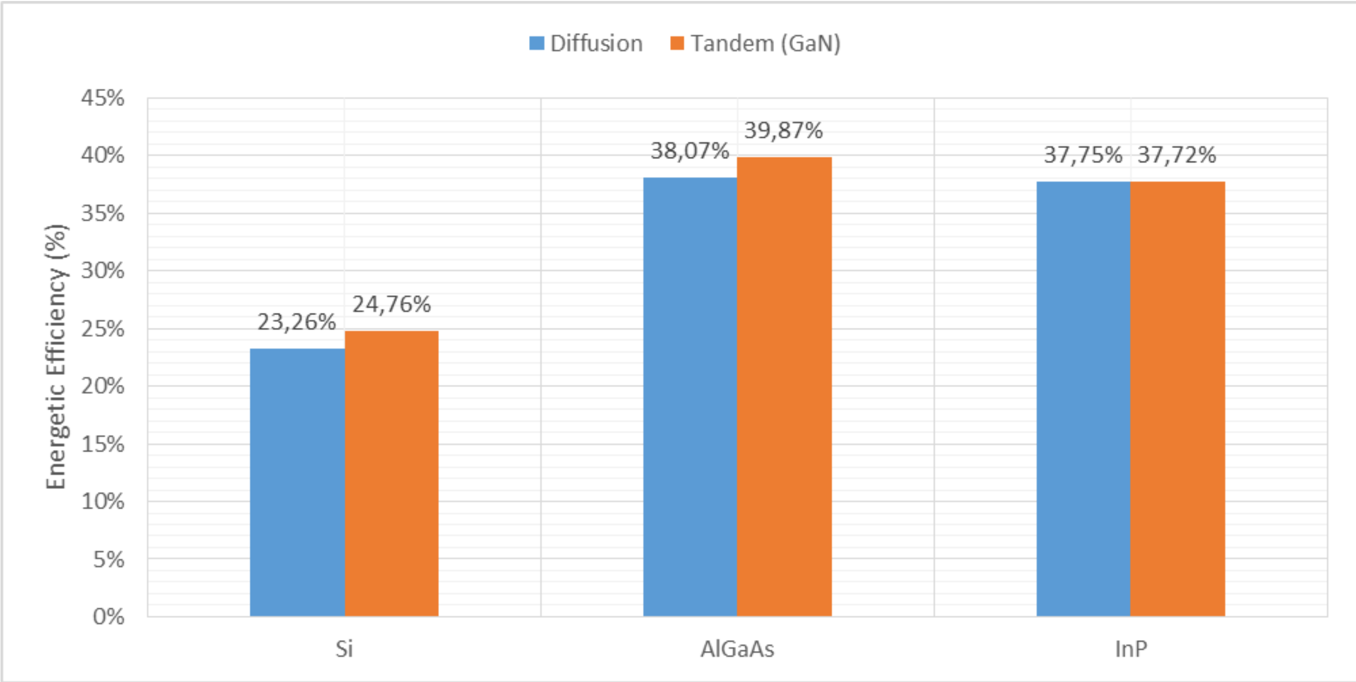

Fig 2. Energetic Efficiency of Solar Cells with and without the effect of a thin GaN layer

In general the most important improvements is in terms of absorbed and generated power, where for these three semiconductors increased between 5% and 11%.

The next step was to compare the results obtained in terms of efficiencies both conversion and energetic efficiency (n and E.E). The first one is obtained by applying the Eq 1. The resulted efficiency is shown is figure 2.

$$n = \frac{Generated\ Power}{Solar\ Radiation * Cell\ Area} \quad (1)$$

Form figure 2 a better estimation can be observed of the effect of adding a GaN layer in different semiconductors, where the most remarkable result was obtained by the InP semiconductor, but even so the increase around the three semiconductor is almost the same which is between 2% and 3%.

For the energetic efficiency a relationship between the produced and the absorbed power is performed and the results are presented in figure 3.

Using the data obtained from figure 3 an increase in the energetic efficiency is denoted a cause of the absorbed energy growth under the same simulation characteristics. Being the AlGaAs semiconductor the most affected with the highest value, but as the conversion efficiency in Figure 2, the overall raise is between 0% and 2%, depending on the semiconductor properties.

Table 3. Electrical Results of InP/Ge-based Solar Cell

Electrical Characteristic	GaN/Si	GaN/AlGaAs	GaN/InP
Isc (Amps)	3,404	3,047	3,282
Voc (Volts)	0,6658	1,026	0,9596
FF (%)	77	84,2	82,9
Pg (Watts)	1,745	2,087	2,632
Pa (Watts)	7,047	5,756	6,922

4. Conclusion

The use of GaN semiconductor as a thin layer in the development of solar cells, makes possible to create high efficiency cells, which are able to absorb and convert more energy than using a commonly Si-based solar cell due to GaN's capacity to extend the range of the solar spectrum absorbed. Additionally this additional layer works combined with different semiconductors, such as Si, AlGaAs and InP, among others.

Solar cells are able to satisfy the energy demand by taking advantage of at least 40 to 60% of the whole solar energy, a cause of its potential, being able to produce in 1 hour the enough energy used in the planet for a whole year.

PC1D is a complete tool in the study and development of solar cells, due to its multiple options, being able to modify chemical and physical behaviour inside the cells. That is the reason why this software was implemented in this paper, allowing to simulate an accurate response of a solar cell by implementing a GaN thin layer in different cell's models.

Photovoltaic industry has the potential to develop in the next years cells with the capacity to compete with non-renewable energy sources (e.g. fossil fuels), as seen in this paper where by adding a GaN thin layer of 0,1 μm made possible to achieve 3% more of energy and absorb even more

The conclusion section should emphasize the main contribution of the article to literature. Authors may also explain why the work is important, what are the novelties or possible applications and extensions. Do not replicate the abstract or sentences given in main text as the conclusion.

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