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ANALYSIS OF QUANTUM AND ENERGETIC EFFICIENCY IN SOLAR CELLS BY MODIFYING THE DIFFUSION DOPING METHOD

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ABSTRACT
In the field of photovoltaic energy, there have developed different methods in order to increase efficiency in the energy converted from solar cells, which commercially does not exceed 16% and has an initial high investment, which results in being amply overcame by other alternatives. From the different studies conducted in the last years, multilayer cell technology is highlighted, which offers a number of advantages in terms of energy, where it is possible to achieve efficiencies above 50%. In this paper, the use of this technology as a replacement to the diffusion doping method in the solar cell is proposed, studying its advantages and disadvantages in a cell-based Ge using two different models: the first one uses the doping method and the second one uses a multilayer cell based on Si/Ge with only a background doping.
Keywords: Renewable Energy, Solar Energy Efficiency, Multilayer Solar Cells, Semiconductor, PC1D, Air Mass 1.5, Quantum Efficiency, Diffusion length, Doping.

INTRODUCTION
In the recent years the effects of global warming and the overexploitation of fossil fuel sources have evidenced, causing different issues like the increase of the products prices, the water shortages, the increasing global temperature and the energy demand in general, which is also related to the increasing overpopulation. That is why in the last 10 years several efforts have made to increase the use of renewable energy, as is the case of solar one, which according to the annual report REN21[1] has increased more than 40 times , from 3.7 GW in 2004 to 177 GW by the end of 2014.
The above is in response to commitments that European Union remarked in 1990 with the treaty 20-20-20 as evidenced[2], which stipulates increasing 20% of the renewable energy production reduce the energy consumed by 20% and increase the efficiency in energy use by 20%. All of this for 2020.
Solar energy is considered as the largest energy source on earth as stipulated[3], where theoretically it produces 89300 TW/s globally, from which 58300 TW/s are available for use, being able to supply the worldwide energy demand, which[4] is for 2014 was 43.74 TW/s.
A cause of the above and considering that photovoltaic cells have a conversion efficiency of 16%, different solutions have been raised earlier.[5,6] The one that has offered the best results is the combination of two or more semiconductors, known as tandem solar cells[7], which has the potential to increase both the converted and the absorbed energy, resulting in a better use of the Solar energy. The last is possible using different zones of the solar wavelength, wherein each semiconductor used captures different sections of this wave and by mixing two or more it is possible to take advantage of more sections of the spectrum produced [8,9].

One of the used techniques for basic operation of a solar cell is the semiconductor doping, being the method by diffusion length of minority carriers one of the most used despite its drawbacks[10], this phenomenon is necessary for the current generation within the cell. A study[11] of the P-type diode behavior doped with GaN was performed, in order to correlate the diffusion-measured length in an electron and its lifetime, with multiple mechanisms of recombination, setting the structural and electronic properties of GaN. In the same way[12] a degradation behavior of solar cells with a front surface metallization was investigated, based on a diffusion barrier based nickel plated, obtaining a direct relationship between the effectiveness of diffusion method efficiency obtained.
As deepening the works performed in this area[13] a solar cell based on silicon was developed using a lightly front diffusion doping, in order to reduce losses in the cell operation, thereby maximizing the produced efficiency.
Of all the works studied, in this paper an analysis of the use of tandem technology it is proposed as a replacement of the doping diffusion method in a cell based on Ge. Obtaining as main result a detailed analysis of the advantages and disadvantages of the proposed method comparing it to the traditional one.

EXPERIMENTAL

To perform the development of diffusion method proposed in this article is necessary to identify, as a first step, the properties of the semiconductors that are going to be used, as shown in Table-1.
To develop the simulation of this doping method, the relationship that this one has on the design of solar cells was identified, in this method[14,15] directly affects the minority carriers, which in turn determine the Isc (short circuit current) and Voc (open circuit voltage) of the cell. Equation-1 defines the calculation of the diffusion length in a cell.
Where L is the diffusion length measured in meters, D is the diffusivity measured in m2/s and τ is the lifetime of minority carriers, which is calculated depending on the design to propose.
Both models were developed and simulated in the specialized software PC1D, using the following parameters: a constant radiation 0.1 W/cm2 by means of AM 1.5 standard test[15,16] a room temperature (25°C), an 5% reflectance factor[17], a textured surface of 3 um depth and an inclination angle of 54.74°.

Table-1: Semiconductors properties at 300K

Properties	SI	GE
Thickness	100 um	100 um
Band gap	1.124 eV	0.664 eV
Lattice constant	5.431 A	5.658 A
Absorption range	0 – 626.7 nm	0 -1306 nm
Quantum efficiency (min-max)	31% - 96.41 %	0 % - 95.73 %
Experimental efficiency (PC1D)	15%	4%
Background Doping	1 x 1020 cm-3 (Si) and 1 x 1017 cm-3 (Ge)	1 x 1020 cm-3
Diffusion Doping	-	1 x 1017 cm-3
Front Recombination	Sn = Sp = 1e4 cm/s	Sn = Sp = 1e4 cm/s
Rear Recombination	Sn = Sp = 1e4 cm/s	Sn = Sp = 1e4 cm/s

The proposed design shown in Figure-1, section (A) offers the possibility of using compound semiconductors of group III-IV, in order to generate the displacement effect of electrons from one layer to the other without the need to dope the primary semiconductor with an additional material (which for the case of silicon usually is boron, phosphorus or arsenic). In the same Figure-1 but section (B) shows the current method and its difference between the two techniques, where this work make a comparative analysis between the proposed and the currently model used.

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

In the development of this technique a silicon layer on a solar cell based in Germanium is used, which in the case of Figure-1, the red sector is the first layer based on N type silicon and the blue area corresponds to the semiconductor P type Germanium.

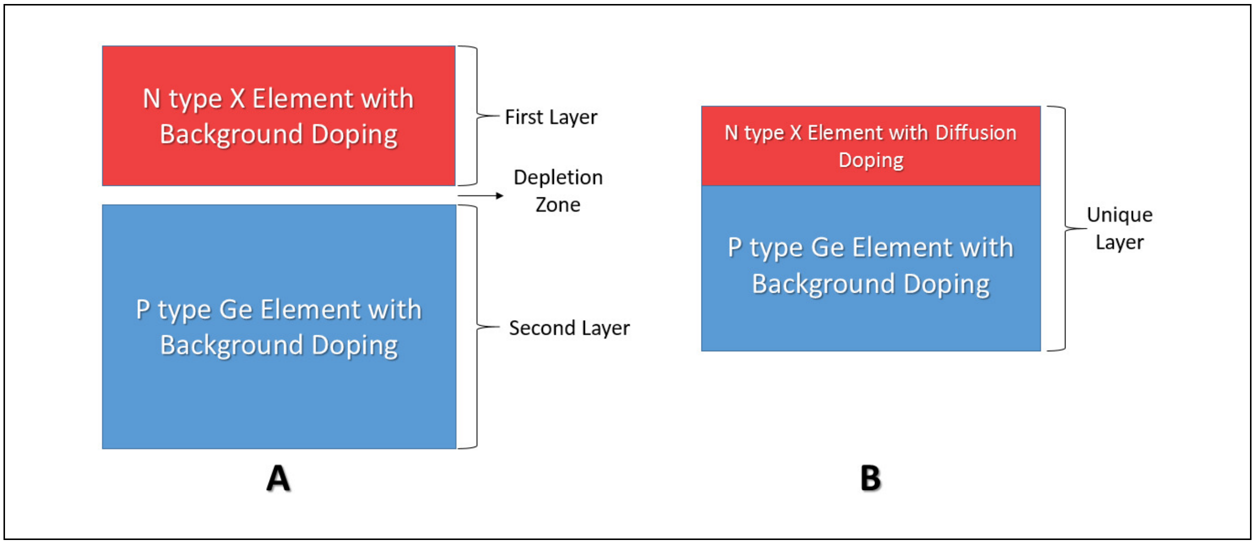

Fig.-1: Tandem Solar Cell Design in PC1D Simulation Program

Once the characteristics of the proposed solar cell are configured, the electrical properties and the efficiencies achieved are analyzed by performing an energetic study.
It is necessary to denote this method replaces the diffusion doping method only and the background doping quantity of the P and N zones must be the same in both models. This in order to study the implications of changing the method correctly and not only the change of the doping amount.
For the energetic analysis, it is necessary to determine the power consumption of material and its energy efficiency. The first one from the internal quantum efficiency of the material it is obtained and defined applying equation-2.

$$EQ = \frac{I_{sc\lambda}}{q\phi_0(1-R)} \qquad (2)$$

Where, $I_{sc\lambda}$ is the spectral density of the short circuit current by means of which the I_{sc} of the cell is defined by integrating it along the wavelength where the panel operates, q is the charge of an electron, ϕ_0 is the electron spectral flux and R is the reflection coefficient of the panel
In order to find the energy efficiency the relationship between the input power and the produced power is found as shown in equation-3. Where the generated power is obtained from the electrical characteristics of each semiconductor, which the simulation program delivers.

$$EE = \left[\frac{Generated\ Power}{Absorbed\ Power}\right] * 100\% \qquad (3)$$

RESULTS AND DISCUSSION

As a first parameter, the quantum efficiency of both models is determined, for this purpose was necessary to use in the simulation an analysis of the solar cell behavior according to the wavelength of the solar spectrum. To this end, the wave section to analyze was defined from 300 nm to 2000 nm as shown in Figure-2 and Figure-3.

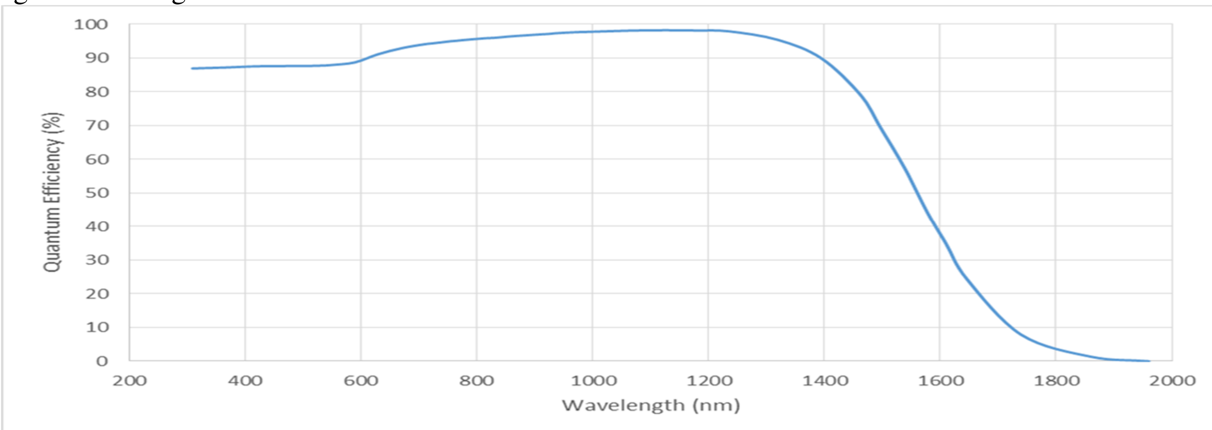

Fig.-2: Quantum Efficiency of Ge-based Solar Cell

Figure-2 shows the quantum analysis of the diffusion doping model, for a stretch of 300 nm to 600 nm the internal quantum efficiency of the design comprises a value of 86% to 90%, then increases exponentially until a value of 98% at 1000 nm and then slowly decreases to 1260 nm with a value of 97.5% and thereafter decreases exponentially to 2000 nm for an efficiency of 0.9%.
Unlike Figure-1 in Figure-2 it is evident that for the same initial section (300-600 nm) the efficiency increases from 86% to 94.9% and from 90% to 99.75%, hence is kept constant until at 1000 nm where it decreases slowly until the 1260 nm with a value of 97.5%, thereafter as with the first model it decreases exponentially to 2000 nm with the same efficiency (0.9%).

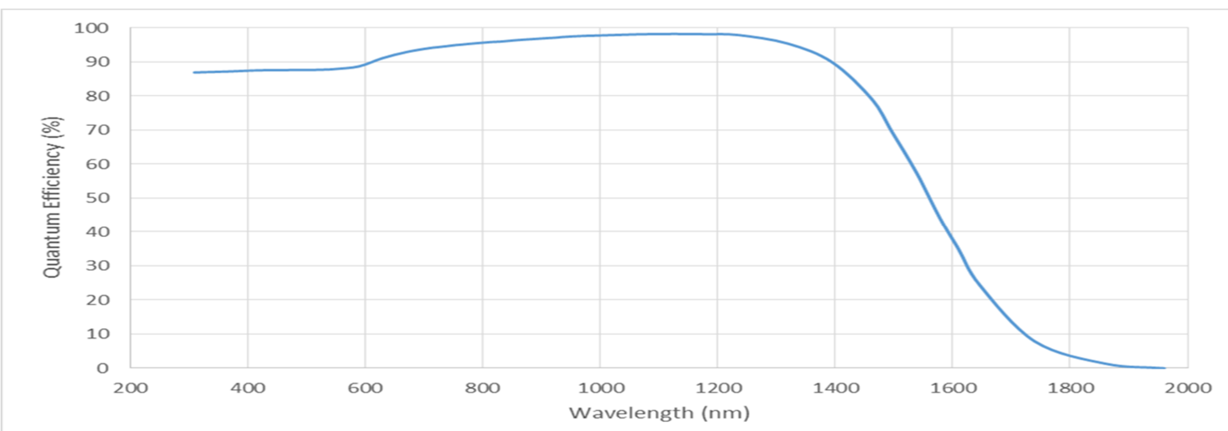

Fig.-3: Quantum Efficiency of Ge-based Solar Cell

Once the quantum efficiency of the model is obtained, then the energetic efficiency is calculated, for which was necessary to make an electrical analysis of each model. The results obtained by the model based Ge are shown in Table-2.

Table-2: Electrical Results of Ge-based Solar Cell

Electrical Characteristic	Ge
Isc (Amps)	4.84
Voc (Volts)	0.2257
Pm (Watts)	0.4941
n (%)	4.941%
FF (%)	0.453

However, as can be evidenced in Table-2 an efficiency of 4.9% is obtained from the standard PC1D value of 4%, using the doping diffusion technique with phosphorus in the Ge-based cell. Likewise, the same test was performed for the model based on Si/Ge, as shown in Table-3.

Unlike Table-2, Table-3 shows an improvement in all analyzed electrical aspects, the current increased 296 mA, the voltage increased 11 mV, the power 55.4 mW and the efficiency increased 0.554%, showing the electrical advantages obtained by using this method.

Table-3: Electrical Results of Si/Ge-based Solar Cell

Electrical Characteristic	Si/Ge
Isc (Amps)	5.136
Voc (Volts)	0.236
Pm (Watts)	0.5495
n (%)	5.495%
FF (%)	0.453

Comparing the results from Table-2 and Table-3, the advantages obtained are not significant, but the main benefit of this method is to increase the amount of energy absorbed from the solar spectrum, under the same conditions of background doping, as you can be seen in Table-4, where a comparison between the energy and quantum efficiency in both methods is performed.

Using equation-2 in Figures-2 and 3, the internal quantum efficiency (EQ) of each of the two models is obtained, as can be seen in Table 4 for the proposed method the amount of the power absorbed increased 6% rising considerably from 8.5 Watts to 9.11 Watts. Being for both designs the maximum possible value of absorbed power in 10 watts.

Table-4: Energetic Results of both models

Characteristic	Si/Ge	Ge
EQ (%)	91.15%	85.42%
PG (Watts)	0.5495	0.4941
PA (Watts)	9.115	8.542
E.E (%)	6.029%	5.784%

Equation 3 was used to obtain the energetic efficiency (EE), by relating the power generated (PG) with the absorbed one (PA). A cause of the low efficiency conversion of the Ge-based solar cell, its EE is low, being evidenced in Table 4. On the other hand, the increased obtained by the proposed model it is demonstrated moving from 5.784% to 6.029%.

CONCLUSIONS

As a first step, the proposed method in this paper presents better results in all energy aspects taken into account. On the other hand, the diffusion doping method is commonly used a cause of its cost but not for its many advantages, as evidenced in the works studied, where as the main disadvantage of this method it was found the control difficulty and the working temperatures, among others.

The studied method in this paper is not a doping technique itself, and its usefulness is more focused on the development of tandem solar cells with over 30% efficiency, but its main advantage, which is the increase in the quantum efficiency of the cell was the main purpose in this work, replacing a doping method with a thin layer of a X element, eliminating by this way the aforementioned disadvantages of the traditional method.

Throughout this work it was possible to show that for the development of more efficient solar cells, first it is necessary to increase the quantum efficiency of the cell, in order to reach 95-100%, thereafter, it is a matter of increase the energetic efficiency, either through several layers of different semiconductors or applying other method, the main purpose is taking advantage of all energy absorbed by the cell.

In this paper, Germanium was proposed to use as a base element in the solar cell, not for its energetic efficiency, but for its quantum efficiency. Due to Ge has a low band gap value, it is able to absorb more energy than other elements either silicon or GaAs.

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