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Study and Analysis of Semiconductors for the Development of Two-layer Solar Cells

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Abstract

In the field of renewable energies, researchers have always looked for the improvement of the conversion method in solar cells, due to the fact that only 14% of the electrical potential is being used. That is why in order to increase efficiency, different designs and materials have been studied. One of the most viable ways is the technology of multilayer solar cells, which the recent investigations focused due to the fact this technique allows the possibility of achieving efficiencies above 30%. Despite the above, the problem of this technique is the cost of manufacturing, which compared to the commercial cells, is inferior in benefit - cost relationship. For this reason, this paper shows a study of different semiconductors to design a two-layer solar cell, with the aim of selecting the best combination of semiconductors according to their own characteristics and results according to the described method.

Keywords*: Renewable Energies, Solar Energy, Efficiency, Cost-Benefit relationship, Tandem Solar Cells, Semiconductors.*

1. Introduction

Nowadays, due to the environmental problems generated by the usage of oil and fossil fuels in recent decades, different alternatives have been studied that do not generate environmental impacts. One of the most investigated options is the sun, because of its energetic potential, its global coverage and the different advantages that this resource offers. Between different developing techniques of the last years for manufacturing and obtaining electric energy from this resource, there is the creation of multilayer solar cells that allows the combination of different semiconductors, exploiting the individual characteristics of each one of them and improving the net conversion efficiency.

Initially, as a first approximation in the design of multilayer solar cells, studies were developed based on the mixture of silicon in different states of purity, as in [1] where amorphous and polycrystalline Silicon were mixed achieving an efficiency of 21% (7.25 % of the above cell and 13.75% of the below cell). Later in [2] the MOCVD method was studied for the manufacture of two-layer monolithic cells mixing GaInP and GaAs with an efficiency of 30.03%.

Furthermore, the possibility of using silicon as part of a six layers solar cell was studied in [3]. To accomplish this, the physical and chemical characteristics of this semiconductor like thermodynamic and conversion efficiency limited at 20 suns were analyzed. Silicon in combination with other semiconductors such as GaAs and GaInP, got a maximum possible efficiency of 55.6% for this design. Similarly, a methodology for analyzing a multijunction solar cell of four layers was designed in [4], using materials such as zinc and selenium, which under standard conditions got an efficiency of 33% and under ideal conditions the efficiency was 76.69%. Where 72% of the efficiency comes from the components of silicon and germanium. Thus from [5-10], for this method, a

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theoretical limit of efficiency between 30 and 68% and an experimental limit of efficiency of 50 to 89% were established.

Additionally, a hybrid solar cell was modeled and designed in [11] using organic and inorganic materials, thus making possible to calculate the increase of the efficiency in a commercial silicon solar cell from 15% to 19.5%. Furthermore, the combination of GaAs and Ge semiconductors was studied in [12], using their individual characteristics (GaAs sensitivity to visible light and Ge sensitivity to infrared radiation), in order to achieve a greater coverage of the solar radiation spectrum. The previous resulted in a 27% of efficiency under 1 sun and 35% under 400 suns. Similarly, a double layer solar cell was developed in [13] based in CdTe and InGaAs, which achieved an efficiency of 26.6% at 1 sun, but presents a greater difficulty in the extraction of these semiconductors, compared to GaAs and Ge. As well, a solar cell was made in [14] with commercial semiconductors such as Si and Ge, getting only a maximum efficiency of 17.86%.

Generally, multilayer solar cells are defined in [15-19] with the aim of using the maximum amount of energy radiated by the sun. For this reason, different semiconductors are chosen according to their own characteristics, such as the value of their bandgap. Which means they have the capability to absorb and transform a specific part of the radiation spectrum. Additionally, these characteristics define the compatibility between these materials and therefore, their capability to develop different combinations and achieve different efficiencies.

That is why this paper shows the results of different combinations for developing a two-layer solar cell using the PC1D software to study the advantages and disadvantages of each design and determine the best. As a main result, a profitability model was established by relating the cell efficiency with the monetary cost of the semiconductors, and thus, generating an index that shows the overall performance of the cell. Additionally, this model is applicable to simulate and compare different designs of solar cells regardless of the amount of layers.

This article is organized into a first section, in which an introduction to the studies and the design of multilayer solar cells is performed. Section two shows the characterization of each semiconductor and the combinations selected. In section three, the results of the simulations are shown as well as the profitability model obtaining process and the performed comparisons between the selected designs. Finally in section five the conclusions are presented.

2. Methodology

For the development of different designs, it is necessary to take into account different characteristics of each semiconductor, in order to ensure compatibility between them, and determine the possible combinations to study. The chosen materials were silicon (Si), Germanium (Ge), indium Fosfuoro (InP), gallium arsenide (GaAs) and aluminum gallium arsenide (AlGaAs), which are the most used for the development of solar cells.

The studied semiconductor properties were the prohibited band or Bandgap, quantum efficiency, absorption coefficient and lattice constant, which are variables with the greatest impact for this study. The set values are shown in Table 1.

Table 1. Simulation Parameters at 300 k

Properties	SI	AlGaAs	GAAS	INP	GE
Thickness	100 um	100 um	100 um	100 um	100 um
BandGap	1,124 eV	1,817 eV	1,424 eV	1,35 eV	0,664 eV
Lattice Constant	5.431	5.6767	5.653	5.869	5.658

	A	A	A	A	A
Doping P zone	2e16 cm-3	2e16 cm-3	2e16 cm-3	2e16 cm-3	2e16 cm-3
Doping N zone	1e20 cm-3	1e20 cm-3	1e20 cm-3	1e20 cm-3	1e20 cm-3
Mass Recombination	Tn = Tp = 7,208 us	Tn = Tp = 7,208 us	Tn = Tp = 7,208 us	Tn = Tp = 7,208 us	Tn = Tp = 7,208 us
Front Surface Recombination	Sn = Sp = 1e5 cm/s	Sn = Sp = 1e5 cm/s	Sn = Sp = 1e5 cm/s	Sn = Sp = 1e5 cm/s	Sn = Sp = 1e5 cm/s
Rear surface Recombination	Sn = Sp = 1e5 cm/s	Sn = Sp = 1e5 cm/s	Sn = Sp = 1e5 cm/s	Sn = Sp = 1e5 cm/s	Sn = Sp = 1e5 cm/s

The simulation conditions in PCD1 were: a radiation constant of 0.1 W / cm2 under standard terrestrial solar irradiance AM 1.5 [20], [21], an environmental temperature (25 ° C), a cell of 20 cm x 20 cm x 100 um, a reflectance factor of 10%, a 2 um textured surface of depth and an inclination angle of 60°. Additionally, it is necessary to perform two simulations per design, due to PC1D not supporting multilayer designs [18], but it has several advantages, such as an interface that considers all existing features, making this a complete software tool for the simulation of photoelectric devices.

The design used for simulating each layer in PC1D is shown in Figure 1, where E and B are the semiconductor emitter and base respectively. The base has a resistance value of 10 Ω, the blue area corresponds to the doping type P and the red one corresponds to N-type doping.

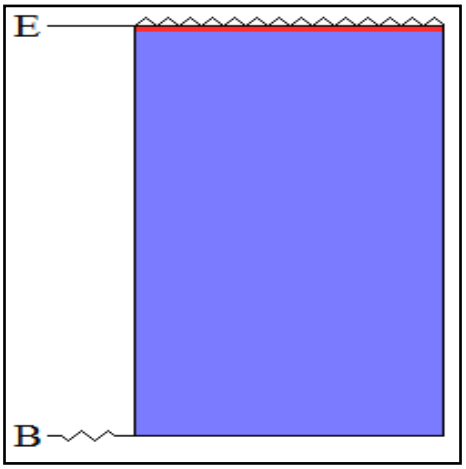

Figure 1. Solar Cell Design in PC1D

3. Results

In order to achieve the best results, four designs were developed based on the characteristics previously mentioned. From the semiconductors shown above, the combinations chosen were the ones with the lattice ratio close to 1, which are:

- Si – Ge ($\frac{5{,}431\ \text{A}}{5{,}658\ \text{A}} = 0{,}956$)
- Si – GaAs ($\frac{5{,}653\ \text{A}}{5{,}431\ \text{A}} = 1{,}0409$)
- AlGaAs – GaAs ($\frac{5{,}6767\ \text{A}}{5{,}653\ \text{A}} = 1{,}0042$)
- AlGaAs – Inp ($\frac{5{,}6767\ \text{A}}{5{,}869\ \text{A}} = 0{,}9672$)

The first design was Si-Ge, where the efficiency of the two most common materials in the construction of solar cells was analyzed. Table 2 shows the results of this design.

Table 2. Si-Ge Relation

Item/Material	Si	Ge	Total
Isc	12,770	10,580	0,253
Voc	0,598	0,182	0,7793
Pm	4,347	0,496	4,8433
n	10,868	1,241	12,10825

Where Isc is the short circuit current, Voc is the open circuit voltage, Pm is the maximum power and n is the efficiency.

For the second design, silicon and a compound semiconductor (GaAs) was used, taking advantage of the second material characteristics in order to increase the efficiency of the first one. Table 3 shows the results.

Table 3. Si-GaAs Relation

Items	Si	GaAs	Total
Isc	12,770	8,979	0,152
Voc	0,598	0,982	1,5796
Pm	4,347	6,630	10,977
n	10,868	16,575	27,4425

For the third design, the lattice constant was considered as the key factor in the decision, showing from the selected materials the two with the most similar lattice constant. The results are shown in Table 4.

Table 4. AlGaAs – GaAs Relation

Item/Material	AlGaAs	GaAs	Total
Isc	6,059	8,979	0,152
Voc	1,351	0,982	2,333
Pm	6,889	6,630	13,519
n	17,223	16,575	33,7975

The last design was simulated using AlGaAs and InP, which are the two compound materials with the best conversion efficiencies trying to take advantage of their characteristics. The results are shown together in Table 5.

Table 5. AlGaAs – Inp Relation

Item/Material	AlGaAs	Inp	Total
Isc	6,059	10,650	0,152
Voc	1,351	0,925	2,2762
Pm	6,889	6,912	13,801
n	17,223	17,280	34,5025

Figure 2 shows the results in terms of efficiency, making a comparison between the selected designs.

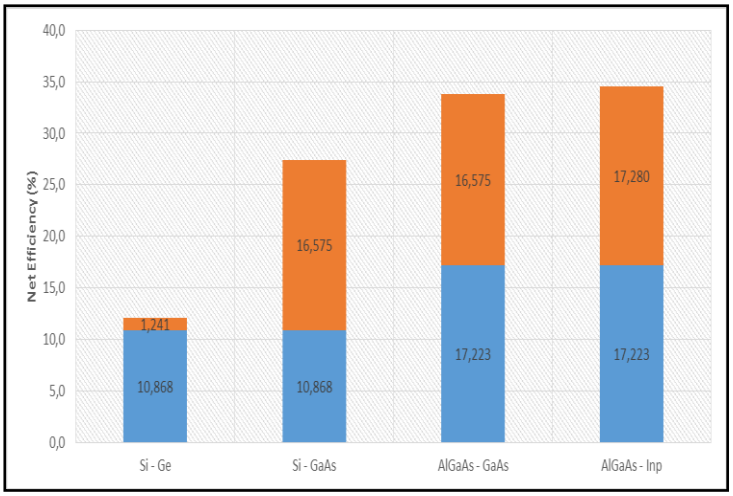

Figure 1. Comparison of Efficiencies in the Double layer Solar Cells designs

In order to select the best design, where it can be displayed the efficiency produced by each one, as well as the cost of production, it is necessary to establish a benefit relationship. For this, an index that relates the cell efficiency and the cost of the raw material is defined. All of this is compared with a commercial standard, established by the price (raw material for a cell creation of 20cm X 20cm X 100um: 0.03 USD) and the efficiency of a multicrystalline silicon (15%).

As a first step, equation 1 shows the net benefit of both efficiency and price, compared to the commercial standard.

$$NetBenefit = FinalQuantity - BaseQuantity \quad (1)$$

Once, the benefits are obtained the values are replaced in equation 2

$$Benefit = \frac{|BaseEfficiency - FinalEfficiency|}{|FinalPrice - BasePrice|} \quad (2)$$

Table 6 shows the results obtained from equation 2.

Table 6. Benefit / Cost Relationship

Semiconductor	Price USD	Efficiency	Cost/Benefit
Si - Ge	$ 28,24	12,11	0,10
Si - GaAs	$ 2,45	27,44	5,13
AlGaAs - GaAs	$ 2,79	33,80	6,80
AlGaAs - Inp	$ 10,13	34,50	1,93

4. Conclusions

From all the studied designs, Table 6 shows that the one with the best performance and profitability is the third one (AlGaAs - GaAs), due to its high efficiency and low cost, compared to the fourth one (AlGaAs - Inp), where its efficiency is greater but its price is higher. Even the second design (Si - GaAs), compared to the fourth one has the potential to be the most profitable adding various factors such as manufacturing techniques and obtaining process.

In the first design (Si - Ge), it can be demonstrated that with the addition of germanium the energy conversion is minimal. Meaning that for develop two layers solar cells, the potential of this material is not exploited resulting in an efficiency of 12,108 %, which is lower than the commercial efficiencies of solar cells that are about 14%.

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