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Improving the Electrical Properties of ITO/Si/GaAs/Si/ITO Solar Cell by Changing the GaAs Layer Position

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Due to the importance of integrating III-V semiconductors with Si technology for future photovoltaic devices. In this paper, the influence of GaAs layer position on the electrical behavior of ITO/Si/GaAs/Si/ITO *p-i-n* junction solar cell has been studied using SILVACO 2D-Atlas simulation software. Current-voltage (*I-V*) and power-voltage (*P-V*) characteristics have been investigated at room temperature and under standard illumination conditions (AM1.5G). Short-circuit current (I_{SC}), open-circuit voltage (V_{OC}), maximum power (P_{max}) and fill factor (*FF*) were extracted. The results showed that the performance of the ITO/Si/GaAs/Si/ITO solar cell improves when the position of the GaAs layer changes, as the electrical parameters of this solar cell increases when the GaAs layer approaches the cathode electrode. The ITO/*p*-Si/Si/GaAs/*n*-GaAs/ITO solar cell showed the best electrical performance compared to the rest of the solar cells, which was characterized by I_{SC} = 3.51 mA/cm², V_{OC} = 1.16 V, P_{max} = 3.29 mW/cm² and *FF* = 80.80 %.

Keywords: Si, GaAs, Heterostructure solar cell, *I-V* and *P-V* characteristic, Electrical parameters.

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1. INTRODUCTION

Solar cells are one of the most important means used in the production of electrical power, because they allow direct conversion of solar energy into electrical energy [1-2]. With regard to sustainable development, it is considered one of the most promising ways to support human beings' demand for renewable energy [3-4]. Over the last several decades, single-junction solar cells in Si technology have captured the majority of the commercial photovoltaic (PV) market [5]. As the efficiency of these solar cells is rapidly approaching the theoretical limit (29.4 %) [5-6], high-efficiency, high-performance and low-cost solar cells are the focus of scientists' attention for decades all over the world. One of the possible ways to increase the performance and efficiency of solar cells is to use multiple semiconductors in a single solar cell structure [6]. This structure consists of a set of serially connected layers (epitaxial growth or surface-activated bonding (SAB) methods) of semiconductor materials with different bandgap widths [7-9].

Currently, the integration of III-V semiconductors with silicon technology is the topical problem for electronics, optoelectronics and photovoltaic devices [10-11], because III-V semiconductors such as GaAs possess high electronic mobility, direct bandgap and high absorption constant which make them very promising for developing functional structures of solar cells.

It should be noted that transparent conductive (TCO) layers can be used to fabricate Si-based TCO/Si solar cells by introducing an *a*-Si:H intermediate layer at the ITO/Si interface [12]. Widely, indium tin oxide (ITO) is known as a *n*-type degenerate semiconductor that has very attractive electrical and optical properties for optoelectronic devices, especially solar cells due to its high transmittance in the visible range of the solar spectrum, bandgap of around 3.5 to 4.3 eV and its relatively low electrical resistivity (~ 10^{-4} Ω·cm) [9]. In addition, these solar cells can be considered as low-cost photovoltaic devices, the cost of which is reduced by the unique properties of the TCO layer, which serves as an anti-reflection coating, a conductive top electrode and an emitter [12].

In this work, the electrical performance of a heterostructure solar cell based on the integration of GaAs with Si (ITO/Si/GaAs/Si/ITO) will be investigated by studying the effect of GaAs layer position on electrical behavior of this *p-i-n* junction solar cell. Therefore, the various static characteristics current-voltage (*I-V*) and power-voltage (*P-V*), and the important electrical parameters of four solar cells with different positions of the GaAs layer will be simulated at room temperature 300 K and under global (AM1.5G) illumination spectra.

2. ITO/SI/GAAS/SI/ITO SOLAR CELL

Fig. 1 shows the four proposed structures of the ITO/Si/GaAs/Si/ITO *p-i-n* junction solar cell according to the GaAs layer positions. Each solar cell contains a silicon layer without defects of a thickness $T_{Si\text{-}1}$, this layer is deposited on an electrode of indium tin oxide (ITO) (cathode). On the silicon layer, there is an absorbent layer of GaAs with a thickness T_{GaAs} = 1 μm. Another silicon layer with a $T_{Si\text{-}2}$ thickness deposited on the GaAs layer. On this last silicon layer, there is the second electrode (Anode) of the same material. The thickness of the electrodes is the same T_{ITO} = 50 nm. Doping of the adjacent areas of the anode and cathode electrodes are p^+ and n^+ types, respectively, with the same concentration of 10^{18} cm^{-3}. The thicknesses of the p^+ and n^+ regions are 10 nm and 500 nm respectively. The remaining area is characterized by n^- type doping with the concentration of 10^{14} cm^{-3}. The length and width of these solar cells are 8 mm and 3 μm, respectively. In this work, the position of the GaAs layer has been changed according to Table 1.

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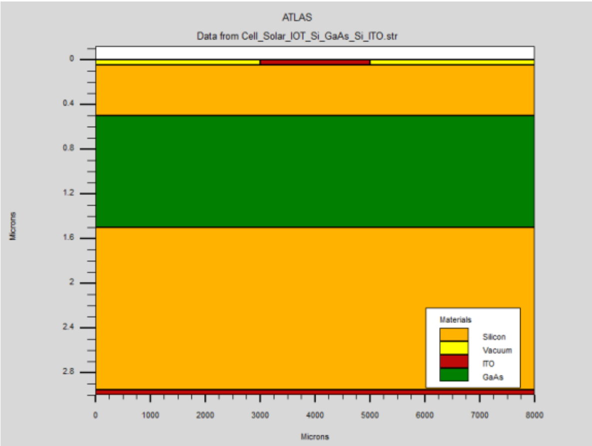
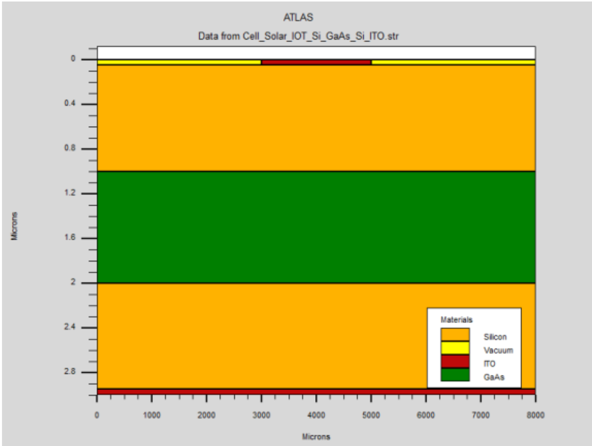
Table 1 – GaAs layer positions in ITO/Si/GaAs/Si/ITO solar cell

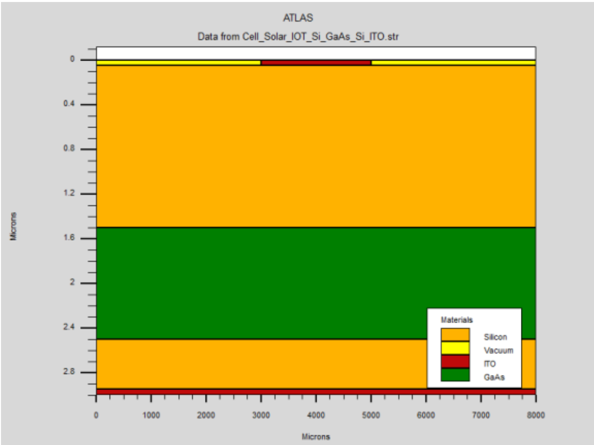
Cells	Solar cells structures	$T_{\text{Si-1}}$ and $T_{\text{Si-2}}$
Cell-1	ITO/*p*-Si/Si/GaAs/Si/*n*-Si/ITO	$T_{\text{Si-1}} > T_{\text{Si-2}}$
Cell-2	ITO/*p*-Si/Si/GaAs/Si/*n*-Si/ITO	$T_{\text{Si-1}} = T_{\text{Si-2}}$
Cell-3	ITO/*p*-Si/Si/GaAs/Si/*n*-Si/ITO	$T_{\text{Si-1}} < T_{\text{Si-2}}$
Cell-4	ITO/*p*-Si/Si/GaAs/*n*-GaAs/ITO	$T_{\text{Si-1}} = 0$



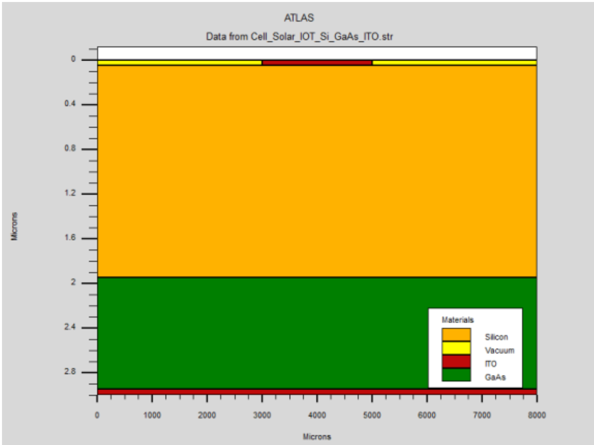
(a) Cell-1



(b) Cell-2



(c) Cell-3



(d) Cell-4

Fig. 1 – ITO/Si/GaAs/Si/ITO solar cell structures

Table 2 – Electrical parameters of ITO/Si/GaAs/Si/ITO solar cells

Electrical parameters / Solar Cells	I_{SC} (mA/cm²)	V_{OC} (V)	$I_{\max}$ (mA/cm²)	V_{max} (V)	P_{max} (mW/cm²)	*FF* (%)
Cell-1: ITO/*p*-Si/Si/GaAs/Si/*n*-Si/ITO	1.23	1.1375	1.03	1.025	1.06	75.76
Cell-2: ITO/*p*-Si/Si/GaAs/Si/*n*-Si/ITO	2.41	1.1500	2.18	1.025	2.23	80.46
Cell-3: ITO/*p*-Si/Si/GaAs/Si/*n*-Si/ITO	2.95	1.1625	2.66	1.025	2.73	79.61
Cell-4: ITO/*p*-Si/Si/GaAs/*n*-GaAs/ITO	3.51	1.1600	3.21	1.025	3.29	80.80

3. RESULTS AND DISCUSSION

Fig. 2 and 3 display respectively the simulated *I-V* and *P-V* characteristics of ITO/Si/GaAs/Si/ITO solar cells for the different positions of the GaAs layer. First, it is of note that the solar cells proposed in this study are very compatible with the working principle of photovoltaic cells. In addition, the different static characteristics of this solar cell are significantly influenced by the position of the GaAs layer.

Table 2 shows the important electrical parameters, short-circuit current (photogenerated current) I_{SC}, open-circuit voltage V_{OC}, maximum power $P_{\max}$ and fill factor *FF* of ITO/Si/GaAs/Si/ITO solar cells acquired from the *I-V* and *P-V* characteristics.

The results clearly show that the photogenerated current I_{SC} is significantly influenced by the position of the GaAs layer, in which this parameter increases when the GaAs layer approaches the cathode electrode of the cell (ITO/Si/GaAs/Si/ITO) due to the increased concentration of electron/hole pairs produced in the semiconductor material of this cell. This can also be

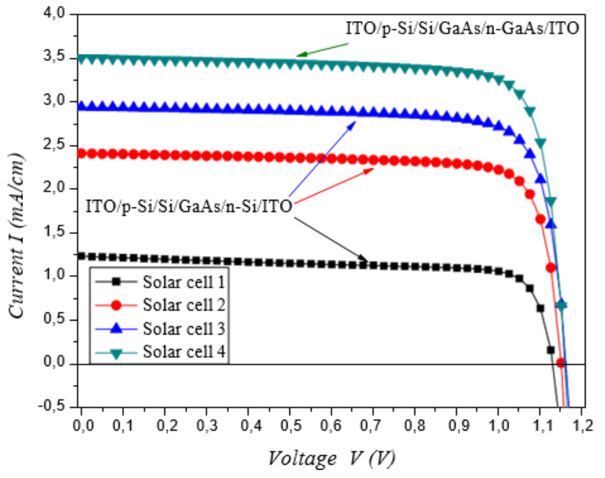


Fig. 2 – *I-V* characteristics of ITO/Si/GaAs/Si/ITO solar cells

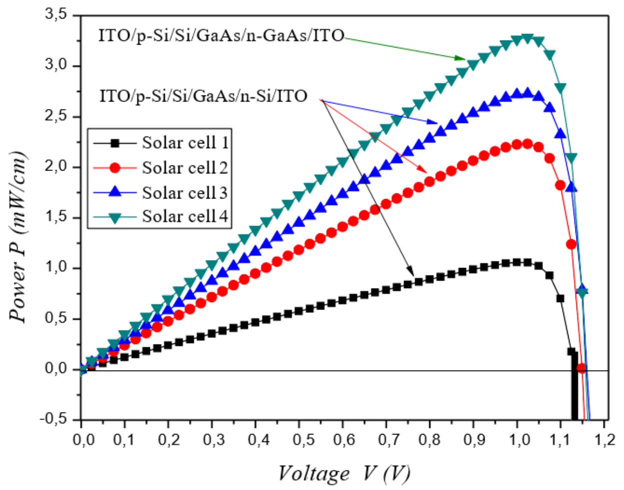


Fig. 3 – *P-V* characteristics of ITO/Si/GaAs/Si/ITO solar cells

attributed to the reduced charge recombination effect in this solar cell due to the increased lifetime of these pairs. On the other hand, the open circuit voltage V_{OC} of the ITO/Si/GaAs/Si/ITO solar cell is slightly affected by the GaAs layer positions as shown in Fig. 2 and Table 2. The fact that the V_{OC} voltage is little affected by the change of position of the GaAs layer is due to the type of the *p-i-n* junction and to the heterostructure of this solar cell.

The maximum current I_{max} of this solar cell increases considerably with the change of the position of the GaAs layer towards the cathode electrode of this cell; on the other hand, the maximum voltage V_{max} remains constant for the different positions of this layer. This leads to a considerable increase in the maximum available power P_{max} of these proposed solar cells.

According to Table 2, one cannot judge the evolution of the fill factor *FF* of this solar cell as a function of the GaAs layer position. But the optimal value of this factor of 80.80 % corresponds to the structure of the ITO/*p*-Si/Si/GaAs/*n*-GaAs/ITO solar cell. In this structure, the GaAs layer is deposited directly on the cathode of this solar cell. Moreover, the large values of the fill factor *FF* (from 75.76 % to 80.80 %) express how ideal the structures of these solar cells are due to the use of flawless Si and GaAs semiconductors.

4. CONCLUSION

In order to improve the electrical performance of solar cells. In this investigation, ITO/Si/GaAs/Si/ITO structure of a *p-i-n* junction solar cell with four different GaAs layer position were studied using SILVACO 2D-Atlas as a simulation tool. Current-voltage and power-voltage characteristics showed the extent to which the electrical behavior of this solar cell was affected by the changing the position of the GaAs layer, so that the proximity of the GaAs layer to the cathode electrode of this solar cell leads to an increase in the I_{SC} and P_{max}. However, the voltage V_{OC} increases slightly and the maximum voltage V_{max} remains constant. Flawless semiconductor technology is responsible for the increase in ideality of these solar cells.

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Покращення електричних властивостей сонячної елемента типу ITO/Si/GaAs/Si/ITO при зміні розташування проміжного шару GaAs

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Через важливість інтеграції напівпровідників III-V групи періодичної системи елементів із технологією Si для майбутніх фотоелектричних пристроїв у статті було вивчено вплив положення шару GaAs на електричну поведінку сонячної батареї з переходом p-i-n ITO/Si/GaAs/Si/ITO за допомогою програмного забезпечення моделювання SILVACO 2D-Atlas. Характеристики струм-напруга (I-V) і потужність-напруга (P-V) були досліджені при кімнатній температурі та стандартних умовах освітлення (AM1.5G). Було виділено струм короткого замикання (I_{SC}), напругу холостого ходу (V_{OC}), максимальну потужність ($P_{\max}$) і коефіцієнт заповнення (FF). Результати показали, що продуктивність сонячної батареї ITO/Si/GaAs/Si/ITO покращується, коли змінюється положення шару GaAs, оскільки її електричні параметри зростають, коли шар GaAs розрашований ближче до катодного електрода. Сонячний елемент ITO/p-Si/Si/GaAs/n-GaAs/ITO продемонстрував найкращі електричні характеристики порівняно з іншими сонячними елементами: I_{SC} = 3.51 mA/cm^2, V_{OC} = 1.16 V, $P_{\max}$ = 3.29 mW/cm^2 and FF = 80.80 %.

Ключові слова: Si, GaAs, Сонячна батарея на гетероструктурі, *I-V* та *P-V* характеристики, Електричні параметри.