



Improvement the Efficiency CIGS Thin Film Solar Cells by Changing the Doping of the Absorbent Layer and Adding the InAsP Layer

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ABSTRACT

In this article the function of solar cells with the structure of $CuIn_{1-x}Ga_xSe_2$ is examined. CIGS solar cell consists of layers of ZnO (Layer TCO), Cd₂S (buffer layer), CIGS (Absorbent layer), and Layer MO (Substrate), which Cd₂S and CIGS layers form a PN Junction. CIGS Thin Film Solar Cell is simulated using SILVACO software. The absorbent layer doping was originally changed. Later doping was kept constant and P-type layer of InAsP was added. Their effect on cell function was observed and examined. It was observed that after doping some parameters of the solar cell have improved whilst some others had decreased. It was also concluded that examined increase of decrease in the amount of dopant would reduce our efficiencies of solar cell. Added the InAsP layer leads to increased open circuit voltage, short circuit current and the solar cell power, consequently gives the yields about 33.2%, which is acceptable efficiency.

1. INTRODUCTION

One of the major problems of today is the limited availability of fossil fuels and hydrocarbons and the consequences of increasing consumption on the environment, quality of life, and human health. For these reasons, it is imperative to shift to other energy sources. Renewable energy is one answer to this problem, and one of the most prevalent forms is solar. Through photovoltaic (PV) technology, solar energy becomes available and widely exploitable.

Today PV technology is experiencing significant growth and development and, as a source of electric energy, is considered sufficiently reliable. The operation and maintenance of PV power plants has a very low cost, and the operation of these systems is silent since they have no moving parts. Most important, PV technology does not produce air pollution. These plants can be installed quickly and

adjusted easily to direct the power supply to the necessary points without the need for transmission lines. There are many applications in various installations already, often supplying energy in places where it would be impossible to provide power otherwise. The social, economic and environmental benefits are evident for a number of local communities [1].

1.1. CIGS SOLAR CELLS STRUCTURE

CIGS solar cell consists of layers of ZnO (Layer TCO), Cd₂S (buffer layer), CIGS (Absorbent layer), and Layer MO (Substrate), which Cd₂S and CIGS layers form a PN Junction. CIGS Solar cell (Copper-Indium-Gallium-Selenium) is a semiconductor I-III-VI₂ with a direct band gap and high absorption coefficient.

The preceding is an alloy between CIS and CGS which is described by the chemical formula $\text{CuIn}_{1-x}\text{Ga}_x\text{Se}_2$, Where X is the ratio between Ga/(Ga+In). By changing x, the concentration of Gallium and Indium will change and as a result would alter the band gap. The value of band gaps change from 1.04eV for x= 0 for the CIS to 1.68eV for x=1, for the CGS, maximized for a Ga content with a value roughly 0.3, resulted in absorber energy band gap values of roughly 1.1–1.2 eV [1]. In these cells, the lowest conduction band has been put against the maximum capacity of the tape and has the highest efficiency compared to other solar cells CIGS solar cells as shown in Figure1 is composed of the following layers [2].

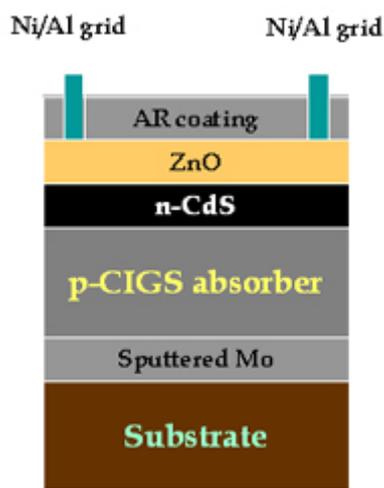


Figure 1: CIGS structure.

The $\text{Cu}(\text{In,Ga})\text{Se}_2$ alloy material belongs to the semiconductor I-III-VI₂ material family that crystallizes in the tetragonal chalcopyrite structure.

In the periodic table, the groups I, III, and VI describe the elements from columns IA, IIIB, and VIB, respectively. The arrangement of atoms in the zinc blende structure is the same as that in the diamond cubic structure, but with alternating types of atoms at the different lattice sites.

The chalcopyrite structure of CIGS is derived from the zinc blende structure (taking ZnS, for example) such that the anion (Se) position in the $\text{Cu}(\text{In,Ga})\text{Se}_2$ lattice structure remains nearly the same as in the zinc blende structure (i.e., S), however, the cat ion in the zinc blende structure (i.e., Zn) is replaced by Cu and (In, Ga).

Each Cu and (In or Ga) atom has four bonds with Se atom.

In return, each Se atom has two bonds to (In or Ga) and two more to Cu. For the simple case of CIS, the Se atom has two bonds to In atoms and two to Cu atoms. In order for the chalcopyrite lattice to be

periodic, two stacked unit cells of zinc blende are used to construct one unit cell of chalcopyrite.

In equilibrium, however, the Se atom in CIGS must be either closer to the Cu atom or to the (In or Ga) atom due to the different strengths of the Cu-Se and (In-Se or Ga-Se) bonds.

This difference in bond lengths results in ratio of lattice constants c/a for chalcopyrite that deviates from 2. For the end-member compositions, the quantity 2(c/a) is -0.01 for CuInSe_2 and +0.04 for CuGaSe_2 , and is a measure of the tetragonal distortion in chalcopyrite.

The lattice parameters for a $\text{Cu}(\text{In}_{1-x}\text{Ga}_x)\text{Se}_2$ with Ga content x = 0 are given by a = 0.578 nm and c = 1.162 nm, and these values decrease linearly with the increase in x [3,4]. The derivation of the CIGS (chalcopyrite structure) from Si (diamond structure) is illustrated in Figure2.

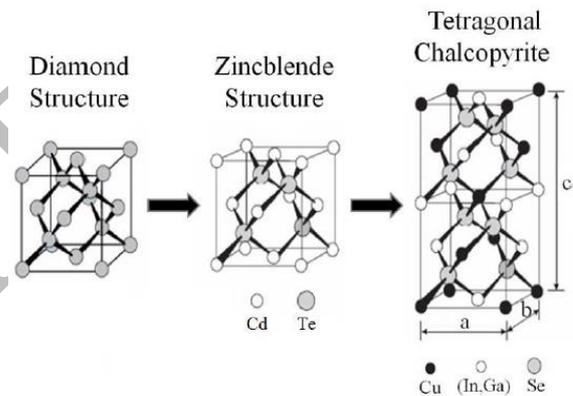


Figure 2: $\text{Cu}(\text{In,Ga})\text{Se}_2$ chalcopyrite structure and its derivation from the diamond structure.

1.2. CIGS CELL CONFIGURATION

CIGS solar cells can be deposited in either the substrate or superstrate configuration. Schematic cross-sections of both configurations are shown in Figure 3.

The solar cell structure includes the glass substrate (or superstrate), transparent conducting oxide (TCO), n-type buffer layer, p-type absorber layer (CIGS), and back metallic contact.

The TCO acts as the front contact to the device and can be either single or multilayer.

In the latter case, it may incorporate a high resistivity transparent layer (HRT). Wide energy band gap TCO's are typically chosen to minimize optical losses and allow most of the incident light to be absorbed within the active layer.

Besides the high transparency requirement, the sheet resistance of the TCO structure must meet

certain criteria to allow efficient photo-generated current collection [5].

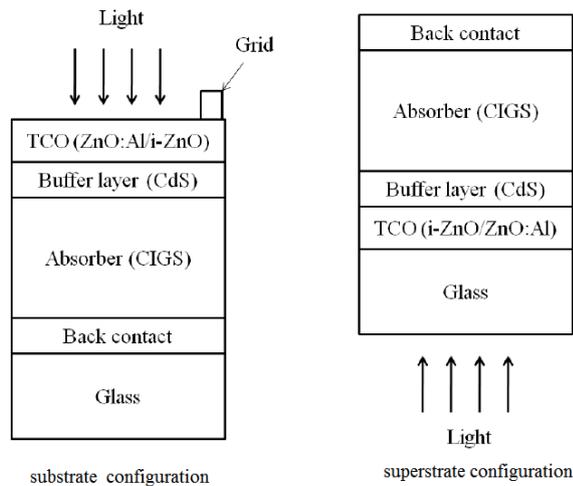


Figure 3: Schematic cross-sections of substrate (left) and superstrate (right) configurations of CIGS solar cells.

The most common CIGS device configuration is the substrate structure that consists of ZnO:Al/i-ZnO/n-CdS/p-CIGS/Mo/glass, where the stack components are listed in reverse order relative to the deposition process.

This configuration gives the highest cell efficiency due to the material compatibility and the process conditions used to deposit each layer. When this complex device structure is deposited in the superstrate configuration, many challenges arise.

The absorber layer is deposited at high temperature and that requires high thermal stability for the underlying buffer and TCO layers. Unfortunately, most of TCO and buffer materials lack thermal stability at substrate temperatures higher than 500°C.

Molybdenum (Mo) is the most common material used as a back contact for CIGS based solar cells. The high thermal stability of Mo and its resistance to alloying with In, Ga, and Cu allow thermal processing of CIGS films at temperatures as high as 650 °C.

Mo back contacts are typically deposited on SLG using direct current (DC) magnetron sputtering from a Mo target in an argon (Ar) gas environment.

The Ar gas pressure used in Mo deposition influences the electrical and physical properties of the as-deposited films.

Generally, films deposited with low Ar pressure exhibit a dense microstructure with low resistivity (10-15 $\mu\Omega\cdot\text{cm}$), poor adhesion, and compressive stress, whereas films deposited with high Ar pressure exhibit a relatively porous structure with high resistivity (50-250 $\mu\Omega\cdot\text{cm}$), good adhesion, and tensile stress [6].

Cadmium sulfide (CdS) is the most widely used buffer layer for CIGS solar cells and is commonly deposited in a solution-based process known as chemical bath deposition (CBD). The CdS layer improves the electrical properties of the solar cell by optimizing the band alignment of the device.

It builds a sufficiently wide depletion layer and establishes a higher contact potential that allows a higher open circuit voltage value. It also protects the junction from damage that may occur during deposition of the window layer which typically involves sputtering [7, 8].

CIGS Solar cell (Copper-Indium-Gallium-Selenium) is a semiconductor I-IIIIV₂ with a direct band gap and high absorption coefficient. The preceding is an alloy between CIS and CGS which is described by the chemical formula $\text{CuIn}_{1-x}\text{Ga}_x\text{Se}_2$, Where X is the ratio between Ga/(Ga+In).

By changing x, the concentration of Gallium and Indium will change and as a result would alter the band gap. The value of band gaps change from 1.04eV for x= 0 for the CIS to 1.68eV for x=1, for the CGS, maximized for a Ga content with a value roughly 0.3, resulted in absorber energy band gap values of roughly 1.1–1.2 eV [9,10].

A ZnO layer, with a band gap of 3.3 eV, is typically used as the n-type semiconductor, the transparent window layer that facilitates solar radiation's passing through the cell [11].

The absorption of solar radiation and creation of electron Hole pairs take place in the p-type semiconductor, namely the chalcopyrite characterized as the absorber [12]. High Absorption coefficients allow the use of thin layers of a few microns thickness with high impurities concentration and intrinsic defects. On the other hand, during the hetero junction formation, the generated interlayers have also high defects percentage, and the carriers' recombination in the interlayer is very likely [13].

The ZnO/CIGS hetero junction is not considered propitious for carriers shift, because ions created during the ZnO preparation reinforce the electron-hole Pairs recombination in the interlayer and can damage the surface of the absorber. For this reason, a very thin Cd_S layer with a band gap of 2.4 eV is used between the ZnO and the absorber layer, and it is usually prepared with the chemical-bath deposition method. Using a buffer layer, we achieve a better band gap adjustment between the window and absorber layer [14].

2. SIMULATION

Physical parameters used in the simulations Table 1 have been identified. Are given in Table 1 physical parameters used in the Simulation.

TABLE 1
PHYSICAL PARAMETERS USED IN THE SIMULATION [15]

Parameters	ZnO	CdS	CIGS
ϵ_r	9	10	13.6
χ_e (eV)	4	3.75	3.89
μ_n (cm ² /Vs)	100	100	100
μ_p (cm ² /Vs)	25	25	25
NA (1/cm ³)	0	0	2e+16
ND (1/cm ³)	1e+18	1e+18	0
NC (1/cm ³)	2.2e+18	2.2e+18	2.2e+18
NV (1/cm ³)	1.8e+19	1.8e+19	1.8e+19
E _g (eV)	3.3	2.4	1.15
Thickness (nm)	75	40	1700

The basic model structure of simulated CIGS solar cells is shown in Figure 4.

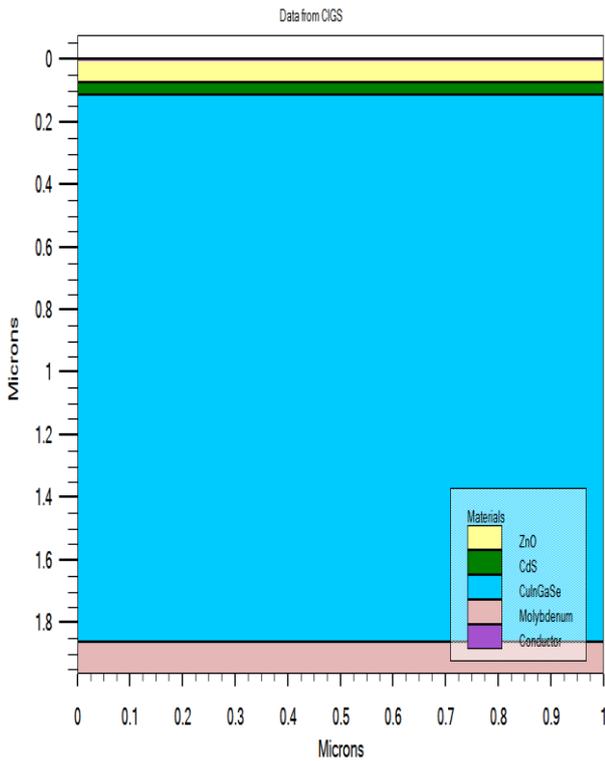


Figure 4: Simulated CIGS Structure.

2.1. CHANGE THE DOPING ABSORBENT LAYER

Simulation was also performed for CIGS layer fixed and equal to 1750nm but different amount of doping 1×10^{15} (CIGS1), 1×10^{16} (CIGS2) and 1×10^{17} (CIGS3) were uses. The results of I-V curve efficiency are given in figure 5 and 6 in respectively.

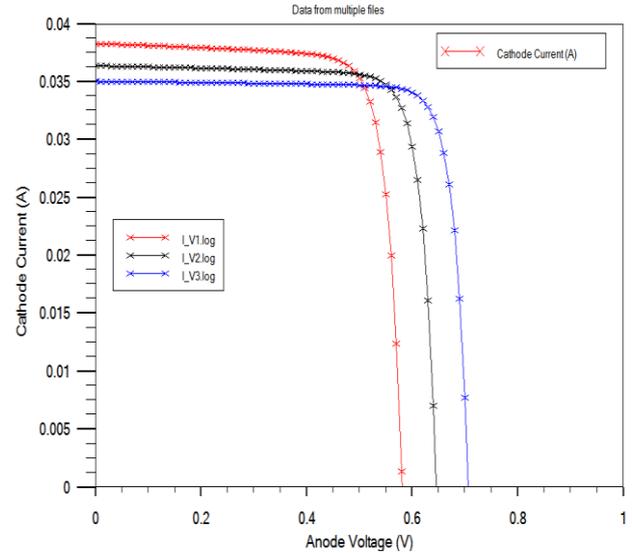


Figure 5: I-V curves for doping change the absorber layer.

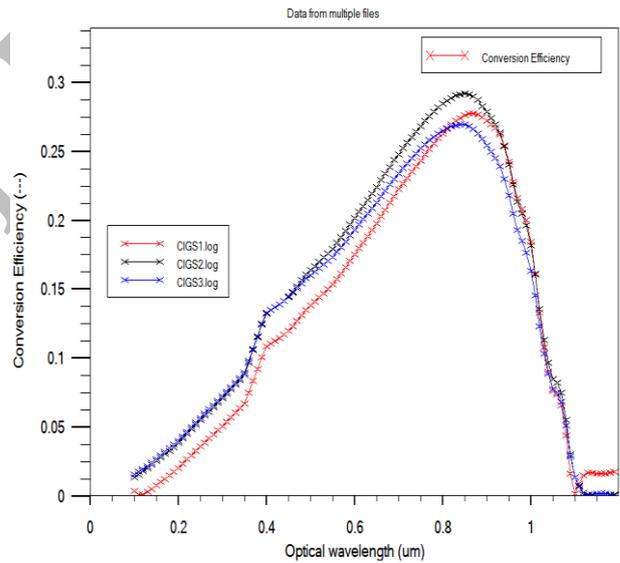


Figure 6: Efficiency curves for doping change the absorber layer.

According to the result obtained as doping increases power and V_{OC} also increases. This is due to increase to minority and majority carriers. However doping increases the I_{sc} decreases this can be attributed to the existence of high number of minority and majority carriers which can cause the recombination process of photons.

Therefore, the recombined photons cannot contribute to the flow of current. It was concluded that extreme increase or decrease in doping can lead to reduced efficiencies.

2.2. ADDING THE INASP LAYER

The improved CIGS Solar Cell was designed using added the layer InAsP and was doped P-type and thickness 200nm. This was placed between the layers of the absorbent and MO. In order not to Change the thickness of the cell the same thickness of 200nm has been reduced from the CIGS. This ensures as the thickness of for the cell 2000nm as before. You can see the specifications of physical parameters given in table 2.

TABLE 2
SPECIFICATIONS OF PHYSICAL PARAMETERS INASP LAYER

NA (1/cm ³)	μ_p (cm ² /Vs)	μ_n (cm ² /Vs)	χ_e (eV)	ϵ_r
2e+16	25	100	4.32	1.27
Thickness (nm)	Ban Gap (eV)	NV (1/cm ³)	NC (1/cm ³)	ND (1/cm ³)
200	1.27	8.54e+18	3.61e+17	0

The Changed model structures of simulated CIGS solar cells shown in Figure 7.

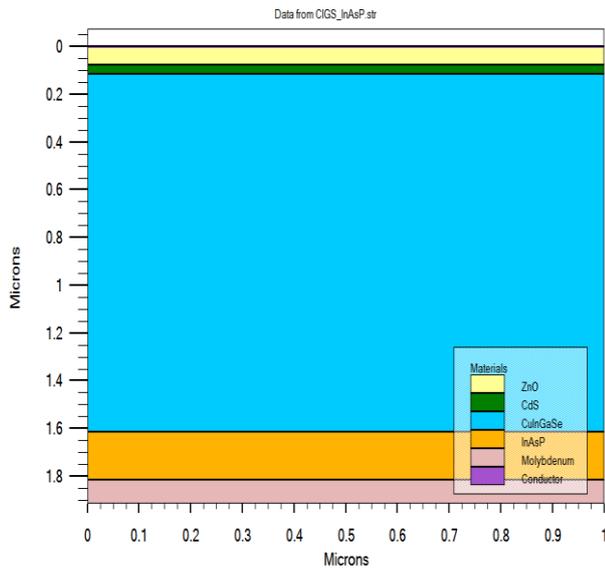


Figure 7: The Changed model structures of simulated.

The efficiency of the changed solar cell is determined by its I-V characteristic. This curve obtained using the simulation is shown in Figure 8.

Figure 9 and a Figure 10 respectively show curves efficiencies and power.

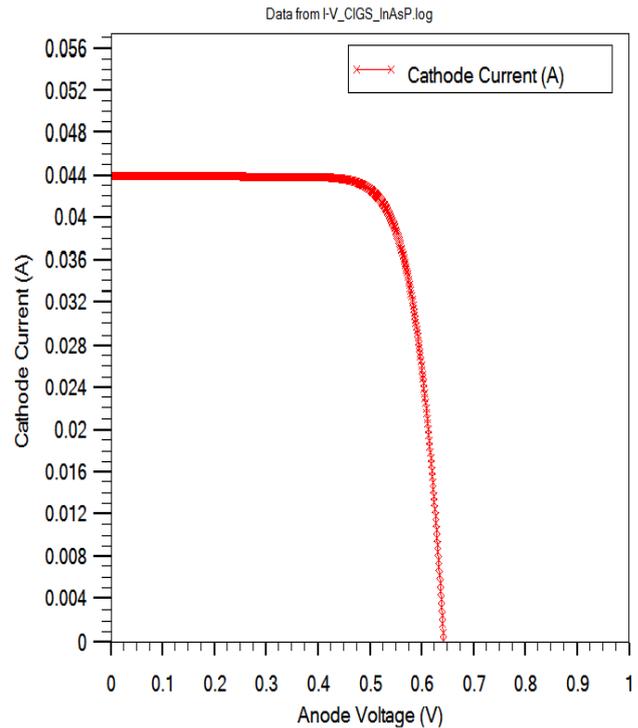


Figure 8: I-V curves for adding the InAsP layer.

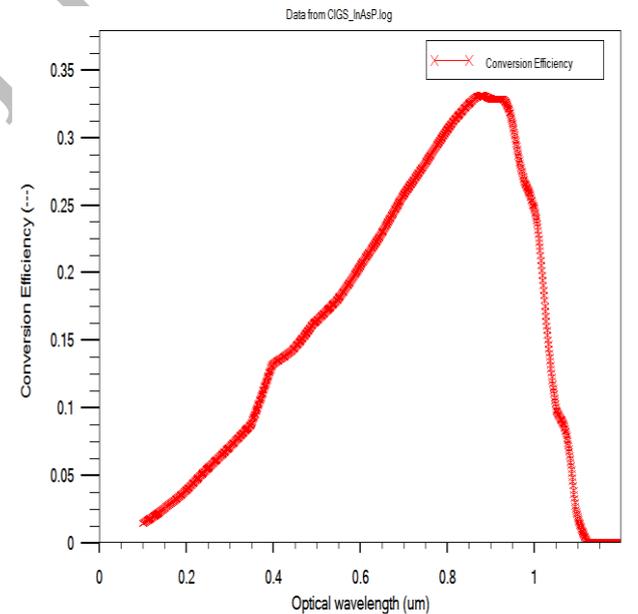


Figure 9: Efficiency curves for adding the InAsP layer.

According to the results the added InAsP layer leads to increased open circuit voltage, short circuit current and solar cell power, consequently increased efficiency, which is a due for absorbing lower energy photons that pass through the absorbing layer and is absorbed in the InAsP layer and produces electron and holes pair. Due the yields is about 33.2%, which is very acceptable efficiency.

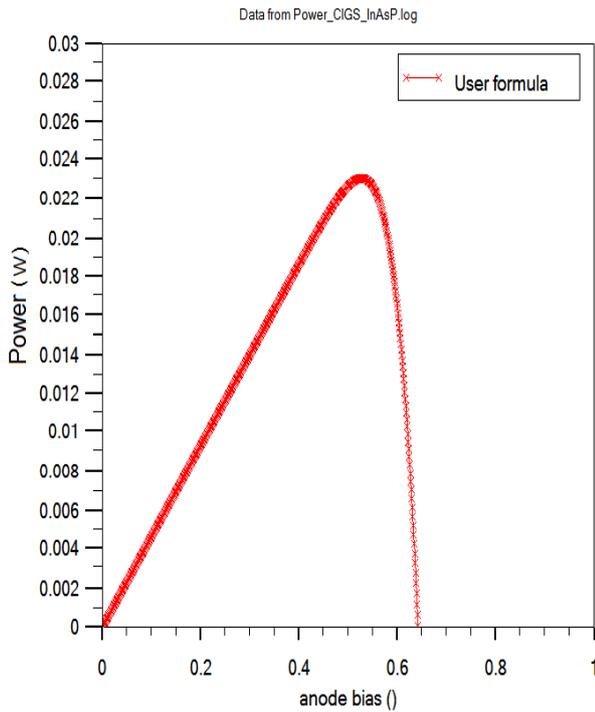


Figure 10: Power curves for adding the InAsP.

3. RESULTS

The results of Efficiencies concerning Change the doping of absorbent layer and adding the InAsP Layer are given in table 3 and 4 respectively.

TABLE 3
RESULTS CHANGE THE DOPING OF ABSORBENT LAYER

Parameters	CIGS1	CIGS2	CIGS3
Doping absorbent layer	1×10^{15}	1×10^{16}	1×10^{17}
Voc (V)	0.581	0.644	0.706
Isc (mA/cm ²)	38.5	36.5	34.5
Pmax (mW/cm ²)	17.66	19.22	17.5
FF (%)	79.8	82.5	83.5
Efficiency (%)	27.8	29.2	26.9

TABLE 4
RESULTS FOR ADDING THE INASP LAYER

Voc (V)	0.625
Isc (mA/cm ²)	44
Pmax (mW/cm ²)	23.2
FF (%)	84.36
Efficiency (%)	33.2

4. CONCLUSIONS

It was clear that extreme increase or decrease in the amount of dopant in the absorbent layer can effects solar cell parameters, also can improve cell function. The amount of dopants can also alter some other

solar cell parameters which are not desirable, the added InAsP layer leads to increased open circuit voltage, and short circuit current and the solar cell power, consequently gives the yields about 33.2%, which is acceptable efficiencies.

5. DISCUSSION

In this paper, by the adding the InAsP layer efficiency 33.2% was obtained which compare with the previous efficiencies had increased by 4-5percent. However, most had worked on the solar cells CIGS thickness. But in this article we had worked with different dopant in the absorbent layer.

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BIOGRAPHIES



Hashem Firoozi was born in 1986 in Fasa, Iran and holds a Masters in electric Engineering - electronic. His research involved solar Cells such CIGS thin film solar Cells and Multi-layer Solar Cells. He is a lecturer at Department of Electrical and Computer Engineering, Fasa Branch, Technical and Vocational University in Fars, Iran.



Mohsen Imanieh was born in 1960 in Shiraz, Iran and holds a Ph.D in electronics from The University of Salford in England. He was also part of research group at the University in late 1990s. His research involved growing semiconductors such as CIS and CIGS. He is a faculty member of Islamic azad University of fasa in Iran and lecturers post-graduate student electronics department.