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SIMULATION STUDY OF EFFECTS, OPERATING TEMPERATURE AND LAYER THICKNESS ON THIN FILM CIGS SOLAR CELL PERFORMANCE

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SCAPS- program is designed basically for the simulation and studying the properties of photonic devices. We explored the important controllable design parameters affecting the performance of the hetero junction solar cells, as operating temperature that we noticed increasing in J-V characteristics by increasing T. The effect of thickness of each layer on the performance of the cell was studied, an increasing of J-V characteristics with increasing p-layer. In the numerical example, 3 *μm absorber layer and* CdS *layer* 0.05 *μm,* ZnO *layer* 0.1 *μm, works the best for given doping density, if we change the optimum value, the efficiency can reach to* 17.72 % *with FF* 83.88 %, $V_{oc} = 0.725$ *Volt,* $J_{sc} = 29.07$ *mA/cm*^{2} *at* 300 *K, in this case, we have come out the optimum parameters to achieve the best performance of this type of cell, and then to made comparison with practical CIGS cell.*

Keywords: *CIGS, SCAPS, SOLAR CELL, HETERO-JUNCTION, OPERATING TEMPERATURE, THICKNESS.*

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1. INTRODUCTION

Simulation of thin film solar cells has become increasingly mature and complex over the last two decades. A number of simulation packages have been developed at universities or research institutes , and use atypically available at no cost and without support .This group of programs includes AMPS-ID, SCAPS-ID, PC-ID, ASA, and AFORS-HET [1]. Among these programs is SCAPS-ID that used in this work, SCAPS-ID, an acronym for “Solar Cell Capacitance Simulator One Dimension”', is a windows application program, developed at the University of Gent with Lab Windows/CVI of National Instruments under Mars Burgelman [2]. This program is designed basically for the simulation and studying the properties of the photonic devices [3]. In this work an identified study was done on hetero-junction thin film solar cells. This cell is basically constructed from Cupped Indium Gallium Selenide (CIGS). Solar cell with Cu(In, Ga)Se$_2$ (CIGS) chalcopyrite semiconducting compound as an absorber are among thin film devices of highest photovoltaic efficiency, which currently is close to 20 % for laboratory cells [4, 5]. The successful development of this technology about fundamental properties of CIGS compounds, especially about defects controlling photovoltaic performance of these device, and used an absorber layer for the incoming light, and Cadmium Sulfide (CdS), which is the main function of the buffer layer is to be a good hetero-junction partner to the p-type absorber layer with minimal lattice mismatch to minimize defects like interface states and be transparent to incident light [5]. The window layers transmit most of the light from the solar spectrum owing to their large band gaps, for the n-type partner in the junction , which at the same time needs to be sufficiently conductive to serve as front contact, ZnO is a cheap and rather easy to grow, making it the general choice [7].

2. SIMULATION RESULTS

Modeling result of the CIGS solar cell that shown in Fig. 1 is the light – dark J-V plots (V_{oc} = 725 mV, J_{sc} = 28.9 mA/cm^2, FF = 84.14, η = 17.65%).

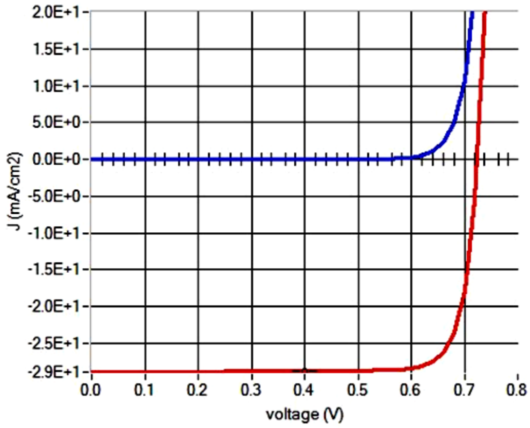

***Fig. 1** – Light/Dark J-V curves of CIGS solar cell*

Quantum efficiency shown in Fig. 2 shows a peak response of (I-R) % = (70-80) and falls off in the range below (300 – 400) nm due to the recombination and absorption in the CdS and ZnO.

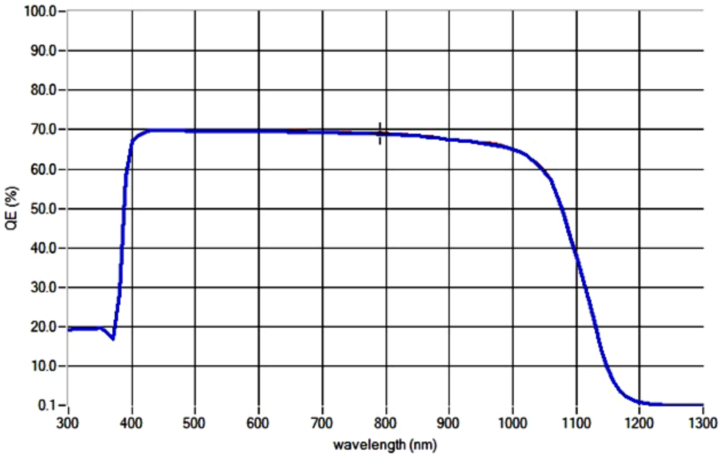

***Fig. 2** – Quantum CIGS solar cell*

3. EFFECT OF THE OPERATING TEMPERATURE

Operating temperature plays a vital role in the performance of solar cells. The optimum operating temperature that has been used for most of the simulation in this study is 300 K or 27 °C .In a solar cell, the parameter most affected by an increase in temperatures is the open circuit voltage (V_{oc}).The impact of increasing temperature on V_{oc} is shown in Fig. 3. Fig. 3 illustrate V_{oc} decrease with temperature because of the temperature dependence of the reverse saturation current (I_s).

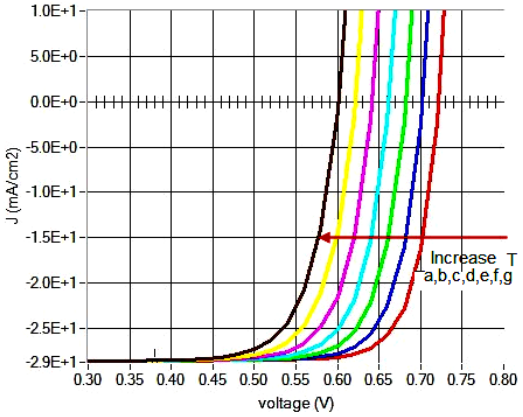

Fig. 3 *– I-V parameters CIGS solar cell at various temperatures, a-300, b-310, c-320, d-330, e-40, f-350, g-360 K*

Many of the parameters of Is have some temperature dependence, but the most significant effect is due to the intrinsic carrier concentration (n_i) The band gap energy has been slightly narrowed and this may accelerate the recombination of electron-hole pairs (EHP) between valance band and conduction band, but the band gap energy at higher temperature is unstable which may lead to recombination of electrons and holes while traveling across the regions. So that J_{sc} is slightly decreased as shown in Table 1. The dependence of the fill factor (FF %) on the operating temperature can be

Table 1 *– J-V parameters CIGS solar cell at various temperatures*

T, (K)	V_{oc}, (Volt)	J_{sc}, (mA)	FF, %	η, %
300	0.722	28.742	83.88	17.42
310	0.702	28.738	83.22	16.79
320	0.682	28.736	82.54	16.18
330	0.660	28.734	81.84	15.58
340	0.640	28.732	81.08	14.96
350	0.620	28.730	80.30	14.34
360	0.600	28.728	79.50	13.72

deviated from the dependence of the V_{oc} on the temperature. FF % inversely proportional with the operating temperature as shown in Table 1.The reduction in the V_{oc} and J_{sc} and FF % with the temperature leads to reduction in the efficiency (η %) with the temperature.

4. EFFECT OF CIGS ABSORBER LAYER THICKNESS

The effect of the CIGS absorber thickness on V_{oc} and J_{sc} is shown in Table 2. Both values increased when the thickness of CIGS absorber layer increased wavelengths of the illumination to be absorbed, which in turn contribute in EHP generation. The long wavelength photons will be deeper with in the CIGS layer, so that the FF %, and η % increased with increases CIGS thickness as shown in Table 2, and we illustrate the best value of the efficiency at the thickness 3 μm of CIGS solar cell and equal to 17.72.

***Table 2** – J-V parameters CIGS solar cell at various absorber layer thickness*

CIGS, Thickness, μm	V_{oc}, (Volt)	J_{sc}, mA/cm^2	FF %	η %
0.3	0.677	27.03	81.39	14.90
0.8	0.694	27.90	82.26	15.95
1.3	0.705	28.30	83.01	16.58
1.8	0.712	28.61	83.47	17.03
2.3	0.719	28.84	83.72	17.37
2.8	0.723	29.01	83.96	17.63
3	0.725	29.07	84.04	17.72

So that the effect of CIGS absorber layer on the quantum efficiency has been occurred in the region extended from (λ = 400-1200nm) as shown in Fig. 4,

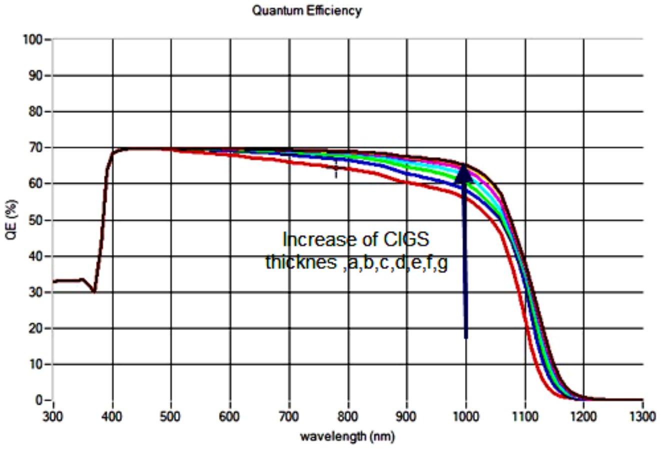

***Fig.4** – Quantum efficiency of CIGS solar cell at various absorber layer thickness a-0.3, b-0.8, c-1.3, d-1.8, e-2.3, f-2.8, g-3 μm*

for thin absorber the generation region will be near the high recombination back contact region, this will reduces the number of the generated electron – hole pairs and the quantum efficiency. For thick absorber cell, the generation process has been occurred far from the back contact region so that the quantum efficiency will increased.

5. EFFECT OF CdS BUFFER LAYER THICKNESS

Generally, the thickness of the optimum CdS buffer layer should be within 50 nm – 60 nm. In this study the thickness of CdS has been varied from (0.001) to (0.1) μm, V_{oc} and J_{sc} will be decreased when the thickness of CdS layer increased as Table 3.

***Table 3** – J-V parameters CIGS solar cell at various CdS layer thickness*

CdS, Thickness, μm	V_{oc}, (Volt)	J_{sc}, mA/cm^2	FF %	,η %
0.001	0.7522	28.955	84.08	17.66
0.005	0.7522	28.946	84.07	17.65
0.025	0.7521	28.916	84.06	17.64
0.05	0.7521	28.894	84.06	17.63
0.06	0.7520	28.890	84.05	17.62
0.08	0.7519	29.888	84.05	17.61
0.1	0.7518	29.886	84.04	17.60

This because a thicker buffer layer will result in higher photon absorption as loss. FF% also decreased due to the reduction in V_{oc} and J_{sc} as shown in Table 1. When the buffer layer increases, more photons which carry the energy ($h\nu \geq E_g$ CdS) are being absorbed by this layer, therefore it will be lead to decrease in the number of photons which could reach the absorber layer as a result the efficiency has been decrease from (17.66) to (17.60) as shown Table 1, and we found that the thickness of CdS of 10 nm give the highest efficiency (17.66).

6. EFFECT OF ZNO WINDOW LAYER THICKNESS

The effect of ZnO thickness on the output parameter of CIGS cell has been found to be the similar to the effect of CdS layer but is defer in magnitude. An increase in the thickness of ZnO layer will decrease in V_{oc}, J_{sc} as shown in Table 4.

***Table 4** – J-V parameters CIGS solar cell at various ZnO layer thickness*

ZnO, Thickness, μm	V_{oc}, (Volt)	J_{sc},mA/cm^2	FF %	η %
0.05	0.7254	29.231	84.1	17.82
0.07	0.7253	29.162	84.09	17.78
0.1	0.7252	29.077	84.08	17.72
0.2	0.7251	28.894	84.06	17.61
0.3	0.7250	28.782	84.05	17.53
0.4	0.7249	28.700	84.04	17.48
0.5	0.7249	28.632	84.03	17.44

FF % decreased from (84.1) to (84.03) as shown in Table 4, the efficiency decreased from (17.82) to (17.44). This effect will also appear as a loss in the quantum efficiency in region (λ = 300-400 nm) as shown in Fig. 5.

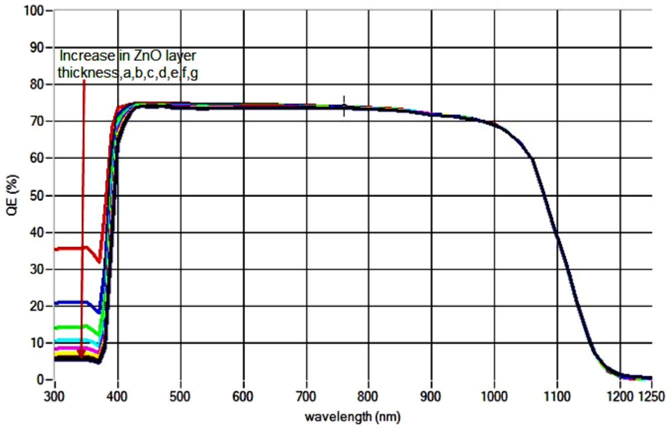

***Fig.5** – Quantum efficiency of CIGS solar cell at various ZnO layer thickness a-0.05, b-0.07, c-0.1, d-0.2, e-0.3, f-0.4, g-0.5 μm*

7. PRACTICAL RESULTS

To compare our simulation results with the practical results obtained by (7), that used thickness of layers, absorber layer equal 2 μm, CdS layer 0.02 μm and ZnO layer equal 0.5 μm, the results for comparison shown in Table 5.

***Table 5** – Output practical and simulation result for CIGS solar cell*

Type	V_{oc}, Volt	J_{sc}, mA/cm^2	FF %	η%
Practical result	0.475	40	68	12
Simulation result	0.715	28.307	83.64	16.94

The difference between the simulation and the practical study was due to interface state and surface recombination included in real device. The parameter from the simulation study is listed in Table 7.

8. CONCLUSION

Intrinsic material properties' including working temperature, and layer thickness, are import factors influencing J-V characteristics of CIGS heterojunction solar cell, and we illustrate the best value of the efficiency at the thickness 3 μm of absorber layer, 0.05 μm for CdS layer, and 0.1 μm for ZnO layer, is equal to 17.72 to cooperate with the practical result 12 %.

ИМИТАЦИОННОЕ МОДЕЛИРОВАНИЕ ВЛИЯНИЯ РАБОЧЕЙ ТЕМПЕРАТУРЫ И ТОЛЩИНЫ СЛОЯ НА ХАРАКТЕРИСТИКИ ТОНКОПЛЕНОЧНОГО СОЛНЕЧНОГО ЭЛЕМЕНТА CIGS

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Программа SCAPS разработана с целью моделирования и изучения свойств фотонных приборов. Были исследованы важные регулируемые конструктивные параметры, влияющие на характеристики солнечных элементов с гетеропереходом, в частности, рабочая температура. Было замечено, что вольт-амперные характеристики (ВАХ) возрастают с увеличением температуры Т. В исследовании было изучено влияние толщины каждого слоя на свойства солнечного элемента. Также было определено, что ВАХ возрастают с увеличением p-слоя. На численном примере, слой поглощения 3 *мкм и CdS слой* 0,05 *мкм, ZnO слой* 0,1 *мкм являются наилучшими параметрами для заданной концентрации примеси. Если изменить оптимальное значение, то эффективность может достигать* 17,72 % *с* FF = 83,88 %, V_{oc} = 0,725 *В*, J_{sc} = 29,07 *мА/см*^{2} *при* 300 *К. В этом случае можно получить оптимальные параметры для достижения наилучших характеристик этого типа фотоэлементов и затем сравнить с характеристиками элементов CIGS (медь-индий-диселенид галлия).*

Ключевые слова: *CIGS, SCAPS, СОЛНЕЧНЫЙ ЭЛЕМЕНТ, ГЕТЕРОПЕРЕХОД, РАБОЧАЯ ТЕМПЕРАТУРА, ТОЛЩИНА.*

ІМІТАЦІЙНЕ МОДЕЛЮВАННЯ ВПЛИВУ РОБОЧОЇ ТЕМПЕРАТУРИ І ТОВЩИНИ ШАРУ НА ВЛАСТИВОСТІ ТОНКОПЛІВКОВОГО СОНЯЧНОГО ЕЛЕМЕНТУ CIGS

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Програма SCAPS розроблена з метою моделювання і вивчення властивостей фотонних приладів. Були досліджені важливі регульовані конструктивні параметри, що впливають на характеристики сонячних елементів з гетеропереходом, зокрема, робоча температура. Було відмічено, що вольт-амперні характеристики (ВАХ) зростають зі збільшенням температури Т. У дослідженні вивчено вплив товщини кожного шару на властивості сонячного елементу. Також було визначено, що ВАХ зростають зі збільшенням p-шару. На чисельному прикладі, шар поглинання 3 *мкм і CdS шар* 0.05 *мкм, ZnO шар* 0.1 *мкм, є найкращими параметрами для заданої концентрації домішки. Якщо змінити оптимальне значення, то ефективність може досягати* 17,72 % *з* FF = 83,88 %, V_{oc} = 0,725 *В*, J_{sc} = 29,07 *мА/см*^{2} *при* 300 *К. В цьому випадку можна отримати оптимальні параметри для досягнення найкращих характеристик цього типа фотоелементів і порівняти з характеристиками елементів CIGS (мідь-індій-диселенід галію).*

Ключові слова: *CIGS, SCAPS, СОНЯЧНИЙ ЕЛЕМЕНТ, ГЕТЕРОПЕРЕХІД, РОБОЧА ТЕМПЕРАТУРА, ТОВЩИНА.*

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