DOCTORAND: HANIFF ULLAH

DIRECTOR: BERNABÉ MARÍ SOUCASE

TITLE: SIMULATION STUDIES OF PHOTOVOLTAIC THIN FILM DEVICES

RESUMEN (IN SPANISH)

Para hacer frente a necesidades energéticas de la sociedad actual es necesario hacer uso de las energías renovables. En particular la energía solar es la fuente más grande y abundante en el planeta Tierra. La tecnología de las células solares fotovoltaicas sigue avanzado día a día y representa un campo de investigación muy activo. Muchos centros de investigación y universidades están trabajando en este campo. Varias generaciones de dispositivos fotovoltaicos, conocidos como 1ª, 2ª y 3ª Generación han sido y estan siendo desarrolladas en la actualidad con el objetivo de mejorar su eficiencia y reducir su coste a menos de 0.2 €/V.

Nuestro trabajo se basa principalmente en el análisis teórico y numérico de dispositivos fotovoltaicos de capa fina. Para el análisis de células fotovoltaicas vamos a utilizar diferentes softwares que permiten simular y analizar el comportamiento de células solares y obtener los principales parámetros que gobienan estos dispositivos como el voltaje de circuito abierto, la corriente de corto-circuito, el Factor de llenado y la eficiencia cuántica externa de células solares de capa delgada. Se van a modelizar dispositivos a partir de absorbentes como CIGS, CIS, CGS, CdTe. Además se introducirán otros semiconductores para la capa buffer y la ventana óptica. La idea es analizar distintas combinaciones de materiales que permitan crear un dispositivo fotovoltaico de bajo coste y elevada eficiencia.

SUMMARY (IN ENGLISH)

To cope with energy requirements the utilisation of renewable energies, particularly the Sun supplies the biggest and abundant energy source in Earth. Photovoltaic and solar cell are the well advance and burning technology and a field of hot research. Majority of research centres and universities are working in this field. 1G, 2G, 3G ..XG generation of photovoltaic cells have been developed and still to improve its efficiency and to decrease it 0.2 $/W cost.

Our work mainly based on the theoretical and physical analysis of thin-film Photovoltaic devices. We will explore different software used for the analysis of PV cells, and will analyse different simulation related to solar cells like open circuit voltage V_{OC}, Short circuit current JSC, Fill Factor FF (%) and external Quantum efficiency (%) for thin film solar cell including CIGS, CIS, CGS, CdTe, SnS/CdS/ZnO etc. To have different analysis for different

combination and different replacement for materials used in the solar cell fabrication. To cope with the PV cost and environmental hazards we have to find alternate solutions.

METODOLOGY TO BE USED

First of all basic theory, parameters and concept of PV devices should be exploited and explored. The physical and mathematical behaviour and electronics properties of the PV cells should be simulated by using the available dedicated simulation software (Mainly free or less costly software). The simulated result that obtained from the analysis will be compare with the highest experimental results and improvement should be proposed for researcher in the research and academic laboratories. Comparison of cost and efficiency for PV devices and module producer will make a costumer friendly environment.

OBJECTIVES

To model and improve Photovoltaic Devices,
To improve the efficiency of available devices
To propose new PV devices based on new materials.
To discover alternative low-cost solutions for PV devices.
To reduce the cost factor of PV devices.

MEANS TO BE USED

Describe the different software available for these purposes

AVAILABLE ACADEMIS FREE SOFTWARE

- PC1D (One-dimensional semiconductor device simulator)
- AMPS (Analysis of Microelectronic and Photonic Structures)
- SCAPS (a Solar Cell Capacitance Simulator)
- ASA (Amorphous Semiconductor Analysis)
- AFORS-HET (Automat For Simulation of Heterostructures)
- SimWindows
- ADEPT-F
- ASPIN

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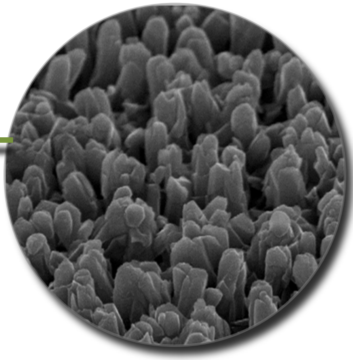
INSTITUTO DE DISEÑO Y FABRICACIÓN

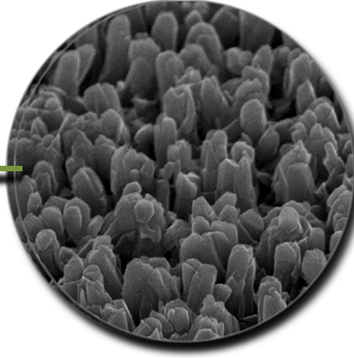
SIMULATION STUDIES OF PHOTOVOLTAIC THIN FILM DEVICES



HANIF ULLAH

Director de tesis
Bernabé Marí Soucase
Departamento de Física Aplicada
Instituto de Diseño y Fabricación

SIMULATION STUDIES OF PHOTOVOLTAIC THIN FILM DEVICES

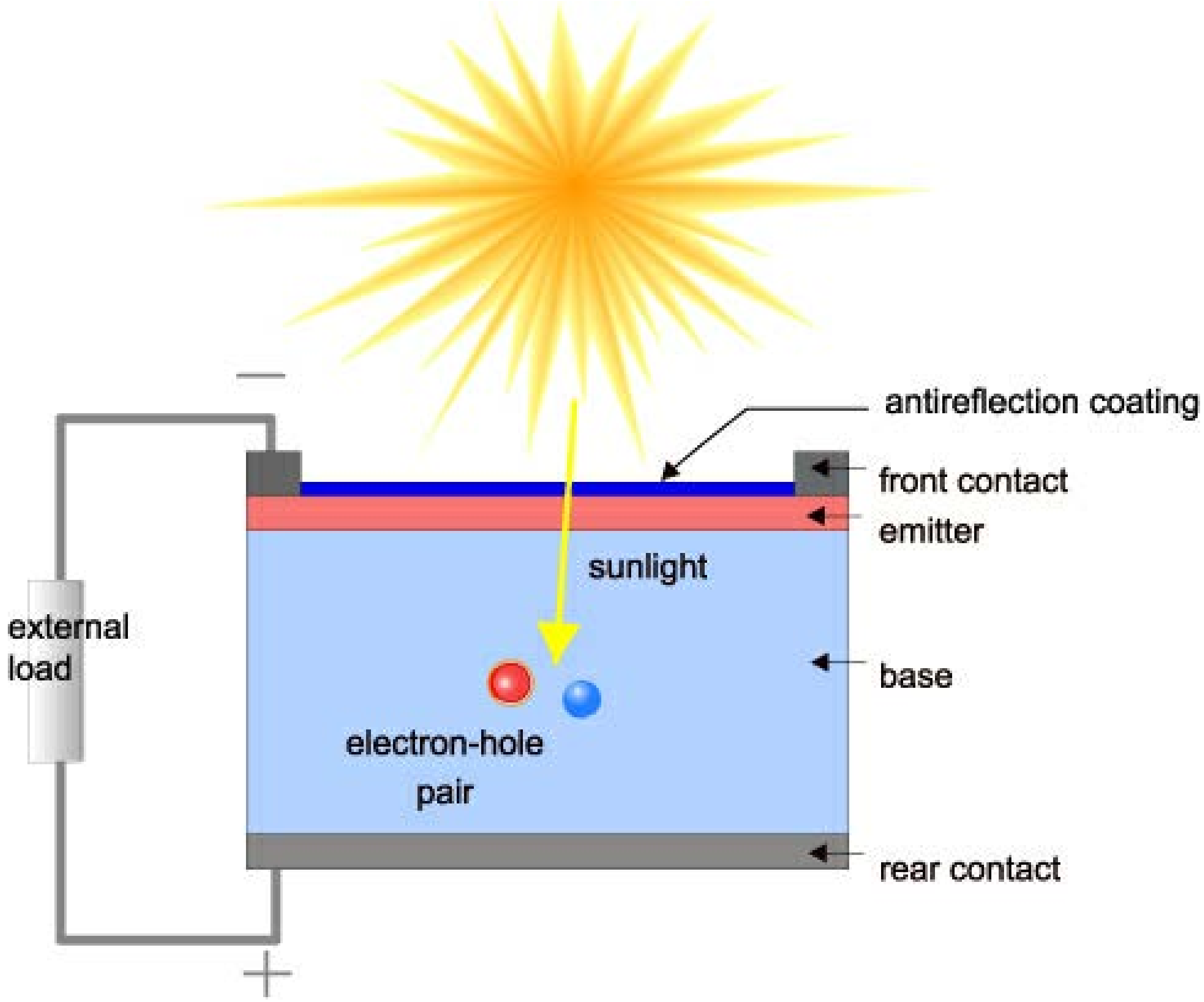


1. INTRODUCTION
2. SIMULATION SOFTWARES
3. SCAPS (SIMULATOR)
4. NUMERICAL ANALYSIS
5. SIMULATION RESULTS
6. CONCLUSION
7. ACKNOWLEDGEMENT

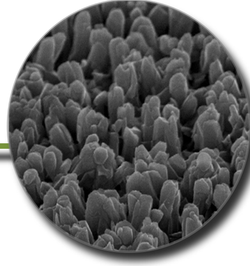
INTRODUCTION

- **Photovoltaics** literally means light-electricity: photo comes from the Greek *phos*, meaning light, and volt from the Italian scientist *Alessandro Volta*; a pioneer in the study of electricity.
- This technology, originally developed for space applications in the 1950s, has many advantages: it is modular, clean, easy to maintain, and can be installed almost anywhere to suit the needs of the user.
- The electricity produced can be used directly, stored locally or fed into an existing electricity grid.

INTRODUCTION



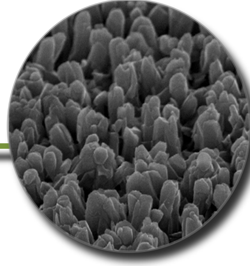
INTRODUCTION



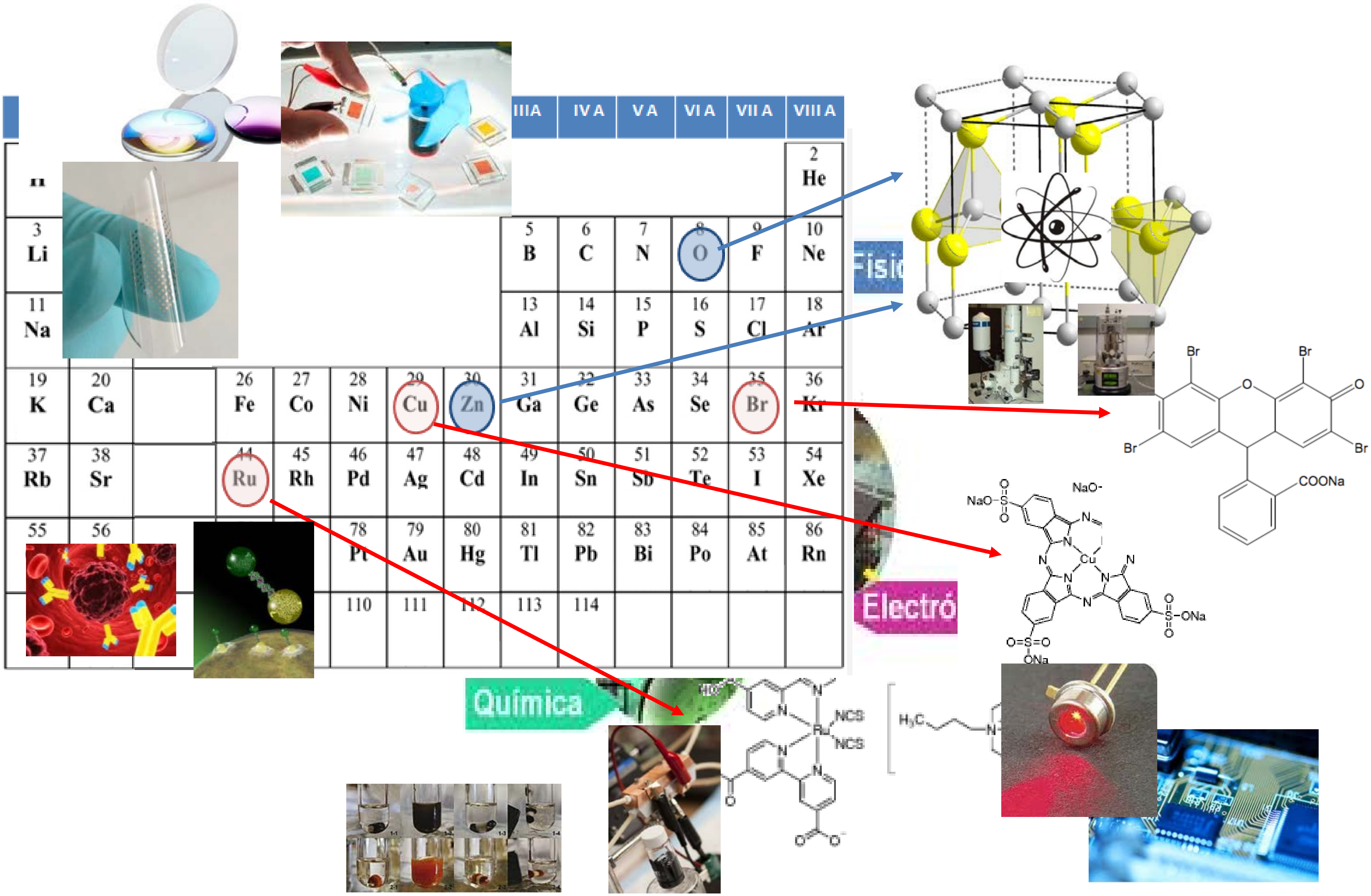
It is a 4-steps process

1. A light absorption process which causes a transition in a material (the absorber) from a ground state to an excited state,
2. The conversion of the excited state into (at least) a free negative – charge and a free positive- charge carrier pair,
3. A discriminating transport mechanism, which causes the resulting free negative-charge carriers to move in one direction(cathode) and the resulting free positive-charge carriers to move in another direction (anode)
4. Closing the circle, the absorber goes to ground state

INTRODUCTION



- First-generation: fabrication of high-quality, low-defect, single-crystal PV devices (Wafer–based)
- Second-generation: Si-based thin-film technologies. Cost 1$/W
- Third generation: Advanced thin film technologies. Requirements for 3rd PV:
  - Reduce the cost per Watt peak (0,20$/W or better)
  - Use materials non toxics and non limited in abundance



IIIA
IV A
V A
VI A
VII A
VIII A
2 He
3 Li
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55
56
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
110
111
112
113
114
Físic
Electró
Química
Br
O
COONa
NaO-
Cu
N
NCS
Ru
H_3C

SIMULATION SOFTWARES

1. PC1D
2. AMPS (Analysis of Microelectronic and Photonic Structures)
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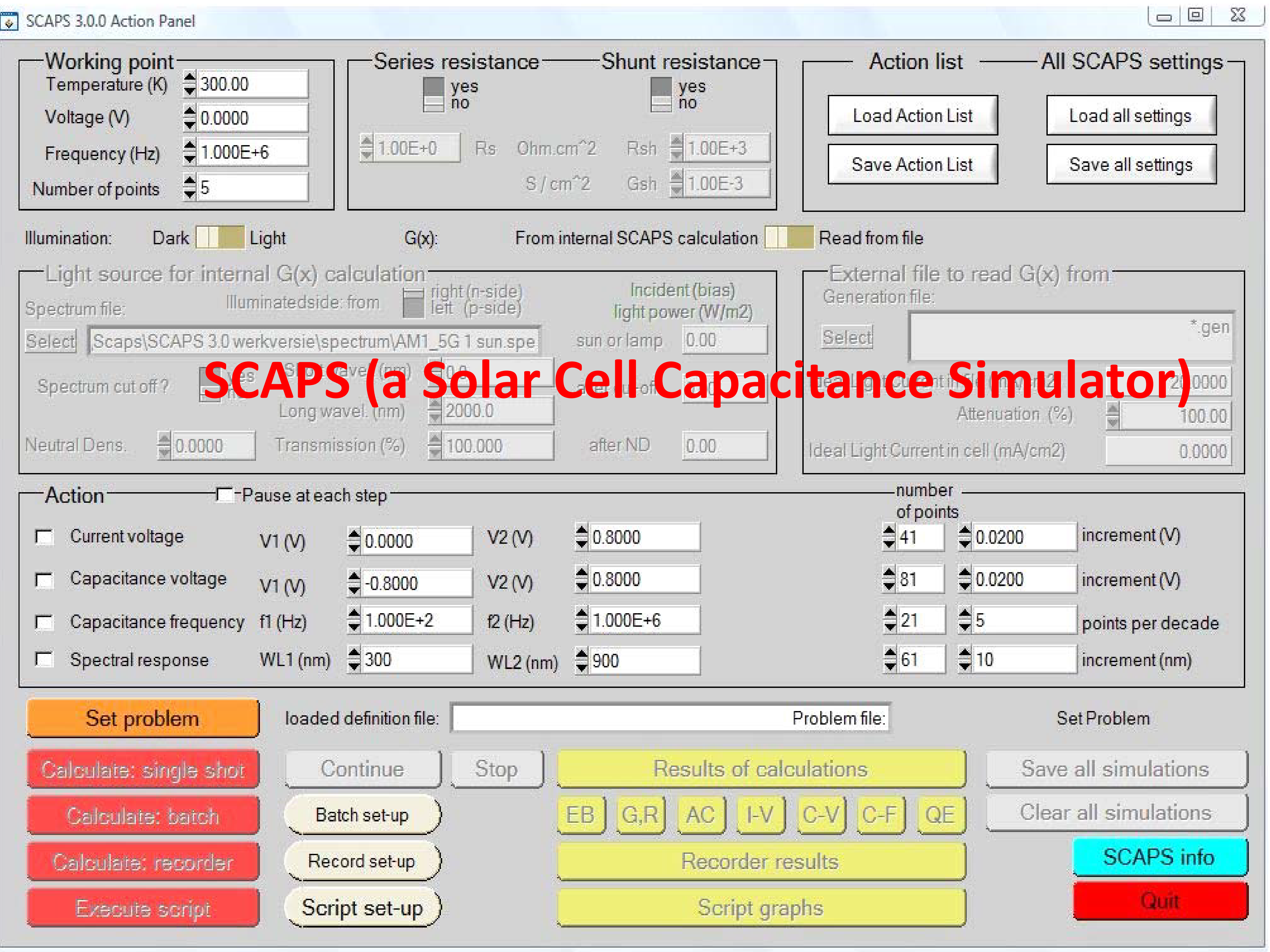
SCAPS (a Solar Cell Capacitance Simulator)



SCAPS Review
(Version, SCAPS 3.2, April 2012

- SCAPS-1D (a Solar Cell Capacitance Simulator) is a one dimensional solar ce simulation programm developed at the
  Department of Electronics and Information Systems (ELIS) of the University of Gent, Belgium.
- It was developed for cell structures of the $CuInSe_2$ and the CdTe family.
- Recent developments make the program now also applicable to crystalline solar cells (Si and GaAs family) and amorphous cells (a-Si and micromorphous Si)
- Works up to 7 semiconductors layers,
- Parameters like *Eg*, χ, ε, *NC*, *NV*, *vthn*, *vthp*, μn, μp, *NA*, *ND*, all traps (defects) *Nt* can be graded.
- Recombination mechanisms used are band-to-band (direct), Auger, SRH-type
- Illumination: a variety of standard and other spectra included (AM0, AM1.5D, AM1.5G, AM1.5Gedition2, monochromatic, white

Cross-sectional diagram of the structure of a typical CIGS solar cell. SUPERSTRATE CONFIGURATION

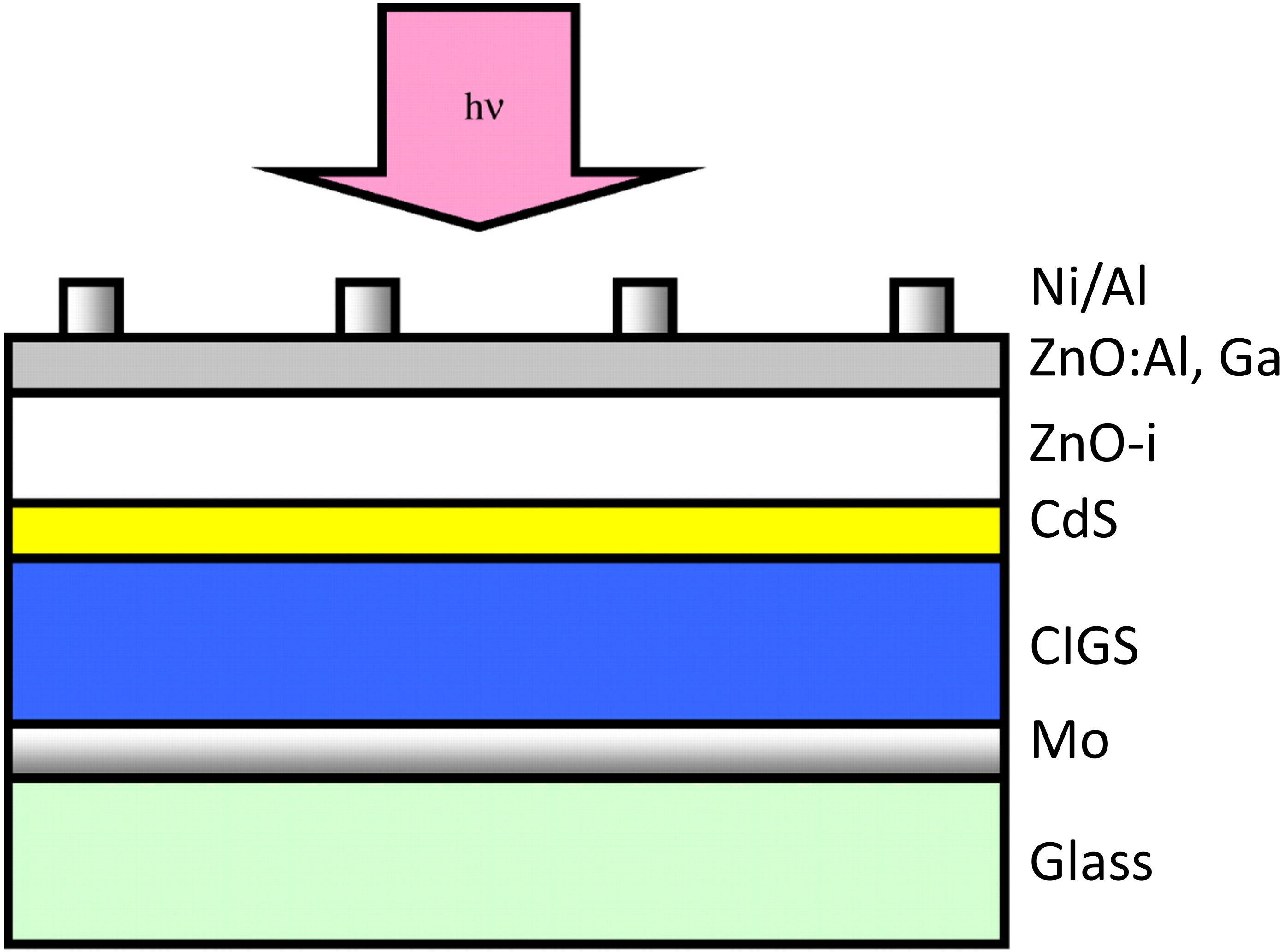
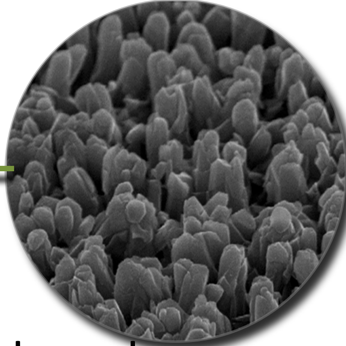


Figure 1. Cross-sectional diagram of the structure of a typical CIGS solar cell. Light enters the cell through the transparent ZnO top contact. From bottom to top: glass, molybdenum, CIGS, CdS, i-ZnO, Al : ZnO, top contacts.



The effect of changing Gallium concentration in the CIGS absorber layer have been analyzed
The physical operation features of a thin-film solar cell structure ware analyzed by using SCAPS
Many parameters influencing the efficiency and performance in PV cell
In order to get confidence into a solar cell model, we have to take different characteristics as well as different possible conditions to be simulated and compared
Taking this into account we have considered the variation of absorber layer band-gape due to change in Ga contents in CIGS layer
The effect of band-gap of CIGS absorber layer.
Thickness of the layer

Experimental results

Quantum Efficiency (QE) Analysis

- The QE is the ratio of the number of charge (electron-holes) carriers collected by the solar cell to the number of photons of a given energy incident on the solar cell.
- The QE is 1 or 100% when all the photons absorbed by the absorber layer and all the resulting carriers are collected
- Improving this conversion efficiency is a key goal of research and helps make PV technologies cost-competitive with more traditional sources of energy.
- The absorber layer absorb photons whose wavelength is either equal or greater than the band-gape (Eg)
- The low energy photons cannot be absorbed and the high energy photon will contribute in thermalization process. Loses: Spectral mismatch, shading losses, incomplete absorption and collection losses will decrease the efficiency

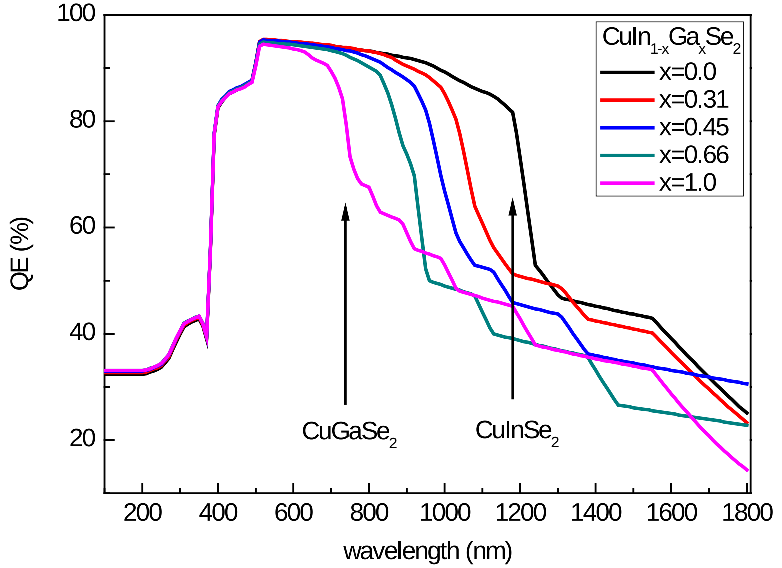


Figure 2. Quantum Efficiency (QE) outputs for CuIn(1-x)Ga_xSe_2 absorbers with different Ga content

Experimental results

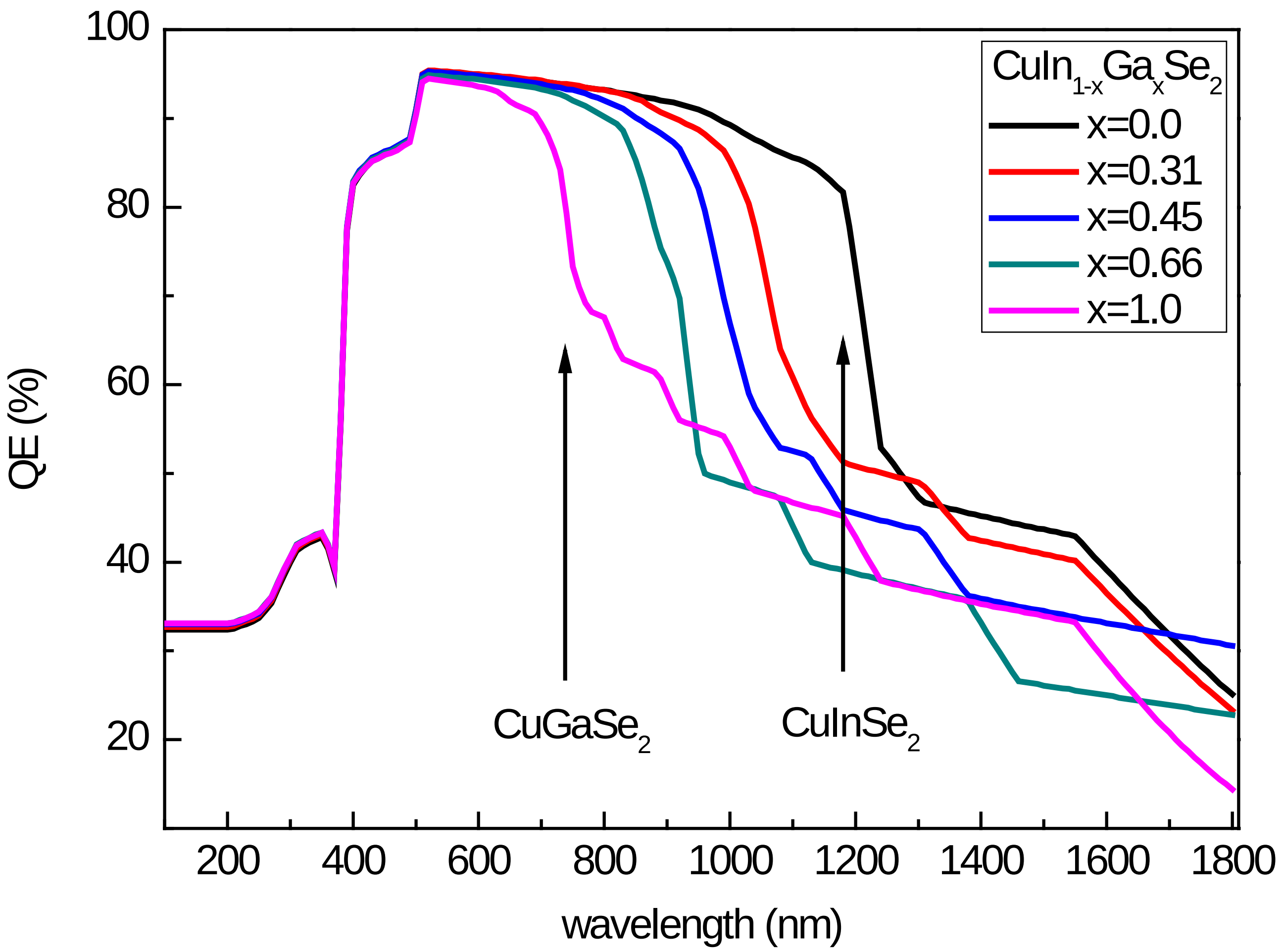


Figure 2. Quantum Efficiency (QE) outputs for CuIn(1-x)Ga xSe₂ absorbers with different Ga content

SIMULATION RESULTS

J-V Characteristics Analysis of CIGS Solar Cells
The graph for J-V characteristics is given for thin film solar cell, the content of Gallium (Ga) were changed in the film

From pure CIS to CGS the graph is plotted. It is clear from the graph that when band-gap increases the open circuit voltage Voc also increases.

Table 1. Base parameters for thin-film layers

$x = Ga / (Ga + In)$	$Eg\ (eV)$
0.00	1.00
0.31	1.18
0.45	1.27
0.66	1.40
1.00	1.69

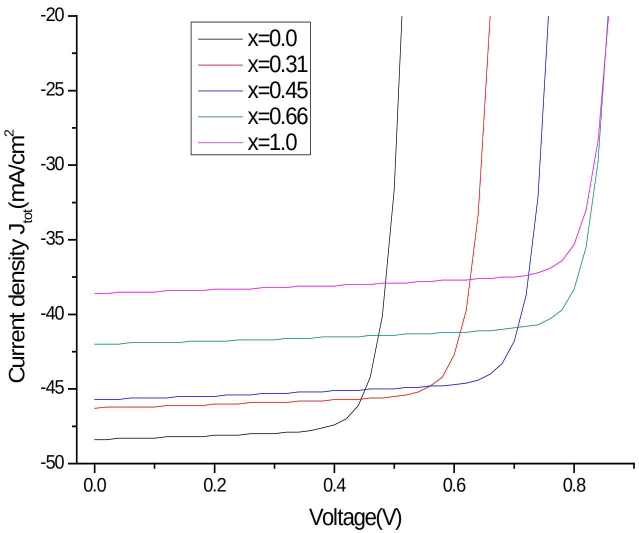


Figure 3. J-V Characteristic curves for CuIn(

Experimental results

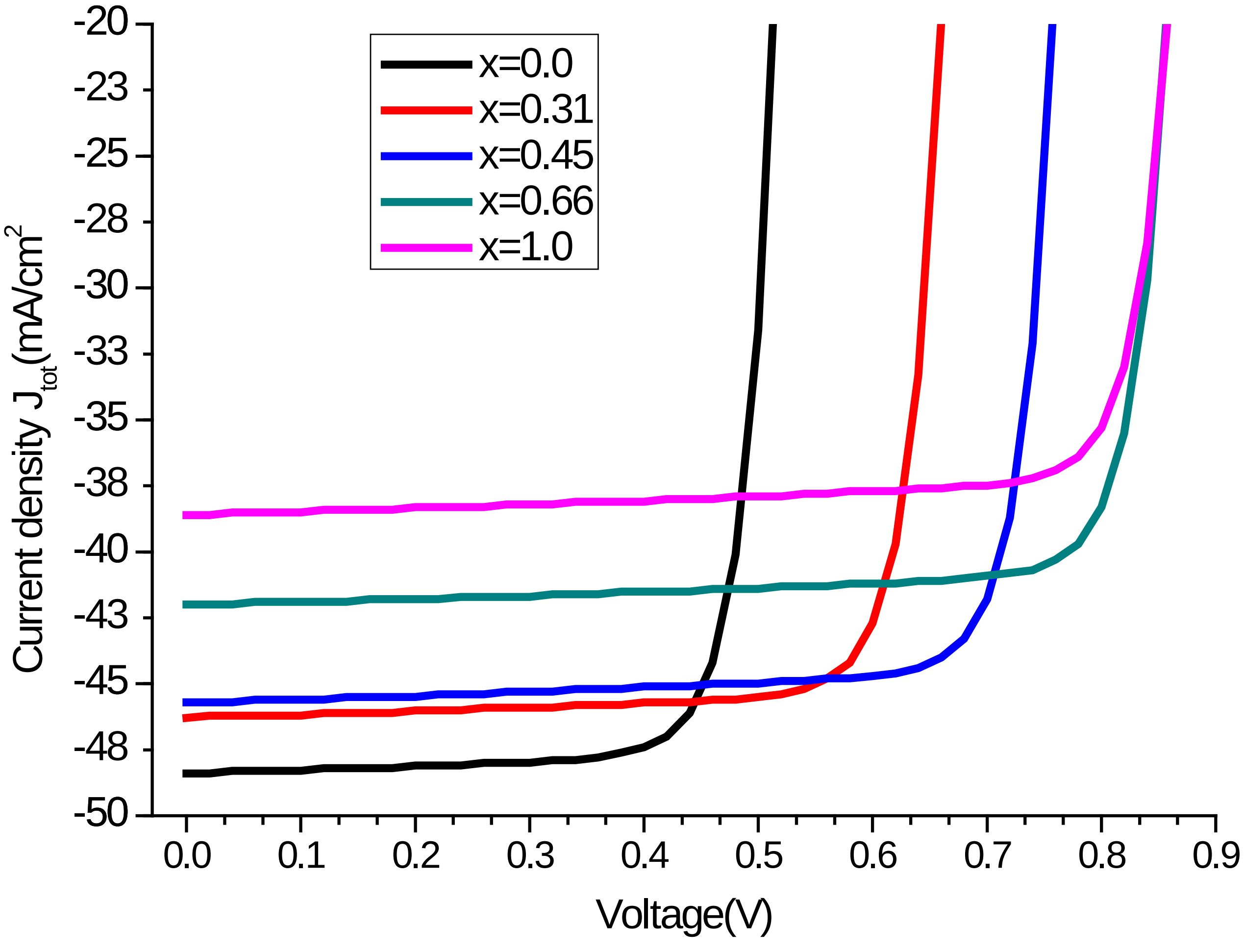


Figure 3. J-V Characteristic curves for $CuIn(1\text{-}x)Ga_xSe_2$

SIMULATION RESULTS

Effect of Gallium (Ga) in the absorber-layer

- The open circuit voltage (Voc) increases as the gallium (Ga) content increases as the band-gap of the CIGS layer increase.
- The short circuit current (J_{tot}) decreases as bandgap increases, it has the reverse effect then that of the Voc.
- Fill-Factor (FF) increases up to increase of Ga up to 50 % after more increase in Ga contents causes decrease in FF,
- The same phenomenon also observed in the case of external quantum efficiency eta (%). In the beginning eta increases up to 60 % of Ga contents but further increase of Ga causes decrease in eta .

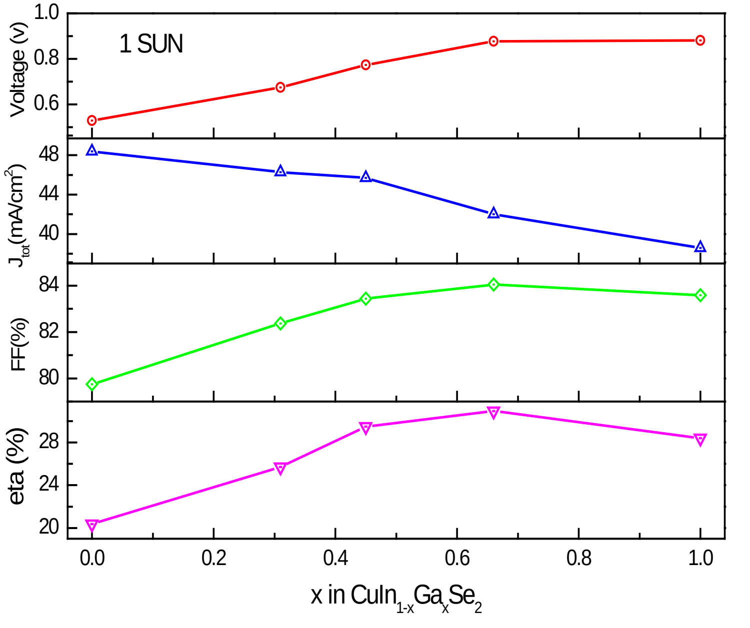


Figure.3 Cell performances with variable Gallium composition in CIGS absorber layer

Experimental results

Results

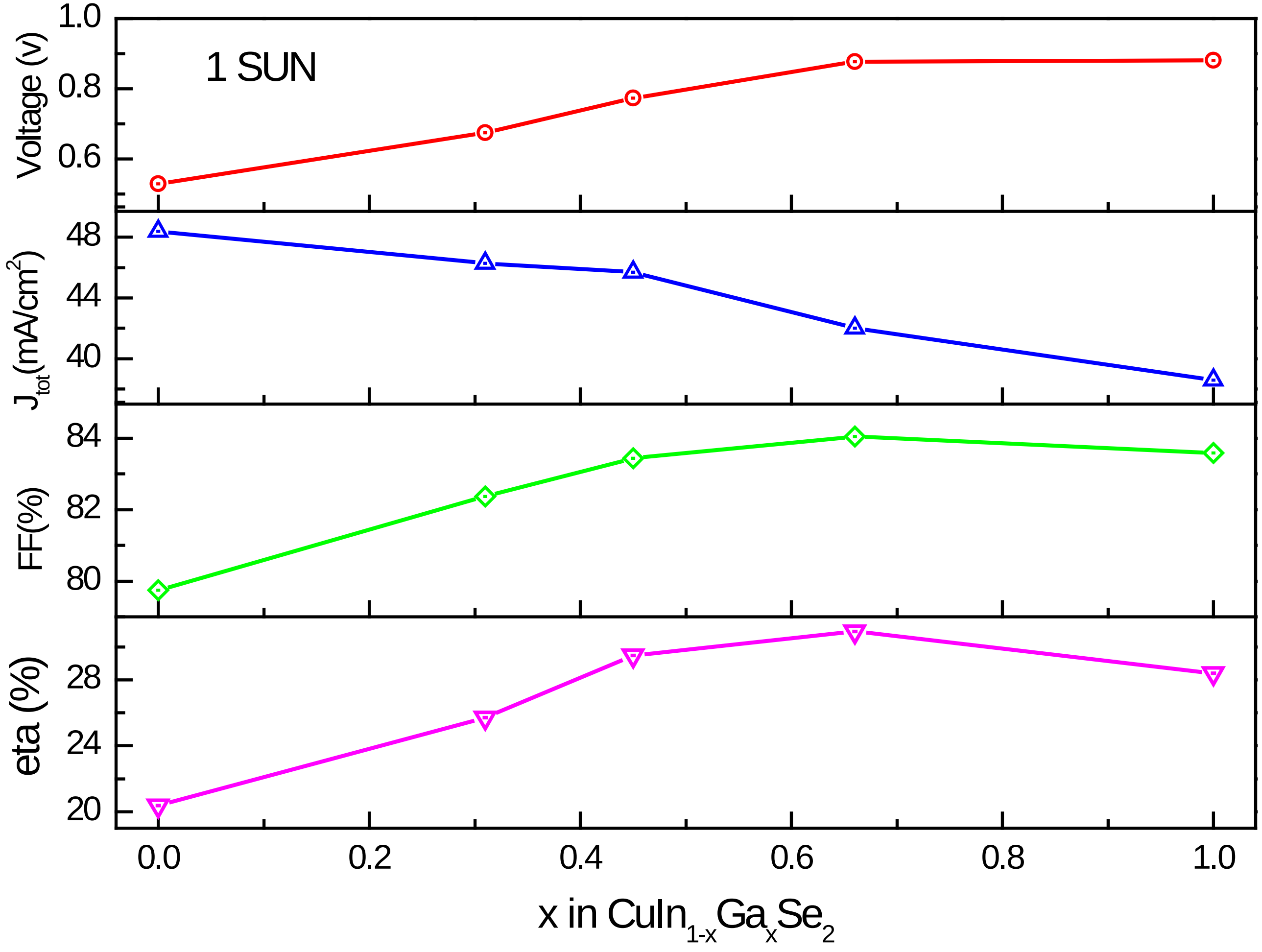


Figure.3 Cell performances with variable Gallium composition in CIGS absorber layer

Potential Improment by Ga- grading

- The increased band gap has two effects on the photo-generated electrons.
  - The recombination probability will be reduced in the regions with increased band gap since this probability is inversely proportional to the band gap [2].
  - An additional electric field is obtained and can be described by Eq. [13].

$$\xi_A = \frac{d\Delta E_g}{dx}$$

ΔE_g is the change in band gap over the distance x due to the Ga-grading.

Potential improment

- The variation of the Ga/(In+Ga) ratio, x, will affect the band gap according to

$$\boldsymbol{E_g[eV] = 1.02 + 0.67x + bx(x-1)}$$

b is the optical bowing coefficient where

$\boldsymbol{0.11 \leq b \leq 0.24}$ [12]

- Improved $\boldsymbol{V_{OC}}$ by reduced impact of regions with high recombination
- Improved $\boldsymbol{J_{SC}}$ due to field assisted carrier collection

CONCLUSION

- The effect of changing Gallium concentration in the CIGS absorber layer have been analyzed
- The physical operation features of a thin-film solar cell structure ware analyzed by using SCAPS
- Many parameters influencing the efficiency and performance in PV cell
- In order to get confidence into a solar cell model, we have to take different characteristics as well as different possible conditions to be simulated and compared
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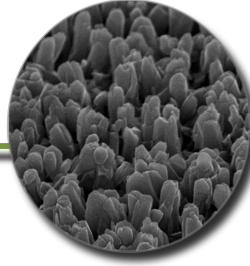
- Thickness of the layer

AKNOWLEGMENTS



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