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THE EFFECT DOPING OF THE OXIDE LAYER ON THE PERFORMANCES OF PHOTOVOLTAICS THIN FILMS STRUCTURES

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Abstract-- In the field of photovoltaic conversion containing thin films, the materials chalcopyrites such as Cu (In, Ga)S, Se_2 are the polycrystalline materials leaders in term of efficiency and profitability, for the production of solar cells in the form of thin films, for terrestrial or space application.

These ternary compounds form a broad group of semiconductor materials with optical, electrical and structural different properties. In order to be able to realized a thin films structures in high-efficiency of conversion, the transparent conducting oxides (TCO) play a significant role in the manufacture of this type of cells.

Indeed, these oxides such as ZnO, SnO_2 , ITO... are in general semiconductors of large gap, suitably doped, to present a figure of merit close to the unity. They can play the role of a conducting layer, a barrier layer of chemical of protection or a layer anti-reflecting.

The objective of this work is to present the effect of the doping of transparent conductor oxide used (ZnO) for a structure ZnO/CdS/CIGS, and the interest which the oxide coating carries on the improvement of the performances of this structure. This fact, we note that the increase in the concentration of the doping of the layer of ZnO play a fundamental role the optical and electric properties of this layer. Indeed, a high doping of the layer of ZnO: Al lead to a high mobility, therefore a better performances. Another significant result obtained by simulation of such a structure enabled us to obtain a spectral response and a characteristic (I –V) better, which leads to a higher conversion efficiency.

***Key words*:** Solar Cells, Thin Films, ZnO, Doping.

I. INTRODUCTION

During these last years, many improvements of the performances of the photovoltaic cells allow to obtain high conversion efficiency at low cost. So the transparent conducting oxides (TCO) were studied and played a significant role in the improvement of the efficiency of the photovoltaic structures in thin films of type CIS, CIGS, CdTe, a-Si:H. The oxide coating is applied as a before contact or in combination with metal in back contact**.** This one must be simultaneously transparent and conducting. The conductivity of these layers must be higher 10^3 (Ω cm^{-1}) Such properties are obtained by using thin layers of SnO_2, In_2O_3, ITO, ZnO... Their transparency is related to the value of their forbidden band, while their electric properties depend on the composition of the layers and a possible doping.

The studies showed that among the chalcopyrites materials as $CuInSe_2$ (CIS), $CuInS_2$ and $CuGaSe_2$ (CGS) and their multinaires alloys of the type Cu(In, Ga) Se_2 are particularly interesting. They have values of gap close to the optimum necessary for a maximum conversion of energy, making it possible to carry out structures with homo junction or heterojunctions, with a window with large gap. Also, they have a direct gap transition, allowing, thus to minimize the constraints relating to the diffusion lengths of the minority carriers, the thickness of the absorber and the optical absorption coefficient which is about 1 to 5.10^5 cm.

This work, concerns the study of the ZnO/CdS/CIGS structure and the interest of doping on the electric and optical properties of the oxide coating, also on the improvement of the performances of this structure. The oxide used is ZnO. He is considered among the most promising materials, considering it has electric and optical properties very interesting. Also, his cost is low compared to the other materials (ITO, SnO_2 ..).

Calculations are carried out by using the numerical simulation program SCAPS 1D. This last enables us to calculate the performances of the studied structure, the calculation of the spectral response as well as the mechanism of recombination to each interface, this last was studied in [1].

The results obtained are very satisfactory. They enabled us to examine the importance of the doping of the oxide coating in this type of structures.

II- THE EFFECT OF DOPING ON THE ELECTRIC AND OPTICAL PROPERTIES OF ZNO.

1) Electrical Properties

Undoped ZnO thin films are not stable especially at high temperatures, doping the zinc oxide can reduce this

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disadvantage. The ZnO doping is achieved by replacing Zn^{+2} atoms of elements of higher valence such as indium [2], aluminium [3] and gallium [4].

These type of oxide materials can be produced by several techniques such as sputtering [5], thermal evaporation [6], CVD [7] and spray pyrolysis [8].

The studies show that the electrical properties are clearly affected by doping. For this, one found necessary to study the effect of the various dopant elements (In, Ga et al.) on the electrical and optical properties of ZnO.

In fig. n°1, we observed a sharp increase of the dopant concentration of 1- 2 at% than it reaches a constant value. This variation could be related to the solubility limit of the dopant elements in the ZnO lattice.

Concerning the mobility (Fig.2), when In or Ga are used as dopant elements an increase in the mobility with the dopant concentration is observed, this effect is more pronounced for In. However, the increase in the Al concentration leads to a decrease in the mobility. This behavior in conformity with the effects of the dopant concentration in the crystallite size [8], since the Al atoms are preferably located at intersticial sites.

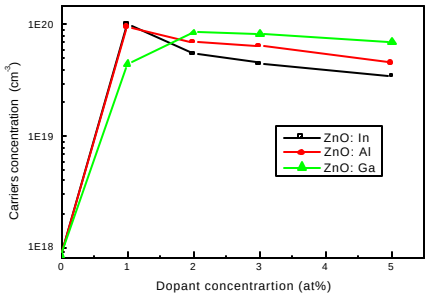

Fig n°1 : Effect of the different dopants in the carrier concentration

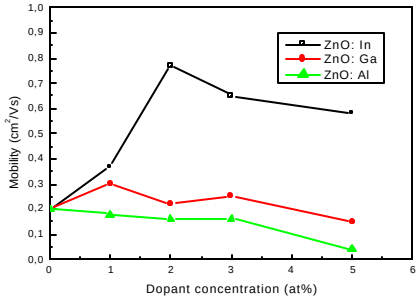

Fig n°2 : Effect of the different dopants in the hall mobility

Due to the effect of the dopant concentration in the carrier concentration and mobility, the resistivity (Fig.3) decreases more than two order of magnitude (until a concentration of 1 –2 at%) and the most significative variation were observed when In was used as dopant element.

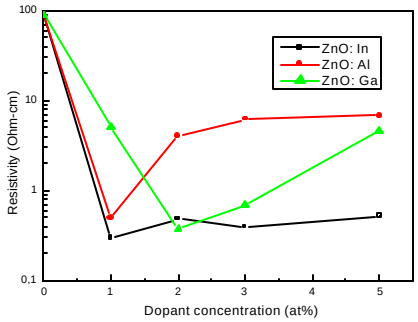

Fig n°3 : : Effect of the different dopants in the

2) Optical properties

The increase in the dopant concentration also leads to a drastic increase in the absorption coefficient and a subsequent stabilization (Fig.4). This behavior could be explained by the variation of the carrier concentration with respect to the dopant concentration and also to the increase of he ionized impurity scattering.

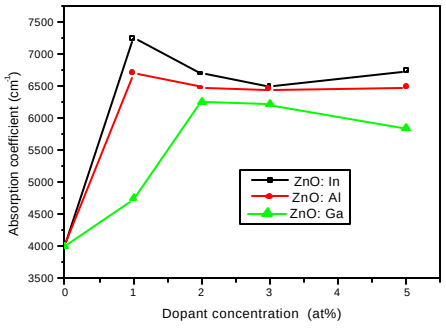

Fig n°4 : Variation of absorption coefficient with dopant concentration for the different dopants

Surface morphology has also a strong influence on the optical properties of the films since textured surfaces lead to a enhacement on the light collected. This is explained by the introduction of the factor Haze (haze Factor) [9].

III MODEL

The work which will follow is a study of simulation carried out by program SCAPS (1-D) developed at the department of electronics and the information systems (ELIS) at the university of Gent in Belgium [10]. The simulations are based on the numerical solution of coupled continuity equations for free charge carriers and the poisson equation, in order to calculate the charge carrier and current densities in each semiconductor layer. The boundary conditions between two adjacent semiconductor layers are given by the model of thermal emission. Bulk defect states are described by the Shockley-Read-Hall recombination model.

The CIGS cells have a complex multiplayer structure. It is often assumed than a thin layer of an ordered defect compound (ODC, supposed $Cu(In, Ga)_3Se_5$) of 15nm thickness is formed at the surface of the CIGS layer, next to the CdS buffer layer [1]. The windows consists of a thin CdS layer (in this case 100nm) realized by CBD [1], the absorber layer CIGS of 1000 nm is carried out by the process of Co evaporation [1]. On top of a buffer layer, a highly conductive, Al doped ZnO layer is deposited by Sputtering [1]. In this case, an undoped ZnO layer is deposited prior to the deposition of the Al doped ZnO. For the simulation of the electronic properties of transport of such a structure, program SCAPS is used [10]. This last enables us to calculate the characteristics of dc and ac for a large variety of semiconductors as well as the mechanisms of recombination, like the recombination Shockley Read Hall with the interface of each layer, this is studied in [1,11]. In our study, one will limit oneself on the influence of doping to the measure of the spectral response and the performances of this structure.

Let us note that the spectral response is calculated under the illumination AM 1.5 G.

IV RESULTS AND DISCUSSION

The results of simulation of the structure are presented on the figure n°5. This figure presents the variation of the quantum efficiency according to the concentration of the doping of the layer of ZnO.

It is clear that the increase in the doping led to more interesting electric properties, therefore with better performances.

It is noted that for a concentration of 10^{18} cm^{3} the quantum efficiency is about 83,21% whereas for a concentration of 10^{16} / cm^{3} it is about 58% and that for a wavelength of 510 Nm. Indeed, the layer of ZnO is located in the front face and thus allows a higher absorption. Also, we note that the decrease in the short wavelength range is due to the absorption in the CdS buffer layer.

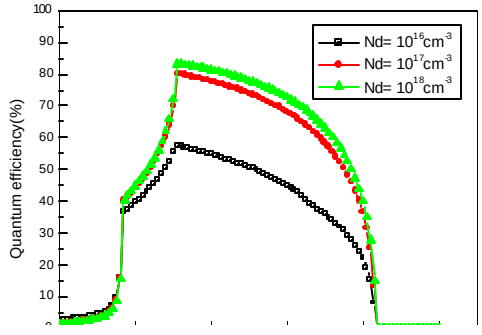

Fig. n°5 Variation of the quantum efficiency of ZnO/CdS/CIGS structure according to the doping of thei :ZnO layer

Characteristic IV is presented on the figure n°6.Onconstate that the efficiency is better for a high doping, whereas the open circuit voltage decreases with increase doping (Table n°1). We conclude that a high doping of the layer oxide led to have a good efficiency, but the problem, remains to have a good conditions for the deposit parameters of the ZnO layer

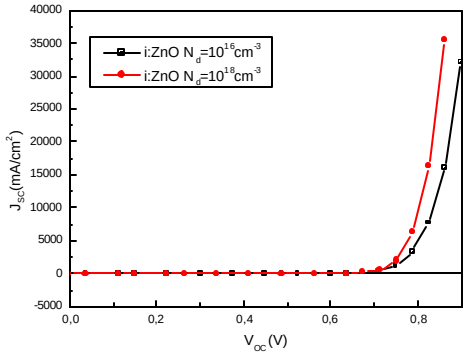

Fig.n°6: I-V characteristic of the ZnO/CdS/CIGS structure according to the doping of ZnO layer

TABLE N°1: PERFORMANCES OF ZNO/CDS/CIGS STRUCTURE ACCORDING TO THE DOPING OF THE ZNO LAYER

	Voc (V)	Jsc (mA/cm^3)	FF	η
Nd = $10^{16}cm^{-3}$: ZnO	0,52	27,13	56,7	8,02
Nd = $10^{17}cm^{-3}$: ZnO	0,51	27,19	58,6	8,19
Nd = $10^{18}cm^{-3}$: ZnO	0,50	27,24	60,1	8,34

V CONCLUSION

The effect of doping play a very significant role on the performances of the ZnO/CdS/CIGS structures. The use of the layer oxide doped allowed us to have very significant changes on the electrical and optical properties of ZnO, especially on the mobility and resistivity. Indeed, a better mobility allowed us to have higher performances.

The simulation carried out by program SCAPS 1D, shows us that the spectral response is very affected by doping, as well as the performances. Let us note that in this case the presence

of the defects to the interface of the various layers are not taken into account. In a futur study, the introduction of these defects will be studied.

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