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# Structural, Electrical and Optical Properties of Transparent Conductive Oxides Thin films (TCOs) based on Al doped ZnO nanoparticles for CIGS solar cells.

A.MOUSSA TANKARI <sup>1,2\*</sup>, K.MEDJNOUN <sup>1,2</sup>, M.BELAQQIZ <sup>4</sup>, I.HALIDOU <sup>5</sup>, M.NOUIRI <sup>3</sup> and K.DJESSAS <sup>1,2</sup>

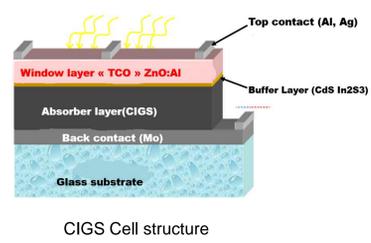
<sup>1</sup> Laboratory of Processes, Materials and Solar Energy (PROMES) CNRS UPR 8521, Rambla de la thermodynamique, Technosud 66100 Perpignan, France  
<sup>2</sup> University of Perpignan Via Domitia (UPVD), 52 avenue Paul Alduy 66860 Perpignan Cedex 9, France  
<sup>3</sup> Laboratory of Physics of Materials and Nanomaterials Applied at Environment (LaPhyMNE), Faculty of Sciences of Gabès, Gabès University, Gabès, Tunisia  
<sup>4</sup> Laboratoire Procédés, Métrologie, Matériaux pour l'Énergie et Environnement (LP2M2E), Université Cadi Ayyad, Faculté des Sciences et Techniques, Marrakech, Morocco  
<sup>5</sup> Université Abdou Moumouni de Niamey, Faculté des Sciences et Techniques, Niamey, Niger  
 \*Correspondence: abdoul.moussa@univ-perp.fr Tel.: +33 4 68 68 22 11

## Abstract

The aim of this work is to optimize the thickness from 100 nm to 300 nm and doping ration between 1 at% and 2 at% of Al doped zinc oxide thin films deposit on soda lime glass substrate by sputtering RF-magnetron. The realization and characterization of the TCO based on Al doped ZnO nanoparticles to design a high-performance nanostructured optical window intended for photovoltaic applications generally found in the technology of second generation thin-film solar cells based on Cu (In, Ga) Se<sub>2</sub> (CIGS) or amorphous silicon require the choice of a purely experimental approach for the optimization of the protocol for synthesizing the Al doped ZnO nanoparticles and an original experimental protocol to develop nanostructured thin films by RF sputtering from the synthesized nanoparticles. Crystal structure, optoelectronic and morphological properties of thin films were investigated by using XRD, SEM, UV-Vis-NIR. The XRD results showed that the films were polycrystalline textured, preferentially oriented along the (002) crystallographic direction normal to the film surface. The SEM images showed that the films has smooth and uniform surface with small ZnO grains. The crystallite size was found to be 27,5 nm. The films show within the visible wavelength region an optical transmittance of more than 90% and an electrical resistivity of  $2 \times 10^{-4} \Omega \cdot \text{cm}$  for the optimum. From optical measurements, the band gap energy value varies from 3.3 to 3.5 eV.

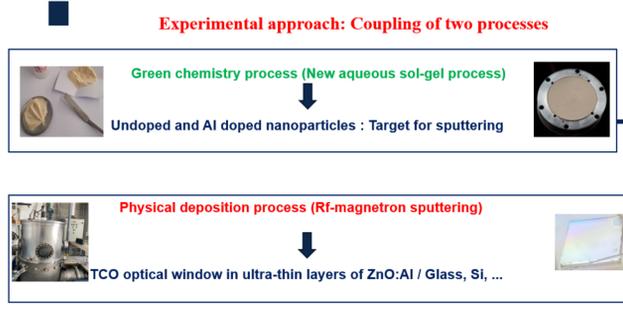
## Context

Copper indium gallium selenide (CIGS) thin film solar cells are now in production for energy conversion devices. This cell provides a high absorption coefficient, high temperature stability, and is low-cost compared to other collection materials.



CIGS Cell structure

A CIGS solar cell consists of several layers of materials, with Cu(In,Ga)Se<sub>2</sub> as the energy absorber layer sandwiched between a substrate, electrical contacts, and a buffer layer. The substrate may be made of glass or made of a polymer material that provides flexibility.



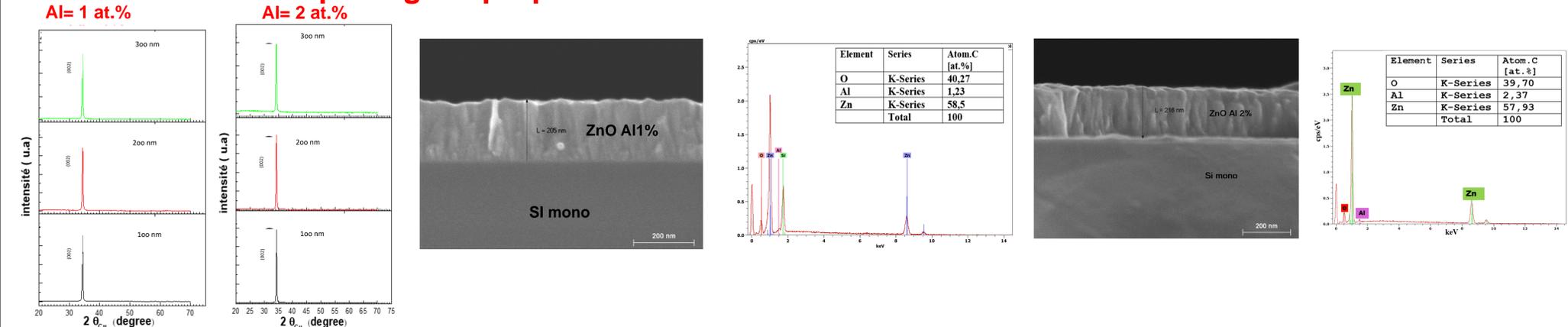
An innovative experimental protocol was developed by coupling two processes:  
 ⇒ A green chemistry synthesis process based on aqueous sol-gel avoiding supercritical conditions for the synthesis of nanoparticles for PVD target  
 ⇒ A physical process based on RFD PVD sputtering to elaborate ultra-thin nanostructured films

## Experimental conditions

Physical vapor deposition (PVD) processes are deposition processes in which atoms or molecules of a material are vaporized from a solid or liquid source, transported in the form of a vapor through a vacuum or low-pressure gaseous environment, and condense on a substrate. PVD processes can be used to deposit films of elemental, alloy, and compound materials as well as some polymeric materials.

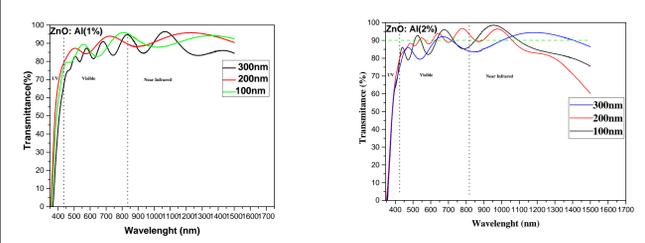
- ⇒ Target : AZO 1 at.% and AZO 2 at.%
- ⇒ Substrate : glass (1 mm thickness), monocrystalline silicon (100) p-type.
- ⇒ Substrate temperature: room temperature
- ⇒ R.f. Power : 60 Watt/cm<sup>2</sup>
- ⇒ R.f. Generator : 13,56 MHz
- ⇒ Target-to-substrates distance : 75 mm
- ⇒ Gas : Argon with (99,9999 %) high purity.

## Structural and morphological properties

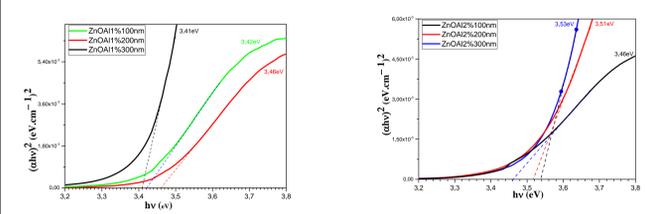


- ⇒ The samples are polycrystalline hexagonal wurtzite structure.
- ⇒ Strange preferential (002) orientation
- ⇒ The film was grown only with the c-axis oriented perpendicular to the surface
- ⇒ The calculated average crystallite sizes of ZnO thin films are of 27.5 nm.
- ⇒ We observe a perfectly columnar and compact structure
- ⇒ The elementary chemical composition studies revealed a rather large quasi-stoichiometry.
- ⇒ A good uniformity and a high density surface without visible holes or faulty zones on the film surface.
- ⇒ The measured thickness of the films are of the order of some microns.

## Optical properties (UV-VIS-NIR)

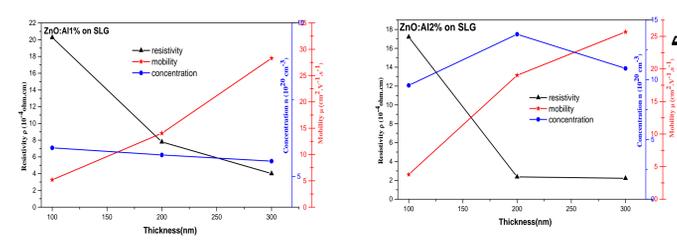


⇒ The average transmittance is about 90% in the visible range.



⇒ The Al doped ZnO film showed an optical band gap in the range of 3.3 to 3.5 eV for the studied samples.

## Electrical properties (Hall effect)



⇒ The mobility increase when increasing the thickness of the thin film while the resistivity decrease when increasing the thickness of the doped ZnO thin films

## Conclusion

In summary, we have prepared highly transparent Al-doped ZnO thin films on glass substrate using sputtering process at room temperature. Structural, electrical and optical properties were investigated to optimize the thickness and doping ratio for a transparent homogenous oxide films. X-ray diffraction spectra indicated that all samples of Al-doped ZnO films are polycrystalline with a hexagonal wurtzite structure with the maximum crystallite size of about 27.5 nm. The average transmittance of the optimized film is about 90% in the visible range and the band gap energy of about 3.27 eV. From this results, it is possible to conclude that Al-doped ZnO thin films deposited by sputtering process at room temperature with an optimize thickness and doping ratio of 200 nm and 2 at% can be used in optoelectronic devices especially in solar cells .

Samples	Thickness (nm)	Resistivity (Ω.cm)	Transmittance Tr(%)
ZnO :Al (1%)	100 nm	2.10 <sup>-3</sup>	90%
	200 nm	8.10 <sup>-4</sup>	87%
	300 nm	4.10 <sup>-4</sup>	85%
ZnO :Al (2%)	100 nm	17.10 <sup>-4</sup>	92%
	200 nm	2.10 <sup>-4</sup>	91%
	300 nm	2.10 <sup>-4</sup>	86%

Table 1: Optoelectronic properties of the thin films