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UV Absorption Analysis Of Nano- Dye Sensitized Solar Cells Fabricated From Zno Thin Films

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Abstract- Zinc oxide (ZnO) is a promising material nowadays for solar cell fabrication because of its unique electrical and optical characteristics. Due to this ZnO thin-films have a great concern worldwide to be used in solar cells preparation. The aim of this study is to investigate the optical absorption spectra of ZnO thin films obtained from different sources using UV-VIS spectrophotometer. Results exhibited that the excitonic absorption of thin film based on commercial ZnO thin-film sample represented the strongest and sharp peaks around 253 nm. Generally, values of α for all samples were in the range of $0.959x10^2$- $5.5x10^2$ cm^{-1} where the highest value of optical coefficient ($5.5x10^2$ cm^{-1}) was recorded for the commercial sample and the lowest one ($0.959x10^2$ $cm^{-}1$) was recorded for the solar cell based on ZnO thin-film prepared from Zn annealed at 1000^oC for 3 hours. However, the transmission spectra revealed that there was a systematic decrease in transparency with the increase of annealing time at 1000^oC. Also findings claimed that dye sensitized solar cell fabricated from commercial ZnO thin-film recorded the highest excitons coefficient (K = $9.3x10^{-6}$) at 210 nm while that prepared from ZnS thin-films annealed for 3 hours showed the lowest excitons coefficient (K = $1.87X10^{-6}$) at 208 nm. Solar cells prepared from different sources of ZnO thin films in this research had an average of transparency in the visible region due to good structural homogeneity of the films. Moreover, the fabrication of thin films had low surface roughness and good uniformity due to the use of high annealing temperature for a long time. This study provides an alternative promising material of low cost and friendly to the environment for solar cell synthesis.

Keywords— Nano- Dye Sensitized Solar Cells, UV absorption, Thin-Films, ZnO, Optical absorption spectra.

I. INTRODUCTION

Zinc oxide (ZnO) is a promising material nowadays for solar cell fabrication because of its unique electrical and optical characteristics. It has a wide band gap of 3.2–3.4 eV, abundant in the nature and nontoxic semiconducting material of low cost [1, 2]. Moreover, it has high optical transmission suitable for solar cell spectrum [2]. The absorption of the synthesis ZnO was at 373 and 379 nm as the annealing temperature increased from300^oC to 500^oC [3]. Thin-films of ZnO have been investigated for the use as transparent and semiconducting layer in solar cells fabrication [4, 5]. Moreover, these thin-films are began to be used as electron selective layer in inverted organic solar cells [6, 7] and as electron transport layer in perovskite based hybrid solar cells [8, 9].

ZnO thin films will be obtained by different methods such as pulsed lazer deposition (PLD) as reported by Sans *et al*., [10], chemical vapour deposition [11], Radio Frequency (RF) magnetron sputtering [12], spray pyrolysis [13], dc magnetron sputtering [14], sol-gel technique [15, 16] and Successive Ionic Layer Adsorption and Reaction (SILAR) [17]. The sol-gel method has distinct potential advantages over methods due to its lower crystallization temperature, ability to tune microstructure via sol-gel chemistry, conformal deposition ability, compositional control and large surface area coating capacity [18, 19]. As reported by Chebil *et al*., [20], the difference between ZnO and substrate material may significantly affect the growth of ZnO film.

The investigation of optical absorption properties of ZnO thin-films prepared from different compounds of zinc after annealing at high temperature for different time intervals is essential and recommended for solar cells synthesis. Therefor the aim of this study is to investigate the optical absorption spectra of ZnO thin-films obtained from different sources using UV-VIS spectrophotometry.

II. MATERIAL AND METHODS

A. Collection of samples and preparation of ZnO samples

Zinc compound of zinc sulphide (ZnS), zinc sulphate ($ZnSO_4$), commercial zinc oxide (British Drug Houses LTD) and zinc metal collected from Faculty of Agriculture at Khartoum University and Faculty of Science at Sudan for Sciences and Technology University. The above mentioned compounds were obtained in a powder form. Three grams of each collected sample put in a crucible and oxidized in a furnace (England, Maximum Temperature 1200^{o}C) at 1000^{o}C for 3, 6, 9 hours respectively while the commercial ZnO was not subjected to the oxidation process (annealed at 1000^{o}C) and used as a control sample.

B. Preparation of ZnO thin-films from prepared ZnO samples

ZnO thin films of each sample prepared on the indium titanium oxide glass slides (ITO) of dimension 2.5x 2.5cm^2 by coating method on the conducting side of the ITO glass. ITO slides purchased from US. Firstly ITO slides cleaned by absolute alcohol (ethanol) and then fixed on a wood plate using scotch tape on the conducting side of the ITO glass. One ml of the absolute ethanol added to one gram of each ZnO sample and then mixed well for 30 min to get homogenized paste (sol-gel method). Then the prepared paste of each ZnO samples coated, spread and flattened with a razor blade on the same side of ITO slide to obtain ZnO thin-films [21]. All prepared thin-films left to dry on the air for three days. It is known as ZnO thin-film electrode.

C. Fabrication of dye-sensitized nano-solar cells of ZnO thin-films

ZnO thin-film (electrode) of each sample dipped into the Coumarin 500 dye for 1-10 min and then washed with ethanol. Another ITO slide coated with graphite of a dark pencil on the conducting surface (counter electrode) for each sample and then coated with Yamidine dye of 10% concentration. Then the ZnO/ dye electrode and counter electrode combined with the counter electrode to face them each other and fixed with the binder clips (Plate 1, 2, 3).

Plate 1. Measuring of conducting side of ITO slide.

Plate 2. Conducting surface of ITO slide coated with graphite of a dark pencil.

Plate 3. ZnO thin-film (electrode) dipped into the Coumarin 500 and Yamidine dyes.

D. Detection of absorption spectra of dye-sensitized nano-solar cells of ZnO thin-films

Absorption spectra measured using Ultra violet-Visible (UV-VIS) spectrophotometer (UV-VIS 12400 spectrophotometer / SHIMADZU/SED-SPEC-48/Japan). It was used to measure the absorbtivity of ZnO samples. The UV-Vis transmittance spectra of ZnO films on quartz microscope coverslips measured from 200-979 nm by a UV-Vis absorption spectroscopy.

III. RESULTS AND DISCUSSION

A. UV absorption analysis of nano - solar cells fabricated from ZnO thin-films

The optical absorption spectra of dye-synthesized nano-solar cells of ZnO thin-films samples obtained from Zn, ZnS, ZnSO4 and commercial ZnO measured by UV-VIS spectrophotometry in the range of 200-979 nm. Results presented in "*Fig 1*," displayed the UV absorption of ZnO thin-films which obtained from different sources after annealing at 1000^{O}C for different time intervals (3, 6 and 9 hours). Results exhibited that the excitonic peaks of ZnO thin-films appeared at 210-253 nm. The excitonic absorption of thin-film based on commercial ZnO thin-film sample represented the strongest and sharp peaks around 253 nm followed by ZnO thin-film samples obtained from Zn, ZnSO4 samples which annealed for 9 hours and ZnS sample which treated for 6 hours.

These findings are lower than that reported by Mohammed [22] who found that the absorption peak of nano-thin films of ZnO obtained by Spin coating method appeared at 364 nm. Another study carried out by Malevu and Ocaya [23] who studied the effect of annealing temperature on the structure, cell system method at different annealing temperature. They found that nano-needles of ZnO showed strong absorption peak at the range of 360- 380 nm. They found that nano-needles of ZnO showed strong absorption peak at the range of 360- 380 nm. Moreover, they observed that the absorbance spectra for the samples decrease slightly with the increase of annealing temperature and the morphological and optical properties of ZnO nano-needles prepared by air absorption edge slightly shift lower energy. However, these results may be attributed to the electronic transition of electrons from valence band to conduction band [24]. This implies that ZnO nano-needles are in the regime of spatial excitonic confinement compared to the bulk of ZnO [23].

The increase of annealing time in this study may raise the intensity, increase the full width at half maximum (FWHM) and enhance the maximum peak in UV range of spectrum as reported by Ghafouri *et al*., [25]. These findings indicated that heat treatment of semiconductors (ZnO obtained from different sources) at 1000^{o}C for different time intervals for a long time is beneficial for the fabrication of low-cost solar cells. The use of combined dyes may enhance their absorption properties. In the DSSC, the dye-sensitized dye adsorbs the photon under solar

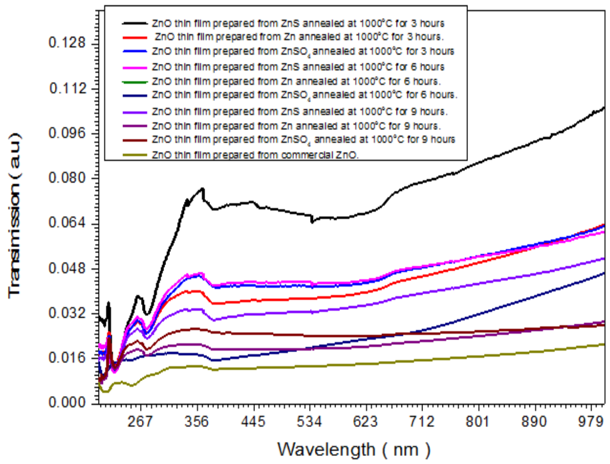

Fig. 1. Optical absorption of sensitized solar cells fabricated from ZnO thin-film samples.

illumination at its interface, then separation of charge take place at the interface. Aligned band positions for charge separation play an important role in the transformation of the photo-generated electrons from the excited dye to the conduction band of the Ti-ZnO where the photocurrent produced by the external circuit [26].

B. Absorption coefficient of nano-solar cells fabricated from ZnO thin films obtained from different sources after annealing at 1000^{o}C for different time intervals

The optical absorption coefficient (α) calculated using its relation with the transmittance T by using the equation α = 1/d ln (1/T), where d is the thickness as reported by Bedia *et al*., [27]. Results shown in *"Fig. 2,"* revealed the optical absorption coefficient of solar cells prepared from nano ZnO thin-films obtained from different sources which annealed at 1000^{O}C for different time intervals (3, 6, and 9 hours). Results claimed that values of α for all samples were in the range of 0.959x10^{2}- 5.5x10^{2} cm^{-1}. High value of optical coefficient (5.5x10^{2} cm^{-1}) recorded for the commercial sample while solar cell based on ZnO sample obtained from Zn after annealing at 1000^{o}C for 3 hours showed the lowest value (0.959x10^{2} cm^{-1}).

Generally, all solar cells fabricated from ZnO thin-film samples are of good quality as all samples present a sharp absorption edge. Similar result reported by Bedia *et al*., [28] who found that all films of ZnO prepared by spray pyrolysis on glass substrates at various temperatures are of good quality as all samples present a sharp absorption edge which located near to 375 nm shifted to shorter wavelengths for sample grown at higher temperature. [29] studied the effect of potential deposition on the parameters of ZnO dye sensitized solar cell. They found that the film C sensitized by the N719 dye exhibited higher absorption than A and B thin-films, with a peak at 350 nm. Those authors revealed that all films were detected in the ultraviolet spectrum at 300-400 nm with lower absorptions in the visible area. Moreover, they proved that this lead to more photogenerated charge carriers and by consequence, higher short-circuits current density as confirmed by Chen *et al.*, [30].

C. Optical transmittance of dye sensitized solar cells fabricated from ZnO thin-films

The optical transmittance of fabricated dye-sensitized solar cells obtained from ZnO thin-films of different sources determined in the wavelength of 200-979 nm which indicates that these solar cells were transparent at visible region and so they are favorable materials for the use in solar energy devices *"Fig. 3"*. Generally, the transmission spectra revealed that there is systematic decrease in transparency with the increase of annealing time at 1000°C.

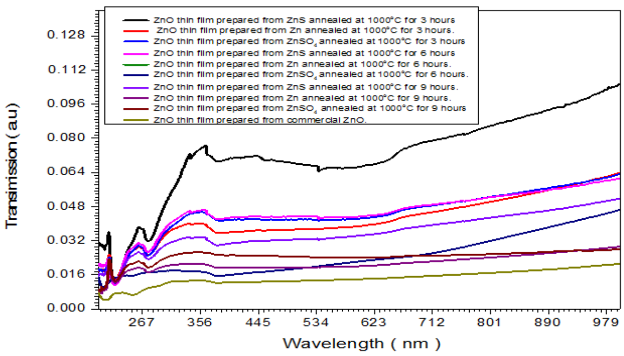

Fig.2. Absorption Coefficient of solar cell fabricated from ZnO Thin-films samples obtained from different sources.

Nano-dye sensitized solar cell thin-film fabricated from ZnS annealed at 1000°C for 3 hours showed high optical transmittance while dye sensitized solar cell thin films prepared from commercial ZnO exhibited low transmission at 212nm. Fluctuations and wave-like patterns appeared on the transmittance spectrum may be due to the interference of light reflected between the air-film and film-glass interfaces, indicating these films had low surface roughness and good uniformity [31].

Nano-dye sensitized solar cells prepared from different sources of ZnO thin-films in this research had an average transparency in the visible region which may be associated with the film's good structural homogeneity and crystallinity [32]. [33] investigated the optical transmittance of ZnO nanowires/$AgGaSe_2$ thin-film core-shell solar cell**.** They found that the optical transmittance of fabricated ZnO thin-films determined in the wavelength range of 325–1100 nm. They revealed that the post-annealing process may end up with reducing defects in polycrystalline structure by which a better crystallinity and homogeneity provided leading to the less scattering of light and transparency enhancement. The decrease of optical transmittance with increase of annealing time at high temperature in this study may be attributed to the effect of the surface roughness and grain size boundary of thin films [34, 35].

As reported by Haarindraprasad *et al.*, [36], ZnO thin-films with a uniform surface exhibited superior absorption capabilities to those with a rough surface. However, commercial ZnO thin-film sample exhibited the lowest transparency value as compared with other samples. This may be attributed to the annealing process conditions, time, sol concentration [37], conditions, substrate [38], film thickness [39], dopants [40], pH of solution [41], solvents [42], chelating agents [43] and preparation method of

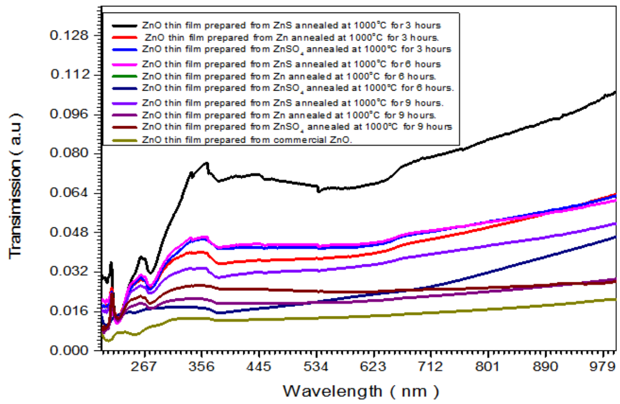

Fig.3. Optical transmittance of solar cell fabricated from ZnO Thin-films samples obtained from different sources.

thin film. Moreover, the purity and grain size of the starting powders, the sintering temperature, the gas reduction atmospheres, temperatures, and annealing times have major effects on the conductivity [44].

D. Excitons coefficient of solar cell fabricated from ZnO thin-films samples obtained from different sources.

The excitons coefficient (K) of fabricated nano-dye sensitized solar cells obtained from ZnO thin-films of different sources determined in the wavelength of 200-979 nm which indicates that these solar cells were transparent at the visible region and so they were favorable materials to be used in solar energy devices production *"Fig. 4,"*. Solar cell thin-film fabricated from commercial ZnO exhibited high excitons coefficient at 210 nm where K value equal $9.3x10^{-6}$, solar cell prepared from ZnS annealed at 1000°C for3 hours showed low excitons coefficient (K = $1.87X10^{-6}$) at 208 nm. The energy values of sample 3, 4, 6 and 7 decreased from 0.00000187 to 0.0000093. The fluctuations and wave-like patterns appeared on the excitons pattern in this research may be referred to the

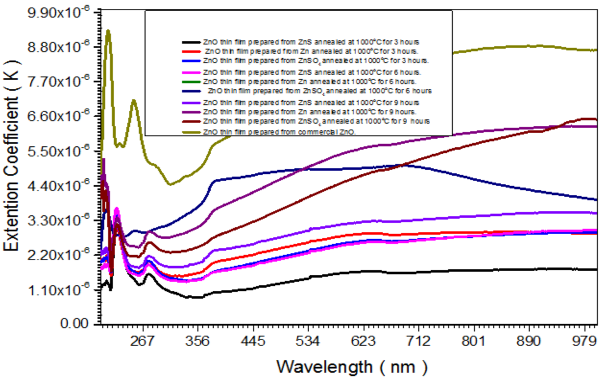

Fig. 4. Excitons Coefficient of solar cell fabricated from ZnO thin-films samples obtained from different sources.

interference of light reflected between the air-film and film-glass interfaces. These findings indicated that the fabricated thin-films had low surface roughness and good uniformity [31].

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