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The Effect of Doping Zinc Oxide Thin Films With (0.5 wt. %) Carbon Nanotubes by Vacuum Evaporation

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ABSTRACT

The study included the production of nano-thin films made of zinc oxide doped with carbon nanotubes (ZnO:CNTs) at a doping ratio of 0.5 wt%. The materials are applied onto glass substrates using the vacuum evaporation process. The structural characteristics of the thin films of undiluted and doped ZnO were assessed using X-ray diffraction (XRD). Additionally, the surface properties of the films were examined using scanning electron microscopy (SEM) and atomic force microscopy (AFM). The optical characteristics of the thin films were analyzed and described using UV-Vis spectroscopy. The ZnO thin films exhibited crystalline formations. The thin films exhibited significant orientations along the (100), (002), and (101) crystallographic planes, indicating their hexagonal phase structures. The crystal size of ZnO thin films exhibited a range of 30.87 nm to 19.96 nm after the process of doping. The study findings demonstrate that the addition of carbon nanotubes leads to an increase in the absorption ratio. Zinc-doped carbon nanotube thin films has features that make them suitable for many applications, such as gas detectors and UV detectors.

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تأثير تشويب أغشية أوكسيد الزنك الرقيقة بأنابيب الكربون النانوية بنسبة (0.5 wt. %) بطريقة التبخير الفراغي

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الملخص

في هذا البحث تم إنتاج أغشية نانوية رقيقة مكونة من أكسيد الزنك المشوب بأنابيب الكربون النانوية (ZnO:CNTs) بنسبة تشويب (0.5٪ وزنيًا). تم ترسيب المواد باستخدام طريقة التبخير تحت الفراغ على ركائز زجاجية. تم تقييم الخصائص البنيوية للأغشية الرقيقة من أكسيد الزنك النقي والمشوب بواسطة حيود الأشعة السينية (XRD). تم استخدام المجهر الإلكتروني الماسح (SEM) ومجهر القوة الذرية (AFM) لقراءة خصائص سطح الأغشية. تم استخدام مطيافية الأشعة فوق البنفسجية والمرئية لفحص وتوصيف الخصائص البصرية للأغشية الرقيقة المنتجة. أظهرت الأغشية الرقيقة من أكسيد الزنك هياكل بلورية كانت الاتجاهات السائدة لهذه الأغشية الرقيقة هي (100) (002) و (101) والتي كانت لها هياكل طورية سداسية. تراوح حجم البلورة للأغشية الرقيقة من أكسيد الزنك من (30.87 نانومتر) إلى (19.96 نانومتر) بعد التشويب. تشير نتائج التحليل إلى أنه عند إضافة نسبة من الأنابيب النانوية الكربونية، تزداد نسبة الامتصاص. تتناسب الأغشية الرقيقة من الأنابيب النانوية الكربونية المخدرة بالزنك مع خصائص مختلفة، وهي جيدة لمجموعة متنوعة من التطبيقات، بما في ذلك أجهزة الكشف عن الغاز وأجهزة الكشف عن الأشعة فوق البنفسجية.

1- Introduction

Zinc oxide (ZnO) offers several benefits when used in semiconductor thin films, including applications in solar cells[1], light-emitting diodes[2], photodetectors[3], gas sensing, and corrosion protection[4]. They have garnered significant interest because to their appealing applications in several fields such as optics and electronics[5]. Researchers have prioritized studying ZnO nanostructures because of its distinctive optical features that improve the absorption of photon energy in thin layers. This is owing to the abundance of ZnO in nature, its inexpensive cost, and its ability to tune energy bands. Zinc oxide (ZnO) has a band gap of 3.37 electron volts (eV), exhibits conductivity, and demonstrates transparency throughout the visible wavelength spectrum. These properties render it well-suited for the production of transparent electronics, photoelectronic devices, and sensors[6]. Combining ZnO with another substance is crucial for obtaining the magnetic[7], electrical[8], and optical[9],[10] characteristics of the device. The addition of carbon nanotubes (CNTs) to ZnO thin films is a straightforward method to enhance the absorption of incoming photons[11]. These thin films may be used as ultraviolet (UV) detectors and light-emitting diodes (LEDs). A multitude of researchers have examined the impact of integrating carbon nanotubes (CNTs) and zinc oxide (ZnO) with semiconductors and other metals using techniques such as thermal spray[12], spin coating [13], sol-gel [14], and other methodologies[4]. A thin layer was created on a glass substrate utilizing a vacuum evaporation deposition procedure in this study. The fabrication process involves creating thin layers of ZnO that have been doped with 0.5 weight percent of carbon nanotubes (CNTs). This is achieved by combining ZnO with CNTs to form ZnO:CNTs. This research also examined the impact of depositing ZnO thin films with CNTs on their structure, morphology, and optical characteristics.

2- Experimental Procedures

This study used micro-sized zinc (Zn) powders obtained from Sigma-Aldrich Chemie GmbH and high-purity multi-walled carbon nanotubes (MWCNTs) also obtained from Sigma-Aldrich Chemie GmbH to create a ZnO thin film that was doped with CNTs. Carbon nanotubes were incorporated into the mixture at a concentration of 0.5% by weight and agitated for 30 minutes using an agate mill. Subsequently, the blend is introduced into a cylindrical steel mold of 1 cm in diameter and subjected to a pressure of 8 tons/cm2 for a duration of 5 minutes. Zinc and zinc doped with carbon nanotubes were applied onto glass substrates and placed on a sample holder inside the vacuum evaporator chamber. The materials underwent evaporation in a tungsten boat at a pressure of about 5×10-5 bar. Pure ZnO and ZnO grafted with (0.5 wt.%) of CNT thin films were obtained after depositing them on glass and then placed in a thermal oxidation furnace at a temperature of 400℃. The estimated thickness of these thin films was 500 nm. The prepared samples were characterized using XRD, SEM, AFM, and UV-Vis spectrophotometers.

3- Results and Discussion

Thin films of pure ZnO and ZnO doped with CNTs were examined using XRD analysis, and the X-rays had a wavelength of (0.15406 nm). The diffraction angle range (2θ) from (20° to 80°) was taken into account for the XRD measurements, and the characteristic peaks of pure ZnO with average crystallite size (30.87 nm) appeared. Regarding the film doped with carbon nanotubes, characteristic peaks appeared in the (100), (002), and (101) crystal directions also with an average crystal size of (19.96 nm). These results agreed with the researchers [3],[4]. As shown in Fig.(1), these results match the standard card number values (COD ID: 00-230-0450)[15][16].

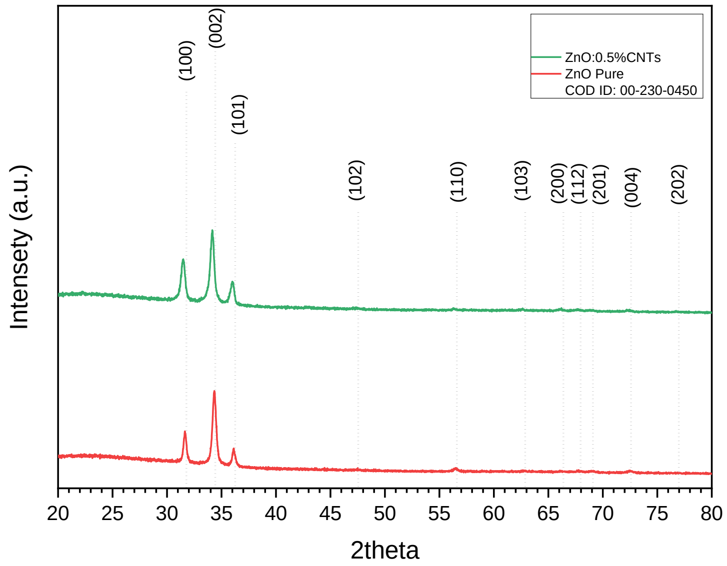

Fig 1. XRD patterns of pure ZnO and ZnO:0.5%CNTs thin films

No diffraction peaks of CNTs were observed at $(2\theta \approx 26^\circ, 45^\circ, 54^\circ)$ due to the low CNTs concentration in the prepared thin films, this agreed with [14][17][18]. Typical XRD patterns of thin films composed of ZnO and ZnO:0.5%CNTs were in the wurtzite phase. The decrease in full width at half maximum (FWHM) of the diffraction peaks indicates a decrease in the crystalline size of ZnO from (30.87 nm) to (19.96 nm). The crystalline size of the prepared thin films was calculated using the Debye-Scherer equation. Figures (2.a and 2.b) show SEM images of thin films composed of ZnO and ZnO:0.5%CNTs, respectively, as these images show the formation of the thin films.

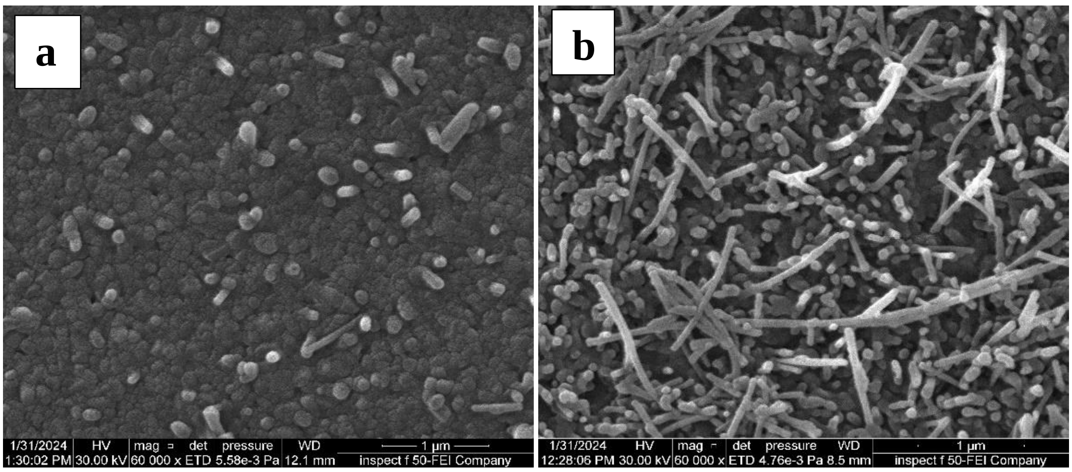

Fig 2. SEM image of (a) pure ZnO thin films, (b) ZnO:0.5%CNTs thin films

It is possible to compare the grain density of ZnO:0.5%CNTs thin films with the grain density found in pure ZnO thin films. The images show how ZnO has completely coated the CNT bodies. The grain size of ZnO:0.5%CNTs thin films is smaller because the CNTs prevent the ZnO nanoparticles from aggregating with each other due to the effect of van der Waals forces

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between the nanoparticles. Figure (3) shows an AFM scan of ZnO thin films doped with CNTs, and the thin films in the 3D images show distinct vertical hierarchical particlesIt is observed that pure ZnO thin films have a surface roughness of root mean square (RMS = 15.88 nm), which may be due to minimal material aggregation.. The surface roughness increases by (RMS = 22.88 nm) after doping. Three-dimensional scanning using AFM and SEM shows that the surface layer of the ZnO thin films distributes the CNTs almost uniformly over the surface and that the ZnO nanoparticles completely envelop the CNTs.

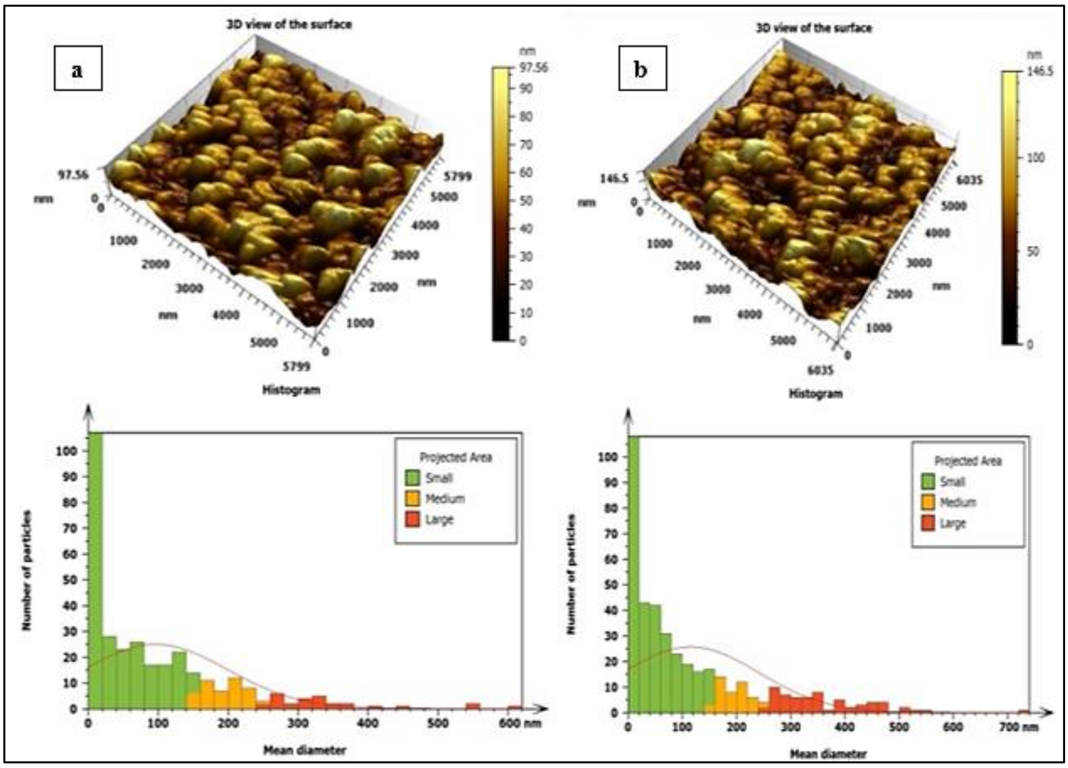

Fig 3. AFM results of: (a) pure ZnO thin films, (b) ZnO:0.5%CNTs thin films

Figure (4) depicts the UV-VIS absorption spectra of ZnO and ZnO:0.5%CNT thin film. The figure shows that the optical energy gap of the pure ZnO film was (3.26 eV) at the wavelength (380.2 nm)[9], whereas the optical energy gap of the ZnO film doped with CNTs was (3.25 eV) at the wavelength (380.9 nm). This is owing to the greater absorption of light photons and their capacity to drive electrons from the valence band to the conduction band, as well as the fact that the transitions in these thin films are direct, so the energy gap is thus direct. The figure shows an increase in the absorption coefficient for thin films grafted with CNTs vs pure ZnO thin films, These results are consistent with researcher[18].

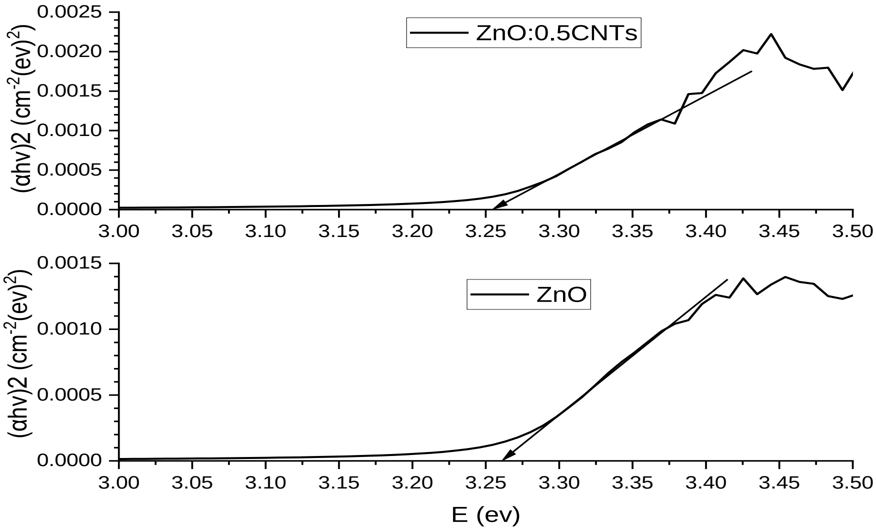

Fig 4. The optical energy gap values of pure ZnO and ZnO doped with 0.5% CNTs thin films

4- Conclusions

This work adds future usefulness to carbon nanotube-doped ZnO thin films for photochemistry and gas detector applications. It has been shown that increasing the doping ratios of CNTs in ZnO thin films improves light absorption, allowing for higher sensitivity to various wavelengths of light. Furthermore, doping induces uniformity in the crystalline geometry of the thin film material, which may be used to improve certain photodetector features. These findings suggest that thin-film doping provides various and customizable features that can boost the efficiency and sensitivity of different photodetectors, such as diodes, transistors, and solar cells.

5- Conflict of interests:

The authors declared no conflicting interests.

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7- Author contribution:

Authors contributed equally in the study

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