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Preparation and Study of the Optical and Morphological Properties of Films SnS/ZnO Prepared by the Thermal Chemical Spray Method

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تحضير ودراسة الخواص البصرية والمورفولجية لاغشية SnS/ZnO المحضرة بطريقة الرش الكيميائي الحراري

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ABSTRACT

Background: The use of film formation with natural solvents and inorganic materials is a step towards sustainable practices in pieces of material science work.

Materials and Methods: In this research, the chlorophyll obtained from celery was used as a green solvent to dissolve tin sulfide (SnS) and zinc oxide (ZnO) compounds. The thin films produced using chemical thermal spraying techniques were of approximately 150 nanometers in thickness. The technique allowed for controlled decomposition of the composite materials directly on the substrates, which resulted in films that were appropriate for optical and morphological investigations. The incorporation of ZnO to the SnS matrix was done systematically to determine its effect on the films' characteristics.

Results: The incorporation of zinc oxide into tin (IV) oxide sulfide films caused a reduction in transmission and reflectivity of the films and consequently affected their light-matter interactions. The ZnO-containing samples showed a reduction in the optical energy gap, signifying that the bandgap of the materials was effectively lowered. These results indicate that their light absorption in the visible range is improved, which is advantageous for solar cells or photodetectors. Based on these observations, it is fair to claim that the films made of ZnO and SnS are compatible with each other because all films demonstrated less strenuous changes in optical behavior.

Conclusion: ZnO incorporation into SnS films processed with chlorophyll solvent modulates both optical and structural characteristics. Further optimization of ZnO concentration and deposition parameters could refine performance for targeted applications.

Key words: Green liquid chlorophyll; Zinc oxide; Tin sulfide; energy gap; Thin film.

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INTRODUCTION

Zinc oxide (ZnO) is a versatile II-VI semiconductor that has emerged as a cornerstone material in nanotechnology and optoelectronics due to its exceptional combination of optical, electrical, and structural properties. At room temperature (300 K), ZnO exhibits a direct wide bandgap of ~3.3 eV, making it highly effective for applications in the ultraviolet (UV) spectral range. Its large exciton binding energy of 60 meV—significantly higher than that of gallium nitride (GaN, ~25 meV) or silicon (Si, ~15 meV)—ensures stable excitonic emissions at elevated temperatures, a critical feature for light-emitting devices (LEDs) and laser diodes [1]. Structurally, ZnO crystallizes in a hexagonal wurtzite lattice, enabling diverse growth morphologies such as nanoparticles, nanowires, nanorods, and thin films. These nanostructures are easily tunable via synthesis techniques, allowing precise control over their optoelectronic performance.

The elements present within ZnO, like oxygen vacancies and zinc interstitials, provide its native and unique n-type conductivity. This, alongside its high utility in eletronic and sensor technology, only makes it better. Furthermore, its new mobility, which is about two hundred square centimeters per volt per second, in combination with 80 percent light transmittance in the visible spectrum makes it fitting for transparent conductive oxides, or TCOs, which are required in solar panels, touchscreens, and other electrical gadgets. Apart from that, it distinguishes itself from ordinary electricity conductors by functioning as an electron transport layer in organic solar cells, perovskite, and other photovoltaic devices, which helps extract electric charges and boost the overall efficiency of the device [2]. Moreover, its piezoelectric characteristic makes it useful for devices that capture acoustic waves and mechano energy.

Owing to the newly structured volume to surface ratio, ZnO transforms into a high capacity gas sensor, making it efficient for detecting organic and nonorganinc pollutants concise. Over that, ZnO can be coupled with pentacene or other catalysts for the ionization of its surface in order to further increase sensitivity which would make the gas sensor even more sophisticated [3].

In optoelectronics, ZnO-based UV photodetectors and LEDs leverage its wide bandgap to achieve high-speed response and energy efficiency. Recent advances in doping ZnO with elements like aluminum (Al) or gallium (Ga) have further optimized its electrical conductivity for flexible electronics and wearable technologies.

MATERIALS AND METHODS

- **Preparation of Thin Films**

The green plant pigment chlorophyll was prepared by dissolving celery plant material at a weight ratio of 22g in 100 ml of ethanol for a period of 72 minutes, after which filter paper was used to obtain only liquid chlorophyll without impurities.

The nano-tin sulfide (SnS) material was dissolved in an amount of 8 g in 80 ml of the prepared liquid chlorophyll and mixed using a magnetic needle at a temperature of 20C for half an hour. Different weight ratios (0.01,0.05 and 0.09)g of zinc oxide(ZnO) were added to 20 ml of the prepared tin sulfide liquid and mixed using a magnetic needle at a temperature of 20 C for half an hour.

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The thermal chemical spray method was used to prepare the thin films SnS and SnS:ZnO and they were prepared with a thickness of 150 nanometers.

RESULTS AND DISCUSSION

- **Optical Properties**
- **Transmittance**

The transmittance was measured using thea device (uv-visible1800), which operates within the wavelength range of 200-1100 nanometers, and based on Equation(1) [4,5]:

$$T = I_T/I_o \quad (1)$$

The transmittance spectrum was calculated for all the prepared thin films as shown in Figure(1). In this paper notice from the figure that the prepared films have a low transmittance at the wavelengths of 300 nanometers, then we notice an increase. In the transmittance spectrum with increasing wavelengths [6,7].

Transmittance spectra showed a decline after zinc oxide was added to the tin sulfide mixture. The reason for this is the significant attenuation of the incident rays on the prepared thin films, which works to increase the dispersion of the incident radiation and thus a decrease in the transmittance values [8,9].

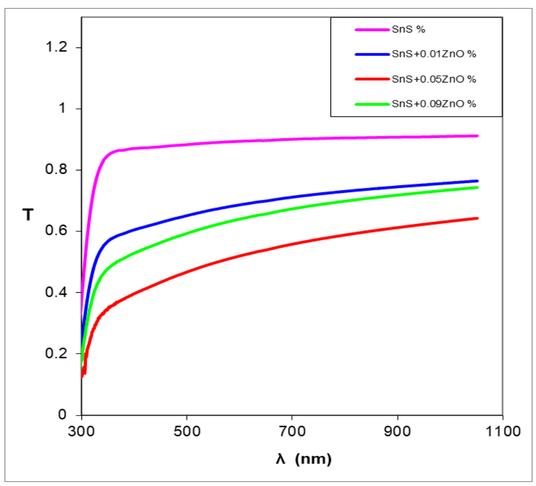

Figure (1) The transmittance spectrum for all prepared membranes.

- **Reflectivity**

The reflectivity of all prepared thin films was calculated based on the law of conservation of energy and using Equation (2) [1]:

$$R+T+A=1 \quad (2)$$

All of the produced films' reflectivity spectra as a function of wavelength are displayed in Figure (2). The results demonstrated that the reflectance spectra of the manufactured films were reduced after adding zinc oxide to the tin sulfide mixture. This is due to the fact that the zinc oxide material altered the surface properties and crystalline structure of the produced thin films. [10,11].

The reflectivity spectrum behaves visually the same when zinc oxide is added to the tin sulfide compound. It was found that the prepared films have low reflectivity values at wavelengths

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close to 300 nm. Then we notice an increase in the reflectivity spectrum values for all the prepared films with increasing wavelength [11,12].

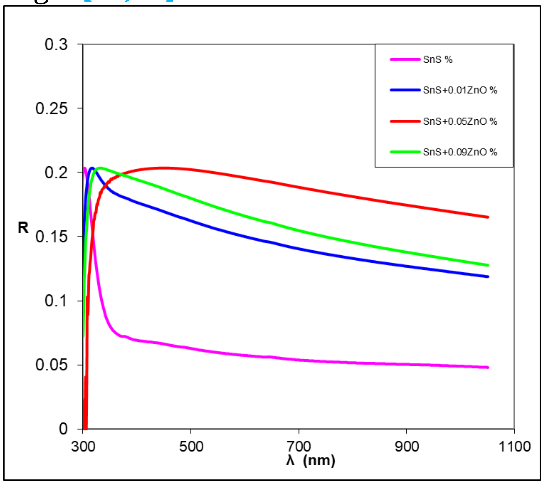

Figure (2): The reflectivity spectrum for all prepared membranes.

- **Optical Energy Gap**

The indirect optical energy gap was calculated for all prepared films by drawing the linear relationship between (α hυ) ½ and the photon energy α hυ, and the straight part of the curve is extended to intersect the photon energy axis at point (α hυ) ½ =0, which represents the value of the indirect optical energy gap and the fig. (3) shows the indirect optical energy gap of the prepared films.

Table (1) shows the indirect optical energy gap values for all prepared thin films. The result showed that adding zinc oxide to the tin sulfide compound led to a decrease in the values of the optical energy gap. The reason for this is that adding zinc oxide led to the formation of donor levels inside the energy gap, which reduces the width of the energy gap, and this in turn leads to a decrease in the values of the optical energy gap[13,14].

Table (1) The indirect optical energy gap values for the prepared films

Thins films	E_g
SnS	3.41
SnS+0.01ZnO	3.2
SnS+0.05ZnO	3.05
SnS+0.09ZnO	2.83

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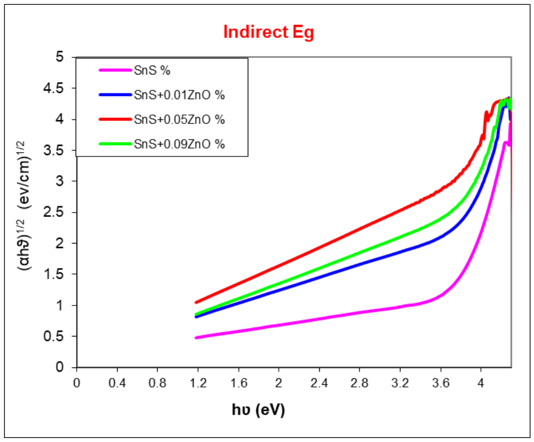

Figure (3) The indirect optical energy gap of the prepared films.

- **Atomic Force Microscope Measurement (AFM)**

Figure (4a, b, c and d) images of the AFM analysis of the prepared thin films, which allowed for the study of their surface morphology. The outcome proved that there are no crystalline flaws or cracks in the films that were created. An increase in surface roughness values and an increase in grain size were seen in the produced thin films when zinc oxide was added to the tin sulfide combination. The reason for this is that the addition of zinc oxide caused a change in the crystalline structure of the tin sulfide compound [14,15,16,17].

Table (2) The Roughness and Grain size of films.

Thin films	Roughness values	Grain size nm
SnS	79	79
SnS+0.01ZnO	88	84
SnS+0.05ZnO	117	106
SnS+0.09ZnO	132	113

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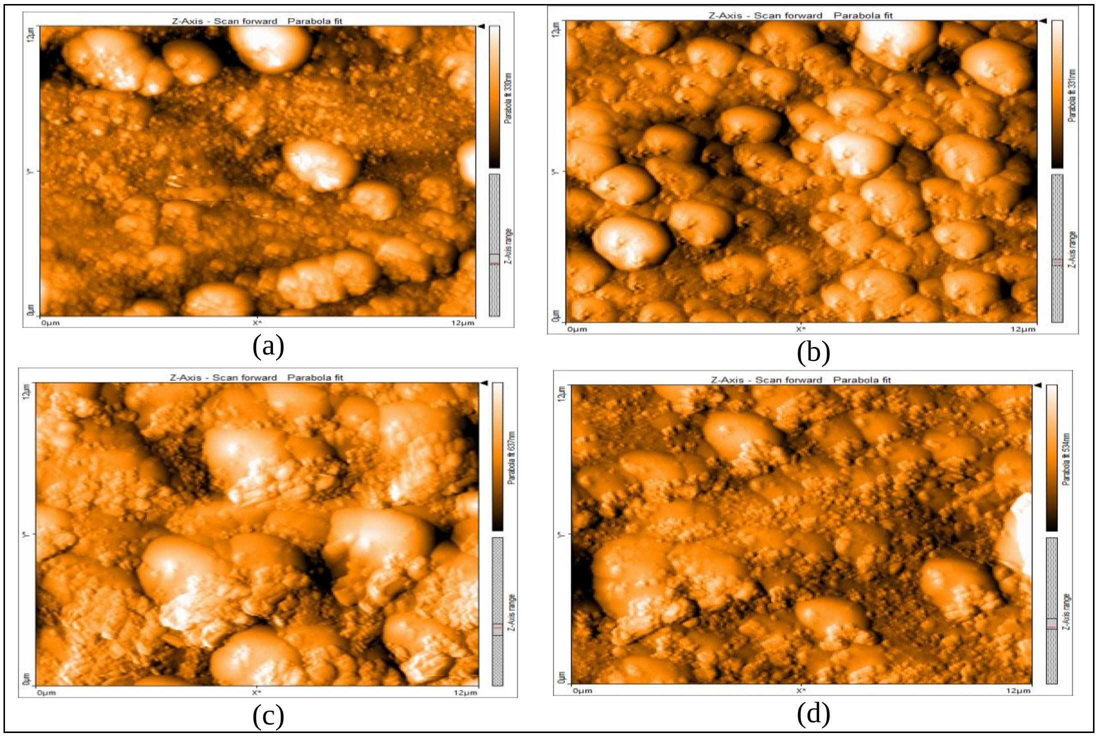

Figure (4) (a) Images of the AFM examination of the thin film f preparation SnS, (b) Shows images of the AFM examination of the thin film f preparation SnS+0.01ZnO, (c) Shows images of the AFM examination of the thin film f preparation SnS+0.05ZnO, (d) Shows images of the AFM examination of the thin film f preparation SnS+0.09ZnO .

Conclusion

Liquid chlorophyll extracted from celery was employed as a green solvent to dissolve tin sulfide (SnS) and zinc oxide (ZnO) compounds. By measuring the optical properties, paper conclude that the addition of zinc oxide led to an increase in the values of transmittance, reflectivity, and optical energy gap.

By measuring the morphological properties, the addition of zinc oxide led to a change in the nature of the topography of the surfaces of the prepared membranes, as it led to an increase in the grain size and roughness of the surfaces of the prepared membranes.

Conflict of interests.

There is no conflict interest

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الخلاصة

المقدمة:

إن استخدام تكوين الفيلم بالمذيبات الطبيعية والمواد غير العضوية هو خطوة نحو الممارسات المستدامة في أعمال علوم المواد.

المواد والطرق:

في هذا البحث، تم استخدام الكلوروفيل المستخرج من الكرفس كمذيب أخضر لإذابة مركبات كبريتيد القصدير (SnS) وأكسيد الزنك (ZnO).كانت الأغشية الرقيقة المنتجة باستخدام تقنيات الرش الحراري الكيميائي بسمك حوالي 150 نانومتر. سمحت التقنية بالتحلل المتحكم فيه للمواد المركبة مباشرة على الركائز، مما أدى إلى أفلام مناسبة للتحقيقات البصرية والشكلية. تم دمج ZnO في مصفوفة SnS بشكل منهجي لتحديد تأثيره على خصائص الأفلام.

النتائج:

تسبب دمج أكسيد الزنك في أغشية كبريتيد أكسيد القصدير (IV) في انخفاض في نفاذية وانعكاسية الأغشية وبالتالي أثر على تفاعلاتها بين الضوء والمادة. أظهرت العينات المحتوية على ZnO انخفاضًا في فجوة الطاقة الضوئية، مما يدل على أن فجوة النطاق للمواد قد انخفضت بشكل فعال. تشير هذه النتائج إلى أن امتصاصها للضوء في النطاق المرئي قد تحسن، وهو أمر مفيد للخلايا الشمسية أو أجهزة الكشف الضوئية. بناءً على هذه الملاحظات، من العدل أن نزعم أن الأغشية المصنوعة من ZnO و SnSمتوافقة مع بعضها البعض لأن جميع الأغشية أظهرت تغييرات أقل إجهاداً في السلوك البصري.

الاستنتاج:

يعمل دمج ZnO في أغشية SnS المعالجة بمذيب الكلوروفيل على تعديل كل من الخصائص البصرية والبنيوية. يمكن أن يؤدي المزيد من تحسين تركيز ZnO ومعلمات الترسيب إلى تحسين الأداء للتطبيقات المستهدفة.

الكلمات المفتاحية: سائل الكلوروفيل الاخضر، اوكسيد الزنك ، كبريتيد القصدير ، فجوة الطاقة، الاغشية الرقيقة.

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