

Influence of Natural Dye Extract on the Optical Properties of Zinc Antimony Sulphide ($ZnSb_2S_4$)

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Abstract

Considering the impact of fossil fuel in environmental pollution, which leads to so many health and economic crisis in Nigeria, it is paramount to investigate in areas that can help to relatively reduce this menace, using dye sensitized thin film, which is eco-friendly, biodegradable and economical. The objective of this work is to deposit and characterize zinc antimony sulphide ($ZnSb_2S_4$) ternary thin film, doped with spinach leaves (*Spinacia oleracea*), red cabbage (*Brassica oleracea*), and zobo (*Hibiscus sabdariffa*), using spray pyrolysis, and also using solvent method of dye extraction to extract dye from spinach leaves (*Spinacia oleracea*), red cabbage (*Brassica oleracea*), and zobo (*Hibiscus sabdariffa*), using methanol as the solvent for extraction. The result obtained from the UV analysis shows that $ZnSb_2S_4$ ternary thin film can be used in UV LEDs, lasers and photodetectors, pollutant degradation, since its band gap is within the range of 3.0-4.0 eV.

Keywords: $ZnSb_2S_4$, Dye, Thin film, Methanol, dye sensitized solar cell.

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I. Introduction

Environmental sanitation is about keeping our surroundings clean and healthy, It includes:

Safe disposal of human waste, managing solid waste, providing clean water and promoting hygiene, it also helps in reducing pollution [1, 2].

Fossil fuels significantly impact environmental sanitation through pollution and climate change [3, 4]

This environmental pollution which is as a result of the usage of fossil fuels, can contribute to ozone layer depletion through the release from aerosol sprays, refrigerators, and industrial processes. Methyl bromide used in agriculture, halons used in producing fire extinguishers. and air pollutants [5]. This ozone layer depletion can increased UV radiation reaching earth's surface, it can cause skin cancer, cataracts, it can also damage the ecosystems and crops [6].

Solar energy can boost environmental sanitation through water purification, waste Management [7], air purification, antimicrobial coatings [8]. lighting and ventilation [9], pumping and distribution [10]. The solar energy can also help to reduced reliance on fossil fuels, lower emissions, pollution and also increased access to sanitation, especially in off-grid areas [11]. Solar cells are devices that convert sunlight into electricity. They are made from semiconducting materials like silicon, when sunlight hits them, it excites electrons, generating an electric current [12, 13].

Thin films is a very thin layers of material that are deposited onto a substrate using various deposition methods. These films are typically nanometers to micrometers thick and can be processed in a solution form, allowing for flexible and scalable fabrication methods for applications like solar cells [14]. Thin-film solar cells, including those using cadmium telluride (CdTe) and copper indium gallium diselenide (CIGS), have lower environmental impacts compared to traditional silicon-based cells. Using thin films to produce solar devices can help mitigate ozone layer depletion [15]. The production of thin films requires less energy, resulting in lower emissions of ozone-depleting substances. It can also replace technologies using ozone-depleting substances which in turn supports ozone layer recovery and reduces climate change impacts [16, 17].

Thin films have emerged as promising materials which can be used in different areas such as energy storage, optoelectronics, and sensing technologies, their performance is always restricted by some inherent material limitations such as low electrical conductivity, poor stability, and insufficient optical absorption. To address these challenges, doping with plant leaf extracts has been identified as a viable strategy for enhancing the performance of ternary thin films. This work is aimed at depositing and characterizing doped zinc antimony sulphide ($ZnSb_2S_4$) ternary thin films using the spray pyrolysis.

II. Experimental Details

Since substrate cleaning lowers defect creation, grain boundary formation, dislocation density and improve the overall quality of thin film, substrate cleaning is vital to thin film deposition. Soda-lime glass substrates measuring 75 × 25 mm with a thickness of 1.0 mm were purchased from a nearby vendor. The substrates were washed with water and rinsed with distilled water, soaked in 200 mL of hydrochloric acid (HCl) for 60 minutes, removed and rinsed thoroughly with water, and washed thoroughly with detergent using a foam sponge. After rinsing with distilled water to remove residual impurities, the substrates were soaked in acetone for 10 minutes and allowed to dry in air. The chemicals used for the spray-deposition of ZnSb₂S₄ ternary thin films were analytical grade. The source of the ZnSb₂S₄ was Zinc Oxide and antimony sulphide while sodium thiosulphate (Na₂S₂O₃) and Acetone (CH₃)₂CO where used as complexing agents.

Solvent extraction method was used for dye extraction from Zobo, Spinach, and Red cabbage leaves; for three hours 48g of zobo, red cabbage and spinach were soaked in 130mL of methanol, after three hours the leaves were removed, filtered with filter paper into a dry container, sealed with a cap and kept at room temperature. Zobo, Spinach and Red cabbage are the dopant used in doping ZnSb₂S₄ ternary thin films.

III. Results and Discussion

In a 50mL glass beaker, 3.0M of ZnO, 0.6M of Sb₂S₄, 0.07g of sodium thiosulfate and 0.7mL of ammonia was added to 20mL of water in the 50mL glass beaker. The mixture was stirred for 5 minutes using a magnetic stirrer to obtain a homogeneous solution. After stirring, 10 mL of the solution was measured using a pump syringe and transferred into a spray pyrolysis sample bottle attached to the airbrush nozzle valve rod. The solution was sprayed for 60 seconds, onto a heated glass substrate maintained at 70 °C, using an electric hot plate. This sample served as the control.

For the doped samples, the same precursor solution was prepared, after which 10 mL of the precursor was measured out and doped with 4mL of Zobo, spinach, or red cabbage extract separately. Each mixture was stirred vigorously for 5 minutes to obtain a homogeneous solution. The doped precursors were then sprayed for 60 seconds onto heated glass substrates maintained at 70 °C.

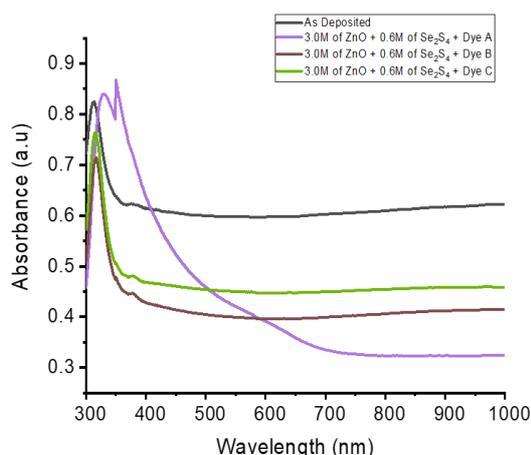


Fig 1: A graph of absorbance against wavelength

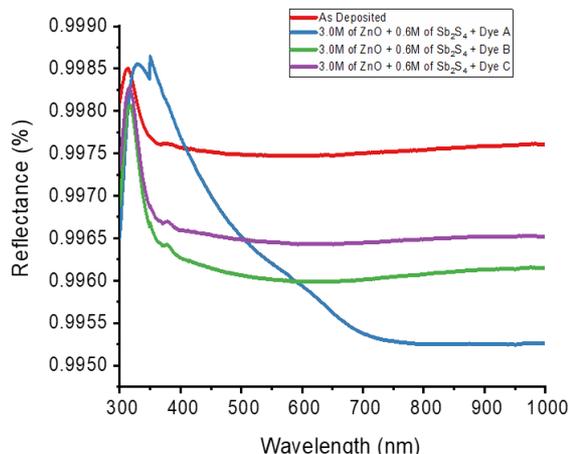


Fig 2: A graph of reflectance against wavelength

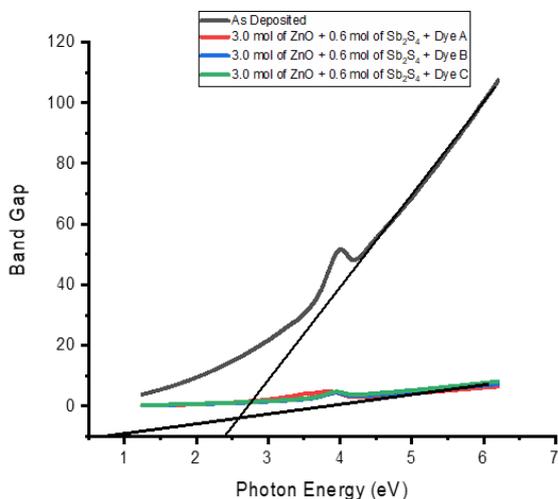


Fig 3: A graph of band gap against Photon energy

D27 represents 3.0M of ZnO and 0.6M Sb₂S₄
 D28 represents 3.0M of ZnO and 0.6M Sb₂S₄ + Zobo extracts
 D29 represents 3.0M of ZnO and 0.6M Sb₂S₄ + Red Cabbage extract
 D30 represents 3.0M of ZnO and 0.6M Sb₂S₄ + Spinach extract.

Analysis of the absorbance of ZnSb₂S₄

The absorbance of D27 increased from 0.5 to 0.82 a.u at 320nm and then had a sharp decrease to 0.62 at 400nm and then maintain a steady absorbance from 400-1000nm, whereas D28 increased from 0.5 to 0.86au at 380nm and it started decreasing till 0.34 at 700nm and from 700-1000nm it maintained a steady absorbance and wavelength. As for D29, it peaked at 0.72au on wavelength of 320nm and had sharp decrease till 0.5au at 350nm and it continue to decrease gradually, but at 0.4au (550nm) it maintained steady wavelength and absorbance till 1000nm. Finally at D30, it peaked at 0.75au (320nm) , it experienced a sharp decrease from 0.7au to 0.5au and a gradual decrease from 370nm to 420nm and then had a steady wavelength and absorbance from 470-1000nm.

The sharp decrease in absorbance shows that the material suddenly becomes more transparent or transmissive, it indicates cutoff or transition, it could also mark boundary in optical properties. It can be used in controlling light sensors or used in detecting changes based on absorbance shifts. The steady absorbance of D27 shows that the absorbance across broad range (Visible to near infrared) means that the material absorbs light consistently across these wavelength, this indicates that the material is useful for application that needs consistent light absorption and it can be applied in solar energy harvesting devices, such as solar cell and also in optical shielding [18].

Analysis of the reflectance of D27, D28, D29, D30

D27 increased from 0.9985au to 0.9985au which is between 300nm to 320nm and started decreasing gradually from 0.9985au at 320nm, it maintained a steady wavelength and reflectance from 400nm to 1000. while D28 increased from 0.9965au at 300nm and peaked at 0.9985au at 370nm, then it started decreasing gradually, but at 0.9950au (700nm) it maintained steady transmittance and wavelength till 1000nm. D29 increased from 0.9965au at 320nm, it experienced a sharp decrease in wavelength, however at 0.9960au (500nm) it had a steady transmittance and wavelength. Finally, for D30 the transmittance increased from 0.9975au at 320nm and it had a sharp decrease till 0.9965au (510nm) after which it had a steady transmittance from 510nm till 1000nm. Sharp increase in transmittance, means that the material suddenly becomes more transparent or allows more light to pass through at a certain wavelength. It can be used as optical filter, it can also be used for controlling light passage in a device [19-23].

Band gap

The result of band gap with the range of 3.0-4.0eV was obtained from the deposition of ZnSb₂S₄ as deposited, doped with Dye A, B and C. This result can be used in UV LEDs, lasers, photodetectors, water splitting, pollutant degradation, gas sensors, biosensors, solar cells, energy storage and also flat-panel displays. This result tallied with the results obtained by these researchers [24-28].

IV. Conclusion

Zinc antimony sulphide (ZnSb S) thin films were successfully deposited using the spray pyrolysis deposition technique. Natural dyes were extracted from red cabbage, Zobo, and spinach leaves using methanol as the extraction solvent. The thin films were doped with the extracted dyes and characterized to determine their optical properties using UV analysis . The results indicate that the thin films have potential applications in UV LEDs, lasers, photodetectors, water splitting, pollutant degradation, gas sensors, biosensors, solar cells, energy storage and also flat-panel displays. It can be used as optical filter, it can also be used for controlling light passage in a device.

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