Green Synthesis, characterization of Zinc oxide nanoparticles using *Chromolaena odorata* extract and evaluation of its properties for photoanode of solar cells

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Abstract

Synthesis of Zinc oxide nanoparticles (ZnONPs) using plant extract was carried out in this work because of its advantages over other method of synthesis namely; simplicity, environmental friendliness and elimination of toxic chemicals. Fresh Siam leaf extract was characterized over a period of 10 days to study the effect of time on the optical photon energy absorption properties. ZnONPs was synthesized and deposited on substrate by spin-coating method and characterized by UV-vis spectroscopy, Fourier transform infra-red spectroscopy, Scanning Electron microscopy, and Energy Dispersive X-ray. ZnONPs thin film device was then fabricated to study the electrical properties. From UV-vis spectroscopic result, as the time (day) increased, there was an increase in the value of the transmittance and corresponding reduction in photon energy absorption. FTIR result gives the functional groups and absorption number at 3448.04 cm\(^{-1}\) O-H single bond, 2524.85 cm\(^{-1}\) C-H bond, 1437.15 cm\(^{-1}\), 880.59 cm\(^{-1}\), 729.06 cm\(^{-1}\), 433.44 cm\(^{-1}\) Zn-OH and Zn-O variety of single bond. The surface morphology shows large grain size. Energy band gap of ZnONPs was approximately 3.7 eV. The fabricated ZnONPs thin film device under illumination has efficiency of 2.010/o. From the morphology, optical, and electrical properties of the ZnONPs thin film and device, it could be a suitable material for crystalline solar cells as photoanode.

**Keywords:** Zinc oxide nanoparticles, *Chromolaena odorata*, photoanode, solar cell, optical properties
1. Introduction

Challenges in provision of eco-friendly and environment-friendly sources of energy have led to intensive research in nanomaterials. Nanotechnology is an arm of technology that studies different materials at a nanometric scale and its application is found in materials science, engineering, and electronics. Nanoparticles have different magnetic and optoelectronics properties that are regulated by their size and shape distribution. Synthesis of nanoparticles using plant extract is gaining importance because this method of synthesis eliminated the need of toxic chemicals method of synthesis and also, because of its simplicity and environmental friendliness. The use of zinc oxide (ZnO) is because of its unique properties and its exciton binding energy [1-5]. Siam weed leaf (Chromolaena odorata) extract was used in this study because of its abundant availability. The use of different plant extracts to synthesize ZnO nanoparticles has been reported [6-8]. Zhang et al. [9] reported the use of ZnONPs in solar cells fabrication. Little or nothing has been reported on green synthesis of zinc oxide nanoparticles using Siam weed leaf extract as a material for solar cells application. The objectives of this research are to synthesis and characterize zinc oxide nanoparticles using Siam weed leaf extract as well studies on the application of zinc nanoparticles thin film device in solar cells fabrication.

2. Materials and Methods

2.1 Materials

Zinc acetate was purchased from Sigma-Aldrich, while other materials used for the research were sourced from local vendors of laboratory wares and reagents.

2.2 Methods

2.2.1 Preparation of the plant extract

Glass slides of dimension 18 mm by 18 mm were used as substrates. The glass substrates were washed with detergent solution for 10 to 15 min in ultrasonic sonicator and rinsed in distilled water for 15 min at 27 °C. The substrate was cleaned with isopropanol alcohol in ultrasonic bath for 15 min at 27 °C and dried in a stream of nitrogen gas. Siam plant was plucked from the surroundings, and the leaves were detached from the stem (Figure 1a). These leaves were thoroughly washed with clean water and then rinsed with distilled water. The fresh leaves were cut into pieces and pounding using the laboratory mortar and pestle. After the pounding process, the liquid content was extracted with the use of Whatman filter paper placed on a
clean conical flask over a period of 8 h. Brownish aqueous solution of the extract precipitated at the bottom of the conical flask (Figure 1b). The extracted aqueous leaf content was sealed and stored for further studies.

![Figure 1. (a) Siam weed leaf after plucking (b) Siam weed leaf extract](image)

### 2.2.2 Green Synthesis of ZnONPs and deposition on substrate

Synthesis of ZnONPs was done by mixing 25 ml of Zinc acetate dihydrate solution with 5 ml of Siam weed extract solution and stirred with magnetic stirrer for 12 h for homogenous mixture. After the reaction, the solution was kept overnight for the nanoparticles to precipitate. Precipitate that settled at the bottom of the sealed beaker was obtained by removal of excess unwanted floating solution. The precipitate was washed with deionized water. The obtained extracted precipitate was heated at the temperature of 400 °C for 30 min to evaporate the solvent under high purity argon gas in a carbolite tubular furnace (model Srw 21-501042 Type-CT17). The pellet-like substance which is white brown was ground to powder particles and stored for further deposition and characterization purposes.

To deposit ZnONPs onto substrate, 0.5 g of synthesized ZnONPs was mixed with 5 ml of ethanol and stirred with the use of magnetic stirrer for 3 h for homogenous mixture, after which it was deposited on substrate with the use of spin-coater at spin coat speed of 3000 rpm for 30 secs. Spin-coating techniques enhance uniform deposition of solution on substrate at set speed. Characterization was carried out on Siam weed leaf extract and ZnONPs nanoparticles after deposition. Characterization tools employed were Scanning Electron Microscopy (SEM) to study the morphology, Electron Dispersive X-ray (EDX) to determine the elemental composition, Fourier Transform Infra-red (FTIR) spectroscopy to reveal the chemical bond present in the sample.
2.2.3 ZnONPs thin film device fabrication and I-V Characterization

To fabricate ZnONPs thin films device, ZnONPs solution was deposited by spin-coating method on Indium tin oxide (ITO) coated glass substrate at 3000 rpm for 30 secs. Silver paste was deposited on ZnONPs as the electrode and ITO coated glass substrate as the counter electrode. ZnO films were heated at 100 °C in an oven for 30 min to evaporate solvent. Then current-voltage characterization of thin films device was carried out under illumination of solar Simulator with Keithley 2400 SMU. Short-circuit current ($I_{SC}$) and open-circuit voltage ($V_{OC}$) were noted. Fill factor (FF) and efficiency ($\eta$) of the thin film device were computed using equations (1) and (2) respectively. The input photon power ($P_{in}$) was obtained by multiplying the measured light intensity with the active cell area.

$$FF = \frac{P_{max}}{I_{SC} \cdot V_{OC}} = \frac{1}{\frac{I_{SC} \cdot V_{OC}}{I_{SC} \cdot V_{OC}}}$$  

(1)

$$\eta = \frac{I_{SC} \cdot V_{OC} \cdot FF}{P_{in}}$$  

(2)

3. Results and Discussion

3.1 Optical properties of Siam weed extract and biosynthesized ZnONPs

Figure 2 shows the effect of time on the optical properties of Siam weed extract. At day 1, peak optical transmittance values of about 55% from 400-500 nm in visible spectrum of wavelength band and 55% from 350-400 nm in the UV spectrum band were obtained. The extract was then characterized after 5 days and 10 days respectively to observe the effect of time on the optical properties of the plant extract. It was observed that the value of transmittance was about 85% both in UV and Visible spectrum of wavelength band. It can be deduced that as the time (day) increases, there is an increase in the value of the transmittance. It also shows that as transmittance increases, there is a decrease in photon energy absorption by the material. Figure 3 shows the graph of absorption of photon energy versus wavelength of Siam weed extract at different days of characterization. The result shows that optical properties characterization carried out on day 1 has the highest optical absorption of photon energy. Figure 4 shows graph of absorbance versus wavelength of ZnONPs. Efficient conversion of solar energy requires materials to absorb strongly in the visible region of the spectrum. Figure 5 shows Tauc Plot of $(ahv)^2$ versus $(hv)$ to obtain the value of the energy band gap of ZnONPs as a function of photon energy.
energy absorption. The energy band gap obtained from straight line plot of \((\alpha h\nu)^2\) vs. \(h\nu\) by extrapolation of the line to base line is 3.7 eV.

**Figure 2.** The transmittances of Siam weed leaf extract at different days

**Figure 3.** The absorbance readings of Siam leaf extract at different days
Figure 4. The absorption spectrum of ZnONPs

Figure 5. TaucPlot of \((\alpha h\nu)^2\) versus \((h\nu)\) energy band gap

3.2 FTIR analysis of ZnONPs

Figure 6 shows the IR spectrum of the sample of ZnONPs with absorption number occurring at 3448.04, 2524.85, 1437.15, 880.59, 729.06 and 433.44 cm\(^{-1}\). The synthesized ZnONPs shows Zn-O, Zn-OH, and variety of single bonds at low wavenumbers as shown in the figure, while O=O, C-H occurs at 1437.15 cm\(^{-1}\) in the fourth region. The first region peaks correspond to...
absorption caused by C-H, O-H and N-H single bonds, and the results are in consistence with similar results reported elsewhere [10-12].

![Figure 6. FTIR spectrum of ZnONPs](image)

**3.3 Morphological analysis of ZnONPs**

Figures 7 and 8 show the surface morphology of synthesized ZnONPs using Scanning Electron Microscope (SEM). In Figure 7, the ZnONPs nanoparticles have large grain size which would be good for the absorption of photon energy.
The elemental composition of ZnONPs

| Element Number | Element Symbol | Element Name | Atomic Conc. | Weight Conc. |
|----------------|---------------|-------------|--------------|--------------|
| 6              | C             | Carbon      | 68.35        | 42.47        |
| 30             | Zn            | Zinc        | 7.92         | 26.79        |
| 20             | Ca            | Calcium     | 4.14         | 8.59         |
| 11             | Na            | Sodium      | 6.78         | 8.07         |
| 8              | O             | Oxygen      | 6.77         | 5.60         |
| 12             | Mg            | Magnesium   | 3.47         | 4.37         |
| 14             | Si            | Silicon     | 0.68         | 0.98         |
| 47             | Ag            | Silver      | 0.13         | 0.75         |
| 13             | Al            | Aluminum    | 0.41         | 0.57         |
| 17             | Cl            | Chlorine    | 0.29         | 0.53         |
| 7              | N             | Nitrogen    | 0.55         | 0.40         |
| 19             | K             | Potassium   | 0.17         | 0.35         |
| 15             | P             | Phosphorus  | 0.19         | 0.31         |
| 16             | S             | Sulfur      | 0.13         | 0.22         |

Figure 7. Surface morphology of ZnONPs at 100 μm and elemental composition

Figure 8. Surface morphology of ZnONPs at 50 μm (b) at 80 μm

3.4 Energy-dispersive X-ray spectroscopy

The EDX spectra revealed the elemental composition of the ZnONPs as shown in Figure 9. Atomic concentration and weight concentration of the elements as tabulated in Table 1. The EDX result shows the presence of some impurities. Carbon has a high concentration, Zn is 26.79% and O is 5.60%. These values might be attributed to high composite ratio of Siam solution to Zinc acetate dehydrate solution or it might be due to high baking temperature of ZnONPs at 400 °C for 30 min to evaporate the solvent. Further studies will be carried out using...
higher Zinc acetate dehydrate solution-composite ratio and low temperature will be employed to evaporate the solvent.

![Energy-dispersive X-ray signals of ZnONPs showing elemental composition](image)

**Figure 9.** Energy-dispersive X-ray signals of ZnONPs showing elemental composition

### 3.5 Electrical properties analysis

Figure 10 shows the I-V characteristics from where the Fill-factor (FF) and efficiency ($\eta$) were computed. The thin film device Fill Factor (FF) is 0.6623, while ZnONPs thin film device efficiency under illumination is 2.01%.

![Current- Voltage characteristics for ZnONPs thin film device](image)

**Figure 10.** Current- Voltage characteristics for ZnONPs thin film device
Conclusion
Synthesis of ZnONPs using plant extract eliminated the need of toxic chemicals method of synthesis of nanoparticles. ZnONPs was deposited by spin-coating method and characterized by UV-vis spectroscopy, Fourier transform infra-red spectroscopy, Scanning Electron microscopy, and Energy Dispersive X-ray. Energy band gap of ZnONPs was 3.7 eV. FTIR result revealed the functional groups and absorption number of ZnONPs which shows that single bonds were found at low wavenumber. The surface morphology shows large grain size which means more adsorption of photon energy by ZnONPs. Efficiency of ZnONPs thin film device fabricated under illumination is 2.01%. Results obtained can lead to performance enhancement when used as photoanode of crystalline solar cells.

Conflict of Interest
The authors declare that there is no conflict of interest regarding the publication of this article.

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