DOI: 10.36108/ujees/5202.70.0161

UNIOSUN Journal of Engineering and Environmental Sciences. Vol. 7 No. 1. March. 2025

Nanocoating Photovoltaic Solar cell (PVC) for Solar Cell Efficiency Enhancement

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Abstract Generating clean energy is still a global desire. Photovoltaic Solar cell (PVC) may ameliorate this concern but for some drawbacks like cost, corrosion, durability and sustenance of efficiency. Nanocoating the conducting surface of PVC may have significant effects on its efficiency. This research work therefore reports the synthesis of *Moringa oleifera* leave extract-mediated zinc oxide nanoparticle (ZnO NP) used to enhance the efficiency of a solar cell by nano-coating. The ZnO NPs were characterized for functional, structural, compositional, morphological properties using XRD, EDX, FTIR and SEM. The green-synthesized ZnO NP-coated solar cell exhibited improved efficiency, increasing from 7.00% to 12.00%, likely due to enhanced solar absorption from ZnO NP coatings on the conducting surface. Hence, coating the conducting surfaces of solar cells with ZnO NP enhances efficiencies.

Keywords: Green synthesis, ZnO NP, nano-coating, PVC, efficiency, fill factor

I. Introduction

Solar cell technology in recent times have increasing concern in the application of nanoparticles to improve the efficiency of photovoltaic devices. Nanoparticles, with their special physico-chemical properties, offer promising solutions to address challenges faced by the solar energy industry[1]. These include; overcoming theoretical efficiency (Shockley-Queisser limit for single cell) approximately 32% for materials like silicon[2]**;** materials limitations for achieving bandgap optimization, high charge carrier mobility, stability and degradation[3], environmental factors like humidity, rain, storms, and dust accumulation, temperature variability management[4], developing cost-effective and reproducible manufacturing processes, efficient solar spectrum capturing and management[5]. Overcoming these limits necessitates innovative approaches, including multi-junction cells, advanced photon management and cost effective techniques.

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Nanotechnology, through the applications of novel material properties and light management techniques, plays a transformative role in enhancing solar cell efficiency[6]. Methods of nanocoating play significant roles in the improvement of solar cell performance by optimizing light absorption, reducing reflection, and providing protective layers that increase durability[7]. Various techniques used for nanocoating include; sol-gel[8], spray [9], chemical vapor deposition (CVD)[10], dip[11], and spin coating[12]

Each nanocoating method offers unique advantages, and technique selection is dependent on the required coating thickness, material properties, and application requirements[13].

Among various nanomaterials, zinc oxide (ZnO) nanoparticles have emerged as a promising component in solar energy applications. ZnO nanoparticles offer several advantages such as eco-friendliness, enhanced photons absorption, efficient charge transport mobility, cost-effectiveness and relative abundance, stability and durability . ZnO nanostructures are also integrated into perovskite solar cells to improve interfacial contact and enhance efficiency[14]. Hence this study aims at enhancing the efficiency of PVC through surface nanocoating with ZnO NP. The method adopted in this article is green synthesis route for the production of ZnO NP; characterized for physical measurements to confirm the nanoparticles formation and growth, coated on solar cell by sol-gel approach, and finally obtained IV characterization to investigate the fill factor and hence efficiency enhancement effects of the nanocoating.

II. Materials and Methods

A. Precursors

The precursors used for the preparation and formation of ZnO NPs are; extraction from the leaves of *Moringa oleifera* , zinc acetate dehydrate $[(CH_3COO)_2Zn.2H_2O]$, Sodium hydroxide (NaOH) pellets and ethanol. All these were pure and analytical grade sourced from Sigma Aldrich.

B. Collection and Identification of Leaves

The leaves collected from the campus of Osun State University, Osogbo, Nigeria, as shown in Fig. 1a; was identified as *Moringa oleifera* by the herbarium at Forestry Research Institute of Nigeria, Ibadan; filed as No. FHI. 113400, shown in Fig. 1b.

C. Preparation of Extract from Fresh *Moringa oleifera* leaves

Fresh moringa oleifera leaves collected were air-dried to a constant mass and powdered. 20 g of the powder leave was put in 100 ml of distilled water and left to age for 24 hours for extraction at ambient temperature.

D. Preparation of Zinc oxide (ZnO) Nanoparticles

A 0.4 moldm^{-3} zinc acetate dihydrate solution was prepared, using distilled water as solvent. After adding 5 ml of leaf extract under continuous stirring, $NaOH_{(aq)}$ was gradually used to maintain a pH of 12 and facilitate precipitation. The precipitate formed was washed repeatedly and dried at low temperature to obtain white ZnO NPs.

E. Characterization

Energy Dispersive Spectroscopy (EDX), Fourier Transform Infra-Red (FTIR) spectroscopy, X-Ray Diffraction (XRD), Spectroscopic electron morphology (SEM) and UV-Vis spectroscopy were used for elemental, functional group, structural properties, morphology and optical studies of the ZnO NPs respectively.

F. Nanocoating Methods and Procedures

Sol-Gel Coating was adopted here by preparing a sol-gel solution of ZnO NP, drop-casting it on the conducting surface of the solar cell, and heating the coated substrate to remove residual solvents and facilitate nanoparticle formation and adhesion.

G. Characteristic Study of Solar Cell and Efficiency Testing

The solar cell kit used for this study is Model No: HO-ED-SC-01, applying 100 W light source, for I-V characteristics of the solar cell. Fill factor, short circuit current, and open circuit voltage; before and after coating were obtained. Fig. 2 shows the graphical procedural steps for the nanocoating.

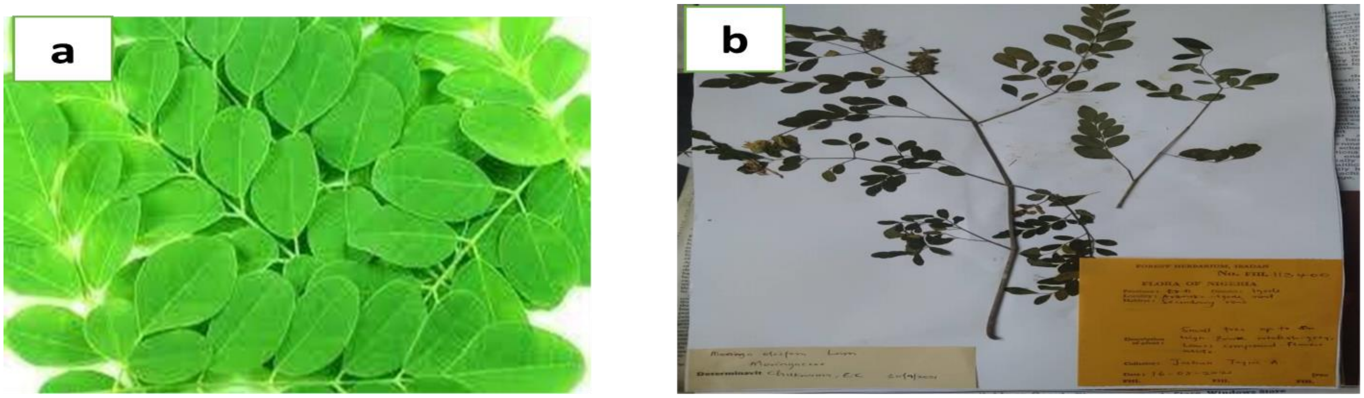

Fig. 1: (a) Fresh *Moringa oleifera* leaves (b) *Moringa oleifera* Forestry Herbarium Ibadan (FHI. 113400)

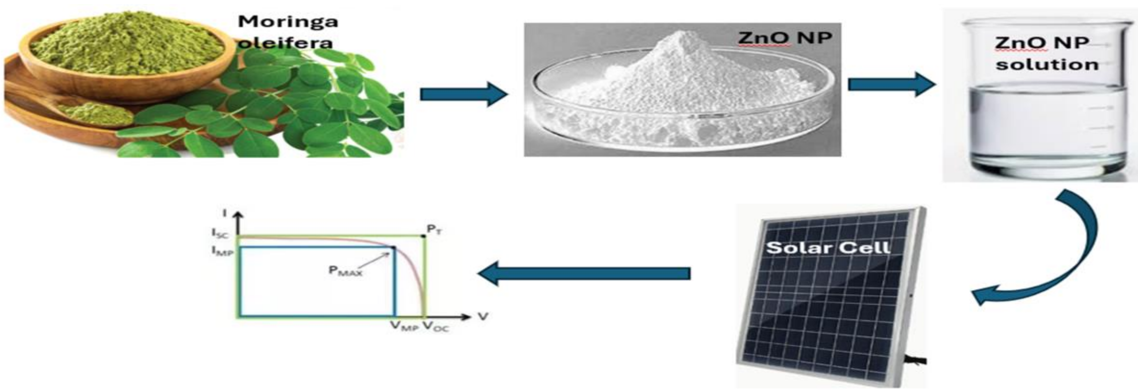

Fig. 2: Graphical Procedural Steps for Sol- Gel ZnO NP Solar Cell Nanocoating

III. Results and Discussion

A. Characterizations

The EDX spectrum of the ZnO NP shown in Fig. 3c displays only zinc (Zn), and oxygen (O) peaks. By implication, the synthesized ZnO NP is highly pure. This agrees with the report of Demirelli, who in their own case prepared ZnO NP by hydrothermal method[15].

The FTIR spectra of ZnO NR as shown in Figure 3b indicates transmittance peaks at 430.0–420.48 cm^{-1} of Zn–O bonds. The 860–900 cm^{-1} stretch suggests a metallic aromatic ring distribution. Peaks at 1530.00–1500.00 cm^{-1} and 1255–1032.00 cm^{-1} correspond to O–H in-plane. A broad peak at 3700–3000 cm^{-1} indicates O–H stretching, associated with hydroxyl groups. These findings confirm bio-reduction due to the involvement of biological molecules in formation of ZnO NPs[16].

X-ray Diffraction (XRD) pattern of the ZnO NP is shown in Fig. 3a, depicting its high orientation and crystallinity; diffraction peaks showing (100), (002), (101), (102), (110), (103), (200), (112), (201), (004), (202), (104), (203) hkl crystal planes at corresponding 2θ values of 31.78, 34.43, 36.27, 47.55, 56.62, 62.88, 66.40, 67.97, 69.11, 72.59, 76.99, 81.41, 89.64 respectively. The peaks were indexed with ICDD card No. 89 – 0510; confirming the crystalline wurtzite structure of the ZnO_NPs. The mean grain size of the ZnO_NPs was calculated to be 10.0 nm by using Debye-Scherrer's Equation [17].

$$D = \frac{K\lambda}{\beta Cos\theta} \mathring{A} \quad (1)$$

Where D denotes average nanoparticles (grain) size; K, the Scherrer constant (0.98); λ , the wavelength (1.54), and β, the full width at half maximum (FWHM)

Fig. 3d. shows the scan electron morphology of the ZnO NP as highly porous crystalline hexagonal nanorods sizes within the range of 10 nm – 25 nm.

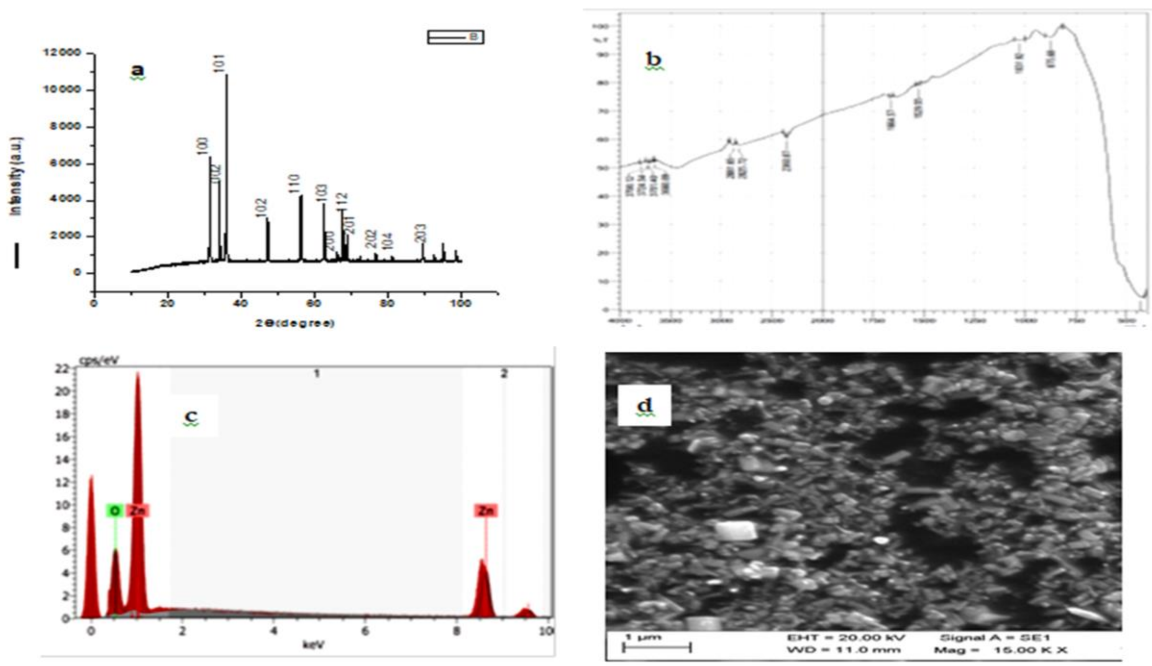

Fig. 3: (a) XRD Pattern of ZnO NPs (b) FTIR Spectrum of ZnO NPs (c) EDX Spectrum of ZnO NPs (d) SEM Micrograph Images of ZnO NPs

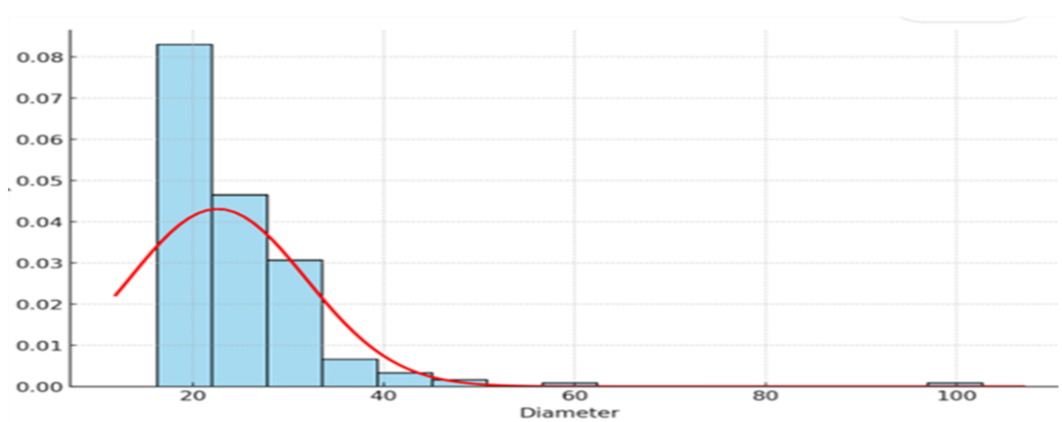

Fig. 4: Histogram of Diameter Values of ZnO NP with a Fitted Normal Distribution Curve

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The histogram of the ZnO NP diameter values with a fitted normal distribution curve (in red) is shown in Fig. 4. The distribution is right-skewed with positive value of 3.086; rather than perfectly normal, but the curve gives a sense of the overall shape.

B. Solar Cell Efficiency Enhancement by ZnO NP Nanocoating

Measurements under varying insolation and temperature conditions for both coated and uncoated cells, including short-circuit current (Isc), open-circuit voltage (Voc), fill factor (FF), and efficiency (η), are summarized in Table 1.

Table 1: I–V Characterization of ZnO NP before Coating and after Coating

	Parameter	I_{mp}	I_{sc}	V_{oc}	V_{max}	P_{in}	P_{max} (mW)	FF	η (%)
Before nanocoating	output	34	51	29	38	986	0.986	0.37	7.04
After nanocoating		36	60	32	38	1151.4	1.151	0.51	11.63

The fill factor of a solar cell is defined by the expression;

$$FF = \frac{I_{max}V_{max}}{(V_{oc})(I_{sc})} \quad (2)$$

$$FF = \frac{P_{max}}{(V_{oc})(I_{sc})} \quad (3)$$

The efficiency, η of the solar cell is also expressed as

$$\eta = \frac{P_{max}}{P_{in}} = \frac{I_{sc}V_{oc}FF}{P_{in}} \quad (4)$$

Where, V_{OC} = the open-circuit voltage, I_{SC} = short-circuit current, P_{max} = maximum power point of the solar cell, at this point, P_{max} = I_{mp} x V_{max}., FF = fill factor that is (Voc x Isc), and η % = percentage efficiency of a solar cell.

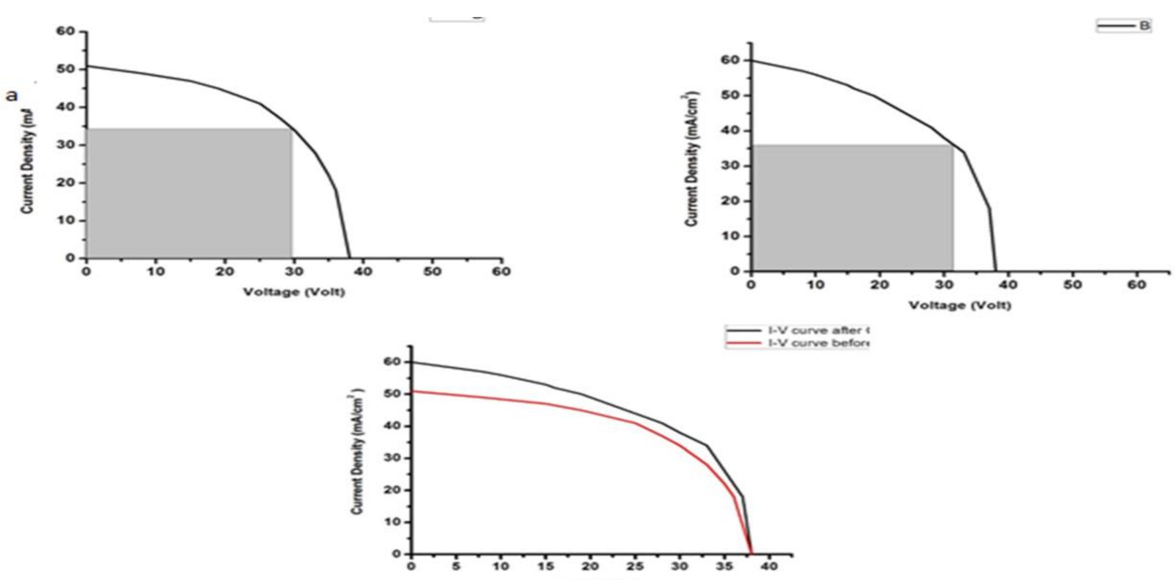

Fig. 5: *I–V* Curve of the Untreated (a), Treated (b) and (c) ombination of Treated and Untreated Solar Cells under Solar Radiation of 100 mW cm^{-2}.

Figure 5 presents the I-V characteristic curves of a photovoltaic cell, providing insights into its performance. This indicates that coating solar cells with green synthesized ZnO NP improves performance of the PVC, increasing short-circuit current and hence, the efficiency from 7.00% to 12.00%. This increase in short-circuit current, fill factor and efficiency, may be due to increase in absorption rate of solar cell after coating its conducting surface with ZnO NP. This is supported by the report of Talal, who showed nanocoated PVC for high transmittance, combatting dust accumulation[18]. Hence, this work has demonstrated a successful green synthesis of ZnO NP for solar cell efficiency enhancement by nanocoating.

IV. Conclusion

Zinc oxide nanoparticles ZnO NP have been successfully synthesized via green synthesis route; using the extract of green leaves of moringa *oleifera*. The leaves were identified at FHI and archived as No. FHI. 113400**.** The green synthesized ZnO NP were characterized for structural, morphological, chemical properties and functional groups using XRD, SEM, EDX and FTIR. All confirmed the formation of ZnO NP which was used for solar cell nanocoating for efficiency enhancement. I-V characteristic graphs were plotted; showing increased fill factor and hence the efficiency of the solar cell nanocoated. This article therefore demonstrates efficiency enhancement of solar cell by nanocoating its conducting surface with green synthesized ZnO NP. Other factors like; optimization, temperature, absorption angle, self-healing and self-cleansing materials that may improve solar cell efficiency may be examined by future research work.

Acknowledgments

International Research Centre (ICR), Kalasalingam University, India is acknowledged for characterization of the synthesized ZnO NP.

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