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THE EFFECT OF VARYING GRAPHENE OXIDE COMPOSITION ON THE OPTICAL PROPERTIES OF ZnO/GO THIN FILMS AS A CANDIDATE MATERIAL FOR SOLAR CELLS

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ABSTRACT

This study aims to investigate the effect of Graphene Oxide (GO) composition variation on the optical and electronic properties of ZnO/GO thin films, which have potential as candidate materials for solar cells. The synthesis method employed is sol-gel, followed by the spin coating technique to produce thin films on glass substrates. Characterization was carried out using X-Ray Diffraction (XRD) to determine the crystalline structure, Scanning Electron Microscopy (SEM) for morphological analysis, and UV-Vis spectroscopy to measure optical properties, including light absorption and band gap. The results indicate that a 3% GO composition significantly affects the optical and electronic properties of ZnO/GO. The addition of GO enhances light absorption in both the UV and visible ranges and reduces the band gap, contributing to improved energy conversion efficiency. Furthermore, SEM characterization shows a better particle distribution at 3% GO compared to other compositions, enhancing the interaction between ZnO and GO. Based on these findings, it can be concluded that a ZnO/GO combination with 3% GO has good potential as a material for solar cell applications. This research is expected to contribute to the development of more efficient and environmentally friendly renewable energy materials.

Keywords : composition variation, optical properties, electronic properties, solar cells

I. INTRODUCTION

The energy crisis has become a global issue that has affected nearly every region of the world over the past few decades [1]. The growing demand for energy combined with the depletion of fossil fuel resources has driven the search for renewable and environmentally friendly alternative energy sources [2]. Global warming caused by excessive fossil fuel consumption, further underscores the urgency of transitioning to more sustainable energy sources [3]. One promising solution is the utilization of solar energy through solar cell technology [4]. The use of renewable energy, particularly solar power has become a key focus in efforts to meet global energy needs sustainably.

Solar cells are a crucial technology in the global effort to meet renewable energy needs, as they convert sunlight into electrical energy that can be used for various purposes [5]. Therefore, scientists continue to develop and refine solar cell technology to improve the efficiency of energy conversion. Significant progress has been made in recent years, both in terms of solar cell design and the selection and development of materials used [6]. One of the key factors determining solar cell efficiency is the semiconductor material used in the device. This material influences how the solar cell absorbs sunlight and how the absorbed energy is converted into electrical current [7].

The optical and electronic properties of semiconductor materials have a major impact on two critical processes in solar cells: light absorption and charge transport [8]. Light absorption refers to the material's ability to capture photons from sunlight and convert them into electron-hole pairs [9]. Meanwhile, charge transport

pertains to the material's ability to efficiently move these electrons and holes to the electrodes of the solar cell, where energy can be extracted [10]. Therefore, developing semiconductor materials with high light absorption and good charge carrier mobility is essential for improving energy conversion efficiency. Currently, materials like Zinc Oxide (ZnO) which possess excellent semiconductor properties are being intensively researched for their potential to enhance solar cell performance. Additionally, the combination of semiconductor materials with other substances, such as Graphene Oxide (GO) is seen as a promising solution to maximize solar cell efficiency in the future.

The use of ZnO and Graphene Oxide in solar cells offers several advantages, as both materials possess beneficial properties. ZnO is a good semiconductor with a wide bandgap (Eg = 3.4 eV) [11], high absorption coefficient [12], and excellent carrier mobility [13]. GO on the other hand, exhibits high electrical conductivity [14]. This materials also environmentally friendly, non-toxic, cost-effective, and have low production costs [15]. The addition of GO to ZnO can enhance solar cell efficiency by improving electrical conductivity and reducing electron-hole recombination [16]. Furthermore, ZnO and GO can also be used as electron transport layers in perovskite-based solar cells, further improving energy conversion efficiency [17].

This study aims to explore the effect of GO composition variation on the optical and electronic properties of ZnO/GO thin films. Using the sol-gel method for synthesis and spin coating technique for thin film preparation, the study will characterize the synthesized films using X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM), and UV-Vis Spectroscopy [18]. It is expected that the results of this study will contribute significantly to the development of more efficient and sustainable solar cell materials.

II. METHOD

This study employs an experimental research approach, aimed at testing and analyzing the effect of Graphene Oxide (GO) composition variation on the optical and electronic properties of ZnO/GO thin films as potential materials for solar cells. Experimental research involves manipulating and controlling certain variables to observe their effects on other variables [19]. In this study, experiments are conducted to evaluate how varying the GO composition in ZnO/GO films affects the physical properties and performance of the material.

The principal materials utilized in this research include Zinc Oxide (ZnO) powder, serving as the primary semiconductor material, and Graphene Oxide (GO) powder, acting as a conductive dopant. Supporting reagents such as distilled water (aquadest), isopropanol, and acetic acid were employed as solvents in the preparation of precursor solutions. Glass microscope slides were used as substrates for thin film deposition.

The experimental process required the following apparatus and tools:

1) A digital analytical balance for precise weighing of raw materials;
2) Standard laboratory glassware, including beakers, pipettes, and measuring cylinders, for solution preparation and transfer;
3) A magnetic stirrer integrated with a hot plate to ensure homogenization and temperature control during the sol-gel process;
4) A spin coater, used to achieve uniform deposition of thin films on glass substrates through centrifugal spreading;
5) A laboratory oven, employed for drying and annealing the coated films to enhance structural integrity and crystallinity.

The research was conducted through a series of experimental stages beginning with the synthesis of ZnO/GO thin films using the sol-gel method, followed by deposition onto glass substrates via spin coating. After synthesis, the thin films underwent further preparation to ensure they were suitable for characterization. The optical properties of the films, such as light absorption and energy bandgap, were analyzed using UV-Visible (UV-Vis) spectrophotometry. To examine the surface morphology and particle distribution, Scanning Electron Microscopy (SEM) was employed. Meanwhile, the crystalline structure of the films was determined through X-Ray Diffraction (XRD) analysis. All procedures were carried out using standardized techniques and appropriate instrumentation within certified research laboratory environments.

The step-by-step procedure of the research can be seen in Figure 1.

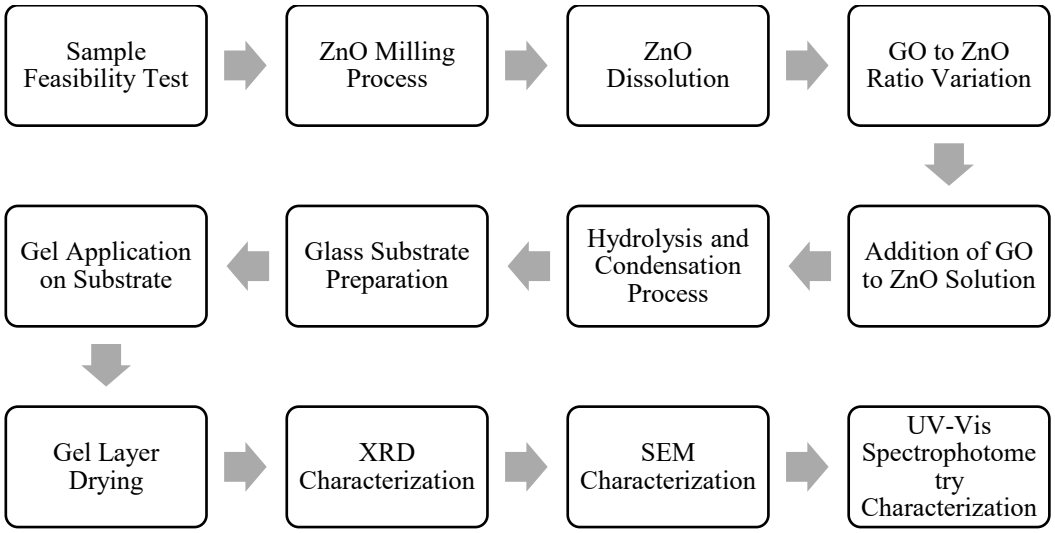

Fig. 1. Research procedures

Data collection techniques in this study were conducted both directly and indirectly [20]. Indirect data collection includes the analysis of the crystal size of ZnO/GO, characterized using X-Ray Diffraction (XRD), where the particle analysis of ZnO provides information about the crystal system and lattice parameters of the material. Additionally, to measure the photocatalytic degradation value, UV-Vis Spectrophotometry is used to analyze the degradation value based on the absorbance obtained [21]. Meanwhile, direct data collection includes testing the morphology of graphene oxide using Scanning Electron Microscopy (SEM) and measuring absorbance, reflectance, and transmission of the ZnO/GO thin films through UV-Vis spectrophotometry, which provides data on the optical properties of the material.

The data analysis technique to calculate the crystal size using XRD can be performed using equation (1).

$$L = \frac{K\lambda}{\beta.\cos\theta} \tag{1}$$

Explanation:
L = Grain size
K = Scherrer constant (k = 0.9)
λ = X-ray wavelength, with a value of 1.521874 Å
β = FWHM (full width at half maximum)

Diffraction peaks with the highest intensity and a divergence angle of 2θ ≥ 30° are selected. The estimated crystal size is calculated by averaging the crystal size values for each selected crystal plane. Based on the SEM results, the surface morphology of ZnO/GO, including the particle size, can be determined. The particle size is calculated by obtaining the ratio of the particle diameter, analyzed using ImageJ software, then averaged and plotted using Origin software. The optical absorption band gap is used to determine the energy band gap. Based on optical absorption, the band gap of a crystal can be classified into two types: direct and indirect band gaps. The band gap of the thin film is obtained by plotting the absorbance data using the direct transition model, as shown by the equation (2).

$$ah\vartheta = K(h\vartheta - Eg)^{1/2} \tag{2}$$

Explanation:
α = absorption coefficient
$h\vartheta$ = photon energy (eV)
Eg = energy band gap (eV)
K = constant

The optical property tested is absorbance as a function of wavelength of the ZnO-G thin film, using a UV-Vis Spectrophotometer. The data obtained from this instrument consists of absorbance values at specific wavelengths, calculated using the equation (3).

$$A = \varepsilon b C \quad (3)$$

Explanation:
A = Absorbance
ε = Molar absorptivity
b = Path length
C = Concentration of the solution

III. RESULTS AND DISCUSSION

The results of the study on the effect of GO composition variation on the optical and electronic properties of solar cell catalyst candidates are presented. This research, using Zinc Oxide (ZnO) as the active material, employed the ball milling method with a milling time of 2 hours. The crystal size was characterized using XRD, particle size was analyzed via SEM, and the energy band gap and optical constants (reflectance and transmittance) were characterized using UV-Vis Spectrophotometry.

The characterization results of ZnO before milling using the XRD instrument are shown in the Figure 2.

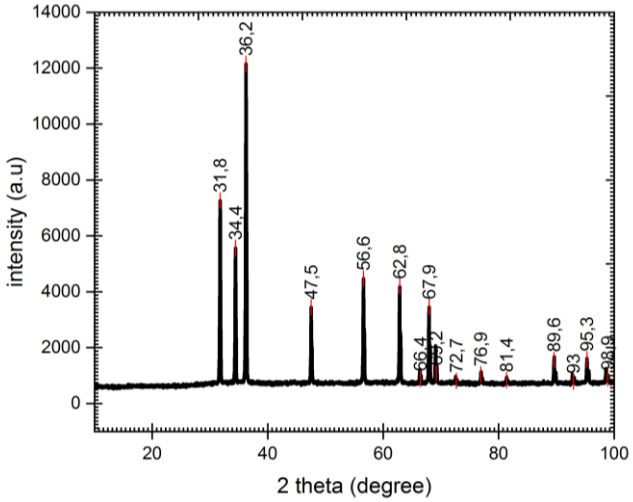

Fig. 2. Data from the characterization of zinc oxide (ZnO) powder using XRD

Figure 2 presents the X-ray diffraction (XRD) pattern of ZnO, showing several significant intensity peaks at specific 2θ angles. These peaks indicate the presence of particular crystal planes within the ZnO structure, reflecting a high degree of crystallinity. This pattern confirms the dominant phase of hexagonal ZnO in the sample. The SEM characterization results of ZnO with a milling time of 0 hours are shown in Figure 3.

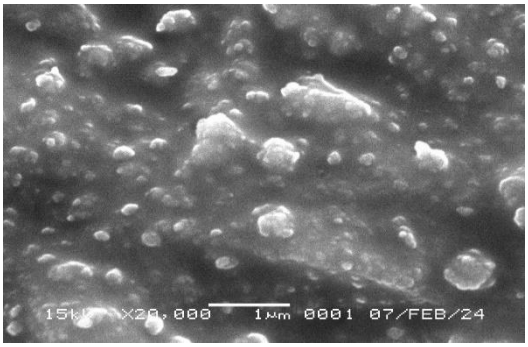

Fig. 3. The SEM characterization data of ZnO with 0 hours of milling time

Figure 3 shows the particle size imaging of ZnO using a magnification of 20,000X. XRD characterization was performed to determine the crystalline phase of GO. The testing was conducted at a 2θ range of 10° to 100°. The results were compared with the peaks from the Crystallography Open Database (COD) database, entry 9011662. The XRD characterization results of GO are shown in Figure 4.

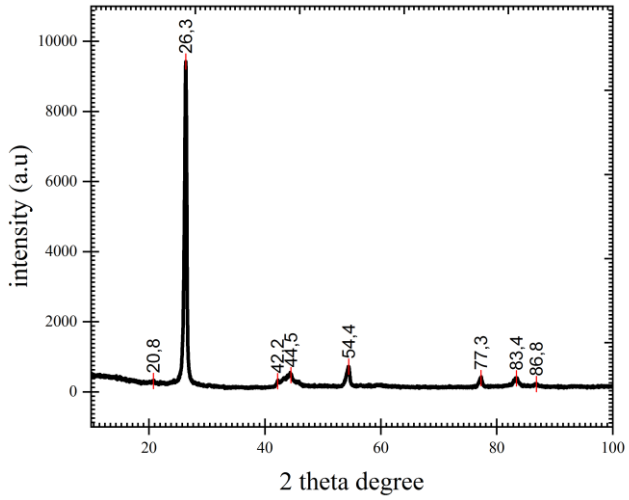

Fig. 4. The XRD diffraction patterns of GO

The Figure 4 shows the X-Ray Diffraction (XRD) characterization results of the Graphene Oxide (GO) sample. A dominant peak appears at the 2θ angle of approximately 26.3°, indicating the presence of a major crystalline structure. Several smaller peaks at 20.8°, 42.2°, 44.5°, 54.4°, 77.3°, 83.4°, and 86.8° suggest minor crystalline phases or possible impurities within the sample.

The SEM characterization results of GO are shown in Figure 5.

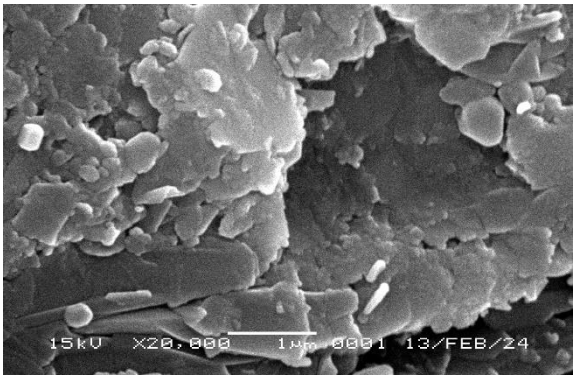

Fig. 5. The SEM characterization data of GO

The XRD results of ZnO with 2 hours of milling time are shown in Figure 6.

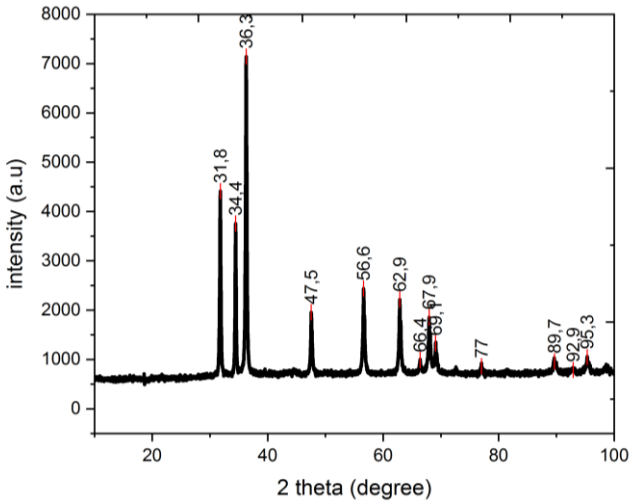

Fig. 6. The XRD diffraction pattern of ZnO with 2 hours of milling time

The SEM characterization results of ZnO with 2 hours of milling time are shown in Figure 7.

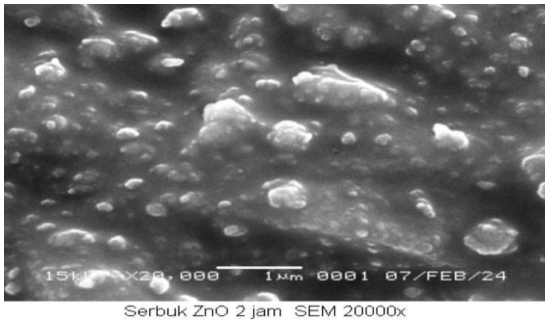

Fig. 7. The SEM characterization data of ZnO with 2 hours of milling time

After data analysis, the results of the XRD analysis of ZnO doped with GO at variations of 1%, 2%, and 3% are shown in Figure 8.

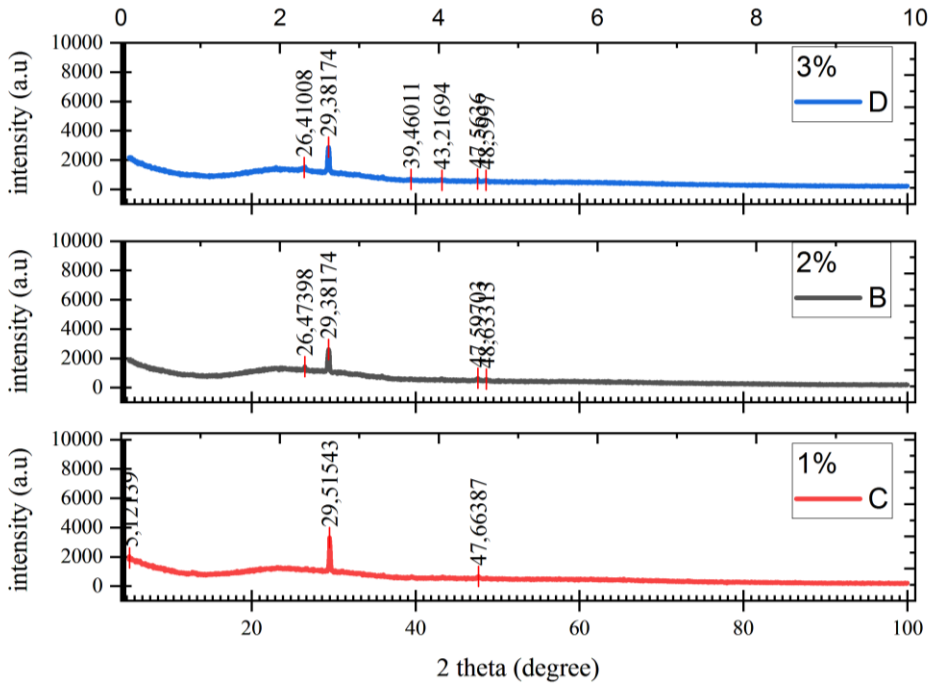

Fig. 8. The diffraction pattern of ZnO with varying GO doping

Based on Figure 8, the diffraction pattern of ZnO with three different GO doping variations (1%, 2%, and 3%) is shown, with each variation measured within a 2θ range of 10-100°. The crystal sizes were determined using the Scherrer equation. The average crystal size for the 1% doping was 39.03 nm, for 2% doping it was 28.05 nm, and for 3% doping, it was 27.04 nm. The diffraction pattern reveals that ZnO with 1% GO doping has the highest peak intensity, with three distinct peaks that consistently appear, indicating high intensity at each composition. Characterization results show that all synthesized crystals exhibit a hexagonal phase with a wurtzite structure, with no detectable impurities. The crystal size obtained from the XRD characterization, calculated using the Scherrer equation, indicates that the material meets the criteria for a nanocrystal (ZnO/GO) if the size is under 100 nm [22]. The largest crystal size was observed in the 1% variation (39.03 nm), while the smallest was in the 3% variation (27.04 nm). Given the smallest crystal size and the highest number of prominent peaks, the 3% variation is considered more effective than the 1% and 2% variations.

The data analysis of ZnO doping with GO at composition variations of 1%, 2%, and 3% using Scanning Electron Microscopy (SEM) provides valuable insights into the morphology, texture, and particle size of the ZnO/GO thin films. The SEM results show significant differences in morphology and particle size among the doping variations [23]. In the 1% doping, ZnO particles appear larger and tend to aggregate, which may reduce particle interaction and hinder electrical conductivity. In contrast, the 3% doping shows more evenly distributed ZnO particles with an average size of approximately 34.804 nm, enhancing the interaction between ZnO and GO, potentially improving the conductivity and optical efficiency of the material. While the 3% variation demonstrates better particle distribution, some agglomerates are still visible. However, the dispersion on the glass substrate remains uniform, which can be effectively utilized. Analysis using ImageJ and Origin software reveals an R-squared (COD) value close to 1 for the 3% variation, indicating excellent particle distribution and a strong relationship between dependent and independent variables. The improved morphology in the 3% variation contributes to better interaction between ZnO and GO, which is crucial for enhancing electrical conductivity. The proper addition of GO creates more efficient conduction pathways, thereby increasing electron mobility and lowering the material's resistivity important factors for solar cell applications. Overall, the SEM analysis shows that GO doping can enhance the physical properties of ZnO, making it a better candidate for solar cell applications. Further research is needed to explore different synthesis methods and deposition conditions to achieve a more optimal composition.

The analysis of data from the characterization of ZnO doped with Graphene Oxide (GO) at compositions of 1%, 2%, and 3% using UV-Vis spectrophotometry provides critical insights into the optical properties of the synthesized materials.

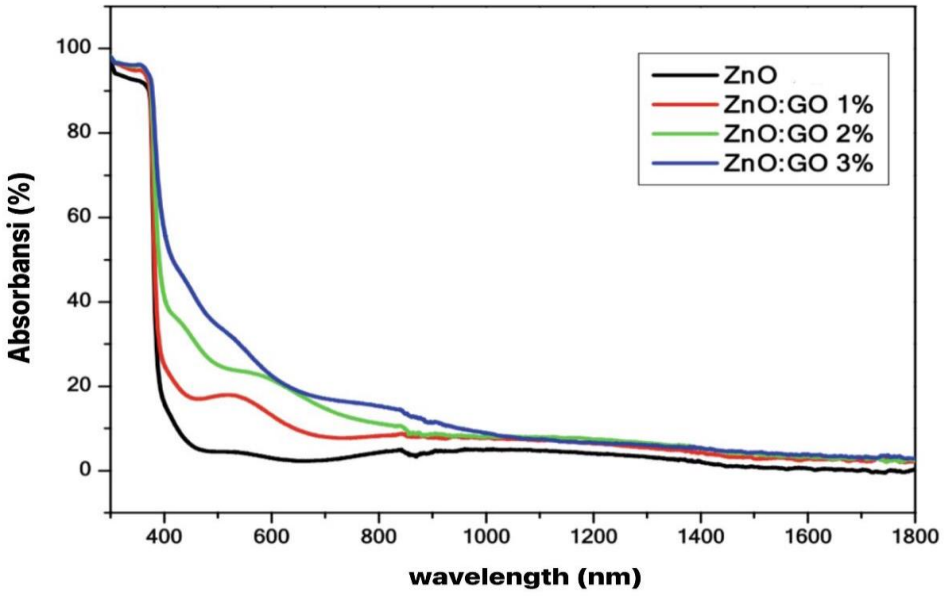

Fig. 9. Absorbance data for three GO composition variations

This figure 9 presents the absorbance spectra of ZnO/GO thin films with three different GO composition ratios. The data indicate that the 2% GO composition exhibits the highest absorbance in the UV and visible regions, suggesting enhanced light-harvesting capability. Increased absorbance is associated with improved photon absorption, which is crucial for solar cell applications.

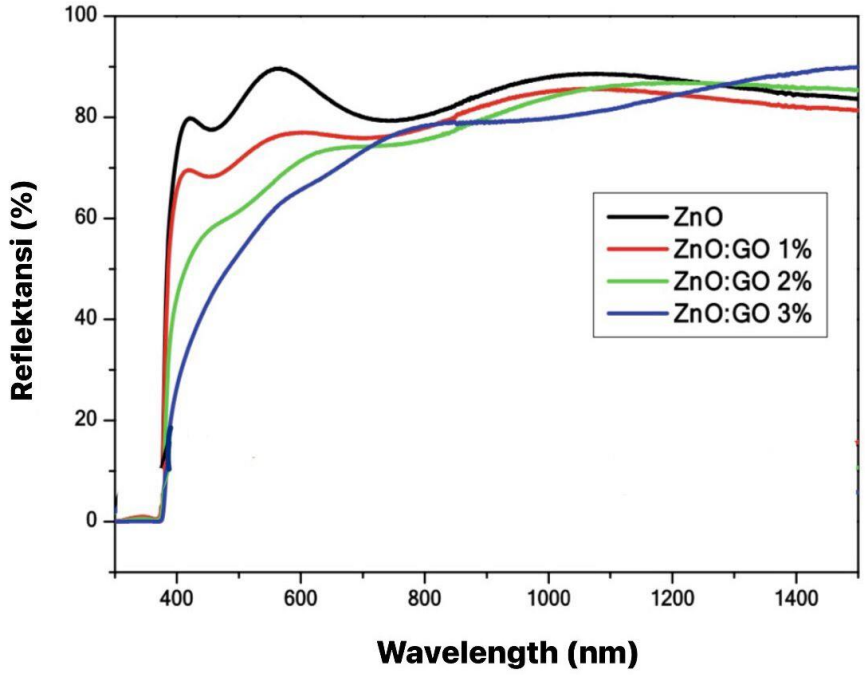

Fig. 10. Reflectance data for three GO composition variations

The figure 10 illustrates the reflectance values of ZnO/GO thin films with varying GO contents. Lower reflectance is observed in the film with 2% GO, indicating better light trapping and reduced surface reflection. This suggests that an optimal GO concentration can enhance the optical performance of the thin film.

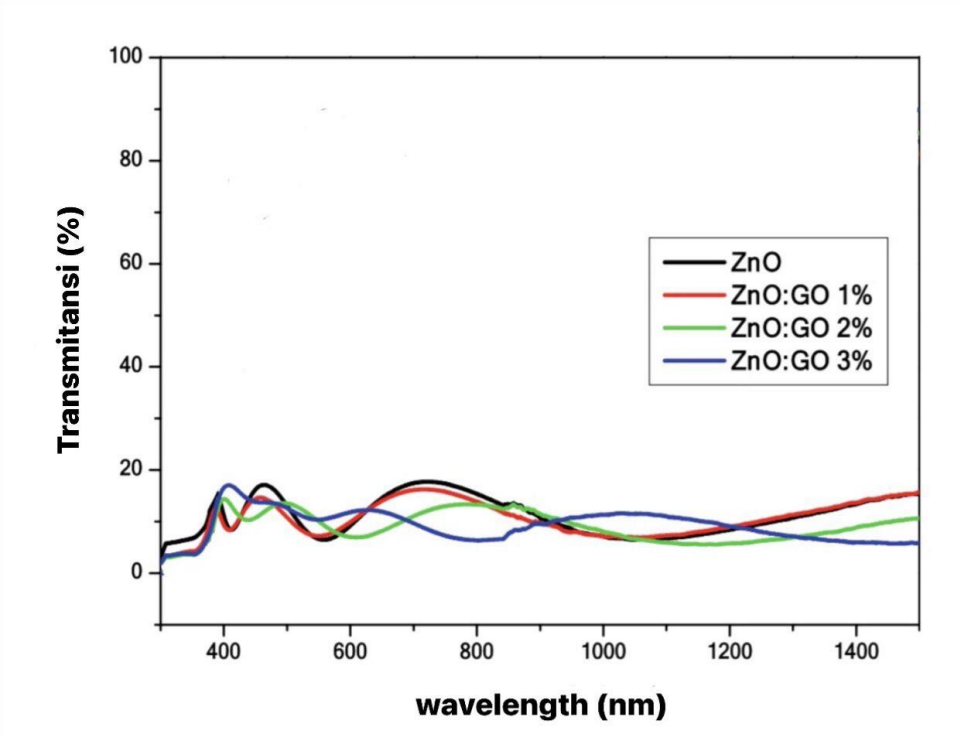

Fig. 11. Reflectance data for three GO composition variations

This figure shows the transmittance spectra of ZnO/GO thin films across different GO compositions. The transmittance decreases as GO content increases, especially at 2% and 3% GO levels, indicating stronger light absorption. Reduced transmittance supports the potential of the films to function as efficient light-absorbing layers in optoelectronic devices.

The UV-Vis measurements revealed that the absorption peaks shifted towards longer wavelengths with increasing GO concentration, indicating enhanced light absorption capabilities in both the UV and visible regions. Specifically, the sample with 3% GO exhibited the highest absorption, which correlates with a decrease in the band gap energy, suggesting that the material becomes more efficient in harnessing solar energy. This finding aligns with the research objective of investigating the influence of varying GO compositions on the optical and electronic properties of ZnO/GO thin films, as it demonstrates that the optimal doping level of 3% significantly improves the material's potential for solar cell applications. The increased light absorption and reduced band gap are crucial for enhancing the efficiency of energy conversion, thereby supporting the development of more efficient and environmentally friendly renewable energy materials. Overall, the results underscore the importance of optimizing GO composition to achieve superior optical properties, which is essential for advancing the performance of solar cells.

IV. CONCLUSION

In this study, the effect of graphene oxide (GO) composition on the optical and electronic properties of ZnO/GO thin films was investigated. The results demonstrate that variations in the GO composition significantly influence the optical characteristics of ZnO/GO films. The incorporation of GO in specific amounts enhances light absorption, which directly contributes to improved solar energy conversion efficiency. Among the different GO compositions, the 3% GO doping showed a substantial impact on both the optical and electronic properties of the ZnO/GO films. The addition of GO enhanced light absorption in both the UV and visible spectra, as well as reduced the band gap, which is a key factor in improving the material's efficiency for energy conversion applications. Furthermore, the doping of 3% GO led to better particle distribution and interaction between ZnO and GO, which is crucial for improving electrical conductivity and optical performance. Overall, the results suggest that GO doping is a promising approach to enhance the properties of ZnO, making ZnO/GO films more suitable for applications in solar cells. Further investigations into optimal doping concentrations and deposition methods are recommended to further optimize the performance of these materials in solar energy applications.

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