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Optimizing Zinc Oxide Concentration for Optoelectronic Device Applications

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***Abstract**: The study described the preparation of Zinc Oxide thin films using the sol-gel method and analysed their optical properties using UV-visible spectrophotometry. The optical properties of ZnO thin films at different concentrations, specifically 0.4ml, 0.8ml, and 1.2ml, and the effect of concentration on the absorbance, transmittance, reflectance, absorption coefficient, extinction coefficient, refractive index, and optical band gap were investigated. The results indicated that the peak absorbance of ZnO increased with increasing concentration, and the highest peak absorbance was obtained at a concentration of 1.2 ml with a peak wavelength of 379 nm. The UV transmittance spectra showed a decreasing trend with increasing concentration, which could be explained by the scattering and absorption of light by the ZnO particles. The reflectance spectra showed a slight increase in reflectance with increasing concentration. The absorption coefficient increased with increasing concentration, and the peak wavelength showed a slight shift towards the blue region as the concentration decreased. The extinction coefficient also increased with increasing concentration. The study has implications for the use of ZnO in optoelectronic devices, such as solar cells, where the concentration of ZnO used in the device must be optimized to achieve the desired absorbance and transmittance spectra.*

***Keywords**: Zinc Oxide, Sol-gel method, Thin films, Optoelectronic devices*

Introduction

Zinc oxide (ZnO) is a well-known inorganic semiconductor material with a wide range of applications due to its unique physical and chemical properties. It has a hexagonal wurtzite crystal structure with a direct bandgap of ~3.37 eV at room temperature, making it an ideal material for optoelectronic devices such as solar cells, light-emitting diodes (LEDs), and sensors. ZnO is also transparent in the visible range, has high electron mobility, and is chemically stable, making it suitable for applications in catalysis, gas sensing, and transparent conductive coatings.

The synthesis of ZnO can be achieved through various methods such as chemical vapor deposition, sol-gel, and hydrothermal techniques. Among these methods, the sol-gel method has gained significant attention due to its simplicity, low-temperature synthesis, and the ability to control the size and shape of the nanoparticles.

Several studies have been conducted on the optical properties of ZnO, including the analysis of absorbance, transmittance, reflectance, absorption coefficient, extinction coefficient, refractive index, and optical band gap. For instance, the optical properties of ZnO nanoparticles were investigated using UV-Visible spectroscopy, and it was found that the bandgap energy of ZnO nanoparticles decreased with increasing particle size (Soosen *et al*., 2009).

The sol-gel method is a promising technique for the synthesis of ZnO nanoparticles due to its simplicity, low-temperature synthesis, and the ability to control the size and shape of the nanoparticles (Dutta *et al*., 2008). Understanding the optical properties of ZnO nanoparticles synthesized using the sol-gel method is essential for optimizing their performance in optoelectronic devices.

One of the main applications of ZnO nanoparticles synthesized using the sol-gel method is in solar cell technology. The optical properties of ZnO nanoparticles play a crucial role in the efficiency of solar cells. For instance, ZnO nanoparticles synthesized using the sol-gel method were used as electron transport layers in perovskite solar cells, and it was found that the optical properties of ZnO played a significant role in improving the device efficiency (Qiu *et al*., 2022). Similarly, the optical properties of ZnO nanoparticles synthesized using the sol-gel method were investigated, and it was found that the nanoparticles exhibited high absorption in the UV region, making them suitable for applications in UV photodetectors (Zainal *et al*., 2018).

Another application of ZnO nanoparticles synthesized using the sol-gel method is in the development of gas sensors. The optical properties of ZnO nanoparticles play a crucial role in the sensitivity and selectivity of gas sensors. In a study by Erol *et al*. (2010), ZnO nanoparticles synthesized using the sol-gel method were used as sensing materials in a humidity sensor, and it was found that the optical properties of ZnO nanoparticles affected the sensitivity and selectivity of the sensor.

Therefore, studying the optical properties of ZnO synthesized using the sol-gel method is essential for optimizing their performance in various optoelectronic applications such as solar cells, photodetectors, and gas sensors.

The objective of this study is to investigate the UV spectroscopic analysis of zinc oxide synthesized through the sol-gel method at concentrations of 0.4ml, 0.8ml, and 1.2ml, and to determine the optical properties of the samples, including absorbance, transmittance, reflectance, absorption coefficient, extinction coefficient, refractive index, and optical band gap.

Experimental procedure

ZnO thin films of different concentrations (0.4 ml, 0.8 ml, and 1.2 ml) were deposited using the sol-gel method. For the precursor solution, 0.22 g, 0.44 g, and 0.66 g of zinc acetate dihydrate were weighed for 0.4 ml, 0.8 ml, and 1.2 ml concentrations, respectively. These were dissolved in 10 ml of distilled water to obtain a clear solution. Next, 10 ml of ethanol was added and stirred until homogenized. 0.5 ml of Diethanolamine (DEA) was added to the solution under constant stirring for stabilization.

The precursor solution was deposited on a glass substrate using spin coating at 3000 rpm for 30 seconds. The coated substrate was then dried at 150 °C for 5 minutes to remove the solvent. The substrate was then heated at 500 °C for 1 hour to form the ZnO thin film.

The optical properties of the ZnO thin films were analysed using a UV-visible spectrophotometer (UV-750 Series). The absorbance, transmittance, and reflectance spectra were recorded in the range of 250-800 nm. The absorption coefficient, extinction coefficient, and refractive index were calculated using the standard formulas. The optical band gap was determined by analysing the Tauc plot of $(\alpha h\nu)^2$ versus $h\nu$, where α is the absorption coefficient, h is the Planck's constant, and ν is the frequency of light.

Result and discussion

The following presents the results of UV spectroscopic analysis conducted on different concentrations of zinc oxide, specifically at concentrations of 0.4ml, 0.8ml, and 1.2ml. Properties obtained from the analysis include the absorbance, transmittance, reflectance, absorption coefficient, extinction coefficient, refractive index, and optical band gap.

The Absorption spectra of different concentration of zinc oxide is represented in figure 1. The results indicate that the peak absorbance of zinc oxide increases with increasing concentration. The highest peak absorbance was obtained at a concentration of 1.2 ml with a peak wavelength of 379 nm, while the lowest peak absorbance was obtained at a concentration of 0.4 ml with a peak wavelength of 365 nm.

These findings are consistent with previous studies by Ghamsari *et al*. (2017), on the optical properties of zinc oxide, which have shown that the absorption spectra of zinc oxide are dependent on the concentration and size of the particles. As the concentration of zinc oxide increases, the number of particles in the solution increases, leading to an increase in the probability of light absorption and subsequently, an increase in the peak absorbance.

The given concentrations of ZnO (1.2 ml, 0.8 ml, and 0.4 ml) show a decreasing trend in the UV transmittance spectra with increasing concentration shown in figure 2. This trend can be explained by the scattering and absorption of light by the ZnO particles. At higher concentrations, the number of ZnO particles per unit area increases, leading to an increase in scattering and absorption of light. This, in turn, leads to a decrease in the transmittance spectra.

This finding is consistent with the results reported by Nagayasamy *et al*. (2013). They observed that the transmittance spectra of ZnO thin films decreased with increasing concentration, which is in line with the trend observed in the given concentrations.

The decrease in UV transmittance spectra with increasing concentration has implications for the use of ZnO in optoelectronic devices. For example, in solar cells, a high transmittance in the UV range is desirable to maximize the absorption of light and improve the efficiency of the device. Therefore, the concentration of ZnO used in the device must be optimized to achieve the desired transmittance spectra.

Figure 3 displays the reflectance spectra of different concentration of zinc oxide. The slight increase in reflectance observed with increasing concentration in the visible and ultraviolet regions can be attributed to the changes in the morphology and size of the ZnO particles as the concentration increases. At higher concentrations, there is be a greater number of ZnO particles in the film, resulting in an increase in surface roughness and scattering of light. Additionally, at higher concentrations, the ZnO particles may be more densely packed, which could affect the reflectance properties of the film.

The fact that the difference in reflectance between the different concentrations is not significant suggests that the changes in the morphology and size of the ZnO particles are small and do not strongly affect the optical properties of the film. However, it is important to note that even small changes in reflectance can have a significant impact on the performance of optoelectronic devices such as solar cells, where maximizing light absorption is crucial.

The results shown in figure 4 is the absorption coefficient spectra of different concentration of zinc oxide. It shows that as the concentration of ZnO increases, the absorption coefficient also increases. This can be attributed to the increase in the number of ZnO particles per unit volume, leading to more photon absorption. The peak wavelength also shows a slight shift towards the blue region as the concentration decreases, with the peak wavelength being 379 nm for a concentration of 1.2 ml, 342 nm for a concentration of 0.8 ml, and 346 nm for a concentration of 0.4 ml.

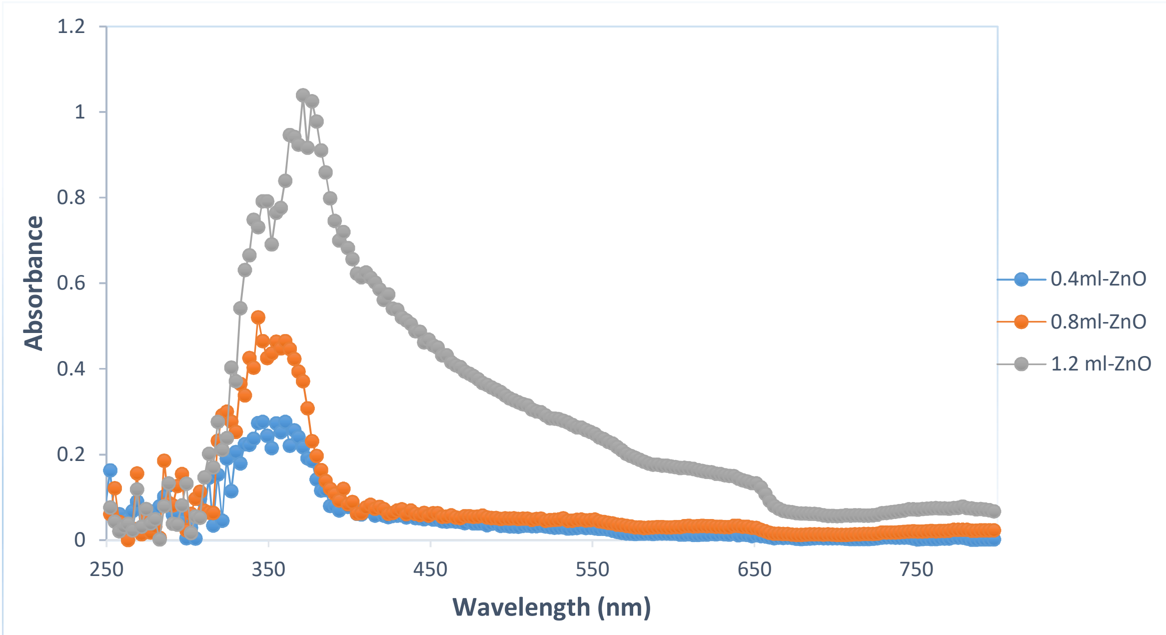

Figure 1: Absorption spectra of different concentration of zinc oxide

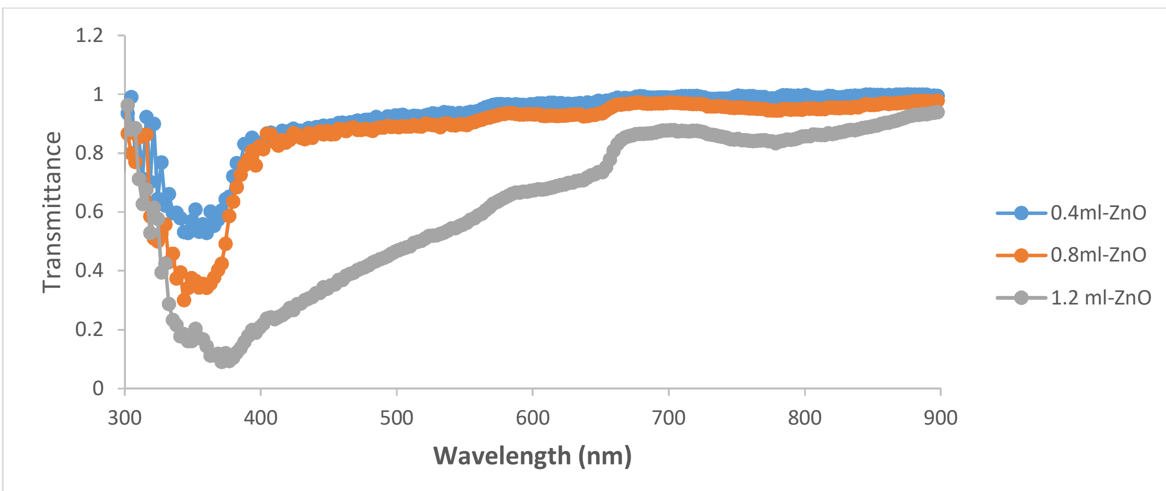

Figure 2: Transmittance spectra of different concentration of zinc oxide

These results are consistent with the findings of a study by Nagayasamy *et al*. (2013). They found that the absorption coefficient of ZnO thin films increased with increasing concentration, which is consistent with the trend observed in the above results. Additionally, they towards the blue region as the concentration decreased.

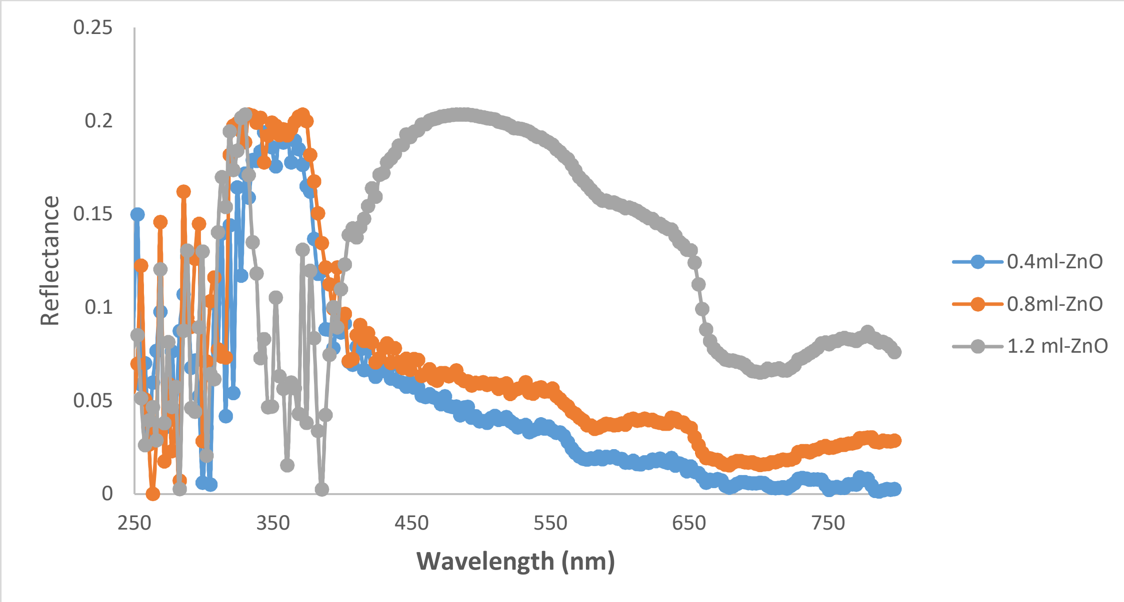

Figure 3: Reflectance spectra of different concentration of zinc oxide

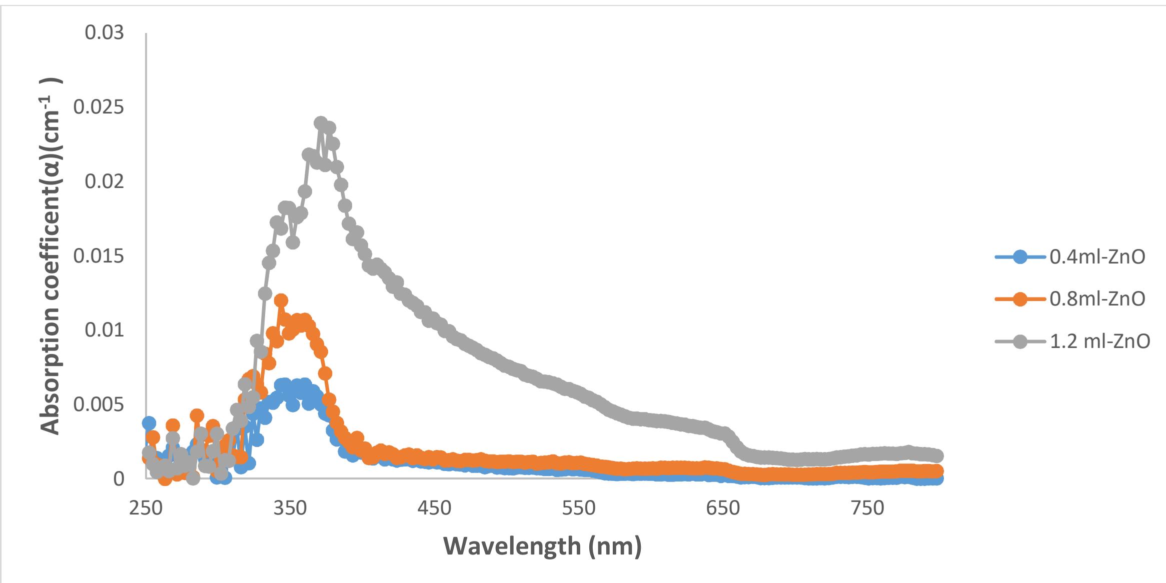

Figure 4: Absorption coefficient of different concentration of zinc oxide

The graph in figure 5 represents the Extinction coefficient of different concentration of zinc oxide. Extinction coefficient is the measure of how strongly a material absorbs light. From the given concentrations, it can be observed that as the concentration of ZnO increases, the extinction coefficient also increases. The peak wavelength of extinction coefficient also shifts towards the visible region, with the peak wavelength being 376 nm for 1.2 ml, 346 nm for 0.8 ml and 351 nm for 0.4 ml.

It is also observed that the extinction coefficient is almost zero towards the ultraviolet region. This can be attributed to the fact that ZnO has a wide bandgap and high transparency in the ultraviolet region.

Figure 6 shows the refractive index different concentration of zinc oxide. The refractive index of the three different concentrations of ZnO is relatively constant, with only small variations observed. As the wavelength increases, the refractive index decreases slightly. This behaviour is consistent with the well-known Sellmeier equation (Voronin & Zheltikov, 2017), which describes the relationship between the refractive index and the wavelength of a material.

Several studies have investigated the refractive index of ZnO thin films prepared by different methods, including sol-gel, sputtering, and pulsed laser deposition. For instance, a study by K. Khamis *et al*. (2020), investigated the optical properties of ZnO thin films prepared by sol-gel spin-coating technique. The authors observed a decrease in the refractive index with increasing wavelength, consistent with our results.

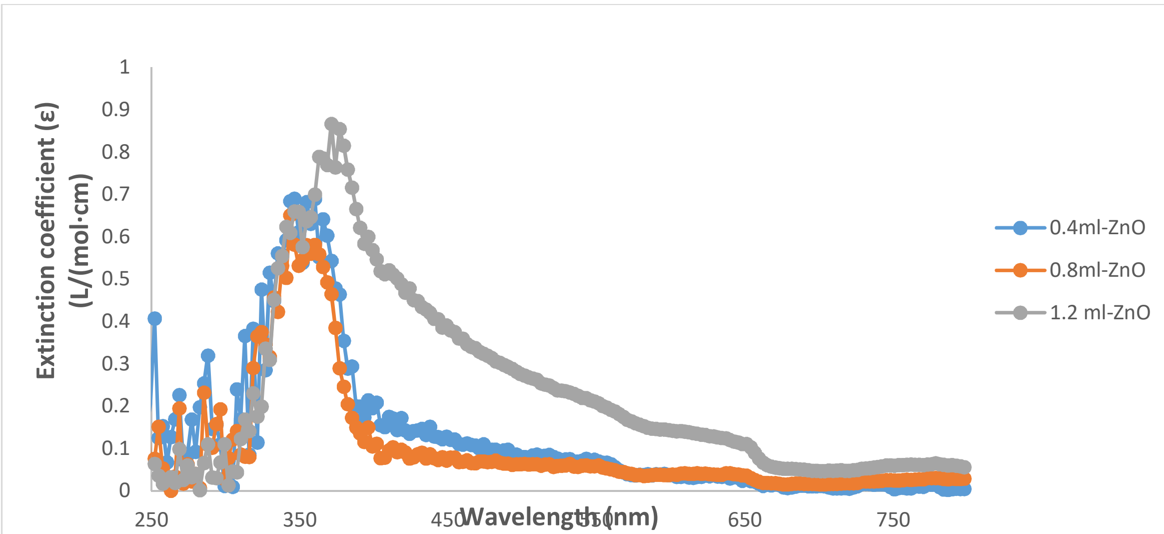

Figure 5: Extinction coefficient of different concentration of zinc oxide

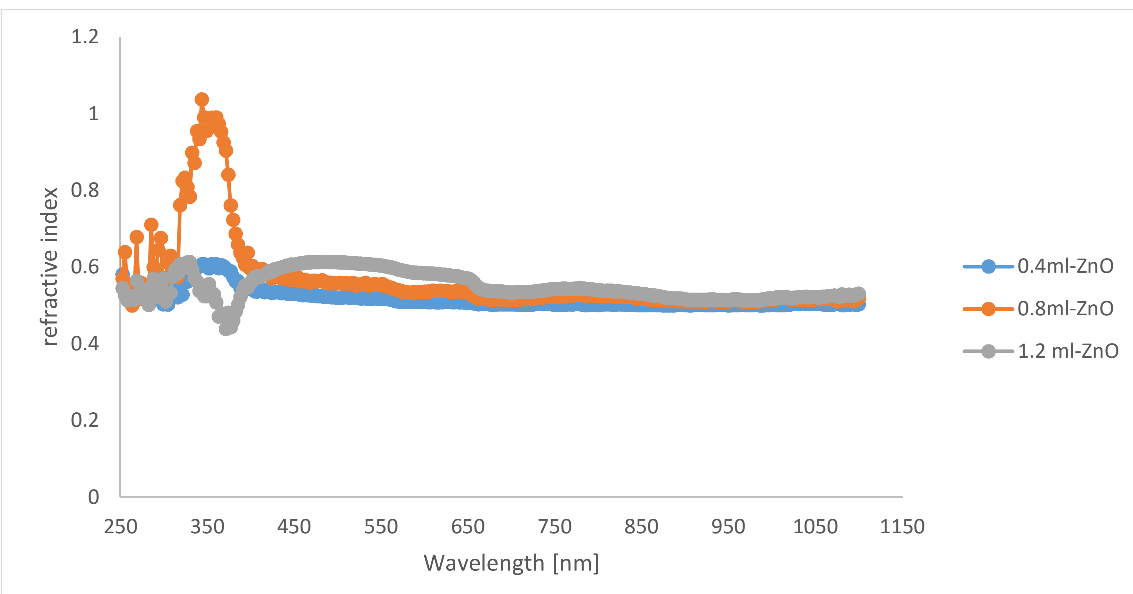

Figure 6: Refractive index different concentration of zinc oxide

The graphs in figures 7, 8 and 9 below show the relationship between $(\alpha h\nu)^{1/2}$ and hv for different concentrations of zinc oxide, where the concentration is indicated in the legend for each graph. The optical band gap was determined from the intercept of the x-axis with the tangent to the curve at the point of maximum slope, which is indicated by the arrow in each graph.

From the graphs, it was observed that the optical band gap of zinc oxide slightly increases with decreasing concentration. The optical band gap values range from 3.19 eV for a concentration of 1.2 ml to 3.2 eV for a concentration of 0.8 ml, with an intermediate value of 3.25 eV for a concentration of 0.4 ml.

This result is consistent with the findings of Dutta *et al*. (2008). They observed that the optical band gap of zinc oxide thin films increased slightly with decreasing sol concentration, which is consistent with the trend observed in the graphs above.

Overall, these results suggest that small changes in concentration can have a slight effect on the optical band gap of zinc oxide thin films, which may be relevant for their use in optoelectronic devices.

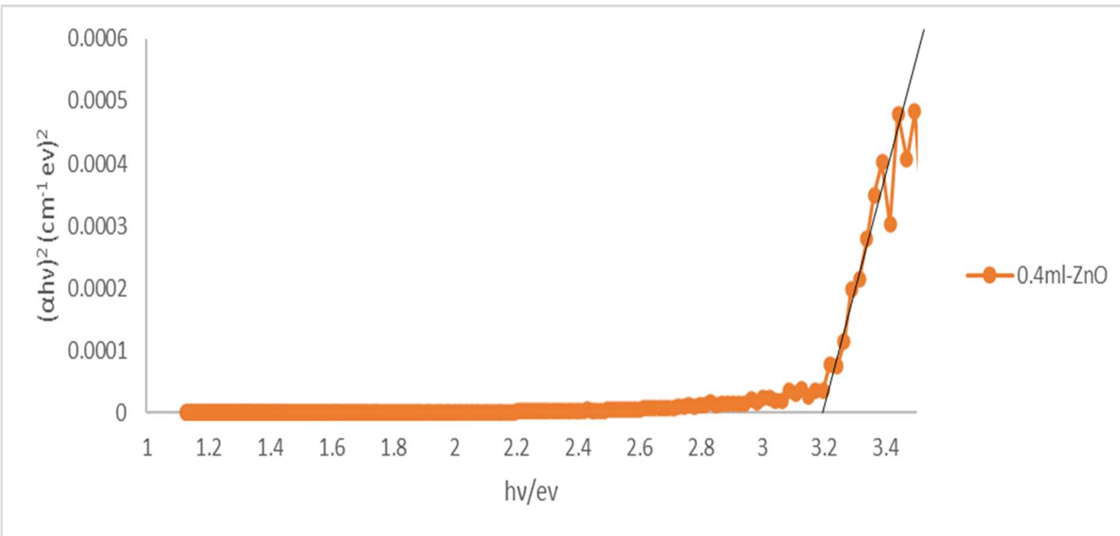

Figure 7: Optical absorption graph of 0.4ml-ZnO

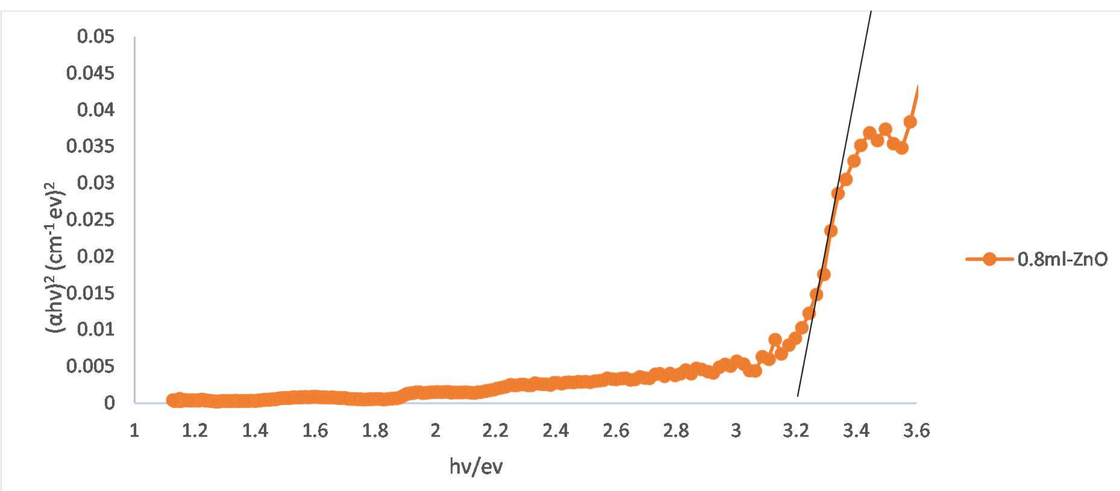

Figure 8: Optical absorption graph of 0.8ml-ZnO

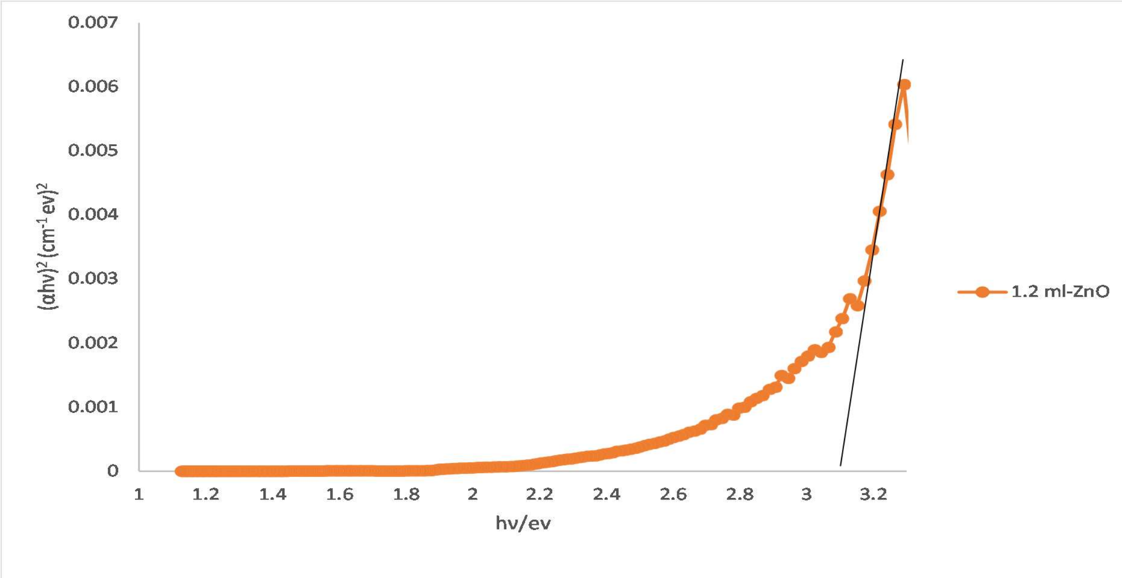

Figure 9: Optical absorption graph of 1.2ml-ZnO

Conclusion

the optical properties of different concentrations of zinc oxide (0.4ml, 0.8ml, 1.2ml), was determined through measurements of absorption spectra, transmittance spectra, reflectance spectra, absorption coefficient, extinction coefficient, and refractive index. The results indicate that the peak absorbance, absorption coefficient, and extinction coefficient increase with increasing concentration, while the transmittance spectra and reflectance spectra decrease slightly. The refractive index is relatively constant with small variations observed, consistent with the Sellmeier equation. These findings are consistent with previous studies and have implications for the use of ZnO in optoelectronic devices, where maximizing light absorption and transmittance is crucial.

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