



Article

Investigation and Study on the Optical and Electrical Properties of Polymeric Nanocomposites

Amer N. Jarad¹, Raed A. Dheyab²

1. Dept. Materials of Science, Polymer Research Centre, University of Basrah, 61004 Basrah, Iraq
 2. Chemical Engineering Department, College of Engineering, University of Basrah, Iraq
- * Correspondence: amer.jarad978@uobasrah.edu.iq, raed.dheyab@uobasrah.edu.iq

Abstract: This Study has prepared the conductive polymers (polyaniline) and their zinc oxide nanocomposites through in-situ polymerization in the presence of Ammonium Persulphate (APS) as the oxidizing agent. We examined the optical band gap of these PANi-ZnO nanocomposites at room temperature over various percentages of ZnO ranging between 10- 40 percent. The structure of the crystal of ZnO was verified to be hexagonal by the X-ray diffraction analysis. The use of Scherer formula calculated an average particle size of ZnO 38.27 nm. All the nanocomposites in terms of the weight percentages showed a characteristic ZnO peak of 375 nm in optical absorption spectroscopy. These extra absorption peaks at 300 nm and 400 nm also confirmed the presence of polyaniline. We also defined an electrical conductivity and dielectric properties and dielectric constant of the materials. These tests were conducted at room temperature and in the frequency range of 40Hz to 5MHz. This paper gives an in-depth study of the structural optical thermal and dielectric characteristics of Polyaniline/ZnO nanocomposites. These materials were produced in the first instance through in-situ polymerization method.

Keywords: Nanocomposites, PANI, Structures, UV-vis, Electrical Conductivity.

Citation: Jarad, A. N & Dheyab, R. A. Investigation and Study on the Optical and Electrical Properties of Polymeric Nanocomposites. Central Asian Journal of Medical and Natural Science 2026, 7(3), 351-358

Received: 10th Mar 2026

Revised: 21th Apr 2026

Accepted: 08th May 2026

Published: 02th June 2026



Copyright: © 2026 by the authors. Submitted for open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>)

1. Introduction

The electrical properties of intrinsically conductive polymers are highly prospective, and this makes it a possibility that they can be exploited in the future in energy storage applications [1], solar cells [2], electronic sensors [3] and electrochromic materials [4]. These applications have gained their attention in the materials science community. Development of the transport of electrical properties of polymer materials is becoming increasingly more relevant due to the huge potential provided by polymer materials in microelectronic devices. Similarly, carrying out polymers and polymer nanocomposites are today receiving a considerable share of focus due to the fact that they can be implemented to a range of electronic and electrical equipments. Under conducting polymer nanocomposites, addition of some amounts of elements which are more insulating may lead to generation of desirable property profiles. Polyaniline is one of the numerous conducting polymers that have been achieved so far and remains the most crucial one owing to its high conductivity, low cost, and easily produced nature in addition to its environmental stable characteristics [5].

This study was succeeded by another one that established that doping of these polymers results in major improvement in the electrical conductivity of the polymers. Figure 1 demonstrates that the protonated form of polyaniline chains in an ionic acid medium has similarities with both sulfonated and chloride forms in their structures as compared to ion-conducting polymers [6]. The attractive electrochemical and physicochemical characteristics of polyaniline make it ideal in microelectronic devices electrochemical supercapacitors batteries, bio sensors and gas sensors. Zinc oxide (ZnO) is a semiconducting substance, which has a direct wide band gap of 3.37eV and a large exciton binding

energy of 60meV at room temperature [7]. It is a non-toxic n-type semiconductor that is a good photocatalytic material. ZnO is a unique compound that has heterogeneous set of properties such as semiconducting and pyroelectric properties. As such, ZnO enjoyed an increase in demand in a number of applications like active materials in batteries [8], photo biosensors [9], optoelectronics [10] and gas sensors [11]. It was a work that entailed in-situ polymerization of aniline monomer with ZnO to produce PANi/ZnO nanocomposites. We made composites with varying weight percentages and gave them characterization in terms of X-ray diffraction (XRD) and UV-Visible spectroscopy. AC conductivity of these composites depending on temperature was also examined. The major aim is to doping ZnO into the polyaniline polymer chains. The aim of this process will be to obtain a new material that has useful physical characteristics that can be used in electronic applications.

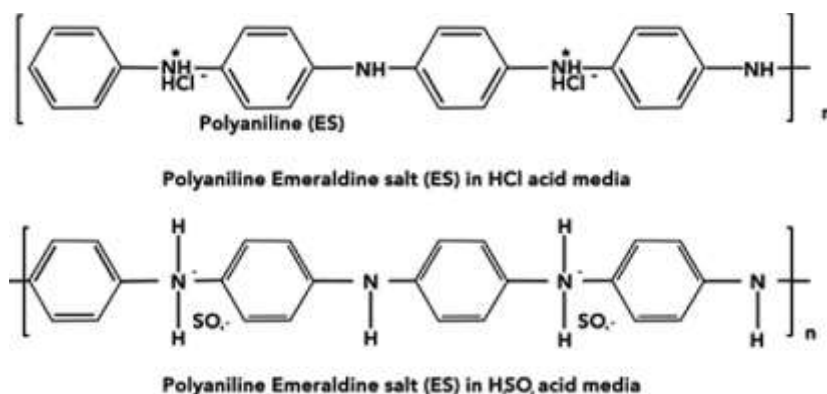


Fig.1: Transition electrons for conductive Polyaniline to $-Cl$ and $-SO_4$ [7].

2. Materials and Methods

2.1 CHEMICAL SUPPLEMENTS:

The current study used the next chemical materials grade chemicals which were all used without further purification. It used the following materials in this research; 93.13% Monomer Aniline (Merck), Ammonium Persulphate (APS) (Merck) as Oxidant agent, ZnO Nano powder (Adano Technology Pvt Ltd) Hydrochloric (HCl) and Sulphuric Acid (H₂SO₄) (Merck), Acetone and demineralized water. In the study and synthesis Polymer and nanocomposite we used.

2.2 MEASUREMENTS AND DEVICES:

The morphological structures of PANi and its nanocomposites were analysed by X-ray diffraction. The synthesized samples were analysed using XRD analysis on a diffractometer using a Cu-K alpha source of radiations of wavelength 1.54 Å. Data were measured in a range of 2 theta between 2 and 150. A Shimadzu 1800 UV-visible spectrophotometer was used to study optical properties. To characterize electrical properties, we made interdigitated electrodes using a shadow mask. The design has two contact electrodes that can be addressed separately and are highly sensitive in analysing the chemical structure of thin films. The following relation was used to evaluate surface conductivity:

$$\sigma_s = \left[\frac{I}{V} \right] \left[\frac{L}{Wt\ell} \right] \dots \dots \dots (1)$$

The kinematic equation in this case is t = the polymer film thickness L = the inter-electrode spacing W = the finger width elliptically and L = the number of electrode fingers. A precision impedance analyser was used to carry out dielectric studies. Such measurements were made in the range of frequencies ranging between 40 Hz and 5 MHz.

2.3 EXPERIMENTAL PROCEDURES:

2.3.1 Preparation Conducting Polymer:

The polyaniline was prepared chemically by oxidizing aniline monomer in situ by polymerization. Ammonium peroxydisulfate was used as a stimulating oxidizer and protonic acids HCl and H₂SO₄ as the stimulating reagents. The initial fabrication process

used one molar of hydrochloric acid stirred through fifteen minutes. In it, it was then mixed with aniline solution (0.1 molar) using Teflon-coated magnetic stirrer at an approximate temperature of -2° C. The molarity of a solution of the ammonium peroxydisulfate of 0.2 molarity of H_2SO_4 was taken.

This aniline mixture was drop wise added to this single molar acid solution. Polymerization of the mixture was then carried out in a round bottomed flask, and stirred. The temperature of the reaction was maintained during the polymerization process and recorded with time. The precipitate was dried and collected as polyaniline precipitates which were cleansed three times with 0.2 molar acid and 150 ml of acetone. The PANi was dried at room temperature of one hour and then annealed at 80 C in a vacuum oven over six hours in order to dry it without taking on moisture. The resulting product was emeraldine salt of a dark green conductive polymer. A fine powder was prepared in a mortar to obtain a fine powder of this PANi. Ground powder was dissolved to make thin film samples to be analyzed further.

2.3.2 Preparation of Polyaniline-ZnO Nanocomposites:

PANi-ZnO nanocomposites were created by an easy in-situ polymerization technique. The synthesis started by dissolving aniline, 0.1M in 1M H_2SO_4 to get aniline hydrochloride. The 10 to 40 percent percentages of zinc oxide nanoparticles were added to this solution and stirred over in twenty minutes. The suspension of ZnO nanoparticles was stirred using high intensity to achieve a homogeneous suspension of the particles in the solution. This mixture was stirred under dropwise addition of a 0.2M ammonium persulfate oxidant solution. This reaction took three hours at 6° C. The polymerization was maintained further four to six hours at about 5° C. The mixture of the reaction was then left in a dark room overnight to finish the process of polymerization. Filtration was used to obtain the resulting precipitate. The ethanol and demineralized water were added consecutively to the nanocomposite suspension until the filtrate turned to a clear color. The dried product was dried in an oven of twenty-four hours. Drying the product produced a fine powder by grinding. This process was able to create PANi-ZnO nanocomposites with different amounts of ZnO which ranged between 10 and 40 weight percent in polyaniline matrix.

3. Results and Discussion

3.1 Analysis of X-Ray Diffraction:

Figure 2 illustrates XRD of pure PANi and PANi-ZnO nanocomposites with 1040 weight percent of ZnO. Diffractometer with Cu-K alpha source of radiation was used to obtain the patterns in a range of 2θ -120 $^{\circ}$ and wavelength of 1.5460 A. The presence of a broad peak at 25.47° is an indicator of a largely amorphous structure of pure PANi. The origin of this peak is the dispersions that are perpendicular to the PANi chains as well as the features at lower angles that show periodicity that is parallel to the polymer chains. The XRD patterns of all the composite samples prove the existence of both PANi and ZnO nanoparticles. The continuous broad peak at 25.47° C in all the composites is an indication of the retained polymeric structure of PANi which has been attributed to the relatively lower concentration of incorporated ZnO. It is shown in Fig. 2 that the peak of the PANi intensification decreases significantly with the increase of the ZnO content. At the same time the ZnO diffraction peaks will be more intense. The composite profiles exhibit insignificant changes of the peak positions compared to pure PANi. This means that there is successful composite formation in which the ZnO nanoparticles cause a conformational change in the chains of polymer instead of an overall change in the basic structure of PANi. The analysis also shows that the availability of ZnO nanoparticles is associated with the enlargement in the crystal sizes and the reduction in the volume of the unit cell. These observations are good indications that the nanoparticles can be successfully incorporated into the polymer mesh of PANi [12].

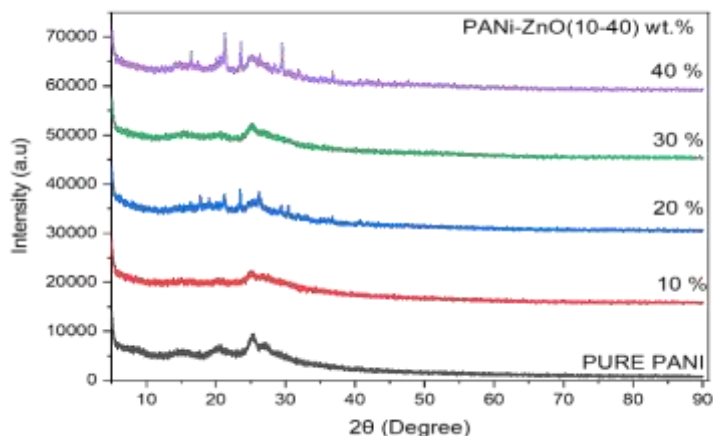


Fig 2. Pure PANi and PANi-ZnO nanocomposite of 10-40 wt%

3.2 Spectroscopy Analysis UV-Visible:

The ready samples of nanocomposites were subjected to UV- Vis absorption analysis on a Shimadzu UV-Visible Spectrophotometer Model Shimadzu 1800. The Tauc relation was used to obtain the energy gap of each sample.

The Tauc relation is expressed by the equation:

$$ahv = A(hv - E_g)^n \dots \dots \dots (2)$$

In this case E_g is the energy of optical band gap. It is the absorption coefficient which is defined as the absorbance of the sample such that the absorption coefficient is the product of $1/t$ and A . The parameter n denotes the nature of electronic transition. In the case of direct band gap semiconductors such as these materials $n = 2$.

The UV-Vis spectra are given in figure 3. Characteristic absorption peaks of PANi in the pure state are at 371 nm 432 nm and 609 nm. The highest peak at 371 nm is attributed to an electronic transition of π -5. This entails the movement of an electron between the highest occupied and the lowest unoccupied molecular orbital of the benzenoid ring and the quinoid ring respectively, along the polymer chain. The peaks at 432 nm and 609 nm are assumed to be the result of polaron transitions. These represent excitation of the polaron quinoid state into the polaron benzenoid π + state. PANi-ZnO nanocomposite spectra had almost similar absorption bands. The red shift of these bands was very slight in comparison with pure PANi. This slight change is attributed to the reactions of the pure PANi polymer chains with the ZnO nanoparticles a finding also consistent with literature [13].

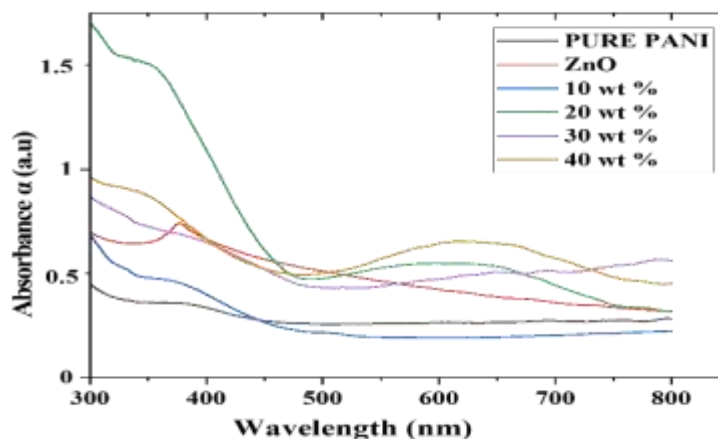


Fig 3. Absorption spectra of PANi and nanocomposites PANi -ZnO after preparation

Figure 4 shows the UV absorption spectra of pure ZnO nanoparticles. The absorption spectrum was taken between the wavelengths of 100 and 800 nm. Pure ZnO nanoparticles are transparent to most of the optical transitions in the UV-visible range. There is a high absorption value at 300-400 nm. This property is explained by the narrow absorption band at around 375 nm being the result of direct transition of electrons directly inside ZnO nanocrystals that also explains the high exciton binding energy of the material [14]. To measure the optical absorption coefficient α of the recorded spectra we used the following relation that takes into consideration the loss of reflection:

$$\alpha(\nu) = 2.303 \frac{A}{d} \dots \dots \dots (3)$$

In the equation we have A as the measured absorbance and d as the sample thickness. Optical absorption analysis is an important critical technique of studying the band structure. Figure 4 shows a Tauc plot of $(\alpha h\nu)^2$ to photon energy in eV. The optical band gap energy of the pure ZnO nanoparticles was found using this plot. The determination was done by extrapolation of the straight-line part of the curve in the Tauc plot to the intersection with the x-axis.

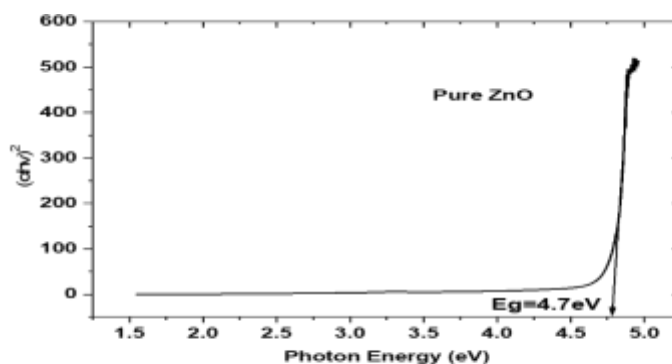


Fig 4. Plot of photon energy of pure ZnO nanoparticles

3.3 Electrical Properties:

3.3.1 AC Conductivity Analysis:

Figure 5 displays the conductivity of the conductive polymer and the nanocomposites of this conductive polymer with frequency at room temperature in AC. Dielectric data was used to calculate the electrical property of AC conductivity (σ_{AC}). The findings revealed that σ_{AC} of pure PANi and the PANi-ZnO nanocomposites do not change with the frequency to 7 Hz. At higher frequencies the conductivity is greater beyond this point. This conductivity increase is explained by the presence of interfacial polarization that is enhanced by the percentage of weight of ZnO nanoparticles in the polyaniline matrix. The PANi-ZnO nanocomposite of 20 wt% had the best conductivity. On the contrary, the AC conductivity declined with the 10% 30 percent and 40 percent weight compositions. This decrease is probably a result of the dipole polarization effects, which prevail at these particular loadings. These results are in line with what has been already reported works [15, 16].

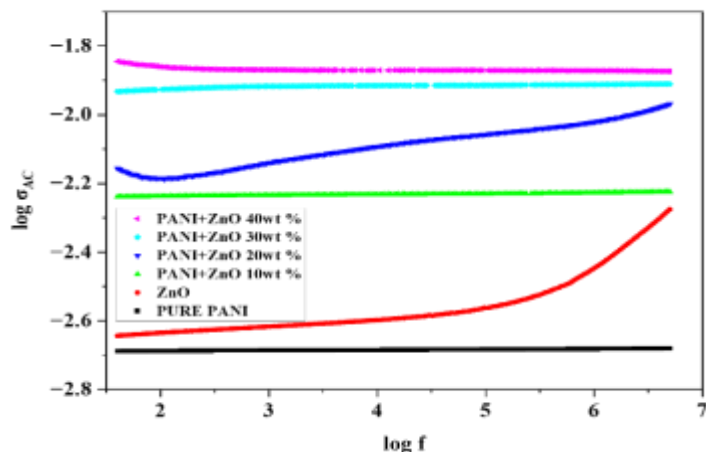


Fig 5. AC conductivity for PANI and nanocomposites samples.

3.2.2 Dielectric Properties:

Dielectric properties of all polymer and nanocomposites samples were investigated depending on frequency at room temperature. Parallel capacitance was determined on pelletized samples at a frequency range of 40 Hz to 5 MHz. Relation (4) was then used to obtain the dielectric constant of pure and doped nanocomposites [17].

$$\epsilon = Cd / \epsilon_0 A \dots\dots\dots(4)$$

where ϵ_0 is the free space permittivity ($8.854 \times 10^{-12} \text{F/m}$), d is the thickness of the sample, A is the area of cross section.

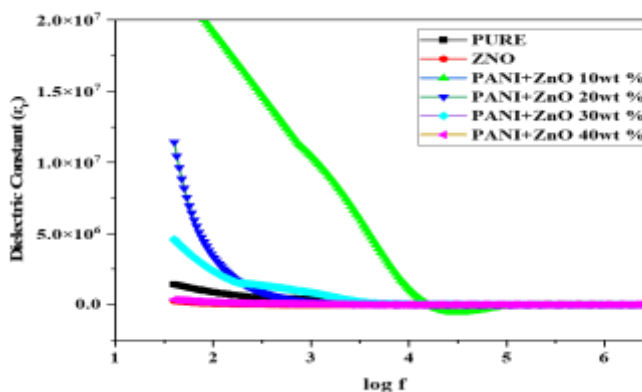


Fig 6. Dielectric constant ϵ' for polymer and nanocomposites with frequency

Figure 6 depicts how the dielectric constant varies with frequency of different percentages weight of nanocomposites. High values of the dielectric constant at low frequencies are found in all the compositions except the 30 wt% sample. This value reduces steadily with the frequency applied. The 10 percent and 20 percent weight structures exhibit a very large dielectric constant in the low frequencies which drops off linearly in the sampled frequency range. This attribute behavior is probably due to a comparable relaxation process as in the Debye model that takes place in these materials.

4. Conclusion

To conclude, we have been able to synthesize polymer-nanocomposites through in-situ polymerization of aniline hydrochloride. The preparation included the following

weight percentages of zinc oxide nanoparticles, ammonium persulfate, which was used as an oxidizing agent. We described the materials obtained with X-ray diffraction UV-visible spectroscopy measurements of AC conductivity and dielectric property. The amorphous character of the polyaniline matrix was confirmed by the XRD analysis, and so was the crystalline structure of the zinc oxide nanoparticles. It led to an average ZnO particle size of 38.26 nm using the Debye-Scherrer relation. Characteristic polyaniline peaks were seen in optical studies at 375 nm. The band gap used in measuring the ZnO nanoparticles was 4.7 eV. Electrical characterization indicated that the AC conductivity rises with the frequency. The maximum conductivity improvement on the nanocomposite was observed at 20 wt% that is associated with enhanced disorder on the composite. Dielectric measurements between a frequency of 40 Hz and 5 MHz were shown to exhibit a Debye-type relaxation whereby the dielectric constant decreases as the frequency increases. These PANi-ZnO nanocomposites have the following properties, which imply that they could form a good candidate to be used practically. Potential applications are capacitors gas sensors and other optoelectronic equipment's.

REFERENCES

- [1] S. Abbas et al., "Facile synthesis of rGO/PANI/ZnO ternary nanocomposites for energy storage devices," *Journal of the Korean Ceramic Society*, vol. 60, pp. 127–140, 2023, doi: 10.1007/s43207-022-00250-9.
- [2] A. Saaedi and P. Shabani, "High performance of methanol gas sensing of ZnO/PANI nanocomposites synthesized under different magnetic field," *Journal of Alloys and Compounds*, vol. 802, pp. 335–344, 2019, doi: 10.1016/j.jallcom.2019.06.088.
- [3] S. Vijayalakshmi et al., "Structural, electrical, and photocatalytic investigations of PANI/ZnO nanocomposites," *Ionics*, vol. 27, pp. 2967–2977, 2021, doi: 10.1007/s11581-021-04041-w.
- [4] K. Daideche, L. Hasniou, and D. Lerari, "Electrosynthesis and characterization of PANI and PANI/ZnO composite films," *Chemistry Proceedings*, vol. 3, no. 1, 2021.
- [5] S. Mutabar et al., "Structural, optical and impedance spectroscopy study of thin film of polyaniline (PANI/ZnO) nanocomposite," *Materials Research Express*, vol. 7, no. 1, 2020, doi: 10.1088/2053-1591/ab5d7e.
- [6] S. M. Hassan, A. G. Baker, and H. I. Jafaar, "A.C. electrical conductivity for polyaniline prepared in different acidic medium," *International Journal of Basic and Applied Science*, vol. 1, no. 2, pp. 352–362, 2012.
- [7] H. D. Kyomuhimbo, I. N. Michira, E. I. Iwuoha, and U. Feleni, "Electroconductive polyaniline-Ag-ZnO green nanocomposite material," *Processes*, vol. 10, no. 3, 2022.
- [8] L. G. Lijin, "Facile electrochemical synthesis of rGO/PANI/ZnO heterostructure for energy storage applications," *Materials Today Proceedings*, 2023.
- [9] H. A. Matar, I. A. Medhat, and M. El-Hagary, "Simple and cost-effective route for PANI-ZnO-rGO nanocomposite as a biosensor for L-arginine detection," *Diamond and Related Materials*, vol. 133, 2023.
- [10] A. Alamgeer et al., "Polyaniline/ZnO hybrid nanocomposite: Morphology, spectroscopy and optimization of ZnO concentration for photovoltaic applications," *Polymers*, vol. 15, no. 2, 2023, doi: 10.3390/polym15020363.
- [11] M. B. Maryam et al., "Enhanced NO₂ gas sensing properties of ZnO-PANI composite nanofibers," *Ceramics International*, vol. 49, no. 1, pp. 1238–1249, 2023, doi: 10.1016/j.ceramint.2022.09.103.
- [12] A. T. Dipak et al., "ZnO-PANI nanocomposite: Enhanced electrochemical performance towards energy storage," *Journal of Energy Storage*, vol. 81, 2024, doi: 10.1016/j.est.2024.110434.
- [13] N. Sannakki et al., "Synthesis and characterization of PANI/PVDF composites for dielectric and AC conductivity," *Journal of Nanoscience and Technology*, vol. 4, no. 5, pp. 516–518, 2018.
- [14] A. Bouaine et al., "Structural, optical, and magnetic properties of Co-doped SnO₂ powders synthesized by the coprecipitation technique," *Journal of Physical Chemistry C*, vol. 111, no. 7, 2007, doi: 10.1021/jp066897p.
- [15] M. Beygisangchin et al., "Recent progress in polyaniline and its composites: Synthesis, properties and applications," *European Polymer Journal*, vol. 210, 2024, doi: 10.1016/j.eurpolymj.2024.112948.
- [16] S. M. Elkatlawy et al., "Optimized PVA-(ZnO)_x-(PANI)_{1-x} nanocomposites: characterization and humidity sensing application," *Journal of Materials Science: Materials in Electronics*, vol. 35, 2024, doi: 10.1007/s10854-024-13934-1.

-
- [17] P. S. Kanavi et al., "Temperature dependent electrical properties of ZnO/PVA/PANI nanocomposite films," *Open Nano*, vol. 7, 2022, doi: 10.1016/j.onano.2022.200020.