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Structural and Magnetic Properties of Polyaniline-CuO Nanocomposites for Advanced Sensing Applications

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ABSTRACT

This research presents a novel exploration into the structural and magnetic characteristics of Polyaniline/CuO (PANI/CuO) nanocomposites, with a focus on their potential utility in sensor-based technologies. The synthesis involved chemical preparation of both polyaniline and copper oxide nanoparticles, followed by the formation of composites using an ex-situ blending technique. The resulting materials were characterized using X-Ray Diffraction (XRD) to examine crystalline structures, Scanning Electron Microscopy (SEM) to observe surface morphology, Fourier Transform Infrared Spectroscopy (FTIR) to identify functional groups, and Vibrating Sample Magnetometry (VSM) to analyze magnetic behavior. The key magnetic parameters—saturation magnetization, remanent magnetization, and coercivity—were successfully evaluated. The findings reveal that the incorporation of CuO significantly enhances the magnetic response of polyaniline, positioning the composite as a strong candidate for application in magnetic and electrochemical sensing devices.

Keywords: Polyaniline, copper oxide, nanocomposite, magnetic behavior, structural analysis, sensing applications, conducting polymers

INTRODUCTION

The emergence of nanocomposite materials combining polymers with metal oxides has sparked widespread interest across diverse scientific fields, particularly in the development of next-generation sensing systems. These hybrid materials, formed by integrating inorganic nanoparticles with organic polymers, exhibit exceptional properties that stem from the synergistic interaction at the molecular interface. Enhanced conductivity, tailored surface chemistry, and mechanical strength are among the features that make them ideal for electronic and environmental sensor applications. Conducting polymers have carved a unique space in materials science, thanks to their tunable electrical behavior, low processing costs, and environmental stability. Among these, polyaniline (PANI) has gained considerable attention due to its adjustable conductivity, ease of synthesis, and suitability for doping. It has been widely used in devices ranging from gas sensors and energy storage systems to biosensors and electromagnetic shielding. Incorporating metal oxide nanoparticles into the PANI matrix further amplifies its functional properties. Copper oxide (CuO), a transition metal oxide with favorable electronic structure and stability, stands out due to its compatibility with polymers and its intrinsic semiconducting and magnetic characteristics. CuO is widely known for enhancing the performance of composites in applications such as gas detection, antimicrobial coatings, batteries, and magnetic storage. When CuO is combined with PANI, the resulting nanocomposite benefits from both the conductive framework of the polymer and the active surface of the metal oxide. This hybrid structure not only improves electrical and thermal behavior but also introduces magnetic features that can be harnessed in sensor technology. Such materials are particularly promising for multifunctional sensing platforms where magnetic sensitivity can enhance selectivity and performance.

This study investigates the synthesis of PANI/CuO nanocomposites through a chemical precipitation method, followed by detailed characterization to evaluate the impact of CuO integration on their structural and magnetic properties. The results provide new insights into how these composites can be engineered for improved sensing capabilities, making them viable for real-world applications in environmental monitoring and smart electronics.

EXPERIMENTAL

Materials and Methods

All chemicals used in the synthesis were of analytical grade and used without further purification. Aniline monomer, ferric chloride ($FeCl_3$), acetone, and copper(II) chloride hexahydrate ($CuCl_2 \cdot 6H_2O$) were sourced from standard

chemical suppliers. Distilled water was used throughout the experimental processes for washing and solution preparation.

Synthesis Procedures

a) Synthesis of Polyaniline (PANI)

Polyaniline was synthesized via oxidative chemical polymerization. Initially, 2 mL of freshly distilled aniline monomer was dissolved in 50 mL of 0.1 M hydrochloric acid (HCl) under continuous magnetic stirring to ensure complete dispersion. Separately, 3.5 g of ferric chloride ($FeCl_3$) was dissolved in 50 mL of distilled water to serve as the oxidizing agent. This $FeCl_3$ solution was then added gradually to the aniline mixture under constant stirring, and the reaction was allowed to proceed for 5 hours at room temperature. The resulting dark green polymer precipitate was filtered, repeatedly washed with distilled water to remove impurities, and dried in an oven at 100 °C to obtain the final PANI powder.

b) Preparation of Copper Oxide (CuO) Nanoparticles

Copper oxide nanoparticles were prepared using a simple precipitation method. An aqueous solution of copper(II) chloride was reacted with sodium hydroxide (NaOH), which was added slowly in a 1:1 molar ratio under vigorous stirring. As the pH increased, a black precipitate corresponding to copper oxide began to form. The precipitate was separated by filtration, thoroughly rinsed with distilled water to remove residual salts, and dried in a hot air oven at 100 °C. The dried mass was finely ground and subsequently calcined at 450 °C for 2 hours in a muffle furnace to enhance crystallinity.

c) Synthesis of PANI/CuO Nanocomposites

The PANI/CuO composites were synthesized using an ex-situ blending technique. Equal proportions (1:1 ratio by weight) of synthesized PANI and CuO nanopowders were dispersed in acetone and mixed thoroughly to ensure uniform distribution. The mixture was subjected to mild stirring and sonication to enhance particle interaction. The resultant composite was dried at 100 °C for one hour to evaporate the solvent and obtain the final nanocomposite material, which was then used for further characterization.

RESULTS AND DISCUSSIONS

X-ray Diffraction Analysis

The crystalline structure of the synthesized materials was examined using Powder X-ray Diffraction (XRD), performed on a Rigaku Miniflex diffractometer equipped with CuKα radiation (λ = 1.5406 Å). Data were collected over a 2θ range of 10° to 80° with a step size of 0.02° per second. The XRD pattern of pure polyaniline (PANI) displays a broad and diffuse peak centered around 2θ ≈ 25°, indicating its predominantly amorphous nature. This broad hump is characteristic of disordered polymer chains lacking long-range crystallinity.

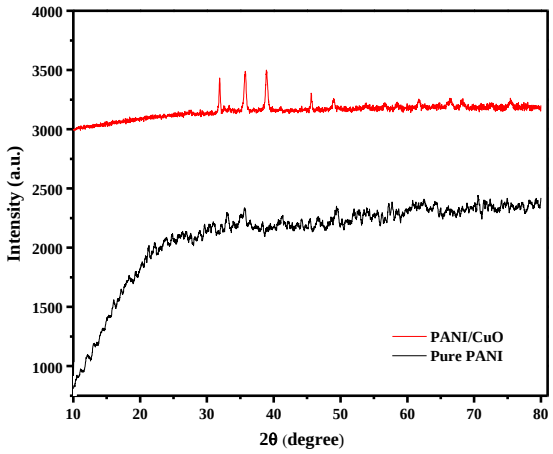

Figure 1: **XRD patterns of PANI/CuO nanocomposites.**

In contrast, the XRD spectrum of the PANI/CuO nanocomposite exhibits several sharp diffraction peaks, notably at 2θ values of approximately 39°, 66°, and 75°. These peaks correspond to the crystalline planes of monoclinic CuO and align well with the standard data reported in JCPDS card No. 41-0254, confirming the successful incorporation and retention of CuO's crystalline structure within the composite matrix. Importantly, no additional peaks were observed in the XRD pattern, indicating the absence of secondary phases or impurities. Moreover, the presence of PANI does not appear to disrupt or alter the crystal structure of CuO, suggesting a stable physical interaction between the polymer and metal oxide components rather than any significant chemical transformation. These results affirm the formation of a

nanocomposite where the crystalline characteristics of CuO are preserved within the amorphous PANI matrix, which is favorable for enhanced functional properties.

Scanning Electron Microscopy (SEM) Analysis

Scanning Electron Microscopy (SEM) was employed to investigate the surface morphology and microstructural features of the synthesized nanoparticles and nanocomposites. The SEM images of pure CuO and polyaniline (PANI) nanoparticles are presented in Figures 2. The SEM micrograph of the CuO sample reveals that the nanoparticles are predominantly spherical in shape and tend to form agglomerated clusters. These clusters exhibit a rough surface texture, likely due to the accumulation of multiple nanocrystallites. Such aggregation is commonly observed in metal oxide nanoparticles as a result of their high surface energy. In the case of polyaniline, the SEM image displays an amorphous and irregular morphology. The polymer appears to form interconnected grain-like structures with no long-range order. This interconnected network facilitates better electron transport, which is advantageous for sensing and conductive applications. Overall, the SEM analysis confirms the formation of distinct morphologies for CuO and PANI, with CuO showing nanocrystalline aggregation and PANI displaying an amorphous, interconnected structure. These morphological features play a vital role in determining the physical and functional behavior of the resulting nanocomposites.

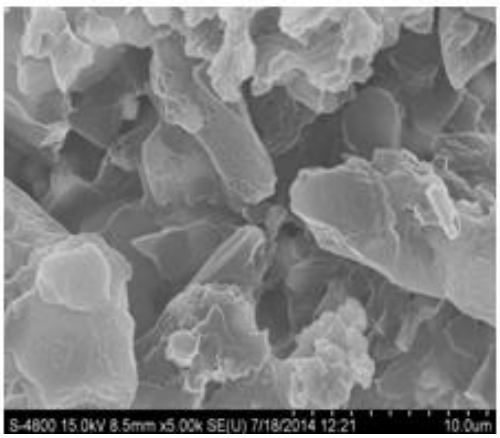

Figure 2: SEM micrographs of synthesized PANI/CuO nanocomposite.

Fourier Transform Infrared Spectroscopy (FTIR) Analysis

Fourier Transform Infrared (FTIR) spectroscopy was utilized to verify the formation of metal oxide structures and to confirm the successful polymerization of polyaniline (PANI). The spectra were recorded in the range of 500–4000 cm^{-1} for the pure materials and their corresponding composites. The FTIR spectrum of pure PANI displays characteristic peaks corresponding to functional groups associated with the polymer backbone. These include peaks around 3211 cm^{-1} and 3139 cm^{-1} attributed to N–H stretching vibrations and hydrogen bonding, as well as strong absorption bands near 1626 cm^{-1} and 1403 cm^{-1} due to N–H bending and C–N stretching of aromatic amines, respectively. In the spectrum of PANI/CuO nanocomposites, similar bands appear with slight shifts—indicative of interactions between PANI and the metal oxide nanoparticles. Notably, peaks around 3356 cm^{-1} and 3444 cm^{-1} suggest intermolecular hydrogen bonding and free N–H stretching. Peaks at lower wavenumbers, such as 595 cm^{-1} and 426 cm^{-1}, are associated with out-of-plane bending vibrations of substituted benzene rings and metal-oxygen bonding, confirming the incorporation of CuO. These spectral features confirm the successful synthesis of PANI and its effective interaction with CuO nanoparticles in the composite matrix.

Table 1: Key FTIR absorption bands for pure PANI and PANI/CuO nanocomposites

Wavenumber (cm^{-1})	Band Assignment
3211.56 / 3356.14	Intermolecular O–H hydrogen bonding
3139.42 / 3444.87	Free N–H stretching vibration
1626.39 / 1508.33	N–H bending vibration
1403.77 / 1317.38	C–N stretching (aromatic amine)
797.73 / 840.96	C–C stretching vibrations
595.72 / 426.27	Benzene ring out-of-plane bending / Cu–O vibration
2269.75 / 2258.94	C≡N stretching vibration
698.79 / 840.96	Aromatic C–H out-of-plane bending

Magnetic Properties Analysis (VSM)

To explore the magnetic behavior of the synthesized nanocomposites, Vibrating Sample Magnetometry (VSM) measurements were performed at room temperature (298 K). The hysteresis loop for the PANI/CuO nanocomposite is shown in Figure 3.

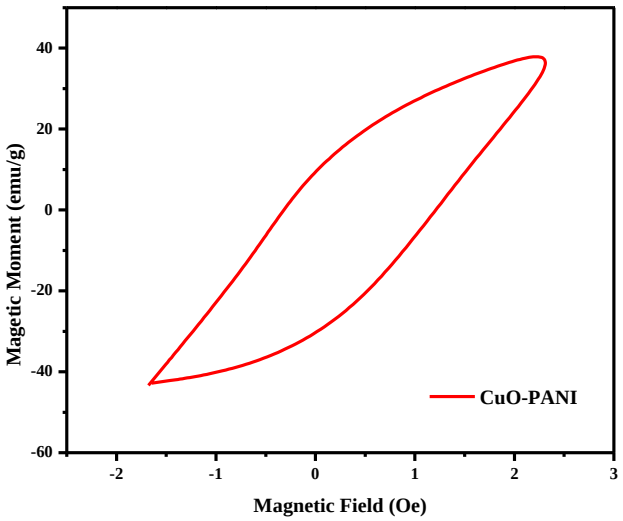

Figure 3: **XRD patterns of PANI/CuO nanocomposites.**

The loop exhibits typical ferromagnetic behavior, characterized by distinct values of coercivity (Hc), remanent magnetization (Mr), and saturation magnetization (Ms). The presence of a narrow but well-defined hysteresis loop signifies that the composite retains magnetization even after the external magnetic field is removed, indicating its ferromagnetic nature.These magnetic parameters, extracted from the hysteresis curve, demonstrate the successful incorporation of CuO nanoparticles into the PANI matrix, resulting in an enhancement of the magnetic properties. This behavior makes the composite suitable for potential applications in magnetic storage, sensors, and spintronic devices.

CONCLUSION

In this study, polyaniline (PANI), copper oxide (CuO) nanoparticles, and their nanocomposites were successfully synthesized using a straightforward chemical polymerization and ex-situ composite formation method. Structural, morphological, and magnetic characterizations were carried out using XRD, SEM, FTIR, and VSM techniques. X-ray diffraction analysis confirmed the amorphous nature of PANI and the crystalline structure of CuO, with no evidence of impurities, indicating the purity of the synthesized materials. SEM images revealed that CuO nanoparticles exhibited a roughly spherical morphology with agglomerated structures, while PANI displayed an amorphous texture with interconnected grains. The nanocomposites retained the structural integrity of the individual components while forming a well-blended matrix. FTIR spectroscopy further confirmed the successful polymerization of PANI and its interaction with CuO through the observation of characteristic absorption bands. These spectral features validated the formation of chemical bonds and the incorporation of metal oxide into the polymer matrix. Magnetic measurements using VSM demonstrated clear ferromagnetic behavior in the PANI/CuO nanocomposites, characterized by significant coercivity and remanent magnetization values. This enhancement in magnetic properties suggests promising potential for applications in sensors, magnetic storage devices, and electromagnetic shielding materials. Overall, the synthesized PANI/CuO nanocomposites exhibit a unique combination of electrical, structural, and magnetic properties, making them promising candidates for advanced multifunctional applications.

REFERENCES

[1]. MacDiarmid AG, Epstein AJ. Polyanilines: A novel class of conducting polymers. Faraday Discuss Chem Soc. 1989;88:317–332.
[2]. Wang Y, Jing X. Intrinsically conducting polymers for electromagnetic interference shielding. Polym Adv Technol. 2005;16(4):344–351.
[3]. Zhang X, Lei L, Liu H, et al. Preparation and characterization of CuO nanoparticles and their catalytic activity. Mater Lett. 2007;61(10):1860–1863.
[4]. Stejskal J, Gilbert RG. Polyaniline. Preparation of a conducting polymer. Pure Appl Chem. 2002;74(5):857–867.
[5]. Li Y, Cao Y, Li H, et al. Synthesis and magnetic properties of CuO/PANI nanocomposites. J Magn Magn Mater. 2011;323(23):2953–2957.

[6]. Armes SP. Optimum reaction conditions for the polymerization of aniline in acidic media. Synth Met. 1987;20(3):365–371.
[7]. Dhawale DS, Pawar SM, Lokhande CD. Chemical synthesis of CuO thin films for supercapacitor application. Appl Surf Sci. 2009;255(6):2603–2607.
[8]. Singh P, Mishra M. Structural, thermal and morphological studies of CuO-polyaniline nanocomposites. J Mater Sci Mater Electron. 2014;25(1):302–307.
[9]. Li X, Zeng Y, Cheng Y, et al. Magnetic and dielectric behavior of polyaniline–CuO nanocomposites. Mater Chem Phys. 2016;173:429–435.
[10]. Gospodinova N, Terlemezyan L. Conducting polymers prepared by oxidative polymerization: Polyaniline. Prog Polym Sci. 1998;23(8):1443–1484.
[11]. Patil SL, Kumbhar SS, Shaikh JS, et al. Nanocrystalline CuO synthesized by combustion method for antibacterial applications. Mater Res Bull. 2013;48(9):3400–3405.
[12]. Rahman MM, Jamal A. Nanostructured polyaniline/CuO composite for photocatalytic degradation of textile dye. J Nanostruct Chem. 2013;3(1):72.
[13]. Kulkarni MV, Patel R, Mhaske ST. Characterization of polyaniline–metal oxide nanocomposites using FTIR and SEM techniques. Indian J Chem Technol. 2009;16:388–392.
[14]. Rakhshani AE. Preparation, characteristics and photovoltaic properties of CuO thin films. Sol Energy. 1986;42(4):323–333.
[15]. Sathish M, Viswanathan B. FTIR and magnetic studies on PANI/CuO nanocomposites. Bull Mater Sci. 2010;33(1):61–67.