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Synthesis and characterization of Ag–ZnO nanocomposites

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This study focuses on synthesizing a hybrid nanocomposite of silver (Ag) and zinc oxide (ZnO) by utilizing their bulk salts as precursors to form the Ag–ZnO nanocomposite. Silver (Ag) and zinc oxide (ZnO) nanoparticles are synthesized via a chemical reduction method, followed by co-mixing and calcination processes to produce the Ag–ZnO nanocomposite. The synthesized nanoparticles are characterized using scanning electron microscope (SEM), high resolution (HRXRD), and energy dispersive X-Ray (EDX) to determine their morphological attributes, crystallographic structure, and elemental composition. The crystallinity pattern revealed distinct reflections corresponding to face-centered cubic (FCC) silver (Ag) and zinc oxide (ZnO) nanoparticles. The XRD peaks of the Ag–ZnO heterostructure confirmed its formation, which aligns well with SEM images. These images demonstrated isotropic Ag–ZnO structures under certain conditions and anisotropic Ag–ZnO structures under others, reflecting the influence of varying synthesis parameters on the material's morphology.

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1. Introduction

Nanomaterials have gained significant attention across various fields in recent years due to their exceptional physical, chemical, and optical properties [1]. The term "nanomaterials" encompasses two primary definitions. Firstly, they refer to materials with at least one dimension smaller than 100 nm, such as nanoparticles, nanowires, and nanofilms [2]. Alternatively, the term applies to materials where the structural unit size of the entire material, such as crystal grains or particle diameters, is less than 100 nm, as seen in nanocrystalline alloys.

Secondly, nanomaterials display exceptional properties at the nanoscale that significantly differ from those of conventional materials. These unique characteristics, including enhanced mechanical strength, superior electrical conductivity, and distinctive optical behavior, stem from quantum effects and the increased surface-area-to-volume ratio inherent at the nanoscale. This results in a range of novel behaviors, such as improved reactivity, light absorption, and charge transport, which are not observed in bulk materials. These properties make nanomaterials highly attractive for a variety of advanced technological applications.

The field of nanomaterials has rapidly advanced into a dynamic and rapidly growing area within nanotechnology. Their unique properties and versatility have established them as critical enablers of technological progress across a wide range of sectors, including energy, healthcare, electronics, and environmental science. By harnessing these remarkable characteristics, nanomaterials are driving innovations that are transforming industries and enabling the development of cutting-edge solutions to complex global challenges.

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ZnO is a wide-bandgap semiconductor known for its exceptional optical and electronic properties [3]. When combined with other materials to form nanocomposites, these properties can be precisely tuned to suit specific applications. The ability to engineer the bandgap, along with enhancing characteristics such as photoluminescence, electrical conductivity, and thermal stability, makes ZnO nanocomposites highly versatile [4]. Additionally, their nanoscale size results in a high surface-area-to-volume ratio, which is crucial for processes like catalysis, sensing, and energy storage [5]. These distinctive features create opportunities for developing advanced materials that meet the evolving demands of modern technology [6].

The significance of zinc oxide nanocomposites lies in their potential to tackle some of the most urgent challenges of our time, including environmental degradation, energy scarcity, and the demand for advanced medical solutions [7]. Their unique properties, such as enhanced conductivity, photocatalytic activity, and biocompatibility, combined with their versatility, make them essential in a wide array of cutting-edge technologies [8]. As research progresses, ZnO nanocomposites are poised to play an increasingly critical role in driving sustainable innovations and shaping the future of technological advancements across various sectors, benefiting generations to come [9].

2. Experiment

The materials used in this study included silver acetate, zinc acetate dihydrate, sodium citrate, ascorbic acid, sodium hydroxide, and ethanol. All reagents were sourced commercially from Sigma-Aldrich and were used as received, without any additional purification.

The zinc oxide nanocomposite was synthesized by dissolving sodium hydroxide and stirring the solution at an elevated temperature of 55°C. A prepared zinc acetate solution was added dropwise over a period of 40 minutes into the heated sodium hydroxide solution while maintaining high-speed stirring. The resulting ZnO nanoparticles were thoroughly washed multiple times with absolute ethanol and distilled water to remove impurities, and then air-dried at 60°C for 3 hours.

The synthesized silver nanoparticles were stirred at 70°C using a magnetic stirrer to obtain a homogeneous solution. The zinc oxide nanocomposite solution was then added dropwise to the silver nanoparticle solution, and the mixture was stirred vigorously at high speed for 30 minutes. The resulting solution was centrifuged at 4400 rpm for 10 minutes at room temperature, yielding a brown precipitate and a supernatant. The supernatant was carefully decanted, and the nanocomposite was dried at 80°C for 5 hours. Finally, the dried nanocomposite was calcined at 300°C for 2 hours in a furnace to enhance its structural properties. The X-ray diffraction patterns were recorded using X-ray diffractomer. The scanning electron microscopy studies were carried out.

3. Results and discussion

The preparation of the Ag–ZnO nanocomposite was followed by comprehensive characterization using techniques such as Energy Dispersive X-ray (EDX) spectroscopy, X-ray diffraction (XRD), and Scanning Electron Microscopy (SEM). Figure 1 displays the EDX spectrum for the Ag/ZnO nanocomposite, highlighting the presence of three key elements. The carbon (C) signal corresponds to the structural matrix, while the oxygen (O) and silver (Ag) peaks confirm the presence of zinc oxide and silver in the nanocomposite. The spectrum thus validates the composition of Ag, O, and C within the material. The optimal annealing temperature was determined to be 500°C through careful analysis, with an annealing duration of 1 hour recommended to prevent damage to the surface pore structure caused by rapid temperature increases.

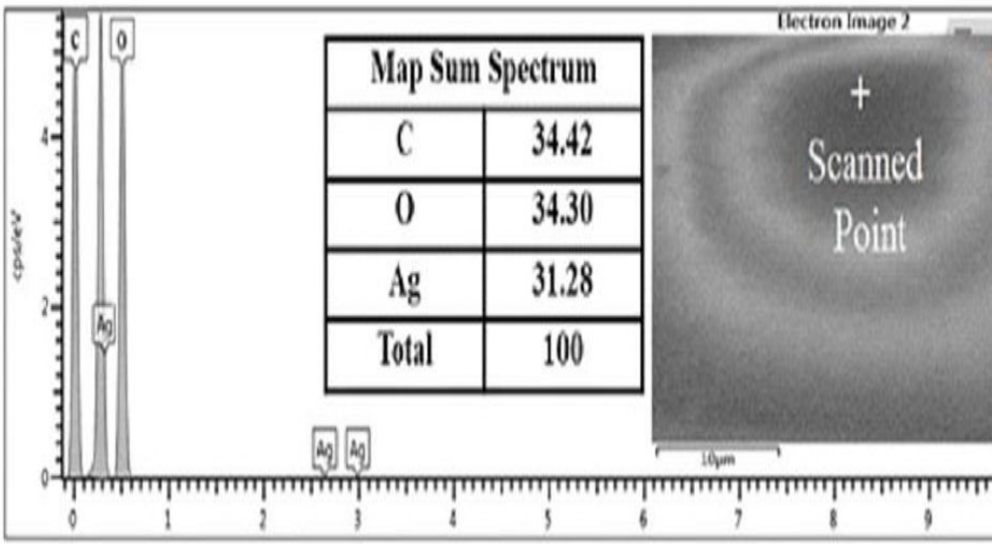

Fig. 1. EDX spectrum of Ag–ZnO nanocomposite.

The primary objective of the annealing treatment is to remove the organic solvent from the film through high-temperature combustion. This process promotes the formation of a porous structure within the film, enhancing its overall properties.

The SEM image (Figure 2) of the Ag–ZnO nanocomposite illustrates the incorporation of silver (Ag) into ZnO nanoparticles, resulting in the formation of spheroidal particles. The Ag–ZnO nanocomposite exhibits a rod-like morphology, with the white zinc oxide surrounding the core-shell structure of the silver atoms. The zinc oxide particles are spherical in shape. Additionally, the image reveals the formation of a nanoparticle network, indicating that agglomeration has occurred during synthesis.

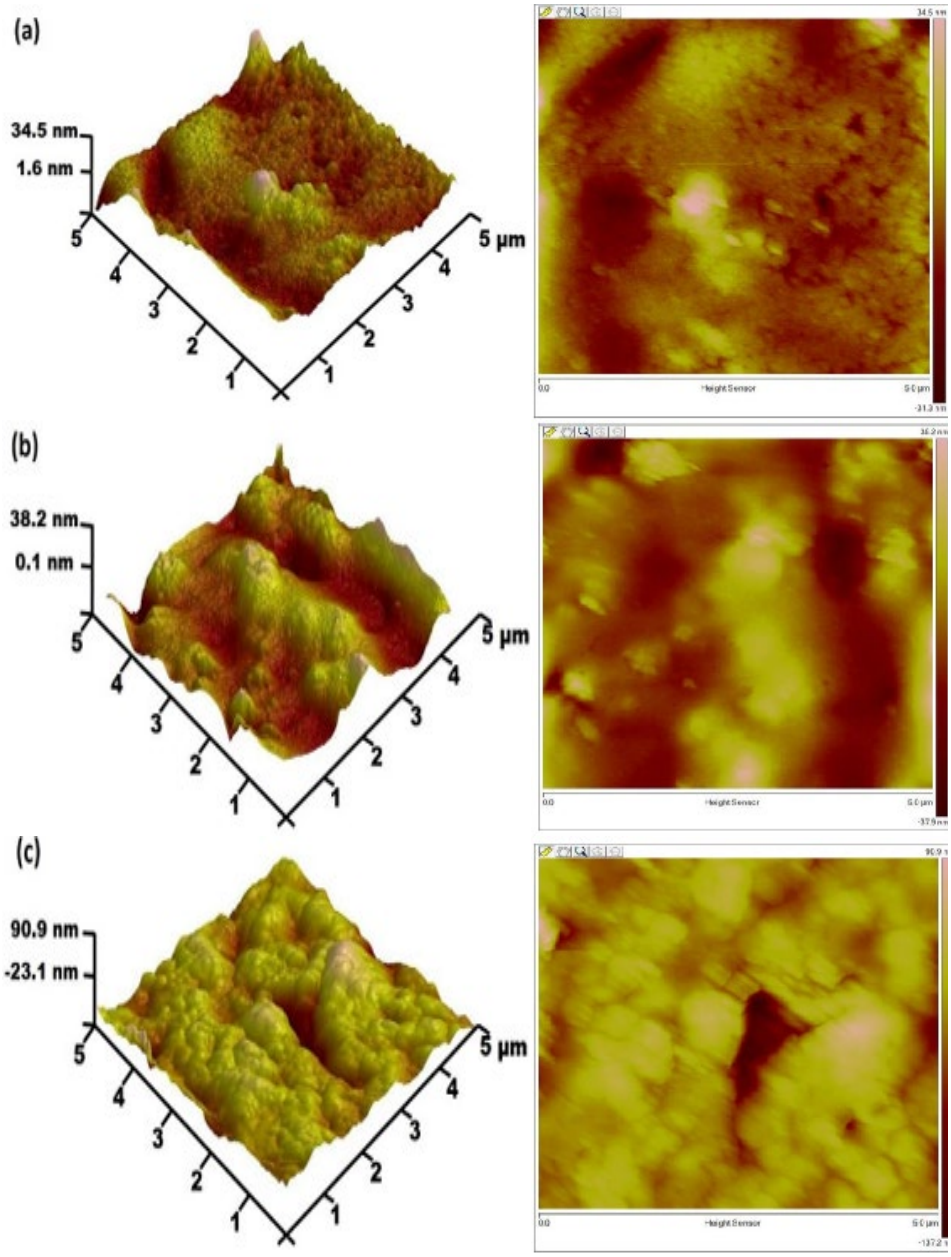

Fig. 2. SEM image of Ag–ZnO nanocomposite.

4. Conclusion

Ag–ZnO composite nanocrystals were synthesized through the reduction of ZnO and Ag ions, followed by the decomposition of Ag on the surface of pre-existing ZnO nanoparticles. The synthesized Ag–ZnO nanocomposite was characterized using SEM, EDX, and XRD spectroscopy to determine its morphological features, elemental composition, and structural properties, respectively.

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