" Green Amalgamation of Silver-Infused Zinc Oxide anoparticles Using Lemon (Citrus limon) Juice "

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Abstract:

Green amalgamation of nanoparticles has attracted notable interest due to its eco-friendly and cost-effective nature. In this study, zinc oxide (ZnO) and silver-doped zinc oxide (Ag–ZnO) nanoparticles were amalgamated using lemon (*Citrus limon*) juice as a natural reducing and stabilizing agent, avoiding toxic chemicals used in conventional methods. The nanoparticles were distinguished by UV–Visible spectroscopy, FTIR, SEM, EDS, and XRD. UV–Vis analysis showed a redshift after silver doping, indicating bandgap narrowing, while FTIR confirmed the role of lemon phytochemicals in stabilization. SEM images disclosed ball-shaped nanoparticles with reduced agglomeration in Ag–ZnO samples, and XRD confirmed the hexagonal wurtzite structure with successful Ag incorporation. The results demonstrate that lemon juice is an effective green reagent for producing functional Ag–ZnO nanoparticles with enhanced optical properties, suitable for photocatalytic and antimicrobial applications

Keywords: Green amalgamation, Zinc oxide nanoparticles, Silver doping, Lemon juice, Nanotechnology

Introduction:

Green synthesis of nanoparticles has accrued notable attention due to its environmental compatibility and cost-effectiveness [6], [7]. In the present study, zinc oxide (ZnO) and silver-doped zinc oxide (Ag–ZnO) nanoparticles were synthesized using lemon (*Citrus limon*) juice as a natural reducing and stabilizing agent [9]–[12]. The use of plant-based extracts eliminates the requirement for toxic chemicals commonly employed in conventional synthesis methods [6]. The amalgamated nanoparticles were distinguished utilizing UV–Visible spectroscopy, Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDS), and X-ray Diffraction (XRD) [17], [18]. UV–Vis analysis revealed a redshift in absorption upon silver doping, indicating bandgap narrowing [4], [12]. FTIR spectra confirmed the involvement of phytochemicals from lemon juice in nanoparticle stabilization [6], [9]. SEM images showed predominantly spherical particles with reduced agglomeration after silver incorporation [14], [22]. XRD analysis confirmed the hexagonal wurtzite structure of ZnO with successful Ag doping [1], [5]. The results demonstrate that lemon juice is an efficient green reagent for synthesizing functional Ag–ZnO nanoparticles with enhanced optical and structural traits, building them promising for photocatalytic and antimicrobial applications [15], [16], [20] Nanotechnology has emerged as a transformative field due to its ability to manipulate materials at the nanoscale, resulting in enhanced physical, chemical, and biological properties [17]. Among various nanomaterials, zinc oxide (ZnO) nanoparticles have dragged vital interest because of their wide bandgap, high exciton binding energy, chemical stability, and multifunctional properties [1], [2]. ZnO nanoparticles are widely used in sensors, photocatalysis, antimicrobial agents, and optoelectronic devices [3], [15].

Infused ZnO with noble metals such as silver further improves its functional properties. Silver-doped ZnO nanoparticles exhibit enhanced antibacterial activity, improved charge separation, and increased photocatalytic efficiency due to localized surface plasmon resonance effects [4], [5], [16]. However, conventional synthesis

methods such as sol–gel, hydrothermal, and chemical precipitation often involve harmful chemicals, high energy utilization, and environmentally harmful by-products [6], [21].

To overcome these limitations, green synthesis approaches using biological resources have gained importance [6], [7]. Plant extracts are particularly advantageous due to their affluent phytochemical composition, which acts as reducing, capping, and stabilizing agents [8], [25]. Lemon (*Citrus limon*) juice contains citric acid, ascorbic acid, flavonoids, and phenolic compounds, making it an excellent candidate for green nanoparticle synthesis [9],[10],[11].

This learning focuses on the eco-friendly amalgamation of ZnO and Ag–ZnO nanoparticles using lemon juice and evaluates their structural, morphological, and optical properties through various characterization techniques

Substances and Procedures :

Substances

Zinc acetate dihydrate was used as the zinc precursor, while silver nitrate served as the silver doping agent, following previously reported green synthesis protocols [12], [19]. Fresh lemons were procured locally and used for extract preparation [9]. Distilled water was used throughout the experimental procedures. All chemicals were of analytical grade and used without further purification.

Preparation of Lemon Juice Extract

Fresh lemons were thoroughly washed with distilled water to remove surface impurities. The fruits were cut, and the juice was extracted manually using a hand press. The extracted juice was filtered using muslin cloth followed by Whatman No. 1 filter paper to remove solid residues. The filtered juice was used immediately to preserve its phytochemical activity [9], [10].

Fig 1: Fresh Lemons

Fig 2: Preparation of ZnO and $AgNO_3$

Green amalgamation of ZnO Nanoparticles

A 0.1 M zinc precursor solution was prepared in distilled water and heated under continuous stirring at 60–80 °C. Lemon juice extract was added dropwise to the solution under constant stirring. The pH of the mixture was adjusted to approximately 10 using sodium hydroxide, developing in the formation of a white precipitate

[11]. The precipitate was centrifuged, washed repeatedly with distilled water and ethanol, and dried to obtain ZnO nanoparticles.

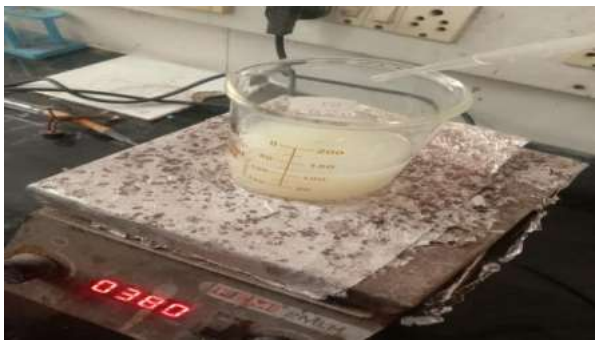


Fig 3: Synthesis of ZnO nanoparticles

Synthesis of Ag–Doped ZnO Nanoparticles

For silver doping, a dilute silver nitrate solution was added to the ZnO precursor solution under stirring. The reaction mixture was maintained for sufficient time to allow silver incorporation [12], [22]. The resulting Ag–ZnO nanoparticles were collected by centrifugation, washed, and dried before characterization.

Fig 4: Synthesis of Ag doped ZnO Nanoparticles

Fig 5: Dried Nanoparticles

Result and Discussion:

UV–Visible Spectroscopy

UV–Visible spectroscopy was employed to study the optical properties of the amalgamated nanoparticles. Pure ZnO nanoparticles revealed a characteristic absorption peak around 370 nm, consistent with earlier reports [1], [11]. After silver doping, a noticeable redshift to approximately 385 nm was observed, indicating bandgap narrowing and enhanced visible light absorption [4], [12], [23].

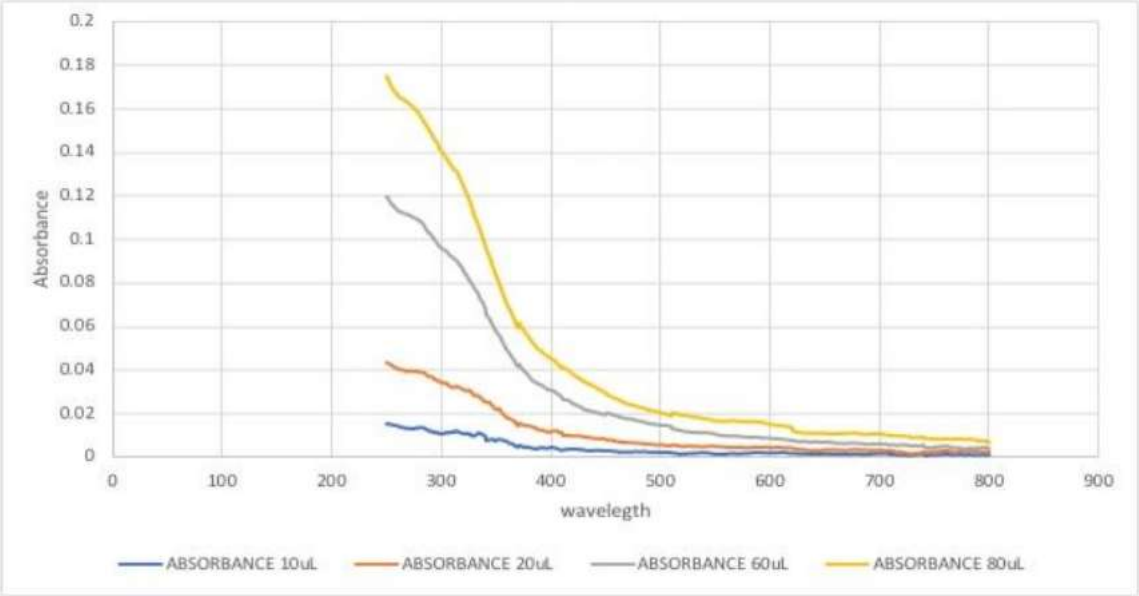


Fig 6: UV-Vis absorption spectrum of the Ag-infused ZnO nanoparticles using Citrus limon juice

Bandgap Analysis

The optical bandgap estimated using Tauc's plot method was approximately 3.25 eV for ZnO nanoparticles, which reduced to about 3.12 eV after silver doping [4], [16]. This reduction is attributed to impurity energy levels introduced by silver ions within the ZnO lattice [5].

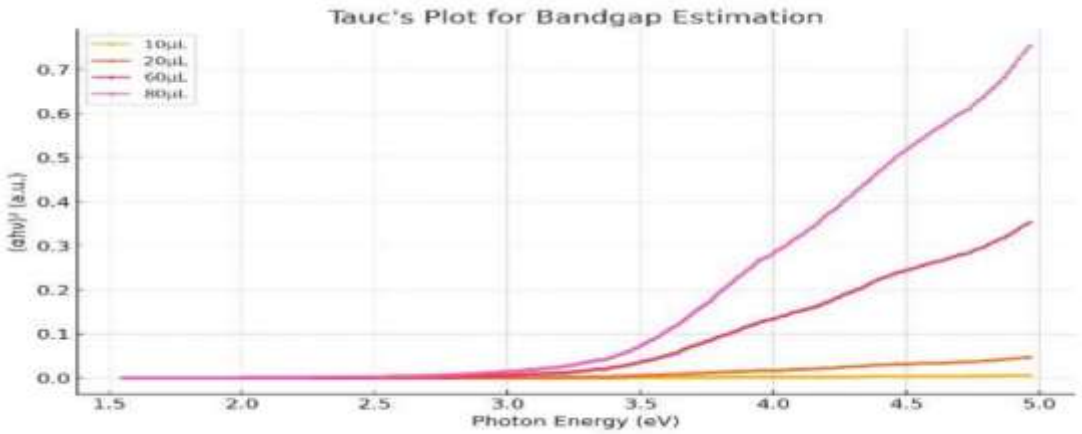


Fig 7: Tauc's Plot for Bandgap Estimation

FTIR Analysis

FTIR spectra verify the presence of functional groups involved in nanoparticle formation and stabilization. FTIR

spectra revealed broad absorption bands around 3300–3400 cm^{-1} corresponding to hydroxyl groups from lemon juice phytochemicals [6], [9]. Peaks near 1650 cm^{-1} indicated carbonyl groups associated with citric acid capping [10]. The Zn–O stretching vibration observed at 500–600 cm^{-1} confirmed ZnO formation [17].The presence of Ag–O related peaks further supported successful silver doping.

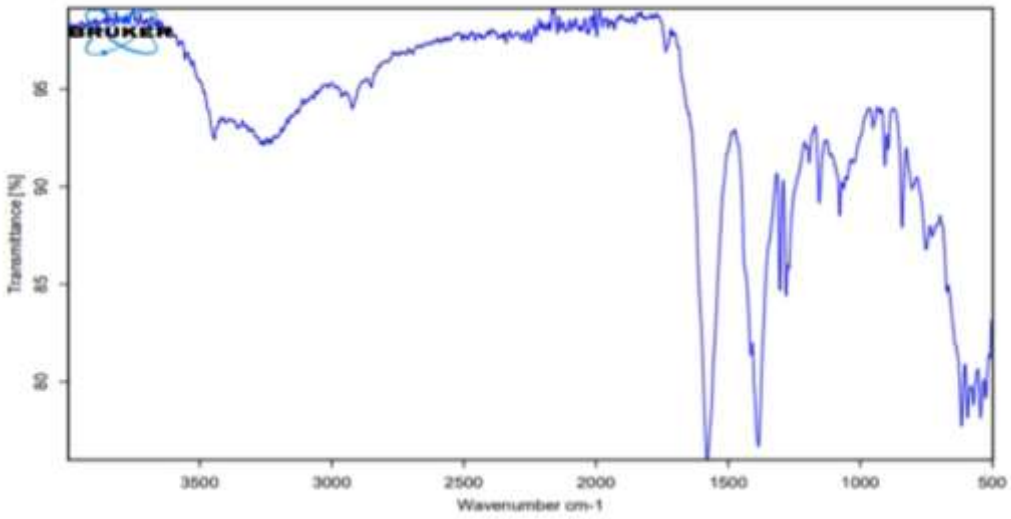
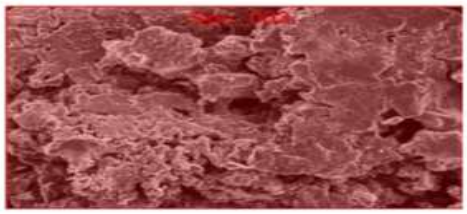


Fig 8: FT-IR spectrum of Ag- doped ZnO

SEM and EDS Analysis

SEM analysis revealed predominantly spherical nanoparticles with moderate agglomeration, while Ag–ZnO showed improved dispersion [14], [22]. EDS spectra confirmed the presence of Zinc, Oxygen, and Silver elements, validating successful silver incorporation of silver into ZnO matrix [5], [23].



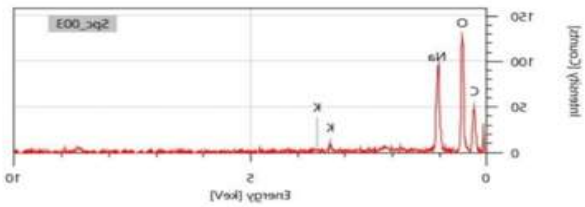


Fig 9 - SEM

Fig 10 - EDS

XRD Analysis

XRD patterns confirmed the hexagonal wurtzite structure of ZnO with sharp diffraction peaks indicating good crystallinity [1], [2]. Additional peaks corresponding to silver were observed, confirming successful doping [5]. The average crystallite size calculated using the Scherrer equation was approximately 25–30 nm, in agreement with reported studies [11], [22].

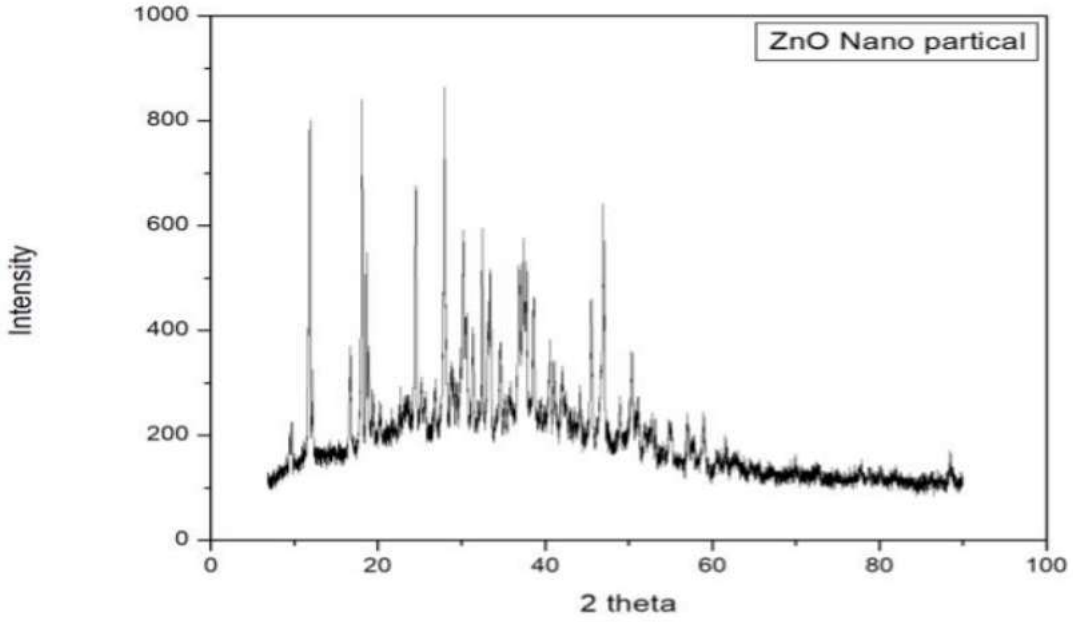


Fig 11: XRD pattern of Ag- doped ZnO nanoparticles

Conclusion :

An eco-friendly and sustainable method for synthesizing ZnO and Ag–ZnO nanoparticles using lemon (*Citrus limon*) juice was successfully demonstrated. The green synthesis approach avoided toxic chemicals while producing nanoparticles with enhanced optical and structural properties [6], [21]. Silver doping resulted in bandgap reduction and improved morphology, enhancing photocatalytic and antimicrobial potential [15], [16], [20]. This study supports plant-mediated synthesis as a viable route for green nanotechnology applications [25].

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