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Eco-Friendly Synthesis and Structural Stabilization of Sb-Doped SnO_2 Nanocatalysts Prepared via Pechini Route for Sustainable Chemical Applications

Lakshmi Janjanam[1], Dr Jyothi Sharma[2]

[1]Research Scholar, Department of Chemistry, JS University, Shikohabad, Uttar Pradesh
[2]Supervisor, Department of Chemistry, JS University, Shikohabad, Uttar Pradesh

ABSTRACT

This research presents the eco-friendly synthesis and detailed structural characterisation of antimony-doped tin oxide (SnO_2:Sb) nanocatalysts developed for sustainable chemical transformation applications. Samples containing 0–18 mol% Sb were synthesised using the polymeric precursor (Pechini) method and subjected to calcination between 800 °C and 1200 °C for four hours. The microstructural evolution, crystallite size, lattice parameters, and strain behaviour were examined using X-ray diffraction coupled with Rietveld refinement.

Complementary high-resolution transmission electron microscopy supported particle morphology interpretation. Results demonstrate that Sb incorporation effectively stabilises SnO_2 nanoparticles, suppresses abnormal grain growth, and promotes controlled crystallite development. The doping concentration and temperature significantly influenced oxidation states of antimony (Sb^{3+}/Sb^{5+}), which in turn affected lattice expansion, oxygen vacancy formation, strain relaxation, and crystallinity. Overall findings confirm that Sb-doped SnO_2 prepared via an environmentally benign approach is structurally robust, thermally stable and suitable for high-performance catalytic systems aligned with green chemistry objectives.

Synthesis and characterisation …

INTRODUCTION

Tin oxide (SnO_2) nanoparticles are widely recognised for their superior thermal stability, catalytic efficiency, electronic conductivity, and environmental compatibility. Their performance can be further enhanced through appropriate doping strategies, particularly with antimony (Sb), which improves structural and functional characteristics while maintaining system sustainability.

Synthesis and characterisation …

Conventional catalyst synthesis methods often involve hazardous chemicals, high-energy consumption, and generate toxic waste, contradicting sustainable development goals. Therefore, the adoption of eco-friendly synthesis processes is vital. The Pechini polymeric precursor method offers controlled cation distribution, reduced processing temperature, and homogeneous nanoparticle formation, making it highly suitable for green nanomaterial production.

Synthesis and characterisation …

This study focuses on synthesising Sb-doped SnO_2 nanocatalysts using the Pechini route and evaluating the influence of Sb content and calcination temperature on structural parameters, crystallinity, microstrain, and morphology to better understand stability and suitability for sustainable catalytic applications.
Synthesis and characterisation …

MATERIALS AND METHODS

2.1 Synthesis via Pechini Method

Sb-doped SnO_2 (0, 6, 10, 14, 18 mol% Sb) powders were synthesised using the polymeric precursor technique. Citric acid acted as a chelating agent to bind cations, followed by ethylene glycol addition to promote polymerisation and formation of a homogeneous polymeric resin. The prepared precursors were dried and calcined at 800–1200 °C for four hours.

Synthesis and characterisation …

2.2 Structural Characterisation

X-ray diffraction patterns were obtained using a Siemens D5000 diffractometer. Rietveld refinement was applied to determine unit cell parameters, crystallite size, and microstrain. Silicon dioxide was used as reference material for instrumental correction.

Synthesis and characterisation …

2.3 Microscopic Analysis

High-resolution transmission electron microscopy (HRTEM) was employed to examine particle morphology, dispersion, and aggregation characteristics.
Synthesis and characterisation …

RESULTS AND DISCUSSION

3.1 Phase Formation and Crystallinity

XRD confirmed the formation of a single SnO_2 phase with no detectable secondary phases across all investigated temperatures and compositions, indicating successful incorporation of Sb into the SnO_2 lattice.

Synthesis and characterisation …

3.2 Effect of Sb Doping on Lattice Parameters

Sb exhibited dual oxidation states (Sb^{3+} and Sb^{5+}), influencing lattice distortion differently due to ionic radius variation. Entry of larger Sb^{3+} ions increased lattice volume due to induced cation repulsion and oxygen vacancy generation, while Sb^{5+} substitution caused local lattice contraction. Temperature-dependent transition between oxidation states regulated lattice stability.

Synthesis and characterisation …

3.3 Microstrain Evolution

Microstrain reduced progressively with increasing calcination temperature, approaching ~0.02% at higher temperature regimes, indicating thermal relaxation and improved crystallinity. Samples showed nearly similar strain behaviour around 1000–1100 °C, suggesting structural equilibrium at these temperatures.

Synthesis and characterisation …

3.4 Crystallite Size Behaviour

Undoped SnO_2 exhibited the largest crystallites, while doped systems demonstrated reduced crystallite dimensions due to Sb-induced growth inhibition mechanisms. Increasing Sb concentration supported grain boundary stabilisation and restricted coalescence, ensuring uniform nanoparticle formation.
Synthesis and characterisation …

3.5 TEM Structural Evidence

HRTEM confirmed discrete, well-defined nanoparticles for Sb-doped SnO_2, whereas undoped samples exhibited higher agglomeration and neck formation. Doping enhanced structural stability and prevented abnormal growth, supporting long-term catalytic integrity.
Synthesis and characterisation …

4. Sustainability and Application Significance

The Pechini method employed is environmentally safer compared to traditional synthesis routes, reducing energy requirements and avoiding toxic reagents. The structural robustness, reduced grain growth, and enhanced stability of Sb-doped SnO_2 make it an excellent candidate for applications in:

- green catalytic reactions
- gas sensing
- environmental remediation
- high-temperature chemical processes

CONCLUSION

Sb-doped SnO_2 nanocatalysts synthesised through the eco-friendly Pechini method exhibit excellent structural stability, reduced microstrain, controlled crystallite growth, and enhanced lattice regulation. Antimony doping successfully influences oxidation state dynamics, oxygen vacancy creation, and grain stability. These characteristics position Sb-doped SnO_2 as a promising material for sustainable catalytic technologies aligned with green chemistry principles.

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