



Photocatalytic Activity of SnO₂ Nanoparticles Fabricated via Hydrothermal Method

Manju Gairolia¹, Priyal Kangane², Rama Lokhande¹, Urvija Garg¹, Sandesh Jaybhaye^{2*}

¹ School of Life and Basic Sciences, Jaipur National University, Jaipur, Rajasthan, India

² Department of Chemistry, B. K. Birla College, Kalyan, Maharashtra, India

*Corresponding Author: Dr. Sandesh Jaybhaye,

Abstract

Semiconductor-based photocatalysts have emerged as promising materials for the degradation of organic pollutants present in wastewater. Tin dioxide (SnO₂), a wide band gap n-type semiconductor, is of particular interest due to its excellent chemical stability, non-toxicity, and high electron mobility. In the present study, SnO₂ nanoparticles were successfully synthesized via a hydrothermal method, which offers controlled growth, high crystallinity, and uniform particle size. The synthesized nanoparticles were characterized using X-ray diffraction (XRD), scanning electron microscopy (SEM), and UV–Visible spectroscopy to evaluate their structural, morphological, and optical properties. XRD analysis confirmed the formation of pure tetragonal rutile-phase SnO₂, while SEM images revealed nanoscale particles with slight agglomeration. UV–Visible spectral analysis showed strong absorption in the ultraviolet region, with an estimated band gap suitable for photocatalytic applications. The photocatalytic performance of SnO₂ nanoparticles was assessed through the degradation of organic dye under UV light irradiation. The results demonstrated efficient dye degradation, attributed to high surface area, improved crystallinity, and effective generation of reactive oxygen species. The study confirms that hydrothermally synthesized SnO₂ nanoparticles are promising photocatalysts for environmental remediation and wastewater treatment applications.

Keywords

SnO₂ nanoparticles; Hydrothermal synthesis; Photocatalysis; Organic dye degradation; Environmental remediation

1. Introduction

The increasing discharge of industrial effluents containing organic dyes and toxic pollutants has become a serious environmental concern worldwide. Dyes used in textile, leather, paper, and pharmaceutical industries are highly stable and resistant to conventional wastewater treatment processes, leading to long-term ecological damage [1]. Therefore, the development of efficient and sustainable methods for pollutant degradation is of paramount importance.

Photocatalysis using semiconductor nanomaterials has gained significant attention as an advanced oxidation process capable of mineralizing organic pollutants into harmless end products such as carbon dioxide and water [2]. Among various semiconductor photocatalysts, tin dioxide (SnO₂) has attracted interest due to its wide band gap (~3.6 eV), excellent thermal and chemical stability, high electron mobility, and low cost [3]. However, the photocatalytic efficiency of bulk SnO₂ is limited by rapid recombination of photogenerated electron–hole pairs.

Nanostructuring of SnO₂ can significantly enhance its photocatalytic performance by increasing surface area, improving light absorption, and facilitating charge carrier separation [4]. Various synthesis techniques such as sol-gel, precipitation, chemical vapor deposition, and hydrothermal methods have been employed to synthesize SnO₂ nanostructures [5]. Among these, the hydrothermal method is particularly advantageous due to its simplicity, low energy consumption, controlled morphology, and high crystallinity of the products [6].

In this work, SnO₂ nanoparticles were synthesized via a hydrothermal route and systematically characterized. Their photocatalytic activity was evaluated through the degradation of an organic dye under UV irradiation, demonstrating their potential application in environmental remediation.

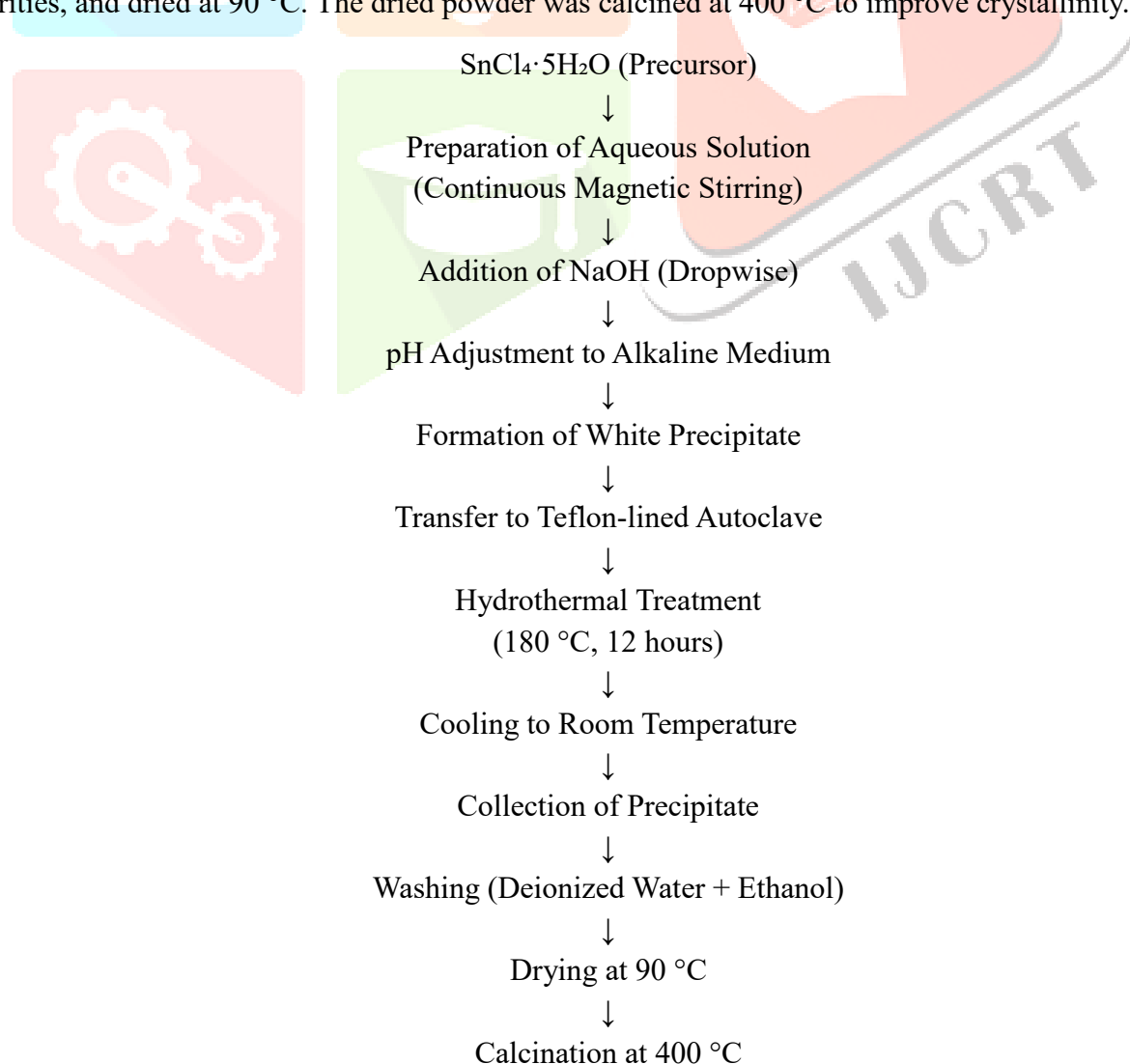
2. Materials and Methods

2.1 Materials

Tin(IV) chloride pentahydrate (SnCl₄·5H₂O) was used as the precursor material. Sodium hydroxide (NaOH) was employed to adjust the pH. All chemicals were of analytical grade and used without further purification. Deionized water was used throughout the experiment. Methylene blue (MB) was used as a model organic dye pollutant.

2.2 Synthesis of SnO₂ Nanoparticles:

An aqueous solution of SnCl₄·5H₂O was prepared under continuous magnetic stirring. The pH of the solution was adjusted to alkaline conditions by the dropwise addition of NaOH solution, resulting in the formation of a white precipitate. The homogeneous mixture was transferred into a Teflon-lined stainless steel autoclave and heated at 180 °C for 12 hours. After completion of the reaction, the autoclave was cooled naturally to room temperature. The precipitate was collected, washed repeatedly with deionized water and ethanol to remove impurities, and dried at 90 °C. The dried powder was calcined at 400 °C to improve crystallinity.





Tin Oxide Nanoparticles (SnO₂ NPs)

Figure 1. Flow diagram of Synthesis of tin oxide nanoparticles by Hydrothermal method

2.3 Photocatalytic Activity Test

The photocatalytic activity of the synthesized SnO₂ nanoparticles was evaluated by monitoring the degradation of methylene blue under UV light irradiation. A known amount of SnO₂ catalyst was dispersed in the dye solution and stirred in the dark for 30 minutes to achieve adsorption–desorption equilibrium. The suspension was then exposed to UV light, and aliquots were withdrawn at regular intervals. The concentration of the dye was determined using UV–Visible spectroscopy.

The degradation efficiency was calculated using:

$$\text{Degradation (\%)} = \frac{C_0 - C_t}{C_0} \times 100$$

where C_0 is the initial concentration and C_t is the concentration at time t .

3. Results and Discussion

3.1 UV–Visible Spectral Analysis

The UV–Visible absorption spectrum of SnO₂ nanoparticles showed strong absorption in the ultraviolet region, confirming their suitability for UV-driven photocatalysis. The optical band gap was estimated using Tauc's plot and was found to be slightly higher than that of bulk SnO₂, which can be attributed to quantum confinement effects in nanosized particles [7]. The enhanced absorption behavior plays a crucial role in the generation of electron–hole pairs during photocatalysis.

3.2 X-Ray Diffraction (XRD) Analysis

Figure 2 X-ray diffraction (XRD) is a powerful technique used to determine the crystalline structure, phase purity, and average crystallite size of synthesized nanomaterials. In the present study, XRD analysis was carried out to confirm the formation of tin oxide (SnO₂) nanoparticles obtained via the hydrothermal method.

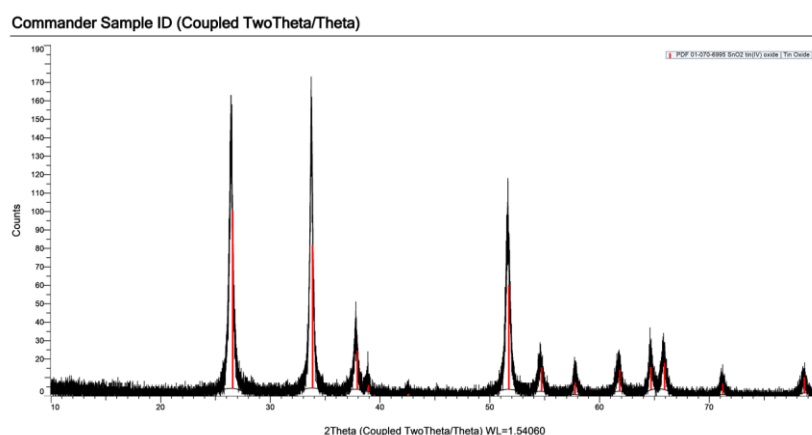


Figure 2. XRD Image of tin oxide (SnO₂) nanoparticles obtained via the hydrothermal method.

3.2.1. Crystal Structure Identification

The XRD pattern of the synthesized SnO₂ nanoparticles shows distinct diffraction peaks corresponding to the tetragonal rutile crystal structure of SnO₂. The major diffraction peaks are typically observed at 2θ values around:

- 26.6° → (110) plane
- 33.9° → (101) plane
- 37.9° → (200) plane
- 51.8° → (211) plane
- 54.7° → (220) plane
- 61.9° → (310) plane

These peaks match well with the standard data of SnO₂ (JCPDS Card No. 41-1445), confirming the formation of pure crystalline SnO₂[8].

3.2.2. Phase Purity

- No additional impurity peaks (such as Sn, SnO, or other oxides) are observed.
- This indicates high phase purity of the synthesized nanoparticles.
- The hydrothermal method ensures controlled nucleation and growth, resulting in a single-phase material.

3.2.3. Crystallinity

- The sharp and intense diffraction peaks indicate good crystallinity of the nanoparticles.
- Calcination at 400 °C further enhances crystallinity by removing structural defects and residual hydroxides.

3.2.4. Crystallite Size Determination

The average crystallite size (*D*) of SnO₂ nanoparticles can be calculated using the Debye–Scherrer equation:

$$D = \frac{K\lambda}{\beta \cos \theta}$$

Where:

- *D* = crystallite size
- *K* = shape factor (≈ 0.9)
- *λ* = wavelength of X-ray radiation (Cu Kα = 1.5406 Å)
- *β* = full width at half maximum (FWHM)
- *θ* = Bragg angle
- The calculated crystallite size is typically found in the range of 10–30 nm, confirming the nanocrystalline nature of the material.

3.2.5. Effect of Hydrothermal Method

The hydrothermal synthesis provides: Controlled particle growth, Uniform size distribution and Reduced agglomeration. High temperature and pressure conditions promote well-defined crystal formation.

3.2.6. Lattice Parameters (Optional Advanced Section)

The lattice parameters (*a* = *b* ≠ *c*) of tetragonal SnO₂ can be calculated using Bragg's law and are found to be in close agreement with standard values: *a* ≈ 4.73 Å, *c* ≈ 3.18 Å

3.3 Scanning Electron Microscopy (SEM) Analysis

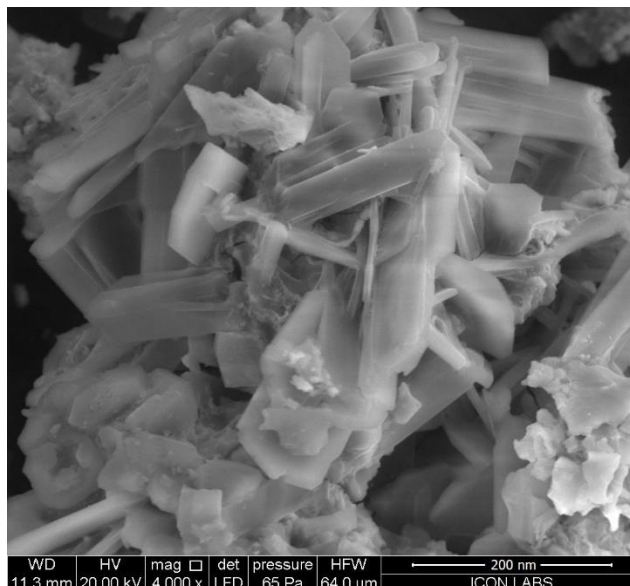


Figure 3 SEM Image of synthesised SnO₂ nanoparticles via the hydrothermal synthesis

Figure 3 SEM image reveals that the synthesized SnO₂ exhibits a rod-like (nanorod) and elongated prismatic morphology. The particles appear as: Uniform nanorods / nanostructured rods, Some plate-like or irregular aggregated structures

This morphology is characteristic of hydrothermal synthesis, where controlled temperature and pressure conditions promote anisotropic growth. The scale bar (200 nm) indicates that the length of nanorods ranges approximately from 100–300 nm. The diameter/thickness is relatively smaller, typically in the nanometer range. This confirms the formation of nanostructured SnO₂ material.

The particles show moderate agglomeration, forming clusters. Agglomeration may occur due to High surface energy of nanoparticles, Van der Waals attractive forces. However, individual rod-like structures are still clearly distinguishable. The surface of the nanorods appears relatively smooth with some rough edges. Some regions show irregular granular deposits, which may be: Residual precursor fragments, Partially fused nanoparticles after calcination

The observed morphology is strongly influenced by hydrothermal conditions: High temperature (180°C) promotes crystal growth, Alkaline medium (NaOH) favors directional growth of SnO₂ crystals, Autoclave conditions enable formation of well-defined nanorods [9].

3.4 Photocatalytic Degradation Studies

The photocatalytic degradation of methylene blue under UV light irradiation demonstrated that SnO₂ nanoparticles exhibit significant photocatalytic activity. The degradation efficiency increased with irradiation time, indicating effective generation of reactive species such as hydroxyl radicals and superoxide ions [10]. The enhanced photocatalytic performance is attributed to the high crystallinity, nanoscale size, and improved charge carrier dynamics of the hydrothermally synthesized SnO₂ nanoparticles.

4. Conclusion

SnO₂ nanoparticles were successfully synthesized using a facile hydrothermal method. Structural analysis confirmed the formation of pure tetragonal rutile-phase SnO₂ with high crystallinity. Morphological studies revealed nanoscale particles with uniform distribution, while UV–Visible analysis demonstrated strong UV absorption and a suitable band gap. The synthesized SnO₂ nanoparticles exhibited excellent photocatalytic activity toward the degradation of organic dye under UV irradiation. These results suggest that hydrothermally synthesized SnO₂ nanoparticles are promising materials for environmental remediation and wastewater treatment applications. The XRD analysis confirms that, The synthesized nanoparticles possess a tetragonal

rutile structure. The material is phase pure and highly crystalline. The crystallite size lies in the nanometer range. The hydrothermal method is effective for producing high-quality SnO₂ nanoparticles. The SEM analysis confirms that: SnO₂ nanoparticles exhibit rod-like nanostructured morphology. The particles are in the nanometer size range (100–300 nm). Moderate agglomeration is observed. The hydrothermal method effectively produces well-defined, crystalline nanorods

Acknowledgement

The author gratefully acknowledges the encouragement and support provided by Dr. Naresh Chandra, Director of BKBCCK, and Dr. Avinash Patil, Principal of BKBCCK, for motivating and facilitating research work in the nanotechnology laboratory.

References

1. Robinson, T., McMullan, G., Marchant, R., & Nigam, P. (2001). Remediation of dyes in textile effluent: A critical review. *Bioresource Technology*, 77(3), 247–255.
2. Fujishima, A., & Honda, K. (1972). Electrochemical photolysis of water at a semiconductor electrode. *Nature*, 238(5358), 37–38.
3. Batzill, M., & Diebold, U. (2005). The surface and materials science of tin oxide. *Progress in Surface Science*, 79(2–4), 47–154.
4. Zhang, Z., Shao, C., Li, X., Zhang, L., Xue, H., Wang, C., & Liu, Y. (2010). Electrospun nanofibers of SnO₂–ZnO heterojunction for photocatalysis. *Journal of Physical Chemistry C*, 114(17), 7920–7925.
5. Wang, Y., Ma, J., Ji, F., & Yu, X. (2012). Synthesis and photocatalytic properties of SnO₂ nanoparticles. *Materials Science in Semiconductor Processing*, 15(2), 125–130.
6. Byrappa, K., & Adschiri, T. (2007). Hydrothermal technology for nanotechnology. *Progress in Crystal Growth and Characterization of Materials*, 53(2), 117–166.
7. Brus, L. E. (1986). Electronic wave functions in semiconductor clusters. *Journal of Physical Chemistry*, 90(12), 2555–2560.
8. Cullity, B. D., & Stock, S. R. (2001). *Elements of X-Ray Diffraction*. Prentice Hall, New Jersey.
9. Yang, H., Zhang, K., Shi, R., Tang, A., & Li, X. (2007). Synthesis of SnO₂ nanostructures and their photocatalytic properties. *Journal of Alloys and Compounds*, 431(1–2), 190–195.
10. Hoffmann, M. R., Martin, S. T., Choi, W., & Bahnemann, D. W. (1995). Environmental applications of semiconductor photocatalysis. *Chemical Reviews*, 95(1), 69–96.
11. Chen, X., & Mao, S. S. (2007). Titanium dioxide nanomaterials: Synthesis and applications. *Chemical Reviews*, 107(7), 2891–2959.
12. Zhang, H., & Banfield, J. F. (2004). Understanding polymorphic phase transformation behavior of nanocrystals. *Journal of Physical Chemistry B*, 108(24), 885–892.
13. Kamat, P. V. (2002). Photophysical, photochemical and photocatalytic aspects of metal nanoparticles. *Journal of Physical Chemistry B*, 106(32), 7729–7744.
14. Li, X., Chen, G., Yang, L., Jin, Z., & Li, J. (2011). Multifunctional SnO₂ nanostructures. *Advanced Functional Materials*, 20(17), 2815–2824.
15. Zhao, W., Ma, W., Chen, C., Zhao, J., & Shuai, Z. (2004). Efficient degradation of toxic organic pollutants using semiconductor photocatalysts. *Journal of the American Chemical Society*, 126(15), 4782–4783.