**A Review on metal ion doped SnO2 Nanocomposites: Synthesis and Application in photocatalytic degradation and antimicrobial activities**

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**Abstract:**

Photocatalysis is the speeding up of the photoreaction in the incidence of light. The most common heterogeneous photocatalysts are transition metal oxides and certain semiconductors. Among the transition metal oxides TiO2, ZnO and SnO2 are low-cost materials with good chemical and thermal stability, large surface area, high adsorption properties, less resistance to diffusion, and show faster rates of equilibrium. The study of SnO2 in the field of photocatalysis is due to its different morphologies, high photochemical stability, strong oxidizing power, low cost, and non-toxic nature. This paper outlines the synthesis of SnO2 by various techniques with different morphologies and reviews the design of SnO2 nanoparticles with enhanced performance in the zone of photodegradation and antimicrobial activities.

**Keywords**: SnO2 nanoparticles, photocatalysis, antimicrobial activities

1. **Introduction:**

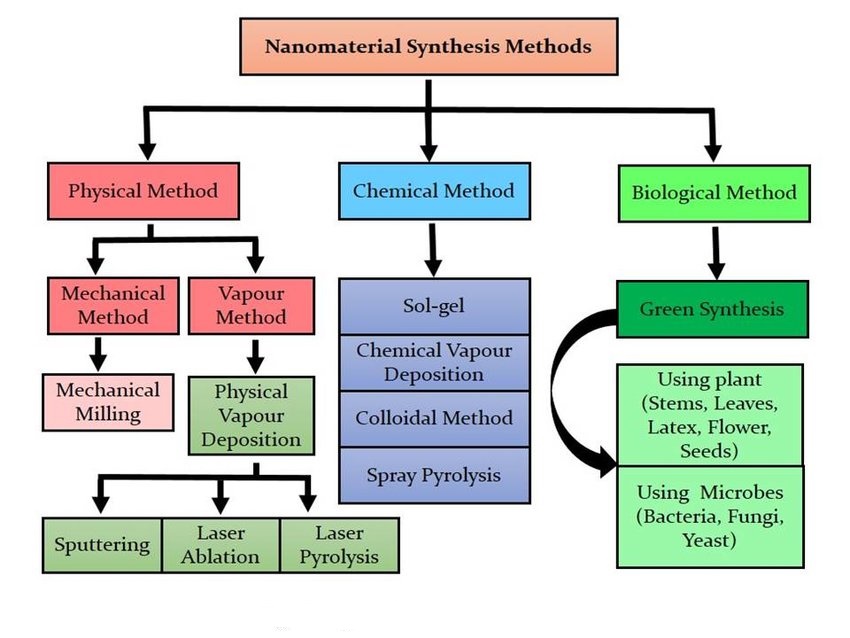
Semiconductor Nps possess properties between metals and non-metals. They possess wide band gaps and showed significant alteration in their properties with band gap tuning therefore, they are very important materials in photocatalysis, photo optics, and electronic devices. Metal oxides are a widely explored and studied class of inorganic solids due to a wide variety of structures, properties, and exceptional phenomena exhibited by their Nps. Metal oxides (MO) are formed when metal ions form coordination bonds with oxides giving rise to a closely packed structure. Metal ions bond with oxides to form metal oxides (MO), which result in a densely packed structure. MO is a significant player in the field of material research because of its exceptional physical and chemical characteristics. Numerous industrial applications have made use of transition metal oxides. Metal oxides are frequently found and exist in a variety of forms with unique compositions, structures, and chemical and physical characteristics [1]. TiO2, ZnO, SnO2, VOx, MoOx, and other well-known MO are some examples.

The abundance, non-toxicity, low cost, strong thermal stability (up to 500 °C), high degree of transparency in the visible spectrum, strong chemical and physical interactions with the adsorbed species with high electron mobility (200 cm2 V-1 s-1), less resistivity, and faster transport of phosgen make tin oxide (SnO2) one of the attractive and promising materials among metal oxides. This makes SnO2 a promising candidate for a potential use in lithium-ion batteries, sensors, catalysis, field emission displays[2], light-emitting diodes[3], dye-based solar cells[4], energy storage, glass coatings, medicine, environmental remediation[5-8], transistors, optoelectronics devices, solar cells, super capacitors, [9-13], catalyst supports, transparent conducting electrodes[14], antireflective coatings[15], and a proto-type material for metal oxide sensors[16]. Due to its high specific area, excellent chemical stability, low electrical resistance, and low density, SnO2 is employed as a sensor to increase response time and sensitivity [17].

The most prevalent heterogeneous photocatalysts are semiconductors and transition metal oxides. TiO2, ZnO, and SnO2 are three transition metal oxides that are inexpensive, have good chemical and thermal stability, a wide surface area, strong adsorption capabilities, little resistance to diffusion, and exhibit quicker rates of equilibrium [18]. SnO2 has a wide range of morphologies, a high degree of photochemical stability, a potent oxidizing capability, is inexpensive, and is non-toxic, all of which make it a valuable photocatalyst [19].

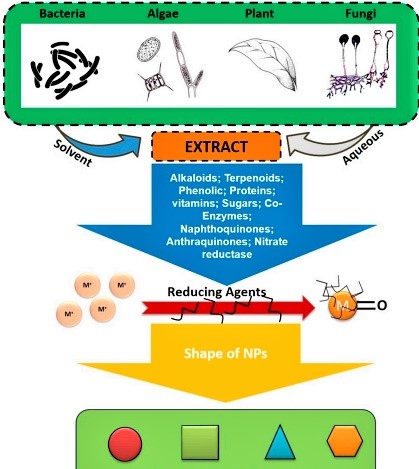
In this review, we describe pure SnO2 hierarchical structure synthesis methodologies and performance improvement techniques. SnO2-based nanostructures' uses in photodegradation and antibacterial processes are also discussed. The addition of metal ions, other semiconductors, or noble metals to SnO2 can moderately increase the separation efficiency of photoexcited (e/h+), enhancing the photocatalytic assets for future research.

SnO2 NPs were prepared using a variety of physical, chemical, and environmentally friendly techniques (Fig. 1). Among the chemical techniques include sol-gel, hydrothermal, precipitation, mechanochemical process, microemulsion, and others [20]. The most popular chemical process is the sol-gel synthesis, which makes use of a tin precursor salt and chemical reagents to control the development of the tin-containing gel. The gel is then subjected to heat treatment at temperatures of up to 800°C to produce SnO2 NPs. In order to regulate the size and prevent agglomeration of the nanoparticles, chemical stabilizers and capping agents were used during the synthesis of SnO2 NPs. The size and morphology of nanoparticles are influenced by the pH, chemical concentration, reaction duration, and calcination temperature [21]. The procedures for making SnO2 NPs mentioned above include the use of hazardous chemical reagents, solvents, and surfactants that pose a major risk to the environment and public health.



**Fig.1: Synthesis methods for nanoparticles [22]**

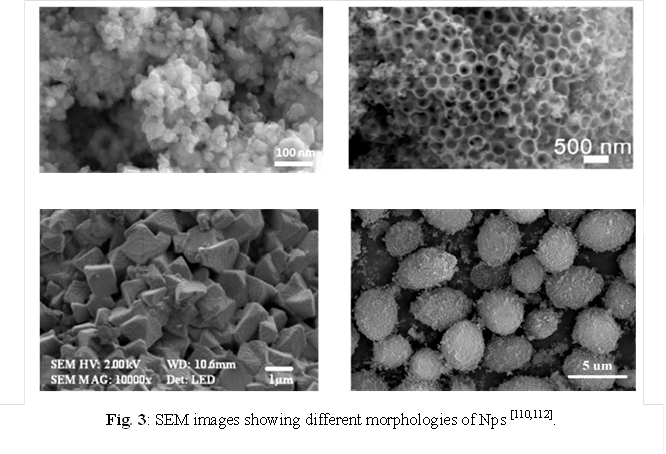
In the green synthetic strategy, biological components such as plant extract, microorganisms, or other environmentally friendly sources could be used instead of traditional physical and chemical processes. Biological synthesis (Fig. 2) has certain specific advantages over physical and chemical approaches, including (a) using nontoxic chemicals, which is a clean and environmentally benign process; (b) using renewable resources. (c) The biologically active elements, such as the enzyme itself and phytochemicals, serve as reducing and capping agents, lowering the overall cost of the manufacturing process. (d) Since high pressure and temperature are not necessary for external experimental conditions, significant energy savings are made [22].Significant work has gone into creating SnO2 nanostructures with a variety of morphologies (Fig. 3), including nanorods, nanowires, nanotubes, nanosheets, and 3D nanospheres that self-assembled from these low-dimensional nanostructures using interactions like van der Waals forces, hydrogen, and covalent bonding.



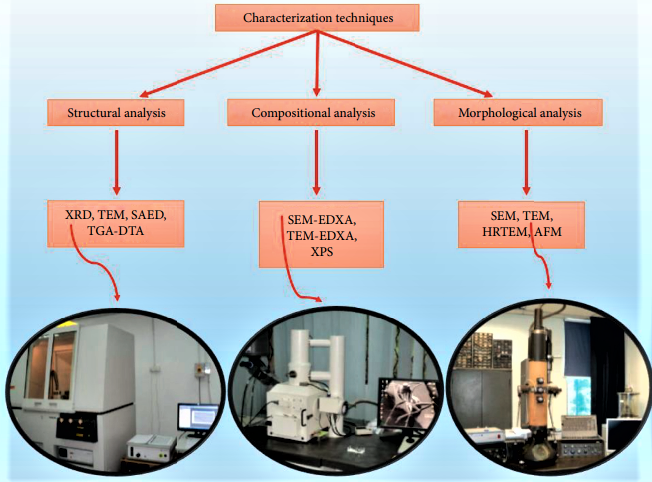
**Fig. 2: Synthesis of nanoparticles using different biological sources [29]**

Many attempts have been made to extend the photo sensitivity of SnO2 from the ultraviolet to the visible range by doping SnO2 NPs with transition metals such as cobalt [26,27], nickel [28], chromium [30], iron [31], and vanadium [32]. The photocatalytic activity is additionally increased by the effective extension of the SnO2 NPs' absorption edge into the visible region by the addition of sufficient concentrations of these dopant species. On the other hand, a broad energy band gap prevents this photo activation and a high doping content can provide electron-hole recombination sites [33].

Different characterization techniques have been practiced for the analysis of various physicochemical properties of NPs. These techniques include X-Ray Diffraction (XRD), X-Ray Photoelectron Spectroscopy (XPS), Infrared Spectroscopy (IR), Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), UV-Vis Spectroscopy, Photoluminescence Spectroscopy (PL), Brunauer–Emmett–Teller (BET) and Particle size analysis (Fig.4) [34]. Finally, the photodecomposition was studied by using pure and metal doped SnO2 nanoparticles as a catalyst under UV/visible light irradiation and antimicrobial assay was evaluated and their performances are reviewed.



**Fig 3: SEM images showing different morphologies of Nps[36,37]**

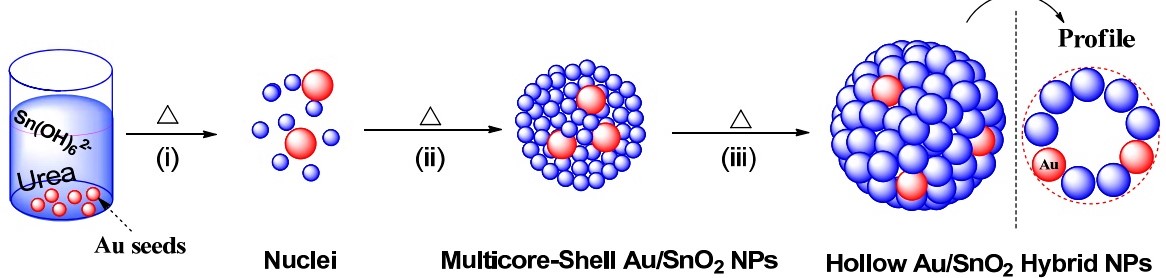


**Fig 4:** **General techniques for the characterization of nanoparticles [34]**

A Sn-containing fluoride compound called KSnF3 was used as the single-source precursor in the effective preparation of heavily F-doped SnO2 nanocrystals by Kumar, V. et al. [38]. The low crystallite size, which was indexed to a tetragonal unit cell with lattice constants a = 4.7106 (1) and c = 3.1970 (1), was shown by powder X-ray diffracted peaks. The TEM examinations showed an accumulation of particles with an average diameter of 57 nm; spot-wise EDX analysis revealed the presence of fluoride ions. Pure SnO2 had a much higher BET surface area (207.81 m2/g) than F-doped SnO2 nanocrystals (45.16 m2/g).The large bands seen at 455, 588, and 874 cm-1 in the room-temperature Raman spectrum of SnO2:F demonstrated the disordered character of the rutile lattice and the massive oxygen vacancies caused by fluoride ion doping. F-doped SnO2 was investigated for its capacity to act as a photocatalyst in the degradation of aqueous Rhodamine-B (RhB) dye solution under UV irradiation as a result of the oxygen vacancies. After 20 minutes of radiation, the fluid became colorless. F-doped SnO2 nanocrystals were shown to have extremely high photocatalytic effectiveness when compared to pure SnO2. Because of the extremely high concentration of oxygen vacancies in SnO2 brought on by F doping, the photocatalytic efficiency was enhanced.

Hollow Au-SnO2 super symmetric nanostructures with high surface area were created by a solution reaction using N, N-dimethylformamide (DMF) as a solvent in the presence of PVP and PEG as capping agents by You, H et al. [40]. This research showed that the initial formation of ultrafine SnO2 nanoclusters assembled to form hollow hexapods and that subsequent in situ self-assembly induced the formation of higher-ordered hollow structures.

By utilizing a seed-mediated hydrothermal technique, Wu, W. et al. [41] created hollow hybrid nanostructures, and XRD patterns showed strong rutile tin oxide phase peaks and weak gold peaks with lattice constants a = 4.738 and c = 3.187 [41]. The HRTEM result and the diameter of 40 tiny grains agreed with the Deby-Scherrer formula's estimated average crystallite size of 10.8 nm. Using the EDX spectrum, it was determined that Au, Sn, and O were present. Hollow SnO2-Au hybrid nanostructures were created, and the evolution of their shape was examined (Fig. 5).



**Fig 5: Schematic illustration of the formation and shape evolution of hollow SnO2-Au hybrid nanostructures [41]**

In order to create highly crystalline, Fe-doped SnO2 nanoarchitectures with effective photocatalytic degradation of RhB under ultraviolet irradiation, Davis, M. et al. [42] used a simple, sol-gel approach. The degradation of RhB with pure SnO2 and each Fe-modified sample (3 and 5%), all of which were annealed at 3500C, served as the basis for the investigation of these materials' photocatalytic activity. In the most active Fe-modified SnO2 sample, EDS verified the presence of Fe. RhB was discovered to have been significantly reduced by the 5% Fe-modified SnO2 after two hours.

Using an EAB free of hazardous substances, surfactants, and organic solvents, Ansari, S. et al. [43] created Ag-SnO2 nanocomposites with various concentrations of silver precursor (1 mM and 3 mM) at ambient temperature. Ag-SnO2 nanocomposites displayed a large absorption peak between 400 and 550 nm, which was attributed to AgNPs' surface plasmon resonance absorption. When methyl orange, methylene blue, 4-nitrophenol, and 2-chlorophenol were degraded by visible light irradiation, nanocomposites demonstrated improved photocatalytic activity in comparison to pure SnO2 nanostructures. Methyl orange (MO) and methylene blue (MB) both underwent almost total disintegration after being exposed to visible light for 6 hours and 5 hours, respectively.

Tin chloride dihydrate, cobalt chloride hexahydrate, sodium hydroxide, and ethanol were used in the chemical precipitation process by Toloman, D. et al. [44] to create a variety of Co-doped SnO2 nanoparticles. With an increase in the level of doping, the samples' crystallinity rose. Under the influence of visible light, the sample's photocatalytic activity was assessed in comparison to a synthetic RhB solution. The best performance was achieved using 1.0% Co-SnO2, though all samples exhibited photocatalytic activity.

Using SiO2 microspheres as hard templates, Ran, L. et al. [45] established a simple infiltration technique for manufacturing hollow-structured SnO2 with a variable Ti doping concentration. Ti doping had no effect on the samples' crystal structure or morphology, and they maintained their highly crystalline condition and hollow spherical nanostructure with a particle diameter of roughly 300 nm. Materials made of SiO2 have Ti4+ integrated uniformly into the lattice Ti-doped SiO2 with a doping content of 20 mol% demonstrated the highest photocatalytic activity when compared to pure SiO2 hollow spherical sample, decomposing 92% of the MB under UV light irradiation and 54% under visible light irradiation within a degradation time of 135 min.

Zn-doped SnO2 hierarchical structures (ZSHAs) of controlled size were created by Zhao, Q. et al. [46] using a simple hydrothermal technique, and they were made of two-dimensional (2D) nanosheets with a thickness of about 40 nm. The crystal was identified by the XRD pattern as belonging to the tetragonal rutile structure of SnO2. A single crystalline feature with a lattice spacing of 0.34 nm was validated by TEM examinations that revealed nanosheet structures. The nanosheet structures' composition of Zn, Sn, and O components was revealed by EDX analysis. Rhodamine B (RhB), methylene blue (MB), and methylene orange (MO) degradation measurements had each been used to assess the photocatalytic activity of ZSHAs.

Using an electrochemically active biofilm, Khan, M. M. et al. [47] produced Au-SnO2 nanocomposite. XRD results were further supported by a Reitfield refinement. The visible part of the spectrum of the Au-SnO2 nanocomposite displayed a wide absorption peak between 500 and 600 nm, which was attributed to the surface plasmon resonance absorption of the Au NPs. The SnO2 nanoparticles ranged in size from 25 to 30 nm. The surface composition and chemical states of the Au-SnO2 nanocomposite and P-SnO2 nanoparticles were examined using XPS. Additionally, the photocatalytic degradation of Congo red and Methylene blue caused by visible light was evaluated using Au-SnO2 nanocomposite, which demonstrated approximately 10 and 6-fold better photocatalytic degradation activity than P-SnO2, respectively. These findings demonstrated that, in comparison to P-SnO2 nanoparticles, the Au-SnO2 nanocomposite exhibited outstanding and greater visible-light-induced photocatalytic activity.

By using the sol-gel process, Chandran, D. et al. [48] successfully synthesized pure and co-doped SnO2 nanoparticles with varying cobalt concentrations (0.75, 3, and 4 at%). When the cobalt concentration was increased, it was found that the diffraction peaks widened and the crystallinity decreased in comparison to pure SnO2.  The samples that have been doped showed an additional peak between 375 and 505 nm when compared to pure SnO2. The degradation of MB solution in the presence of natural light was used to assess the photocatalytic effectiveness of pure and doped samples.

SnO2 and Co-doped SnO2 nanoparticles were successfully produced by Sivakarthik, P. et al. [49] using the organic solvent-assisted simple solution approach and calcined at 300–5000C. In the presence Co-doped SnO2 at various concentrations, photocatalytic degradation of synthetic organic dye, namely Crystal violet, has been studied. The outcome showed that 4% Co doping calcined at 5000C displayed the maximum photocatalytic activity towards destruction of Crystal violet dye.

Mani, R et al. [50] also synthesized pure and Co-doped SnO2 nanoparticles by simple chemical precipitation method. Powder XRD results revealed that both pure and Co-doped SnO2 nanoparticles were indexed to a tetragonal rutile type structure. The photocatalytic degradation of phenol and benzoic acid was systematically investigated using Co–SnO2 catalyst under UV irradiation. The result showed that Co-doped SnO2 possessed the highest photo-catalytic properties as compared to pure SnO2.

Highly iron-doped tin dioxide nanoparticles (Sn1-xFexO2 NPs), with x ranging from 0 to 0.2, were effectively created by Ben Haj Othman et al. [51] using a straightforward hydrothermal process. The outcomes demonstrated a reasonably narrow particle size distribution for the SnO2 NPs, which have a diameter of roughly 10 nm. The measured size is comparable to that found in XRD data and shown that SnO2 structure is maintained even at rather high Fe doping levels. The band gap of SnO2NPs might be adjusted by adding Fe, according to UV-Vis measurements. The addition of Fe to the SnO2 NPs enhances RhB degradation when exposed to visible light, and this is due to both the stimulation of electron exchanges and the lowering of the gap value.

By using the polyol method at atmospheric pressure, Soltan, W. B. et al. [52] effectively produced nanocrystalline mesoporous pure and vanadium-doped (0-10 at%) SnO2 nanopowders from ammonium metavanadate and tin (IV) tetrachloride from a mixture of tin and vanadium precursors. When the vanadium concentration was raised up to 10%, the XRD patterns of both undoped and V-doped SnO2 materials showed the usual rutile-type tetragonal structure of SnO2, with average crystallite sizes ranging from 8.8 to 5.4 nm. Particle size was reduced from UV-visible diffuse reflectance spectroscopy by a decrease in the band gap energy value from 3.36 eV for pure SnO2 down to 2.2 eV for 10 at% V-doped SnO2. Vanadium doping caused the mean crystallite size to decrease, which in turn caused the specific area to slightly increase and the average pore size to simultaneously decrease. Since the vanadium content could be adjusted to adjust the optical absorption of these materials, this development paved the way for exciting potential applications of these V-doped nanopowders in the area of visible light photocatalysis.

By using a straightforward precipitation process, Sinha, T. et al. [53] successfully manufactured Ag-SnO2 nanocomposites. Ag-SnO2 nanocomposite with sphere-shaped particles and an average particle diameter of 8–10 nm were clearly visible in the TEM pattern. The SnO2 surface was successfully decorated by Ag, and the production of an Ag-SnO2 nanocomposite was demonstrated by the X-ray and EDAX data. The resulting Ag-SnO2 nanocomposite was used as an antibacterial and antioxidant agent as well as for the removal of four industrially emerging pollutants from the aqueous phase (MB, RB, MV6B, and 4-NP).

Co-doped SnO2 NPs with an average size of 30–40 nm was successfully created by Nasir, Z. et al. [54] using the co-precipitation approach utilizing SnCl2.2H2O and CoCl2.2H2O as Sn and Co precursors. The production of the nanoparticles was verified by XRD and SEM. Through a degradation process in the presence of MB dye under UV light irradiation, the increasing photocatalytic activities of the NPs with higher doping concentrations were reported.

By utilizing an easy and affordable co-precipitation technique, Qamar, M. A. et al. [55] were able to successfully synthesis Co-doped SnO2 nanoparticles. The band gap energy was further reduced when these SnO2 were co-doped. Undoped SnO2 nanoparticles had a band gap of 3.36 eV, and doped SnO2 nanoparticles had a band gap of 1.48 eV. Based on the inhibition zone (mm), Co-doped SnO2 nanoparticles were found to have antibacterial activity against the selected microorganisms. Co-doped SnO2 nanoparticles at a concentration of 500 L showed considerable and maximal antibacterial activity against both bacterial strains, namely Escherichia coli and Bacillus subtilis, with zones of inhibition of 16 ± 0.8 mm and 22 ±1.6 mm, respectively.

By using a chemical precipitation approach and 500°C annealing, Karpuraranjith, M., et al. [56] were able to successfully synthesize a biotemplate-zinc-tin oxide hybrid structure. The unique rutile structure of SnO2 with average crystalline sizes of 1.54–9.01 nm was revealed by the X-ray diffraction peaks. The hybrid structure's optical band gap energy was determined to be 3.19 eV. It was discovered that the CS-Zn0.25Sn0.75O hybrid structures material had a higher value for the surface area and pore volume assessed. Thus, the zinc-tin oxide hybrid structure based on a bio template emerged as a viable component for enhancing photocatalytic activity.

Pristine and (Mg+Co) doped tin oxide nanoparticles were effectively made by Mala, N. et al. [57] using a practical wet chemical process. The fact that the XRD pattern of the (Mg+Co) doped SnO2 nanoparticles matched that of the unaltered SnO2 nanoparticles suggests that the doped nanoparticles also exhibited a rutile hexagonal structure. The antibacterial and photocatalytic properties of the material were mostly caused by the presence of hydroxyl groups.

Using SnCl2, MnCl2, and triethanolamine, Sakwises, L. et al. [58] successfully synthesized SnO2 and Mn-doped SnO2 nanoparticles. 40% wt of Mn was entirely substituted, according to FTIR and XRD. For four hours, the photocatalytic activity on the breakdown of methylene blue was studied to determine the effectiveness of SnO2 and SnO2 with Mn doping. Even with partial substitution of the Mn atom, there was no discernible difference in photocatalytic efficacy.

By using a microwave irradiation technique and attaching it to the surface of Silk fibroin (SF), Bhuvaneswari, K. et al. [59] successfully synthesized pure SnO2, Cd / Zn-doped SnO2 nanopowders. The lowering crystallite size increased active surface area, and reduced particle distribution after connecting SF all contributed to the increase in photocatalytic activity. Zn-doped SnO2 photocatalyst with SF links displayed more MB degradation.

SnO2 quantum dots (QDs) with various Mn concentrations were effectively produced via solution combustion synthesis by Babu, B. et al. [60]. X-ray diffraction patterns displaying the tetragonal rutile structure of SnO2 were used to analyze the structural characteristics of the undoped and Mn-doped SnO2 QDs. Under visible light irradiation, the Mn-doped SnO2 QDs were used as catalysts to assess the photocatalytic degradation of MO dye. Within 240 minutes, SnO2 QDs with a 3 mol% Mn dopant displayed a 17-fold improvement in photocatalytic performance.

Using a straightforward co-precipitation approach, Asaithambi, S. et al. [61] produced pure and cobalt (Co)-doped SnO2 nanoparticles successfully. Energy-dispersive X-ray spectra revealed the existence of tin, oxygen, and Co species. By examining the photodecomposition of bright green dye, an organic pollutant, the photo-catalytic activities of pure and Co-doped SnO2 nanoparticles were studied.

The co-precipitation approach was used by Sujatha, K. et al. [62] to manufacture and analyze pure, zinc-doped, and surfactant-assisted Zn-doped SnO2 NPs. The band gap values calculated from Tauc's plot for the Zn-doped SnO2 nanoparticles showed a significant change from 3.292 eV to 3.695 eV. The highest photocatalytic activity (80%) and best optical characteristics were obtained in Zn-doped SnO2 nanoparticles produced with triton assistance. In contrast to TRITON-assisted Zn-doped SnO2 NPs, pure, CTAB- and SDS-assisted Zn-doped SnO2 NPs exhibit a very high rate of photogenerated electron-hole pair (e, h+) recombination, which inhibits the generation of the hydroxyl radical.

An innovative photo-catalytic investigation of vanadium-doped SnO2 nanoparticles (SnO2:V NPs) in Rhodamine-B degradation was published by Letifi, H. et al. [63]. These NPs were made using the co-precipitation process, with vanadium concentrations ranging from 0% to 4%. With increasing vanadium concentration, optical measurements revealed that the SnO2:V NPs' absorption edge shifted toward the red. The optical band gap decreased as a result of this redshift from 3.25 eV to 2.55 eV. All manufactured NPs' photo-catalytic degradation has been investigated using the Rhodamine B dye (RhB). The photocatalytic activity of SnO2:V NPs had been enhanced in comparison to undoped SnO2 NPs.

The increased antibacterial and photocatalytic activity of pure and Copper (Cu) doped SnO2 nanoparticles was successfully investigated by Sathish Kumar, M et al. [64] using the microwave-assisted technique. The synthesis of NPs utilized the tin and copper sources tin chloride dihydrate (SnCl2.2H2O) and copper chloride hexahydrate (CuCl2.6H2O), respectively. The band gap energy value for pure SnO2 nanoparticles was determined to be 3.54 eV, while it was reduced to 3.20 eV for Cu-doped SnO2 nanoparticles. Optical properties were explored by UV visible and Photoluminescence spectroscopy. Cu-doped SnO2 nanoparticles showed excellent zone of inhibition against both pathogens in antibacterial activity tests using the disc diffusion method against P. aeruginosa and S. aureus. The large particle size and minimal release of Sn4+ ions, which produce little ROS, caused pure SnO2 to have a smaller inhibitory zone than Cu-doped SnO2. Due to an increase in the rate of release of Cu2+ ions and Sn4+ ions as well as the large surface area of the crystal, which amplified the formation of ROS, a larger inhibition zone was generated against both bacteria when the Cu doping concentration was raised. Under UV light, the produced materials' photocatalytic gradation abilities for the dyes Methylene blue and Rhodamine B were also assessed.

Sujatha, K. et al. [65] used tin chloride dihydrate and ferric chloride as precursors with ethanol and ammonia to successfully synthesize Fe-doped and surfactant-assisted (CTAB, SDS, and Triton) Fe-doped SnO2 NPs. The addition of Fe and surfactants was found to increase the band gap. The photocatalytic analysis verified that pure SnO2 NPs showed a considerable photo-degradation of methylene blue dye in the presence of sunshine. In contrast to Fe-doped and surfactant-assisted Fe-doped SnO2 NPs, maximum dye (MB) degradation was seen above 120 minutes in pure SnO2 NPs. The shape, energy gap, and particle size of the NPs all affect their photocatalytic properties.

Tin chloride (SnCl2.5H2O; 98%), ethanol (C2H5OH), iron chloride (FeCl2.5H2O; 98%), and sodium hydroxide (NaOH; 99%) were used in the preparation of pure and Fe-doped tin SnO2 nanoparticles by Ali Baig et al. [66]. Due to the Fe dopant's nominal defect, the intensity will be reduced. Maximum MO dye degradation efficiency of 87.2% has been achieved 200 min under visible light using the 4% of Fe-doped SnO2 NPs, which had greater photocatalytic action compared to the pure and 2% of Fe-SnO2. Gram-negative (E. coli) and gram-positive (S. aureus) bacteria were used to test the antibacterial activity of both pure and Fe-doped SnO2 nanoparticles. The research shown that the antibacterial activities of the manufactured Fe-doped SnO2 NPs have a remarkable performance against various gram-positive (G+) and gram-negative (G-) bacteria.

Using SnCl2.2H2O, FeCl3.6H2O, aqua ammonia, and urea as raw materials, Wang, Q et al. [67] synthesized novel material Fe (1, 2 and 3 wt%) doped SnO2 adorned layered g-C3N4 using a straightforward chemical precipitation technique. The as-prepared hybrid material 1wt% Fe-SnO2/g-C3N4 (1 wt% Fe-SCN) showed improved activity or both photodegradation of Rhodamine B and Methylene blue under simulated solar light irradiation. It was discovered that Fe doping decreased the band gap of Fe-SnO2 and created a heterojunction between Fe-doped SnO2 and g-C3N4 that efficiently aided in the separation of photo-generated electrons and holes.

By chemically precipitating tin (II) chloride dehydrate (SnCl2.H2O), oxalic acid dehydrates (C2H2O4.2H2O), and manganese (II) acetate tetrahydrate (CH3COO)2Mn.4H2O), Ramamoorthy, M. et al. [68] created Mn-doped SnO2 that was loaded with a (0.5 g) corn co methylene blue was photodegraded in sunlight to estimate the photocatalytic performance of the substance. In comparison to samples of pure SnO2 and Mn-doped SnO2, the band gap value for Mn: SnO2/CCAC was lower (3.49 eV). In comparison to pure SnO2 and Mn-doped (0.10 M) SnO2, it was demonstrated that the Mn (0.10 M) SnO2/CCAC photocatalyst had improved particle size, band gap, emission, hydroxyl group, and surface area.

Suthakaran, S et al. [69] successfully prepared Zr-doped SnO2 NPs by surfactant-assisted hydrothermal method using Tin (IV) chloride pentahydrate (SnCl4.5H2O), Zirconyl chloride octahydrate (ZrOCl2.8H2O), sodium hydroxide (NaOH), and sodium hexametaphosphate as starting materials. The results of XRD confirmed that the bare, SHMP-assisted, and Zr-doped SnO2 NPs were polycrystalline in nature with a tetragonal structure and remained stable even after higher concentrations of Zr doping. Photocatalytic measurements showed that doped NPs improved the photodegradation percentage of the MV dye, which could open up a new way to address water contamination and environmental pollution.

According to Baig, A. et al. [70], nanocrystalline pristine and Zr-doped SnO2 NPs were organized by simple hydrothermal co-precipitation mode, and the crystallite size was approximately between 41 and 36 nm. A detailed investigation of the photocatalytic capabilities of 4% Zr-doped SnO2 nanoparticles (NPs) in the photodegradation of the methyl orange (MO) dye revealed better photocatalytic activity in the degradation of MO than pristine and 2% Zr-doped SnO2 under visible-light exposure. In comparison to pure SnO2, the 4% Zr doped SnO2NPs were more photocatalytically capable and shown antibacterial activity against E. coli and S. aureus bacteria using an agar well diffusion technique.

Using a straightforward hydrothermal chemical process with varying Y doping concentrations (0, 2, and 4 at%), Baig, A. et al.[71] successfully produced SnO2 NPs. Although the size decreased after Y3+doping, X-ray diffraction (XRD) examinations revealed that the undoped and Y: SnO2 NPs had a fine crystalline texture with a tetragonal structure and particle sizes ranging from 27 to 15 nm. HRSEM showed equivalent crystallite spreading and agglomeration morphologies. The Y3+ doped SnO2 NPs showed a red shift in bandgap energy, enhanced photocatalytic activity was noted for the doped samples, and the 4% Y: SnO2 NPs displayed excellent photodegradation of methylene blue aqueous dye in visible light, demonstrating 92.34% degradation in 180 minutes. Optical absorption was investigated using UV-visible diffuse reflectance spectroscopy. The other photocatalysts likewise showed high stability and better than 85% photodegradation efficiency, with no discernible activity loss after five cycles. The 4% Y: SnO2 NPs (100 L) had a higher ZOI than the undoped and 2% Y: SnO2 samples, according to the antibacterial study. Due to the low concentration of the as-prepared NPs found in the E. coli and S. aureus bacterial strains, the undoped/pristine SnO2 NPs exhibited the least antibacterial action. However, the ZOI was distinctly discernible at the greatest Y doping concentration (4%) in SnO2 NPs.

In-SnO2 nanomaterial was produced by Carolin, L. et al. [72] by precipitation and sonication. Band gap energies of 3.7 and 3.1 eV were determined for the synthesized SnO2 and In-doped SnO2 nanocomposites. SnO2photo catalyst demonstrated the catalyst's excellent reusability characteristics. Under UV light, the RR 120 dye was used to test the photocatalytic efficiency of the photocatalyst at pH 7 and 0.150 g, the ideal pH and catalytic concentration. OH Radical production is directly linked to the photocatalytic activity of In-SnO2 nanocomposite. In-doped SnO2 has greater antibacterial activity than undoped SnO2.

One-step hydrothermal synthesis of Bi-doped SnO2 quantum dots was accomplished by Chu, L. et al. [73]. By using photocatalytic degradation of Rhodamine B (RhB) and Ciprofloxacin hydrochloride (CIP) solution, photocatalysts were assessed under simulated sunshine irradiation. Due to improved light absorption and the efficient separation and migration of photo-generated carriers, the produced composites had exceptional photodegradation efficiency. After being exposed to 5Bi-SnO2, the antibacterial effect of CIP on Escherichia coli DH5a had essentially disappeared. Due to their exceptional stability and high efficiency, bi-doped SnO2 quantum dots had a wide range of potential practical applications.

Through the use of a high-temperature oxy-acetylene flame, Prabhu et al. [74] created pure SnO2 and Zn: SnO2 nanoparticles. Nano cubical and nanoflake Zn: SnO2 nanoparticles with an improved crystalline structure replace irregular, agglomerated, nanoflowers, and nano clustered SnO2 nanoparticles. Due to the production of highly reactive (OH-) hydroxyl and superoxide (O2-) radicals, MB degradation study demonstrates the strong performance of SnO2 and Zn: SnO2 nanoparticles as photocatalysts under UV light.

By using Populus ciliate leaf extract, Salah Ud Din et al. [75] created SnO2 nanoparticles. The experiments included XRD, EDAX, and antioxidant ones. The diffusion technique based on agar wells was used to examine the antibacterial properties of produced SnO2 nanoparticles against Gram-positive bacteria (S. pyogene and S. aureus) and Gram-negative bacteria (K. pneumoniae and E. coli).

**Table 1: Summary of various methods for metal ion doped SnO2-based nanostructure synthesis**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Authors and year** | **Sample** | **Synthesis route** | **Structural characterization** | **Applications & results** | **Ref.** |
| Kumar, V et al. (2011) | F- SnO2 | sol-gel method | PXRD (a = 4.7106 Å & c = 3.1970 Å), TEM (Agglomeration with an average diameter of 57 nm ), BET (45.16 m2 /g), Raman spectrum (455, 588, and 874 cm-1 ), EDX, Pore size analysis (13.97 nm) | Increased photocatalytic efficiency in the degradation of aqueous Rhodamine-B (RhB) dye solution under UV irradiation. | 39 |
| You, H  et al. (2013) | Au–SnO2 | solution reaction | XRD( rutile-type ), SEM(dendrites with staggered form and perpendicular form), TEM (nanotubes, diameter 50 nm & shell thickness of about 25 nm), SAED, BET (300.2 m2 g-1). | Enhanced photocatalytic performance in the photodegradation of R6G molecules. | 40 |
| Wu, W  et al. (2013) | Au–SnO2 | hydrothermal method | XRD (crystallite sizes 10.8 nm ), HRTEM, BET ( 93.2 m2g-1), EDX, BET(93.2 m2g-1 ) pore size(16.8 nm), UV-DRS(Eg= 3.32eV) | The improved photocatalytic degradation of RhB under UV and visible light irradiation. | 41 |
| Davis, M  et al. (2013) | Fe-SnO2 | sol–gel method | XRD(3nm), Gas sorption analyses (330 m2 g-1), Electron microscopy studies, Pore size analysis, EDX | RhB was efficiently photocatalyzed under ultraviolet irradiation, and within two hours, 5% Fe-modified SnO2 had reduced RhB by more than half. | 42 |
| Ansari, S  et al. (2014) | Ag–SnO2 | EAB  (electrochemically active biofilm). | XRD(Crystallite sizes of 11.00 nm, 14.20 nm and 14.57 nm)., surface plasmon resonance absorption(400–550nm) | increased photocatalytic activity for the breakdown of methyl orange and methylene blue when exposed to visible light. | 43 |
| Toloman, D et al. (2014) | Co -SnO2 | chemical precipitation method | XRD (tetragonal rutile, crystallite size 8.8 nm for 5% Co-doped SnO2), EPR. | Under visible light irradiation, the sample's photocatalytic activity was assessed against a synthetic RhB solution. | 44 |
| Ran, L  et al. (2015) | Ti-SnO2 | facile infiltration route (stober method) | XRD(the crystalline state with a particle diameter of about 300 nm). BET (from 26.2 ± 0.5 m2 g−1 in SiO2 to 35.6 ± 0.5 m2 g−1 in SiO2 (20% Ti)). | Highest photocatalytic activity with 92% and 54% of the MB photo catalytically decomposing in 135 minutes of UV light exposure. | 45 |
| Zhao, Q  et al. (2015) | Zn-SnO2 | hydrothermal method | XRD (tetragonal rutile structure), SEM(2D nanosheets), TEM (single crystalline feature with the lattice spacing of 0.34nm), EDX. | Photocatalytic degradation of methylene blue (MB-91%), methylene orange (MO-40%), and rhodamine B (RhB-60%) in 60min. | 46 |
| Khan, M. M  et al. (2015) | Au–SnO2 | electrochemically active biofilm. | XRD (crystallite size is of 25–30 nm). UV-Vis(500-600nm), XPS. | Photocatalytic degradation of Congo red and Methylene blue by 10 and 6 times, respectively. | 47 |
| Chandran, D et al. (2015) | Co- SnO2 | sol–gel method | XRD (tetragonal rutile-type), HRTEM (interplanar spacing of 0.34 nm), UV spectra(375-505nm) | The degradation of the MB solution under natural light was used to calculate the photocatalytic efficiency. | 48 |
| Sivakarthik, P et al. (2016) | Co -SnO2 | simple solution method | XRD (tetragonal structure & particle size of 18 nm to 22 nm)., SEM (spherical morphology) | displayed high photocatalytic activity for the breakdown of Crystal violet dye. | 49 |
| Mani, R  et al. (2017) | Co -SnO2 | chemical precipitation method | XRD (tetragonal rutile, average crystalline size 48, 41, and 32 nm), TEM, FTIR, UV-Vis(Eg=3.58, 3.32, 3.12ev) | Under UV irradiation, the photocatalytic degradation of phenol and benzoic acid was studied. | 50 |
| Ben Haj Othmen  et al. (2016) | Fe-doped SnO2 NPs | hydrothermal method. | XRD (tetragonal rutile structure), HRTEM, BET, UV-Vis. | Enhanced photocatalytic degradation of RhB under visible light irradiation. | 51 |
| Soltan, W. B et al. (2016) | V- SnO2 | polyol route | XRD(rutile-type tetragonal structure with average crystallite sizes 8.8 to 5.4 nm), UV-DRS(2.2eV) | Vanadium variations in photocatalysis under visible light enabled adjustment of the optical absorption. | 52 |
| Sinha, T et al.(2016) | Ag-SnO2 | Simple precipitation method | XRD, TEM (average particle diameter of 8−10 nm), EDAX, SAED | Utilized for the reduction of four industrially developing pollutants (MB, RB, MV6B, and 4-NP) and as an antibacterial agent against Pseudomonas aeruginosa, Escherichia coli, and Bacillus subtilis | 53 |
| Nasir, Z  et al. (2017) | Co -SnO2 | co-precipitation method | XRD (tetragonal-rutile type structures ), SEM, TEM, SAED | Enhanced photocatalytic degradation of MB dye under UV light irradiation & also antimicrobial effect. | 16 |
| Qamar, M. A et al. (2017) | Co-SnO2 | co-precipitation method. | XRD (tetragonal structure having average crystallite size 24.86 nm), SEM(spherical shape), EDX, UV-Vis(Eg=1.48eV) | Antibacterial activity against both bacterial strains i.e. Escherichia coli(16 ± 0.8 mm) & Bacillus subtilis(22 ± 1.6 mm) | 17 |
| Karpuraranjith, M et al. (2017) | Zn-SnO2 | Chemical precipitation method | XRD(distinctive rutile structure with average crystalline sizes of 1.54–9.01 nm), SEM(cluster), EDAX, TEM(agglomerated), UV-Vis(3.19eV) | bio-based templates Zn-SnO2 has shown to be an effective substance for enhancing photocatalytic activity. | 18 |
| Mala, N  et al. (2017) | (Mg+Co) doped SnO2 | wet chemical method | XRD (rutile hexagonal structure with an average crystallite size of 24 and 25 nm), FTIR. | For Malachite Green (MG) and MB, the degradation efficiency of pure SnO2 was 82% and 86%, respectively. | 19 |
| Sakwises, L et al. (2017) | Mn-SnO2 | wet chemical synthetic route | FTIR and XRD revealed 40% wt of Mn completely substituted, EDX. | The degradation of organic pollutants (MB) under UV irradiation. | 20 |
| Bhuvaneswari, K et al. (2018) | Cd / Zn-doped SnO2 | Microwave irradiation method | XRD (rutile-tetragonal system with an average crystallite size 43.4, 22.8, and 24.3 nm), FTIR, UV-Vis spectra. | Zn-doped SnO2 nanoparticles' photocatalytic activity showed a remarkable MB degradation efficiency of 99.6%. | 21 |
| Babu, B  et al. (2018) | Mn-SnO2 | solution combustion | XRD (tetragonal rutile structure with an crystallite size ranging from 5 to 4.4 nm), SAED, FT-IR, UV-Vis(Eg=3.07ev) | Under visible light irradiation, the photocatalytic degradation of MO dye was measured. | 22 |
| Asaithambi,S et al. (2019) | Co- SnO2 | co-precipitation method | XRD (cassiterite tetragonal SnO2 structure with average crystalline between 26.4 nm and 23.1 nm), FTIR, UV-Vis(Eg=3.47eV), HRTEM, SAED. | Co-doped SnO2 had higher photocatalytic activity & and maximum degradation efficiency of 91% under visible light irradiation. | 23 |
| Sujatha, K et al. (2019) | Zn -SnO2 | co-precipitation method | XRD (rutile tetragonal with crystallite size 9.34 nm), SEM(Spherical), EDX, UV-Vis(Eg=3.69eV) | Better optical characteristics and a high (80%) photocatalytic activity. | 24 |
| Letifi, H  et al. (2019) | V-SnO2 | co-precipitation method | XRD (tetragonal structure & the average crystal size is 10nm), UV-Vis(Eg=2.55eV) | The photocatalytic degradation has been studied using the Rhodamine B dye (RhB; 95 percent in 150 minutes). | 25 |
| Sathishkumar, M  et al. (2020) | Cu- SnO2 | microwave assisted method | XRD (tetragonal rutile phase and average crystal size was found to be 29 nm ), TEM(Spherical), UV-Vis(3.20eV). | Enhanced antibacterial (P. aeruginosa & S. aureus) and photocatalytic activity (MB, RhB) | 26 |
| Sujatha, K et al. (2020) | Fe-SnO2 | co-precipitation method | XRD (tetragonal rutile structure with a crystallite sizes 6.347 nm), SEM, TEM, EDAX, UV-Vis. | Enhanced degradation of dye (MB) was found to be 49% respectively. | 27 |
| Ali Baig  et al. (2020) | Fe- SnO2 | co-precipitation method | XRD (tetragonal structure with crystalline size was found to be between 28 nm), HRTEM (agglomerated), UVDRS(Eg=2.65eV) | Higher photocatalytic MO dye degradation efficiency of 87.2 % under visible light & antibacterial activity was determined against E.coli and S.aureus bacteria. | 28 |
| Wang, Q  et al. (2020) | Fe -SnO2 | simple chemical precipitation method | XRD, HRTEM, EDS, XPS, UVDRS | enhanced photocatalytic activity and photodegradation of methylene blue and rhodamine B in the presence of simulated solar light. | 29 |
| Ramamoorthy, M  et al. (2020) | Mn-SnO2 | chemical precipitation method | XRD (rutile tetragonal structure, crystallite size 13.79nm), UV-Vis(Eg=3.49eV) | photocatalytic performance was estimated by photodegradation of methylene blue under sunlight irradiation. | 30 |
| Suthakaran, S  et al. (2020) | Zr -SnO2 | hydrothermal method | XRD (polycrystalline in nature with tetragonal structure),  TEM(hexagonal morphology with an average particle size of 4.1 nm), PL. | Photocatalytic measurements showed that doped NPs improved the photodegradation percentage of the MV dye. | 31 |
| Baig, A  et al. (2020) | Zr-SnO2 | facile hydrothermal co-precipitation | XRD(tetragonal rutile-type construction and the crystallite size was about ~ 41 to 36 nm), SEM, EDX, UVDRS(2.87eV) | Methyl orange (MO) dye photodegradation demonstrated increased photocatalytic activity. E. coli and S. aureus germs were successfully eradicated with antibacterial activity. | 32 |
| Baig, A  et al. (2020) | Y-SnO2 | hydrothermal chemical route | XRD (tetragonal structure and particle size range of 27–15 nm), SEM(agglomeration), UVDRS | Enhanced photodegradation of methylene blue dye in visible light (92.34% in 180min), antibacterial activity against E. coli and S. aureus | 33 |
| Carolin, L et al. (2020) | In–SnO2 | precipitation method and sonication technique | XRD (cassiterite structure and average size of 40–50 nm & 60–80 nm)  HRTEM (showed Particle size of 8–10 nm for In–SnO2 & 20–30 nm for bare SnO2), EDX, UVDRS(Eg=3.1ev) | With the aid of RR 120 dye and improved antibacterial activity against B. subtilis and V. cholera (22 mm and 14 mm), the photocatalytic effectiveness of the catalyst was tested under UV light. | 34 |
| Chu, L  et al. (2020) | Bi-SnO2 | hydrothermal method | XRD (revealed that Bi has entered into the SnO2 crystal lattice to substitute Sn during the synthesis process) XPS, BET, Pore volume analysis. | Rhodamine B (RhB) and Ciprofloxacin hydrochloride (CIP) solutions were subjected to photocatalytic degradation under the influence of simulated sunlight. Escherichia coli DH5a and the antibacterial properties of CIP. | 35 |
| Sivarama Prabhu P  (2021) | Zn:SnO2 | Flame oxidation process | XRD showed average crystalline size 20 to 30nm and a band gap found to be 3.5 to 3.6V | Photocatalytic degradation of methylene blue dye was found to be 88% | 74 |
| Salah Ud Din etal [2022] | SnO2 | biosynthesis | The FTIR and TGA results confirm the presence of a hydroxyl group in the sample. Band gap was found to be <1v | Antibacterial studies were carried out | 75 |

**3. Conclusions**

This review covered the creation of SnO2 hierarchical structures, their doping and compositional modifications, as well as the creation of stannate nanomaterials with various morphologies, such as nanoparticles, nanorods, nanosheets, nanospheres, and porous and hollow structures. Tin oxide nanomaterials have been expected to be powerful photocatalysts for the degradation of organic pollutants in aqueous solution due to their excellent properties such as transparency, low cost, environmental friendliness, good chemical and biological inertness, nontoxicity, easy production and high photosensitivity, photostability, and thermodynamic stability. Tin oxide is also known for its antimicrobial activity especially antibacterial properties against many gram-positive and gram-negative bacteria.

The high activation energy of the metal oxide limits the experimental use of SnO2 semiconductors as a pure material, despite their excellent promise for photo-catalytic applications and their antioxidant activity against free radicals. This activation energy corresponds to UV light exposure and the direct (rapid) recombination rate of the photo-generated conduction electron (e CB) in the Sn 4d(5S) band and with a hole in the O 2p valence band. The rate of electron-hole pair recombination needs to be suppressed in order to improve the industrial use of SnO2 and boost the photo-catalytic activity. Doping other semiconductors with metal oxides that have differing band gaps for electron energies is one method. The new combination material's photo-catalytic activity might then be enhanced as a result of the reduced activation energy and rate of electron-hole pair recombination.

SnO2-based nanomaterial gained widespread usage after the addition of components with various chemical compositions. The large-scale synthesis of SnO2 nanocrystals with more specialized facets exposed is still a difficulty, though. Future advancements will be made and novel and intriguing nanosystems will produce the technologies of the future thanks to extensive research in the synthesis of nanostructures to precisely control dimension and composition, a critical understanding of the modified properties of materials at the nanoscale, and the hierarchical assembly of nanostructures with exquisite spatial control.

**4. References**

[1] Nair, M. G., Nirmala, M., Rekha, K., & Anukaliani, A. (2011). Structural, optical, photocatalytic, and antibacterial activity of ZnO and Co-doped ZnO nanoparticles. ***Materials Letters***, *65*(12), 1797-1800

[2] Li, L., Zong, F., Cui, X., Ma, H., Wu, X., Zhang, Q., & Zhao, J. (2007). Structure and field emission properties of SnO2 nanowires. ***Materials Letters***, *61*(19-20), 4152-4155

[3] Wang, Y., & Chen, T. (2009). Nonaqueous and template-free synthesis of Sb doped SnO2 microspheres and their application to lithium-ion battery anode. ***Electrochimica Acta***, *54*(13), 3510-3515.

[4] Snaith, H. J., & Ducati, C. (2010). SnO2-based dye-sensitized hybrid solar cells exhibiting near unity absorbed photon-to-electron conversion efficiency. ***Nano letters***, *10*(4), 1259-1265.

[5] Branci, C., Benjelloun, N., Sarradin, J., & Ribes, M. (2000). Vitreous tin oxide-based thin film electrodes for Li-ion micro-batteries. ***Solid State Ionics***, *135*(1-4), 169-174.

[6] Hong, Z. R., Liang, C. J., Sun, X. Y., & Zeng, X. T. (2006). Characterization of organic photovoltaic devices with indium-tin-oxide anode treated by plasma in various gases. ***Journal of applied physics***, *100*(9), 093711.

[7] Pandey, P. C., Upadhyay, B. C., Pandey, C. M. D., & Pathak, H. C. (1999). Electrochemical studies on D96N bacteriorhodopsin and its application in the development of photosensors. ***Sensors and Actuators B: Chemical***, *56*(1-2), 112-120.

[8] Tazikeh, S., Akbari, A., Talebi, A., & Talebi, E. (2014). Synthesis and characterization of tin oxide nanoparticles via the Co-precipitation method. ***Materials Science-Poland***, *32*(1), 98-101.

[9] Courtel, F. M., Baranova, E. A., Abu-Lebdeh, Y., & Davidson, I. J. (2010). In situ polyol-assisted synthesis of nano-SnO2/carbon composite materials as anodes for lithium-ion batteries. ***Journal of Power Sources***, *195*(8), 2355-2361.

[10] Pradel, K. C., Ding, Y., Wu, W., Bando, Y., Fukata, N., & Wang, Z. L. (2016). Optoelectronic properties of solution-grown ZnO np or pn core–shell nanowire arrays. ***ACS Applied Materials & Interfaces***, *8*(7), 4287-4291.

[11] Chopra, K. L., Major, S., & Pandya, D. K. (1983). Transparent conductors status review. ***Thin solid films***, *102*(1), 1-46.

[12] Cojocaru, L., Olivier, C., Toupance, T., Sellier, E., & Hirsch, L. (2013). Size and shape fine-tuning of SnO2 nanoparticles for highly efficient and stable dye-sensitized solar cells. ***Journal of Materials Chemistry A***, *1*(44), 13789-13799.

[13] Mishra, Y. K., Modi, G., Cretu, V., Postica, V., Lupan, O., Reimer, T., & Adelung, R. (2015). Direct growth of freestanding ZnO tetrapod networks for multifunctional applications in photocatalysis, UV photodetection, and gas sensing. ***ACS applied materials & interfaces***, *7*(26), 14303-14316.

[14] Harrison, P. G., & Willett, M. J. (1988). The mechanism of operation of tin (IV) oxide carbon monoxide sensors. ***Nature***, *332*(6162), 337-339.

[15] He, Y. S., Campbell, J. C., Murphy, R. C., Arendt, M. F., & Swinnea, J. S. (1993). Electrical and optical characterization of Sb: SnO2. ***Journal of Materials Research***, *8*(12), 3131-3134.

[16] Semancik, S., & Fryberger, T. B. (1990). Model studies of SnO2-based gas sensors: vacancy defects and Pd additive effects. ***Sensors and actuators B: chemical***, *1*(1-6), 97-102.

[17] Wang, S. C., & Shaikh, M. O. (2015). A room temperature H2 sensor fabricated using high-performance Pt-loaded SnO2 nanoparticles. ***Sensors*,** *15*(6), 14286-14297.

[18] Rashad, M. M., Ismail, A. A., Osama, I., Ibrahim, I. A., & Kandil, A. H. T. (2014). Photocatalytic decomposition of dyes using ZnO doped SnO2 nanoparticles prepared by solvothermal method. ***Arabian Journal of Chemistry***, *7*(1), 71-77.

[19] Rana, S., Srivastava, R. S., Sorensson, M. M., & Misra, R. D. K. (2005). Synthesis and characterization of nanoparticles with magnetic core and photocatalytic shell: anatase TiO2–NiFe2O4 system. ***Materials Science and Engineering: B*,** *119*(2), 144-151.

[20] Chakravarty, R., Chakraborty, S., Shukla, R., Bahadur, J., Ram, R., Mazumder, S., & Dash, A. (2016). Mechanochemical synthesis of mesoporous tin oxide: a new generation nano sorbent for 68 Ge/68 Ga generator technology. ***Dalton Transactions***, *45*(34), 13361-13372.

[21] Farrukh, M. A., Tan, P., & Adnan, R. (2012). Influence of reaction parameters on the synthesis of surfactant-assisted tin oxide nanoparticles. ***Turkish Journal of Chemistry***, *36*(2), 303-314.

[22] Gebreslassie, Y. T., & Gebretnsae, H. G. (2021). Green and Cost-Effective Synthesis of Tin Oxide Nanoparticles: A Review on the Synthesis Methodologies, Mechanism of Formation, and Their Potential Applications. ***Nanoscale Research Letters***, *16*(1), 1-16.

[23] Chen, S., Wang, M., Ye, J., Cai, J., Ma, Y., Zhou, H., & Qi, L. (2013). Kinetics-controlled growth of aligned mesocrystalline SnO2 nanorod arrays for lithium-ion batteries with superior rate performance. ***Nano Research***, *6*(4), 243-252.

[24] Dai, Z. R., Gole, J. L., Stout, J. D., & Wang, Z. L. (2002). Tin oxide nanowires, nanoribbons, and nanotubes. ***The Journal of Physical Chemistry B***, *106*(6), 1274-1279.

[25] Zhang, J., Guo, J., Xu, H., & Cao, B. (2013). Reactive-template fabrication of porous SnO2 nanotubes and their remarkable gas-sensing performance. ***ACS applied materials & Interfaces***, *5*(16), 7893-7898.

[26] Li, X., Meng, X., Liu, J., Geng, D., Zhang, Y., Banis, M. N., ...& Verbrugge, M. W. (2012). Tin oxide with controlled morphology and crystallinity by atomic layer deposition onto graphene nanosheets for enhanced lithium storage. ***Advanced Functional Materials***, *22*(8), 1647-1654

[27] Chetri, P., & Choudhury, A. (2015). Investigation of structural and magnetic properties of nanoscale Cu doped SnO2: an experimental and density functional study. ***Journal of Alloys and Compounds***, *627*, 261-267.

[28] Babu, B., Reddy, C. V., Shim, J., Ravikumar, R. V. S. S. N., & Park, J. (2016). Effect of cobalt concentration on morphology of Co-doped SnO2 nanostructures synthesized by solution combustion method. ***Journal of Materials Science: Materials in Electronics***, *27*(5), 5197-5203.

[29] Zhuang, S., Xu, X., Pang, Y., Li, H., Yu, B., & Hu, J. (2013). Variation of structural, optical, and magnetic properties with Co-doping in Sn1− x CoxO2 nanoparticles. ***Journal of Magnetism and magnetic materials***, *327*, 24-27.

[30] Liu, B., Wang, X., Cai, G., Wen, L., Song, Y., & Zhao, X. (2009). Low-temperature fabrication of V-doped TiO2 nanoparticles, structure, and photocatalytic studies. ***Journal of hazardous materials***, *169*(1-3), 1112-1118.

[31] Sakuma, J., Nomura, K., Barrero, C., & Takeda, M. (2007). Mössbauer studies and magnetic properties of SnO2 doped with 57Fe. ***Thin Solid Films***, *515*(24), 8653-8655.

[32] Toloman, D., Popa, A., Raita, O., Stan, M., Suciu, R., Miclaus, M. O., & Biris, A. R. (2014). Luminescent properties of vanadium-doped SnO2 nanoparticles. ***Optical Materials***, *37*, 223-228.

[33] Letifi, H., Litaiem, Y., Dridi, D., Ammar, S., & Chtourou, R. (2019). Enhanced photocatalytic activity of vanadium-doped SnO2 nanoparticles in rhodamine B degradation. ***Advances in Condensed Matter Physics***, *2019*.

[34] Shume, W. M., Murthy, H. C., & Zereffa, E. A. (2020). A review on synthesis and characterization of Ag2O nanoparticles for photocatalytic applications. ***Journal of Chemistry***, Article ID 5039479, 15 pages, https://doi.org/10.1155/2020/5039479*.*

[35] Marimuthu, S., Antonisamy, A. J., Malayandi, S., Rajendran, K., Tsai, P. C., Pugazhendhi, A., & Ponnusamy, V. K. (2020). Silver nanoparticles in dye effluent treatment: A review on synthesis, treatment methods, mechanisms, photocatalytic degradation, toxic effects and mitigation of toxicity. ***Journal of Photochemistry and Photobiology B: Biology***, *205*, 111823.

[36] Asaithambi, S., Sakthivel, P., Karuppaiah, M., Murugan, R., Yuvakkumar, R., & Ravi, G. (2019). Preparation of SnO2 nanoparticles with the addition of Co ions for the photocatalytic activity of brilliant green dye degradation. ***Journal of Electronic Materials***, *48*(4), 2183-2194.

[37] Sakwises, L., Pisitsak, P., Manuspiya, H., & Ummartyotin, S. (2017). Effect of Mn-substituted SnO2 particle toward photocatalytic degradation of methylene blue dye. ***Results in Physics***, *7*, 1751-1759.

[38] Kumar, V., Govind, A., & Nagarajan, R. (2011). Optical and photocatalytic properties of heavily F-doped SnO2 nanocrystals by a novel single-source precursor approach. ***Inorganic chemistry***, *50*(12), 5637-5645.

[39] Kumar, V., Govind, A., & Nagarajan, R. (2011). Optical and photocatalytic properties of heavily F-doped SnO2 nanocrystals by a novel single-source precursor approach. ***Inorganic chemistry***, *50*(12), 5637-5645.

[40] You, H., Liu, R., Liang, C., Yang, S., Wang, F., Lu, X., & Ding, B. (2013). Gold nanoparticle doped hollow SnO2 supersymmetric nanostructures for improved photocatalysis. ***Journal of Materials Chemistry A***, *1*(12), 4097-4104.

[41] Wu, W., Liao, L., Zhang, S., Zhou, J., Xiao, X., Ren, F., & Jiang, C. (2013). Non-centrosymmetric Au–SnO2 hybrid nanostructures with strong localization of plasmonic for enhanced photocatalysis application. ***Nanoscale***, *5*(12), 5628-5636..

[42] Davis, M., Hung-Low, F., Hikal, W. M., & Hope-Weeks, L. J. (2013). Enhanced photocatalytic performance of Fe-doped SnO2 nano architectures under UV irradiation: synthesis and activity. ***Journal of Materials Science***, *48*(18), 6404-6409.

[43] Ansari, S. A., Khan, M. M., Ansari, M. O., Lee, J., & Cho, M. H. (2014). Visible light-driven photocatalytic and photoelectrochemical studies of Ag–SnO2 nanocomposites synthesized using an electrochemically active biofilm. ***RSC advances***, *4*(49), 26013-26021.

[44] Toloman, D., Popa, A., Raita, O., Stan, M., Suciu, R., Miclaus, M. O., & Biris, A. R. (2014). Luminescent properties of vanadium-doped SnO2 nanoparticles. ***Optical Materials***, *37*, 223-228.

[45] Ran, L., Zhao, D., Gao, X., & Yin, L. (2015). Highly crystalline Ti-doped SnO2 hollow structured photocatalyst with enhanced photocatalytic activity for degradation of organic dyes. ***CrystEngComm***, *17*(22), 4225-4237.

[46] Zhao, Q., Deng, X., Ding, M., Gan, L., Zhai, T., & Xu, X. (2015). One-pot synthesis of Zn-doped SnO2 nanosheet-based hierarchical architectures as a glycol gas sensor and photocatalyst. ***CrystEngComm***, *17*(23), 4394-4401.

[47] Khan, M. M., Ansari, S. A., Khan, M. E., Ansari, M. O., Min, B. K., & Cho, M. H. (2015). Visible light-induced enhanced photoelectrochemical and photocatalytic studies of gold decorated SnO2 nanostructures. ***New Journal of Chemistry***, *39*(4), 2758-2766.

[48] Chandran, D., Nair, L. S., Balachandran, S., Babu, K. R., & Deepa, M. (2015). Structural, optical, photocatalytic, and antimicrobial activities of cobalt-doped tin oxide nanoparticles. ***Journal of Sol-Gel Science and Technology***, *76*(3), 582-591.

[49] Sivakarthik, P., Thangaraj, V., Perumalraj, K., & Balaji, J. (2016). Synthesis of co-doped tin oxide nanoparticles for photo catalytic degradation of synthetic organic dyes. ***digest journal of nanomaterials and biostructures***, *11*(3), 935-943.

[50] Mani, R., Vivekanandan, K., & Vallalperuman, K. (2017). Synthesis of pure and cobalt (Co) doped SnO2 nanoparticles and its structural, optical and photocatalytic properties. ***Journal of Materials Science: Materials in Electronics***, *28*(5), 4396-4402.

[51] Ben Haj Othmen, W., Sieber, B., CORDIER, C., Elhouichet, H., Addad, A., Gelloz, B., & Boukherroub, R. (2016). Iron addition induced tunable band gap and tetravalent Fe ion in hydrothermally prepared SnO2 nanocrystals: Application in photocatalysis***, Materials Research Bulletin***,83, 481-490.

[52] Soltan, W. B., Mbarki, M., Ammar, S., Babot, O., & Toupance, T. (2016). Structural and optical properties of vanadium doped SnO2 nanoparticles synthesized by the polyol method. ***Optical Materials***, *54*, 139-146.

[53] Sinha, T., & Ahmaruzzaman, M. (2016). Indigenous north eastern India fern mediated fabrication of spherical silver and anisotropic gold nano structured materials and their efficacy for the abatement of perilous organic compounds from waste water-A green approach. ***RSC advances***, *6*(25), 21076-21089.

[54] Nasir, Z., Shakir, M., Wahab, R., Shoeb, M., Alam, P., Khan, R. H., & Mobin, M. (2017). Co-precipitation synthesis and characterization of Co doped SnO2 NPs, HSA interaction via various spectroscopic techniques and their antimicrobial and photocatalytic activities. ***International journal of biological macromolecules***, *94*, 554-565.

[55] Qamar, M. A., Shahid, S., Khan, S. A., Zaman, S., & Sarwar, M. N. (2017). Synthesis characterization, optical and antibacterial studies of Co-doped SnO2 nanoparticles. ***Dig J Nanomater Biostruct***, *12*(4), 1127-1135.

[56] Karpuraranjith, M., & Thambidurai, S. (2017). Hybrid structure of biotemplate-zinc-tin oxide for better optical, morphological and photocatalytic properties. ***Semiconductor Science and Technology***, *32*(3), 035014.

[57] Mala, N., Ravichandran, K., Pandiarajan, S., Srinivasan, N., Ravikumar, B., & Nithiyadevi, K. (2017). Enhanced antibacterial and photocatalytic activity of (Mg+Co) doped tin oxide nanopowders synthesised using wet chemical route. ***Materials technology***, *32*(11), 686-694.

[58] Sakwises, L., Pisitsak, P., Manuspiya, H., & Ummartyotin, S. (2017). Effect of Mn-substituted SnO2 particle toward photocatalytic degradation of methylene blue dye. ***Results in Physics***, *7*, 1751-1759.

[59] Bhuvaneswari, K., Bharathi, R. D., & Pazhanivel, T. (2018). Silk fibroin linked Zn/Cd-doped SnO2 nanoparticles to purify the organically polluted water. ***Materials Research Express***, *5*(2), 024004.

[60] Babu, B., Kadam, A. N., Rao, G. T., Lee, S. W., Byon, C., & Shim, J. (2018). Enhancement of visible-light-driven photoresponse of Mn-doped SnO2 quantum dots obtained by rapid and energy efficient synthesis. ***Journal of Luminescence***, *195*, 283-289.

[61] Asaithambi, S., Sakthivel, P., Karuppaiah, M., Murugan, R., Yuvakkumar, R., & Ravi, G. (2019). Preparation of SnO2 nanoparticles with addition of co ions for photocatalytic activity of brilliant green dye degradation. ***Journal of Electronic Materials***, *48*(4), 2183-2194.

[62] Sujatha, K., Seethalakshmi, T., Sudha, A. P., & Shanmugasundaram, O. L. (2019). Photocatalytic activity of pure, Zn doped and surfactants assisted Zn doped SnO2 nanoparticles for degradation of cationic dye. ***Nano-Structures & Nano-Objects***, *18*, 100305.

[63] Letifi, H., Litaiem, Y., Dridi, D., Ammar, S., & Chtourou, R. (2019). Enhanced photocatalytic activity of vanadium-doped SnO2 nanoparticles in rhodamine B degradation. ***Advances in Condensed Matter Physics***, Article ID 2157428, 11 pages, https://doi.org 1155/2019/2157428.

[64] Sathishkumar, M., & Geethalakshmi, S. (2020). Enhanced photocatalytic and antibacterial activity of Cu: SnO2 nanoparticles synthesized by microwave assisted method. ***Materials Today: Proceedings***, *20*, 54-63.

[65] Sujatha, K., Seethalakshmi, T., Sudha, A. P., & Shanmugasundaram, O. L. (2020). Photoluminescence properties of pure, Fe-doped and surfactant-assisted Fe-doped tin-oxide nanoparticles. ***Bulletin of Materials Science***, *43*(1), 1-10.

[66] Ali Baig, A. B., Rathinam, V., & Ramya, V. (2021). Synthesis and investigation of Fe-doped SnO2 nanoparticles for improved photocatalytic activity under visible light and antibacterial performances. ***Materials Technology***, *36*(10), 623-635.

[67] Wang, Q., Tian, J., Wei, L., Liu, Y., & Yang, C. (2020). Z-scheme heterostructure of Fe-doped SnO2 decorated layered g-C3N4 with enhanced photocatalytic activity under simulated solar light irradiation. ***Optical Materials***, *101*, 109769.

[68] Ramamoorthy, M., Ragupathy, S., Sakthi, D., Arun, V., & Kannadasan, N. (2020). Enhanced sunlight photodegradation activity of methylene blue using Mn doped SnO2 loaded on corn cob activated carbon. ***Results in Materials***, *8*, 100144.

[69] Suthakaran, S., Dhanapandian, S., Krishnakumar, N., Ponpandian, N., Dhamodharan, P., & Anandan, M. (2020). Surfactant-assisted hydrothermal synthesis of Zr doped SnO2 nanoparticles with photocatalytic and supercapacitor applications. ***Materials Science in Semiconductor Processing***, *111*, 104982.

[70] Baig, A. B. A., Rathinam, V., & Palaninathan, J. (2020). Fabrication of Zr-doped SnO2 nanoparticles with synergistic influence for improved visible-light photocatalytic action and antibacterial performance. ***Applied Water Science***, *10*(2), 1-12.

[71] Baig, A. B. A., Rathinam, V., & Palaninathan, J. (2020). Photodegradation activity of yttrium-doped SnO2 nanoparticles against methylene blue dye and antibacterial effects. ***Applied Water Science***, *10*(2), 1-13.

[72] Carolin, L. R., & Samuel, S. S. A. (2020). Hierarchical nanostructures of In–SnO2 with enhanced photocatalytic activity for the degradation of RR 120 dye. ***Journal of Materials Science: Materials in Electronics***, *31*(15), 12796-12806.

[73] Chu, L., Duo, F., Zhang, M., Wu, Z., Sun, Y., Wang, C., & Sun, J. (2020). Doping induced enhanced photocatalytic performance of SnO2: Bi3+ quantum dots toward organic pollutants. ***Colloids and Surfaces A: Physicochemical and Engineering Aspects***, *589*, 124416.

[74] , P. Kathirvel1, D. Maruthamani , S.D. Gopal Ram, . Sivarama Prabhu P (2021). Synthesis of SnO2 and Zn doped SnO2 Nanoparticles by Flame Oxidation Process for photocatalytic degradation of Methylene Blue dye, ***Research Square*** under review

[75] Salah Ud Din, Sabah Hanif Kiani , Sirajul Haq , Pervaiz Ahmad, Mayeen Uddin Khandaker , Mohammad Rashed Iqbal Faruque , Abubakr M. Idris and M. I. Sayyed (2022), Bio-Synthesized Tin Oxide Nanoparticles: Structural, Optical, and Biological Studies in ***Crystals*** , 12, 614, pp 1-12.