**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 prevalence 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 surface structures and reviews the design of SnO2 nanoparticles over improved performance in the zone of photodegradation and antimicrobial activities.

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

1. **Introduction:**

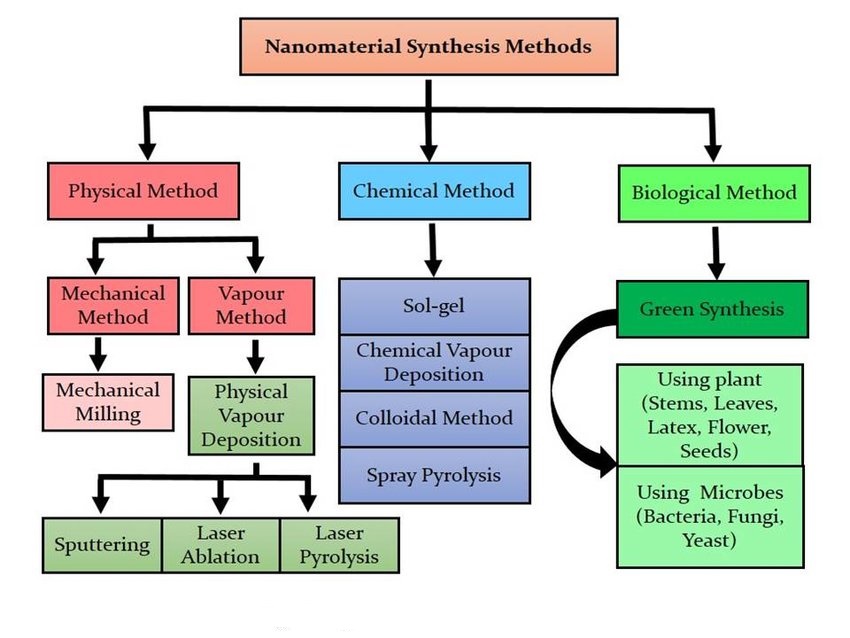
Semiconductor Nps have properties between metals and non-metals. They have wide band gaps and displayed significant alteration in their properties with band gap tuning therefore, they are very significant materials in photocatalysis, photo optics, and electronic devices. Metal oxides are a widely explored 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. 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]. Some examples are TiO2, ZnO, SnO2, VOx, MoOx, and other well-known MO.

Tin oxide (SnO2) is one of the most attractive and promising materials among metal oxides. This makes SnO2 a promising candidate for 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, supercapacitors[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 d-block 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].

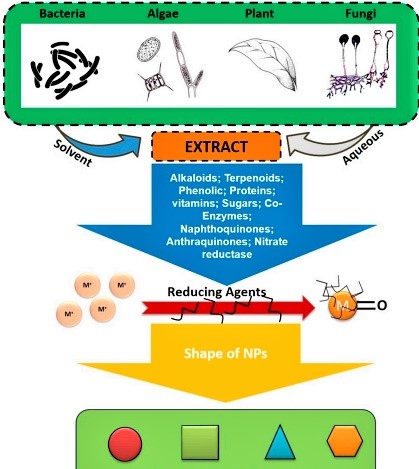
In this review, we describe pure SnO2 hierarchical structure synthesis methodologies and performance improvement techniques. SnO2-based nanostructures' use in photodegradation and antibacterial processes is also discussed. The addition of metal ions, or noble metals to SnO2 can moderately increase the 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). The chemical techniques comprise sol-gel, hydrothermal, precipitation, mechanochemical process, microemulsion, and others [20]. The most popular chemical process is 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 a temperature of 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 magnitude 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 well-being.



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

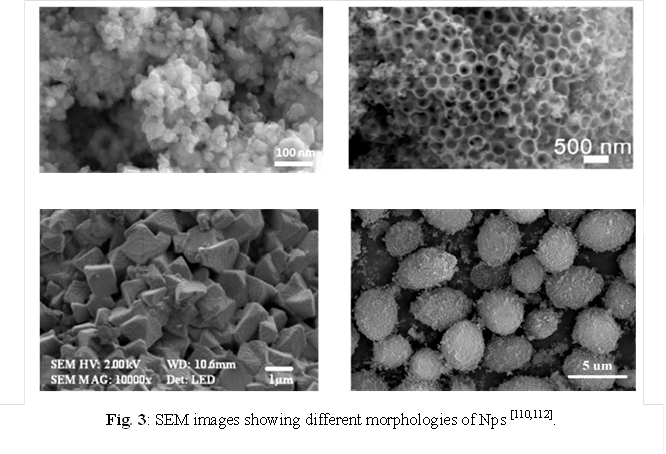
In the green synthetic approach, biotic components such as plant extract, microorganisms, or other environmentally friendly sources might be used instead of traditional physical and chemical processes. Biological synthesis (Fig. 2) has certain specific advantages over physical and chemical approaches, 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 plugging agents, lowering the overall cost of the manufacturing process [22].Significant work has been carried out in producing SnO2 nanocomposites having different surface features (Fig.3) like nanorods, nanowires, nanotubes, nanosheets, and 3D nanospheres that self-assembled from these low-dimensional nanostructures having interactions like van der Waals forces, hydrogen, and covalent bonding.



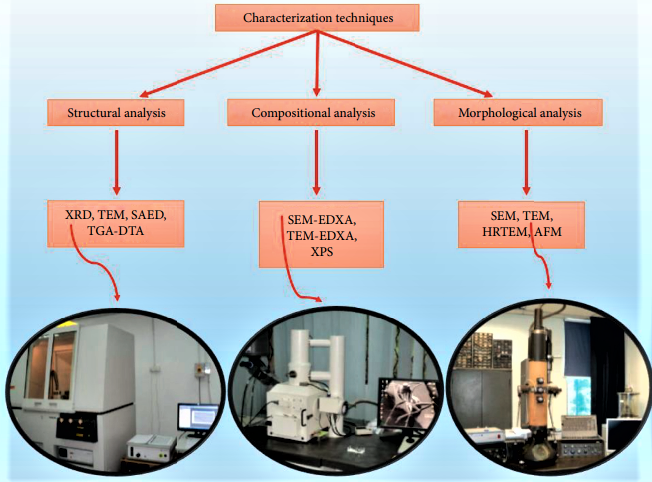
**Fig. 2: Synthesis of nanoparticles using different biological sources [29]**

Many attempts have been made to extend the photosensitivity 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 addition of sufficient concentrations of these dopant species. Abroad 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 investigation 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 catalytic agent under UV/visible light irradiation, and antimicrobial assay was evaluated and their performances were reviewed.



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

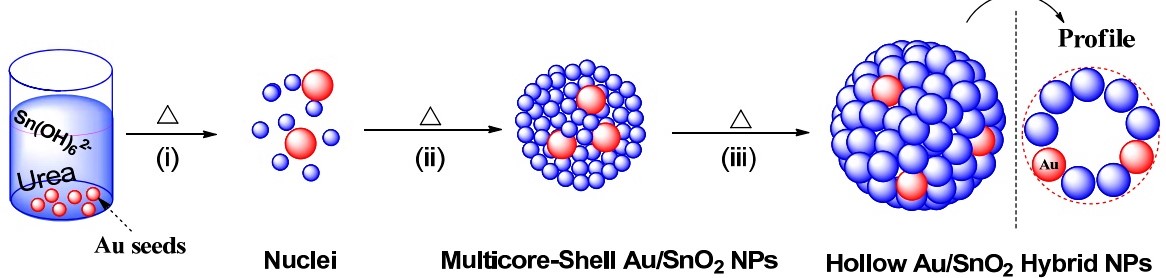


**Fig 4:** **Techniques for identifying nanoparticles [34]**

An 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 was shown by powder X-ray diffracted peaks. EDX analysis revealed the presence of fluoride ions. Undoped SnO2 had a much higher BET surface area (207.81 m2/g) than F-doped SnO2 nanocrystals (45.16 m2/g).F-doped SnO2 nanocrystals were shown to have extremely high photocatalytic effectiveness when compared to pure SnO2. The photocatalytic effectiveness was improved because F doping caused an unusually high concentration of oxygen vacancies in SnO2.

Super symmetric nanocomposites with a high superficial area of hollow Au-SnO2 were formed by a solvothermal reaction using DMF solvent in the presence of capping agents by You, H et al. [40]. This work showed that the preliminary formation of ultrafine SnO2 nanoclusters accumulated to form hollow hexapods.

By employing 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]. Using the EDAX studies confirmed the presence of Au, Sn, and O. Hollow SnO2-Au hybrid nanostructures were prepared, and the development of their form was studied (Fig. 5).



**Fig 5: Schematic representation of the formation of hollow SnO2-Au hybrid nanostructures [41]**

A modest sol-gel approach was used to produce fine iron-doped SnO2 nano architectures with effective photocatalytic removal of water-soluble dyes under electromagnetic irradiation by Davis, M. et al. [42]. All the materials were annealed at 3500C. The presence of iron was confirmed by EDAX.

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. Ag-SnO2 nanocomposites demonstrated improved photocatalytic activity in comparison to pure SnO2 under visible light for the degradation of cationic and anionic dyes and nitrophenols.

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 Cobalt-doped SnO2 nanoparticles. An increase in the level of doping increase in the samples' crystallinity was observed. Under the influence of visible light, the sample's photocatalytic activity was assessed.

Using SiO2 microspheres as hard templates, Ran, L. et al. [45] established a simple infiltration technique for manufacturing hollow-structured SnO2 with a variable Titanium doping concentration. Titanium 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.

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. TEM examination revealed nanosheet structures. The nanosheet structures' composition of Zinc, tin, and Oxygen components was revealed by EDAX analysis. Both cationic and anionic dyes were used for degradation 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 surface composition and chemical states of the Au-SnO2 nanocomposite and P-SnO2 nanoparticles were examined using XPS. In comparison to P-SnO2 nanoparticles, the Au-doped SnO2 nanocomposites showed remarkably enhanced photocatalytic activity.

By using the sol-gel process, Chandran, D. et al. [48] successfully synthesized pure and cobalt-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 methylene blue 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 of Co-doped SnO2 at various concentrations, photocatalytic degradation of synthetic organic dye Crystal violet has been studied.

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 studied under UV irradiation using a Co-SnO2 catalyst. In comparison to pure SnO2, the results indicated that Co-doped SnO2 had the strongest photo-catalytic abilities.

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 conventional hydrothermal process. UV-Vis measurements suggest that adding iron could change the band gap of SnO2 NPs. Degradation studies show addition of iron to SnO2 nanoparticles enhances catalytic activity.

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 using ammonium metavanadate and tin (IV) tetrachloride. As the concentration of vanadium increased, a decrease in mean crystallite size, average pore size, and increase in surface area was observed.

By using the precipitation process, Sinha, T. et al. [53] successfully manufactured Ag-SnO2 nanocomposites. TEM studies indicate that Ag-SnO2 nanocomposites are sphere-shaped particles with an average particle diameter of 8–10 nm. The resulting Ag-SnO2 nanocomposite was used as an antibacterial and antioxidant agent as well as for the removal of industrially emerging pollutants from the aqueous phase.

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 confirmed by XRD and SEM.

By utilizing an easy and affordable co-precipitation technique, Qamar, M. A. et al. [55] were able to successfully synthesize 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. Inhibition zone (mm) experiments show Co-doped SnO2 nanoparticles have antibacterial activity against the selected microorganisms.

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. Zinc-tin oxide hybrid structure based on a bio template emerged as a suitable component for photocatalytic degradation.

Pristine and (Mg+Co) doped tin oxide nanoparticles were effectively made by Mala, N. et al. [57] using a wet chemical process. XRD pattern of the (Mg+Co) doped SnO2 nanoparticles matched with the undoped SnO2 nanoparticles suggests that the doped nanoparticles also exhibited a rutile hexagonal structure. The antibacterial and photocatalytic properties of the material were 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 FT-IR and XRD. The photocatalytic activity on the breakdown of methylene blue was studied to determine the effectiveness of SnO2 and Mn-doped SnO2.

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, and 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 exhibited more dye degradation.

Tin oxide quantum dots (QDs) with various Manganese concentrations were effectively produced through green synthesis by Babu, B. et al. [60]. X-ray diffraction patterns were used to analyze the structural characteristics of the undoped and Mn-doped SnO2 QDs. The photocatalytic removal of MO dye was tested using Mn-doped SnO2 QDs as a catalytic agent under visible light.

Using the co-precipitation approach, Asaithambi, S. et al. [61] produced pure and cobalt (Co)-doped SnO2 nanoparticles successfully. EDAX results showed the presence of tin, oxygen, and cobalt species. Catalytic activities of pure and Cobalt-doped SnO2 nanoparticles were investigated by photodegradation of green dye, an organic contaminant.

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.

Innovative vanadium-doped SnO2 nanoparticles (SnO2:V NPs) were reported 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, the 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. 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 used tin chloride dihydrate (SnCl2.2H2O) and copper chloride hexahydrate (CuCl2.6H2O) as tin and copper sources respectively. Optical properties were explored by UV visible and Photoluminescence spectroscopy. Copper-doped SnO2 nanoparticles showed an excellent zone of inhibition against both pathogens. Under UV light, photocatalytic degradation abilities for the cationic dyes were also assessed.

Sujatha, K. et al. [65] used tin chloride dihydrate and ferric chloride as precursors with ethanol and ammonia to successfully synthesize Iron-doped and surfactant-assisted (CTAB, SDS, and Triton) Iron-doped SnO2 NPs. The addition of iron and surfactants was found to increase the band gap. The photocatalytic analysis confirmed that undoped SnO2 NPs showed considerable photocatalytic activity under visible light.

Tin chloride (SnCl2.5H2O; 98%), ethanol (C2H5OH), iron chloride (FeCl2.5H2O; 98%), and sodium hydroxide (NaOH; 99%) were used in the preparation of undoped and iron-doped tin SnO2 nanoparticles by Ali Baig et al. [66]. Due to the Fe dopant's nominal defect, the intensity will be reduced. Degradation studies show Fe-doped SnO2 NPs had more photocatalytic activity than pure SnO2. The synthesized nanoparticles exhibit exceptional antibacterial activity.

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 of photodegradation under simulated solar light irradiation.

By chemically precipitating stannous chloride, Ethane dioic acid, and Manganese diacetate tetrahydrate, Ramamoorthy M. et al. [68] created Manganese-doped SnO2. Manganese doped tin oxide shows less band gap than undoped one and an improved size, and superficial 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), caustic acid (NaOH), and sodium polymetaphosphate. The results of XRD confirmed the simple, polycrystalline nanoparticles with a tetragonal structure and remained stable even after higher concentrations of Zirconium dopant. Photocatalytic measurements showed that doped NPs improved the photodegradation percentage of the MV dye.

According to Baig, A. et al. [70], nanocrystalline pristine and zirconium-incorporated tin oxide NPs were prepared by simple hydrothermal co-precipitation mode. A detailed investigation of the photodegradation capabilities of 4% doped tin oxide nanoparticles (NPs) was studied under visible light. In comparison to undoped SnO2, doped NPs photo-catalytically are more capable and show good antibacterial activity against E. coli and S. aureus bacteria.

Using a hydrothermal chemical process with varying Y doping concentrations (0, 2, and 4 at%), Baig, A. et al.[71] successfully produced SnO2 NPs. Both pure and yttrium-doped NPs show tetragonal crystalline texture. XRD studies show the size decreased after Y3+doping. HRSEM showed equivalent crystallite spreading and agglomeration morphologies. Even after five cycles, the yttrium-doped nanoparticles showed efficient photodegradation.

In-SnO2 nanomaterial was produced by Carolin, L. et al. [72] by precipitation and sonication. UV absorption studies were carried out to determine the band gap of both pure and indium-doped nanoparticles. SnO2 photo catalyst confirmed the catalyst's excellent reusability characteristics. Hydroxyl Radical production is directly associated 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]. Under visible light, the efficiency of the photocatalyst was assessed. Due to improved light absorption and the efficient parting and migration of photo-generated carriers, the produced composites had exceptional photodegradation efficiency. Bi-doped SnO2 quantum dots had a wide range of potential practical applications due to their exceptional stability and high efficiency,

Using 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, both doped and undoped SnO2 nanoparticles show excellent photocatalytic activity under UV light.

By using Populus ciliate leaf extract, Slah Ud Din et al. [75] created SnO2 nanoparticles. XRD and EDAX studies confirmed the formation of composites. The diffusion technique based on agar wells was used to examine the antibacterial properties.

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

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| **Authors and year** | **Sample** | **Synthesis route** | **Structural characterization** | **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). | Improves photodegradation | 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) | 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 | Enhanced photocatalytic performance under UV light.. | 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, BET | 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 25–30 nm). UV-Vis(500-600nm), XPS. | Efficient photodegradation of cationic and anionic dyes. | 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 . | 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 industrially developing pollutants and as an antibacterial agent. | 53 |
| Nasir, Z  et al. (2017) | Co -SnO2 | co-precipitation method | XRD (tetragonal-rutile type structures), SEM, TEM, SAED | Enhanced catalytic property under UV light and has increased 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) | Improved Antibacterial activities | 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 and is 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), FT-IR. | 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 | FT-IR, XRD, and EDAX. | The degradation of water-soluble dyes 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), FT-IR, 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 a particle size ranging from 5 to 4.4 nanometer), SAED, FT-IR, UV-Vis. | Removal of water-soluble dye under sunlight | 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), FT-IR, UV-Vis(Eg=3.47eV), HRTEM, SAED. | Co-doped SnO2 shows enhanced photocatalytic activity. | 23 |
| Sujatha, K et al. (2019) | Zn -SnO2 | co-precipitation method | XRD (rutile tetragonal with crystallite size 9.34 nm), SEM(Spherical), EDAX, 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 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 size 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, HRTEM (agglomerated), UV-DRS. | Higher photocatalytic dye degradation efficiency under visible light and 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, UV-DRS | 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 | Removal of methylene blue dye under visible light was determined. | 30 |
| Suthakaran, S  et al. (2020) | Zr -SnO2 | hydrothermal method | XRD, TEM, 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, UV-DRS(2.87eV) | increased photocatalytic degradation and antibacterial activity. | 32 |
| Baig, A  et al. (2020) | Y-SnO2 | hydrothermal chemical route | XRD ,SEM(agglomeration), UV-DRS | Enhanced photodegradation of cationic dye in apparent light, enhanced antibacterial activity | 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, EDAX, UV-DRS | improved antibacterial activity against B. subtilis and V. cholera and photocatalytic activity under UV light. | 34 |
| Chu, L  et al. (2020) | Bi-SnO2 | hydrothermal method | XRD XPS, BET, Pore volume analysis. | photocatalytic degradation and antibacterial studies. | 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 cationic dye | 74 |
| Salah Ud Din etal [2022] | SnO2 | biosynthesis | The FT-IR and TGA results confirm the presence of a hydroxyl group in the sample. | Antibacterial studies were carried out | 75 |

**3. Conclusions**

This review covered the formation 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.

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 is still difficult, and tough. Future advancements will be made and novel intriguing nanosystems will produce the technologies in the synthesis of nanostructures to precisely control dimension and composition.

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