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MatSci Express
ISSN: 2997-8440 www.aristonpubs.com/matsci-express https://doi.org/10.69626/mse.2025.0093

REVIEW ARTICLE

An Insight into SnO_2 Nanoparticles: Synthesis and Applications

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ABSTRACT: Transition metal oxide-based semiconductors are a significant class of materials used in cutting-edge technology. It is important to consider the size, shape, surface charge, and the existence of both bulk and surface defects when preparing these materials: all of which are determined through the synthesis process and the conditions of experiment that significantly influences these material's performances. Among the oxide semiconductors, the inherent properties of SnO_2 nanoparticles, n-type semiconductors with band gap in the range of 3.6-4.0 eV have interesting features like high sensitivity, good chemical and thermal stability, non-toxic and environmentally benign, rapid electron mobility, electrical conductivity, quick response, and recovery speed. Due to these excellent properties, SnO_2 nanoparticles are substantially used in transparent conductors, transistors, optoelectronic devices, and electrochemical modifiers on electrodes, gas sensors, batteries, electrochromic devices, and heterogeneous photo-catalytic applications. This review work will provide insights into various synthesis processes of SnO_2 nanoparticles and their effect on the multiple applications especially focusing on energy and environmental sustainability.

Keywords: SnO_2 nanoparticles, Synthesis processes, Oxide semiconductors, Photocatalytic applications, Energy and environmental sustainability.

Received: 17 August 2024; Revised: 03 October 2024; Accepted: 25 November 2024; Published Online: 11 January 2024

1. INTRODUCTION

SnO_2 is an n-type semiconductor material with a large band gap (3.6eV to 4eV), good electrical conductivity, fast response, and recovery speed [1]. It can therefore be seen as one of the most potent candidates for wide applications in various fields, from electronics and optoelectronics to energy and environmental sustainability [2]. SnO_2 nanoparticles' size, shape, surface charge, and inclusion of bulk and surface defects, are all factors that affect their performance and usefulness, and these factors are impacted by the synthesis techniques and setup for experiments used to prepare them [3]. The synthesis route determines the structural and morphological characteristics of SnO_2 nanoparticles (NPs) and their surface chemistry, electronic properties, and overall functional performance [4, 5]. As a result, significant research has been directed towards exploring various synthesis techniques to fine-tune these properties to achieve desired functionalities for specific applications. The shape and size of SnO_2 NPs, in the context of semiconductor technology, strongly influence their optical and electronic properties [6, 7]. For instance, narrowing down the particle size to nanometers significantly increases its surface area, which results in surplus active sites and desirable traits for application areas that include gas sensing, photocatalysis, and energy storage [8]. Surface charge and defects are paramount in SnO_2 NPs functionality [9, 10]. In detail, oxygen vacancies as well as other surface defects play a vital role in the electrical conductivity and photocatalytic properties of SnO_2 NPs; therefore, controlling this aspect becomes a crucial issue during the synthesis process [11]. For example, high surface defect density can increase the sensitivity of SnO_2 - based gas sensors by offering ample active sites toward gas adsorption. In sharp contrast, such

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defects should be minimized in applications requiring high electrical conductivity and stability, as is necessitated by transistors and transparent conductive electrodes [12]. Such versatility in their applications originates not only from the intrinsic properties of SnO_2 NPs but also from manifold existent techniques, like the sol-gel [13], hydrothermal [14], solvothermal [11], vapor phase [15], and microwave-assisted [16] processes.

Different methods have different advantages and limitations to render nanoparticles suitable for particular applications, concerning particle size control, morphology, crystallinity, and surface properties [13]. For example, very uniform nanoparticles can be developed by the sol-gel technique, with a narrow distribution in the area of the population of particles falling into certain particle-size distribution ranges, while hydrothermal synthesis provides special morphologies, finer crystallinity, and fewer surface defects [17]. This has been the information era and the utilization of SnO_2 NPs has been intense in the energy and environmental protection areas [18, 19].

The most typical gas sensors are usually made up of SnO_2 nanoparticles. These sensors are fast and sensitive to different gases, including gases required for environmental monitoring and safety, for instance, carbon monoxide, methane, and hydrogen [8]. Furthermore, SnO_2 NPs can be involved in photocatalytic reactions in the presence of UV light and produce reactive oxygen species that let organic dyes degrade into wastewater. Besides the previous applications, the material is used in batteries and super-capacitors [12]. In such applications, the appreciable surface area and high electrochemical performance resulted in efficient energy storage and conversion along with the other benefits it offers [17]. This overview aims to summarize the ways to produce SnO_2 NPs, the effect of the synthesis routes on different applications in detail, and, at the same time, fostering energy and environmental sustainability [20]. The most common synthesis methods of SnO_2 NPs are compared in this review, with an emphasis on how they affect the tin oxide's characteristics and performance in diverse applications. This study sheds light on effective ways to optimize SnO_2 materials for various applications by analysing how well each technique works for usage. This paper also highlights areas that require further investigation and makes recommendations for future paths to enhance the sustainability, scalability and efficiency of SnO_2 synthesis.

2. SYNTHESIS METHODS

The nanomaterials' dimensions, size, and form alter their properties depending on the preparation conditions. Thus, the synthesis process is essential for changing the characteristics of nanoparticles. Up to now, numerous research groups have reported synthesizing SnO_2 in various ways. The following section discusses the different routes and mechanisms involved in the production of SnO_2 NPs [11].

2.1. Sol-Gel Synthesis

The Sol-Gel process is among the primary techniques for preparing SnO_2 NPs due to the enhanced control of size [21], shape [9], and surface conditions [22]. A chemical solution is known as *sol* is used in the wet-chemical *sol-gel* procedure to create an interconnected network known as *gel*. This cycle involves the use of precursors of tin, such as $SnCl_4$or tin alkoxides, which are hydrolyzed in a solvent, generally water or alcohol. This reaction leads to the formation of a *gel* that, after drying [23] and calcination [22], yields SnO_2 nanoparticles (presented in Figure 1). Concerning the morphology, crystallinity, and defect density; pH, temperature, type of solvent, and precursor concentration are the effective experimental parameters [24, 25].

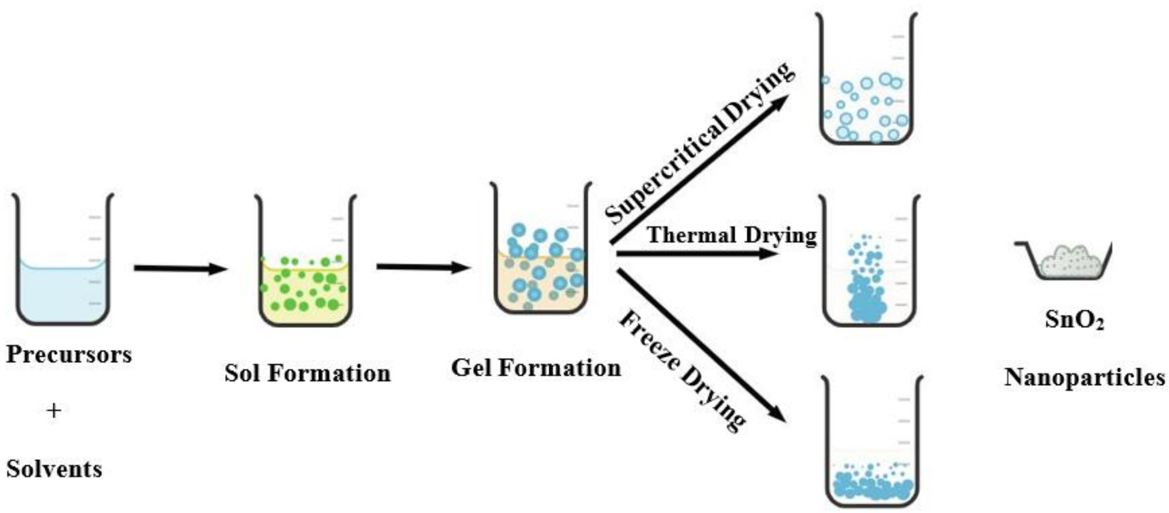

Fig. 1. Preparation of SnO_2 using Sol-Gel method.

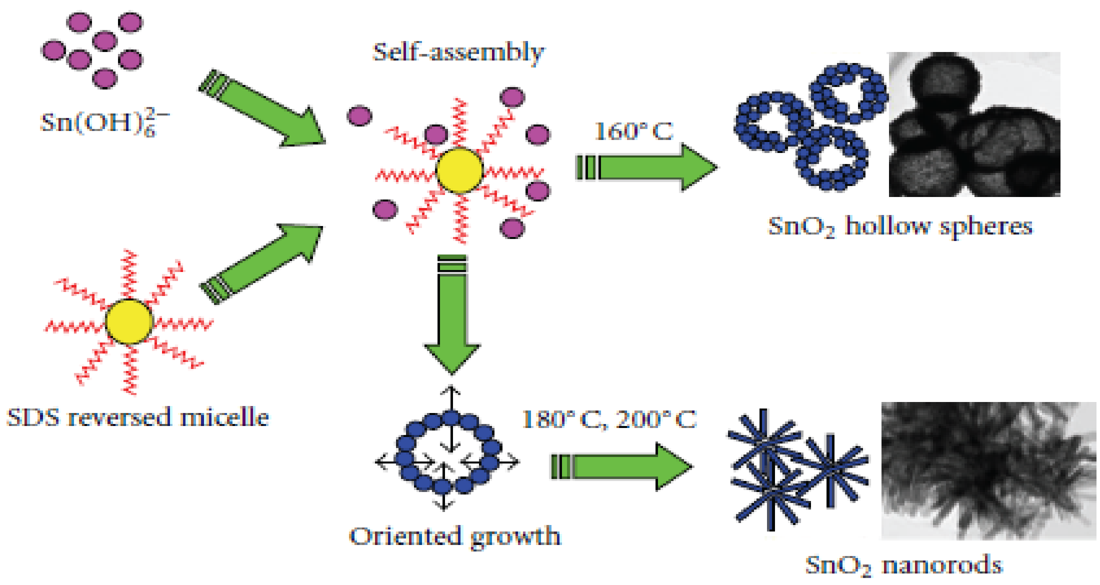

Fig. 2. Showing the suggested process by which SnO_2 hollow spheres and nanorods develop at various hydrothermal temperatures. Reprinted with permission from ref. [30], Tan, L., Wang, L. and Wang, Y., 2011. Hydrothermal synthesis of SnO2 nanostructures with different morphologies and their optical properties. *Journal of Nanomaterials*, *2011*(1), p.529874. Copyright © John Wiley & Sons.

2.2. Hydrothermal synthesis

SnO_2 NPs can be created in a high-pressure [26], high-temperature aqueous solution using one of the most practical processes available: hydrothermal synthesis (Figure 2) [27]. Because of its homogenous reaction environment, size, and shape are well-regulated, hence it is mostly used in the production of well-defined nanoparticles [14]. Therefore, it would be possible to tailor the crystallinity and surface flaws of the produced particles by adjusting parameters like temperature, pressure, reaction time, and precursor concentration [28]. Additional advantages comprise the recognition that the produced nanoparticles, frequently possess strong electrical and stability characteristics [29]; two things that are essential for applications in photocatalysis and gas sensing [4, 14].

2.3. Vapour phase synthesis

The primary reactants are vaporized in vapour-phase nanoparticle synthesis, and the resulting vapours are then forcefully quenched on a cold metal substrate [31]. Under regulated condensation conditions, the vapours condensate homogeneously into nanoparticulate form [32, 33]. This is because supersaturated conditions are formed when the vapour phase combination is thermodynamically unsteady relative to a solid material [4].

2.4. Microwave-assisted synthesis

As a high-speed synthesis method, microwave-assisted synthesis has drawn increased attention due to its quick and consistent heating to eliminate thermal gradients, and lack of solvent superheating. [34]. This synthesis method has proven to be a beneficial and quick method of producing nanoparticles, reducing reaction durations from hours to minutes. This powerful approach for synthesizing tin dioxide (SnO_2) NPs uses microwave irradiation to efficiently and uniformly heat reactants [35]. Microwaves produce heat inside the reaction mixture by interacting with polar molecules or ions, in contrast to traditional heating, which transfers heat externally [16]. This results in quick and even heating. This leads to significantly faster reaction times, frequently cutting down on procedures that would otherwise take hours or days to only a few minutes. Tin-based precursors, such as tin chloride or tin alkoxides, are dissolved in polar solvents like water or alcohol and heated to 500 °C at 320W to synthesize SnO_2 nanoparticles [16]. Figure 3 shows a schematic illustration of the hydrothermal synthesis of SnO_2 nanoparticles with microwave assistance.

SnO_2 particles are rapidly nucleated and developed as a result of the microwave energy; this process may be carefully regulated by varying factors such as microwave power, irradiation time, and precursor concentration [16]. Significant benefits of this approach include homogeneous heating throughout the reaction, energy efficiency, and enhanced control over size and shape of nanoparticles [27]. Rapid and consistent heating encourages the creation of highly crystalline SnO_2 NPs with a greater surface area and smaller particle size, which is advantageous for several applications such as energy storage, photocatalysis, and gas sensors [27]. Furthermore, compared to traditional techniques, microwave-assisted synthesis is more energy and environmentally efficient, which increases its potential for broad industrial use [36]. Adjusting the reaction conditions precisely enables the adjustment of SnO_2 characteristics, which improves its performance in sensors, electronic devices, and catalytic applications [16].

2.5. Green synthesis

SnO_2 nanoparticles have been effectively manufactured using plant parts. Green synthesis is part of a bottom-up approach [37]. Environmentally friendly chemical ideas are validated by the implementation of green synthesis of nanomaterials, which promotes sustainable technological progress [38]. The advantages of using plant extract instead of common reducing chemicals are non-toxic, affordable, and renewable qualities [39]. Multiple research studies have been reported stating the application of plant extract as a bio-reductant [40] for metal oxide nanoparticles, such as in the production of metal oxide nanoparticles [41–44]. Several studies have described the green synthesis method for SnO_2 nanoparticles for photocatalysis applications, as green-synthesized SnO_2 Nps have high activity and stability [45]. The main plant parts involved in the creation of SnO_2 nanoparticles are the leaves [45], buds [46], flowers [7], fruits [47] and bark [48]. The accumulation of the plants and the separation of required components then cleaning and drying, grinding, dispersion and heating in distilled water are the different steps involved in the development of SnO_2 nanoparticles via green synthesis [49].

SnO_2 bio-synthesis utilizing Brassica oleracae L. var. botrytis extract was reported by Osuntokun et al. $SnCl_2$ was heated to 60 °C for six hours while stirring and boiling the extract to produce SnO_2. After centrifuging and washing the precipitate, it was dried for eight hours at 75 °C. The product was allowed to dry and then heated to two distinct temperatures, 300 °C and 450 °C. The authors were able to synthesize spherical particles with sizes 3 - 6 nm [50]. Green synthesis is mostly caused by the phytochemicals that exist in different plants and bacterial enzymes. The procedure for green synthesis is shown in Figure 4.

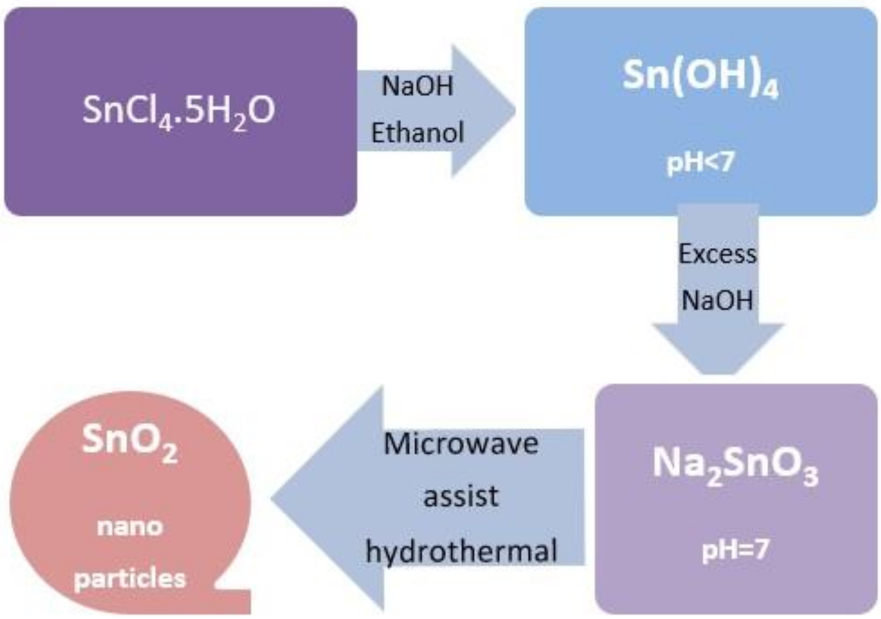

Fig. 3. An illustration showing the hydrothermal production of SnO_2 nanoparticles with microwave assistance.

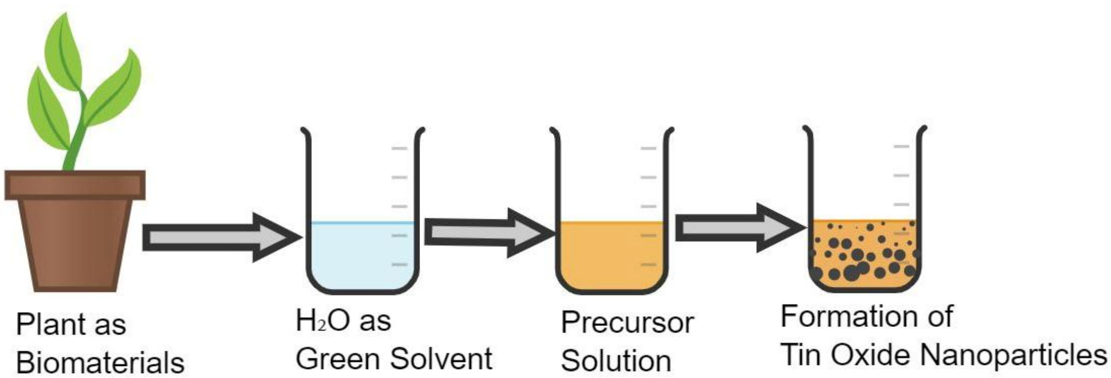

Fig. 4. Standard technique for the synthesis of SnO_2 NPs from plant extract.

Table 1. Advantages and disadvantages of the most common synthesis techniques for SnO_2 nanoparticles.

Synthesis Methods	Advantages	Disadvantages	Ref.
Sol-Gel	Sol-gel approach has several benefits, including low cost, ease of functionalization, low processing temperature, excellent reproducibility, exact stoichiometry control and simplicity.	The production of ultra-thin films with thicknesses less than 10 nm might be challenging. Furthermore, the final materials may have poor resistance to wear, porosity and crystallinity problems. The process's drying phase is especially prone to cracking and the finished product may have interface and bulk flaws.	[15, 22, 24, 31, 116]
Hydrothermal	An appealing method for creating SnO_2 nanomaterials, the hydrothermal method stands out for its ease of use, affordability and appropriateness for large-scale synthesis.	Relatively long reaction times, possible safety issues with high-pressure and high-temperature settings and difficulties reaching the maximum levels of crystal quality in comparison to certain other methods are some of these.	[27, 28, 30, 35, 117]
Vapour Phase (Chemical Vapour Deposition)	For SnO_2 synthesis, the vapour phase deposition method has several advantages, such as beneficial crystal quality, accurate stoichiometry control and epitaxial growth, which make it possible to fabricate high-performance electrical and optoelectronic devices.	It can be complicated to scale up for large-scale production since it is often a costly and intricate procedure. Furthermore, there could be a restricted selection of appropriate dopants for this technique.	[33, 69, 78, 118]
Microwave-Assisted	Energy savings, better reaction times and enhanced control over particle characteristics are just a few benefits of using microwave-assisted synthesis to produce SnO_2.	It is necessary to carefully assess the high cost of the equipment, possible scaling-up difficulties and safety concerns.	[35, 63, 67, 119]
Green Synthesis	A potential method for creating SnO_2 nanoparticles with improved biocompatibility and less environmental effect is green synthesis.	Issues in maintaining repeatability, managing particle features and increasing output must be resolved.	[9, 40, 41, 43, 120]

Table 1 presents an overview of the advantages and disadvantages associated with the most commonly used synthesis techniques for SnO_2 nanoparticles. Each method offers distinct benefits, such as cost-effectiveness, control over particle characteristics, or improved environmental sustainability. For instance, the sol-gel method is praised for its low cost, ease of functionalization, and precise stoichiometry control but faces challenges related to cracking, porosity, and low crystallinity. Similarly, hydrothermal synthesis is notable for its scalability and affordability but suffers from long reaction times and safety concerns under high-pressure conditions. Advanced techniques like microwave-assisted synthesis provide better energy efficiency and reaction control but are limited by high equipment costs and scalability issues. Green synthesis stands out for its eco-friendliness and biocompatibility, yet challenges remain in ensuring repeatability, controlling particle properties, and achieving large-scale production.

Additionally, throughout the synthesis, active chemicals contained in the green sources serve as reducing, stabilizing, and capping agents [51]. After calcination or annealing at predetermined temperatures, the required nanoparticles of SnO_2 were achieved. Green synthesized SnO_2 NPs have been employed in developing various sensor sensors and have an extensive list of other applications due to their antifungal, antibacterial, photocatalytic, and antioxidant properties [45].

3. APPLICATIONS

SnO_2 NPs have a wide area of applications. Some of its important applications are discussed in this section (Figure 5).

3.1. Gas Sensing

The use of SnO_2 NPs in gas sensing is among their most innovative applications. Evidence has been presented that SnO_2 NPs have broad gas sensitivity, encompassing oxygen, carbon monoxide, nitrogen oxides, and volatile organic compounds [18]. Due to high surface area of SnO_2 NPs, they have capacity to both adsorb and desorb gases, which can alter their electrical resistance or conductivity, make them sensitive to these gases [52]. To detect gases in a range of settings, such as industrial, automotive, and environmental applications, SnO_2 NPs have been utilized to create gas sensors with high sensitivity, selectivity and stability [11]. Employing SnO_2 nanoparticles to make a thin film for smart windows [53] that regulate heat and light transmission have also been prepared [54]. The conventional hypothesis for managing surface resistance states that when SnO_2 is exposed in to the air, the atmospheric molecular oxygen will physically adsorb on the material's surface first (the mechanism is shown in Figure 6), then it takes electrons from SnO_2's conduction band to form the oxygen O_2^-, O^-, or O^{2-}[55, 56].

Fig. 5. Schematic of various applications of SnO_2 Nanoparticles.

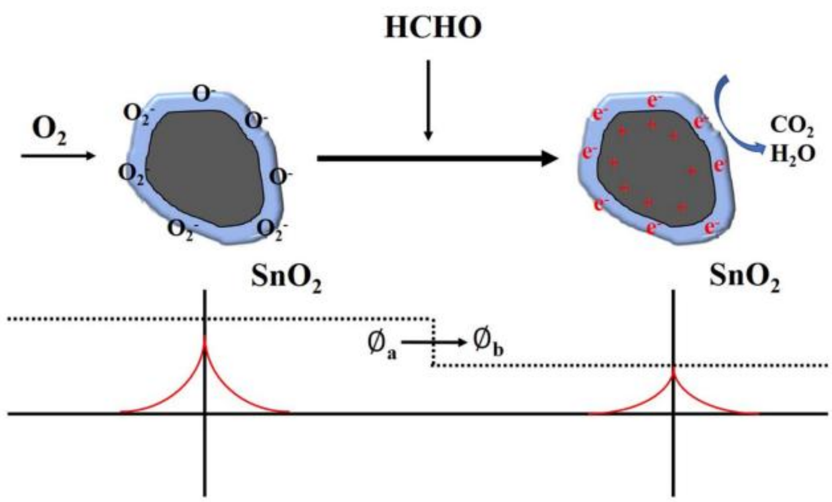

Fig. 6. Gas sensing mechanism of SnO_2 nanoparticles. Reprinted with permission from ref. [61], Liu, P., Wang, J., Jin, H., Ge, M., Zhang, F., Wang, C., Sun, Y. and Dai, N., 2023. SnO_2 mesoporous nanoparticle-based gas sensor for highly sensitive and low concentration formaldehyde detection. *RSC Advances*, *13*(4), pp.2256-2264. Copyright © Royal Society of Chemistry.

Reduction gas will enter the system and react with negative oxygen species, releasing stored electrons into the conduction band of SnO_2 NPs [57]. A significant change in material conductivity as a result of this charge transfer may be used for gas detection applications [58]. However, the gas sensing mechanism is rather complex, because the atomic arrangement and chemical environment at the material surface, which may have a significant impact on sensing capabilities is hardly reachable [55, 58].

According to scientists, by dip-coating techniques, smooth thin film of SnO_2 could be made onto glass substrates [59]. The SnO_2 NPs were prepared through sol-gel methods. SnO_2 NPs gas sensors prepared in this way are quite efficient. It means an increase in their performances due to better control over the film's shape [60]. The sol-gel method is usually carried out to produce SnO_2 coatings [52] which makes it possible to control both the thickness and the uniformity of the film [60]. Therefore, it is an excellent method for sensing applications that require precision manufacturing like ethanol sensing and heat-resistant coatings [59].

3.2. Energy storage

Energy conversion and storage is another application for SnO_2 nanoparticles. Fuel cells, supercapacitors, and lithium-ion batteries have all been proven to benefit from using SnO_2 nanoparticles as electrodes [4, 17]. Because they can assist the passage of ions and electrons during charge and discharge operations, SnO_2 nanoparticles' high surface area and conductivity make them appealing for these applications [27]. Excellent cyclability and rate performance have been demonstrated for SnO_2 nanoparticles, which have been utilized to create high-performance lithium-ion battery electrodes. Supercapacitors owing high specific capacitance and good stability, as well as fuel cells with high power density and strong durability, have both been developed using SnO_2 nanoparticles [34].

3.2.1. Li -ion batteries

Compared to conventional graphite anode materials, SnO_2, one of the usual materials with good theoretical qualities, suggests that Li-ion batteries may achieve a higher energy density [62]. To improve SnO_2 NPs' rate performance, the nanoparticles' dimensions and form can be adjusted, which would speed up the charging and discharging operations [38]. SnO_2 can exhibit less volume change due to the volume change that occurs during the cycles. This phenomenon is expected to prolong the battery's life while preventing electrode deterioration simultaneously [34]. Due to its relative non-toxicity and ecological benignity, SnO_2 is a more sustainable alternative when compared to several other battery production materials.

3.2.2. Supercapacitors

It is considered that SnO_2 has potential applications in solar cells, Li-ion batteries, and electrochemical supercapacitors [63]. SnO_2 performs better than other metal oxides due to its high electric conductivity (21.1 S/m) [39], low cost, non-toxicity, high potential capacity, and simple manufacturing. Supercapacitors with SnO_2 electrodes offer high power output and quick charging for gadgets such as computers, smartphones, and wearable electronics. Enhancing the electrochemical characteristics of SnO_2-based electrodes and expanding their potential applications in energy storage, electronics, and sensing technologies can be accomplished by researchers by refining the synthesis and fabrication processes [64]. Because of their strong chemical stability and high electrochemical capacitance (EC), SnO_2-based supercapacitors have drawn a lot of attention [65]. The method for coating amorphous MnO_2 onto crystalline SnO_2 nanowires on a stainless-steel substrate, utilized their electronic conductivity as a backbone for supercapacitor electrodes. Galvanostatic charge/discharge techniques and cyclic voltammetry were used to examine the composites' capacitive characteristics. Here, three things could be facilitating the process: the ion diffusion channel might be shortened and a rapid, reversible faradic reaction facilitated by a thin coating of MnO_2, a direct route for electron transport might be offered through high conductivity SnO_2 nanowires, and they could provide channels for effective electrolyte transfer [66].

The SnO_2/MnO_2 composite electrode showed high specific capacitance, good rate capability and excellent long-term cyclic stability, which making it a promising supercapacitor material. Figure 7 depicts the process. Also, SnO_2/graphene nanocomposites are used as supercapacitor material.

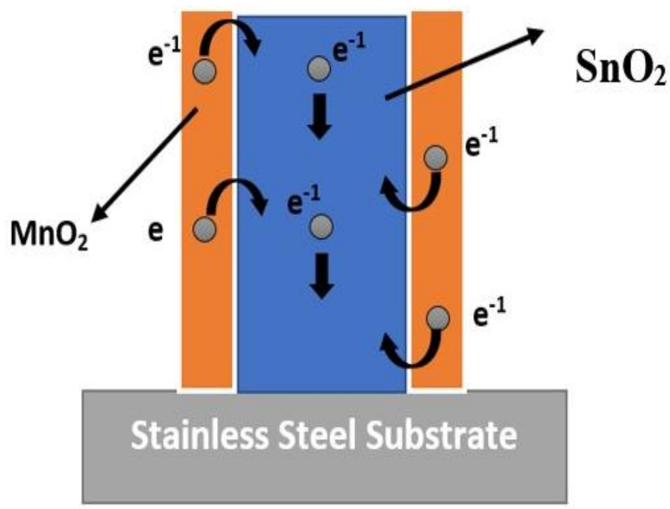

Fig. 7. Schematic representing the amorphous MnO_2 submerged on the SnO_2 nanowires grown on the substrate made of stainless steel. The electrons have a straight route through the SnO_2 nanowire.

Hybridization between pseudo-capacitors and two-dimensional (2D) structured graphene has been achieved. Graphene is a novel and distinctive EDLC-based carbon material with a one-atom-thick layer that has been used as a supercapacitor electrode material to solve the issue of low specific capacitance [67]. Likewise, Polyaniline/SnO_2 nanocomposite can be utilized for supercapacitor applications due to Polyaniline's (PANI) adjustable electrical conductivity and stability in the environment. When electrically conducting polymers (ECPs) were de-doped, their conductance was extremely low. This led to a significant ohmic polarization in the supercapacitor, which decreased its stability and reversibility. It has been assumed that a collaborative effect of polyaniline–inorganic nanocomposites, particularly polyaniline–metal oxide composites, will be employed in electrode materials for supercapacitors in order to overcome the problem [68].

3.3. Energy Conversion

SnO_2 nanoparticles have been investigated for their potential in energy conversion devices, as in solar cells and thermoelectric generators in addition to their usage in energy storage devices [27]. High-performance transparent conductive electrodes for solar cells have been created using SnO_2 nanoparticles, and high-performance thermoelectric materials have also been developed using them [54].

3.3.1. Transparent Conductive Layer

In recognition of its versatility, SnO_2 is used effectively as a transparent conductive oxide (TCO) [53] on a wide range of optoelectronic devices. It's the perfect fit for this function because of its special blend of qualities, which include strong electrical conductivity, chemical stability, and transparency [39]. Devices such as solar cells, touchscreens, and displays may effectively transmit light owing to the optical transmittance of SnO_2 in the near-infrared and visible wavelengths of the spectrum [69]. Because of its high electrical conductivity, SnO_2 can effectively carry electrical currents in optoelectronic devices. SnO_2's relative stability against oxidation and corrosion ensures long-term performance and dependability [70].

3.3.2. Solar Cell

SnO_2, a transparent conducting oxide, is now a demanding material for solar cell applications. Its oxide compound allows light to pass through the window [60]. Ideally, the product should not absorb or reflect any of the light. A simple description of the solar cell consists of the outer and inner layers, the n-type and p-type layers, and the p-n junction region in the middle [71]. Moreover, SnO_2 is a highly stable material that would not be easily dissolved, thus, ensuring the long-term reliability and efficiency of solar devices [72]. The properties of SnO_2 nanomaterials and thin films and make it a significant ingredient for quite a few solar cell designs [73]. It is widely used as an n-type window layer in CdTe solar cells [74].

3.4. Water Remediation

SnO_2 NPs are considered beneficial to water treatment processes and it has started to receive a good deal of attention [75]. This compound is a promising choice for the decomposition of pollutants due to two main mechanisms: photocatalysis and electrochemical processes [76]. SnO_2 NPs are noteworthy for their oxidation strength [77]. These properties enable them to decompose harmful organic substances effectively, such as dyes and phenolic compounds that are normally found in wastewater [78]. Thus, enhancing the surface area and catalytic activity of these nanoparticles by different approaches such as sol-gel procedures is one of the ideal ways. Besides photocatalysis [79, 80], SnO_2 is now a significant player in electrochemical treatment [81]. SnO_2 NPs make n-type electrodes that actively took part in the removal of contaminants from water by electrochemical oxidation [73] have received much attention. Very often they are coupled with other metal oxides like titanium dioxide (TiO_2) to improve the efficiency of the process by adding their capability to degrade persistent organic pollutants [82]. SnO_2 electrodes are found to be useful in electrochemical wastewater treatment as recent studies pointed out [81]. They can mineralize organic compounds in water, promising a better and more environmentally friendly approach to water purification. This novel use of SnO_2 not only deals with pollution but also is part of the transition towards cleaner water solutions (Figure 8) [83].

Fig. 8. Applications of SnO_2 towards water remediation.

3.4.1. Treatment of pollutant dyes

SnO_2 nanoparticles are new materials used to eliminate industrial dyes from water. Their unique characteristics, like huge surface area and catalytic activity, enable them to destroy organic dyes by photocatalytic methods in the presence of UV-light [27]. When sunlight contacts the nanoparticles directly, oxygen compounds are formed, which oxidize and breakdown dye molecules, providing a more efficient solution to the waste-water problem that does not result in pollution [73]. The basic photocatalytic mechanism utilizing the Ag-doped SnO_2 photocatalyst is depicted in Figure 9. Silver (Ag) doped SnO_2 will lower the bandgap of pure SnO_2 and stop the electron/hole pair from recombining. Ag's work function, cost, and non-toxicity all contribute to its increased demand. Ag helps in creating a successful band alignment. Under solar irradiation, Ag-doped photocatalyst exhibits remarkable photocatalytic activity because of Ag's surface plasmon resonance [84, 85]. The valence band (VB) electrons of SnO_2 are induced to move into the higher-energy conduction band (CB) by visible or ultraviolet light, creating electron-hole pairs. Crucially, these pairs can recombine less frequently thanks to the structure of SnO_2, which keeps them apart for a longer duration which might be the key element in raising the semiconductor's efficiency in the excitation state with decreased recombination rate [55].

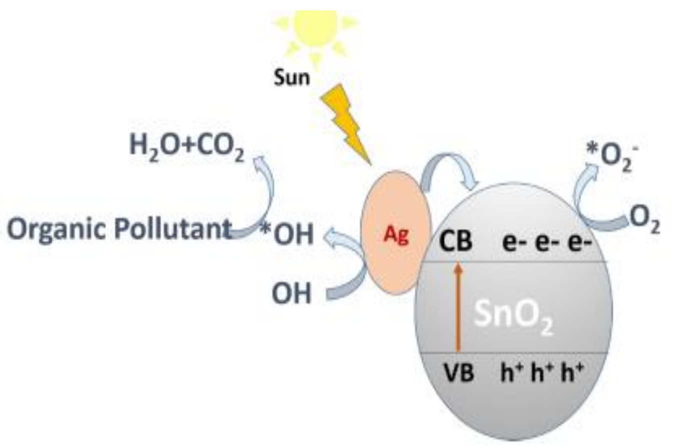

Fig. 9. A Schematic photocatalytic process involving the Ag-doped SnO_2 photocatalyst. Reprinted with permission from ref. [84], Shittu, H.A., Adedokun, O., Kareem, M.A., Sivaprakash, P., Bello, I.T. and Arumugam, S., 2023. Effect of low-doping concentration on silver-doped SnO_2 and its photocatalytic applications. *Biointerface Research in Applied Chemistry* *13*(165.10), p.33263. Copyright © Biointerface Research in Applied Chemistry.

3.4.2. Extraction of aromatic compounds

SnO_2 nanoparticle-based adsorbents are quite effective for removing aromatic pollutants from wastewater, including benzene, toluene, ethylbenzene, and xylene. The π-π interactions are primarily responsible for the adsorption of aromatic chemicals on SnO_2 NPs [86]. The compounds' aromatic rings form a connection with the π-electron cloud on the SnO_2 surface [87]. Moreover, the hydroxyl groups on the SnO_2 surface and the functional groups on the aromatic molecules interactions hydrogen to facilitate the adsorption process [80]. Particle size, surface modification, pH, and temperature all have an impact on SnO_2 NPs adsorption effectiveness with aromatic chemicals [88].

3.4.3. Heavy metal removal

SnO_2 NPs can extract heavy metals from industrial wastewater from mining, metal polishing, and electroplating [89]. SnO_2 NPs could possess complexation, ion exchange or electrostatic attraction on their surface which allows them to adsorb heavy metal ions due to their particular crystal structure [43]. SnO_2's vast surface area makes a lot of sites available for the adsorption of heavy metal ions [90]. Under certain conditions, SnO_2 may react with the heavy metal ions to produce an insoluble precipitate and quickly sediment or filter out of water [91]. Under UV illumination, SnO_2 NPs may also function as a photocatalyst, releasing reactive oxygen species (ROS) that can oxidize heavy metal ions into less hazardous forms [91, 92].

Recent discoveries for purifying water include graphene and it's oxide, reduced oxide, nanocomposites, as well as boron nitride nanoparticles [93]. Because of its electrical conductivity, chemical stability, flexible structure, and immense theoretical surface area, graphene oxide (GO) is a significant and adaptable material [94]. Because of electrostatic repulsion, it offers active areas for reactant molecules with low binding affinities to be absorbed [95]. However, metal oxide nanocomposites effectively eliminate organic chemicals and colors from wastewater. Among them, perovskites have an adaptable arrangement of elements from the periodic table. In particular, ABO_3-type perovskites are drawn to them primarily because of their unique electrical and magnetic characteristics, where transition metals live at site B and trivalent ions at site A.

In particular, $CoCrO_3$ nanocomposites are the most efficient, widely applied, and economical [95, 96]. Cu(II) ions have been eliminated from wastewater using a hybrid CNF/MWCNTs/SnO_2 nanocomposite structure formed by enhanced functionalized cellulose nanofiber (CNF) and laser ablation. The CNF/MWCNTs/SnO_2 nanocomposite structure was prepared with a nonwoven fiber membrane morphology. The hybrid MWCNTs composite increases the capture selectivity and effectiveness by providing additional chains using adsorptive-COOH groups in addition to SnO_2 on the CA fiber [97].

3.4.4. Treatment of pharmaceutical waste

Antibiotics, analgesics, and hormones are among the majority of the contaminants that pharmaceutical waste would include [91]. Some of these pollutants have been known to contaminate water sources and risk human health. Pharmaceutical compound-polluted wastewater from hospitals, residential sources, and pharmaceutical production lines may be treated using SnO_2 nanoparticles [98]. A variety of adsorption mechanisms, including complexation, ion exchange, and physical adsorption, enable SnO_2 nanoparticles to adsorb the medicinal ingredient on their surface (Figure 10) [83]. Furthermore, a multitude of sites for the adsorption of these pollutants are visible on the highly scattered surface of SnO_2 nanoparticles [99]. Hence, when SnO_2 nanoparticles are exposed to UV/visible light, they can function as photocatalysts, generating reactive oxygen species (ROS) that can convert pharmaceutical compounds into less harmful or dangerous by-products. SnO_2 nanoparticles can catalyze the Fenton-like reaction that produces hydroxyl radicals when hydrogen peroxide is present [100].

3.5. Ceramics and Glass Coating

SnO_2 NPs are widely used in ceramics and glass coatings due to its optical and conductive properties [70]. It is the main component in glass coatings for its transparency and electrical conductivity [59]. The transparent conductive films of SnO_2 are widely used in energy-efficient windows, solar panels, and displays, where it is used to regulate heat transmission while remaining transparent [101]. The mechanical durability and thermal stability of ceramics is improved by SnO_2 NPs., which are important aspects for the development of advanced ceramics [60, 84].

Table 2 highlights the diverse applications of SnO_2 nanoparticles synthesized through different methods, demonstrating the compatibility of each approach for specific uses. The sol-gel method is highly suitable for producing porous SnO_2 with controlled surface area and particle size, making it ideal for gas sensors, photocatalysis, and energy storage. Hydrothermal synthesis excels in creating nanostructured SnO_2 with high surface area and stability, preferred for gas sensors, lithium-ion batteries, and photocatalytic applications. Vapor phase deposition, on the other hand, is optimal for fabricating high-quality crystalline thin films, which are essential for thin-film sensors, solar cells, and transparent electronics. Microwave-assisted synthesis offers rapid, energy-efficient production of SnO_2 with enhanced electrochemical efficiency, making it suitable for supercapacitors and photovoltaics. Lastly, green synthesis stands out for its eco-friendliness, leveraging natural resources to produce SnO_2 for sustainable applications like environmental cleanup, energy storage, and photocatalysis.

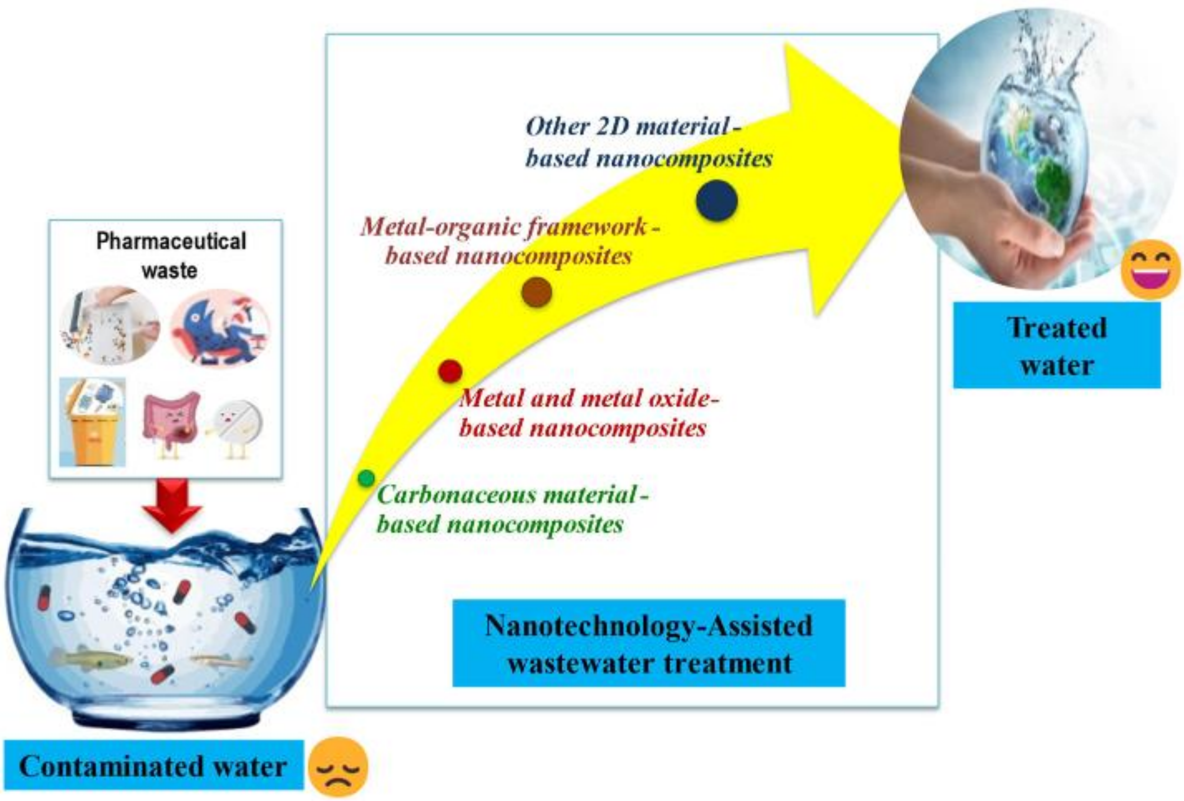

Fig. 10. A representation of water pollution and how it is treated using a method aided by nanotechnology to produce treated water. Reprinted with permission from ref. [100], Saroa, A., Singh, A., Jindal, N., Kumar, R., Singh, K., Guleria, P., Boopathy, R. and Kumar, V., 2023. Nanotechnology-assisted treatment of pharmaceuticals contaminated water. *Bioengineered*, *14*(1), p.2260919. Copyright © Informa UK Limited.

Table 2. Application of SnO_2 with Suitable Synthesis Method.

Application	Synthesis Methods	Compatibility	Ref.
Gas sensors, Photocatalysis and Energy storage	Sol-Gel	Appropriate for creating SnO_2 NPs that are porous and have a regulated surface area and particle size. It is a high-purity substance that can be used in photocatalysts and sensors.	[15, 31, 24, 116]
Photocatalysis, Gas sensors and Lithium-ion batteries	Hydrothermal	Preferred for gas-sensing and photocatalytic applications because of the control over shape, this nanostructured SnO_2 offers high surface area and exceptional stability.	[28, 30, 35, 117]
Thin films for sensors, Solar cells and Transparent electronics	Vapor Phase (Chemical Vapor Deposition)	Ideal for creating high-crystalline quality, thin, homogeneous SnO_2 films. Suitable for thin-film solar cell and sensor applications.	[69,71 ,118]
Supercapacitors and Photovoltaics	Microwave-Assisted	Rapid and energy-efficient, enabling regulated SnO_2 development with enhanced electrochemical efficiency. Ideal for uses such as sensors and supercapacitors.	[63, 67, 119]
Environmental clean-up, Energy storage and Photocatalysis	Green Synthesis	Utilizes natural resources or plant extracts, making it eco-friendly and suitable for sustainable and environmental applications. For energy storage and photocatalytic degradation, preferred.	[9, 41, 43, 120]

4. CHALLENGES AND FUTURE SCOPE FOR IMPROVEMENT

SnO_2 nanoparticles, with their unique properties, can be advantageous in domains as explained in this article. However, particle aggregation, limited sensitivity, and selectivity are a few operational challenges preventing their commercialization. The impact on environmental safety and economy should be considered in the design and synthesis of SnO_2-based applications. Nanotechnology has offered many strategies to address these challenges. For example, different chemical approaches could be employed to alter particle sizes, morphologies, and surface properties [102]. Similarly, the sensitivity and selectivity can be increased by embedding various functional groups or other materials into the surface [103]. SnO_2, as well as other materials like graphene and graphene-based compounds and carbon nanotubes, other 2D materials, or other metal oxides, can be combined to create a sequence of synergistic phenomena that improve performance [104].

The major hurdle in gas sensing is the selectivity of SnO_2 sensors for a particular gas among different gases [105]. One way is to functionalize sensors with specific materials or expand into heterostructures (in which several materials are combined). Moreover, the shape optimization or hierarchical structures of nanomaterials can lead to faster response and recovery speeds for the SnO_2 sensors that are necessary for good real-time gas detection [106].

There are four major challenges which include low energy density, short cycle life, poor rate capability and electrolyte compatibility faced by SnO_2-based high-performance supercapacitors [107]. These limitations need to be addressed by novel electrode materials, better structural stability, and optimized electrolyte compositions [108]. The efficiency and spectral response are important features of semiconductor optoelectronic devices [25]. In other words, to improve the charge carrier transport, it is necessary to fine-tune the device architecture and modify the bandgap of SnO_2 via doping or heterostructures [109]. In planar perovskite solar devices, Ga-doped SnO_2 as electron transport provides a notable improvement in the performance of these gadgets due to their high electron mobility [110].

The excellent Hall mobility and the transparency of Ta-doped SnO_2 epitaxial films with a band gap larger than 3 eV, in the near UV-B range, are useful for transparent electrical and optoelectronic devices [111]. The tendency of SnO_2 NPs to aggregate, which reduces their effective surface area and restricts their adsorption ability, is one of the main obstacles in environmental remediation. Larger contaminants, in particular, may cause the adsorption process to move slowly, which reduces effectiveness of remediation. SnO_2 nanoparticle toxicity may raise questions even though they are usually thought to be biocompatible, particularly when released into the environment [112]. Using methods like nano-structuring, we can overcome these obstacles for example, by forming nanowires and nanosheets of SnO_2 [113], functionalization/nano-composite: by combining SnO_2 NPs into other materials (such as graphene or carbon nanotubes) [114] and adding functional groups (such as amines or thiols etc) to SnO_2 [115].

5. CONCLUSION

Considering their distinct semiconducting, photocatalytic, and electrochemical properties SnO_2 nanoparticles hold significant potential across diverse fields, including gas sensing, energy storage, optoelectronics and environmental remediation. The high surface area-to-volume ratio enhances sensitivity and efficiency, particularly in gas sensors and photocatalytic applications. This makes them ideal for detecting gases like CO, methane, and NO_x in environmental monitoring. Their oxygen vacancies and surface defects further improve adsorption and reaction kinetics, making them suitable for industrial and environmental applications.

In energy storage, SnO_2 nanoparticles show promise for lithium-ion batteries (LIBs) and supercapacitors. Their high surface area and Li-ion storage capacity improve energy density and cyclability, making them a superior alternative to conventional anode materials. Their supercapacitive properties enable fast charge-discharge cycles for portable electronics and renewable energy systems.

Additionally, SnO_2 NPs demonstrate effective photocatalytic properties for water purification and air detoxification, generating reactive oxygen species (ROS) that degrade organic pollutants. They also improve solar cell efficiency, making them valuable for next-gen photovoltaic technologies. However, challenges remain in optimizing synthesis techniques for better control over particle size, morphology, and surface properties. Issues with scalability, cost, and toxicity must be addressed, driving interest in green synthesis methods that are more eco-friendly.

In this short review, we have tried to summarize different synthesis processes of SnO_2 nanoparticles and various applications of SnO_2 nanoparticles. In conclusion, SnO_2 nanoparticles offer immense potential across diverse industries overcoming current challenges and will unlock further advancements in energy, sensor technologies, and sustainable environmental solutions.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

REFERENCES

[1] Qi, L., Song, B., Wu, H., Tong, Y., Li, L., Wu, H. and Shi, K., **2024.** Synthesis of Ag-doped SnO_2 nanoflowers and applications to room temperature high-performance NO_2 gas sensing. *Sensors and Actuators B: Chemical*, *420*, p.136494. https://doi.org/10.1016/j.snb.2024.136494

[2] Ren, W., Yang, J., Zhang, J., Li, W., Sun, C., Zhao, H., Wen, Y., Sha, O. and Liang, B., **2022.** Recent progress in SnO_2/g-C3N4 heterojunction photocatalysts: Synthesis, modification, and application. *Journal of Alloys and Compounds*, *906*, p.164372. https://doi.org/10.1016/j.jallcom.2022.164372.

[3] Fatimah, I., Purwiandono, G., Jauhari, M.H., Maharani, A.A.A.P., Sagadevan, S., Oh, W.C. and Doong, R.A., **2022.** Synthesis and control of the morphology of SnO_2 nanoparticles via various concentrations of Tinospora cordifolia stem extract and reduction methods. *Arabian Journal of Chemistry*, *15*(4), p.103738. https://doi.org/10.1016/j.arabjc.2022.103738

[4] Mohanta, D. and Ahmaruzzaman, M., **2016.** Tin oxide nanostructured materials: an overview of recent developments in synthesis, modifications and potential applications. *RSC advances*, *6*(112), pp.110996-111015. https://doi.org/10.1039/C6RA21444D

[5] Pan, J., Shen, H. and Mathur, S., **2012.** One-Dimensional SnO_2 Nanostructures: Synthesis and Applications. *Journal of nanotechnology*, *2012*(1), p.917320. https://doi.org/10.1155/2012/917320

[6] Wang, H. and Rogach, A.L., **2014.** Hierarchical SnO_2 nanostructures: recent advances in design, synthesis, and applications. *Chemistry of Materials*, *26*(1), pp.123-133. https://doi.org/10.1021/cm4018248

[7] Gorai, S., **2018.** Bio-based synthesis and applications of SnO_2 nanoparticles-an overview. *J. Mater. Environ. Sci*, *9*(10), pp.2894-2903.

https://www.jmaterenvironsci.com/Document/vol9/vol9_N10/317-JMES-3960-Gorai.pdf

[8] Elango, G. and Roopan, S.M., **2016.** Efficacy of SnO_2 nanoparticles toward photocatalytic degradation of methylene blue dye. *Journal of Photochemistry and Photobiology B: Biology*, *155*, pp.34-38. https://doi.org/10.1016/j.jphotobiol.2015.12.010

[9] Garrafa-Galvez, H.E., Nava, O., Soto-Robles, C.A., Vilchis-Nestor, A.R., Castro-Beltrán, A. and Luque, P.A., **2019.** Green synthesis of SnO_2 nanoparticle using Lycopersicon esculentum peel extract. *Journal of Molecular Structure*, *1197*, pp.354-360. https://doi.org/10.1016/j.molstruc.2019.07.052

[10] Manjula, N., Selvan, G., Perumalsamy, R., Thirumamagal, R., Ayeshamariam, A. and Jayachandran, M., **2016.** Synthesis, structural and electrical characterizations of SnO_2 nanoparticles. *International Journal of Nanoelectronics & Materials*, *9*(2). https://ijneam.unimap.edu.my/images/PDF/IJNEAM%20No.%202%202016/Vol_9_No_2_2016_5_143-156.pdf

[11] Kharbanda, J. and Priya, R., **2022.** Synthesis and applications of tin oxide nanoparticles: an overview. *Materials Today: Proceedings*, *68*, pp.916-921. https://doi.org/10.1016/j.matpr.2022.07.131

[12] Luque, P.A., Nava, O., Soto-Robles, C.A., Chinchillas-Chinchillas, M.J., Garrafa-Galvez, H.E., Baez-Lopez, Y.A., Valdez-Núñez, K.P., Vilchis-Nestor, A.R. and Castro-Beltrán, A., **2020.** Improved photocatalytic efficiency of SnO_2 nanoparticles through green synthesis. *Optik*, *206*, p.164299. https://doi.org/10.1016/j.ijleo.2020.164299

[13] Sharma, A., Arya, S., Chauhan, D., Solanki, P.R., Khajuria, S. and Khosla, A., **2020.** Synthesis of Au–SnO_2 nanoparticles for electrochemical determination of vitamin B12. *Journal of Materials Research and Technology*, *9*(6), pp.14321-14337 https://doi.org/10.1016/j.jmrt.2020.10.024

[14] Kamakshi, P., Joshitha, C. and Chella, S., **2023.** Enhancing photocatalytic applications with SnO_2/Ti_3C_2 Mxene nanocomposite: Synthesis and characterization. *Chemical Physics Letters*, *833*, p.140945. https://doi.org/10.1016/j.cplett.2023.140945

[15] Gautam, D., Gautam, Y.K., Sharma, K., Kumar, A., Kumar, A., Srivastava, V. and Singh, B.P., **2024.** Recent developments in SnO_2 nanostructures inspired hydrogen gas sensors. *International Journal of Hydrogen Energy*, *81*, pp.313-345. https://doi.org/10.1016/j.ijhydene.2024.07.253

[16] Preethi, T., Pachamuthu, M.P., Senthil, K., Arulmani, S., Pugalmani, S. and Ashokan, S., **2024.** Microwave-assisted synthesis of SnO_2: ZnO nanocomposites for photocatalytic, antimicrobial and electrochemical urea detection applications. *Journal of Molecular Structure*, *1304*, p.137667. https://doi.org/10.1016/j.molstruc.2024.137667

[17] Bathula, B., Gurugubelli, T.R., Yoo, J. and Yoo, K., **2023**. Recent progress in the use of SnO_2 quantum dots: from synthesis to photocatalytic applications. *Catalysts*, *13*(4), p.765. https://doi.org/10.3390/catal13040765

[18] Nagirnyak, S. and Dontsova, T., **2017.** Effect of modification/doping on gas sensing properties of SnO_2. *Nano Res. Appl*, *3*(2), p.8. https://doi.org/10.21767/2471-9838.100025

[19] Vindhya, P.S., Suresh, S. and Kavitha, V.T., 2024. Biofabrication and Characterisation of Ni-Doped SnO_2 Nanoparticles With Enhanced Cytotoxicity, Antioxidant, Antimicrobial and Photocatalytic Activities. *Applied Organometallic Chemistry*, p.e7875.

[20] Wicaksono, W.P., Sahroni, I., Saba, A.K., Rahman, R. and Fatimah, I., **2020.** Biofabricated SnO_2 nanoparticles using Red Spinach (Amaranthus tricolor L.) extract and the study on photocatalytic and electrochemical sensing activity. *Materials Research Express*, *7*(7), p.075009. https://doi.org/10.1088/2053-1591/aba55b

[21] Chen, Z., Huang, Q., Zhang, Y., Sheng, P. and Cui, Z., **2021.** Confined generation of homogeneously dispersed Au and SnO_2 nanoparticles in layered silicate as synergistic catalysts. *Langmuir*, *37*(7), pp.2341-2348. https://doi.org/10.1021/acs.langmuir.0c03216

[22] Singh, V., Banotra, A., Khan, S., Singh, A. and Goutam, S., **2023.** Pristine SnO_2 and SnO_2/rGO nanocomposites: Synthesis, microstructural, optical and electrical characteristics for potential sensing applications. *Diamond and Related Materials*, *133*, p.109704. https://doi.org/10.1016/j.diamond.2023.109704

[23] Liu, L., Zhao, J., Jin, Z., Liu, F., Zhao, D., Liu, Z., Wang, F., Wang, Z., Liu, J. and Wu, L., **2024.** NO_2-Sensitive SnO_2 Nanoparticles Prepared Using a Freeze-Drying Method. *Materials*, *17*(15), p.3714. https://doi.org/ 10.3390/ma17153714

[24] Karmaoui, M., Jorge, A.B., McMillan, P.F., Aliev, A.E., Pullar, R.C., Labrincha, J.A. and Tobaldi, D.M., **2018.** One-step synthesis, structure, and band gap properties of SnO_2 nanoparticles made by a low temperature nonaqueous sol–gel technique. *ACS omega*, *3*(10), pp.13227-13238. https://doi.org/10.1021/acsomega.8b02122

[25] Khan, D., Rehman, A., Rafiq, M.Z., Khan, A.M. and Ali, M., **2021.** Improving the optical properties of SnO_2 nanoparticles through Ni doping by sol-gel technique. *Current Research in Green and Sustainable Chemistry*, *4*, p.100079. https://doi.org/10.1016/j.crgsc.2021.100079

[26] Ibarguen, C.A., Mosquera, A., Parra, R., Castro, M.S. and Rodríguez-Páez, J.E., **2007.** Synthesis of SnO_2 nanoparticles through the controlled precipitation route. *Materials Chemistry and Physics*, *101*(2-3), pp.433-440. https://doi.org/10.1016/j.matchemphys.2006.08.003

[27] Kumari, K. and Ahmaruzzaman, M., **2023.** SnO_2 quantum dots (QDs): synthesis and potential applications in energy storage and environmental remediation. *Materials Research Bulletin*, p.112446. https://doi.org/10.1016/j.materresbull.2023.112446

[28] Akhir, M.A., Mohamed, K., Lee, H.L. and Rezan, S.A., **2016.** Synthesis of tin oxide nanostructures using hydrothermal method and optimization of its crystal size by using statistical design of experiment. *Procedia Chemistry*, *19*, pp.993-998. https://doi.org/10.1016/j.proche.2016.03.148

[29] Lee, N.E., Cheon, S.U., Lee, J. and Cho, S.O., **2023.** Tin Oxide/Vertically Aligned Graphene Hybrid Electrodes Prepared by Sonication-Assisted Sequential Chemical Bath Deposition for High-Performance Supercapacitors. *ACS omega*, *8*(7), pp.6621-6631. https://doi.org/10.1021/acsomega.2c07075

[30] Tan, L., Wang, L. and Wang, Y., **2011.** Hydrothermal synthesis of SnO_2 nanostructures with different morphologies and their optical properties. *Journal of Nanomaterials*, *2011*(1), p.529874. https://doi.org/10.1155/2011/529874

[31] Deepa, S., Philip, A.M., George, A.S. and Prasannakumari, K., **2021.** Microstructural, optical and dielectric variations in SnO_2 nanoparticles synthesized via surfactant-assisted sol–gel route. *Bulletin of Materials Science*, *44*(4), p.283. https://doi.org/10.1007/s12034-021-02567-3

[32] Li, H., Pokhrel, S., Schowalter, M., Rosenauer, A., Kiefer, J. and Mädler, L., **2020.** The gas-phase formation of tin dioxide nanoparticles in single droplet combustion and flame spray pyrolysis. *Combustion and flame*, *215*, pp.389-400. https://doi.org/10.1016/j.combustflame.2020.02.004

[33] Tibayan Jr, E.B., Muflikhun, M.A., Al Rey, C.V., Kumar, V. and Santos, G.N.C., **2020.** Structures and UV resistance of Ag/SnO2 nanocomposite materials synthesized by horizontal vapor phase growth for coating applications. *Journal of Materials Research and Technology*, *9*(3), pp.4806-4816. https://doi.org/10.1016/j.jmrt.2020.03.001

[34] Tibayan Jr, E.B., Muflikhun, M.A., Al Rey, C.V., Kumar, V. and Santos, G.N.C., 2**020.** Structures and UV resistance of Ag/SnO_2 nanocomposite materials synthesized by horizontal vapor phase growth for coating applications. *Journal of Materials Research and Technology*, *9*(3), pp.4806-4816. https://doi.org/10.1155/2015/850147

[35] Kim, H.W., Na, H.G., Kwon, Y.J., Kang, S.Y., Choi, M.S., Bang, J.H., Wu, P. and Kim, S.S., **2017.** Microwave-assisted synthesis of graphene–SnO_2 nanocomposites and their applications in gas sensors. *ACS applied materials & interfaces*, *9*(37), pp.31667-31682. https://doi.org/10.1021/acsami.7b02533

[36] Ponzoni, A., **2022.** A statistical analysis of response and recovery times: the case of ethanol chemiresistors based on pure SnO_2. *Sensors*, *22*(17), p.6346. https://doi.org/10.3390/s22176346

[37] Tasisa, Y.E., Sarma, T.K., Sahu, T.K. and Krishnaraj, R., **2024.** Phytosynthesis and characterization of tin-oxide nanoparticles (SnO_2-NPs) from Croton macrostachyus leaf extract and its application under visible light photocatalytic activities. *Scientific Reports*, *14*(1), p.10780. https://doi.org/10.1038/s41598-024-60633-2

[38] Hang, L.T.T., Thuy, H.T.B. and Dung, D.T., **2021.** Facile synthesis of Sn/SnOx@ CMK-3 composite for standout performance lithium-ion batteries. *Vietnam Journal of Chemistry*, *59*(4), pp.486-493. https://doi.org/10.1002/vjch.202000210

[39] Abdel-Galil, A., Moussa, N.L. and Yahia, I.S., **2021.** Synthesis and optical characterization of nanocrystalline fluorine-doped tin oxide films: conductive window layer for optoelectronic applications. *Applied Physics A*, *127*(6), p.474. https://doi.org/10.1007/s00339-021-04632-4

[40] Bathula, B., Gurugubelli, T.R., Yoo, J. and Yoo, K.,

2023. Recent progress in the use of SnO_2 quantum dots: from synthesis to photocatalytic applications. *Catalysts*, *13*(4), p.765. https://doi.org/10.3390/catal13040765

[41] Naikoo, G.A., Mustaqeem, M., Hassan, I.U., Awan, T., Arshad, F., Salim, H. and Qurashi, A., **2021.** Bioinspired and green synthesis of nanoparticles from plant extracts with antiviral and antimicrobial properties: A critical review. *Journal of Saudi Chemical Society*, *25*(9), p.101304. https://doi.org/10.1016/j.jscs.2021.101304

[42] Singh, J., Dutta, T., Kim, K.H., Rawat, M., Samddar, P. and Kumar, P., **2018**. 'Green'synthesis of metals and their oxide nanoparticles: applications for environmental remediation. *Journal of nanobiotechnology*, *16*, pp.1-24. https://doi.org/10.1186/s12951-018-0408-4

[43] Ashour, M., Mansour, A.T., Abdelwahab, A.M. and Alprol, A.E., **2023.** Metal oxide nanoparticles' green synthesis by plants: prospects in phyto-and bioremediation and photocatalytic degradation of organic pollutants. *Processes*, *11*(12), p.3356. https://doi.org/10.3390/pr11123356

[44] Aldossari, S.M., Rehman, L.U., Ahmad, I., Aslam, M., Fozia, F., Mohany, M., Milošević, M., Al-Rejaie, S.S. and Aboul-Soud, M.A., **2023.** Phytosynthesized Iron Oxide Nanoparticles Using Aqueous Extract of Saccharum arundinaceum (Hardy Sugar Cane), Their Characterizations, Antiglycation, and Cytotoxic Activities. *ACS omega*, *8*(44), pp.41214-41222. https://doi.org/10.1021/acsomega.3c04484

[45] Najjar, M., Hosseini, H.A., Masoudi, A., Sabouri, Z., Mostafapour, A., Khatami, M. and Darroudi, M., **2021.** Green chemical approach for the synthesis of SnO_2 nanoparticles and its application in photocatalytic degradation of Eriochrome Black T dye. *Optik*, *242*, p.167152. https://doi.org/10.1016/j.ijleo.2021.167152

[46] Gomathi, E., Jayapriya, M. and Arulmozhi, M., **2021.** Environmental benign synthesis of tin oxide (SnO_2) nanoparticles using Actinidia deliciosa (Kiwi) peel extract with enhanced catalytic properties. *Inorganic Chemistry Communications*, *130*, p.108670. https://doi.org/10.1016/j.inoche.2021.108670

[47] Fatimah, I., Sahroni, I., Muraza, O. and Doong, R.A., **2020.** One-pot biosynthesis of SnO_2 quantum dots mediated by Clitoria ternatea flower extract for photocatalytic degradation of rhodamine B. *Journal of Environmental Chemical Engineering*, *8*(4), p.103879. https://doi.org/10.1016/j.jece.2020.103879

[48] Haritha, E., Roopan, S.M., Madhavi, G., Elango, G., Al-Dhabi, N.A. and Arasu, M.V., **2016**. Green chemical approach towards the synthesis of SnO_2 NPs in argument with photocatalytic degradation of diazo dye and its kinetic studies. *Journal of Photochemistry and Photobiology B: Biology*, *162*, pp.441-447. https://doi.org/10.1016/j.jphotobiol.2016.07.010

[49] Amutha, T., Rameshbabu, M., Razia, M., Bakri, M., Florence, S.S., Muthupandi, S. and Prabha, K., **2023.** Structural, optical and antibacterial activity of pure and co-doped (Fe & Ni) tin oxide nanoparticles. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *287*, p.121996. https://doi.org/10.1016/j.saa.2022.121996

[50] Matussin, S., Harunsani, M.H., Tan, A.L. and Khan, M.M., **2020.** Plant-extract-mediated SnO_2 nanoparticles: synthesis and applications. *ACS Sustainable Chemistry & Engineering*, *8*(8), pp.3040-3054.
https://doi.org/10.1021/acssuschemeng.9b06398

[51] Pirsaheb, M., Gholami, T., Dawi, E.A., Majdi, H.S., Hashim, F.S., Seifi, H. and Salavati-Niasari, M., **2023.** Green synthesis and characterization of SnO_2, CuO, Fe_2O_3/activated carbon nanocomposites and their application in electrochemical hydrogen storage. *International Journal of Hydrogen Energy*, *48*(61), pp.23594-23606. https://doi.org/10.1016/j.ijhydene.2023.03.186

[52] Naz, S., Javid, I., Konwar, S., Surana, K., Singh, P.K., Sahni, M. and Bhattacharya, B., **2020.** A simple low cost method for synthesis of SnO_2 nanoparticles and its characterization. *SN Applied Sciences*, *2*, pp.1-8. https://doi.org/10.1007/s42452-020-2812-2

[53] Liu, H., Zong, H., Yan, L., Zhou, D., Yin, Y., Cao, G., Bian, L., Kang, C. and Li, M., **2021.** $SnO_2/VO_2/SnO_2$ tri-layer thermochromic films with high luminous transmittance, remarkable solar modulation ability and excellent hydrophobicity grown on glass substrates. *Infrared Physics & Technology*, *113*, p.103648.
https://doi.org/10.1016/j.infrared.2021.103648

[54] Mishra, S.R. and Ahmaruzzaman, M., **2022.** Tin oxide based nanostructured materials: synthesis and potential applications. *Nanoscale*, 14(5), pp.1566-1605. DOI: https://doi.org/10.1039/D1NR07040A

[55] Barsan, N., Schweizer-Berberich, M. and Göpel, W., **1999.** Fundamental and practical aspects in the design of nanoscaled SnO_2 gas sensors: a status report. *Fresenius' Journal of Analytical*

Chemistry, *365*, pp.287-304. https://doi.org/10.1007/s002160051490

[56] Li, M., Zhu, H., Wei, G., He, A. and Liu, Y., **2019.** VOCs gas sensing properties on SnO_2 (110) surface with dissociated oxygen species pre-adsorbed: experiments and DFT analysis. *Journal of Materials Science: Materials in Electronics*, *30*(21), pp.19625-19638. https://doi.org/10.1007/s10854-019-02336-3

[57] Göpel, W. and Schierbaum, K.D., **1995.** SnO_2 sensors: current status and future prospects. *Sensors and Actuators B: Chemical*, *26*(1-3), pp.1-12. https://doi.org/10.1016/0925-4005(94)01546-T

[58] Williams, D.E., **1999.** Semiconducting oxides as gas-sensitive resistors. *Sensors and Actuators B: Chemical*, *57*(1-3), pp.1-16. https://doi.org/10.1016/S0925-4005(99)00133-1

[59] Sotelo, J.G., Bonilla-Ríos, J., García-Escobar, F. and Gordillo, J.L., **2021.** Film growth of tetragonal SnO_2 on glass substrate by dip-coating technique for ethanol sensing applications. *Coatings*, *11*(3), p.303. https://doi.org/10.3390/coatings11030303

[60] Yadav, S., Yadav, K., Dhar, R. and Mohan, D., **2023.** Synthesis and characterization of thermally evaporated Er-doped SnO_2 thin films for photonic applications. *Micro and Nanostructures*, *174*, p.207493. https://doi.org/10.1016/j.micrna.2022.207493

[61] Liu, P., Wang, J., Jin, H., Ge, M., Zhang, F., Wang, C., Sun, Y. and Dai, N., **2023.** SnO_2 mesoporous nanoparticle-based gas sensor for highly sensitive and low concentration formaldehyde detection. *RSC Advances*, *13*(4), pp.2256-2264. https://doi.org/10.1039/d2ra06745e

[62] Yu, J. and Xia, Y., **2014.** Facile synthesis of the SnO_2@OCNTs (open-tips carbon nano tubes) composite with superior cyclability for Li-ion batteries. *Electrochimica Acta*, *147*, pp.720-725. https://doi.org/10.1016/j.electacta.2014.09.153

[63] Manikandan, K., Dhanuskodi, S., Maheswari, N. and Muralidharan, G., **2016,** May. SnO_2 nanoparticles for supercapacitor application. In *Dae Solid State Physics Symposium 2015* (Vol. 1731, No. 1, p. 050048). https://doi.org/10.1063/1.4947702

[64] Dalapati, G.K., Sharma, H., Guchhait, A., Chakrabarty, N., Bamola, P., Liu, Q., Saianand, G., Krishna, A.M.S., Mukhopadhyay, S., Dey, A. and Wong, T.K.S., **2021.** Tin oxide for optoelectronic, photovoltaic and energy storage devices: a review. *Journal of Materials Chemistry A*, *9*(31), pp.16621-16684. https://doi.org/10.1039/d1ta01291f

[65] Dheyab, M.A., Aziz, A.A., Jameel, M.S. and Oladzadabbasabadi, N., **2022.** Recent advances in synthesis, modification, and potential application of tin oxide nanoparticles. Surfaces and Interfaces, 28, p.101677. https://doi.org/10.1016/j.surfin.2021.101677

[66] Yan, J., Khoo, E., Sumboja, A. and Lee, P.S., **2010.** Facile coating of manganese oxide on tin oxide nanowires with high-performance capacitive behavior. *ACS nano*, *4*(7), pp.4247-4255. https://doi.org/10.1021/nn100592d

[67] Lim, S.P., Huang, N.M. and Lim, H.N., **2013.** Solvothermal synthesis of SnO_2/graphene nanocomposites for supercapacitor application. *Ceramics International*, *39*(6), pp.6647-6655. https://doi.org/10.1016/j.ceramint.2013.01.102

[68] Hu, Z.A., Xie, Y.L., Wang, Y.X., Mo, L.P., Yang, Y.Y. and Zhang, Z.Y., **2009.** Polyaniline/SnO_2 nanocomposite for supercapacitor applications. *Materials Chemistry and Physics*, *114*(2-3), pp.990-995. https://doi.org/10.1016/j.matchemphys.2008.11.005

[69] Adedokun, O., **2018.** Review on Transparent Conductive Oxides Thin Films deposited by Sol-gel spin coating technique. *International Journal of Engineering Science and Application*, *2*(3), pp.88-97. https://dergipark.org.tr/en/pub/ijesa/issue/39397/427973

[70] Lee, N., Bang, J.H., Kim, H.W. and Jeon, H., **2021.** New approach to SnO_2-based transparent conducting oxides incorporating synergistic effects of Au nano particles and microwave irradiation. *Ceramics International*, *47*(8), pp.10628-10634. https://doi.org/10.1016/j.ceramint.2020.12.175

[71] Xiong, L., Guo, Y., Wen, J., Liu, H., Yang, G., Qin, P. and Fang, G., **2018.** Review on the application of SnO_2 in perovskite solar cells. *Advanced Functional Materials*, *28*(35), p.1802757. https://doi.org/10.1002/adfm.201802757

[72] Wang, C., Wu, J., Liu, X., Wang, S., Yan, Z., Chen, L., Li, G., Zhang, X., Sun, W. and Lan, Z., **2021.** High-effective SnO_2-based perovskite solar cells by multifunctional molecular additive engineering. *Journal of Alloys and Compounds*, *886*, p.161352. https://doi.org/10.1016/j.jallcom.2021.161352

[73] Chakraborty, S., Roy, M. and Saha, R., **2020.** Cost-effective synthesis method of facile environment

friendly SnO2 nanoparticle for efficient photocatalytic degradation of water contaminating compound. Water Science and Technology, 81(3), pp.508-517. https://doi.org/10.2166/wst.2020.130

[74] Singh, J., Kaur, H., Kukkar, D., Mukamia, V.K., Kumar, S. and Rawat, M., **2019.** Green synthesis of SnO_2 NPs for solar light induced photocatalytic applications. *Materials Research Express*, *6*(11), p.115007. https://doi.org/10.1088/2053-1591/ab4412

[75] Apostolov, A.T., Apostolova, I.N. and Wesselinowa, J.M., **2018.** A comparative study of the magnetization in transition metal ion doped CeO_2, TiO_2 and SnO_2 nanoparticles. *Physica E: Low-dimensional Systems and Nanostructures*, *99*, pp.202-207. https://doi.org/10.1016/j.physe.2018.02.007

[76] Magdalane, C.M., Kanimozhi, K., Arularasu, M.V., Ramalingam, G. and Kaviyarasu, K., **2019.** Self-cleaning mechanism of synthesized SnO_2/TiO_2 nanostructure for photocatalytic activity application for waste water treatment. *Surfaces and Interfaces*, *17*, p.100346. https://doi.org/10.1016/j.surfin.2019.100346

[77] Jarvin, M., Inbanathan, S.S.R., Rosaline, D.R., Prabha, A.J. and Dhas, S.M.B., **2022.** A study of the structural, morphological, and optical properties of shock treated SnO_2 nanoparticles: removal of Victoria blue dye. *Heliyon*, *8*(6). https://doi.org/10.1016/j.heliyon.2022.e09653

[78] Kaur, M., Prasher, D. and Sharma, R., **2022.** Recent developments on I and II series transition elements doped SnO_2 nanoparticles and its applications for water remediation process: a review. *Journal of Water and Environmental Nanotechnology*, *7*(2), pp.194-217. https://doi.org/10.22090/jwent.2022.02.007

[79] Kumar, S., **2017.** Water treatment using photocatalytic and antimicrobial activities of tin oxide nanoparticles. *Indian Journal of Chemical Technology (IJCT)*, *24*(4), pp.435-440. https://doi.org/10.56042/ijct.v24i4.12536

[80] Karthik, R., Vinoth Kumar, J., Chen, S.M., Karuppiah, C., Cheng, Y.H. and Muthuraj, V., **2017.** A study of electrocatalytic and photocatalytic activity of cerium molybdate nanocubes decorated graphene oxide for the sensing and degradation of antibiotic drug chloramphenicol. *ACS Applied Materials & Interfaces*, *9*(7), pp.6547-6559. https://doi.org/10.1021/acsami.6b14242

[81] Najjar, M., Hosseini, H.A., Masoudi, A., Sabouri, Z., Mostafapour, A., Khatami, M. and Darroudi, M., **2021.** Green chemical approach for the synthesis of SnO2 nanoparticles and its application in photocatalytic degradation of Eriochrome Black T dye. *Optik*, *242*, p.167152. https://doi.org/10.1016/j.ijleo.2021.167152

[82] Kanan, S., Moyet, M.A., Arthur, R.B. and Patterson, H.H., **2020.** Recent advances on TiO2-based photocatalysts toward the degradation of pesticides and major organic pollutants from water bodies. *Catalysis Reviews*, *62*(1), pp.1-65. https://doi.org/10.1080/01614940.2019.1613323

[83] Ehsan, R., Haq, S., Shahzad, N., Ali, M.B., Abdallah, F.B., Hassan, M.M., Hedfi, A., Din, S.U. and Shahzad, M.I., **2022.** Tin dioxide nanoparticles for waste water treatment: facile synthesis and characterization. *Materials Research Express*, *9*(5), p.055006. https://doi.org/10.1088/2053-1591/ac6cce

[84] Shittu, H.A., Adedokun, O., Kareem, M.A., Sivaprakash, P., Bello, I.T. and Arumugam, S., **2023.** Effect of low-doping concentration on silver-doped SnO2 and its photocatalytic applications. *Biointerface Res. Appl. Chem*, *13*(165.10), p.33263. https://doi.org/10.33263/BRIAC132.165

[85] Tiki, Y.L., Tolesa, L.D., Tiwikrama, A.H. and Chala, T.F., **2024.** Ginger (Zingiber officinale)-Mediated Green Synthesis of Silver-Doped Tin Oxide Nanoparticles and Evaluation of Its Antimicrobial Activity. *ACS omega*, *9*(10), pp.11443-11452. https://doi.org/10.1021/acsomega.3c07855

[86] Yang, C., Fan, Y., Shang, S., Li, P. and Li, X.Y., **2021.** Fabrication of a permeable SnO_2-Sb reactive anodic filter for high-efficiency electrochemical oxidation of antibiotics in wastewater. *Environment International*, *157*, p.106827. https://doi.org/10.1016/j.envint.2021.106827

[87] Feng, Y.J. and Li, X.Y., **2003.** Electro-catalytic oxidation of phenol on several metal-oxide electrodes in aqueous solution. *Water Research*, *37*(10), pp.2399-2407. https://doi.org/10.1016/S0043-1354(03)00026-5

[88] Sun, C., Yang, J., Xu, M., Cui, Y., Ren, W., Zhang, J., Zhao, H. and Liang, B., **2022.** Recent intensification strategies of SnO_2-based photocatalysts: A review. *Chemical Engineering Journal*, *427*, p.131564. https://doi.org/10.1016/j.cej.2021.131564

[89] Merola, M. and Diaz, O., **2018.** Energy and Environment. *The Modernisation of State aid for Economic and Social Development*, pp.169-236. https://doi.org/10.1007/978-3-319-99226-6_9

[90] Jabbarzare, S., **2023.** Heavy metal removal using SnO_2

nanoparticles prepared in a grape extract media. *Journal of Particle Science and Technology*, *9*(2), pp.51-61. https://doi.org/10.22104/JPST.2023.6385.1236

[91] Alizadeh, R., Kazemi, R.K. and Rezaei, M.R., **2018.** Ultrafast removal of heavy metals by tin oxide nanowires as new adsorbents in solid-phase extraction technique. *International Journal of Environmental Science and Technology*, *15*, pp.1641-1648. https://doi.org/10.1007/s13762-017-1481-1

[92] Ali, S.I., Dutta, D., Das, A., Mandal, S. and Mandal, A.C., **2023.** Understanding the structure-property correlation of tin oxide nanoparticles synthesized through the sol-gel technique. *Journal of Luminescence*, *253*, p.119465. https://doi.org/10.1016/j.jlumin.2022.119465

[93] Baskoro, F., Wong, C.B., Kumar, S.R., Chang, C.W., Chen, C.H., Chen, D.W. and Lue, S.J., **2018.** Graphene oxide-cation interaction: Inter-layer spacing and zeta potential changes in response to various salt solutions. *Journal of Membrane Science*, *554*, pp.253-263. https://doi.org/10.1016/j.memsci.2018.03.006

[94] Palai, A. and Sahu, D., **2022.** sol-gel synthesized SnO_2 nanoparticles showing advanced photocatalytic attributes for environmental pollution control. https://doi.org/10.31788/RJC.2022.1558230

[95] Batool, K., Rani, M., Rasool, F., Karami, A.M., Sillanpää, M., Shafique, R., Akram, M. and Sohail, A., **2023.** Multinary nanocomposite of GO@ SrO@ $CoCrO_3$@ $FeCr_2O_4$@ SnO_2@ SiO_2 for superior electrochemical performance and water purification applications. *Heliyon*, *9*(10). https://doi.org/10.1016/j.heliyon.2023.e20675

[96] Mishra, P., Lee, J., Kumar, D., Louro, R.O., Costa, N., Pathania, D., Kumar, S., Lee, J. and Singh, L., **2022.** Engineered nanoenzymes with multifunctional properties for next-generation biological and environmental applications. *Advanced Functional Materials*, *32*(8), p.2108650. https://doi.org/10.1002/adfm.202108650

[97] Mwafy, E.A. and Mostafa, A.M., **2020.** Tailored MWCNTs/SnO_2 decorated cellulose nanofiber adsorbent for the removal of Cu (II) from wastewater. *Radiation Physics and Chemistry*, *177*, p.109172. https://doi.org/10.1016/j.radphyschem.2020.109172

[98] Nazim, V.S., El-Sayed, G.M., Amer, S.M. and Nadim, A.H., **2023.** Functionalized SnO_2 nanoparticles with gallic acid via green chemical approach for enhanced photocatalytic degradation of citalopram: synthesis, characterization and application to pharmaceutical wastewater treatment. *Environmental Science and Pollution Research*, *30*(2), pp.4346-4358. https://doi.org/10.1007/s11356-022-22447-5

[99] Al-Toriahi, A.K.M., Azooz, E.A. and Al-Mulla, E.A.J., **2023**. Metal Nanoparticles and Nano-Filters for the Disposal of Hospital Waste: A Review. *Nano Biomedicine & Engineering*, *15*(2). https://doi.org/10.26599/NBE.2023.9290017.

[100] Saroa, A., Singh, A., Jindal, N., Kumar, R., Singh, K., Guleria, P., Boopathy, R. and Kumar, V., **2023.** Nanotechnology-assisted treatment of pharmaceuticals contaminated water. *Bioengineered*, *14*(1), p.2260919. https://doi.org/10.1080/21655979.2023.2260919

[101] Najafi, N. and Rozati, S., **2017.** Structural and Electrical Properties of SnO_2: F Thin Films Prepared by Chemical Vapor Deposition Method. Acta Physica Polonica A, 131(2), pp.222-225. http://doi.org/10.12693/APhysPolA.131.222

[102] Gebreslassie, Y.T. and 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), p.97. https://doi.org/10.1186/s11671-021-03555-6

[103] Kumar, S.K., Harisha, S., Jalaja, P., Jayanna, B.K., Kumar, K.Y. and Anantha, M.S., **2024.** Evolution of SnO_2 nanoparticles for the electrochemical sensing of dopamine including photocatalytic toxic dyes degradation. *Sensors International*, *5*, p.100278. https://doi.org/10.1016/j.sintl.2023.100278

[104] Nurzulaikha, R., Lim, H.N., Harrison, I., Lim, S.S., Pandikumar, A., Huang, N.M., Lim, S.P., Thien, G.S.H., Yusoff, N. and Ibrahim, I., **2015.** Graphene/SnO_2 nanocomposite-modified electrode for electrochemical detection of dopamine. *Sensing and Bio-Sensing Research*, *5*, pp.42-49. https://doi.org/10.1016/j.sbsr.2015.06.002

[105] Liu, X., Cheng, S., Liu, H., Hu, S., Zhang, D. and Ning, H., **2012.** A survey on gas sensing technology. *Sensors*, *12*(7), pp.9635-9665. https://doi.org/10.3390/s120709635

[106] Comini, E., **2020.** Metal oxides nanowires chemical/gas sensors: Recent advances. *Materials Today Advances*, *7*, p.100099. https://doi.org/10.1016/j.mtadv.2020.100099

[107] Huang, S., Zhu, X., Sarkar, S. and Zhao, Y., **2019.**

Challenges and opportunities for supercapacitors. *Apl Materials*, *7*(10). https://doi.org/10.1063/1.5116146

[108] Meng, J., Guo, H., Niu, C., Zhao, Y., Xu, L., Li, Q. and Mai, L., **2017.** Advances in structure and property optimizations of battery electrode materials. *Joule*, *1*(3), pp.522-547. https://doi.org/10.1016/j.joule.2017.08.001

[109] Zhou, H., Deng, R., Li, Y.F., Yao, B., Ding, Z.H., Wang, Q.X., Han, Y., Wu, T. and Liu, L., **2014.** Wavelength-tuned light emission via modifying the band edge symmetry: doped SnO_2 as an example. *The Journal of Physical Chemistry C*, *118*(12), pp.6365-6371. https://doi.org/10.1021/jp411128m

[110] Hoang Huy, V.P., Nguyen, T.M.H. and Bark, C.W., **2023.** Recent Advances of Doped SnO_2 as Electron Transport Layer for High-Performance Perovskite Solar Cells. *Materials*, *16*(18), p.6170. https://doi.org/10.3390/ma16186170

[111] He, L., Luan, C., Feng, X., Xiao, H., Yang, X., Wang, D. and Ma, J., **2019.** UV–vis transparent conducting Ta-doped SnO_2 epitaxial films grown by metal-organic chemical vapor deposition. *Materials Research Bulletin*, *118*, p.110488. https://doi.org/10.1016/j.materresbull.2019.05.013

[112] Santoyo, V.R., Serrano-Diaz, P., Andrade-Espinoza, B.A., Fernández-Arteaga, Y. and Arenas-Arrocena, M.C., **2024.** Metal Oxide-based Nanoparticles for Environmental Remediation: Drawbacks and Opportunities. *Periodica Polytechnica Chemical Engineering*, *68*(3), pp.311-325. https://doi.org/10.3311/PPch.36670

[113] Cheng, C., Liu, B., Yang, H., Zhou, W., Sun, L., Chen, R., Yu, S.F., Zhang, J., Gong, H., Sun, H. and Fan, H.J., **2009.** Hierarchical assembly of ZnO nanostructures on SnO_2 backbone nanowires: low-temperature hydrothermal preparation and optical properties. *ACS nano*, *3*(10), pp.3069-3076. https://doi.org/10.1021/nn900848x

[114] Scipioni, R., Gazzoli, D., Teocoli, F., Palumbo, O., Paolone, A., Ibris, N., Brutti, S. and Navarra, M.A., **2014.** Preparation and characterization of nanocomposite polymer membranes containing functionalized SnO_2 additives. *Membranes*, *4*(1), pp.123-142. https://doi.org/10.3390/membranes4010123

[115] Fadillah, G., Wicaksono, W.P., Fatimah, I. and Saleh, T.A., **2020.** A sensitive electrochemical sensor based on functionalized graphene oxide/SnO_2 for the determination of eugenol. Microchemical Journal, 159, p.105353. https://doi.org/10.1016/j.microc.2020.105353

[116] Duduman, C.N., Perez, M.I.B., da Salazar, J.M.G., Carcea, I., Chicet, D.L. and Palamarciuc, I., **2016.** Synthesis of SnO_2 by Sol-Gel Method. Solid State Phenomena, 254, p.200. DOI: 10.4028/www.scientific.net/SSP.254.200

[117] Kim, H.J., Son, J.H. and Bae, D.S., **2011.** Synthesis and characterization of SnO_2 nanoparticles by hydrothermal processing. Korean Journal of Materials Research, 21(8), pp.415-418. https://doi.org/10.3740/MRSK.2011.21.8.415

[118] Mishra, M.K., Singh, N., Pandey, V. and Haque, F.Z., **2016.** Synthesis of SnO_2 nanoparticles and its application in sensing ammonia gas through photoluminescence. Journal of Advanced Physics, 5(1), pp.8-12.

[119] Rahman, M.T., Ahmed, Z., Ahmed, Y., Rahman, M.S. and Toma, F.T.Z., **2022.** Investigating the Effect of Annealing Temperatures on SnO_2 Nano Structural Thin Films and their Properties. Journal of Nanoscience, Nanoengineering & Applications, 12(1), pp.28-39p. DOI (Journal): 10.37591/JoNSNEA

[120] Najjar, M., Hosseini, H.A., Masoudi, A., Sabouri, Z., Mostafapour, A., Khatami, M. and Darroudi, M., **2021.** Green chemical approach for the synthesis of SnO_2 nanoparticles and its application in photocatalytic degradation of Eriochrome Black T dye. Optik, 242, p.167152. https://doi.org/10.1016/j.ijleo.2021.167152.

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