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Review Article

Exploring the synthesis, characterization and the different Potential applications of SnO_2 and TiO_2 Nanoparticles: A Comprehensive Review

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Abstract

Nanotechnology is one of the most developed sciences which different researchers need to see its application in industry. This review examines the utilization of SnO2 and TiO2 nanoparticles (NPs) in photocatalytic and microbial activities, focusing on their potential applications and recent advancements. SnO2 and TiO2 NPs have emerged as promising candidates for addressing environmental challenges and public health concerns due to their unique properties, including high surface area, photostability, and antimicrobial efficacy. Photocatalysis, driven by solar energy, offers an efficient pathway for pollutant degradation and renewable energy production, with TiO2 NPs demonstrating exceptional performance in various catalytic processes. Moreover, the antimicrobial properties of both SnO2 and TiO2 NPs make them effective agents for disinfection and sanitation applications, holding significant promise for combating microbial contamination in healthcare and water treatment. Despite their considerable potential, challenges such as optimizing nanoparticle characteristics and assessing potential risks to human health and the environment remain. Future research directions should focus on enhancing the efficiency and selectivity of SnO2 and TiO2 NPs through tailored synthesis approaches and understanding their interactions with biological systems. Overall, this review underscores the importance of SnO2 and TiO2 NPs in advancing sustainable technologies for environmental remediation and public health protection.

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INTRODUCTION

One billionth is referred to as a nano, while a nanometer is one billionth of a metre. If at least one of a material's dimensions falls inside the length scale of 1-100 nm, it is referred to as a nanomaterial. Nanomaterials differ greatly from their bulk counterparts in terms of their physical and chemical characteristics. For instance, when a material is in nano form, it can go from being opaque to transparent, insoluble to soluble, and chemically inert to an effective catalyst. In contrast to nanoparticles, whose physical and chemical properties are heavily influenced by their form and size, bulk materials have qualities that are independent of their size and shape. As a result, by adjusting size, shape, and composition, these qualities can be controlled quite effectively(Samuel et al., 2022). The surface to volume ratio greatly rises as size is reduced. Nanomaterials are more reactive because a greater proportion of atoms are located at the surface than in the body of the material. Silver, gold, and other noble metal NPs exhibit localised surface plasmon resonance (SPR) (Ghosh et al., 2020). Similar to this, when a substance shrinks to a nanoscale scale, many of its physical and chemical properties are altered.

The electrical conductivity of NPs typically decreases for a variety of reasons, including quantization in conduction, band gap augmentation, change in size and shape, and enhanced surface scatterings, such as grain boundary scattering(H. J. Li et al., 2005). Nanomaterials also experience changes in their magnetic characteristics(Woods et al., 2001). This review describes the environmentally friendly method for producing titanium nanoparticles (TiO_2-NPs) that use a variety of plant extracts, fungus, and bacteria, as well as its applications.

The motivation behind conducting a comprehensive review on SnO_2 and TiO_2 nanoparticles (NPs) and their application in photocatalytic and microbial activity stems from the pressing need to address environmental pollution and microbial contamination, which pose significant threats to public health and ecosystem sustainability. Harnessing the unique properties of these nanoparticles presents promising solutions for mitigating pollution and combating microbial pathogens, thereby contributing to a cleaner and healthier environment.

MATERIALS AND METHODS

Methods for Preparing Nanoparticles

The much-known techniques to produce metal oxides can be mostly categorized in two approaches, those are top-down and bottom-up approaches (Figure 1). In the top-down method, the bulk macroscopic atoms are splinted into nanoscopic particles during different physical techniques such as etching, milling, pulse laser ablation, evaporation-condensation methods, sputtering, etc. On the other hand, in a bottom-up techniques, the atomic nuclei are tied together by a self-assembly routes and nanosized particles are produced by means of numerous methods and procedures like sol-gel process, chemical vapor deposition, flame spraying, sonochemical, hydrothermal, spinning, green synthesis, etc. (Samuel et al., 2022) .

The bottom-up methods have grown attention due to its benefit of dimension and structural control in the preparation of NPs. On the other hand, the chemical techniques are cost-efficient, group manufacture is limited, needs more energy, more temperature and pressure, employs poisonous and unstable reagents that produce a danger to the surroundings and human wellbeing. Therefore, the scientific society has discovered a novel system of production of NPs that is a eco-friendly method, which is ecologically caring, harmless, uses cheap chemicals, and needs small energy for price-efficient manufacture (Samuel et al., 2022).

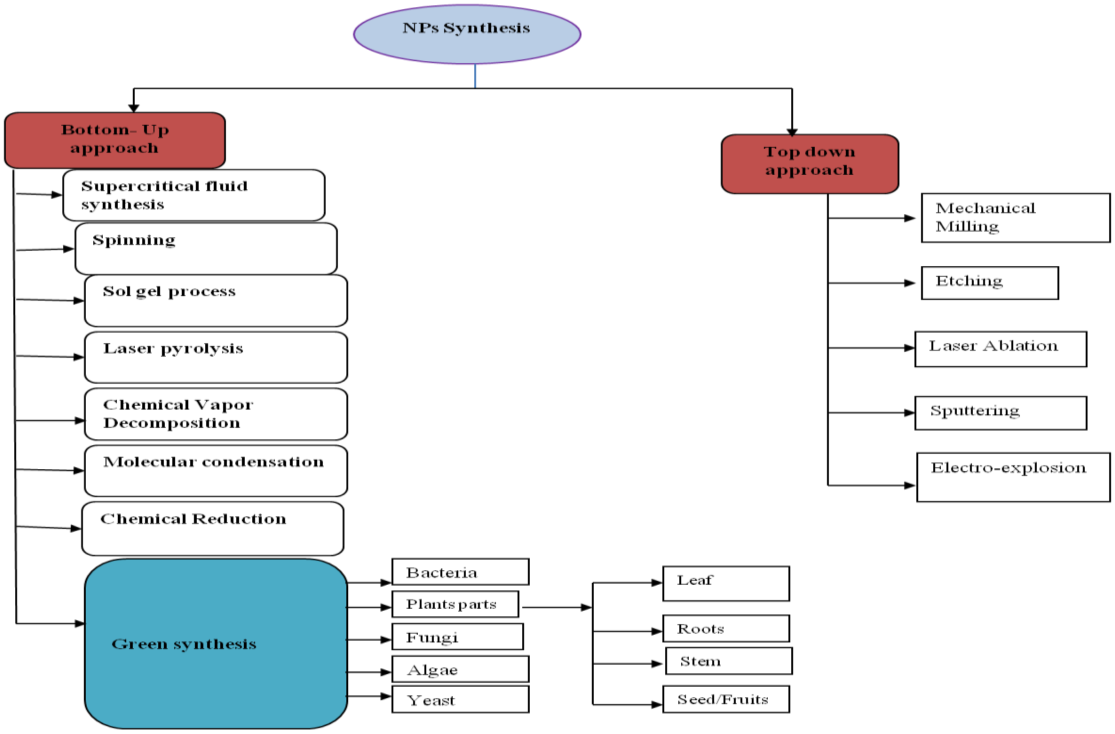

Figure 1. *Nano particle production routines*

Eco-friendly (biodegradable) methods

Biological production of nanoparticles has numerous purposes in ecological and biomedicines fields. Eco-friendly synthesis intends especially at declining the usage of poisonous chemicals. For example, the application (importance) of natural materials such as plants is typically secure. Green (biodegradable) synthesis contains synthesis via parts of plants, bacterial, fungus, algae and like. Plants also enclose reducing and capping agents when used in preparations of nanoparticles. A nanoparticle prepared from biomimetic method shows more catalytic activities and limits the usage of affluent and poisonous compounds. The biological synthesis comprises the biological as well as green preparation technique which is the choice for physical as well as chemical approaches it is ecologically benefits and have naturally covering mediator which constrain the agglomerations of nanoparticle this types of preparation do not necessity an artificial covering agents(Singh et al., 2019). The biological methods of TiO2 Nanoparticles are bottom-up approaches that mostly involve decrease and oxidations reactions(Jagdish & Nehra, 2022). The synthesis reactions take in one step, and so the molecules that have double properties such as dropping as well as covering agents are favored(Aldeen et al., 2022). Eco-friendly foundations are measured as assets for biologically synthesis of Nano particles and they are parts of plants extracts, bacterial, fungus is notable bases(El-Belely et al., 2021).

Some plant ingredients such as leaves, roots, Pods, fruits, seeds are also used for the nanoparticles productions as their extracts are riches in phyto-chemicals that perform as both reducing plus stabilizations agents(Faisal et al., 2021).

Figure 2. *Biodegradable and cheap routes for the green synthesis of nanoparticles using plants extract.*

Review of different preparations, Characterization Techniques and applications used in TiO_2, SnO_2 NPs and TiO_2/SnO_2 nanocomposites

Instrumentation is particularly important to study, analyze, and control the properties of nanomaterials for both fundamental understanding and the rapidly expanding range of possible applications. Nanomaterials' structural and optical characteristics are part of their characterization. While certain characterization tools are used to examine their morphology, sizes, and forms, others are used to examine their structural details and spectroscopic data. The samples' structural investigation was done using XRD, TEM, SEM, and SAED measurements. PL spectroscopy, OA spectroscopy, FTIR spectroscopy, and EDS have all been employed to investigate the optical characteristics(Smith, 2015).

TiO_2 and SnO_2 Nanoparticles produced by chemical and physical techniques

Table 1 lists a widespread study of different methods, chemical used, properties, characterization techniques, various chemicals and physical methods used for the preparations of TiO_2 /SnO_2 nanoparticles.

Table 1

TiO_2 and SnO_2 NPs produced by chemical and physical techniques

S.No	Method	Chemicals used	Size, Morphology	Characterization techniques	Application	References
Material : *TiO_2*						
1	Sol-gel ultrasonication	Titanium tetraisopropoxide	16.97nm, rutile and anatase	XRD, SEM, FTIR, DRS, EDS	Photocatalytic Potential	(Lal et al., 2022)

Table.1 Continues.

2	Scalable Flame pyrolysis	Titanium Isopro poxide(TTIP)	153.01±5.89nm, Tetragonal anatase phase	XRD, UV-Vis, SEM, TEM, FTIR, EDS	Dye Removal Applications	(Inamdar et al., 2023)
3	Hydrothermal method	Sodium hydroxide (NaOH,) hydrochloric acid (HCl), gold (III) chloride hydrate, absolute ethanol, potassium persulfate , α-(4-Pyridyl 1-oxide)-N-tert-butylnitrone, hydrogen peroxide solution	-	SEM-EDX, TEM, UV-Vis	Heterogeneous Photocatalysis	(Slapničar et al., 2023)
4	Sol-gel method	Titanium n-Butoxide, Nitric Acid, Titanium (IV) Oxide, Copper Nitrate	20 nm	XRD, UV-Vis	Photocatalytic Activity	(Adamu et al., 2023)
5	Electro chemical method	Ti foils, Dihydrogen hexachloroplatinate (IV) hydrate, Isopropanol, Dimethyl sulfoxide	12nm regularly combined with TiO_2 nanotubes.	XRD, SEM	Physicochemical Properties And Antibacterial Activity	(Jamil et al., 2022)
Material : *SnO_2*						
1	Hydrothermal methods	$SnCl_2.2H_2O$ (Stannous chloride)	11.71 nm, tetragonal structure.	PXRD, PL,FTIR, FSEM, UV-Vis	Photo catalytic activity and kinetic study	(Jarvin et al., 2022)
2	TCE concentrations and reduction methods.	$SnCl_2$. $2H_2O$	6.9,28.4, 26.5,21.9nm, Spherical	UV–Vis, XRD, FSEM, TEM	Photocatalytic activity	(Fatimah et al., 2022)
3	Solvothermal method	Stannous sulfate	Spherical nanoparticles,particle sizes ranging from 3 to 5 nm.	XRD, UV-Vis, FSEM, XPS, BET	Photocatalytic degradation	(Rajput & Kale, 2022)
4	Sol-gel method	Tin tetrachloride, Tin (II) Sulfate	5.5nm, spherical	XRD, FTIR, SEM, HRTEM	Enhancing the catalytic activity	(Rashidashmagh et al., 2020)
5	Hydrothermal method	Stannic chloride pentahydrate	Pure tetragonal rutile	XRD, SEM, BET	Gas sensing mechanism	(Lian et al., 2019)

Biosynthesized TiO_2 and SnO_2 NPs

The creation of nanoparticles via plant extracts engages complex chemical reactions and needs particular situations. The bioactive compounds present in plant parts may contribute to nanoparticle formation through their reducing, stabilizing, or capping properties. While their specific role in nanoparticle formation is not well-documented, different alkaloids, hydroxyl (-OH) groups, etc have been investigated as potential reducing agents and stabilizers in the synthesis of nanoparticles. The functional groups present in plant parts, such as hydroxyl (-OH) or carbonyl (-C=O) groups, can interact with the metal or metal oxide surface of nanoparticles through coordination or electrostatic interactions. This capping layer helps prevent the agglomeration or aggregation of nanoparticles and provides stability to the nanoparticle system. Table 2 shows a widespread study of different methods, chemical used, properties, characterization techniques, various plant parts used for the preparations of TiO_2 /SnO_2 nanoparticles and their applications.

Table 2

Plant mediated TiO_2 and SnO_2 Nanoparticles (Green synthesis)

S. no	Species	Chemicals used	Parts of Plants	Size, morphology	Characterization study	Application	References
Material: TiO_2							
1	Azadirachta Indica	Titanium isopropoxide	Leaf	10 to 50 nm,spherical	XRD, SEM, TEM, FTIR, UV-Vis	-	(Shekhar et al., 2023)
2	Luffa acutangula	Titanium sulfate	Leaf	10 to 49nm, Rutile structure	XRD, FTIR, SEM, TEM – SAED,	Antimicrobial efficacy	(Anbumani et al., 2022)
3	Myristica fragrans	Titanium trichloride ($TiCl_3$)	Seed	24.58nm, Anatase structure, Spherical shape	FTIR, XRD, FESEM, EDX	Photocatalytic activity and antibacterial efficacy	(Sagadevan et al., 2021)
4	Nervila aragona, Ceaspina pulcherrima, and Manihot esculante	Titanium tetra isopropoxide	Leaves, flower, Peel	15-28nm, spherical	XRD, SEM, TEM, FTIR, EDX, UV-Vis	Photocatalytic degradation and microbial activities	(Rathi & Jeice, 2023)
5	Cola nitida	$TiO(OH)_2$, distilled water,	leaf, pod, seed and seed shell	25.00-191.41nm, spherical-shaped.	XRD, SEM, FTIR, TEM	Degradation activity, Antimicrobial, antioxidant and anticoagulant activities	(Akinola et al., 2020)
Material: SnO_2							
1	Tinospora cordifolia	$SnCl_2.2H_2O$	Stem	6.9-21.9nm, non-uniform spherical	XRD, FESEM, TEM, EDS, UV–Vis, FTIR	Photocatalytic activity	(Fatimah et al., 2022)

Table 2 continues.

2	Actinidia deliciosa (Kiwi)	Tin (IV) chloride pentahydrate ($SnCl_4 \cdot 5H_2O$)	Peel	5 to 10 nm, Spherical shape	XRD, SEM, TEM, FTIR, EDX, UV–Vis	Photocatalytic properties	(Gomathi et al., 2021)
3	Green papaya	$SnCl_4$. $5H_2O$	Leaves	7.10nm, portrayals structure	XRD, TEM, XPS, SEM, FTIR, EDS	Nanoelectronics (LPG sensing) application	(Jadhav & Kokate, 2020)
4	Tradescantia spathacea	Tin tetrachloride pentahydrate	leaves	73.64nm,65.01 nm and 46.36 nm, tetragonal rutile type structure	UV–Vis, FTIR, XRD, SEM, EDS	Photo antioxidant studies	(Najihah et al., 2020)
5	Vitexagnus-castus	Tin chloride ($SnC_{l2}.2H_2O$)	Fruits	8nm, spherically shaped	DRS, FTIR, TEM, XRD,	Catalytic activity and kinetic study	(Ebrahimian et al., 2020)

Recent progress of chemical and bio-mediated preparations of TiO_2/SnO2 nanocomposites (TiO_2/SnO_2 NCPs)

Quick developments and technological novelty in the field of science and technology have caused huge attention among the research area across the world to discover fresh features of nanotechnology. In some literature data, higher photocatalytic activity is associated with TiO_2-SnO_2 nanocomposite structures, sooner than their solid solutions(Dontsova et al., 2020). Table 3 shows some studies done on TiO_2-SnO_2 nanocomposites and their application.

Table 3

TiO_2/SnO_2 NCPs prepared by Chemical and Physical Methods

S.No	Method	Chemicals	Size, morphology	Characterization techniques	Application	References
1	Hydrothermal method	Titanium(IV) isopropoxide, tin(II) chloride, isopropyl alcohol, nitric acid, titanium(IV) oxide (TiO_2)	4.0-20.1nm	XRD, XPS, EPR, PL, and low-temperature adsorption	Photocatalytic Activity	(Dontsova et al., 2020)
2	One-pot simple synthetic method	$NiCl_2 \cdot 6H_2O$, Titanium isopropoxide, Hydrogen peroxide	Spherical with various size distributions	XRD, FTIR, UV–Vis DRS, SEM, EDX, HRTEM, XPS, and XANES	Photocatalytic application	(Renganathan et al., 2022)

Table.3 Continues

3	In situ sol–gel technique	SiO_2,Al_2O_3, MgO,Fe_2O_3, TiO_2, Mn_2O_3, K2O, CaO and MnO, Tetrabutyl titanate ($Ti(OBu)_4$) and hydrous sub-stannic chloride ($SnCl_2·2H_2O$)	10 nm, spherical	BET,SEM,TEM & XRD	Photo degradation	(Zhang et al., 2009)
4	Sol-gel method	TTIP and $SnCl_2·5H_2O$	3-6 nm, uniform while the shape of grains is regular	BET, XRD and TEM	Gas sensing and photocatalysis	(Kusior et al., 2013)
5	Sol-gel method	Titanium (IV) n-butoxide, isopropyl alcohol, Tin(II) ethylhexanate	-	XRD and TEM	Photocatalytic Properties	(Duraisamy & Thangavelu, 2013)

Applications of TiO_2 and SnO_2 Nanoparticles

Because of their exceptional or enhanced physicochemical properties, nanoparticles (NPs) find utility in a wide array of applications across various fields. Furthermore, numerous potential applications are currently under study and development. Below, we outline some examples of these applications.

Applications in medication and pharmaceutical industry

Metallic and semiconductor nanoparticles offer significant potential for cancer diagnosis and therapy due to their enhanced light scattering and absorption properties stemming from the localized surface plasmon resonance (LSPR) effect. Over the past decade, there has been considerable focus on developing environmentally friendly nanoparticles for effective drug delivery purposes (Khan et al., 2019).

Drug Delivery Systems

TiO_2 nanoparticles (NPs) are used as drug carriers due to their biocompatibility, stability, and ability to be functionalized. They can be engineered to deliver drugs to specific targets within the body, enhancing the efficacy and reducing side effects. TiO_2 NPs can be designed to provide controlled and sustained release of drugs, improving therapeutic outcomes and patient compliance(You et al., 2016).

Photodynamic Therapy (PDT)

TiO_2 NPs are used in PDT for cancer treatment. When exposed to UV or near-UV light, TiO_2 generates reactive oxygen species (ROS) that can kill cancer cells. This method allows for targeted therapy with minimal damage to surrounding healthy tissues (You et al., 2016).

Antimicrobial Agents

TiO_2 is used in antimicrobial coatings for medical devices and implants. Its photocatalytic properties under UV light produce ROS, which have potent antibacterial and antiviral effects, reducing the risk of infections. TiO_2 NPs are incorporated into wound dressings to provide antimicrobial protection and promote healing (Imani et al., 2020).

Gas Sensors for Medical Diagnostics

SnO_2-based gas sensors are used in non-invasive medical diagnostic devices to detect volatile organic compounds (VOCs) in human breath. These sensors can help in the early diagnosis of diseases such as diabetes, lung cancer, and infections by identifying specific biomarkers (B. Li et al., 2020).

Biosensors

Detection of Biomolecules: SnO_2 NPs are employed in biosensors for the detection of biomolecules such as glucose, cholesterol, and DNA. Their high surface area and electrical properties enable sensitive and selective detection, which is crucial for medical diagnostics and monitoring. SnO_2-based biosensors are integrated into portable devices for point-of-care testing, providing rapid and accurate results for patient management (Kumar & Singh, 2021).

Antimicrobial Coatings

Medical Devices and Implants: SnO_2 can be used in antimicrobial coatings for medical devices and implants. The incorporation of SnO_2 enhances the antimicrobial properties of coatings, reducing the risk of infections associated with implanted medical devices.

Hospital Surfaces: SnO_2-based coatings are applied to surfaces in hospital environments to reduce the spread of pathogens and improve hygiene (Evstropiev et al., 2019).

CONCLUSIONS

In conclusion, the review on SnO_2 and TiO_2 nanoparticles (NPs) and their applications in photocatalytic and microbial activity underscores their significant potential in various fields. SnO_2/TiO_2-NPs have gained a bundle of attention due to their lot of important applications. It has a numeral of purification and biomedical applications, including antibacterial, antifungal, antiviral, anticancer, antioxidant, and drug delivery. Both SnO_2 and TiO_2 NPs exhibit remarkable photocatalytic properties, effectively harnessing solar energy to drive chemical reactions for environmental remediation and energy production. Additionally, their antimicrobial properties make them promising candidates for disinfection and sanitation applications, particularly in healthcare and water treatment.

However, the review also highlights certain challenges and areas for further research. The performance of SnO_2 and TiO_2 NPs is influenced by factors such as particle size, morphology, surface area, and doping. Optimization of these parameters is crucial to enhancing their efficiency and selectivity in catalytic and antimicrobial applications. Moreover, the potential toxicity of these nanoparticles to human health and the environment necessitates comprehensive risk assessment and mitigation strategies.

In general, the review underscores the importance of continued research and development efforts to fully harness the capabilities of SnO_2 and TiO_2 nanoparticles in addressing global challenges related to pollution, energy sustainability, and public health. By overcoming existing limitations and advancing our understanding of their properties and behaviour, these nanoparticles hold promise for transformative applications in diverse sectors, paving the way for a cleaner, healthier, and more sustainable future.

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DECLARATION

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

Data will be made available on request.

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