A Review On: Synthesis, Characterizations and Applications of Zn_2SnO_4

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***Abstract*- Zinc stannate (Zn_2SnO_4), also known as zinc tin oxide, is a compound composed of zinc (Zn), tin (Sn), and oxygen (O). It has a wide band gap, typically around 3.3-3.7 eV. Zn_2SnO_4 exhibits n-type conductivity, meaning it has an excess of electrons as charge carriers. This property is advantageous for various electronic and sensing applications. This wide bandgap makes it transparent to visible light and enables its potential use in optoelectronic applications. It belongs to the family of ternary metal oxides and has attracted significant attention due to its unique properties and potential applications in various fields. Due to versatile physical, chemical, electrical and mechanical properties of Zn_2SnO_4 it mostly used in variety of applications including gas sensors, optical devices, solar cell, lithium-ion batteries, transparent conducting electrodes, photo catalysis as well as thermoelectric materials. It can be synthesis using different bottom-up and top down approaches such as hydrothermal, participation, sol-gel, PVD, CBD and others. In this review articles, we will provide a brief overview of the synthesis, characterizations, and applications of Zn_2SnO_4.**

***Keywords*: Zinc stannate, synthesis, conductivity, ternary oxide semiconductor, photo catalysts.**

1. INTRODUCTION:

Due to its significant ternary oxide semiconductor circumstance, strong electrical conductivity, and excellent stability, Zn_2SnO_4 is regarded as a promising photocatalyst. Yet due to its poor adsorption and the rapid recombination rate of the photo-generated charge carriers, photocatalytic activity of Zn_2SnO_4 is undesirable. It is generally known that the bandgap, grain size, and shape of photocatalysts have a significant impact on their capacity for photocatalysis [1, 2]. According to review, zinc stannate, an n-type semiconductor, has the ability to create H_2 or break down organic contaminants in aqueous solution when exposed to UV light [2]. The crystal structure of Zn_2SnO_4 crystallizes in a cubic spinel structure, where zinc and tin cations occupy tetrahedral and octahedral sites, respectively, within the oxygen framework. Zn_2SnO_4 possesses a wide bandgap, typically around 3.3-3.7 eV [3]. Electrical conductivity of Zn_2SnO_4 exhibits n-type conductivity, meaning it has an excess of electrons as charge carriers. This property is advantageous for various electronic and sensing applications. Thermal stability of Zn_2SnO_4 shows good thermal stability, making it suitable for applications requiring high-temperature operation. It is very important to note that ongoing research and development efforts continue to explore the synthesis methods, characterizations, and applications of Zn_2SnO_4, aiming to further enhance its properties and expand its potential use in different fields [3, 4]. Due to their distinct unique properties of Zn_2SnO_4, ternary metal oxide semiconductor materials have up till now drawn a lot of research from all around the world. As a traditional ternary oxide, Zn_2SnO_4 has a broad band gap, low visible light absorption, strong electron mobility, and adaptable electrical band structures [5]. This makes it the perfect substance for use in sensors, lithium batteries, photo-catalysts, solar cells, and other practical applications [4-7]. With an emphasis on the synthesis techniques, nanostructures, and the ensuing impacts on the crystal structure, optical characteristics, and photoelectrochemical properties, we highlight the latest research progress of this material in this review. Additionally, their prospective uses in various devices are emphasized and thoroughly discussed.

2. SYNTHESIS OF ZN_2SNO_4:

Zinc stannate can be synthesized through different methods, including solid-state reactions and solution-based techniques. In solid-state synthesis, zinc oxide (ZnO) and tin oxide (SnO_2) powders are mixed in stoichiometric ratios and heated at high temperatures to promote a solid-state reaction between the precursors. Solution-based synthesis methods involve the preparation of precursor solutions containing zinc and tin salts, followed by a controlled precipitation or hydrothermal process to obtain Zn_2SnO_4 nanoparticles or thin films. Zn_2SnO_4 can be synthesized through various methods, including solid-state reaction, sol-gel process, hydrothermal, vapour deposition method and chemical vapor deposition. The choice of synthesis method depends on factors such as desired morphology, purity, structural parameters and scalability. The on the basis of literature review, the synthesis methods of Zn_2SnO_4 are discussed in brief in this section.

Zeng et al [7] synthesized the Zn_2SnO_4 nanocrystals with the mineralizer of NaOH and explored emphatically the influence of the mineralizer concentrations, reaction temperatures, reaction times on the products. The result indicated that Zn_2SnO_4 was more stable than ZnSn(OH)4 based on the principle of thermodynamics. It was easily that the Zn_2SnO_4 turned into ZnO with a rise of temperature. It is noticed that the phase transformation possible formed by a "dissolution-recrystallization" mechanism and associated with the "Ostwald ripening" process.

Zhihui et al [2] reported the degradation of common indoor air pollutants was accomplished by using nanocrystalline Zn_2SnO_4 microcubes that were produced by a hydrothermal method, according to the authors. The nanocrystalline Zn_2SnO_4 microcubes showed enhanced photocatalytic activity for the degradation of NO and HCHO at typical concentrations for indoor air quality when

compared to hydrothermally synthesized ZnO, SnO2 counterparts, Degussa TiO_2 P25, as well as C doped TiO_2. Additionally, the nanocrystalline Zn_2SnO_4 as it was produced showed excellent photochemical stability in the NO breakdown process when exposed to UV-vis light. The produced nanocrystalline Zn_2SnO_4 microcubes may be used as photocatalysts for the purification of indoor air, according to this study, which also offers a promising method for scaling up industrial production of Zn_2SnO_4 catalysts.

Chen, Z., et al [8] three-dimensional and flower-like superstructures made of highly ordered Zn_2SnO_4 were produced using a simple, one-step hydrothermal approach at 180 °C. X-ray diffraction, transmission electron microscopy, field-emission scanning electron microscopy, and selected-area electron diffraction were used to describe the products. It was discovered that the concentrations of EDA and CTAB employed had a significant impact on the morphology of the final products. The production of self-assembled superstructures that resemble flowers made of Zn_2SnO_4 is suggested to have a potential mechanism. The new Zn_2SnO_4 three-dimensional superstructures also displayed remarkable gas-sensing properties, greater than those of the rival binary metal oxide - Fe_2O_3 and In_2O_3 sensors. This material is intriguing for use in a variety of related electrochemical applications in addition to sensor devices because of its strong gas-sensing capabilities.

Alpuche et al [9] This study examines the band gap (Eg) and the energetics of the conduction band (CB) and valence band (VB) for films of Zn_2SnO_4 nanoparticles with the inverse-spinel structure that were made using the hydrothermal process. The films were examined using scanning electron microscopy (SEM), photoelectrochemistry, electrochemistry, and UV-vis spectroscopy. With a direct-forbidden transition, the fundamental Eg for Zn_2SnO_4 is predicted to be between 3.6 and 3.7 eV. The flat band potential, Efb, as determined by the photocurrent onset potential, was used to estimate the position of the CB. Author reported the electrochemical scale revealed that the Efb of n- Zn_2SnO_4 is more positive than TiO2 anatase in both aqueous and nonaqueous solutions. With an extrapolated Efb at pH 0 of 0.08 V versus NHE, it was discovered that the Efb of Zn_2SnO_4in aqueous solutions follows a 59 mV/pH slope. The Efb of Zn_2SnO_4 was discovered to be more positive than TiO_2 vs. I/I3 pair and substantially reliant on the electrolyte composition in acetonitrile solutions that replicate the electrolyte for dye-sensitized solar cells (DSCs). Due to TiO_2's greater rates of electron-triiodide recombination and the fact that Zn_2SnO_4 CB is located lower on the vacuum scale, the reversal trend for the open-circuit voltage observed in some DSC electrolytes can be explained. This demonstrates that Zn_2SnO_4 is a promising material for photoanode supports in dye-sensitized solar cells because it significantly reduces photobleaching and exhibits a decreased rate of electron-triiodide recombination.

Zhao, Q et al [10] a conventional hydrothermal procedure was used for effectively producing hollow cubic Zn_2SnO_4 sub-microstructures. In this synthesis process $ZnCl_2$, $C_6H_8O_7{\cdot}H_2O$, and solid NaOH are used. The mixed solution of $ZnCl_2$ (1.0 mmol) and citric acid monohydrate (1.0 mmol, $C_6H_8O_7{\cdot}H_2O$) in water (10 mL) was added to a solution of $SnCl_4{\cdot}5H_2O$ in anhydrous ethanol (1.0 mmol, 5 mL), then solid NaOH (10.2 mmol) was directly added into the mixed solution under vigorous magnetic stirring. The 0.5–1 m-sized surfaces of the Zn_2SnO_4 nanostructure are quite rough. High photocatalytic activity toward diverse reactive dyes (including MB, MO, and RhB) is displayed by the unique nanostructure. In contrast to $ZnSn(OH)_6$, which only degrades to around 20% of MB, MB dyes can degrade to roughly 95% under UV light irradiation in 20 minutes. A strong photocatalytic performance Zn_2SnO_4 material is thus reported by authors to be a promising candidate for the destruction of MB dyes.

Yang, H et al [11] reported synthesis method for n-type semiconductor gas sensors based on ZnO and SnO_2. The hydrothermal approach is used for producing uniform Zn_2SnO_4 solid and hollow microcubes, which are then heated in the air during the annealing phase. SEM, TEM, and XRD were used to characterize the morphology and structure. Additionally, a potential process for how the hollow microcubes formed is presented. In comparison to solid nanocubes, hollow Zn_2SnO_4 microcubes were discovered to have higher and quicker response-recovery features. The response of a hollow microcube sensor to 200 ppm acetone at the ideal operating temperature (260 °C) is 141.7, which is three times greater than the response of a solid nanocube sensor (41.9). The considerable reduction in response-recovery time is ascribed to both the multiple interlacing petal-like structures of the nanoflowers as well as the surface accessibility made possible by the hollow designs.

Chen, C et al [12] Using an easy one-step hydrothermal procedure, Zn_2SnO_4 three-dimensional (3D) flower-like hierarchical nanostructures have been effectively produced. Results from field emission scanning electron microscopy (SEM) and transmission electron microscopy (TEM) show that nanorods are used to assemble the Zn_2SnO_4 flower-like structures. The as-synthesised hierarchical Zn_2SnO_4 is used to make a gas sensor to show the potential uses. The hierarchical Zn_2SnO_4 sensor demonstrates noticeably greater sensing properties than the compact Zn2SnO4 structures, according to the findings of gas sensing tests. Unique 3D hierarchical nanostructures, a larger contact surface area between Zn_2SnO_4 and the target gases, and a higher density of surface active sites on the surface of the as-prepared gas-sensing material are all ascribed with the improved sensing ability.

Young, D et al [13] prepared single-phase, spinel zinc stannate thin films onto glass substrates. The thin films of zinc stannate were grown by RF magnetron sputtering technique. The resistivity of films was found to be in the range of 10^{-2}–10^{-3} Ωcm and mobilities of prepared films was found to be in the range of 16 –26 cm^2/Vs. It is also noticed that, a high density of intragrain defects appears to limit the electron relaxation times, and hence, the electron mobility to unacceptably low values.

Ayesha, B. et al [14] Synthesised of zinc stannate oxide (ZTO) nanoparticles by sol-gel method at room temperature. The synthesized zinc stannate nanoparticles used for photocatalysis of commercial dyes. Field emission scanning electron microscopy (FE-SEM), powdered X-ray diffraction, UV-visible spectroscopy, and Fourier transform infrared spectroscopy were all used to analyze the ZTO nanoparticles as they had been developed. ZTO thin films were created on glass substrates in order to assess the photocatalytic activity of zinc stannate as it had been produced. ZTO nanoparticle thin films were used to determine the photocatalytic degradation of methyl orange and methylene blue when UV light was irradiated for one hour. When ZTO nanocrystals were used to photocatalyze the degradation of MO and MB in unfiltered natural sunshine with an irradiation of 300 W/m2, the ZTO demonstrated its potential as a photocatalyst. In the presence of ZTO nanoparticles, the MO dye deteriorated by about 73% and the MB dye by about 62% in 60 minutes, respectively.

Rovisco, A et al [15] Synthesized of Zn_2SnO_4 Nanostructures by Microwave-Assisted method. The synthesized Zn_2SnO_4 NPs used for Photodegradation of Rhodamine B under UV and Sunlight. Authors reported that the lengthy hydrothermal synthesis timeframes

associated with the conventional approach can be cut down from several hours to less than 60 minutes because to microwave-assisted synthesis's more uniform heating rate. These three unique Zn2SnO4 nanostructures—polyhedrons, nanoplates, and nanoparticles—were successfully synthesized hydrothermally with the use of microwaves at 200 °C without the use of any post-annealing processes in the work. The time needed to create polyhedrons, nanoplates, and nanoparticles was reduced from around 24 hours to 60 minutes utilizing this synthesis technique. These time reductions were made possible by employing a standard oven as the heating source. The three various Zn_2SnO_4 nanostructures (polyhedrons, nanoplates, and nanoparticles) were put to the test as photocatalysts for the destruction of rhodamine B under UV and ordinary sunlight irradiation. The nanoparticles with a 10 minute synthesis time had the best performance out of all the various morphologies tested. In under 60 minutes under UV radiation and 90 minutes in natural sunshine, these nanoparticles enabled RhB degradation of >90% and >93%, respectively. The Zn_2SnO_4 nanoparticles' photocatalytic mechanism has been studied in both UV and natural sunlight, and the results indicate that while superoxide radicals have a greater impact in natural sunlight than UV light does on RhB photodegradation. Consequently, the Zn_2SnO_4 nanostructures generated by microwave-assisted hydrothermal synthesis at 200 °C and without any post-annealing treatment demonstrated an extraordinary performance in the photodegradation of an organic dye, emphasizing the versatility and significant use of this material.

An, D et al [16] in this investigation, uniform Zn_2SnO_4 nanoparticles are made using an easy co-precipitation technique and hydrothermal post-treatment. The same technique was used to obtain pure samples of ZnO and SnO2 for comparison. XRD, FESEM, and N2 absorption-desorption analyses were used to analyze these compounds. The hexagonal wurtzite structure of ZnO could be extrapolated from the XRD patterns of the ZnO NP's diffraction peaks, which were in good accordance with the ZnO standard JCPDS Card (No. 36-1451). The as-prepared Zn_2SnO_4 nanostructure sensor's ethanol-sensing capabilities were thoroughly examined and compared to those of pure ZnO and SnO2 sensors. As a result of the tests, it was discovered that the Zn_2SnO_4-based sensor had a low operating temperature, a high responsiveness, resilient stability, and long-term stability toward ethanol gas. It was simple to synthesize homogenous Zn_2SnO_4 nanoparticles (approximately 20 nm), which had a greater surface area and narrower pore size distribution than pure ZnO and SnO_2 powders generated using the same technique. Zn_2SnO_4 demonstrated lower operating temperature (180 °C) than ZnO, SnO2, and Zn_2SnO_4 reported elsewhere under conditions of 50 ppm ethanol gas among ethanol gas-sensing studies of as-synthesised compounds.

3. CHARACTERIZATIONS OF ZN_2SNO_4:

Several characterization techniques can be employed to study the structure, morphology, and properties of Zn_2SnO_4 [17-22]. These techniques include:

3.1 X-ray diffraction (XRD): XRD analysis can determine the crystal structure and phase purity of Zn_2SnO_4. The diffraction pattern helps identify the crystalline phases and calculate the lattice parameters.

3.2 Scanning electron microscopy (SEM): SEM allows for the examination of the surface morphology, size, and shape of Zn_2SnO_4 nanoparticles. It provides high-resolution images of the synthesized material.

3.3 Transmission electron microscopy (TEM): TEM provides detailed information about the internal structure, grain boundaries, and defects within Zn_2SnO_4. It can reveal the nanoscale features and crystallographic orientation of the material.

3.4 Energy-dispersive X-ray spectroscopy (EDS): EDS analysis is used to determine the elemental composition of Zn_2SnO_4. It can confirm the presence of zinc, tin, and oxygen and quantify the stoichiometry of the compound.

3.5 Fourier-transform infrared spectroscopy (FTIR): FTIR spectroscopy is employed to identify the chemical bonding and functional groups present in Zn_2SnO_4. It provides information about the vibrations and modes of the molecules.

4. APPLICATIONS OF ZN_2SNO_4:

Zinc stannate oxide has shown promise in various applications due to its unique properties [21-25]. Some of the notable applications include:

4.1 Gas sensors: Zn_2SnO_4 is used as a sensing material in gas sensors due to its high sensitivity and selectivity towards a wide range of oxidising and reducing gases, including carbon monoxide (CO), ammonia (NH_3), hydrogen (H_2), and nitrogen dioxide (NO_2).

4.2 Photocatalysis: Zn_2SnO_4 exhibits excellent photocatalytic activity, enabling it to degrade organic pollutants and purify water under UV light irradiation. It has potential applications in wastewater treatment and environmental remediation.

4.3 Lithium-ion batteries: Zn_2SnO_4 has been investigated as an anode material in lithium-ion batteries due to its high theoretical capacity and good cycling stability. It shows promise for improving the energy storage capacity and performance of batteries.

4.4 Transparent conducting electrodes: Zn_2SnO_4 thin films can be used as transparent conducting electrodes in optoelectronic devices, such as solar cells and touchscreens, due to their combination of electrical conductivity and optical transparency.

4.5 Thermoelectric materials: Zn_2SnO_4 has been explored as a potential thermoelectric material for converting waste heat into electricity. Its unique electronic and thermal properties make it promising for thermoelectric energy harvesting applications.

4.6 Biomedical applications: Zn_2SnO_4 is now a days used in biomedical applications such as drug delivery, detection of cancer cell, in chemosensors etc.

It is worth noting that ongoing research and development efforts continue to explore and expand the range of applications for Zn_2SnO_4. Figure 1 shows applications of Zn_2SnO_4.

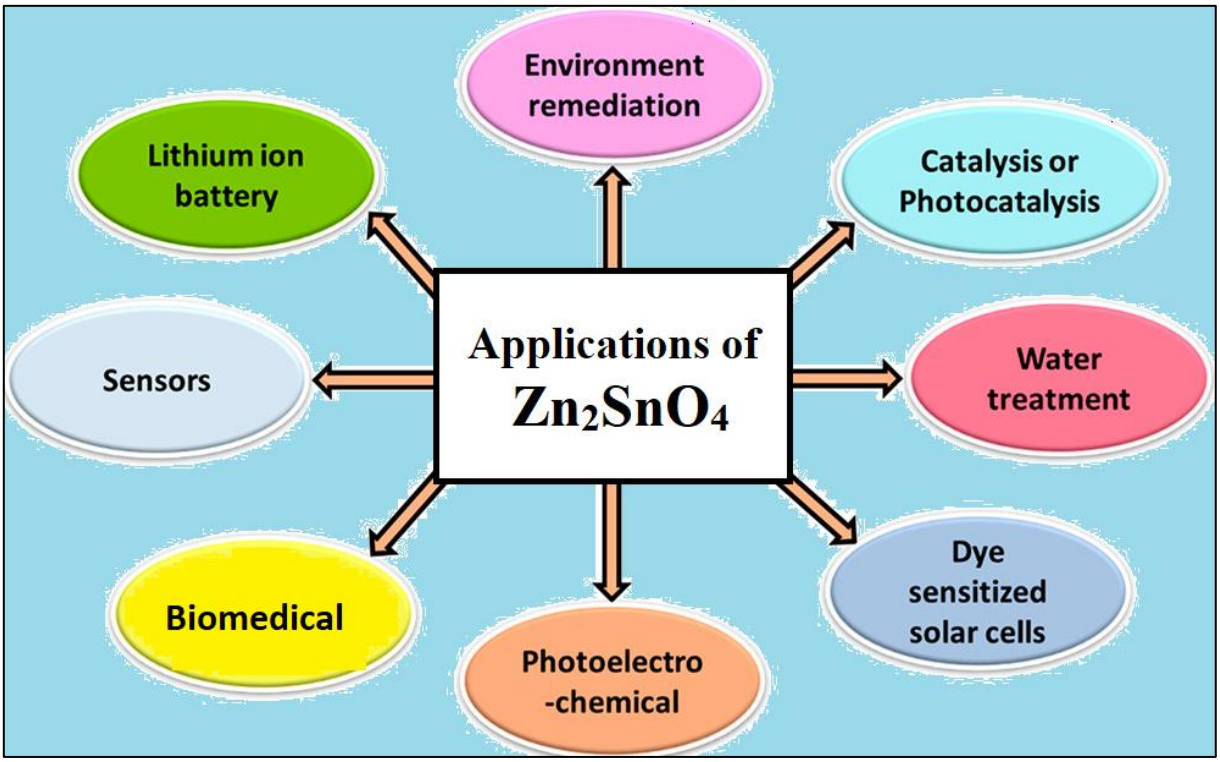

Figure 1: Applications of Zn_2SnO_4.

CONCLUSION

It's important to point that the specific applications and performance of Zn_2SnO_4 can vary depending on factors such as synthesis method, morphology, and doping. Ongoing research and development efforts aim to further optimize its properties and explore new application areas. Among the multicomponent oxide materials, zinc-tin oxide (ZTO) is a low-cost and environmentally friendly material with a wide range of attractive properties. This metal oxide can crystallize in two different phases: Zn_2SnO_4 and $ZnSnO_3$. Zn_2SnO_4 has good stability in adverse conditions, a wide band gap (3.4–4.0 eV), and high mobility already achieved for specific nanostructures (112 $cm^2 V^{-1} s^{-1}$). Additionally, Zn_2SnO_4 is ZTO's most stable phase and presents a cubic inverse spinel structure. In the various fields the noticeable scope for Zn_2SnO_4 material in future in the nanoscience as well as nanotechnology.

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