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# A STUDY ON STANNATE NANO STRUCTURES AND THEIR CHARACTERIZATION & SYNTHESIS

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## Abstract

*The unusual properties and wide range of possible applications of stannate nanostructures—nanostructures composed of tin (Sn) and oxygen (O)—have garnered considerable interest in these materials. Using a wide range of experimental techniques, this study investigates both the synthesis and characterization of stannate nanostructures. To manipulate the nanostructures' size, shape, and crystalline structure, researchers are looking into several synthesis methods. The solvothermal, hydrothermal, and template-assisted approaches fall under this category. The optical, electrical, and structural characteristics of the materials are studied using state-of-the-art characterization methods such as spectroscopic analysis, electron microscopy, and X-ray diffraction. In areas including gas sensing, photocatalysis, energy storage, and biomedical devices, the results give helpful suggestions for improving the functionality of stannate nanostructures. These results provide light on the connections between stannate nanostructure production, structure, and characteristics. This comprehensive study lays the groundwork for new synthesis methods and specific applications in many fields, and it significantly advances our basic knowledge of stannate nanostructures.*

**keywords:** *Nano, Structures,, Characterization*

## Introduction

There has been a lot of buzz around nanomaterials recently due to their unique properties and the many possible uses they may have in fields as diverse as electronics and medicine. The creation and analysis of nanomaterials have been the primary foci of this study. Due to their exceptional properties and diverse array of applications, stannate nanostructures have recently gained attention as a possible subset of these nanomaterials. The desirable electrical, optical, and catalytic characteristics of stannate compounds make them sought-after for many different uses. Oxygen and tin are the main components of stannate compounds. The regulated synthesis of stannate nanostructures opens the door to the prospect of property customization for particular applications. Gas sensing, photocatalysis, energy storage, and medical devices are only a few examples of these uses. Despite the increasing fascination with stannate nanostructures, further in-depth studies are required to clarify their properties, morphologies, crystal structures, and methods of production. Having a firm grasp of the fundamental principles that govern the formation and behavior of stannate nanostructures is crucial for optimizing their performance and achieving their full potential in various applications. To address this knowledge gap, this work investigates the production and characterization of stannate nanostructures in great detail. A range of synthetic techniques, including solvothermal, hydrothermal, and template-assisted approaches, will be employed to study the impact of reaction parameters on the size, shape, and crystalline structure of stannate nanostructures. To further examine the materials' electrical, optical, and structural characteristics, we will employ advanced characterization techniques such as spectroscopic analysis, electron microscopy, and X-ray diffraction. Researchers hope that these findings will shed light on important questions about the theory and practice of stannate nanostructures and add significantly to our understanding of these materials. Furthermore, the findings from this study might inspire new ways of synthesising materials and the development of stannate-based nanomaterials with enhanced functionalities and performance descriptions. How stannate nanostructures were synthesized and characterized is going to be discussed in detail in the parts that follow. The results and their consequences will then be thoroughly examined.

## Zinc stannate crystal structure

It is common for zinc stannate to crystallize as ZnSnO3 when subjected to temperatures ranging from 300 to 500 degrees Celsius. This is a metastable transition. During the reaction that takes place in the solid state, this process is launched. Under these circumstances,

however, the formation of the stable zinc orthostannate, Zn2SnO4, occurs when the temperature is higher than 600 degrees Celsius. One of the difficulties associated with the utilization of high-temperature synthesis processes, such as thermal evaporation, for the purpose of producing pure Zn2SnO4 phase is that the end result is often a mixed phase consisting of ZnSnO3, Zn2SnO4, and SnO2. In contrast to orthostable Zn2SnO4, which has a cubic spinel structure, metastable ZnSnO3 possesses a perovskite structure that is face-centered for its structure. In Figure 1, the crystalline structures of zinc stannate are depicted for your understanding.

**Typical synthesis methods**

The methods that have been published for the synthesis of ZTO nanostructures may be categorized into the four types that are given below. This is a wide definition of the term.

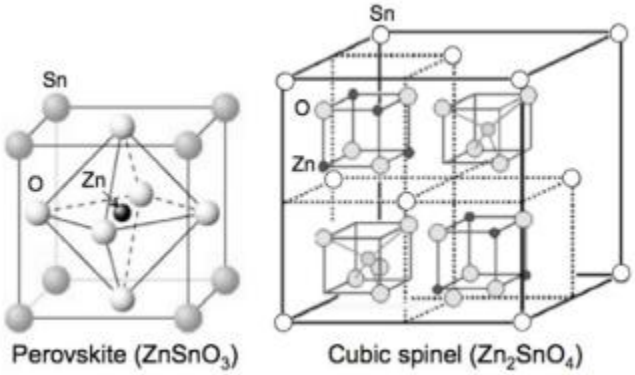


**Figure 1 provides a visual representation of the crystal structures of zinc stannate, which include the perovskite structure of zinc metastannate (ZnSnO3) and the cubic spinel structure of zinc orthostannate (Zn2SnO4). It is generally agreed that both of these formations are examples of crystal structures. Within the structural diagrams, each component is represented by a single atom, and a label is assigned to each individual atom used to represent the component.**

**Types:**

1. To begin, thermal evaporation.
2. High-temperature calcination.
3. The third method is mechanical grinding.
4. Sol-gel synthesis.
5. Hydrothermal reaction, number five.
6. Ion-exchange reaction, number six.

Zn and Sn powders are subjected to thermal evaporation at temperatures that are more than 800 degrees Celsius in order to generate a broad range of nanostructures. These nanostructures include nanoparticles, nanorods, nanobelts, and many others. It is possible to carry out this procedure either with or without the introduction of catalysts. The synthesis of Zn2SnO4 nanostructures has been demonstrated to be possible by the exploitation of catalyst-assisted thermal evaporation, as demonstrated by a significant number of research that have supplied evidence to support this claim. Gold serves as the catalyst that is employed in this process the majority of the time. When metal oxides such as zinc oxide (ZnO), stannic oxide (SnO2), and stannous oxide (SnO) are used as the source materials for the synthesis of ZTO nanostructures, it is vital to have a high growth temperature. This condition is necessary in order to get the desired results. It is imperative that this work be carried out. A further key characteristic is that the final product will contain significant amounts of zinc oxide (ZnO), which will be present in high quantities. Using a solid—melt ion exchange process, which was carried out at a temperature of 350 degrees Celsius, it was possible to effectively perform the synthesis of crystalline ZnSnO3. This was done. For the purpose of carrying out the reaction, lithium stannate, also known as Li2SnO3, was employed. In contrast, the Li2SnO3 that was necessary for the ion exchange process was produced by a solid-state reaction between lithium carbonate (Li2CO3) and tin oxide (SnO2) that took place at a high temperature ranging from 650 to 1000 degrees Celsius. This reaction was carried out in order to generate the Li2SnO3 that was required for the process. As mentioned, zinc chloride (ZnCl2) and stannic chloride (SnCl4) are the initial reactants that are employed in the production of zinc trichloride (ZTO) nanopowder. This is a statement that has been made. An approach known as the sol–gel technique was applied in order to get this outcome. As a result of the incorporation of ammonium hydroxide (NH4OH), the sol was transformed into a gel. After that, the gel was subjected to calcination at a temperature of 600 degrees Celsius in order to produce the nanopowders that were needed. The research that was carried out by Kurz and colleagues involved the deposition of transparent conducting coatings of doped Zn2SnO4 on substrates that were composed of borosilicate and aluminosilicate glass structures. For the purpose of producing these coating solutions, the necessary amounts of metal chlorides or alkoxides were dissolved in ethanol at a zinc-to-tin molar ratio that ranged from 0.3 to 0.9. For the purpose of manufacturing the coating solutions, this was carried out. After that, a sol–gel approach was utilized in order to perform the process of coating deposition. As part of the research, an inquiry into the creation of polycrystalline zinc stannate spinels by a solid-state reaction was carried out over the course of the investigation.

On top of this, an investigation was conducted to determine the impact that mechanical stimulation had on the formation of these spinels. On the basis of their findings, they came to the conclusion that the rate of zinc stannate creation might be increased by grinding for a longer period of time, which is another way of stating by increasing the amount of time that is spent grinding.

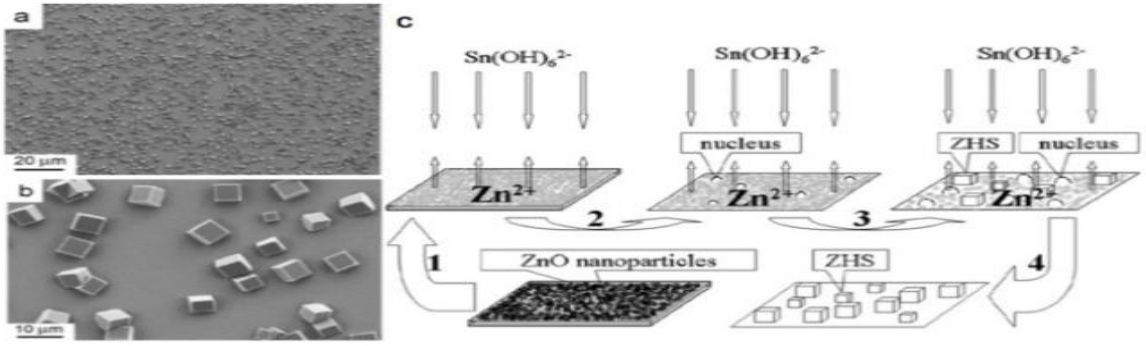


**Figure 2. (a) Low magnification SEM image of zinc hydroxystannate (ZHS) microcubes, (b) High magnification image, and (c) Growth process schematics. (The original source, [25], is Elsevier B.V., acknowledged with permission.)**

regardless of when the activation really takes place in the present time. After being activated for a period of 160 minutes, the samples were sintered at a temperature of 1200 degrees Celsius for a duration of two hours. This process was repeated until the samples were completely formed. Because of this, a single-phase polycrystalline zinc stannate was produced as a result. It is difficult to create highly crystalline and phase-pure ZTO nanostructures using high-temperature solid-state processes due to the evaporation of ZnO. However, the hydrothermal approach has been demonstrated to be an efficient and uncomplicated way for accomplishing this production goal. Furthermore, it has been demonstrated that this strategy is one that is not only easy but also results in positive outcomes. An in-depth discussion on the hydrothermal synthesis of a wide range of ZTO nanostructures will be offered in the subsequent part, which will come after the one that is now being discussed.

**Hydrothermal growth of ZTO nanostructures**

When zinc stannates are subjected to the process of hydrothermal development, which occurs at temperatures ranging from around 120 to 150 degrees Celsius, a hydrated form of zinc stannates is formed. ZHS, which is an abbreviation that is occasionally used to refer to this particular kind, is the term that is given to this particular type. A thin covering of zinc oxide

nanoparticles that had been pre-synthesized was used to describe the process of creating microcubes composed of zinc hydroxystannate. When it came to the hydrothermal growth process, these nanoparticles were the source of zinc that was produced. In order to carry out the reaction, which was carried out at a temperature of 120 degrees Celsius, an autoclave that was lined with Teflon was utilized. In order to thoroughly immerse the substrate, which had been coated with ZnO nanoparticles in the past, a solution of tin chloride was utilized. The reaction was permitted to proceed for a period of twenty-four hours, and the microcubes that were created were little, measuring somewhere between five and eight micrometers in size. The pictures of the ZHS microcubes that were obtained via the utilization of scanning electron microscopy (SEM) are displayed in figures 2(a) and (b) at two magnifications that are quite distinct from one another by a significant margin. A schematic representation of the growth process is shown in Figure 2(c), which displays an illustration of the procedure. An instance of the process of growth is presented here. In the vast majority of the research that has been conducted on the subject of the hydrothermal formation of zinc stannate nanostructures, an aqueous combination of stannic chloride and a zinc salt (such as zinc nitrate, zinc chloride, zinc sulfate, and so on) has been utilized. This combination has been used to create the nanostructures. After that, the mixture is reduced by employing sodium hydroxide or ammonium hydroxide at temperatures ranging from 200 to 250 degrees Celsius while being subjected to high pressure in an enclosed atmosphere. This process is continuing until the mixture is completely reduced. This process is continued until the combination has been reduced to its lowest possible level. Nanometer-sized ZnSnO3 particles were manufactured synthetically by the utilization of hydrothermal synthesis in a manufacturing method that consisted of a single step.

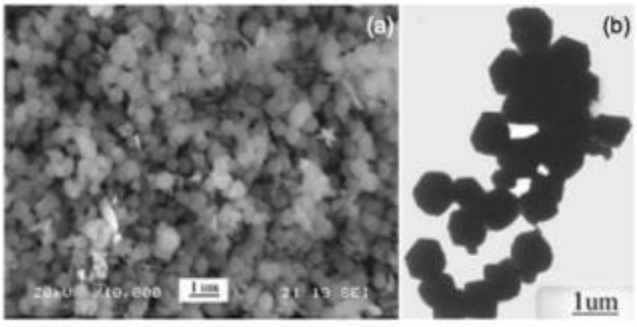


**Figure 3. The ZnSnO3 nanoparticles' hexagonal shape is clearly visible in the scanning electron image (a) and the transmission electron image (b) provided by Xu et al. In 2006, Elsevier B.V. authorized the copyrighted use of this material.**

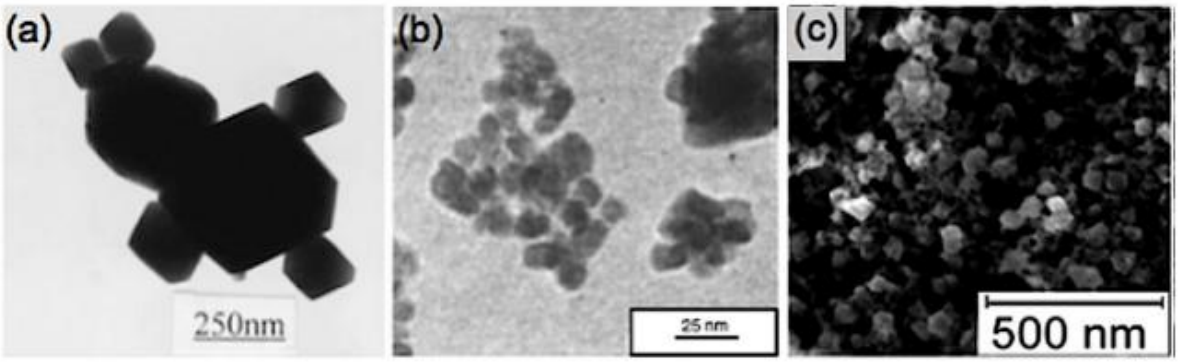


**Figure 4. The coordinating agent used in the transmission electron microscopy (TEM) images of Zn2SnO4 nanoparticles was tert-butylamine, and the images were taken at (a) 220 ◦C, (b) 200 ◦C, and (c) 170 ◦C. (This content is used with permission from [47] © 2001 Elsevier B.V.). According to reference 44, the American Chemical Society gave their stamp of approval to this replication in 2009.**

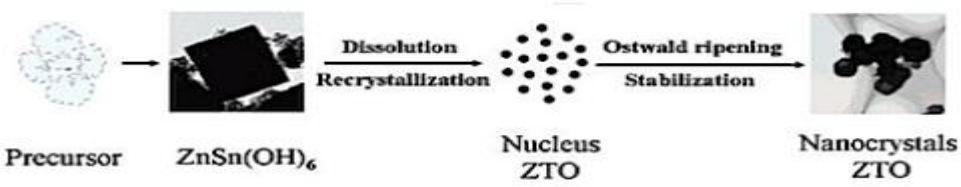


**Figure 5. The schematic for the process of crystallization, dissolution, and recrystallization used to make ZTO nanocrystals. The replication of this work was made possible by the American Chemical Society, who granted copyright in 2008.**

**The synthesis of ZTO nanostructures by hydrothermal means: an account**

Hydrothermal synthesis is a method that may be used to produce metastable zinc stannate (ZnSnO3), which can have either an ilmenite or perovskite structural structure. ZnSnO3 and Zn2SnO4 have been shown to have evolved into highly crystalline structures by the process of hydrothermal development, as shown in Figures 6(d)-(f), 6(a, d), and 10(a, b). This may be verified using SAED patterns. An example of an x-ray diffraction (XRD) pattern of zinc sulfide (ZnSnO3) that was created by hydrothermal means is presented in Figure 11(a). It appears that face-centered perovskite ZnSnO3 is the most likely source of the majority of the diffraction peaks, according to the data that was obtained from the JCPDS data file 11-0274. In the JCPDS file number 36-1451, the remaining peaks were denoted as stars; these stars can be utilized as an index to zincite. As a result of the fact that the ZnO peaks are not as noticeable as the ZnSnO3 peaks, it was concluded that the amount of ZnO present in the

sample in its current state is not substantial. On the other hand, the trisymmetric inverse cubic spinel structure of the orthostable zinc stannate (Zn2SnO4) form allows it to be distinguished from other forms. As shown in Figure 11(b), the XRD pattern of Zn2SnO4 nanoparticles that were produced using Na2CO3 as the mineralizer is displayed. The peak that is most noticeable is the one that is located on the (311) plane. Using the various XRD peaks and the least-squares approach, it was found that the Zn2SnO4 nanoparticles that were produced by hydrothermal processes had a lattice parameter of 8.62 Å. This value is consistent with the values that have been revealed in previous publications. The diffraction peaks of the XRD pattern of the Zn2SnO4 octahedron, as seen in figure 7(c), are in accordance with the data obtained from the JCPDS (74-2184) for the pure spinel Zn2SnO4, which has a lattice parameter of 8.65 Å. This inversion of the spinel structure is illustrated by the peaks, which show that all of the Sn4+ atoms have octahedral coordination, while half of the Zn2+ atoms have tetrahedral coordination. Because there are no peaks that may be the result of contaminants, it would appear that there are pure ZTO phases present.

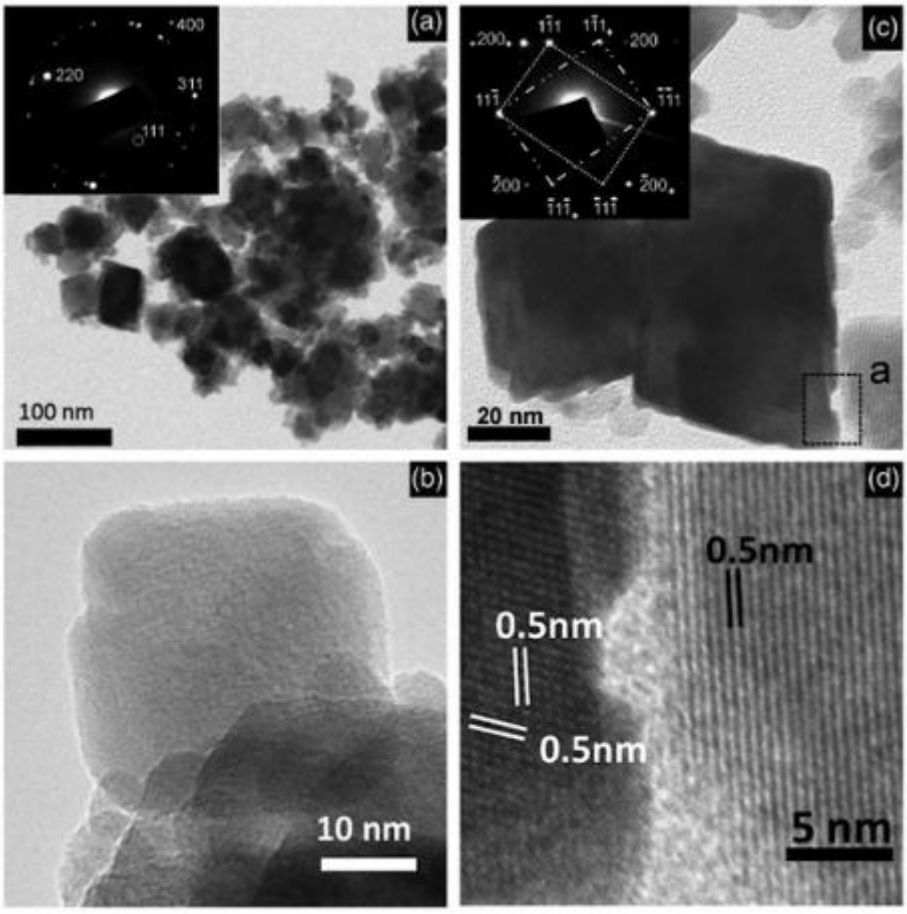


**Figure 6. Under these conditions—a molar ratio of 2:1:4, 24 hours at 200 ◦C—were the nanoparticles of Zn2SnO4 most successfully produced. TEM pictures reveal the**

**nanoparticles. You may see SAED patterns in the insets. The dot in panel (d) is an expansion of panel (c). In 2010, Elsevier B.V. gave their approval for this copy.**

Similar to image 8, figure 7(d) illustrates the XRD pattern of ZTO nanorods. This pattern is parallel to picture 8. All of the peaks have the potential to be indexed to cubic ZTO, which is found in JCPDS No. 74-2184 and has a lattice parameter of 8.65 Å. On the regular JCPDS card, the relative intensity of the (111) peak was roughly 36.4% greater than the relative intensity of the peak, which was approximately 56 percent higher. The (222) peak was the most intense of the bunch; however, the other peaks were relatively close to the intensities that are typically found on cards such as these. According to the findings of this study, the researchers came to the conclusion that the direction of development was the most typical for Zn2SnO4 nanorods. As demonstrated by Alpuche-Aviles and Wu [44], the X-ray diffraction (XRD) pattern of Zn2SnO4 films was altered as a result of heat treatment applied at a temperature of 500 degrees Celsius for a period of thirty minutes. Within the high-index planes, it was seen that there was a movement towards lower 2θ values, which may be interpreted as a bigger d spacing being observed. The low-index planes did not exhibit any signs of evolution, despite the fact that the degree of inversion remained same. In accordance with this correction, the lattice constant undergoes a shift of around thirty percent. The X-ray diffraction (XRD) study revealed that the Zn2SnO4 particles, in their as-prepared state, had an average particle size of 25 nanometers, with a standard deviation of 3 nanometers. This conclusion was reached as a result of thorough examination of the aircraft (111), (220), (311), (400), (511), and (440). Additionally, the researchers came to the conclusion that their findings did not exhibit any indications of stress-induced artifacts on their part.

**Applications of hydrothermally grown ZTO nanostructures**

Zinc stannate, which is a wide-gap semiconductor with a bulk bandgap of approximately 3.6 eV, has a number of potential applications, including gas sensors, photocatalysis, and solar cell electrodes. The removal of harmful pollutants from the environment into their component parts can be accomplished through photocatalysis, which is one of the most appealing methods. Through the utilization of wide-gap semiconductors, such as ZTO, it is possible to provide a description of the overall mechanism of photocatalysis by employing the consequent equations:

$$ZTO \rightarrow e^- + h^+,$$

$$e^- + h^+ \rightarrow \text{energy},$$

$$h^+ + H_2O \rightarrow H^+ + OH^-,$$

$$h^+ + OH^- \rightarrow OH^-,$$

$$e^- + O_2 \rightarrow O_2^{-},$$

$$O_2^{-} + H^+ \rightarrow HO_2^-,$$

$OH^{\cdot}$ , $O^{\cdot -}_2$ , $HO^{\cdot}_2$ )+ organic molecule→ degradation products.

When electrons (e−) are exposed to light with an energy that exceeds the ZTO bandgap, they are stimulated to move from the valence band into the conduction band. In the valence band, holes (h+) are produced as a result of this process. In the event that these electron-hole pairs come back together, this energy can be released. A highly reactive radical, such as OH•, O•− 2, and HO• 2, is produced when electrons and holes interact with water. This interaction results in the formation of radicals. These radicals have the potential to initiate a number of reactions, one of which is the destruction of the majority of azo dyes into mineralization by-products. In the few articles that have been written about ZTO as a photocatalyst up until this point, the majority of the conversations have focused on the dissolution of various kinds of chemicals.

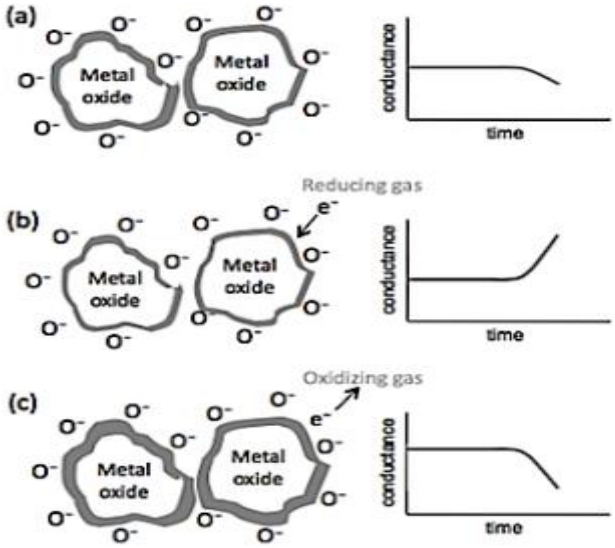

**Figure 7. The fundamental working concept of a metal oxide semiconductor gas sensor is as follows: (a) in room temperature and humidity, (b) with reducing gas present (an increase in conductance), and (c) with oxidizing gas present (a reduction in conductance).**

Irradiation with light that has a higher energy than the ZTO bandgap causes electrons (e−) to be stimulated from the valence band into the conduction band. This occurs during the process of irradiation. Because of this, holes (h+) are produced in the valence band, which is the result of the process. It is possible to describe the phenomenon by referring to the ability of these electron–hole pairs to recombine, which ultimately results in the release of energy. Electrons and holes are subjected to a reaction when water is present, which ultimately leads to the generation of highly reactive radicals such OH, O− 2, and HO 2. These radicals have the ability to oxidize the vast majority of azo dyes, which ultimately results in the production of mineralization end-products from the process. Among the few articles that are currently available on the topic of the utilization of ZTO as photocatalysts, the majority of them focus their attention primarily on the degradation of a wide range of chemical compounds.

## Conclusion

The results of this study have shed light on the synthesis and characterisation of stannate nanostructures, which is a significant accomplishment. The optical, electrical, and structural properties of stannate nanostructures have been illuminated by these results. A better understanding of the parameters controlling the size, shape, and crystalline structure of stannate nanostructures has been attained through an exhaustive investigation of various synthesis methods and characterisation techniques. This was achieved by improving our grasp of the parameters. The results demonstrate the versatility of synthesis methods in modifying stannate nanostructure properties, including solvothermal, hydrothermal, and template-assisted approaches. Through careful manipulation of reaction parameters like temperature, precursor concentration, and pH, we have attained full command over the nanostructures' shape and size distribution. Because of this, we have managed to get this under control. Electron microscopy, X-ray diffraction, and spectroscopic analysis are some of the contemporary techniques that have been used to study stannate nanostructures. The structural, optical, and electrical properties of these nanostructures have been extensively studied using these methods. Thanks to these characterizations, we have shed light on the connection between synthesis conditions and nanostructure properties. Many different fields stand to benefit from this study's findings: gas sensing, photocatalysis, energy storage,

biomedical devices, and many more. We can tailor the characteristics of stannate nanostructures to meet the demands of individual applications by learning about the structure-property interactions of these materials. We can improve the usefulness and functionality of these nanostructures as a result. Additional research is needed to better understand novel synthesis methods, assess potential uses of stannate nanostructures, and enhance current processes and approaches. It will also be important to look into new ways of synthesis. We can further advance our understanding of nanomaterials and use stannate nanostructures to their full potential in many technological applications by expanding upon the information we have gained from this study. We can keep pushing the boundaries of nanomaterials research because of this. In conclusion, the presented study provides a foundational understanding of stannate nanostructures and paves the way for their widespread application in various scientific and technological fields. The publication in question is this article from Nano Letters.

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