Review on: Applications of Pure and doped SnO_2 Nanoparticles

Devendra Bhikaji Sonwane

Department of Physics,
S. P. H. Arts, Science and Commerce College,
Nampur, Tal- Baglan, Dist.- Nasik, Affiliated to SPPU, Pune, and Maharashtra, India.

***Abstract*: Tin oxide (SnO_2) is most promising material in the last few decades. It is one of the important n-type oxide in metal oxide semiconductors (MSO). Its band gap is wide near about 3.6 eV. It is belongs to the family transitional metal oxides (TMO). Because of unique properties like physical, chemical, electrical, and structural of SnO_2, it is implemented in different applications. Gas sensor, optical sensor, photo degradation, catalyst, biological domains, solar cells, chemosensor, battery, energy storage applications. As a result, the suggested review includes both historical and recent advancement on the relevant areas of tin oxide. The current research article also give brief idea of future important of SnO_2 in the modern research.**

Keywords: Tin oxide, transitional metal oxides, gas sensor, structural properties.

1. Introduction

Metal oxides have extraordinary promise as building blocks for cutting-edge technologies. Significant study has recently been done on these materials to evaluate potential uses in the optical, electrical, optical, and biological fields. The reaction and effectiveness of the devices in such purposes are highly reliant, among other factors, on the size, structure, and surface of the active oxide materials [1]. Metal oxides have long been recognised as good materials for gas sensors and biosensors. These materials' surfaces have a strong contact with gas molecules. The surface characteristics of metal oxide can be tailored using several approaches to improve sensing properties. Due to quantum confinement, grain size reduction at the nanoscale leads to a huge active surface area and unique effects such as bandgap widening and room temperature photoluminescence. These novel physical features in metal oxide nanostructures pave the opportunity for sensor technology advancements with advanced parameters. Nanomaterials made of metal oxides that have certain features, such as composition. Various synthesis techniques can be used to accomplish stoichiometry, phase control, and morphology [2, 3]. Metal oxides with various nanostructures, such as nanowires, nanofibers, nanotubes, nanosheets, and nanospheres, have superior gas sensing characteristics due to their huge surface area and mass reactive sites [3]. A sensitive metal oxide surface layer makes up the metal oxide semiconductor gas sensors. These metal oxides use electrical resistance to determine the gas concentration of a target gas. The reversible gas adsorption mechanism at the metal oxide surface is the basis for these sensors [4]. Nanomaterials based on metal oxides are a diverse class of materials in terms of electronic structure and physical, chemical, and electromagnetic properties [6]. The application of metal oxide nanomaterials and nanocomposites based on them is becoming increasingly popular in applied ecology, especially where they can be used as adsorbents and photocatalysts as well as a material for the manufacture of environmental monitoring devices. Adsorption materials based on nanosized metal oxides have a large specific surface area, high capacity, fast kinetics, and specific affinity for various contaminants [7]. The use of nanostructured metal oxides in photocatalytic processes allows the oxidation of organic compounds that are not decomposed biochemically, and the pre-treatment of aqueous solutions by their use is considered to be the most promising [7, 8].

The first generation gas sensor, made by Figaro Engineering Inc. in October 1960 utilizing tin oxide (SnO_2), was introduced at Osaka, Japan. It was the initial commercially viable gas sensor. Thick SnO_2 films were used to make these sensors, which were employed to detect explosive gases [9]. SnO_2 is remains the most often used material for gas sensors in research even now, despite the use of other materials. Tin dioxide is an n type semiconductor with a 3.6 eV band gap. Tin oxide and stannic oxide are other names for tin dioxide.

Due to its wide range of uses in areas including catalysis, transparent conducting oxides, battery materials, solar cells, optics, gas sensing, and other fields, SnO_2 has received a lot of special attention in the field of material science. The physical characteristics and practical uses of these materials are strongly influenced by their structure and electronic structure. The most common and stable in terms of thermodynamics is SnO_2. Because the Sn ion possesses two stable oxidation states, the stability can be attributed to this [9, 10]. The unit crystal structure of SnO_2 is shown in Figure 1.

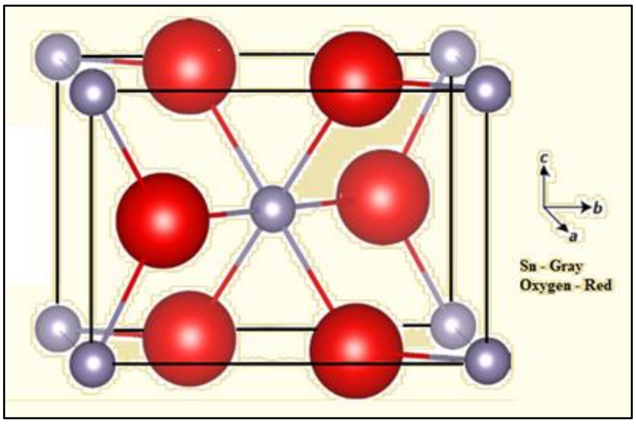

Figure 1: Unit cell of SnO_2

2. Literature survey

Tin is hardly entirely found in the environment as chromite, or tinstone, which is a tin, v oxide [11]. Tin oxide is a metal oxide which has the potential to be used in a variety of research applications [12, 13]. Tin oxide was first made via thermal breakdown of ‘Sn’ compounds, particularly chlorides, nitrides, and organotin, in the early years [14]. The special characteristics of the ‘d’ electrons, metal-oxygen bonding, which ranges from virtually ionic to metallic [15], is responsible for the remarkable features of these oxides.

SnO_2 is an n-type degenerative semiconductor with a large energy gap (Eg) and electrical properties. Increased grain size at high substrate temperature, medium electrical mobility, and high carrier concentration are all factors that contribute to its good electrical conductivity [15, 16]. The gas sensing characteristics of SnO_2 nanobelts were explored by Law et al. [16].

Comini et al. [17] proved use of SnO_2 nanowires as a sensor material in a synthetic air atmosphere, demonstrating significant current changes in response to ethanol and CO exposure, respectively, while Law et al. evidenced the first photochemical NO_2 nanosensors working at room temperature.

Tupe et al. [18] synthesised stannous oxide nanoparticles by conventional and cost effective co precipitation method. The thick film sensors of SnO_2 nanoparticles were fabricated by standard screen-printing technique by photolithography. The prepared SnO_2 material was characterized by several techniques to confirm the structural properties. Author reported from XRD data the average particle size of prepared thick films was found to be 21.87 nm calculated using Debye-Scherer formula. SEM data clearly indicates the heterogeneous surface, and some voids present over the surface of SnO_2 nanoparticles. The fabricated thick film was exclusively used to sense the hydrogen sulfide gas vapours at various concentrations. The prepared sensor of SnO_2 was found to be highly sensitive to H_2S vapors nearly 63.8% sensitivity was recorded. The response and recovery study shows the response time of 9 seconds and recovery time of 19 seconds for H_2S gas.

Moalaghi, M et al. [19] Describe a tin oxide gas sensor that has been brought to operational temperature using a 10 micron thick, undoped tin oxide microheater that can function at 850 °C, which is hot enough to cause methane to spontaneously pyrolyze. The device selectively detects methane in atmospheres contaminated with CO and H_2 while operating at temperatures exceeding 700 °C. The constructed sensor is suitable for online monitoring of methane level in hot exhaust fumes because response and recovery durations are both 10 s and the CH_4 detection limit is 50 ppm. The device doesn't show any aging over the 30-day test period when running constantly at 700 °C in air.

Velmathi, G. et al. [20] reported several gas sensing mechanisms, factors that influence them, methods for enhancing gas sensitivity, and state-of-the-art fabricating methods and materials. The article also addresses a brand-new class of gas sensor developed using the materials and mechanisms examined. Tin oxide has been used to build low-cost, easily implemented semiconductor-based gas sensors that have good stability and sensitivity.

The gas sensing characteristics of single crystalline SnO_2 nanorods towards acetone and triethylamine were investigated by Wang et al. [21]. Sun et al. [22] used a hydrothermal technique to make porous SnO_2 hierarchical nanosheets and investigated their gas sensing characteristics. They demonstrated that the unique structures had a high sensing performance to ethanol, and they explained this to the novel hierarchical structure, which greatly enhances gas diffusion and mass transit in the sensing material.

Zhang et al. [23] described the easy manufacture of a well-ordered porous Cu doped SnO2 thin film and demonstrated that Cu doping improved the sensitivity, selectivity, reaction time, and recovery time for H_2S sensing by SnO_2 thin film. The Cu doped porous SnO_2 sensor was found to have a sensitivity one order of magnitude higher than the undoped SnO_2 sensor.

Mishra et al. [24] investigated the effects of Cu doping on the structural, optical, and formaldehyde sensing properties of SnO2 nanoparticles, demonstrating that a 1.5 at. percent Cu doped SnO2 nanoparticles based sensor exhibits a selective high sensor response (80 %) to formaldehyde over methanol, ethanol, propanol-2-ol, acetone, and n-butyl The electrical characteristics of SnO_2 thin films can be efficiently adjusted by adding small amounts of doping materials, according to Promsong et al. [25], resulting in their employment in gas-sensitive devices for the detection of organic and inorganic vapours.

Rani et al. [26] investigated the influence of Fe doping on the gas detecting capabilities of nanocrystalline SnO_2 thin films, finding that films with 2 wt% Fe had a high sensor response and good selectivity for CO when compared to ammonia and ethanol.

Choi et al. [27] used gamma ray radiolysis to achieve highly sensitive and selective NO_2 sensing with networked SnO_2 microrods functionalized with Ag nanoparticles.

Kim et al. [28] investigated the CO gas sensing capabilities of direct-patternable SnO2 films incorporating graphene or Ag nanoparticles, finding that the integration of graphene and Ag nanoparticles considerably improved the gas sensitivity of the SnO2 thin film sensor.

Using electrospun SnO_2 nanofibers modified by Pd loading, Yang et al. [29] demonstrated ultrasensitive and highly selective gas sensors. When compared to their unloaded counterparts, the Pd-loaded SnO_2 sensors have a 4 order of magnitude higher resistivity and are substantially more sensitive to H_2. The enhanced electron depletion at the surface of the PdO-decorated SnO2 crystallites and the catalytic activity of PdO in accelerating the oxidation of H_2 into H_2O were attributed to these findings.

Choi et al. [30] found that Pd doping on SnO_2 hollow nanofibers dramatically improved sensor response to C_2H_5OH. With Pd doping in SnO_2 hollow nanofibers, selective detection of C_2H_5OH was found.

Song et al. [31] used SnO_2 quantum wire/reduced graphene oxide (rGO) nanocomposites to make room temperature H_2S gas sensors. At 22 °C, the best sensor response to 50 ppm H_2S was found to be 33 in 2 s. The improved electron transport resulting from the favourable charge transfer at SnO2/ rGO integrations and the superb transport capability of rGO can be attributed to the superior sensing performance of SnO_2 quantum wire/ rGO nanocomposites, in addition to the excellent gas adsorption of SnO_2 quantum wires.

According to the literature review, SnO_2 NPs were synthesis various methods. Changing the parameters of method allows us to change the properties of SnO_2, making it suited for a certain use. As a result, the strategies for preparation are essential. One can use a suitable preparation technique regardless of the type of devices, size, and intended performance. It is also found that the fabrication method of films also impact on structural, optical, electrical, and gas sensing properties of SnO_2.

3. Applications of SnO_2 Nanoparticles

The SnO_2 nanoparticles have different applications. The applications of SnO_2 nanoparticles is illustrate in Figure 2.

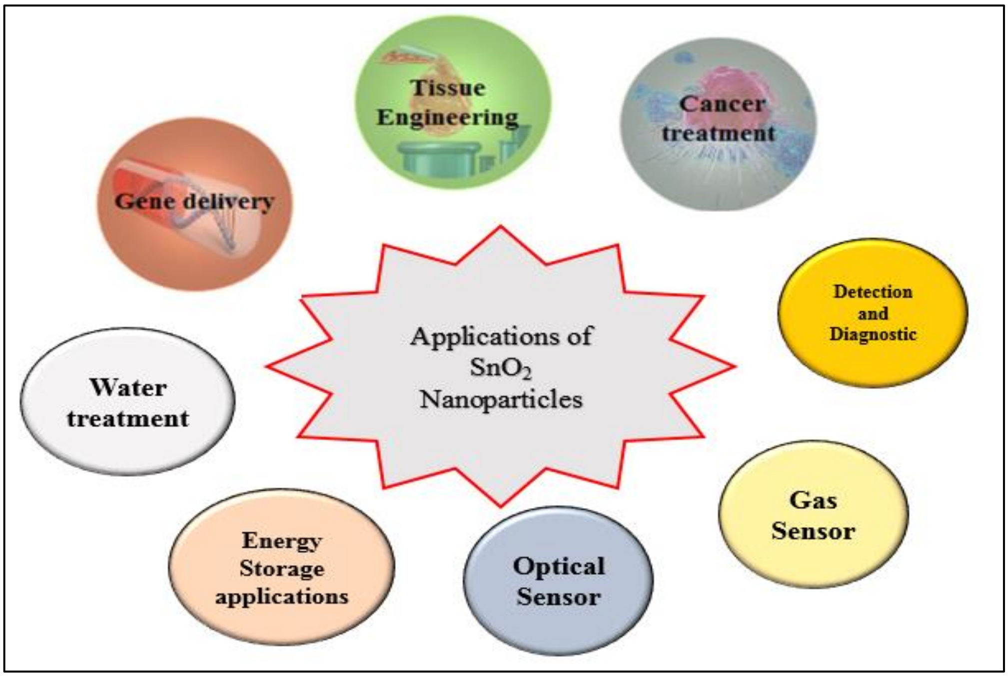

Figure 2: Applications of SnO_2 Nanoparticles

Conclusion

The current review provides brief idea of tin oxide nanoparticles important in different fields. The doped SnO_2 nanoparticles are shows good results for applications as compare to pure SnO_2 nanoparticles. Because the physical and electrical properties of metal oxide materials are usually influenced by dopants as well as synthesis and film fabrication methods. The additive or dopants also produce ionic, structural and electronic variations in variety of applications. The position of the Fermi energy level is influenced by these defects, which is likely to affect the gas sensitivity of semiconducting oxides like tin oxide. Due to a versatile properties of SnO_2 in future it has will be included in smart sensor applications with artificial intelligence.

References:

1. Das, S. and Jayaraman, V., 2014. *Progress in Materials Science*, *66*, pp.112-255.
2. Fahrenbach, A.C., Sampath, S., K.J., Liu, Z., Dravid, V.P., Schatz, G.C. and Van Duyne, R.P., 2012. *ACS nano*, *6*(11), pp.9964-9971.
3. Ahamed, M., Akhtar, M.J. and Alhadlaq, H.A., 2019. *International Journal of Environmental Research and Public Health*, *16*(17), p.3199.
4. Awang, Z., 2014. Gas sensors: A review. *Sens. Transducers*, *168*(4), pp.61-75.
5. Dontsova, T.A., Nahirniak, S.V. and Astrelin, I.M., 2019. *Journal of Nanomaterials*, *2019*.
6. Fierro, J.L.G. ed., 2005. *Metal oxides: chemistry and applications*. CRC press.
7. Kumar, S.R. and Gopinath, P., 2017. *Handbook of Advanced Industrial and Hazardous Wastes Management*, pp.27-48.
8. Zhang, Y., Wu, B., Xu, H., Liu, H., Wang, M., He, Y. and Pan, B., 2016.. *NanoImpact*, *3*, pp.22-39.
9. Lantto, V. and Romppainen, P., 1988. *Journal of the electrochemical society*, *135*(10), p.2550.
10. Baik, N.S., Sakai, G., Miura, N. and Yamazoe, N., 2000 *Sensors and Actuators B: Chemical*, *63*(1-2), pp.74-79.
11. Rollinson, C.L., Bailar, J.C., Emelens, H.J., Nyholm, R. and Trotman-Dickensen, A.F., 1973. Comprehensive Inorganic Chemistry. *Pergamon Press, New York, NY*, pp.703-742.
12. Granqvist, C.G. ed., 1995. *Handbook of inorganic electrochromic materials*. Elsevier.
13. Chopra, K.L., Major, S. and Pandya, D.K., 1983. Transparent conductors a status review. *Thin solid films*, *102*(1), pp.1-46.
14. Rao, C.N.R., Vanitha, P.V. and Cheetham, A.K., 2003. In *Advances In Chemistry: A Selection of CNR Rao's Publications (1994–2003)* (pp. 37-44).
15. Chen, M.F., Lin, K.M. and Ho, Y.S., 2011. *Materials Science and Engineering: B*, *176*(2), pp.127-131.

16. Turgut, G., 2015. Investigation of characteristic properties of Pr-doped SnO2 thin films. *Philosophical Magazine*, *95*(14), pp.1607-1625.
17. E. Comini, G. Faglia, G. Sberveglieri, Z. Pan, L. Zhong, *Appl. Phys. Lett.*,81, 2002, 1869.
18. Tupe, U.J., Patil, A.V., Zambare, M.S. And Koli, P.B., 2021. Material Science Research India.
19. Moalaghi, M., Gharesi, M., Ranjkesh, A. and Hossein-Babaei, F., 2020. *Materials Letters*, *263*, p.127196.
20. Velmathi, G., Mohan, S. and Henry, R., 2016. *IETE Technical review*, *33*(3), pp.323-331.
21. D. Wang, X. Chu, M. Gong, *Sens. Actuators B*, 117, 2006, 183-187.
22. P. Sun, W. Zhao, Y. Cao, Y. Guan, Y. Sun, L. Geyu, *CrystEngComm*, 2011, 13, 3718-3724.
23. S. Zhang, P. Zhang, Y. Wang, Y. Ma, J. Zhong, X. Sun, *ACS Appl. Mater. Interfaces*, 2014, 6, 14975−14980.
24. R. K. Mishra, A. Kushwaha, P. P. Sahay, *RSC Adv.*, 2014, 4, 3904–3912.
25. L. Promsong, M. Sriyudthsak, *Sens. Actuators B*, 1995, 25, 504–506.
26. S. Rani, S. C. Roy, M. C. Bhatnagar, *Sens. Actuators B*, 2007, 122, 204–210.
27. S. W. Choi, A. Katoch, G. J. Sun, P. Wu, S. S. Kim, *J. Mater. Chem. C*, 2013, 1, 2834-2841.
28. H. Kim, C. S. Park, K. M. Kang, M. H. Hong, Y. J. Choi, H. H. Park, *New J. Chem.*, 2015, 39, 2256-2260.
29. D. J. Yang, I. Kamienchick, D. Y. Youn, A. Rothschild, Il D. Kim, *Adv. Funct. Mater.*, 2010, 20, 4258–4264.
30. J. K. Choi, I. S. Hwang, S. J. Kim, J. S. Park, S. S. Park, U. Jeong, Y. C. Kang, J. H. Lee, *Sens. Actuators B*, 150, 2010, 191-199.
31. Z. Song, Z. Wei, B. Wang, Z. Luo, S. Xu, W. Zhang, H. Yu, M. Li, Z. Huang, J.
32. Zang, F. Yi, H. Liu, *Chem. Mater.*, 2016, 28, 1205−1212.