Flame Synthesised Tin Oxide Nanoparticles for Photocatalytic Application of Chemical Dye

P.Sivarama Prabhu[1], N.Sriharan[2], V.Regina Delcy[3]
[1,2]*Professor, Department of Physics, P.A. College of Engineering and Technology, Pollachi, Tamil Nadu, India 642002*
[3] *Professor, Department of Physics, Dr.Mahalingam College of Engineering and Technology, Pollachi, Tamil Nadu India - 642003*

***Abstract*—For the photocatalytic degradation of Methylene Blue (MB) dye, pure Tin Oxide (SnO2) nanoparticles are successfully synthesized from metallic Tin (Sn) and Zinc (Zn) powders using a very straightforward and quick flame oxidation method. The nanoparticles' structural, optical, elemental, and chemical properties are then studied. The produced SnO2 nanoparticles have pure tetragonal phases, according to X-ray diffraction analysis (XRD). Energy dispersive X-ray analysis (EDX) was used to analyze purity, atomic percentage, and chemical composition. The UV-visible spectroscopy study showed that SnO2 has a band gap value of 3.5 eV. Pure SnO2 nanoparticles exhibit uneven, agglomerated, nanoflowered, and nanoclustered formation, according to FESEM research. When exposed to UV light, the addition of SnO2 increased the photocatalytic activity. SnO2 degrades MB with an efficiency of more than 80%, demonstrating its effectiveness as a photocatalyst.**

***Index Terms*—Tin oxide, FESEM , flame synthesis, Methylene Blue, photocatalyst**

I. INTRODUCTION

Every nation's economy depends on the goods and products produced by its industries on a daily basis[1]. While industrial expansion has numerous benefits for society, the environmental industries also have certain drawbacks[1]. Due to its existence in the ecosystem, industrial effluent mostly reflects its effects on human life[2]. The textile industry is the one that produces dyes, however most industries generally emit effluents while creating goods[1]. One of the primary pollutants that endangers the ecosystem and all life on Earth is dyes. These dyes are more stable due to their complex structure, and it is highly challenging to remove or degrade these complex compounds from effluents[3]. Recent studies have concentrated on using physical, chemical, and biological methods to remove hazardous organic contaminants from wastewater; however, these methods have certain drawbacks[4].
The photocatalyst is known to be a successful technique for treating wastewater that contains organic pollutants[5]. The presence of UV radiation, which functions as a stimulant for light-induced redox processes, increases the catalytic capabilities of the nanoparticles in the photocatalytic degradation process[6]. The degradation of organic dyes has improved due to the use of nanoparticles as photocatalysts; as a result, new methods are needed to create a variety of nanomaterials with the necessary chemical, physical, and electrical characteristics[7]. Among these, metal oxide semiconductor nanoparticles with huge band gaps have recently been extensively studied because of the unexpected changes in their characteristics when they are reduced to small sizes due to quantum confinement or the quantum size effect[8]. SnO_2 is one of the most important metal oxide nanoparticles with a wide band gap (3.6 eV) among those produced for various uses[9]. Applications such as gas sensors, LEDs, solar cells, photocatalysts, spintronic devices, optoelectronic devices, supercapacitors, and lithium-ion batteries were investigated for n-type semiconductors[7]. Due to its capacity to dope with a variety of dopants, including iron, graphene, manganese, antimony, iodine, copper, zinc, indium, silicon, and fluorine, SnO_2, an inorganic compound

with a significant exciton binding energy of 130 meV, was widely chosen[3]. The optical, structural, chemical compositional, magnetic, photovoltaic, gas sensing, electrical, and electrochemical properties of SnO_2 were all affected when it was doped with any of these dopants[1,2]. Due to the significant oxygen deficiency, SnO2's optical, structural, chemical compositional, magnetic, photovoltaic, gas sensing, electrical, electrochemical, and other properties were significantly altered when doped with any of these dopants[9].

Numerous techniques, including hydrothermal, sol-gel, low temperature solution process, chemical precipitation, co-precipitation, electrospinning, magneton co-sputtering, laser pyrolysis, gas phase technique, and chemical spray pyrolysis, have been reported for the synthesis of SnO_2 nanostructures[1]. However, the majority of these techniques used dangerous chemicals, required complex equipment, and took longer to react[10]. Flame oxidation or flame synthesis is a very important, low-cost, high-purity, high-quantity, one-step technique that produces materials in nanodimension for the manufacture of SnO_2 nanoparticles[1]. Methylene blue (MB) is a common cationic dye used in the textile industry, while most textile businesses employ azo-based acidic dyes to bond dyes on fabrics[11].

II. MATERIALS AND METHODS

2.1. Synthesis of pure SnO_2 and Zn: SnO_2 nanoparticles

Flame synthesis method's process involves mixing the oxygen and acetylene gases equally and sending them through the nozzle from the oxygen and acetylene cylinders[1,2]. The flow of gases via the nozzle can be controlled with a regulator to produce a bluish flame. The powders were fed into the flame using a stopper-equipped powder feeder[1,2]. To collect the deposited nanopowders, a powder collector was positioned over the reaction chamber approximately 25 cm away from the nozzle[1,2]. The stopper controlled the homogeneity of the powder flow while metallic Sn granules, about 40 μm in size, were placed in the powder feeder and guided toward the bluish flame under gravity[1,2]. The metallic Sn powders are melted in a high-temperature flame and directly oxidized to produce SnO_2 nanoparticles, which are then coated over the powder collector and described for more research[1,2].

2.2. Photocatalytic degradation experiment

The decolorization of MB aqueous solution was used to assess the photocatalytic degradation activity of pure SnO_2 nanoparticles as catalysts on Methylene Blue (MB) exposed to UV light[1,2]. In order to reach adsorption-desorption equilibrium, 10 mg of SnO_2 and nanoparticles were magnetically agitated with 50 ml of aqueous MB solution to produce uniform dispersion. The mixture was then left in the dark for two hours[1,2]. A UV-visible spectrophotometer was used to measure the steady state absorption after the reaction mixture including the photocatalysts and MB dye was exposed to UV light for regular intervals of 30, 60, 90, 120, 150, and 180 minutes[1,2].

III. RESULTS AND DISCUSSION

XRD, EDX, UV visible spectroscopy, and FESEM are used to analyze pure SnO_2 nanoparticles produced by direct oxidation of the flames[1,2]. The structural characteristics of the produced nanoparticles, such as their size, crystalline structure, and phases, were examined using X-ray diffraction[1,2]. Energy Dispersive X-ray Analysis (EDX) was used to verify the chemical makeup and purity of SnO_2 and nanoparticles[1,2]. Their optical characteristics were examined using a UV visible spectrophotometer (JASCO V-770) in the 200–900 nm measuring range[1,2].

3.1. Structural analysis

One of the most important characterisation techniques for determining the typical crystallite sizes, structures, and phases found in the produced nanoparticles is XRD[1,2]. The xrd pattern of pure SnO_2 and nanoparticles using the quick and easy flame oxidation approach is displayed in figure 1[1,2]. The tetragonal phase of the SnO2 nanoparticles is confirmed by Figure 1, and the planes (110), (101), (200), (111), (211), (220), (002), (301), (112), (301), (202), and (321) match the tetragonal structured SnO2 (JCPDS card No. 00-041-1445, space group: P42/mnm, group number: 136) [1,2]. For both the SnO2 and nanoparticles, the

average crystallite size was determined to be 29 nm[1,2].

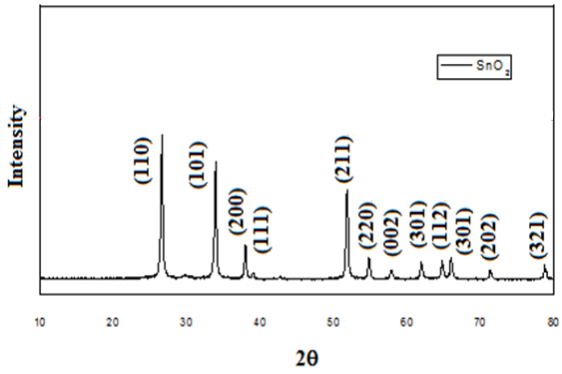

Fig.1 XRD Spectra of pure SnO_2 nanoparticles

3.2 Chemical analysis

EDX is a crucial technique for verifying the elemental, chemical, and purity of flame-synthesised SnO_2 nanoparticles[1,2]. The EDX spectrum of SnO_2 shows the distinctive peaks for oxygen at 0.5 eV and tin at 3 and 3.4 eV, as seen in figure 2[1,2]. One of the key benefits of the flame synthesis approach is that this spectrum verifies that the produced nanoparticles are pure and free of extraneous contaminants[1,2]. The weight and atomic percentages of the elements found in the produced nanomaterials are displayed in Table 1[1,2].

Table 1: EDX data of pure SnO_2 nanoparticles

Element	Series	Weight %	Atomic %
O	K	30.36	76.38
Sn	L	69.64	23.62

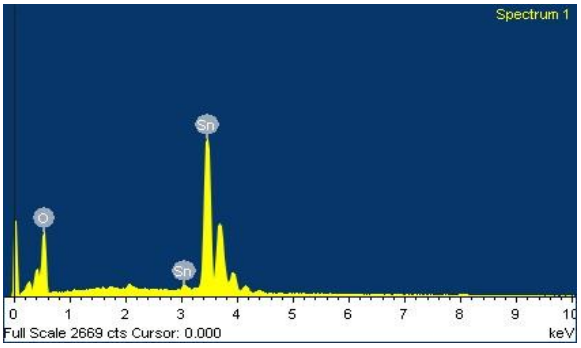

Fig.2 EDX Spectra of pure SnO_2 nanoparticles

3.3. Optical studies

The best method for examining the different optical characteristics of the flame-synthesized nanoparticles is UV visible absorption spectroscopy[1,2]. The absorbance versus wavelength peaks for pure SnO_2 nanoparticles are displayed in figure 3[1,2]. SnO_2 has modest absorbance above 400 nm and very high absorbance around 300 nm. The band gap value of SnO_2 nanoparticles is found to be 3.5 eV[1,2].

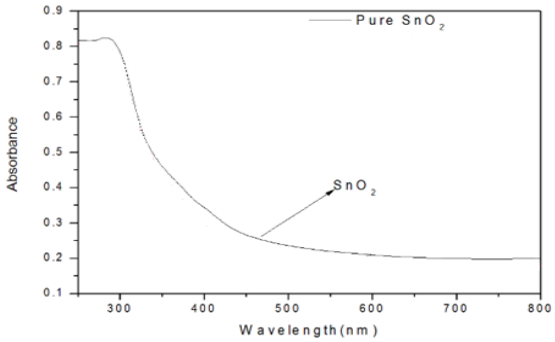

Fig.3 Absorbance spectra of SnO_2 nanoparticles

3.4. Surface analysis

The best characterisation technique for examining the surface appearance and crystalline structure of SnO_2 and nanoparticles is FESEM[1,2]. The FESEM pictures of pure SnO_2 nanoparticles produced by flame synthesis are shown in figure 4[1,2]. When bulk metal Sn powders fall on the oxy-acetylene flame during the synthesis of SnO_2 nanoparticles, the extremely high temperature of the flame causes Sn to instantly melt and combine with oxygen to generate irregular, agglomerated, nano flowered, and nano clustered SnO_2 nanoparticles[1,2].

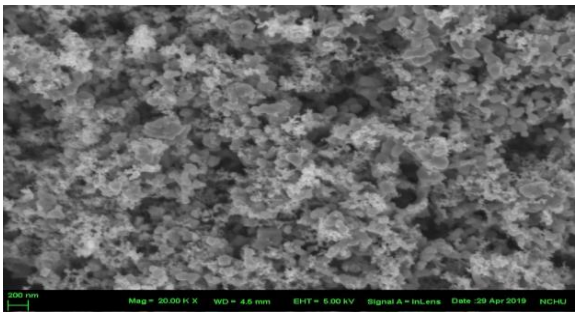

Fig.4 FESEM image of pure SnO_2 nanoparticles

IV. PHOTOCATALYTIC DEGRADATION OF MB

Figure 5 shows the absorbance spectra of MB in the presence of synthesized photocatalysts under ultraviolet irradiation. Due to the degradation of MB dye, around 661 nm range the absorption intensity

decreases linearly with the increase of irradiation time from 0-180 min[1,2]. It was also noted that the color of the aqueous solution gradually diminishes as the time of uv irradiation increases. The MB dye degradation in the presence of SnO_2 nanoparticles is depicted in Fig. 8[1,2]. Prior to irradiation, the MB solution was tested both with and without a catalyst in the dark, which showed very little photolysis[1,2]. Highly reactive hydroxyl (OH^-) and superoxide (O_2^-) radicals are created when ultraviolet light strikes the surface of SnO_2, absorbing it and causing electrons to move from the lower energy level (valence band) to the higher energy level (conduction band) [1,2]. Both these radicals plays a vital role in the degradation of MB dye solution[1,2]. At the end of 180 min uv irradiation, the degradation efficiency of MB dye in the presence of SnO_2 catalyst reaches 82%, which can be revealed from the decolorization of the MB solution[1,2].

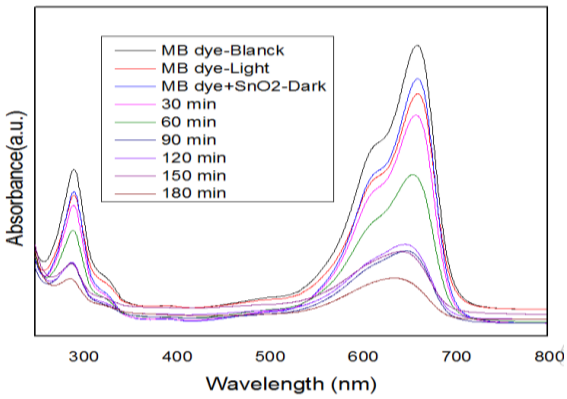

Fig.5 MB degradation in presence of SnO_2 nanoparticles

V. CONCLUSION

Using the high temperature oxy-acetylene flame, pure SnO_2 nanoparticles were effectively produced using the flame synthesis method. The XRD examination verified the formation of tetragonal structured pure SnO_2 and cubical phased nanoparticles. Atomic weight % and chemical composition from the EDX examination verify that SnO_2 nanoparticles are pure and free of contaminants. The band gap value of 3.5 eV for SnO_2 nanoparticles is confirmed by UV-visible absorption spectra. It is evident from the FESEM study that the SnO_2 nanoparticles are uneven, agglomerated, nano flowered, and nano clustered. Due to the production of extremely reactive (OH^-) hydroxyl radicals and superoxide (O_2^-) radicals, MB degradation study demonstrates the great performance of SnO_2 nanoparticles as photocatalysts under UV light.

VI. DECLARATIONS

Conflicts of interest/Competing interests

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.

Consent for publication

This manuscript has not been published previously and it is not under consideration for publication elsewhere, its publication is approved by all authors and if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright holder.

REFERENCES

[1] P.S. Prabhu, P.K.D. Maruthamani, S.D.G. Ram, Photocatalytic Activity of Pure and Zinc Doped Tin Oxide Nanoparticles Synthesized by One Step Direct Injection Flame Synthesis, J. Inorg. Organomet. Polym. Mater. (2021). https://doi.org/10.1007/s10904-021-02167-y.

[2] P.S. Prabhu, P. Kathirvel, D. Maruthamani, S.D.G. Ram, Enhanced photocatalytic activity of methylene blue dye by DIFS synthesized pure and Mn doped MgO nanostructures, Optik (Stuttg). 283 (2023) 170869. https://doi.org/10.1016/j.ijleo.2023.170869.

[3] Zulfiqar, Y. Yuan, Q. Jiang, J. Yang, L. Feng, W. Wang, Z. Ye, J. Lu, Variation in luminescence and bandgap of Zn-doped SnO2 nanoparticles with thermal decomposition, J. Mater. Sci. Mater. Electron. 27 (2016) 9541–9549. https://doi.org/10.1007/s10854-016-5006-3.

[4] P.S. Prabhu, P. Kathirvel, H.B. Ramalingam, Synthesis of pure and Cr doped Zinc Sulfide nanoparticles for charge transport layers applications, Mater. Today Proc. 5 (2018) 16466–16471.

https://doi.org/10.1016/j.matpr.2018.05.146.

[5] P. Sivarama Prabhu, P. Kathirvel, D. Maruthamani, S.D.G. Ram, Enhanced photocatalytic activity of zinc oxide and tin doped zinc oxide nanoparticles synthesized by direct injection flame synthesis, Inorg. Nano-Metal Chem. 0 (2023) 1–12. https://doi.org/10.1080/24701556.2023.2271460.

[6] R. Medhi, C.H. Li, S.H. Lee, M.D. Marquez, A.J. Jacobson, T.C. Lee, T.R. Lee, Uniformly Spherical and Monodisperse Antimony- And Zinc-Doped Tin Oxide Nanoparticles for Optical and Electronic Applications, ACS Appl. Nano Mater. 2 (2019) 6554–6564. https://doi.org/10.1021/acsanm.9b01474.

[7] J.H. Kwon, S. Jang, H.J. Kim, B.S. Joo, K.N. Yu, E. Choi, M. Han, J.H. Park, Y.J. Chang, Microscopic and chemical analysis of room temperature UV laser annealing of solution-based zinc-tin-oxide thin films, J. Anal. Sci. Technol. 11 (2020) 0–8. https://doi.org/10.1186/s40543-020-00216-8.

[8] B. Venugopal, B. Nandan, A. Ayyachamy, V. Balaji, S. Amirthapandian, B.K. Panigrahi, T. Paramasivam, Influence of manganese ions in the band gap of tin oxide nanoparticles: Structure, microstructure and optical studies, RSC Adv. 4 (2014) 6141–6150. https://doi.org/10.1039/c3ra46378h.

[9] A.M. Al-Hamdi, M. Sillanpää, J. Dutta, Photocatalytic degradation of phenol by iodine doped tin oxide nanoparticles under UV and sunlight irradiation, J. Alloys Compd. 618 (2015) 366–371. https://doi.org/10.1016/j.jallcom.2014.08.120.

[10] S. Liu, Z. Wang, Y. Zhang, J. Li, T. Zhang, Sulfonated graphene anchored with tin oxide nanoparticles for detection of nitrogen dioxide at room temperature with enhanced sensing performances, Sensors Actuators, B Chem. 228 (2016) 134–143. https://doi.org/10.1016/j.snb.2016.01.023.

[11] D.T.T. Trinh, D. Channei, A. Nakaruk, W. Khanitchaidecha, New insight into the photocatalytic degradation of organic pollutant over BiVO4/SiO2/GO nanocomposite, Sci. Rep. 11 (2021) 1–11. https://doi.org/10.1038/s41598-021-84323-5.

[12] S.P. P, B. Prakash, Synthesis of Pure and Mg Doped Zno Nanoparticles for Photocatalytic Degradation of Organic Dye, 17 (n.d.) 1–8.

[13] Y. Bin Ramli, Z.A.B.M. Yazid, A.B.A. Aziz, Preparation and Characterization of Zn and Al Doped SnO2 Nanofibers by Electrospinning Method, Proc. 2019 IEEE Reg. Symp. Micro Nanoelectron. RSM 2019. (2019) 69–71. https://doi.org/10.1109/RSM46715.2019.8943523.