

Original Research

Investigation of Structural and Morphological Properties of Hydrothermally Synthesized nanocomposites SnO₂/MoS₂

Md. Mostafa Kamal^{1*}, Md. Tushar Ahmed¹, Gazi Ishmam Hasan¹

¹Department of Physics, Gono Bishwabidyalay, Savar, Dhaka 1344

* **Corresponding Author:** Md. Mostafa Kamal; Email: mostafaphysicsju@gmail.com; Mobile: +8801571424588.

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Abstract

In this work, pure SnO₂ and SnO₂-MoS₂ nanocomposites were successfully synthesized via the hydrothermal method using a stainless-steel autoclave. The synthesis was carried out at a temperature of 140° C and a pressure of 30 pounds per square inch (psi). The nanocomposites were characterized using X-ray diffraction (XRD), scanning electron microscopy (SEM), and Fourier transform infrared spectroscopy (FTIR). The formation of the nanocomposites was confirmed by both XRD patterns and SEM micrographs. The XRD results revealed that all samples exhibited a stable tetragonal SnO₂ phase. The crystallite size and lattice strain of the samples were investigated, with crystallite sizes ranging from 18.70 nm to 20.87 nm. A slight increase in crystallite size was observed with increasing MoS₂ content. The SEM micrographs confirmed the formation of non-uniform spherical particles. The average particle diameters for the 90% SnO₂-10% MoS₂, 80% SnO₂-20% MoS₂, and 70% SnO₂-30% MoS₂ samples were found to be 25.62 nm, 27 nm, and 31.21 nm, respectively. Similarly, the corresponding average particle areas were measured as 462.32 nm², 503.2 nm², and 548.32 nm², respectively. The FTIR spectra confirmed the formation of stable tetragonal SnO₂, and the vibrational behavior of the chemical bonds was also investigated.

Keywords: Tin (IV) oxide nanoparticles (SnO₂), Molybdenum disulfide nanoparticles (MoS₂), XRD, SEM, FTIR

Introduction

Tin dioxide (SnO₂), an n-type wide-bandgap semiconductor with a bandgap of (3.6–4.0 eV), has acquired significance in nanotechnology owing to its exceptional optoelectronic characteristics, elevated carrier mobility, and chemical stability [1, 9]. Its versatility includes applications in gas sensing [5, 6], photocatalysis [10–14], energy storage [4, 15], and solar cells [9], enabled by its adjustable surface shape and defect-mediated functions [2, 17]. Recent studies highlight the efficacy of SnO₂ in hybrid composites, where synergistic interactions improve charge separation and interfacial activity, essential for environmental remediation and energy conversion [4, 13]. SnO₂-based heterostructures exhibit enhanced photocatalytic degradation of organic contaminants under visible light, underscoring their potential to tackle energy and environmental issues. Molybdenum disulfide (MoS₂), a layered transition metal dichalcogenide, improves SnO₂ due to its high surface-to-volume ratio, tunable bandgap (1.2–1.9 eV), and catalytic edge sites [16, 21]. The combination of MoS₂ and SnO₂ employs interfacial band alignment, enhancing electron-hole separation and photoresponse [14, 15]. Previous studies have demonstrated the production of composites through sol-gel and chemical vapor deposition (CVD) methods; however, these techniques often involve high energy costs, poor stoichiometric control, and limited scalability. Hydrothermal synthesis presents a practical alternative, enabling precise control over morphology, facilitating low-temperature processing, and promoting environmentally sustainable practices [19, 23]. Nonetheless, the regulated hydrothermal synthesis of SnO₂/MoS₂ nanocomposites with systematic compositional variation remains insufficiently explored, particularly regarding structural evolution and morphological interdependence [4, 13]. Recent research has revealed several significant deficiencies in the comprehension of SnO₂/MoS₂ systems: (i) the mechanisms regulating crystallite growth during hydrothermal treatment are insufficiently clarified [9,13]; (ii) enduring inconsistencies persist between crystallite sizes measured by XRD and particle sizes observed through SEM, frequently ascribed to agglomeration but seldom quantified [36, 41]; and (iii) the impacts of lattice strain and full-width at half maximum on charge transport have not been comprehensively examined [22, 35]. Resolving these difficulties is crucial for

enhancing the design of composites for practical devices. Asaithambi et al. [4] and Zhang et al. [14] exhibited improved supercapacitor and photocatalytic performance in $\text{SnO}_2/\text{MoS}_2$ systems; nevertheless, their approaches were deficient in the precise compositional gradients required to establish a conclusive correlation between structure and characteristics. This study addresses these gaps by utilizing controlled hydrothermal synthesis to produce $\text{SnO}_2/\text{MoS}_2$ nanocomposites with 10–30 M% MoS_2 content. This study seeks to achieve three objectives: (i) employ XRD, SEM, and FTIR to elucidate the structural and morphological evolution of nanocomposites; (ii) quantify discrepancies between crystallite (XRD) and particle (SEM) sizes and correlate them with agglomeration phenomena; and (iii) assess lattice parameter shifts and functional group interactions to identify strain-induced factors. We illustrate the efficacy of our hydrothermal method in generating homogeneous composites with tailored surfaces by comparing it to sol-gel and CVD approaches [8, 18]. This represents progress in the design of scalable nanomaterials for energy applications.

Experimental

The nanocomposites of SnO_2 - MoS_2 were synthesized by using an autoclave-assisted synthesis process, named hydrothermal synthesis. All the reagents were analytical grade, purchased from Sigma Aldrich, and used without further purification. The reagents involved in this process were stannic chloride pentahydrate [$\text{SnCl}_4 \cdot 5\text{H}_2\text{O}$] as the precursor material and SnO_2 (AR grade, 99% pure, Sigma Aldrich Ltd., USA-made). Ammonium heptamolybdate tetrahydrate (AR grade, > 98% pure, Sigma Aldrich Ltd., USA made) as a precursor of MoS_2 materials was added to the starting solution as a precursor for composite material. Thiourea [$\text{CH}_4\text{N}_2\text{S}$] as the precursor of the sulfur source (AR grade, > 98% pure, Sigma Aldrich Ltd., USA made). The other chemicals that were used for the preparation of samples, were concentrated sodium hydrogen carbonate (NaHCO_3) (AR grade, > 98% pure, Sigma Aldrich Ltd., USA made), vitamin C, and ethanol ($\text{C}_2\text{H}_5\text{OH}$).

SnO_2 nanoparticles preparation

Tin (IV) chloride pentahydrate [$\text{SnCl}_4 \cdot 5\text{H}_2\text{O}$] was used as the precursor for synthesizing SnO_2 nanoparticles. A solution was prepared by dissolving 16.28 grams of $\text{SnCl}_4 \cdot 5\text{H}_2\text{O}$ and 2.91 grams of citric acid in 240 mL of deionized (DI) water. This solution was stirred using a magnetic stirrer at 60–75 rpm for 1 hour at room temperature to achieve homogeneity. Then, 15.62 grams of sodium hydrogen carbonate was added, followed by another 30 minutes of stirring. Afterward, 10 mL of deionized water containing 6.084 grams of dissolved vitamin C was added, and the solution was stirred for an additional 50 minutes. The resulting solution was transferred to a Teflon-lined stainless-steel autoclave, sealed, and heated at 140°C under a pressure of 30 psi (equivalent to 2.04138 atm) for 20 hours. After hydrothermal treatment, the system was allowed to cool to room temperature. The SnO_2 precipitates formed were separated by filtration, washed five times with distilled water to remove residual ions, and then washed with ethanol to aid in water removal. Finally, the product was dried at 80°C in an electric oven for 8 hours, yielding SnO_2 nanoparticles in powder form.

Chemical reaction:



MoS_2 nanosheets preparation

Ammonium heptamolybdate tetrahydrate [$(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$] (7.721 grams) and citric acid were dissolved in 240 mL of DI water to prepare the MoS_2 precursor solution. The solution was stirred using a magnetic stirrer at 60–75 rpm and heated at 90°C for 1 hour to ensure homogeneity. Several drops of ammonia solution (NH_4OH) were added dropwise to adjust the pH to around 4. Then, 7.54 grams of thiourea was added, followed by 30 minutes of continuous stirring. The resulting solution was transferred to a Teflon-lined stainless-steel autoclave, sealed, and heated at 140°C and 30 psi for 20 hours. After the hydrothermal treatment, the solution was cooled to room temperature, yielding black MoS_2 precipitates. These were separated by filtration, washed five times with distilled water, and rinsed with ethanol to assist in water removal. Finally, the product was dried at 80°C in an electric oven for 8 hours, resulting in MoS_2 nanosheets.

SnO₂/MoS₂ nanocomposite formation

The formation of SnO₂–MoS₂ nanocomposites was achieved by adding MoS₂ nanoparticles on SnO₂. The nanocomposites were prepared by using xM% SnO₂ (x = 90, 80, 70) and (100-x) M% MoS₂ weight ratio. Where M% represents the weight in percentage. In this synthesis technique, the amount of MoS₂ nanoparticle was dispersed in deionized water as shown in Table-2.1, followed by ultrasonication for around 30 minutes at 50 Hz. The prepared nanostructure was settled by centrifugation at 7000 rpm for 15 min to ensure good dispersion of MoS₂ nanoparticles. Subsequently, 90M% SnO₂, 80M% SnO₂, and 70M% SnO₂ weight amounts of SnO₂ nanoparticles were repeated in a solution containing MoS₂ nanoparticles and stirring. The obtained solution was shifted into a Teflon-lined stainless-steel autoclave. The autoclave was compactly closed and heated at 140° C with a pressure of 30 psi, which is equivalent to 2.04138 atm, for 20 hours, then allowed to cool to room temperature. After finishing the hydrothermal treatment, the obtained solution was black precipitates. The precipitates were separated by filtration and washed five times with distilled water for removal of ionic remains in the final products. The resulting products were further washed with ethanol to facilitate water evaporation and finally dried at 80° C in an electric oven for 8 hours, obtaining the SnO₂–MoS₂ nanoparticles.

By varying the MoS₂ content, a series of composites with different SnO₂:MoS₂ weight ratios were obtained:

Nanocomposite 1 – 90M% SnO₂ / 10M% MoS₂

Nanocomposite 2 – 80M% SnO₂ / 20M% MoS₂

Nanocomposite 3 – 70M% SnO₂ / 30M% MoS₂

Table 2.1: Combination ratio of the SnO₂ and MoS₂.

Ratio (M%)	SnO ₂ (g)	MoS ₂ (g)	Total (g)
90%:10%	6.3	0.7	7.0
80%:20%	5.6	1.4	7.0
70%:30%	4.9	2.1	7.0

Result and Discussions

In this work, pure SnO₂ and SnO₂–MoS₂ nanocomposites were synthesized via a hydrothermal method using a stainless-steel autoclave. The reaction temperature and pressure were maintained at 140 °C and 30 psi, respectively. The samples were kept in the autoclave for approximately 20 hours. After completing the hydrothermal cycle, the samples were dried in an electric oven, yielding pure SnO₂ and SnO₂–MoS₂ nanocomposite powders. These nano powders were characterized using several techniques. X-ray diffraction (XRD) was used for structural and phase identification, scanning electron microscopy (SEM) was employed to evaluate the surface morphology and particle shape, and Fourier-transform infrared spectroscopy (FTIR) was used to identify functional groups in the pure and composite materials.

Crystallographic structural properties

The structural properties of the synthesized SnO₂ and SnO₂–MoS₂ nanocomposites were investigated using an X-ray powder diffractometer (X'Pert PRO, Philips PW3040). From the XRD data, the full width at half maximum (FWHM) and crystallite size (D) were determined. XRD patterns were used to confirm the crystallographic phases of the as-synthesized products. Figure 3.1 shows the XRD patterns of pure SnO₂ nanoparticles and SnO₂–MoS₂ nanocomposites with varying MoS₂ weights (M%). All diffraction peaks observed for pure SnO₂ were indexed to the tetragonal phase (JCPDS card no. 41–1445) [20], with lattice constants a = b = 4.74 Å and c = 3.19 Å. Prominent peaks at (110), (101), (211), and (301) planes appeared at Bragg angles of 26.67°, 33.67°, 51.80°, and 64.60°, respectively. Additionally, MoS₂ peaks at (002), (100), and (101) planes were observed [21]. Low-intensity diffraction peaks appeared at (200) in all pure and composite samples. No impurity peaks were detected, indicating successful formation of SnO₂–MoS₂ composites. The peak intensities decreased with increasing MoS₂ content, and enhanced intensity of the (110), (101), and (211) planes indicated highly anisotropic growth [13, 20, 22, 23].

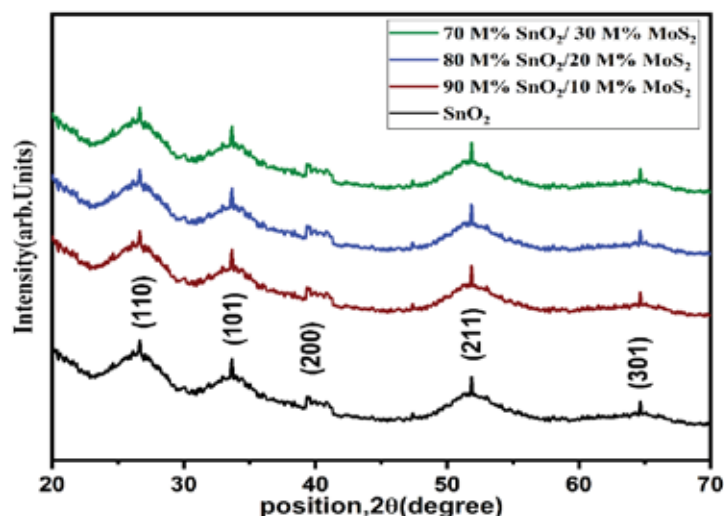


Figure 3.1 X-ray diffraction patterns of (a) pure SnO_2 (black) 90 M% SnO_2 /10 M% MoS_2 (red), 80 M% SnO_2 /20 M% MoS_2 (blue) and 70 M% SnO_2 /30 M% MoS_2 (green) nanocomposites.

Lattice parameter

Crystal structures are made up of repeating units of atoms in well-defined locations in a lattice. To describe these structures, it is helpful to define the smallest unit of this structure. Which is called the unit cell. The unit cell is the smallest unit of a crystal structure that can be used to tile space and make the larger macroscopic structure. There are many shapes and patterns of unit cells. To describe these shapes, we are used lattice parameters or variables that describe the orientation of the unit cell. The typical lattice parameters that are used in the length of each side, which is typically labelled a , b , and c , and the angles between these sides, which generally are labeled α , β , and γ . The lattice constants ' a ', ' b ', and ' c ' of the tetragonal structure of SnO_2 can be determined from the inter planer spacing of the $\{h k l\}$ plane with the miller indices h , k , and l by using the flowing equation [24, 25].

$$\frac{1}{d_{hkl}^2} = \frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2} \dots \dots \dots (3.1)$$

Where, d_{hkl} is the inter-planer spacing of the plane $\{h k l\}$. The inter-planer spacing of given Miller indices h , k and l . The inter-planer space d_{hkl} values were calculated by using the Bragg's equation [26]

$$2d_{hkl} \sin \theta_{hkl} = n\lambda \dots \dots \dots (3.2)$$

Where ' n ' is the order of diffraction (usually $n=1$) and ' λ ' is the X-ray wavelength of Cu $K\alpha 1$ radiation ($\lambda=1.5406 \text{ \AA}$) and ' θ_{hkl} ' is the Brags diffraction angle.

Table 3.1: Diffraction angle, $2\theta_{hkl}$ (degree) of pure SnO_2 and $\text{SnO}_2\text{--MoS}_2$ nanocomposites.

Samples	Braggs diffraction angle $2\theta_{hkl}$ (deg)			
	20	20	20	20
SnO_2	26.67	33.67	51.8	64.6
90M% $\text{SnO}_2\text{--}10\text{M}\%$ MoS_2	26.64	33.63	51.78	64.57
80M% $\text{SnO}_2\text{--}20\text{M}\%$ MoS_2	26.69	33.68	51.84	64.62
70 M% $\text{SnO}_2\text{--}30\text{M}\%$ MoS_2	26.63	33.69	51.79	64.59

In Table 3.1 and Table 3.2, the calculated diffraction angles and interplanar distances were tabulated. The hkl and d_{hkl} values for the Pure and deposited at different percentage concentrations are well matched with the values found in the JCPDS card. The calculated values of lattice parameters of pure SnO_2 lattice constants were $a = b = 4.74 \text{ \AA}$ and $c = 3.19 \text{ \AA}$ for tetragonal phase which are in good agreement with standard results and previous reported values [11, 27, 28, 29, 30].

Table 3.2: Inter planar distance d_{hkl} (nm) of pure SnO_2 and $\text{SnO}_2\text{-MoS}_2$ nanocomposites.

Samples	Inter planner distance, d_{hkl} (nm)			
	d_{110}	d_{101}	d_{211}	d_{301}
SnO_2	0.33397	0.26597	0.176337	0.14416
90M% SnO_2 -10M% MoS_2	0.33652	0.26374	0.17267	0.14753
80M% SnO_2 -20M% MoS_2	0.33537	0.26745	0.17569	0.14376
70M% SnO_2 -30M% MoS_2	0.33643	0.26478	0.17634	0.14673

Table 3.3: Lattice parameters and volume of unit cell of pure SnO_2 and $\text{SnO}_2\text{-MoS}_2$ nanocomposites obtained from XRD spectra.

Samples	Lattice parameter			b/a	b/c	c/a	Volume $V(\text{\AA}^3)$	Ref.
	a ($\text{\AA}$)	b ($\text{\AA}$)	c ($\text{\AA}$)					
SnO_2	4.7456	4.7456	3.1930	1	1.4862	0.6728	71.9086	[31]
90M% SnO_2 -10M% MoS_2	4.7354	4.7354	3.1892	1	1.4848	0.6734	71.5146	[32]
80M% SnO_2 -20M% MoS_2	4.7543	4.7543	3.1934	1	1.4887	0.6716	72.1816	[33]
70M% SnO_2 -30M% MoS_2	4.7646	4.7646	3.1827	1	1.4970	0.6679	72.2518	[33]

According to Tables 3.1 and 3.2, the diffraction angle and interplanar spacing distance somewhat as the MoS_2 content in the SnO_2 matrix vary. The lattice parameters are observed to be dependent on the SnO_2 percent concentration of MoS_2 . In Table 3.3 SnO_2 and $\text{SnO}_2\text{-MoS}_2$ nanocomposites, the unit cell volume gradually increases as the percent concentration of MoS_2 increases. $\text{SnO}_2\text{-MoS}_2$ has the lowest unit cell volume of $71.9086 (\text{\AA})^3$ and the most significant unit cell volume of $72.2518 (\text{\AA})^3$ of 70M% SnO_2 -30M% MoS_2 percent.

Full-width at half maximum (FWHM)

The width of a line form at half of its highest amplitude is called the full width at half maximum (FWHM). The half-width at half maximum (HWHM), also known as the Resolving Resolution, is a closely related metric that is half of the FWHM. FWHM is the full-width at half maximum and θ is the Bragg angle. FWHM was calculated from the peak having the highest intensity in all the samples [34]. The FWHM is used to define resolution, and while the concept is simple, it is a critical quantity. If the FWHMs of two peaks overlap, they are unresolvable and appear to be one peak. In other words, it is the width of a spectrum curve measured between those points on the y-axis that are half of the maximum amplitude. FWHM is applied to such phenomena as the duration of pulse waveforms and particular width of sources used for optical communications and the resolution of spectrometers. The FWHM is a very an essential parameter that helps to analyze the X-ray diffraction patterns.

Table 3.4: Different FWHM, β_{hkl} (deg.) values pure SnO_2 and $\text{SnO}_2\text{-MoS}_2$ nanocomposites.

Samples	Fullwidth at half maximum, β (degree)			
	β	β_{101}	β	β
SnO_2	0.39604	0.38629	0.473045	0.666372
90M% SnO_2 -10M% MoS_2	0.38527	0.36278	0.46245	0.66534
80M% SnO_2 -20M% MoS_2	0.37854	0.35535	0.45834	0.66067
70M% SnO_2 -30M% MoS_2	0.37253	0.35094	0.45123	0.65545

The values of FWHM measured in degree of pure SnO₂ and SnO₂-MoS₂ nanocomposites are listed in Table 3.4. These values of FWHM are used to calculate the crystallite size. The FWHM value can be found to fit with the Lorentzian function by origin software. With rising MoS₂ concentration, the whole breadth at half maximum value steadily decreases. As a result, the XRD peaks of pure SnO₂ and SnO₂-MoS₂ nanocomposites from a higher to a lower angle as the MoS₂ concentration increases.

Crystallite size (D)

The mean size of single-crystal nanoparticles or crystallites in nanocrystalline bulk materials can be determined using X-ray diffraction. Paul Scherrer was the first to examine the influence of particle size limitations on X-ray diffraction patterns, and his findings were reported in a publication that included the Scherrer equation. This equation, however, appears to be incorrectly referred to as the 'Debye-Scherrer equation [35].

Where, D , λ , k , β_{hkl} , θ_{hkl} are the crystallite size, the wavelength of X-ray radiation ($\lambda = 1.5406 \text{ \AA}$ for Cu- α), the shape factor and constant ($k = 0.90$), the full width half maximum (FWHM) of the Bragg's diffraction peak (in radians) located at 2θ and the Bragg angle (in degrees), respectively. In table 5.6, the various crystallite size values are described using Debye-Scherrer's approach. Size broadening is independent of the order of a reflection, as shown by equation (3.3). As the concentration of MoS₂ rises, so does the average crystallite size is increased [9, 36]. This result is in line with past investigations on pure SnO₂ and SnO₂-MoS₂ nanocomposites [9].

Table 3.5: Crystallites size of pure and SnO₂- MoS₂ nanocomposites.

Samples	Crystallites size, d_{hkl} (nm)				Average Crystallites size d_{hkl} , (nm)
	d_{110}	d_{101}	d_{211}	d_{301}	
SnO ₂	20.62	21.49	18.67	14.04	18.70
90M%SnO ₂ -10M%MoS ₂	21.19	22.87	19.09	14.12	19.31
80M%SnO ₂ -20M%MoS ₂	21.56	23.36	19.27	15.22	19.85
70M%SnO ₂ -30M%MoS ₂	22.92	23.65	20.57	16.35	20.87

Surface Morphological Characteristics

Morphology

Scanning electron microscopy (SEM) is one of the most extensively utilized methods for analyzing nanomaterials and nanostructures. The signals generated by electron-sample interactions provide information about the sample, such as the sample's surface shape. grain size of nanocrystals mainly depends upon the relative rates of nucleation and growth processes, as well as the extent of agglomeration. The pH of the reaction mixture largely affects the size, shape, and morphology of the SnO₂ nanoparticles [37]. In this work, SnO₂ nanoparticle is synthesized by hydrothermal methods by adjusting PH around 7.5 by adding several drops of ammonia solution (NH₄OH). Prepared SnO₂, MoS₂ and SnO₂-MoS₂ nanocomposites are investigated by SEM model: JSM 7600F JEOL.

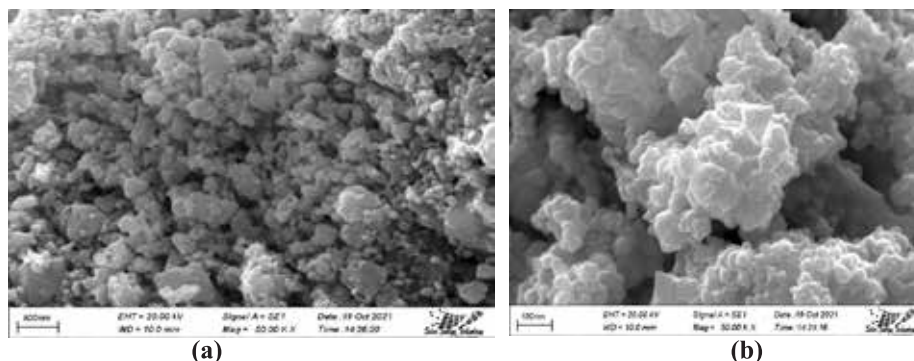


Figure 3.2 SEM micrographs of pure (a) SnO₂ nanoparticles (b) MoS₂ nanoparticles

It reveals randomly arranged irregular spherical sized [38, 39] compact grains with sponge like structure. Some deep pits are observed in morphology. Clustering of particles seems to have occurred on the surface. In this image, cubic structures can be easily seen. It is now well established that different particle morphologies of nano-SnO₂, e.g., nanotube, nanobelt, and nanorod, uniform spherical and non- uniform spherical shape can be obtained under different synthesis conditions. The catalysts are formed of aggregate particles with a varied size distribution ranging between 22 and 31 nm nanoparticles, as shown by SEM micrographs of SnO₂ and SnO₂-MoS₂ nanoparticles. The agglomeration effect has an impact on the size of the particles. Agglomeration Occurs in Nanocomposites due to High Surface Energy, Van der Waals Forces and Solvent Effects or Drying During Sample Preparation [43].

Pure SnO₂ nanoparticles

Figure 3.2(a) shows the morphology of pure SnO₂ nanoparticles. The irregular spherical shaped SnO₂ nano particles with approximately non uniform size are shown in this SEM micrographs. The size was measured by ImageJ software. The average diameter and area of SnO₂ are 22.34nm and 433.93 nm², respectively the particles were agglomerated, as seen in the SEM image. This result is in line with past investigations on pure SnO₂ nanoparticles [40, 41].

Pure MoS₂ nanoparticles

Figure 3.2(b) shows the SEM micrograph of pure MoS₂ of nanoparticles synthesized using hydrothermal method. Many nanoparticles, especially the larger ones, exhibit a non-uniform growth shaped morphology. These non-uniform nanoparticles are aggregated each other. The average diameter and area of MoS₂ are 37.32nm and 582.5 nm².

SnO₂/MoS₂ composites

Figure 3.3 (a-c) shows the SEM micrographs of 90 M% SnO₂-10 M% MoS₂, 80 M% SnO₂-20 M% MoS₂ and 70 M% SnO₂-30 M% MoS₂ respectively. There are many nanoparticles. They are aggregated each another. Among them some nanoparticles are larger and clear shaped.

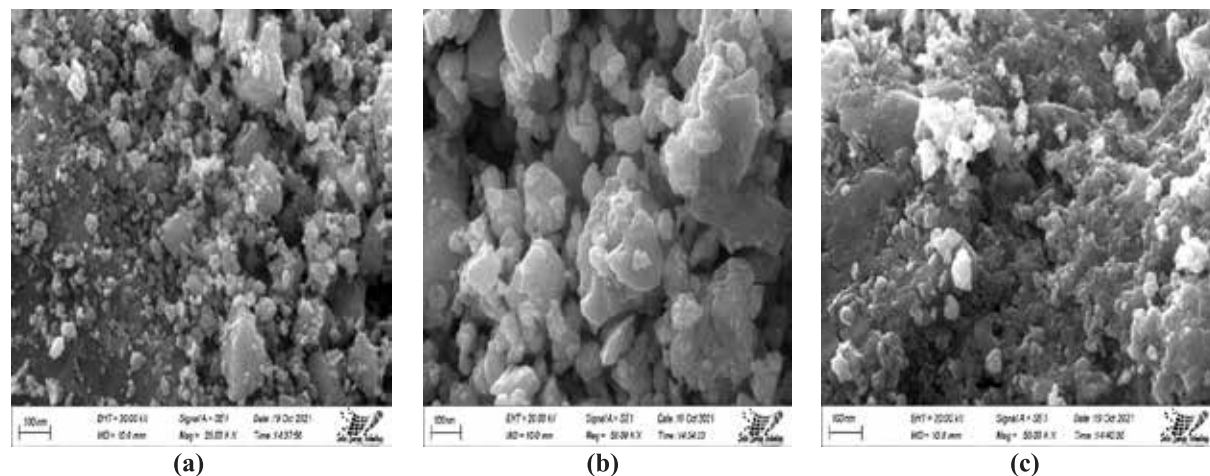


Figure 3.3 SEM micrographs of (a) 90 M% SnO₂-10 M% MoS₂ (b) 80 M% SnO₂-20 M% MoS₂ and (c) 70 M% SnO₂-30 M% MoS₂.

The average diameter are 25.62 nm, 27 nm and 31.21 nm respectively. The average area of the samples is 462.32 nm², 503.2 nm² and 548.32 nm² respectively. The average diameter and area of the SnO₂-MoS₂ nanocomposites are gradually increased with the increasing of MoS₂ M%.

Functional group analysis

FTIR analysis is used to identify organic, inorganic, and polymeric materials utilizing infrared light for scanning the samples. Alterations in the characteristic pattern of absorption bands indicate a change in the material composition. FTIR helps identify and characterize unknown materials, detect contaminants in a material,

find additives, and identify decomposition and oxidation. FTIR can collect high spectral resolution data over a wide range, usually between 4000 cm^{-1} and 400 cm^{-1} for mid-IR region wavelength and between 10,000 cm^{-1} and 4000 cm^{-1} for near-IR region wavelength. Fig. 3.4 shows the FTIR spectra of pure SnO_2 and $\text{SnO}_2\text{-MoS}_2$ nanocomposites. The strong O-H stretching vibration peak is observed at around 3428 cm^{-1} , and O-H bending vibration is appeared at 1646 cm^{-1} . The weak absorption peak is observed at 2935 cm^{-1} is related to the mode of C-H stretching vibration. The antisymmetric Sn-O-Sn mode and terminal Sn-O mode of vibration peak is attributed at 648 cm^{-1} and 550 cm^{-1} , respectively. In the case of $\text{SnO}_2\text{-MoS}_2$ structures, only SnO_2 related absorption peaks are observed. There is no characteristic peak of MoS_2 , which may be due to the small MoS_2 incorporated into these composites. This result is in line with past investigations on pure SnO_2 and $\text{SnO}_2\text{-MoS}_2$ nanocomposites as reported in the published articles [4, 9, 42].

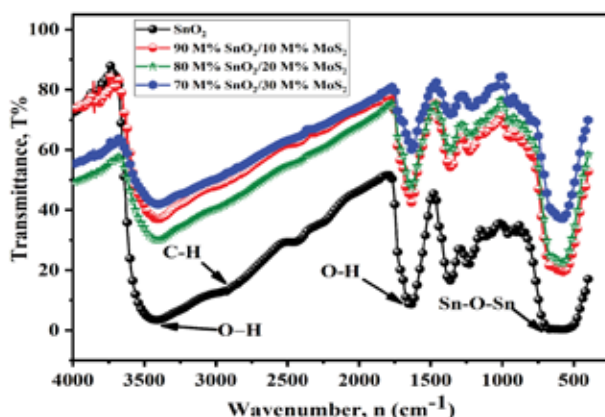


Figure 3.4: FTIR transmittance spectra of SnO_2 , 90M% SnO_2 -10M% MoS_2 , 80M% SnO_2 -20M% MoS_2 and 70M% SnO_2 -30M% MoS_2 .

Conclusion and Future Directions

In this study, pure SnO_2 and $\text{SnO}_2\text{-MoS}_2$ nanocomposites were successfully synthesized using a hydrothermal method. Characterization was conducted using XRD, SEM, and FTIR techniques. XRD analysis confirmed the tetragonal phase of SnO_2 and allowed determination of lattice strain and crystallite size using the Williamson–Hall and Scherrer methods, respectively. Crystallite sizes increased from 18.70 nm to 20.87 nm with higher MoS_2 content. SEM images revealed irregular spherical morphologies and increasing particle size with MoS_2 incorporation. The difference between crystallite and particle sizes may be attributed to agglomeration. FTIR spectra identified O–H, C–H, and Sn–O–Sn vibrational modes. The future prospects of this research include the determination of the optical bandgap of $\text{SnO}_2\text{-MoS}_2$ nanocomposites using UV-vis spectroscopy. Additionally, the electrical conductivity of the nanocomposites can be measured by preparing thin films and employing the four-point probe method. These investigations may further support the potential application of the material in solar cell technology.

Authors Contributions

Conceptualization, study design and writing-original draft were contributed by Md. Mostafa Kamal. Data entry, table and figure preparation were done by Md. Tushar Ahmed and Gazi Ishmam Hasan. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that they do not have any conflict of interest.

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