Morphological analysis of Tungsten Diselenide Nanosheet for Optoelectronic Applications

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Abstract

Tungsten diselenide (WSe2) nanosheets have become a potential material for optoelectronic applications because of its special electrical and optical characteristics. The structural characterizations of WSe2 nanosheets produced by the hydrothermal technique is the main objective of this work. The distribution of nanoparticles, surface shape, and chemical bonding were examined using Fourier-transform infrared spectroscopy (FTIR) and scanning electron microscopy (SEM). The effective fabrication of WSe2 nanosheets with an average particle size of around 60 nm was verified by SEM examination. The material's purity was confirmed by FTIR spectra, which showed distinctive peaks connected to W-Se, W-O-W, and hydroxyl groups. The results show that WSe2 nanosheets have favorable structural characteristics for possible use in optoelectronic devices such solar cells, light-emitting diodes, and photo detectors.

Introduction

The remarkable electrical, optical, and mechanical features of transition metal dichalcogenides (TMDs) have attracted a lot of attention [1]. Among these, tungsten diselenide (WSe_2) is a layered substance with special two-dimensional (2D) properties that make it an excellent choice for optoelectronic applications of the future [2]. Materials like WSe_2 are being investigated more and more for their potential in solar cells, transistors, and photodetectors as a result of the development of flexible electronics and nanoelectronics [3].

WSe_2 is a member of the transition metal dichalcogenide (TMD) family and resembles graphene in its hexagonal layered structure [4]. Nevertheless, WSe_2 has a direct bandgap in its monolayer form, which makes it extremely effective for optoelectronic applications in contrast to graphene, which has a zero bandgap. WSe_2 is a potential material for application in photodetectors, light-emitting devices, and other nanoscale electronic components because of its bandgap, which permits strong light-matter interactions [5]. The shape, chemical makeup, and structural integrity of WSe_2 all have a significant impact on its characteristics [6]. To produce high-quality WSe_2 nanosheets, a number of synthesis techniques have been investigated, such as hydrothermal synthesis, mechanical exfoliation, and chemical vapor deposition (CVD). Because of its affordability, scalability, and capacity to generate highly crystalline nanosheets with regulated thickness and shape, the hydrothermal technique has become the most preferred of these [7]. The thickness and size of WSe_2 nanosheets may now be precisely controlled because to recent developments in nanotechnology, which enables researchers to customize the materials' electrical and optical characteristics for particular uses [8]. The performance of WSe_2-based devices has been further improved by the addition of doping, in a semiconductor material [9]. WSe_2 sheet are used for their direct band gap and 2D structure which can improve the optical and electrical properties [10]. An in-depth examination of the structural properties of WSe_2 nanosheets produced using the hydrothermal process is the goal of this work [11]. We examine the microstructure, particle size distribution, and chemical bonding of the produced nanosheets using Fourier-transform infrared spectroscopy (FTIR) and scanning electron microscopy (SEM). Optimizing WSe_2's performance in real-world applications requires an understanding of these fundamental characteristics.

Experimental Methods

Synthesis of WSe2 Nanosheets by hydrothermal process

The hydrothermal approach, which offers a quick and effective means to create high-quality nanosheets, was used to synthesis WSe_2 nanosheets. This procedure involved dissolving precursors of tungsten as 99.99 % purity of tungsten VI chloride (WCl_6) and selenium source as 99.99 % purity of sodium selenide (Na_2Se). These precursors added in an appropriate solvent as deionized water as well as a reducing agent to speed up the reaction. After that, the solution was moved to a stainless-steel autoclave lined with Teflon, sealed, and heated for a certain amount of time (for example, 12 to 24 hours) at a regulated temperature between 150°C and 200°C. WSe_2 nanosheet nucleation and growth are encouraged by the high temperature and high pressure. The autoclave was allowed to naturally cool to ambient temperature once the reaction was finished, then centrifugation was used to gather the final product. After being repeatedly cleaned with ethanol and deionized water to get rid of any remaining contaminants, the resulting nanosheets were vacuum-dried at 60°C for further characterization.

Results and Discussion

Fourier-transform infrared spectroscopy (FTIR)

Fourier transform infrared spectroscopy (FTIR) is a technique used to obtain an infrared spectrum of absorption or emission of a solid, liquid or gas. A Fourier transform Infrared Spectroscopy FTIR spectrums of all samples were recorded in the range of 500 – 4000cm^{-1} to investigate the influence of samples preparation on chemical bonding between Tungsten Selenide (WSe_2) nanosheet. The region from 600 – 1500

cm^{-1} is called fingerprint region and this region only proved useful information about identification of metal-oxide bonding in inorganic compounds. In figure 1-4,

1. The peaks at 600, 603, 600 and 600 represent the W-Se bonding.
2. The peaks at 970, 942, 809 and 804 represents the W-O-W Bonding's.
3. The peaks at 1157, 1363, 1328, 1356, 1532, 1606, 1631 and 1662 represent the hydroxyls groups.
4. The peaks at 2362, 2359, 2352 and 2358 show us the alkyne double bonding peeks.

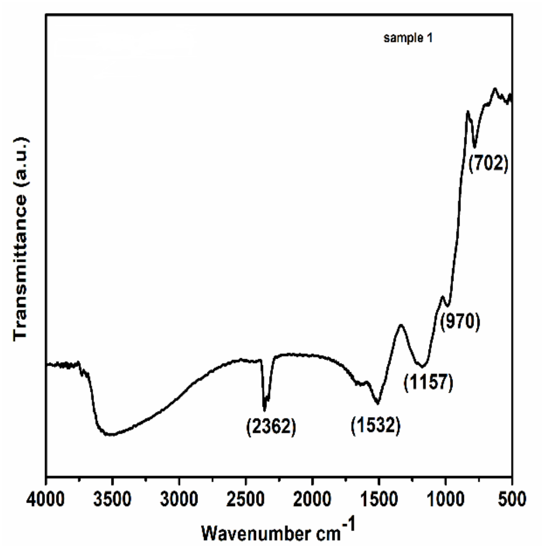

Figure 1. FTIR of WSe2

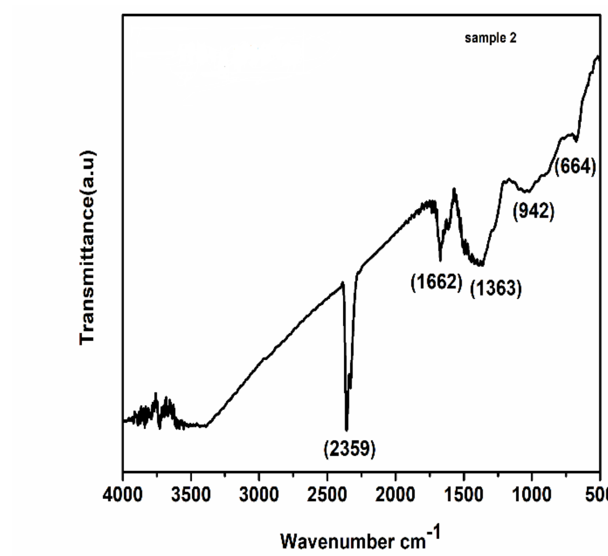

Figure 2. FTIR of WSe2

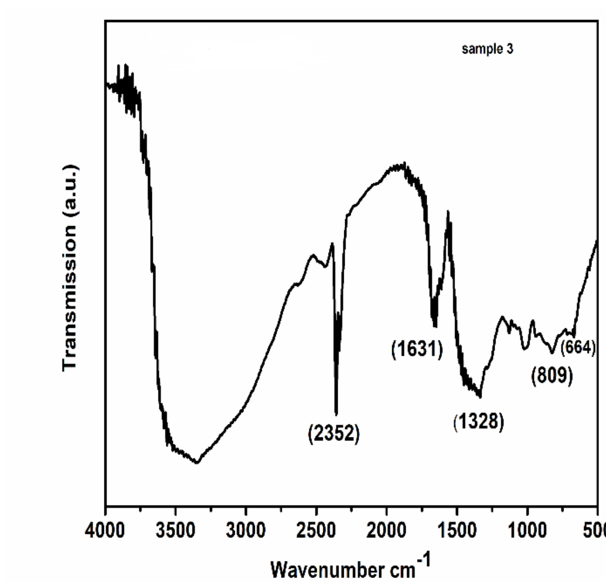

Figure 3.FTIR of WSe2

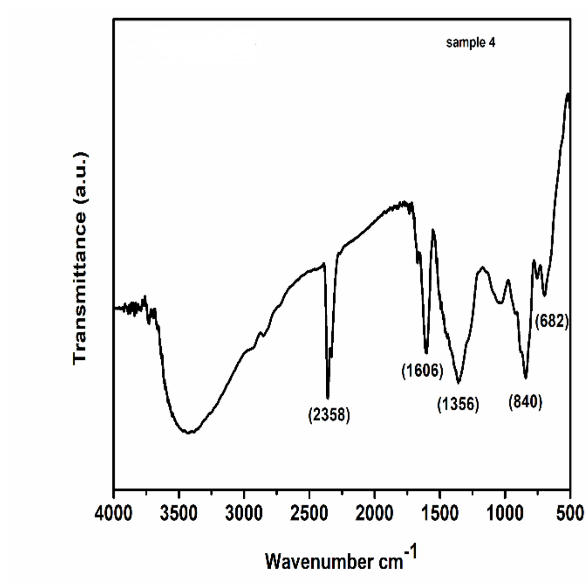

Figure 4. FTIR of WSe2

The results show that no impurities were found in the samples, and the samples were not oxidized during the synthesis of WSe_2 nanosheet. The Fourier transform infrared spectroscopy (FTIR) analysis is operated for the analysis of the functional groups attached to a material. This method includes the collection of interferogram of a sample by treating the infrared rays followed by a Fourier transform (FT) on the interferogram to obtain the spectrum.

Structural Analysis of Tungsten Selenide (WSe2) nanosheet (SEM)

Through SEM analysis, it was confirmed that the nanoparticles were successfully synthesized using the hydrothermal method. The Scanning Electron Microscope (SEM) is used to study the surface morphology and diameter of the nanoparticles. The surface features, morphology, and distribution of the nanoparticles were investigated using the SEM technique. Figure 5-8 shows the scanning electron microscopic images of Tungsten Selenide (WSe_2) nanosheets. To analyze the overall geometry of the nanoparticles, images were captured at different resolutions. Image analysis software indicated that the nanoparticles have an approximate diameter of 60 nm, as shown in Figure 5-8.

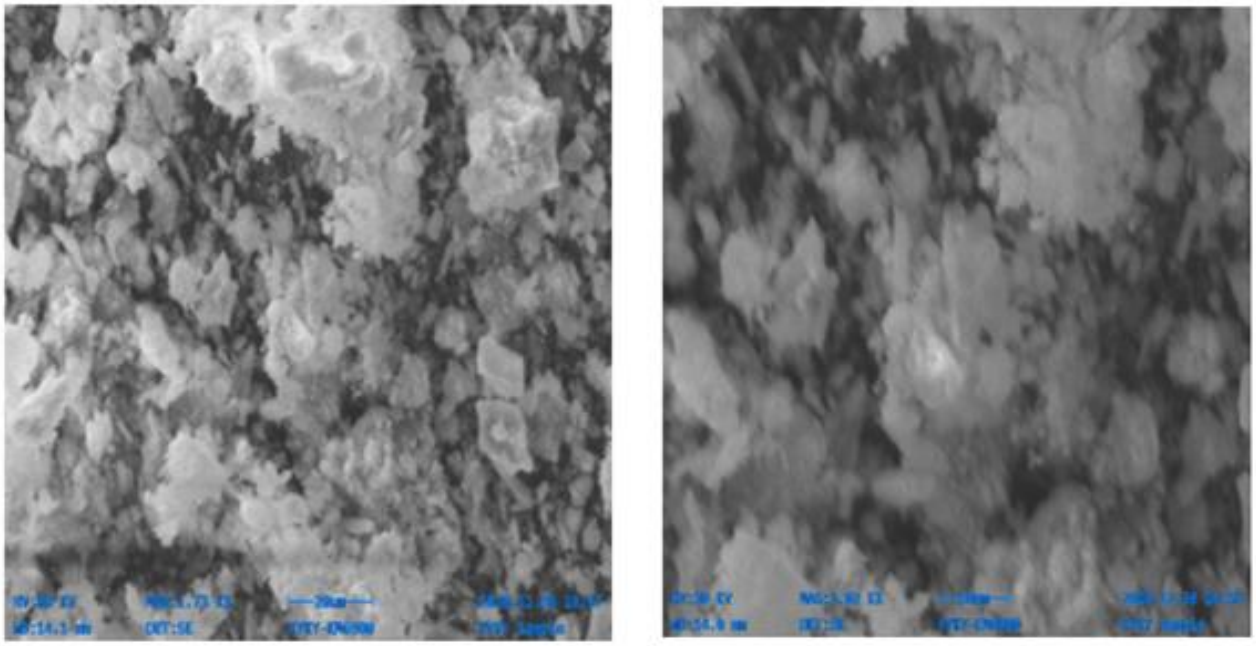

Figure 5. shows the SEM images of WSe2 nanosheet with different resolutions.

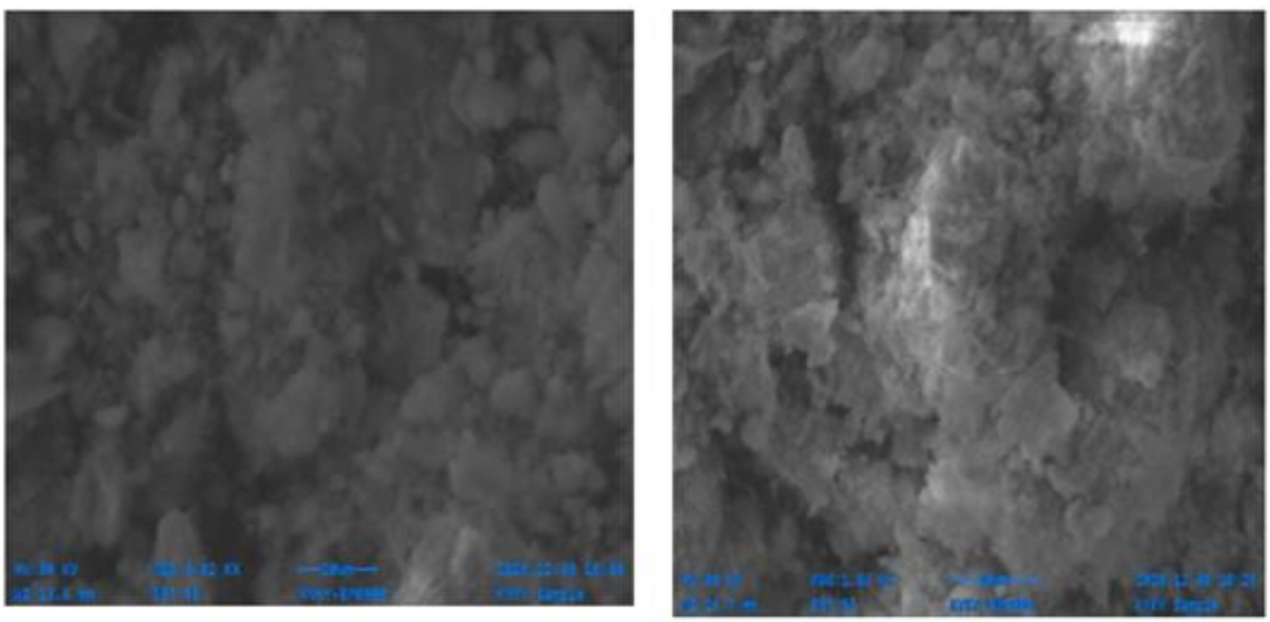

Figure 6. Shows the SEM images of WSe2 nanosheet with different resolutions.

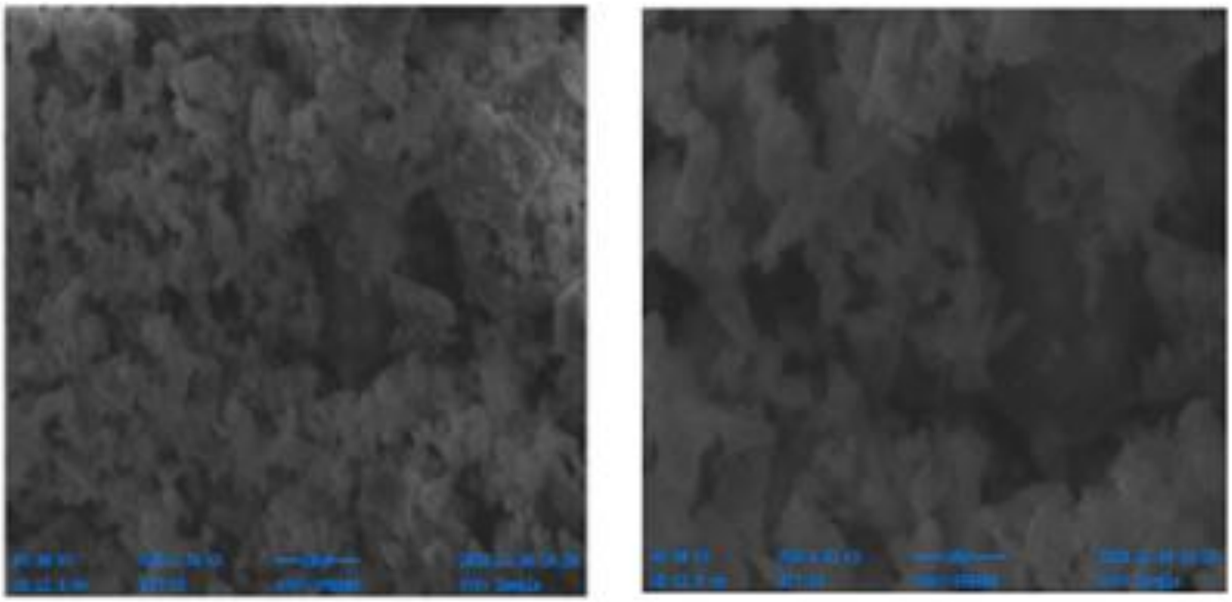

Figure 7. shows the SEM images of WSe2 nanosheet with different resolutions.

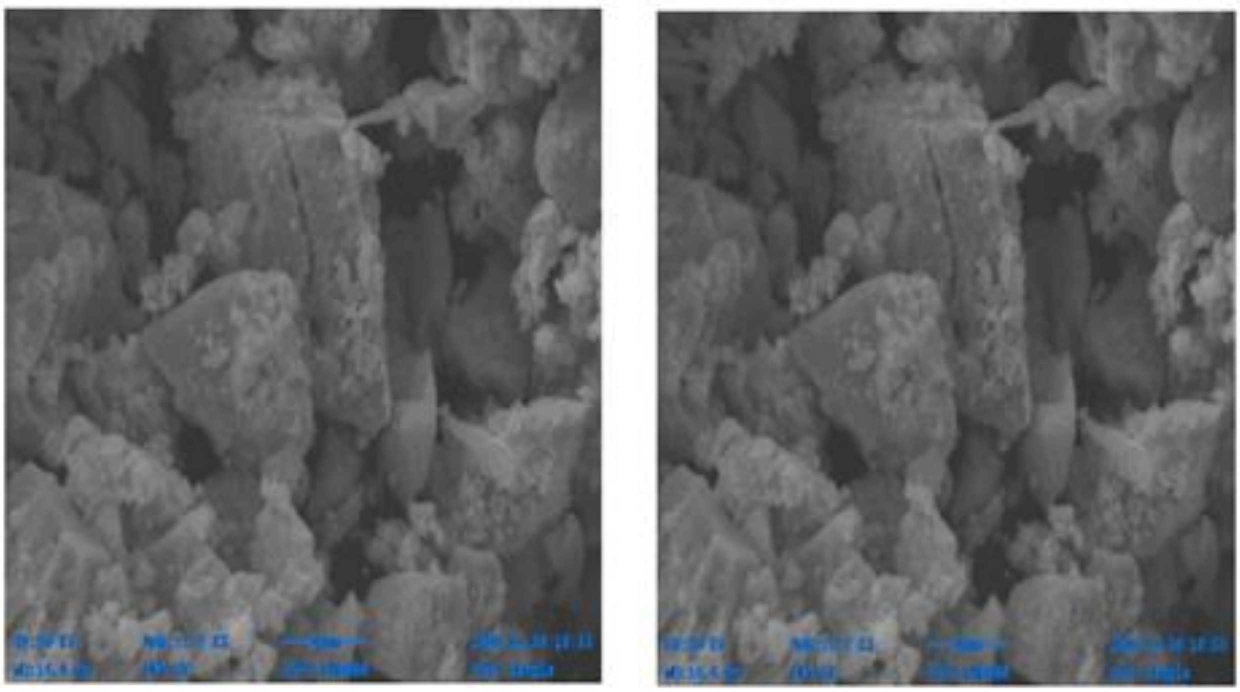

Figure 8. Shows the SEM images of WSe2 nanosheet with different resolutions.

Conclusion

This work utilized the hydrothermal approach to effectively produce and analyze WSe_2 nanosheets. While FTIR analysis validated the material's chemical composition and purity, SEM revealed the consistent shape and nanoscale size of the nanosheets. These results pave the way for further investigation into the electrical and optical properties of WSe_2 nanosheets, suggesting that they hold significant potential for use in optoelectronic devices.

References:

1. Wang, H., Yuan, H., Hong, S. S., Li, Y., & Cui, Y. (2015). Physical and chemical tuning of two-dimensional transition metal

dichalcogenides. Chemical Society Reviews, 44(9), 2664-2680.

2. Kumar, V. P., & Panda, D. K. (2024). 2D Material Tungsten Diselenide (WSe_2): Its Properties, Applications, and Challenges. Nanoelectronic Devices and Applications, 271-296.

3. Cheng, Q., Pang, J., Sun, D., Wang, J., Zhang, S., Liu, F., ... & Zhou, W. (2020). WSe_2 2D p-type semiconductor-based electronic devices for information technology: design, preparation, and applications. InfoMat, 2(4), 656-697.

4. Joseph, S., Mohan, J., Lakshmy, S., Thomas, S., Chakraborty, B., Thomas, S., & Kalarikkal, N. (2023). A review of the synthesis, properties, and applications of 2D transition metal dichalcogenides and their heterostructures. Materials Chemistry and Physics, 297, 127332.

5. Tao, L., Chen, Z., Li, Z., Wang, J., Xu, X., & Xu, J. B. (2021). Enhancing light-matter interaction in 2D materials by optical micro/nano architectures for high-performance optoelectronic devices. InfoMat, 3(1), 36-60.

6. Cheng, Q., Pang, J., Sun, D., Wang, J., Zhang, S., Liu, F., ... & Zhou, W. (2020). WSe_2 2D p-type semiconductor-based electronic devices for information technology: design, preparation, and applications. InfoMat, 2(4), 656-697.

7. Ndlwana, L., Raleie, N., Dimpe, K. M., Ogutu, H. F., Oseghe, E. O., Motsa, M. M., ... & Mamba, B. B. (2021). Sustainable hydrothermal and solvothermal synthesis of advanced carbon materials in multidimensional applications: A review. Materials, 14(17), 5094.

8. Azam, A., Yang, J., Li, W., Huang, J. K., & Li, S. (2023). Tungsten diselenides (WSe2) quantum dots: Fundamental, properties, synthesis and applications. Progress in Materials Science, 132, 101042.

9. Rastikian, J. (2021). Experimental investigation of charge and spin transport in WSe_2 connected with palladium contacts (Doctoral dissertation, Université Paris Cité).

10. Alzaid, M., Hadia, N. M. A., Shaaban, E. R., El-Hagary, M., & Mohamed, W. S. (2022). Thickness controlling bandgap energy, refractive index and electrical conduction mechanism of 2D Tungsten Diselenide (WSe_2) thin films for photovoltaic applications. Applied Physics A, 128(2), 94.

11. Azam, A., Yang, J., Li, W., Huang, J. K., & Li, S. (2023). Tungsten diselenides (WSe_2) quantum dots: Fundamental, properties, synthesis and applications. Progress in Materials Science, 132, 101042.