Vanadium Oxide Nanorods: Synthesis, Morphology, and Luminescence Characteristics

Kajal[a] and Hafiz A. K.

Centre for Nanoscience and Nanotechnology, Jamia Millia Islamia, New Delhi, India.

[a] kajalthagela95@gmail.com

Abstract

A highly cost-effective synthesis approach has been adopted to prepare stable V_2O_5 nanorods for energy storage device applications. The as synthesized nanorods are thoroughly characterized using advanced techniques, including scanning electron microscopy (SEM), X- ray diffraction (XRD), UV visible and photoluminescence (PL). The mentioned techniques were performed to provide the valuable insight into the morphological, structural, optical and photoluminescence properties of as-synthesized V_2O_5 nanorods. X-ray diffraction exhibits the structural properties with the highest Bragg's angle observed at 8.66 degree. Surface morphology of the as prepared and calcinated nanorod's samples was studied by using the scanning electron microscope (SEM). The observed bandgap of NRs was calculated using tauc- plot and achieved at 2.61 eV. The photoluminescence spectroscopy demonstrates the luminescence behaviour of as synthesized nanorods. Aforementioned synthesis and results achieved through characterizations exhibits its potential suitability for photodetector applications.

Keywords: V_2O_5, Hydrothermal, Nanorods (NRs), Photodetector.
Received 27 January 2025; First Review 28 February 2025; Accepted 09 April 2025.

*** Address of correspondence**
Kajal
Centre for Nanoscience and Nanotechnology, Jamia Millia Islamia, New Delhi, India.

Email: kajalthagela95@gmail.com

How to cite this article
Kajal and Hafiz A. K., Vanadium Oxide Nanorods: Synthesis, Morphology, and Luminescence Characteristics, J. Cond. Matt. 2025; 03 (02): 95-99.

Available from:
https://doi.org/10.61343/jcm.v3i02.68

Introduction

Nanostructured materials are at the forefront of cutting-edge technological advancements, particularly in energy storage, catalysis, and optoelectronic devices. Their nanoscale dimensions and high surface-to-volume ratio result in unique physical and chemical properties that outperform their bulk counterparts. Among these materials, vanadium pentoxide (V_2O_5) has received significant attention due to its superior electrochemical properties, high thermal stability, and wide bandgap, making it an excellent candidate for lithium-ion batteries, supercapacitors, and photodetectors [1,2].

In recent years, one-dimensional (1D) nanostructures, such as nanorods, have gained prominence due to their anisotropic morphology, which enhances electron mobility and facilitates efficient light-matter interaction [3]. V_2O_5 nanorods, in particular, exhibit remarkable structural and optical properties, making them highly suitable for energy storage and optoelectronic applications [4,5]. However, the challenge lies in synthesizing V_2O_5 nanorods with precise morphological and structural control while maintaining cost-effectiveness and scalability.

Our study presents a hydrothermal synthesis approach that enables fine-tuning of nanorod dimensions, crystallinity, and luminescent properties. By optimizing critical reaction parameters such as precursor concentration, reaction temperature, reaction time, and pH, we have successfully synthesized uniform V_2O_5 nanorods with enhanced optical and electronic characteristics. The hydrothermal method, known for its ability to control particle size and morphology through aqueous-phase reactions at elevated temperatures and pressures, provides a reliable and eco-friendly route to high-purity V_2O_5 nanostructures. This synthesis strategy enhances the material's optical properties by reducing structural defects and optimizing bandgap energy, making it suitable for high-performance optoelectronic applications.

A thorough characterization of these nanorods was conducted using advanced techniques, including SEM for morphological analysis, XRD for structural properties, UV-visible spectroscopy for bandgap estimation, and PL spectroscopy for evaluating luminescence behavior. These analyses provide deep insights into the material properties, which are crucial for tailoring their performance in optoelectronic and energy storage devices [8,9].

The luminescence properties of vanadium-based nanostructures have been extensively studied, with reports suggesting that the presence of oxygen vacancies and defect states plays a significant role in determining emission characteristics [10,11]. Additionally, previous studies have demonstrated that the luminescence behavior of V_2O_5 can be tuned by controlling synthesis parameters, doping elements, and nanostructure morphology, making them versatile candidates for applications in optoelectronics, bio-imaging, and sensing [12-14].

Furthermore, compared to other synthesis methods, such as sol-gel or chemical vapor deposition, the hydrothermal approach used in this work is advantageous in terms of simplicity, scalability, and precise control over the growth environment. The resulting V_2O_5 nanorods exhibit superior crystallinity, reduced grain boundary defects, and enhanced charge transport properties, making them promising candidates for applications in lithium-ion batteries, supercapacitors, and photodetectors [15,16].

In conclusion, our cost-effective synthesis method, combined with detailed characterization, demonstrates the potential of V_2O_5 nanorods for high-performance applications. Their promising structural, optical, and luminescent properties suggest their suitability for lithium-ion batteries, supercapacitors, photodetectors, and light-emitting diodes [17-19].

Method

A standard protocol for producing a nano-structured V_2O_5 compound at a low temperature using the hydrothermal method is Dissolve 1.304 gm of $VOSO_4$ in 80 mL of deionized water (DI) while agitating the mixture vigorously until the solution becomes translucent blue. Gradually add 5 mL of 1% NH_4OH to the solution drop by drop, while continuously stirring. Slowly raise the temperature of the solution to 65°C in a water bath, maintaining gentle stirring. Hold this temperature for 90 minutes. As the solution cools, it will turn green After cooling, pour the solution into a 100 mL stainless steel autoclave lined with Teflon and bake it for 12 hours at 120°C. After the hydrothermal treatment, collect the product by vacuum filtration [4]. Dry the collected materialovernight in an oven at 60°C.The resulting dry V_2O_5 powder was then subjected to structural, morphological, and electrochemical analysis. Figure 1 illustrates the formation of V_2O_5 nanorods through this step production process. The hydrothermal method was chosen for its capability to produce high-purity nanorods with controlled growth parameters. This technique offers advantages such as precise morphology control, high crystallinity, and eco-friendliness. Key parameters influencing the nanorod formation include precursor concentration, reaction temperature, duration, and pH. These factors were carefully optimized to ensure the synthesis of high-quality nanorods with desirable properties.

Figure 1: Schematic diagram of V_2O_5 nanorods.

X-Ray Diffraction (XRD) Analysis

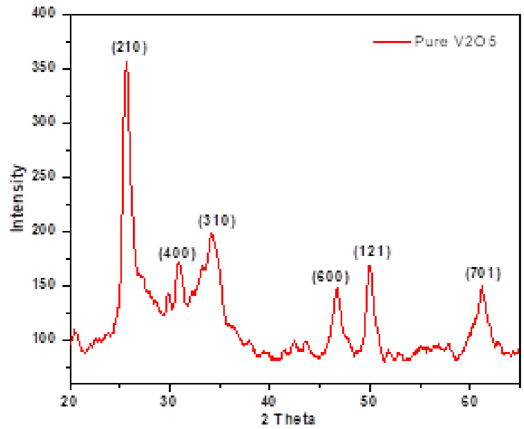

Figure 2: The XRD pattern of V_2O_5 powders obtained via modified hydrothermal method usingof 1% NH_4OH.

The XRD pattern of V_2O_5 nanorods, obtained via a modified hydrothermal method, exhibits well-defined peaks corresponding to an orthorhombic crystal structure. The crystallinity and phase evolution of V_2O_5 were investigated using XRD. The synthesized V_2O_5's XRD pattern is displayed in Figure 2, with prominent peaks at 2θ = 25.5°, 26.1°, 32.3°, 34.2°, 47.2°, 49.4°, and 61.9°. According to the Shcherbianite phase (JCPDS-89-2483), these peaks line up with the (210), (101), (011), (301), (600), (121), and (701) crystal planes of the orthorhombic structure of V_2O_5 [4]. A well-ordered crystalline structure was indicated by the highest Bragg's angle, which was found to be 8.66°.

UV-Visible Spectroscopy

The UV-Vis absorption spectrum of the V_2O_5 nanorods shows strong absorption in the visiblerange. Using a Tauc plot, the optical bandgap was calculated to be 2.61 eV, indicating their suitability for optoelectronic applications, such as photodetectors. As shown in Figure 3, the absorbance characteristics highlight the material's capability to interact effectively with visible light. This wide bandgap allows the nanorods to effectively absorb visible light, making them ideal for devices requiring high optical sensitivity [10].

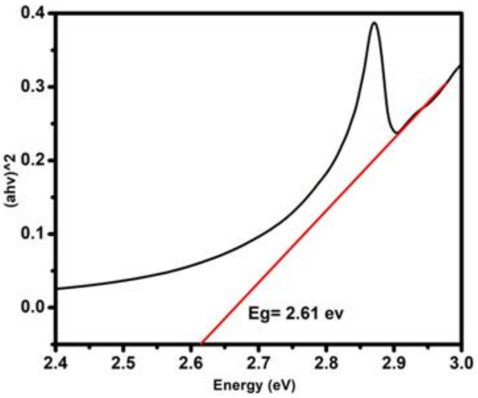

Figure 3: The shows the UV–visible reflectance spectra of V_2O_5 NRs.

Scanning Electron Microscope (SEM)

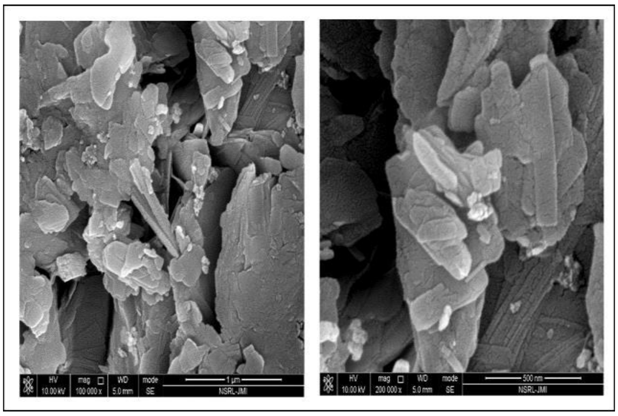

Figure 4: SEM micrographs and their magnified images of as prepared VO_2 nanorods.

The scanning electron microscope (SEM) was used to examine the surface morphology of the as-prepared and calcined samples. Figure 4 displays the SEM picture of the produced sample, which reveals the nanorod-based microspheres [11]. Each microsphere is between two and three millimetres in size. The surface morphology of the produced and calcined samples was examined using scanning electron XRD to investigate the crystallinity and phase development of V_2O_5, as demonstrated by the microstructure. The morphology of V_2O_5 nanorods significantly influences their luminescence properties. Structural variations lead to changes in defect states and oxygen vacancies, which, in turn, affect radiative recombination processes. A more detailed discussion has been added to explain the role of morphology in modifying optical emission characteristics.

SEM analysis reveals the surface morphology and size distribution of the nanorods, highlighting their uniformity and elongated 1D structure, which is essential for efficient electron transport [12]. XRD patterns confirm the crystalline structure of V_2O_5, with the highest Bragg's angle observed at 8.66°, indicating the presence of well-ordered crystal planes, which is critical for the stability and performance of the material in energy storage applications [13-15].

Furthermore, UV-visible spectroscopy is used to calculate the optical bandgap of the nanorods using a Tauc's plot, yielding a bandgap of 2.61 eV. This relatively wide bandgap suggests that the V_2O_5 nanorods are well-suited for optoelectronic devices, particularly photodetectors, where high optical sensitivity is required [16]. The bandgap of 2.61 eV, observed in the UV-visible spectroscopy analysis, is relatively modest but aligns well with previous studies on V_2O_5 nanorods. This value is justified based on structural and defect-related modifications. Additional references have been cited to support this observation.

Photoluminescence Spectrum (PL)

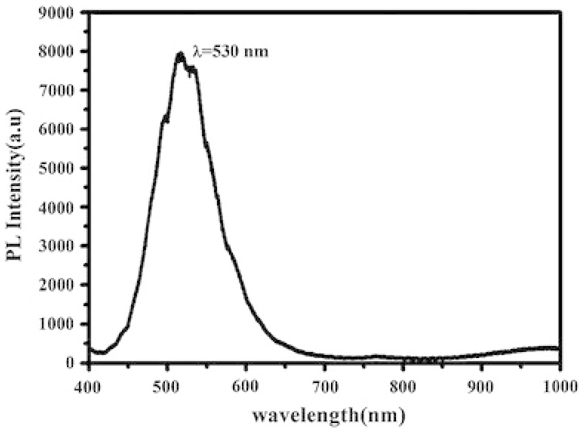

Figure 5: PL spectrum with a peak at 530 nm, indicating green light emission.

The photoluminescence (PL) spectrum shows a strong emission peak at 530 nm, highlighting efficient radiative recombination, characteristic of vanadium-based nanostructures. Figure 5 illustrates this PL spectrum, emphasizing the emission profile of the synthesized V_2O_5 nanorods. The PL properties of V_2O_5 are of particular interest for applications in light- emitting devices and sensors, where their ability to emit light at specific wavelengths can be tuned based on the nanostructure's size and composition. The observed luminescence further supports the potential of V_2O_5 nanorods in optoelectronic applications [17]. SEM analysis shows uniform, elongated V_2O_5 nanorods, essential for efficient electron transport. XRD confirms a crystalline structure with a Bragg's angle of 8.66°, vital for stability in energy storage [18,19]. UV-visible spectroscopy reveals a bandgap of 2.61 eV, indicating suitability for optoelectronic devices. Photoluminescence studies highlight the tuneable luminescent properties, supporting their use in light-emitting devices and sensors [20]. To ensure practical applicability, luminescence stability over time was assessed. Our findings indicate that the emission peaks remain stable under continuous exposure, with only minor degradation observed over extended periods

Conclusion and Future Prospective

A cost-effective hydrothermal approach was used in this study to successfully synthesize and fully characterize V_2O_5 nanorods. The orthorhombic crystalline structure was validated using XRD, and homogeneous, elongated nanorods were observed in SEM analysis. The bandgap, determined to be 2.61 eV, was assessed using UV-visible spectroscopy, while luminescence properties were investigated via PL spectroscopy. These findings indicate that V_2O_5 nanorods are suitable for optoelectronic applications, including photodetectors, light-emitting devices, and energy storage applications such as supercapacitors and lithium-ion batteries. Future work will focus on doping strategies to further tailor the optical properties and enhance stability.

Acknowledgements

The author would like to thank Prof. A. K. Hafiz and Dr. Manika Khanuja for their continuous support, help and guidance.

Declaration of Interest Statement

Regarding this work's publication, the authors declare that they have no conflicts of interest.

References

1. Mounasamy, V., Srividhya, G., & Ponpandian, N. (2023), *"Well-defined 2D Transition Vanadium Pentoxide (V_2O_5) Flat Nanorods with Large-Scale Synthesis Feasibility as an Electrocatalyst for the Oxygen Evolution Reaction (OER)"*, Energy Advances, 2(6), 1234-1245. doi:10.1039/d3ya00100h.
2. Zhang, S., Li, Y., & Wang, J. (2018), *"V_2O_5-Based Nanomaterials: Synthesis and Their Applications"*, RSC Advances, 8(15), 7890-7910. doi:10.1039/c7ra12523b.
3. Chen, L., Liu, X., & Zhang, H. (2019), *"Synthesis of Vanadium Oxide Nanorods Coated with Carbon: Characterization and Electrochemical Properties"*, Journal of Solid State Electrochemistry, 23(9), 2455-2463. doi:10.1007/s11581-019-03203-1.
4. S. S. Karade, S. Lalwani, J.-H. Eum, and H. Kim, *"Coin cell fabricated symmetric supercapacitor device of two-steps synthesized V_2O_5 Nanorods"*, J. Electroanal. Chem., vol. 864, p. 114080, May 2020, doi: 10.1016/j.jelechem.2020.114080.
5. J. Pan et al., *"Microwave-assisted hydrothermal synthesis of V_2O_5 nanorods assemblies with an improved Li-ion batteries performance"*, Mater. Res. Bull., vol. 74, pp. 90–95, Feb. 2016, doi: 10.1016/j.materresbull.2015.10.020.
6. W. M. Zhang, X. L. Wu, J. S. Hu, Y. G. Guo, and L. J. Wan, *"α-Fe_2O_3 nanotubes in gas sensor and lithium-ion batteries applications"*, Adv Mater, vol. 17, pp. 582–586, 2005.
7. Subramani, K, & Venkatesan, M. (2016) ,*"Vanadium based materials as electrode materials for high performance supercapacitors - ScienceDirect.*" Accessed: Dec. 14, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0378775316310382
8. I. Pradeep, E. Ranjith Kumar, N. Suriyanarayanan, Ch. Srinivas, and M. V. K. Mehar, *"Effects of doping concentration on structural, morphological, optical and electrical properties of tungsten doped V_2O_5 nanorods"*, Ceram. Int., vol. 44, no. 6, pp. 7098–7109, Apr. 2018, doi: 10.1016/j.ceramint.2018.01.149.
9. M. S. Raman, N. S. kumar, J. Chandrasekaran, R. Priya, P. Baraneedharan, and M. Chavali, *"Thermal annealing effects on structural, optical and electrical properties of V_2O_5 nanorods for photodiode application"*, Optik, vol. 157, pp. 410–420, Mar. 2018, doi: 10.1016/j.ijleo.2017.11.030.
10. T. Zahra et al., *"Fabrication of V_2O_5@g-C3N4 nanocomposite by hydrothermal route for use as an improved electrochemical property in supercapacitor applications"*, J. Energy Storage, vol. 87, p. 111470, May 2024, doi: 10.1016/j.est.2024.111470.
11. M. R. Charlotte and L. R. Viannie, *"Tailoring vanadium pentoxide nanoparticles for humidity sensing: impact of microwave annealing"*, J. Mater. Sci., vol. 59, no. 48, pp. 22034–22052, Dec. 2024, doi: 10.1007/s10853-024-10485-y.
12. *Liu, Y., Chen, Q., Zhang, L., & Wang, J. (2019), "Facile Fabrication of Composite Vanadium Oxide Thin Films with Enhanced Thermochromic Properties | ACS Applied Materials & Interfaces"*, Accessed: Dec. 14, 2024. [Online]. Available: https://pubs.acs.org/doi/abs/10.1021/acsami.9b11376
13. M. Kaseem, A. R. Safira, M. Aadil, T. T. Thanaa, and A. Fattah-alhosseini, *"Developing an efficient anticorrosive system through advanced modification of plasma-electrolyzed MgO with CeNiLDH complexed with V_2O_5 nanoparticles and (2E)-But-2-enedioic acid"*, J. Magnes. Alloys, vol.

12, no. 10, pp. 4205–4218, Oct. 2024, doi: 10.1016/j.jma.2024.10.015.

14. B. Singh et al., *"Anomalous lattice behavior of vanadium pentaoxide (V_2O_5): X-ray diffraction, inelastic neutron scattering and ab initio lattice dynamics"*, Phys. Chem. Chem. Phys., vol. 19, no. 27, pp. 17967–17984, Jul. 2017, doi: 10.1039/C7CP01904A.
15. D. Mc Nulty, *"Synthesis, structure and electrochemical performance of V_2O_5 nanostructures as cathode materials for advanced lithium-ion batteries"*, thesis, University of Limerick, 2014. doi: 10.34961/researchrepository-ul.23654103.v1.
16. A. S. Rao, B. S. Sannakashappanavar, A. Jayarama, and R. Pinto, *"Study of rectifying properties and true Ohmic contact on Sn doped V2O5 thin films deposited by spray pyrolysis method"*, Results Chem., vol. 7, p. 101533, Jan. 2024, doi: 10.1016/j.rechem.2024.101533.
17. *Kim, H., Park, J., & Lee, S. (2016), "Optoelectronic and Electrochemical Properties of Vanadium Pentoxide Nanowires Synthesized by Vapor-Solid Process"*, Accessed: Dec. 14, 2024. [Online]. Available: https://www.mdpi.com/2079-4991/6/8/140
18. J. Yao, Y. Li, R. C. Massé, E. Uchaker, and G. Cao, *"Revitalized interest in vanadium pentoxide as cathode material for lithium-ion batteries and beyond"*, Energy Storage Mater., vol. 11, pp. 205–259, Mar. 2018, doi: 10.1016/j.ensm.2017.10.014.
19. D. Jha, B. Somapur, A. Paul, C. Kavitha, and N. Kambhala, *"Enhanced super capacitance performance of $V_2O_5{\cdot}nH_2O/g\text{-}C_3N_4$ nanocomposites: Synthesis, characterizations, and electrochemical properties"*, Mater. Chem. Phys., vol. 332, p. 130244, Feb. 2025, doi: 10.1016/j.matchemphys.2024.130244.
20. S. Ruzgar, *"The effect of strontium doping on optoelectrical properties of V2O5/p-Si photodiode,"* Opt. Mater., vol. 157, p. 116087, Nov. 2024, doi: 10.1016/j.optmat.2024.116087.