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Preparation of Vanadium Pentoxide Materials and Their Supercapacitor Performance

Xinyi Zhang

Manchester Metropolitan Joint College, Hubei University, Wuhan, China
21909274@stu.mmu.ac.uk

Abstract. The large-scale development of renewable energy is still advancing, and the efficient and stable electrochemical energy storage technology has been pushed to a more important position, which has gradually become an indispensable key pillar in energy transformation. Supercapacitors rely on high power density and long cycle life, so there has been a lot of attention in the field of energy storage ; but it has a limited energy density, which would restrict a wider range of applications. Based on this background, this paper takes vanadium pentoxide (V_2O_5)-based electrode materials as the core. Firstly, the energy storage mechanism of supercapacitors is systematically reviewed, and the preparation methods and morphology control strategies of V_2O_5 and its composites are also reviewed. Looking further down, pure-phase V_2O_5 has the disadvantages of poor conductivity and unstable structure, which cannot be ignored. In view of them, this paper summarizes the modification methods such as carbon compositing, porous structure construction, heteroatom doping, and ternary synergistic effect, and also summarizes the mechanism of these methods to improve electrochemical performance. In addition, this study further examines the inherent limitations of the above modification strategies in practical applications, that is, after putting these strategies into real scenarios, what are the limitations.Among these limitations, there are not only the trade-off of carbon content, but also the lattice distortion caused by doping, and the volumetric capacitance loss caused by porous structure. Focusing on these problems, this work first distinguishes the intrinsic pseudocapacitance from the diffusion-controlled energy storage mechanism, clarifies the role of oxygen vacancies in regulating ion diffusion kinetics, and reviews the differences in the existing literature on dopant selection, optimal doping concentration and vanadium dissolution suppression mechanism. In practice, low-loading thin-film electrodes in the laboratory often have excellent performance. However, once the actual devices based on high-loading thick electrodes are corresponding, the stringent requirements are completely different, and the significant gap between the two is thus highlighted. On the basis of these analyses, this paper proposes a feasible and targeted research direction. The purpose is to provide practical guidance for the design of high-energy-density and long-cycle-life supercapacitor electrodes suitable for practical applications.

Keywords: Vanadium pentoxide, supercapacitors, electrode materials, electrochemical performance, composite materials

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1. Introduction

Nowadays, the problems of global energy shortage and environmental pollution have become more and more prominent. Renewable energy sources such as wind energy and solar energy are intermittent, which makes direct power storage difficult. If supply and demand do not match in time and space, it will waste a lot of power resources. Therefore, energy storage devices that take into account high power, long life and high safety are important for building sustainable energy systems. Supercapacitors have the advantages of high power density, fast charg-discharge rate, long cycle life and good safety, which can effectively overcome the performance limitations of traditional capacitors and batteries. However, their limited energy density hinders their practical applications, which makes the development of high-performance electrode active materials a key way to break through. Transition metal oxides have attracted considerable attention because of their rich redox sites and outstanding pseudocapacitive properties [1]. Among these materials, V_2O_5 is more prominent: it has a unique layered structure, multi-valence redox properties, and a relatively high theoretical specific capacitance; in addition, the raw materials are cheap and easy to obtain, making it a promising pseudocapacitive electrode material [2]. However, pure-phase V_2O_5 also cannot bypass the problems of poor conductivity, structural collapse during cycling, and rapid capacity decay, which will limit its practical application [3]. This review first summarizes the energy storage principle and application advantages of supercapacitors, and also systematically summarizes the mainstream preparation methods and electrochemical characteristics of V_2O_5. The focus is on the modification of morphology and structure, and how they affect the electrochemical performance. In this way, it can point out the optimization direction for the development of high-performance vanadium-based electrode materials, and also provide some theoretical guidance and technical support.

2. Supercapacitors and their devices

A supercapacitor is a device that rapidly stores and releases energy mainly through the interfacial behavior between the electrode and the electrolyte. Compared with secondary batteries, it has higher power density, faster charge-discharge response, and good cycle stability, so it is more suitable for intermittent energy storage and high-power transient applications. In this sense, it has become a key energy storage technology that can support the development of clean energy systems.

2.1. Introduction to supercapacitors

Supercapacitors use high-specific-surface-area electrodes, mainly through electrostatic adsorption and rapid Faradaic reaction, to store energy mainly on the electrode surface. In this way, some limitations of traditional capacitors will be overcome, and the cycle life will also be excellent [4]. If it is divided according to its mechanism, it can usually be divided into three types: electric double-layer type, pseudocapacitance type and mixed type. Hybrid supercapacitors can provide a balance between energy density and power density, so they have become a hot spot in current research.

2.2. Energy storage devices of supercapacitors

Supercapacitors are a high-performance electrochemical energy storage device, which mainly uses the interface effect to complete the storage and release of electrical energy. As far as the charge storage mechanism is concerned, it generally depends on two ways: one is the electric double-layer

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capacitance, and the other is the pseudocapacitance. The electric double-layer capacitance is the most widely used mechanism. Specifically, when there is an applied electric field, the electrolyte ions will physically adsorb to the interface of the porous carbon electrode, thus forming the electric double layer. This process itself does not involve chemical reactions, so the energy loss will be relatively low, and hundreds of thousands of stable cycles can be achieved. The other type of pseudocapacitance is different. It stores the charge on the surface of the active material through a reversible Faradaic redox reaction, which will obviously increase the energy density of the device. However, if the redox process is repeated, the structural degradation of the material will be caused, so its cycle stability will be lower than that of the double-layer system.

It can be seen from Figure 1 that supercapacitors usually combine four core components together, namely electrode material, electrolyte, separator and current collector. They have their own division of labor: the electrode material is the place where the electrochemical reaction occurs; the role of the electrolyte is mainly to promote the ion transport process; the separator will separate the two electrodes, so as to prevent short-circuit; as for the current collector, it is responsible for enabling the energization process to proceed smoothly.

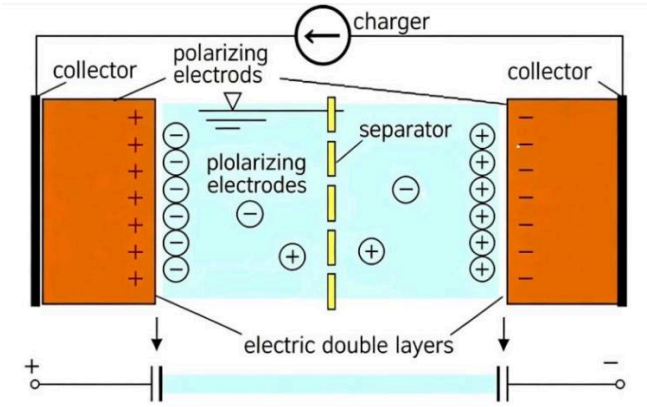


Figure 1. Schematic diagram of electrical double-layer supercapacitor

3. Energy storage principles of supercapacitors

A supercapacitor is an electrochemical energy storage device capable of rapid charging and discharging, composed of high-surface-area electrodes, ion-conductive electrolyte, and an insulating separator. Under applied voltage, charges accumulate at the electrode-electrolyte interface, storing energy through electrostatic adsorption or reversible Faradaic reactions. The total capacitance is formed by the series connection of double-layer capacitances at the positive and negative electrode interfaces, influenced by surface charge density, electrolyte ion concentration, and dielectric properties. Due to fast interfacial charge transfer kinetics, supercapacitors exhibit outstanding power density, enabling high-current fast charging and discharging.

3.1. Electric double-layer energy storage principle

Double-layer capacitors are based on the Helmholtz double-layer model, storing energy through a non-redox, non-Faradaic physical process with high reversibility. Electrodes typically use high-surface-area porous carbon materials such as activated carbon, graphene, and carbon nanotubes. As shown in Figure 2, during charging, cations and anions form double layers at the interfaces of the positive and negative electrodes, respectively, storing energy via charge separation; during

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discharging, ions desorb and release electrical energy. Because the distance between charge layers is much smaller than the dielectric thickness in conventional capacitors, their capacitance is significantly higher. The purely physical adsorption/desorption mechanism results in low internal resistance, fast charge/discharge rates, and long cycle life. However, the energy storage can only be confined to the electrode surface, which makes the energy density relatively low [5].

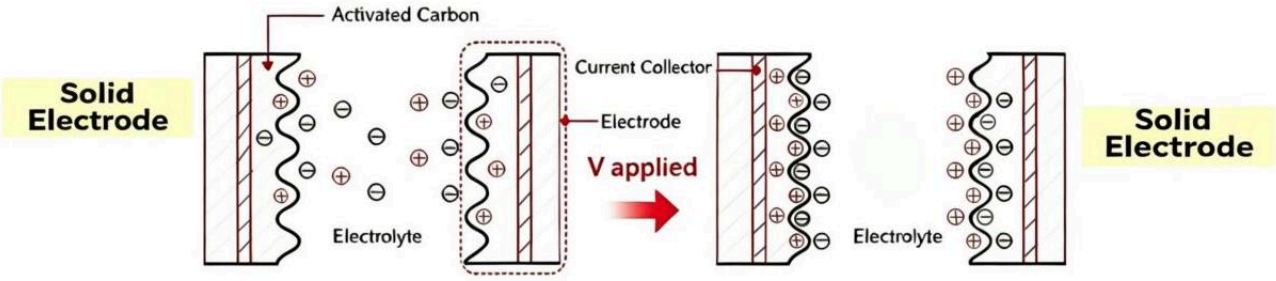


Figure 2. Schematic illustration of charge-discharge principle for electrical double-layer supercapacitor

3.2. Pseudocapacitive energy storage principle

Pseudocapacitance refers to a kind of capacitance behavior occurring on or near the electrode surface, which comes from a fast and reversible Faradaic reaction. Under the applied potential, the ions will undergo redox reaction on the electrode surface and store the charge. When the discharge process, it will in turn release the charge. As shown in Figure 3, pseudocapacitance can be divided into adsorption type, redox type and intercalation type. They all exhibit approximately linear charge–voltage characteristics, and also give a quasi-rectangular cyclic voltammogram, which is distinguished from the redox peaks observed in the batteries [6]. Compared with double-layer materials, pseudocapacitance can provide higher specific capacitance and energy density. However, metal oxides and conductive polymers are prone to structural degradation during cycling, and the cycle life is relatively poor, which limits their large-scale application, so it is still a key challenge in current modification research.

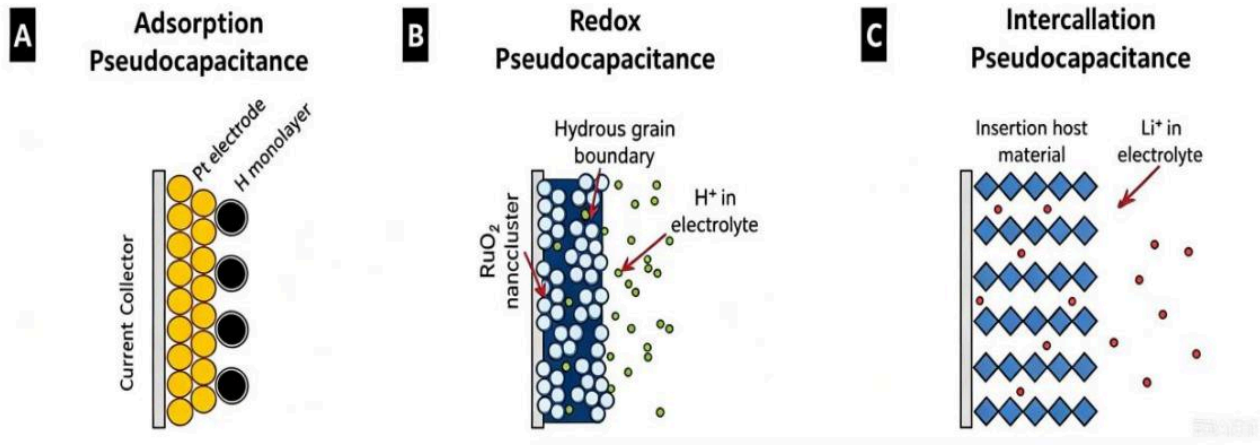


Figure 3. Schematic diagrams illustrating three types of pseudocapacitive mechanisms

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4. Vanadium pentoxide and its vanadium-based composite electrode materials and preparation processes

Vanadium, with its rich oxidation states, can form various functional materials. As a typical layered vanadium oxide, V_2O_5 possesses high theoretical capacity, abundant resources, and low cost. Because this layered structure is more favorable for reversible cation insertion and extraction, it is also promising to obtain a better application prospect in pseudocapacitive supercapacitors.

V_2O_5-related materials can be roughly divided into three categories: pure V_2O_5, vanadates, and V_2O_5-based composites. As for the preparation methods commonly used for each type of material, they are listed in Table 1. As far as pure V_2O_5 is concerned, it can actually be made into a variety of morphologies, such as nanosheets, films, aerogels, etc. The hydrothermal/solvothermal method can control the morphology better and the crystallinity of the product will be higher, but it has requirements for high temperature and high pressure, and there will be limitations on this side of the reactor, so it is not easy to achieve large-scale production. The sol-gel method is more suitable for the preparation of aerogels and powders, but its processing time will be too long, and it is prone to shrinkage and agglomeration during the calcination process [7]. On the side of electrochemical deposition, it can directly grow thin films and nanoarrays without binder, which will be very suitable for miniaturized flexible devices. However, it is still challenging to fabricate thick electrodes with high loading [8]. The structural stability will be enhanced by introducing Ni, Co or Fe elements into vanadate. Hydrothermal synthesis method can prepare high purity hierarchical structure, but the process window will be narrow [9]. The co-precipitation method has low cost and scalability, but it usually brings out element segregation and particle agglomeration. V_2O_5-based composites can improve the conductivity by introducing carbon or conductive polymers, and can also solve the problem of vanadium dissolution. The chemical vapor deposition method can prepare carbon-coated structures, but the equipment cost will be relatively high. The one-dimensional self-supporting fiber electrode made by electrospinning is suitable for flexible devices, but the yield will be relatively low [10].

In general, all kinds of preparation technologies have their own advantages, but they also have shortcomings. It is basically unrealistic to rely on a certain method to achieve high performance, low cost and scalability. Therefore, in order to industrialize the vanadium-based electrodes, it is necessary to further optimize the process and develop multi-functional composite materials.

Table 1. Classification and preparation of V_2O_5-based electrode materials

No.	Material Category	Material System	Precursors / Raw Materials	Preparation Process	Application Scenario	Reference
1	Pure-phase V_2O_5	V_2O_5 nanosheets	Ammonium metavanadate, vanadium pentoxide powder	Hydrothermal / Solvothermal	Low-dimensional nanostructured electrodes	[7, 8]
		V_2O_5 thin films, nanoarrays	Vanadium salt solution, conductive substrate Vanadium alkoxide, ammonium metavanadate	Electrochemical deposition	Thin-film micro supercapacitors, flexible devices	
		V_2O_5 aerogels, porous powders	Vanadium alkoxide, ammonium metavanadate	Sol-gel method	Porous powder electrodes, coating type electrodes	

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Table 1. (continued)

		$Ni_3V_2O_5$ $Co_3V_2O_5$ $NiCoV_2O_5$	Nickel salt / Cobalt salt + vanadium source	Hydrothermal method	High-specific capacitance pseudocapacitive positive electrodes	
2	Vanadate materials	$FeVO_4$, ZnV_2O_4, CuV_2O_6	Metal nitrate + ammonium metavanadate	Coprecipitation method	Large-scale powder electrodes	[9]
		V_2O_5/carbon nanofibers	V_2O_5/CNT Polyac rylonitrile/lignin + vanadium salt	Electrospinning	Flexible self supporting electrodes, high power devices	
3	V_2O_5-based composites	V_2O_5@carbon coating layer	V_2O_5 powder + carbon source	Chemical vapor deposition (CVD)	Surface coating modification, long-cycle stable electrodes V2O5/carbon/ conductive polymer ternary composite	[10]
		V_2O_5/carbon/conductive polymer ternary composite	Vanadium source + carbon matrix + monomer	Hydrothermal+ in-situpolymerization two-step method	High performance ternary composite electrodes, long cycle energy storage devices	

5. Performance advantages and analysis of vanadium pentoxide-based electrode materials for supercapacitors

V_2O_5 features abundant natural reserves, mature preparation technology, low cost, favorable electrochemical reversibility and wide voltage window. Its layered structure enables controllable nano-morphology and ion channels. Orthorhombic α-V_2O_5 can reversibly intercalate alkali cations; vanadium's multivalent redox gives a high theoretical capacitance of 2120 F/g, surpassing carbon-based capacitors [11]. Yet pure V_2O_5 nanosheets suffer from low conductivity, large charge transfer resistance, structural failure and vanadium dissolution, with merely 62% capacity retention after 5000 cycles [12]. Long ion diffusion paths further restrict practical energy storage.

In order to solve these shortcomings, the main modification strategies include carbon-based composites, porous structure construction, heteroatom doping and multi-component composites. Heteroatom doping often inadvertently generates lattice defects such as oxygen vacancies. These defects reduce the activation energy for ion insertion and extraction, raise the density of electronic states near the Fermi level and enhance ion mobility in solid matrix, jointly improving electrode high rate performance. However, excessive vacancies aggravate lattice distortion and electron scattering, hindering charge transfer. The charge storage of V_2O_5-based electrode originates from two complementary mechanisms: surface-driven pseudocapacitance controlled by rapid redox at electrode-electrolyte interface, and diffusion-limited intercalation pseudocapacitance relying on ion insertion and extraction in bulk material [13]. Different modifications affect them differently: oxygen vacancy engineering and large-surface nanostructures enhance surface redox; rationally designed ordered layered framework optimizes ion transport kinetics and bulk intercalation capacity.

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In fact, various modification methods also have their own limitations. It is difficult to say which one can solve the problem at one time. Taking carbon composites as an example, it can indeed enhance the conductivity of vanadium-based materials, but the carbon content is not a random addition and it often has to be optimized in a relatively narrow window. It is hard to balance active site preservation and conductive network construction. Insufficient carbon cannot form continuous conductive paths, leading to high electronic resistance and limited improvement of rate performance. Conversely, excessive carbon dilutes the active V_2O_5 component. Over-thick carbon coating may block surface active sites, reduce effective active substances per unit volume and lower volumetric capacitance. As for heteroatom doping, it introduces defects and polar functional groups to provide additional pseudocapacitive sites. However, substituting heteroatoms into the lattice may destroy the original crystal structure and induce local distortion. Moderate defects benefit energy storage, but over-doping generates massive distorted sites acting as electron scattering centers, increasing lattice disorder, hindering electron transport, raising electrode resistance and deteriorating high-current rate performance. In extreme cases, severe lattice distortion even collapses channels and blocks ion diffusion pathway.

Constructing hierarchical porous structures shortens ion diffusion paths and improves gravimetric capacitance at the cost of reduced bulk density and volumetric capacitance. Micropores provide adsorption sites, while mesopores and macropores facilitate ion transport. Increased pore volume fraction reduces bulk density and volumetric energy storage. Excess compaction lowers mesopore and macropore proportion, increases ion diffusion tortuosity, blocks fast transport channels and impairs rate performance [14].

Carbon-based composites build continuous conductive networks to reduce internal resistance and suppress vanadium leaching, though excessive carbon dilutes active components. Heteroatom doping introduces lattice defects and hydrophilic groups to enhance wettability and extra pseudocapacitance [15]. The N-doped sample delivers 595.1 F/g with 97% capacity retention after long cycles [16]. Porous engineering enlarges specific surface area, shortens ion diffusion paths and boosts rate performance. Ternary composites utilize multi-component synergy to integrate high capacitance, good rate capability and cycling stability, becoming the mainstream route for high-performance vanadium-based electrodes [17].

Table 2. TABLE II. Summary of Electrochemical Performances of V_2O_5-based Electrodes

No.	Electrode Material System	Measured Specific Capacitance (F/g)	Capacity Retention (Cycle Number)	Energy Density (Wh/kg)	Power Density (W/kg)	Reference
1	Pure-phase V_2O_5 nanosheets	231	62% (5000 cycles)	28.7	3900	[12]
2	V_2O_5/RGO (RGO mass fraction 26%)	316	78% (10000 cycles)	36.2	4210	[15]
3	V_2O_5/CNTs (V_2O_5 mass fraction 50%)	57.3	81% (5000 cycles)	46.3	5260	[17]
4	N-doped V_2O_5/CNF	595.1	97% (12000 cycles)	82.6	250	[16]
5	S-doped V_2O_5/RGO (VOGS)	484.9	80% (10000 cycles)	51.4	4650	[16]
6	V_2O_5/CNTs-SAC ternary composite	357.5	92% (8000 cycles)	53.7	7100	[17]

In vanadium-based energy storage electrode modification, literature differs on doping element types and optimal concentration. Doping performance is influenced by precursors, preparation processes and test systems, so this article will not further discuss differences among doping

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strategies. No consensus has been reached on the mechanism of suppressing vanadium dissolution in aqueous systems. Some research indicates pre-embedding organic conductive polymers can expand interlayer spacing and stabilize crystal frameworks to restrain vanadium leaching. Other work proposes regulating electrolyte solvation structure reduces free water activity and weakens interactions between active materials and water molecules to mitigate vanadium dissolution [18]. These strategies follow distinct inhibition mechanisms, and deeper investigations are still required.

From the perspective of practical application, gravimetric capacitance remains the most widely adopted index in laboratory research. High porosity and carbon composite structures can improve gravimetric capacitance but reduce bulk density and sacrifice volumetric capacitance. Thus gravimetric index alone cannot evaluate the practical feasibility of electrode materials. The impressive capacitance values reported in literature are usually acquired from thin-film electrodes with low active material loading below 5 mg/cm^2, which feature short ion diffusion paths and minimized polarization. Practical devices adopt thick electrodes with high loading to achieve high areal capacitance. Thick electrodes bring increased polarization and severe capacitance attenuation, widening the gap between laboratory performance and device application. For vanadium-based systems, most V_2O_5 supercapacitor studies focus on gravimetric capacitance, while volumetric capacitance and high-loading data are rarely reported. This limitation hinders comprehensive practical evaluation. Table 3 summarizes key parameters of representative materials in literature.

Table 3. Volume-specific capacitance and electrode loading parameters for different electrode material systems

No.	Material System	Electrode Loading (mg/cm²)	Current Density (A/g)	Specific Capacitance (F/g)	Volumetric Capacitance (F/cm³)	Reference
1	Coal-tar-derived templated carbon PCS	2	-	-	277	[19]
2	Coal-tar-derived templated carbon PCS	8	-	-	244	[19]
3	Nanocellulose/reduced graphene oxide NC/rGO	Not specified (film electrode)	0.3	269.33	350.13	[20]
4	Nanocellulose/reduced graphene oxide NC/rGO	Not specified (film electrode)	10.0	215.88	280.62	[20]
5	Bithiophene-bridged polypyrrole film	Not specified (film microelectrode)	-	-	68.4	[21]

6. Conclusion

Research has shown that V_2O_5 possesses a layered crystal structure and multivalent redox characteristics. If the microstructure of V_2O_5 is well controlled by hydrothermal and solvothermal process, it is possible to prepare pseudocapacitive electrode materials with high performance. However, pure-phase V_2O_5 still encounters some unavoidable problems, such as poor conductivity, structural collapse during cycling, and leaching of active ions. In view of these situations, composite strategies such as carbon incorporation, porous structure design, heteroatom doping and multi-component modification can often produce synergistic effects, which can significantly enhance the specific capacitance, rate performance and cycle stability of the electrode. This paper focuses on the application of V_2O_5 in supercapacitors. Firstly, the energy storage mechanism of supercapacitors is systematically reviewed. Then, various preparation methods of vanadium-based electrode materials are summarized. The enhancement mechanism of electrochemical performance by different modification methods is also analyzed. The comprehensive performance of various vanadium-based

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electrodes is compared, so as to reveal the potential of vanadium-based materials in energy storage. In general, V_2O_5 has abundant raw material reserves and excellent energy storage capacity, so it will be a promising candidate material for industrial applications. However, there are still problems. The repeatability of the doping process is relatively poor, the vanadium dissolution inhibition mechanism has not been really solved, the equipment-level evaluation protocol is still relatively lacking, the composite material preparation process is complex, and the batch-to-batch consistency is not satisfactory. These will make it not so easy for vanadium-based electrodes to move from laboratory research to practical application. Therefore, if we want to push this matter forward in the future, the focus should fall on several places: to clarify the structure-performance relationship related to heteroatom doping quantitatively, to establish a robust and repeatable doping control strategy, to explain the various mechanisms of vanadium dissolution inhibition, and to determine the scope of application of each modification method. Only in this way, it is more likely to promote the practical application of vanadium-based electrodes. In addition, the performance evaluation method has to be changed from the perspective of device-oriented. More electrochemical tests should be done on the thick electrode with high loading, and the gravimetric capacitance and volumetric capacitance should be considered together to optimize the two. In addition, the trade-off between porous structure and bulk density must also be balanced. The volume-related performance degradation caused by porous modification should be minimized, and the preparation process of multi-component composites should also be simplified. In this way, it is more likely to achieve scalable material production and further device-level verification.

References

[1] Adekunle, A., Aluko, E. O., Elugoke, E. S., et al. (2026). Transition metal oxides as electrode materials for advanced energy storage-a decade of research on batteries and supercapacitors. *Chemical Physics Impact, 13*: 101112. DOI: 10.1016/j.chphi.2026.101112.

[2] Temam, A. G., Alshoaibi, A., Cetaneh, S. A., et al. (2023). Recent progress on V_2O_5 based electroactive materials: Synthesis, properties, and supercapacitor application. *Journal of Energy Storage, 38*: 101239. DOI: 10.1016/j.coelec.2023.101239.

[3] Huseyin, A., Salih, A. J. S. (2025). Batteries and supercapacitors: An analytical perspective on electrode materials and performance challenges. *Journal of Alloys and Compounds, 1037*: 181972. DOI: 10.1016/j.jallcom.2025.181972.

[4] Yan, H., Su, J., Xiao, Y., et al. (2025). Comprehensive insight of charge storage and ion transport in bioinspired nanostructure electrode-patterned supercapacitors by multiscale investigation. *Journal of Power Sources, 628*: 235922. DOI: 10.1016/j.jpowsour.2025.235922.

[5] Sikiru, S., Olutoki, J. O., Musa, S. A., et al. (2025). The projection role of surface charge density in electric double-layer capacitance for enhanced energy storage. *Journal of Energy Storage, 138*: 118728. DOI: 10.1016/j.est.2025.118728.

[6] Gopi, C. V., Alzahmi, S., Al-Haik, M. Y., et al. (2024). Recent advances in pseudocapacitive electrode materials for high energy density aqueous supercapacitors: Combining transition metal oxides with carbon nanomaterials. *Materials Today Sustainability, 28*: 100981. DOI: 10.1016/j.mtsust.2024.100981.

[7] Thien, G. S. H., Cheng, Z. X., Tan, M. Y., et al. (2026). Precursor concentration-tuned optical and electrochromic performance of sol-gel-derived V2O5 thin-film devices. *Materials Today Communications, 51*, 114653. DOI: 10.1016/j.mtcomm.2026.114653.

[8] Yao, P., Wang, T., Yu, H., et al. (2024). Bi_2O_3@reduced graphene oxide and $NiCo_2$@Ni_3Co electrodes for all-electrodeposited high-performance supercapacitors. *Journal of Power Sources, 613*, 234958. DOI: 10.1016/j.jpowsour.2024.234958.

[9] Srinivasan, S. B., Devendiran, S., Savunthari, K. V., et al. (2025). Insights into multifarious heteroatom-doped/enriched carbon-based materials and their composites: Synthesis and supercapacitor applications – a crucial review. *Progress in Materials Science, 153*, 101470. DOI: 10.1016/j.pmatsci.2025.101470.

DOI: 10.54254/2755-2721/2026.BA38788

[10] Patel, A. P., Sharma, D. S., Kapdi, Y. G., et al. (2026). Spinel $CuMn_2O_4$ carbon nanofiber composite electrodes for flexible solid-state supercapacitor. *Materials Science and Engineering: B, 333*, 119737. DOI: 10.1016/j.mseb.2026.119737.
[11] Siwińska-Ciesielczyk, K., Kurc, B., Gross, X., et al. (2026). Zirconia decorated with vanadium oxide as a promising electrode material in supercapacitors. *Journal of Power Sources, 684*, 240428. DOI: 10.1016/j.jpowsour.2026.240428.
[12] Kumbhar, S. S., Bhosale, S. B., Bhosale, R. P., et al. (2026). Yoking compositional synergy among 2-D nanohybrids of cobalt vanadium oxide nanoplates and reduced graphene oxide nanosheets based cathode material for hybrid supercapacitors. *Journal of Energy Storage, 141*(C), 119327. DOI: 10.1016/j.est.2025.119327.
[13] Mashkoor, F., Shoeb, M., Zhu, S., et al. (2025). Synergistic effect of heterointerface engineering coupled with oxygen vacancies enriched Ag_2O-$WO_{2.8}$-SnO_2 anchored carbon nanotubes nanocomposite for high-performance supercapacitor devices and their charge storage mechanism. *Surfaces and Interfaces, 62*: 106198. DOI: 10.1016/j.surfin.2025.106198.
[14] Gao, B., Huang, Y., Gao, Y., et al. (2025). Hierarchical Bi_2O_3 nanosheets and ZIF-8 derived porous nitrogen-doped carbon fibers as novel assembled nanocomposites for high-performance flexible supercapacitors. *Journal of Colloid and Interface Science, 677*(B): 560-570. DOI: 10.1016/j.jcis.2024.08.070.
[15] Gaber, A., Al-Obidi, M., Celik, M. & Sinag, A. (2026). Next-generation flexible and free-standing supercpacitors: Conducting polymers as electrode materials. *Journal of Power Sources, 679*: 240168. DOI: 10.1016/j.jpowsour.2026.240168.
[16] Sun, S., Zong, J., Xue, Q. Y., et al. (2026). Coupled intercalation-defect engineering modulates ion transport dynamics in V_2O_5 cathode for aqueous zinc-ion batteries. *Journal of Energy Storage, 153*: 120900. DOI: 10.1016/j.est.2026.120900.
[17] Li, H. L., Xu, H. Y., Wang, C. H., et al. (2024). Synergistic engineering of amorphous network and oxygen vacancies in vanadium oxides for enhanced sodium-ion storage. *Chemical Engineering Journal, 479*: 147597. DOI: 10.1016/j.cej.2023.147597.
[18] Zhu, Y. R., Wang, Y. D., Li, T. C., et al. (2025). Electrostatic supramolecular self-assembly of vanadium oxide and conductive polymer for highly efficient zinc ion storage. *Chemical Engineering Journal, 513*: 163002. DOI: 10.1016/j.cej.2025.163002.
[19] Wu, D. Y., Sun, F., Fan, W., et al. (2024). Pore structure reformation of tar-derived templated carbons with high volumetric capacitive properties. *Clean Coal Technology, 30*(2), 186-196. DOI: 10.13226/j.issn.1006-6772.YS23112802.
[20] Zhang, Y., Wei, L., Liu, X. J., et al. (2022). Tromethamine functionalized nanocellulose/reduced graphene oxide composite hydrogels with ultrahigh gravimetric and volumetric performance for symmetric supercapacitors. *Journal of Power Sources, 543*, 231851. DOI: 10.1016/j.jpowsour.2022.231851.
[21] Hou, P. X., Jiang, K. Y., Zhai, G. Q., & Zhuang, X. D. (2021). Thieno [3, 2-b]thiophene-bridged polypyrrole film-based micro-supercapacitors. *Journal of Functional Polymers, 34*(5), 434-443. DOI: 10.14133/j.cnki.1008-9357.20210110001.