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Improve Charging and Discharging Efficiency by Sb_2Se_3

Siyu Chen[1]

[1]WuhanYingzhong, Wuhan, China
*Corresponding author:
chensiyu2026@163.com

Abstract:
Replacing the lithium-ion battery by potassium-ion battery demonstrated the potential in the development of sustainable energy sources. However, there are some issues may occur after using potassium-ion battery. So, this essay will talk about how to improve the potassium-ion battery by using new material, Sb_2Se_3. This article will demonstrate the properties and the production method of Sb_2Se_3. Then, this template describes five methods about how to improving the objects of Sb_2Se_3. It demonstrates the method of resolving or alleviating the issues of Sb_2Se_3,using strategies such as material nanofabrication, carbon material modification, and impurity doping can be employed to optimize the geometric structure, composition, electronic structure and interface properties of the material, thereby achieving the modification and modification of the Sb_2Se_3 material.

Keywords:. Potassium-ion battery; Sb_2Se_3; modification.

1. Introduction

With the development of science and technology, the all-electric vehicles begin to become common. The popularizing of electric vehicles generates some issues. For instance, the range of the electric vehicles cannot suit their need and the number of charging piles under the level of people needs. Furthermore, there are some dangerous may be caused when the electric vehicle is undergoing fast charging. They may not control the dissipation of thermal energy by using contemporary materials.

In the research of improving of charging electric vehicles, some issues are hard to solve. For instance, it is hard for lithium battery to control heat dissipation to bring the temperature to the appropriate level. This problem may damage the integrity of the negative electrode protective film. In extreme cases, when the battery temperature exceeds the safety threshold, it may cause thermal runaway. So, we need a new material to assist battery to reject thermal energy and remain the temperature in a specific range. Also, the scarcity and high cost of lithium resources, as well as the uneven geographical distribution, have severely hindered the sustainable development of lithium-ion batteries in large-scale energy storage devices. Therefore, it is urgent to develop new types of battery energy storage systems with high stability and low cost to alleviate these problems. And a metal has less electric resistance or electrical resistivity, which is a better material for improving charging efficiency in the aspect of anode material. This new battery is potassium battery. However, the larger radius of K^+ and the higher surface activity of K metal have led to problems such as significant volume expansion of the PIBs negative electrode during charge and discharge

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cycles, severe decomposition of the electrolyte on the K metal surface, and severe capacity degradation of the PIBs, which hinder the practical development of PIBs [1]. For instance, the fast-charging capability of lithium-ion batteries is inversely proportional to the internal resistance of the battery. Therefore, choosing a positive electrode material with lower internal resistance is an important condition for achieving fast charging of the battery.

Many articles indicate that Sb_2Se_3 is a highly promising candidate for use as a new battery material. However, the Sb_2Se_3 material has poor electronic conductivity, poor interface compatibility with the electrolyte, poor temperature adaptability, and severe volume deformation during charging and discharging. This reaction is Sb_2Se_3 undergoes intercalation reaction with K^+ to form K_3SbSe_3 during the discharge process. Through a conversion reaction, K_2Se and Sb are produced. Finally, through an alloying reaction, K_3Sb is formed. This material generates the initial product Sb_2Se_3 at the final charging stage, demonstrating the high reversibility of the reaction of the Sb_2Se_3 material during charging and discharging. And the repeated potassium extrusion and reinsertion process of the large-sized K^+ during the cycling process will cause irreversible volume deformation of the electrode material. This article will introduce the method of solving the issues of using Sb_2Se_3. However, the production costs of lithium have risen and the reserves of lithium have decreased. Also, the reserves of potassium elements are approximately 1,000 times that of lithium elements. And this method will focus on optimizing the microstructure and material composition, constructing the solvation structure, regulating the coordination strength of potassium ions, multi-side chain isomerization and stabilizing the molecular conformation. This research tends to reduce charging time and decrease the loss of energy. So, it could reduce the quantity of charging piles because of higher charging efficiency, reducing the cost in the aspect of new energy construction for businesses.

2. Main body

2.1 The properties of Sb_2Se_3

Sb_2Se_3 is a typical transition metal selenide material, with a covalent tube-like one-dimensional crystal structure, which is a highly anisotropic semiconductor. And Sb_2Se_3 has low cost and high storage volume. In the charging process, Sb_2Se_3 react with K^+ and form K_3SbSe_3, which is a conversion reaction, forming both K_2Se and Sb togrther. Finally, through the alloying reaction, K_3Sb is formed. This product forms the original product $SbSe_3$.This reaction illustrates the high reversibility during the reaction of Sb_2Se_3 charging and discharging. Sb_2Se_3 exhibits a relatively high theoretical capacity (669 mAh g^{-1}) due to the transformation reactions and alloying reaction mechanisms during the potassium storage process [2]. This has attracted numerous researchers to develop various new Sb_2Se_3 composite materials. It means that Sb_2Se_3 is a highly competitive negative electrode material for improving the charging and discharging efficient of potassium-ion batteries. Conversely, there are some issues restricting the development of this new material. Firstly, the poor electronic conductivity of the Sb_2Se_3 material results in slow ion migration and diffusion kinetics during potassium storage, leading to poor battery rate and cycle performance, as well as poor temperature stability. The another one is the issue of the large size of K^+, there is a relatively huge volume change during the process of potassium removal and incorporation, causing the material to undergo pulverization and agglomeration during the cycling process. As a result, it may destroy the structure stability of material during potassium storage process. However, the larger K^+ radius leads to problems such as slow potassium storage kinetics, poor electrochemical performance, and poor temperature adaptability in various materials [3]. Relevant reports indicate that among many transition metal selenide materials, the tubular one-dimensional crystal structure of Sb_2Se_3 has certain advantages in the energy storage process, and Sb_2Se_3, as a material with both conversion and alloying energy storage mechanisms, can provide a high theoretical capacity and has great development and application potential in potassium-ion batteries.

2.2 The production method of Sb_2Se_3

Sb_2Se_3 has a direct band gap of approximately 1.15 eV, a large absorption coefficient (>105 cm^{-1}, short wavelength), and a low grain growth temperature (~300°C), which is conducive to the fabrication of low-cost thin-film materials for manufacturing thin-film solar cells. Sb_2Se_3 is an inorganic compound with the chemical formula Sb_2Se_3 [4]. It is a binary single-phase compound. Due to its large raw material reserves, low toxicity, low price, appropriate band width (~1.15 eV), high absorption coefficient (greater than 105 cm^{-1}), and low crystal growth temperature, it is highly suitable for the production of new, low-cost, and low-toxic solar cells. It Includes hydrothermal method, microwave-assisted process, vacuum evaporation, pulsed laser deposition method and near-space evaporation method. The vacuum evaporation method is one of the most commonly used methods for preparing Sb_2Se_3 thin films [5]. Sb_2Se_3 has a relatively low melting point (611°C) and a relatively high saturated vapor pressure. Moreover, during the preparation process, almost no secondary phase is produced, making it very suitable for using the vacuum evaporation method to prepare Sb_2Se_3 thin films. The reversible capacity and cycle stability of Sb_2Se_3 materials are greatly influenced by the synthesis method and reaction conditions. Therefore, it is urgent to explore an environmentally friendly and high-yield method for preparing Sb_2Se_3 materials. For instance, Luo and others mixed antimony acetate, sodium selenite and hydrazine hydrate, and through a simple hydrothermal method, they synthesized ultra-long Sb_2Se_3 nanowires. Then, through a simple filtration process, they further transformed the nanowires into independent membranes containing the ultra-long Sb_2Se_3 nanowires.

2.3 The method of improvement project of Sb_2Se_3

To address or alleviate the issues of the application of Sb_2Se_3 material, strategies such as material nanofabrication, carbon material modification, and impurity doping can be employed to optimize the geometric structure, composition, electronic structure and interface properties of the material, thereby achieving the improvement of the using rate of Sb_2Se_3.

The design of nanostructures should focus more on improving the cycle and rate performance. The newly designed materials should be able to withstand large volume changes and have good chalk resistance. And low-dimensional materials are designed into porous 3D structures is helpful to buffer the large volume changes and shorten the diffusion path and increase the large specific surface area, which could increase the performance of storage of K^+ [6]. For instance, Ge and others prepared a unique one-dimensional structure of Sb_2Se_3 material through hydrothermal method, which resulted in a shorter ion diffusion distance during the storage process [7]. The reversible capacity after 100 cycles at a current density of 1.0 A g^{-1} was 308.2 mAh g^{-1}. Fang and others prepared the lamellar-structured porous Sb_2Se_3 using the template method and ion exchange method. The one-dimensional porous nanoscale framework structure endows it with strong electrochemical reaction kinetics. The first discharge capacity of the lamellar Sb_2Se_3 at 0.3 A g^{-1} is close to 700 mAh g^{-1}, and it still exhibits a high discharge capacity of nearly 200 mAh g^{-1} after 80 charge-discharge cycles at 0.3 A g^{-1} [8].

Guo and others synthesized a capsule-shaped carbon-layer-restricted Sb_2Se_3 nano-composite material through a simple solvothermal method and sintering process [9]. Capsule-shaped carbon-layer-restricted Sb_2Se_3 could effectively reduce the chance of high active volume changes and pulverization, maintaining the continuous transmission channel of K^+. The obtained material achieved a capacity of 410 mAh g^{-1} at a current density of 0.1 A g^{-1}, and maintained this performance for over 1000 cycles, with a capacity degradation of only 0.07% per cycle. Another method is the reaction of Yi and others [10]. Yi designed the Sb_2Se_3/rGO composite material through the hydrothermal method and the subsequent selenylation process. The Sb_2Se_3 particles with a particle size of approximately 50 nm were encapsulated within the rGO nanosheets. The highly elastic rGO nanosheets inhibited the volume changes of the Sb_2Se_3 particles and exhibited high structural stability during the cycling process. After 460 cycles at a current density of 0.5 A g^{-1}, this electrode could provide a high capacity of 203 mAh g^{-1}.

Lattice structure optimization: Introducing anions and cations into the material lattice or performing heteroatom doping not only enhances the structural stability of the material, but also optimizes the Fermi level, which is conducive to the improvement of electrical conductivity, thereby increasing its reversible capacity and long-cycle performance. Yu and others prepared Ni-doped Sb_2Se_3 nanorods and encapsulated them with N-doped carbon films [11]. The carbon film coating prevented electrode pulverization, and the Ni doping enhanced the electronic conductivity and electrochemical reaction kinetics of Sb_2Se_3. When used as the negative electrode material for PIBs, it exhibited excellent rate performance, with a capacity of 223 mAh g^{-1} at 5.0 A g^{-1} and 140 mAh g^{-1} at 10.0 A g^{-1}.

Improve the electric structure: Combining various components and utilizing the interactions between them to achieve electron transfer, thereby inducing the material to exhibit a lower energy storage barrier. For example, doping with heteroatoms can effectively improve the electronic structure and chemical reactivity of graphene, significantly enhancing the electrochemical performance of the material. Due to the difference in electronegativity between the heteroatoms and carbon atoms, graphene materials doped with heteroatoms that modify the electronic structure can provide higher electrochemical active centers.

Optimize interface compatibility: In the design of electrode materials, polar functional groups such as hydroxyl groups are often introduced to enhance the compatibility between the electrode materials and the electrolyte interface. This, in turn, significantly improves the geometric structure of the materials, homogenizes the ion flux distribution, enhances the thermodynamic stability of the materials, and is conducive to the improvement of their high-temperature performance.

3. Conclusion

As traditional fossil energy sources become increasingly

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depleted, the development of renewable energy technologies has become the mainstream trend. However, the development of new energy sources is hard to continue because of its boundedness. Therefore, the development of large-scale energy storage devices becomes extremely important. However, the high cost and scarcity of lithium resources in the earth's crust are destined to be unable to meet the ever-growing energy demands. This led the researchers to shift their focus to the development of other inexpensive alkali metal ion batteries. The potassium ion battery, which shares similar properties with lithium-ion batteries, has become one of the strong competitors of lithium-ion batteries due to its low cost and abundant resource reserves. However, the larger radius of K^+ leads to problems such as slow potassium storage kinetics, poor electrochemical performance, and poor wide-temperature adaptability for various materials. To address the above issues, this paper aims to improve the potassium storage performance of materials by constructing a new type of composite material. Relevant reports indicate that among numerous transition metal selenide materials, the tubular one-dimensional crystal structure of Sb_2Se_3 has certain advantages in the energy storage process. Moreover, as a material with both conversion and alloying energy storage mechanisms, Sb_2Se_3 can provide a high theoretical capacity and has great development and application potential in potassium-ion batteries.

References

[1] Feng Zheng, Lin Zhang, Zhang Wenchao, et al. Study on electrochemical performance optimizationand interface modification mechanism of tin phosphideused as anode of potassium ion battery. South China University of Technology, 2023.

[2] Liu Bingbing, Qing Guohui, et al. Preparation of Sb_2Se_3 composites and their application in Electrochemical Energy Storage. Qingdao University of Science & Technology, 2023.

[3] Fang Yongjin, Yu Xin-Yao, Lou Xiong Wen, et al. Formation of polypyrrole-coated Sb_2Se_3 microclips with enhanced sodium-storage properties. Angewandte Chemie International Edition, 2018, 57(31): 9859779863.

[4] Guo Ling, Cao Liyun, Huang Jianfeng, et al. Guiding Fabrication of Continuous Carbon-Confined Sb_2Se_3 Nanoparticle Structure for Durable Potassium-Storage Performance. ACS Applied Energy Materials, 2021, 4(9): 10391-10403.

[5] Yi Zheng, Qian Yong, Jiang Song, et al. Self-wrinkled graphene as a mechanical buffer: A rational design toboost the K-ion storage performance of Sb_2Se_3 nanoparticles. Chemical Engineering Journal, 2020, 379: 122352.

[6] Zhao Guoqiang, Wang Xingyong, Wang Shaolan, et al. Heteroatom-doped $MoSe_2$ nanosheets with enhanced hydrogen evolution kinetics for alkaline water splitting. Chemistry-An Asian Journal, 2019, 14(2): 301-306.

[7] Mingtai Wang, Chengfeng Ge, et al. Solution-processed Sb_2Se_3 bulk/nano structures for solar cells, University of Science and Technology of China, 2023.

[8] Luo Miao, Leng Meiying, Liu Xinsheng, et al. Thermal evaporation and characterization of superstrate CdS/Sb_2Se_3 solar cells. Applied Physics Letters, 2014, 104(17): 173904.

[9] Guo Huafei, Chen Zhiwen, Wang Xing, et al. Ehancement in the efficiency of Sb_2Se_3 thin-film solar cells by increasing carrier concertation and inducing columnar growth of the grains. Solar RRL, 2019, 3(3): 1800224.

[10] Eftekhari Ali, Jian Zelang, Ji Xiulei, et al. Potassium secondary batteries. ACS Applied Materials & Interfaces, 2017, 9(5): 4404-4419.

[11] Liu Yajie, Tai Zhixin, Zhang Jian, et al. Boosting potassium-ion batteries by few-layered composite anode sprepared via solution-triggered one-step shear exfoliation. Nature Communications, 2018, 9(1): 3645.