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RESEARCH ARTICLE

Highly Ordered Silicon/Carbon Composite Materials Based on Biomass and Their Application in Lithium Batteries

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ABSTRACT

With the rapid development of electric vehicles and mobile devices, the performance and safety of energy storage and conversion devices mainly with lithium-ion batteries have been paid attention to. Negative electrode material is an important component of lithium-ion battery, which has an important influence on the overall performance of the battery. In recent years, the research of highly ordered silicon / carbon composites as the negative electrode has been significantly developed. Highly ordered silicon / carbon composites have great potential to increase the energy density of lithium-ion batteries and improve the battery performance with the characteristics of high capacity, low cost and environmental friendliness. In this paper, the application of highly ordered silicon / carbon composites in lithium-ion batteries is expected to provide reference to relevant personnel.

Keywords: Lithium ion battery; Ultraviolet spectrophotometry; Rapid detection; Cathode material

1. Introduction

With the rapid development of the global economy, non-renewable energy is heavily consumed, bringing about a series of environmental problems. The importance of high-value and refined utilization of coal and other non-renewable energy sources is becoming increasingly prominent. At the same time, solar, wind, water, water, tidal, geothermal energy and other green and renewable energy is widely concerned. However, these renewable energy sources are intermittent, regional and high cost, which limits their widespread application. Therefore, it is very important to develop efficient and green

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energy conversion and storage technologies, such as solar cells, fuel cells, supercapacitors, metal ion cells, etc.Carbon materials have been widely studied for their advantages of high specific surface area, adjustable pore structure and good chemical stability. Usually, carbon materials are prepared from fossil fuels, and the synthesis process is energy-intensive, environmentally harmful and costly. In recent years, countries around the world pay more and more attention to energy conservation and emission reduction. In order to achieve the goal of "carbon neutral", people are committed to the development of green preparation methods. As a renewable and green raw material, biomass has the advantages of rich resources, environmental protection and low cost. In recent years, the preparation of functional carbon materials from renewable biomass resources has attracted wide attention from researchers. Compared with fossil fuel-derived carbon materials, biomass-based carbon materials have the following advantages: renewability; as a biological material, it can be prepared by simple biological template method; inherent porous or graded porous structure provides a large amount of accessible surface area and smooth transfer path for electrolyte ions; most biomass contains N, S and P elements, so heteroatoms can be doping in the synthesis of materials to form additional active sites in biomass-based carbon materials [1]. These characteristics make biomass-based carbon materials one of the most promising functional materials for energy storage and conversion devices. Therefore, it is urgent to review the design and preparation of biomass-based functional carbon materials (BFCs) and their research progress in the field of energy conversion and storage, in order to provide new clues for the emerging application of BFCs in a wide range of fields [2].

2. Cause analysis of lithium battery accidents

According to the recent 2018–2021 lithium battery industry development report, as well as the lithium battery accident data reported on the network, the inducing factors of lithium battery accidents are summarized, and these factors are classified and summarized from the people, objects, pipes and rings of safety management. Statistics show that lithium battery accidents are mainly divided into spontaneous combustion, explosion and electrolyte leakage. (1) Spontaneous combustion of lithium battery. Spontaneous combustion accident is the most common lithium battery accident. Due to the influence of improper human operation, battery design defects, substandard quality and wet working environment, the short circuit in the positive and negative electrodes of the lithium battery causes spontaneous combustion, and then ignite the surrounding combustible and causes the fire accident. In recent years, the spontaneous combustion accident of lithium batteries is the first among all accidents. (2) Lithium battery explosion. Lithium battery explosion accident common in lithium battery processing, manufacturing, transportation and charge and discharge, the main cause of the explosion accident is the battery internal space is narrow, once encountered battery short circuit phenomenon, internal temperature will rise rapidly, the battery internal liquid heated volume rapid expansion, internal pressure increases to a certain extent after the explosion. In particular, lithium batteries are most prone to explosion accidents in the process of charging. For example, since its launch in 2012, Tesla ModelS has caused more than 50 combustion or explosion accidents worldwide, most of which are related to batteries. (3) electrolyte leakage. The shell of lithium battery is not strong. Under the influence of extrusion, collision, internal collision and internal corrosion, the shell breaks, leading to the leakage of corrosive electrolyte, causing personal injury or environmental pollution events. The electrolyte leakage accidents are occur in the recycling and recycling of waste lithium batteries [3].

3. Properties and preparation methods of highly ordered silicon / carbon composites

Highly ordered silicon/carbon composites are widely used as anode materials for lithium-ion batteries. Highly ordered silicon/carbon composites also have good electrochemical properties and stability under the premise of high energy density, low cost, and fast charge and discharge speed. The preparation method of highly ordered silicon/carbon composites has an important influence on the performance and application of highly ordered silicon/carbon composites, so the screening and optimization of the preparation method is one of the core problems in the application of highly ordered silicon/carbon composites in lithium ion batteries [4].

Highly ordered silicon carbon composites have two physical and chemical characteristics. Physically speaking, highly ordered silicon/carbon composites have high density, low cost, and are easy to prepare. In addition, the highly ordered silicon/carbon composites have good thermal stability, high chemical stability, are not easy to react with the electrolyte, and can effectively reduce the battery self-discharge. Physically and chemically speaking, highly ordered silicon/carbon composites exhibit excellent electrochemical properties and reversible capacity, thus providing a higher energy density.

There are many methods to prepare highly ordered silicon/carbon composites, including chemical vapor deposition, physical vapor deposition, sol gel method, pyrolysis method, etc. Different preparation methods will have different effects on the morphology, structure and purity of highly ordered silicon/carbon composites, and then affect the characteristics and application of highly ordered silicon/carbon composites as lithium-ion batteries. For example, chemical vapor deposition and physical vapor deposition can prepare high performance silicon film, and sol gel law can prepare high purity silicon powder.

Raw material selection, reaction conditions and heat treatment system should be considered in the preparation of highly ordered silicon/carbon composites. These factors have a significant impact on the morphology, structure, and properties of highly ordered silicon/carbon composites. For example, high performance silicon film can be made from metal silane, and high purity silicon powder can be obtained from organic silane. The reaction conditions and heat treatment system will also affect the crystallinity and purity of highly ordered silicon/carbon composites, and then affect the performance and application of highly ordered silicon/carbon composites in lithium-ion batteries.

4. The principle and structure of silicon-based lithium-ion batteries

Silicon-based lithium ion battery takes highly ordered silicon/carbon composite material as the anode, lithium-ion as the medium, and the cathode material adopts transition metal oxide, which belongs to rechargeable battery and has broad development prospects. The principle is the same as that of ordinary lithium-ion batteries, where they are stored in silicon-based materials through the migration between positive and negative electrodes. Because of its high energy density, long life and fast energy discharge, the battery has become a new energy storage technology [5].

Silicon-based lithium-ion batteries usually include the following parts in structure: (1) cathode materials: In silicon-based lithium-ion batteries, highly ordered silicon/carbon composites are dominant. When charging and discharging, lithium-ion batteries s are embedded from the highly ordered silicon/carbon composite material, and use its atomic structure and physicochemical properties to store and release energy. (2) Cathode materials: transition metal oxide silicon-based lithium-ion battery cathode materials. It can undergo a reversible redox reaction with lithium ions to store and release the energy in the positive electrode. (3) Electrolytes: silicon-based lithium ion battery electrolyte is usually organic liquid or solid electrolyte. This kind of electrolyte not only requires good ionic conductivity, but also requires being compatible with the positive and negative electrode materials to ensure the safety and stability of the battery. Specifically, this paper takes a typical silicon-based lithium-ion battery as an example. The negative electrode is made of silicon carbon composite material, and the lithium-ion is embedded in the battery to realize energy storage and release. Lithium nickel-cobalt manganese oxide can carry out reversible redox reaction with lithium-ion batteries. Electrolyte is an organic liquid electrolyte, with good ion conductivity and compatibility. During charging and discharging, lithium ions are transferred to the positive and negative electrodes to store and release energy. Silicon-based lithium-ion battery has higher energy density and long life than ordinary lithium-ion battery. Taking the silicon-carbon composite material as an example, the reversible capacity can reach 1500 mAh/g when the charge-discharge cycle life exceeds 1000 times. In addition, silicon-based lithium-ion batteries have the advantages of fast charge and discharge speed, which can bring huge energy to electronic devices in a short period of time [6].

5. Application of highly ordered silicon/carbon composites in lithium-ion batteries

5.1 Silicon in the cathode material

The development of lithium ion battery cathode materials has always been committed to increasing energy density and extending cycle life. The traditional lithium ion battery cathode material is mainly lithium transition metal oxides, such as lithium cobalt oxide, lithium manganese oxide, etc. However, due to the limited capacity and performance limitations, researchers are constantly looking for better alternative materials, among which silicon is regarded as promising. Highly ordered silicon/carbon composites have larger theoretical capacity than conventional cathode materials and outstanding electrochemical properties. Compared with graphite materials, silicon is more than 10 times higher than graphite materials, so it can increase the energy storage density. However, the volume expansion of silicon charge and discharge is serious, resulting in the fracture of the electrode material and capacity loss. To overcome this problem, the researchers took various measures.For example, the volume expansion of highly ordered silicon/carbon composite can be slowed down by the synthesis and structural design of nanoparticles. By regulating the size and morphology of highly ordered silicon/carbon composite nanoparticles, the stress concentration and structure rupture can be effectively reduced. In addition, the cycle life can be extended by syntheshighly ordered silicon/carbon composites and controlling conductive side reactions. Specifically, the capacity of highly ordered silicon/carbon composite can be calculated according to the formula, namely the theoretical capacity of silicon (mAh/g) =3579 ρ Si/MwSi, where ρ Si represents the density of Si and MwSi represents the molar mass of Si. In contrast, the theoretical capacity of graphite materials is about 372 mAh/g. Therefore, the use of highly ordered silicon/carbon composites as the cathode materials for lithium-ion batteries can help to achieve a higher energy density, thus improving the overall performance and cycle life of the battery. At present, highly ordered silicon/carbon composites have been widely studied in lithium-ion batteries, and have achieved good results. Although there are still some problems to be solved, the use of highly ordered silicon/carbon composites in lithium-ion batteries still shows great room for development [7].

5.2 Silicon in the cathode materials

The anode materials of lithium-ion batteries have long been mainly graphite, but their capacity is limited. Comparatively speaking, highly ordered silicon/carbon composites have been widely studied because of their large capacity and rich resources, and become one of the alternative materials. However, due to the alloy formation of lithium ions and silicon, the volume of the highly ordered silicon/carbon composite will be severely expanded in the charge-discharge cycle. This can cause anode material fracture, capacity loss and other problems, which can restrict the use of highly ordered silicon/carbon composites in lithium-ion batteries. To overcome this difficulty, many researchers are trying to find multiple ways to alleviate the volume expansion of highly ordered silicon/carbon composites. One common method is to embed silicon nanoparticles in the interior of carbon-based materials to prepare silicon/carbon composites. Carbon-based materials provide support and elasticity to reduce volume expansion and structural rupture of highly ordered silicon/carbon composites. In addition, highly ordered nanostructured silicon/carbon composites can also reduce volume expansion by increasing the surface area. Researchers have made some progress through these approaches. According to the formula, the theoretical capacity (mAh/g) of silicon anode materials is about 4200 mAh/g, which is much higher than the theoretical capacity of graphite materials. This means that using the highly ordered silicon/carbon composite as the anode material can significantly improve the battery energy storage density.While silicon anode materials will also face the problems of volume expansion control and cycle life stability in lithium-ion batteries, researchers have actively studied a number of possible solutions to address these challenges. At present, silicon-based cathode materials have made important progress in the field of lithium-ion batteries. With the deepening of scientific research and continuous technological progress, the application of highly ordered silicon/carbon composites in lithium-ion batteries is expected to be commercialized, thus providing higher energy density and higher reliability of battery solutions for electric vehicles and renewable energy storage [8].

6. Application trend of high-performance lithium battery materials

6.1 The current situation of lithium battery application

At this stage, lithium battery has developed rapidly and has been widely used. The adoption of lithium-ion battery energy technologies in areas such as aerospace and new energy vehicles will help clarify the thinking and direction of power research and development, and increase their types and quantities, thus increasing the demand for lithium batteries. In the context of extensive publicity and environmental protection, the public interest and concern in lithium batteries has increased, which indicates the importance and value of high-performance lithium battery materials in the future. After the concept of green environmental protection won people’s hearts, the attention to lithium batteries began to increase, and the frequency and number of use also began to increase. In many areas, lithium batteries are considered as the preferred choice, such as new energy vehicles and space shuttles, all of which reinforce the development of lithium battery technology. Once this technology is improved and optimized, the development process of the whole industry will inevitably be accelerated, so that the efficiency and effect of lithium battery materials can be fully utilized. In fact, the scientific use of high-performance lithium battery is obviously more competitive in the market, and it is not difficult to see the placement [9].

6.2 Future development trend of high-performance lithium battery materials

The future development prospect of lithium battery is very good. On the one hand, it can be applied to different industrial sectors; on the other hand, the research of high-performance lithium battery has been influenced by the support and promotion of the relevant policies in China. In order to effectively deal with the development and production problems of lithium battery and ensure that the product quality meets the relevant requirements, different aspects of product quality, professionals and technology must be used as the entry point to promote the reform process. From the perspective of talents, there are few professional talents in this field in China, so it is necessary to pay attention to the training and education work, encourage universities to actively explore the lithium battery industry, effectively carry out talent training work, accumulate more talents, and drive the development and progress of the whole industry. From a technical point of view, due to the certain lag in domestic research and development and production technology, it is necessary to use imports to ensure the effective and continuous supply of lithium batteries. For this department, the workers must pay more attention to the research and analysis of equipment, achieve the research goal—independent development, reduce the import cost. Since high-performance lithium-ion batteries are still in the development stage, it is necessary to ensure their quality, performance and safety before they are formally used [3].

7. Conclusions

In conclusion, the application of silicon materials in lithium-ion batteries has great potential. Through reasonable improvement strategy, the problems of silicon material as the anode of lithium ion battery can be effectively solved, and the energy density and safety of lithium ion battery can be further improved. However, a lot of research work is still needed to realize the wide application of silicon materials in lithium-ion batteries, to meet the practical needs of electric vehicles, mobile devices and other fields.

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