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Review of the development of carbon-based battery

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Abstract. In today's society, people are increasingly aware of the importance of protecting the environment. In the past, some batteries and power generation methods were extremely harmful to the environment. So people began to seek sustainable energy sources, such as hydropower, solar power, and wind power. Among them, how to efficiently and sustainably store electric energy for these power generation methods while using the most environmentally friendly materials has become an important research direction. Carbon-based batteries have become the preferred energy storage device due to their many advantages, such as easy material acquisition, low cost, environmental protection and degradability. This paper mainly summarizes the advantages of carbon-based batteries such as simple and relatively mature preparation process, high stability and strong sustainability, as well as unit energy from the aspects of carbon-based supercapacitors, solar cells, solid-state batteries and bio-carbon-based batteries. This paper finds that shortcomings of carbon-based batteries such as low density and poor safety in special environments require further innovation in materials and processes. If the above shortcomings can be made up, carbon-based batteries will have huge application space.

Keywords: Carbon-based battery, Carbon-based super-capacitor, Carbon-based solar cell, Carbon-based solid-state battery

1. Introduction

Since Robert Wilhelm Bunsen invented the carbon electrode in 1841, the development of carbon-based batteries has been continuously improved. From dry batteries that appeared at the end of the 19th century to today's super-capacitors, the advantages of carbon-based batteries are also constantly being recognized by people. The sustainability and stability of carbon-based batteries provide many possibilities for many of today's contracted technology products, advanced cutting-edge technologies such as new energy vehicles, portable electronic devices, drones, renewable energy storage, aerospace and satellites all use carbon-based batteries, which shows the importance of developing carbon-based batteries. With the continuous development of current technology, the requirements for batteries are also constantly increasing, such as the energy density, charging speed, cycle life, sustainable performance and safety performance of carbon-based batteries. There is continued high demand. Among them, sustainability, safety and low cost are the most prominent advantages of carbon-based batteries and are worthy of in-depth study. Through literature analysis, this article uses literature analysis method to synthesize the development results of carbon-based super-capacitors, solar cells, solid-state batteries, and bio-batteries., analyzes the current development situation and bottleneck of carbon-based batteries, and summarizes the considerable development focus and direction of carbon-based batteries. This paper can have a guiding role in the development of smartphones, new energy vehicles, aerospace and sustainable energy.

2. Introduction to carbon-based batteries

The history of carbon-based batteries can be traced back to the voltaic battery in the early 19th century, the original carbon-zinc battery. Later, with the development of technology, alkaline carbon-zinc batteries, nickel-cadmium batteries, nickel-metal hydride batteries, and lithium-ion batteries appeared. Carbon-based batteries such as batteries and lithium polymer batteries. The principle is to match carbon materials with different metal materials to make electrodes and electrolytes. Chemical oxidation-reduction reactions or physical ionization occur to generate or store electrical energy, which benefits from the high conductivity, high stability, and high surface area of carbon materials. With many advantages such as embeddability and ease of material extraction, carbon materials will be favored whether as electrodes or conductive additives. Carbon-based batteries have also been widely praised and recognized by many electronic product markets such as electric vehicles, smartphones and laptops, and carbon-based batteries play a large role in storing electric energy in renewable energy power generation such as wind power generation, solar power generation and hydropower generation. It can be mainly divided into four development directions: carbon-based supercapacitors, solar cells, solid-state batteries and biocarbon-based. Each development direction has great development space and strategic significance.

3. Application fields of carbon-based batteries

3.1. Carbon-based super-capacitor

Carbon-based supercapacitors (SCs), also known as electric double layer capacitors (EDLC), are popular energy storage devices today. Generally speaking, the reason why capacitors can store energy is because the chemical potential energy generated by the electrostatic separation of charges on the interface between the conductive electrode and the electrolyte is stored. However, compared with traditional capacitors, supercapacitors have unique water properties. Organic electrolytes provide ions that can move between electrodes, thereby physically separating charges rather than coming from chemical reactions. This means that the charging and discharging efficiency, speed, cycle life and stability of supercapacitors are superior to traditional capacitors.

Depending on the carbon electrode of the carbon-based supercapacitor, many derivative changes can be made to adapt it to the needs of more working environments. Research shows that the performance of porous carbon-based supercapacitors is mainly affected by the characteristics of porous carbon-based SCs, and the hierarchical porous structure can effectively improve the energy density and power density of SCs. Therefore, the pore structure should be considered when preparing or designing new porous carbons. Therefore, selecting appropriate probe gases and models is of great significance for evaluating the specific surface area and pore size distribution of porous carbons [1]. Another study noted that a new type of nitrogen-doped activated carbon was synthesized through a one-step method. The obtained Nitrogen-doped Activated Carbon (NAC) material exhibits excellent electrochemical properties, with a specific capacity as high as 129 mA h g-1 and a capacity retention rate of 86% after 500 cycles. N-doping of NAC was found to help improve performance [2].

3.2. Carbon-based solar cells

All solar cells use the photovoltaic effect to convert solar energy into electrical energy. The difference between carbon-based solar cells and traditional solar cells is that carbon-based solar cells use organic (carbon-based) materials as the active layer. Not only are they low-cost and easily available, but their flexibility and compatibility are far superior to other types of solar cells. Organic solar panels can be produced on flexible substrates, which means they are not only light and soft, but can also be equipped for use on curved devices.

The use of carbon materials in inorganic solar cells has also received great attention. Taking the development of traditional inorganic perovskite solar cells as an example, the laboratory inorganic perovskite solar cell sample efficiency certified by the U.S. National Renewable Energy Laboratory (NREL) As high as 20.1%, its low cost, efficient photoelectric conversion rate and suitability for curved surfaces were widely welcomed at the time. However, with the continuous advancement of the times, the market's requirements for time and economic benefits have further improved. Due to the complex and expensive synthesis process of spiro-OMeTAD, its hole transport material, and the use of Au electrodes, it is no longer suitable for commercial applications. However, the emergence of new carbon materials has saved the decline of inorganic perovskite solar cells. Carbon-based nanomaterials such as activated carbon, graphene, and carbon nanotubes have completely replaced the Au electrode with their excellent physical properties and optimized hole transport. Materials also improve the photoelectric conversion efficiency of the battery [3]. After assembly line production, the commercialization of organic solar cells is just around the corner.

3.3. Carbon-based solid-state batteries

Graphite-$LiCoO_2$, as shown in Figure 1, is a lithium-ion battery and the most recognized material combination among carbon-based solid-state batteries. It is widely used in energy storage for electric vehicles, smartphones, laptops, cameras and renewable energy. Unlike carbon-based supercapacitors, carbon-based solid-state batteries store energy through chemical reactions. Because of their solid electrolyte, the charge and discharge speed will be slower than that of carbon-based supercapacitors, but it also means that they have higher energy density. Coupled with the participation of chemical reactions, carbon-based solid batteries can store more energy per unit volume or mass than carbon-based supercapacitors.

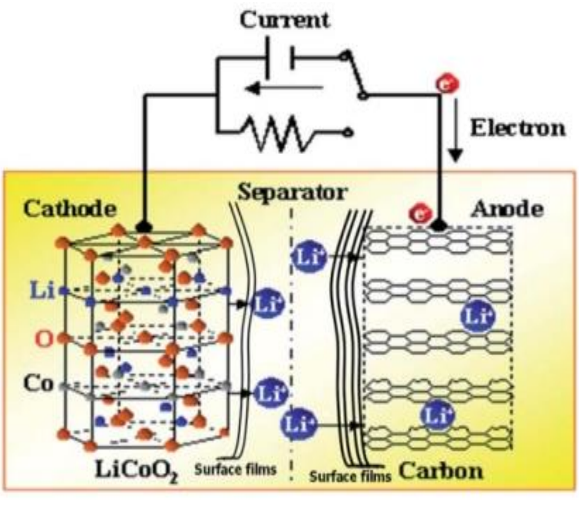

Figure 1. A schematic presentation of the most commonly used Li-ionbattery based on graphite anodes and LiCoO cathodes [4].

In carbon-based solid-state batteries, carbon materials can be used as anodes like graphite-LiCoO2 to provide stable chemical reactions, or they can be used as conductive additives, such as carbon nanotubes or graphene, to enhance conductivity. Compared with traditional metal batteries such as lithium-sulfur batteries or lithium-air batteries, this not only has a longer cycle life, but it is also easy to obtain materials and can be recycled, with very high economic benefits.

3.4. Bio-carbon based materials

As the name suggests, biocarbon-based carbon materials are carbon materials obtained after simple physical processing of agricultural waste, plant residues or other organic materials. Its most prominent advantage is that it is not only environmentally friendly and convenient to obtain, but also cheaper than carbon materials such as carbon nanotubes, has a simple preparation process, and is more stable than commercial carbon materials such as conductive carbon black. In addition, biocarbon materials have a naturally loose porous structure. Compared with artificial carbon materials, although the efficiency of ion passage is almost the same, biocarbon materials are definitely more cost-effective in terms of preparation process and cost. According to research, biomass carbon-based perovskite solar cells (PSCs) also have smaller hysteresis and better long-term stability. Among them, the soybean residue carbon (SDC)-based battery with a large pore structure has fewer interface defects, better charge transfer performance and better interface contact. After being placed at room temperature for 60 days, the SDC-based photoelectric conversion efficiency (PSCs) device still retains 96% of its original PCE, demonstrating excellent long-term stability [5]. This also reflects that biological carbon sources have the characteristics and sustainability of carbon sequestration and are one of the most environmentally friendly carbon sources.

4. Analysis of the development prospects of carbon-based batteries

4.1. Advantages and disadvantages of carbon-based batteries

As for carbon-based supercapacitors, their most prominent advantages are that they have high power density and a longer life span than traditional batteries. They can quickly transmit and store electrical energy and have a high number of cycles. The second is low maintenance cost, suitable for a variety of environmental conditions, and the material is relatively environmentally friendly. The disadvantage is that the energy density is low and has a lower voltage limit compared with ordinary batteries, which also means that it is suitable for those who need to store large amounts of electric energy for a long time. Scenario-wise, carbon-based supercapacitors do not have many advantages.

For carbon-based solar cells, their most prominent advantages are low manufacturing cost, high flexibility, lightweight, and can be used on curved surfaces. They are a good choice for the aerospace and electronic product industries. However, the shortcomings are also obvious. Compared with traditional silicon solar cells, the efficiency is lower, and the stability in special environments such as moisture or exposure is limited, further deteriorating its efficiency.

For carbon-based solid-state batteries, the most prominent advantage is their strong safety performance. The design of the solid-state electrolyte avoids the risk of flammability of the liquid electrolyte in traditional lithium-ion batteries, thereby reducing the probability of thermal runaway. Secondly, it has higher energy density and longer cycle life than traditional lithium-ion batteries, and the overall design is lighter and more compact than traditional liquid electrolyte batteries. The disadvantage is that it is more complex and costly than traditional lithium-ion battery manufacturing. How to better commercialize it is one of its important challenges.

For biocarbon-based batteries, its most prominent advantages are renewable, sustainable utilization and biocompatibility. Compared with commonly used fossil materials, biocarbon sources have unique significance for sustainable development. They are not only biodegradable but also beneficial to Environmental climate change, and its wide range of uses, it has inherent advantages in the biological and medical fields. The disadvantage is that the production of biocarbon materials may be limited by the availability of biological resources when production demand is high. In addition, the efficiency of biodegradation is different, which may conflict with other industries in the scenario of large demand in a short period of time. Secondly, it is difficult to achieve precise quality and performance consistency with biocarbon materials, and in some cases, the production cost of biocarbon materials may be more expensive than synthetic materials. Some biocarbon materials may have technical limitations compared to synthetic materials. This includes properties such as strength, durability, or resistance to certain environmental conditions.

In general, the advantages of carbon-based batteries are simple and relatively mature preparation processes, high stability and strong sustainability; the more prominent disadvantages are low unit energy density and poor safety in special environments. Further innovations in materials and processes are needed.

4.2. The current development situation and bottlenecks of carbon-based batteries

Most of the current carbon-based batteries use graphite as the anode, which is widely used and mature enough to be put into commercial production, with a good balance between cost and cost. In terms of conductive additives, there are technologies such as carbon black and carbon nanotubes. Research directions currently include carbon composite materials such as graphene-based materials to improve electrode conductivity, mechanical strength and stability; there are also carbon-based materials used as cathodes to enhance the performance of certain batteries. The first bottleneck that needs to be broken through is the improvement of energy density, followed by performance guarantee under extreme conditions, and finally how to control costs and achieve a balance with them to move toward marketization.

4.3. Future development direction of carbon-based batteries

For now, how to improve the energy density of carbon-based batteries and improve their safety under extreme conditions are the two bottlenecks that carbon-based batteries need to break through. Take the current carbon-based batteries in new energy vehicles as an example, their energy density is not only closely related to their mileage but also may accelerate the aging of the batteries when using more power-consuming electronic equipment in the vehicle, such as air conditioners. Coupled with its sensitivity to extreme conditions such as temperature, batteries may undergo extreme phenomena such as spontaneous combustion and explosion [6].

5. Conclusion

This paper mainly summarizes the advantages of carbon-based batteries such as simple and relatively mature preparation process, high stability and strong sustainability, as well as relatively high unit energy density from the aspects of carbon-based supercapacitors, solar cells, solid-state batteries and bio-carbon-based batteries. Shortcomings such as low temperature and poor safety in special environments require further innovation in materials and processes. Improving the energy density of carbon-based batteries and improving safety under extreme conditions are the two bottlenecks that carbon-based batteries need to break through most. This article may not involve enough cases, and the analysis is relatively general. Data analysis and comparative analysis can be used to further support the arguments of this article. Future research can focus on processing technology and material innovation to improve the performance of carbon-based batteries and make up for their shortcomings.

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