Three Kinds of Energy Storage Devices

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ABSTRACT: Recently, environmental issues are continuing to exert pressure on an already stretched world energy infrastructure. Significant progress has been made in the development of renewable energy technologies such as solar cells, fuel cells and biofuels. However, these energy sources have been marginalized with the increasing specific energy and power demands. Among various new energy storage technologies, Lithium ion batteries and supercapacitors are the stars because of high energy density and high power density respectively.
KEYWORD: Energy storage devices; Lithium ion battery; Supercapacitor; Hybrid supercapacitor

1 INTRODUCTION

In general, the major resources of our energy necessities are mostly dependent on fossil fuels. Limited reservoirs of fossil fuels and escalating utilization of energy, especially after the era of electronics industry, have posed solemn crisis of energy. Development of commercially available, extremely capable, novel and nontoxic pathways for energy storage has now become indispensable. Researchers have made their incessant efforts and devised many physical and chemical advantageous strategies of energy production and storage. Batteries and supercapacitors (SCs) are also the dynamic results of such substantial efforts [1-3].

Each battery technology has its own advantages and drawbacks. For example, Lead-acid is the cheapest to produce, but has low cycle-life and energy density, NiMH has good power capability, but lower energy and lower cycle life than Lithium ion. SC and Lithium ion battery (LIB) devices are interesting because they stand at two ends of the spectrum: LIBs have the highest energy density of all systems, which can vary from 120 to 200 Wh/kg. SCs have the highest power density, that can range from 2 to 5 kW/kg or more, combined with the highest cycle life, on the order of hundreds of thousands to million cycles. But their energy density is low, from 2 to 5 Wh/kg [4, 5].

LIBs with high energy density and SCs with excellent power density are currently considered to be two excellent candidates as novel, environmental-friendly, low-cost, and high-performance energy storage devices to meet the needs of increasing demand [6].

With a combination of the fast charging rate of SCs and the high energy density of LIBs, a novel supercapacitor–battery hybrid energy storage system, also called hybrid supercapacitor (HSC) has emerged, which is expected to possess the best features of both SCs and LIBs. HSCs are composed of a capacitor-type electrode and a lithium ion battery-type electrode in a Li salt containing organic electrolyte. The combination of two different types of electrode would result in the storage of more energy due to the much wider working voltage window of the organic electrolyte and the great specific capacity of the battery-type electrode [7, 8].

2 LITHIUM ION BATTERY

Among various new energy storage technologies, LIBs have become the prime candidate due to the high voltage, high energy density and environmental friendliness [9, 10]. In the past years, LIBs have dominated the portable electronic markets [11]. However, the power density of LIBs still needs to be further improved to fulfill the demand of the industrial battery products although they have the highest energy density [12, 13].

2.1 *The electrode materials of LIBs*

For LIBs, the main components are the electrode materials including anode and cathode [9].

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2.1.1 *The anode materials*

The commercialized anode used in LIBs is graphite. It's cheap and non-toxic.

2.1.2 *The cathode materials*

A vast series of Li-storage cathode materials has been explored in the past years, such as layered $LiMO_2$ (M¼ Co, Mn, Ni, or $Mn_xNi_yCo_z$), layered Li-rich $xLi_2MnO_{3(1-x)}LiMO_2$(M¼ Co, Mn, or Ni), spinel$LiMn_2O_4$, spinel $LiNi_{0.5}Mn_{1.5}O_4$ (LNMO), and olivine $LiMPO_4$(M ¼ Fe, Co, Mn, or Ni). The exploration of the cathode materials attracts intensive attention.

3 SUPERCAPACITOR

Supercapacitors may be used to complete the electrical power capability of batteries or fuel cells in numerous applications. They can be used to store energy and to provide peak power demands in power electronic systems. For example, in a hybrid vehicle, the supercapacitors can provide peak power requirement in transient state and can store the regenerative energy. Supercapacitors offer huge capacitance, small series resistance, high power density, long lifetime, good cyclability and can easily controlled by power electronic conversion. In some specific applications, supercapacitors are deeply charged and discharged with high current. This effect causes supercapacitors heating and accelerates their ageing.

All in all, supercapacitors are designed to bridge the gap between batteries and capacitors to form fast charging energy-storage devices of intermediate specific energy. They are seen to have a potential market both in hybrid electric vehicles and pure electric vehicles to improve regenerative braking (through fast charge capability) and deliver larger acceleration (through fast discharge capability) [11].

Several supercapacitor designs have tried to introduce effective methods for increasing the capacitance to enhance the storable electrochemical energy. Typically, most material designs that have been proposed to improve supercapacitors have focused on higher surface area, larger working potential window, use of Faradaic reaction with specified metal oxide, etc., because energy densities are based on the capacitance and working potential window.

3.1 *The classification and work principles of supercapacitors*

There are two categories of supercapacitors: an electric double layer capacitor (EDLC) and pseudo-capacitor, which differ in their charge storage mechanisms [15].

The EDLC uses electrostatic separation at the electrode/electrolyte interface, whereas a pseudo-capacitor performs faradaic reactions within the active material of the electrode. EDLCs are composed of porous carbon-based materials, They have excellent cyclic stability, fast kinetics, and high power density due to the rapid adsorption and desorption of ions and enormous charge capacity, Extensive explorations have shown that to achieve EDLCs with high performance, several factors of the carbon-based materials are crucial: the specific surface area (SSA), electrical conductivity, and pore size and distribution.

Another type of supercapacitor, referred to as a pseudocapacitor, derives its capacitance from the storage of charge in the bulk of a redox material in response to a redox reaction. This fast redox reaction acts like capacitance (hence the name pseudocapacitance). A pseudo-capacitor typically stores a greater amount of capacitance per gram than and EDLC, as the bulk of the material (not just the surface layer) reacts [13].

The pseudocapacitive materials could be conducting polymers and transition metal oxides. The most widely explored electroactive materials include three types: a) transition metal oxides or hydroxides, such as ruthenium oxide, manganeseoxide, and nickel hydroxide; b) conducting polymers, such as polyaniline, polypyrrole, and polythiophene; and) materials possessing oxygen- and nitrogen-containing surface functional groups. Compared with EDLCs, pseudo-capacitors can achieve much higher pseudo-capacitance than the EDLC capacitance. Nevertheless, further practical applications of these electroactive materials to pseudocapacitors are still limited by the low power density that arises from the poor electrical conductivity restricting fast electron transport, and by the lack of a pure cycling stability owing to the easily damaged structure of the materials during the redox process. Hence, to resolve these problems, carbon-based materials with high electrical conductivity and large SSA are usually used as the backbone materials to combine with these active materials for pseudo-capacitor electrodes [9-12].

4 HYBRID SUPERCAPACITOR

LIBs can provide high energy density (~150 W h/kg) as a result of Faradaic reactions derived from the intercalation of large numbers of lithium ions into the electrodes. However, intrinsically slow solid-state lithium diffusion in the bulk and the accompanying volumetric strain has limited its high-power capability. On the other hand, supercapacitors can provide good power as a result of fast surface reactions, while they suffer from low energy density because charge is stored only on the surface. For emerging new applications, the current status of energy storage using LIBs or supercapacitors barely satisfies the demands in terms of both energy and power. Thus, bridging the performance gap between LIBs and supercapacitors is becoming an important issue in the field of energy storage [1-5].

To combine the advantages of LIBs and supercapacitors, a new concept—i.e., hybrid supercapacitor—was recently proposed. As it is shown in Figure 1, it uses a Faradaic lithium-intercalation cathode (such as $LiMn_2O_4$) or anode (such as $Li_4Ti_5O_{12}$), which are commonly used as LIB electrodes, and combines it with a non-Faradaic capacitive anode or cathode (typically a carbonaceous material, activiated carbon), which are used in supercapacitors, in a non-aqueous electrolyte. The Li-ion capacitor asymmetrically and simultaneously stores charges by surface ion adsorption/desorption on one electrode and by lithium de/intercalation in the other electrode. The combination of the Faradaic intercalation and nonFaradaic surface reaction provides an opportunity to effectively improve the energy and power densities [14, 15].

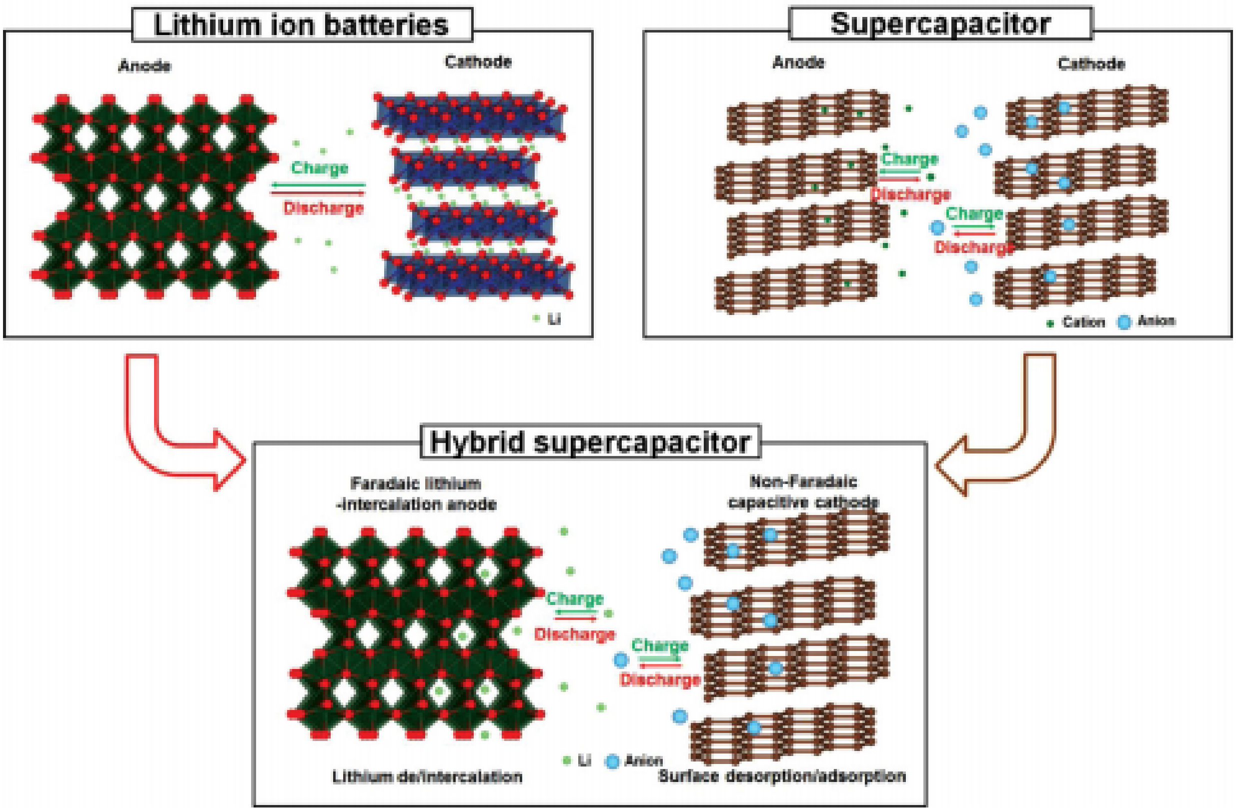

Figure 1 Illustration of a typical hybrid supercapacitor. The hybrid supercapacitor uses a non-Faradaic capacitive cathode like those used in supercapacitors and a Faradaic lithium-intercalation anode like those used in LIBs

5 CONCLUSION

The investigation of novel, low-cost, environmentally friendly, and high-performance energy storage systems has been under an ever increasing demand as a result of the needs of modern society and emerging ecological concerns. One of the challenges encountered by electrochemical energy system is to possess both high specific energy, high power density and cycling stability. A promising approach is the combination of lithium-ion battery and supercapacitor. By the aid of hybridization the system can possess energy and power density values between those of lithium ion batteries and supercapacitors as well as a suitable cycle life [12-15].

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