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A review on structure model and energy system design of lithium-ion battery in renewable energy vehicle

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ABSTRACT

Structure properties of lithium-ion battery determine the specific energy and specific power of renewable energy vehicle and have attracted extensive concerns. Fundamental innovations in battery system depend on the structure properties, of which graphene and concentration gradient structures become increasingly prospective. As the performance of structure closely relates to the battery performance and the advancement of battery technologies, the paper, based on the research work at our laboratory, discusses about the structure model and energy system design and analyzes the evolution of lithium batteries to provide scientific insights and technical advices for the development of renewable energy vehicle. The review shows that nano and graphene models, with their corresponding energy systems, significantly improve the performance of lithium batteries, thus supporting longer mileage and service life, while providing new ideas for the design of renewable energy vehicles. Compared with other power batteries, lithium-ion batteries are advantageous in addressing the requirements raised by battery electric vehicles, such as, long mileage, high-current charging, and safety. Therefore, lithium batteries are reliable and feasible for the deployment in battery electric vehicles.

Contents

1. Introduction

The whole world's total oil demand is predicted to reach 1500 million tons by year 2030, forming a sharp contradiction between market demand and energy constraints and making transformation in energy utilization imperative [1,2]. Renewable energy vehicle are strategic products to help solve the emission problem. If 30% of all vehicles were transformed to use renewable energy, The whole world would save 22% of its total oil demand [3]. The focus of renewable energy vehicle is on the battery (accounting for approximately half of the total cost) [4], which is required to possess high energy and power densities with fast charging ability at low cost and long lifetime. Energy density enables longer mileage while power density affects the acceleration and climbing performance of vehicles. Structure model and energy system design, therefore, emerges as decisive factors for renewable energy batteries [5]. To assure energy

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conversion efficiency, battery needs to be charged and discharged frequently, resulting in significant alternations in both voltage and current. But renewable energy vehicle requires battery to maintain power density, charge efficiency, and stability [6].

As traditional batteries cannot provide adequate energy density and power density, more and more vehicles are using lithium batteries because of its high working voltage (3 times of traditional battery) and high energy density (up to 165 Wh/kg, 5 times of traditional battery) [7,8]. Known as "green battery", lithium battery is able to remain stable under extrusion and overcharge, with capacity retention rate exceeding 93% after 1500 cycles, life expectancy of 5–7 years, and monthly self-discharge rate less than 5% [9,10]. The battery consists of electrodes and separator, of which structure functions (micro- and nano-scale characteristics) have significant impact on performance. Based on the technical and economic indicators, lithium ion batteries are primary choice for renewable energy vehicle and play a key role in assuring national energy safety [11]. During the charge–discharge cycles in batteries, lithium ion moves back and forth between anode and cathode, a process similar to a rocking chair, and the system is termed as "rocking-chair battery" [12], as shown in Fig. 1.

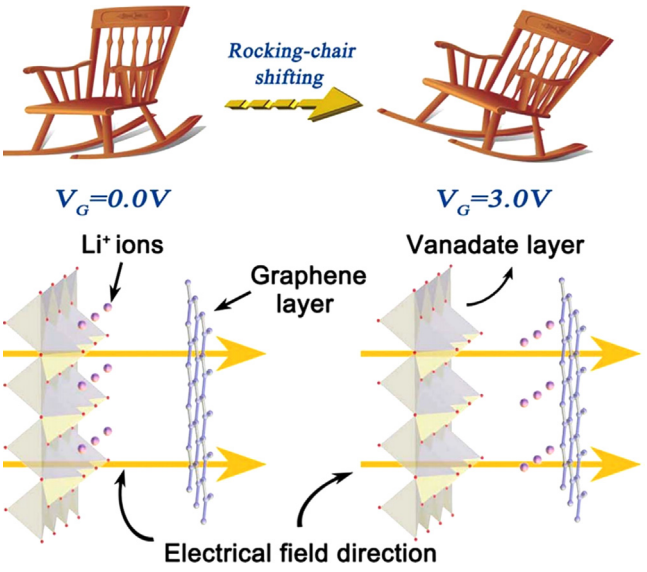

Fig. 1. Rocking-chair graphene battery energy system design and vanadate layer structure model of lithium battery for vehicle [12].

2. Structure model and energy system design for electrode of lithium ion battery

Concentration gradient materials have extensive applications in lithium battery [13,14]. Take Ni/Co binary material for instance, Ni gradually decreases from the interior to the exterior, while Co gradually increases, improving the performance of the composite [15]. At micro-scale level, structure can change the material properties [16], and doping technologies help to enhance conductivity [17]. Such unique structure creates novel properties through material integration and complementation [18]. Hence, research on nanostructure properties becomes a critical sector in recent years [19]. Sun et al. [20] designed a spherical nano-scale gradient structure for Li^+, as shown in Fig. 2, to achieve better magnification and higher tap density. $Li(Ni_{0.8}Co_{0.1}Mn_{0.1})O_2$ is used as inner material for high capacity, while $Li(Ni_{0.46}Co_{0.23}Mn_{0.31})O_2$ at surface for stability under high voltage. The gradient structure allows the material to be made into a thin film of any area in any shape [21]. Lithium ion batteries using such composite film possess a higher capacity. Li et al. [22] created a flexible film structure, as shown in Fig. 3, suitable for high-power charging and discharging, of which the three-dimensional gradient absorbs and retains electrolyte efficiently to assure high conductivity and flexibility. Under large current of discharge the structure generates little heat and the polymerization reactions occurred at high temperatures will close the micropores automatically and resist creep for structural integrity and dimensional stability. Such system becomes a new direction for battery materials.

Guo et al. [23] concluded that $LiFePO_4$ is much safer than traditional materials for applications under large current discharge. The structure of $LiFePO_4$ is orthogonal olivine, as shown in Fig. 4(c), where oxygen atoms stack closely with Fe and Li locating at the center to form octahedrons of FeO_6 and LiO_6. The neighboring FeO_6 octahedrons share one oxygen atom and connect with each other as a layer. Within layers of FeO_6, the neighboring LiO_6 octahedrons are connected via two oxygen atoms so that Li^+ can diffuse in one dimension. The diffusion is one-dimensional along the crystallographic b-axis. Located between layers of FeO_6, PO_4 takes the form of tetrahedron and can block the diffusion of Li^+ to some extent. The structure differs from the continuous structures such as lattice (Fig. 4a) and spinel (Fig. 4b) that have MO_6 octahedron. The multi-wall porous $LiFePO_4$ can be

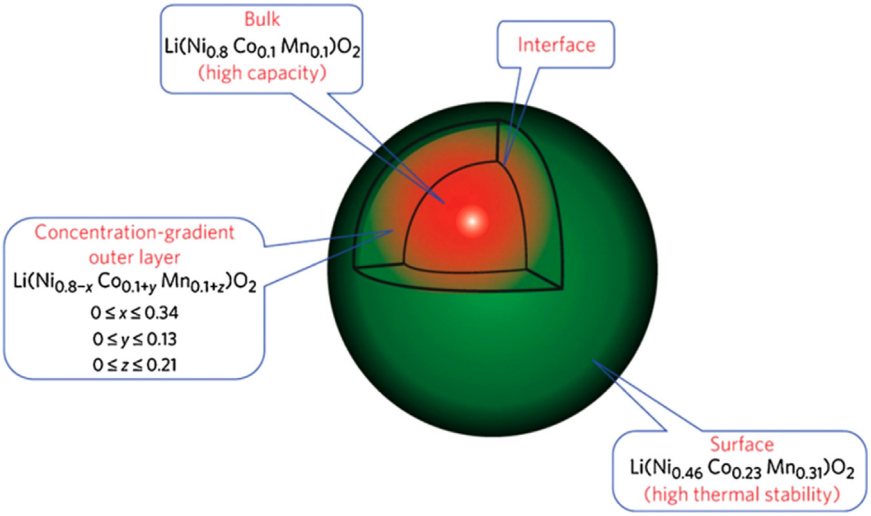

Fig. 2. Spherical gradient structure model and energy system design [20].