Editorial for advanced energy storage and conversion materials and technologies

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With the rising demand for fast-charging technology in electric vehicles and portable devices, significant efforts have been devoted to the development of energy storage and conversion technologies. Nowadays, remarkable progress has been made in the field of various energy storage and conversion devices, i.e., lithium-ion batteries (LIBs), lithium-metal batteries (LMBs), lithium-sulfur batteries (LSBs), sodium-ion batteries (SIBs), sodium-metal batteries (SMBs), magnesium-ion batteries (MIBs), zinc-ion batteries (ZIBs), electrochemical capacitors (ECs), the corresponding electrode materials have always been the focus and difficulty to further improve the electrochemical performance of the devices.

It is our great pleasure as Guest Editors of the journal “Rare Metals” to present the topic on “Advanced Energy Storage and Conversion Materials and Technologies”. It provides the most recent research developments in various rechargeable batteries. Six review articles and nine research articles focus on the electrode and electrolyte materials for LIBs, LMBs, LSBs, SIBs, SMBs, MIBs, ZIBs, and ECs.

The main contents on this topic are as follows:

LIBs, which possess the advantages of high safety, high power density, large capacity, long charge/discharge life, and low self-discharge rate, are becoming the best energy

supply option for various electronic devices, especially electric vehicles (EVs). Titanium dioxide (TiO_2) is considered to be one of the most suitable anodes for LIBs on account of their low cost, a high discharge voltage plateau, very good structural stability, and environmentally friendly properties. The morphology (wall thickness, tube length, etc.) and crystallography (amorphous, anatase, and rutile) of TiO_2 nanotubes were carefully analyzed, and how they affect the electrochemical performances of LIBs was summarized [1].

SIBs have emerged as one of the most promising candidates for next-generation energy storage systems because sodium is abundant in nature. The practical application of SIBs critically depends on developing robust electrode materials with high specific capacity and long cycling life, and developing suitable anode materials is even more challenging. Alloy-type anodes are attractive for their high gravimetric and volumetric specific capacities, demonstrating great potential for high-energy SIBs. Research progress of alloy-type anodes and their compounds for sodium storage was summarized [2].

MIBs have been recognized as the optimal alternative to LIBs due to their low cost, superior safety, and environment-friendliness. However, research and development on rechargeable MIBs are still underway as some severe problems need to be resolved. One of the most serious obstacles is the generation of an irreversible passivation layer on the surface of the Mg anode during cycling. Wang et al. briefly introduced the composition and working principle of MIBs. The up-to-date research progress on alternative anode materials for MIBs had been summarized [3].

With the rising demand for fast-charging technology in electric vehicles and portable devices, significant efforts have been devoted to the development of high-rate

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batteries. Rechargeable aqueous ZIBs are a promising option due to its high theoretical capacity, the low redox potential of zinc metal anode, and the inherent high ionic conductivity of the aqueous electrolyte. Zhu et al. [4] reviewed the state-of-the-art ultrafast aqueous ZIBs and focused on rational electrode-designing strategies. Recent research directions and future perspectives were also proposed in this review.

Alloy-type metals/alloys hold the promise of increasing the energy density of metal-ion batteries because of their theoretical high gravimetric capacities. A review by Li et al. [5] focused on the development and advances of electrolytic semiconductors (Si, Ge) and semiconductor-like metals (Sb, Bi, Sn) for metal-ion batteries, including electrochemical preparation mechanisms, manufacture strategies, and applications in LIBs, SIBs, potassium-ion batteries, and MIBs.

Supercapacitors are favorable energy storage devices in the field of emerging energy technologies with high power density, excellent cycle stability, and environmental benignity. Nickel sulfides have attracted extensive interest in recent years due to their specific merits for supercapacitor applications. Ma et al. overviewed the progress in the reasonable design and preparation of nickel sulfides and their composite electrodes combined with various bifunctional electric double-layer capacitor-based substances and pseudocapacitive materials [6].

As a promising candidate for anode material in high-power LIBs, Ni/T-Nb₂O₅ nanoparticles encapsulated in mesoporous carbon nanofibers were successfully prepared through a simple electrospinning route and succedent heating treatment [7]. The presence of Ni in carbon nanofibers is beneficial for enhancing electronic conductivity and the initial Coulombic efficiency. Ni/T-Nb₂O₅ nanoparticles are homogeneously incorporated in carbon nanofibers to form a nanocomposite system, which provides effective buffering during the lithiation/delithiation process for cycling stability.

Porous silicon nanostructures have aroused much interest as LIB anodes because of the large space to accommodate the volume change in lithiation and delithiation and shorter ion transfer distance. A modest magnesiothermic reduction reaction was demonstrated to produce blackberry-like porous Si nanospheres controllably using magnesium silicide as Mg source and SiO₂ nanospheres as the reactant [8]. This strategy offers a new route to fabricate high-performance porous Si anodes and can be extended to other materials such as germanium.

TiO₂ is a promising LIB anode material due to its high discharge plateau, inexpensive, non-toxic, and abundant reserves on earth. The three-dimensional (3D) TiO₂ nanotube arrays/porous Ti as a novel electrode material was synthesized by the nonsolvent-induced phase separation

and electrochemical anodization method [9]. The novel nanotube arrays@3D porous architecture effectively shortens the electron/ion transmission path, which could pave the way for optimizing the design of high-performance anode materials for the next-generation energy storage system.

Flexible, lightweight, and high conductivity substrates are required for the development of next-generation flexible LIBs. A cost-effective chemical plating method is adopted using the flexible cotton cloth (CC) as an alternative substrate for in situ fabrication of active materials, resulting in a self-supporting electrode without a binder. The work by Shi et al. [10] presents a novel route to develop desirable substrates for next-generation flexible LIBs.

The volume of the metallic lithium anode in all-solid-state LMBs increases significantly due to the lithium dendrite formation during the battery cycling, and the rough surface of lithium metal also reduces Li-ion transport in the Li/electrolyte interface. Wei et al. [11] developed a solid polymer composite by adding the low-cost Si₃N₄ particles to protect the lithium anode in all-solid-state LMBs. The lithium dendrite growth suppression by this composite electrolyte indicates the possible application of these low-cost composite electrolytes for lithium metal protection.

With the popularization of portable electronic equipment and the rapid development of electric vehicles, LSBs are believed as the most encouraging secondary batteries. Activated graphene/sulfur structure sheathed in a flexible graphene layer was presented as the cathode material of LSBs [12]. The results suggest that the in situ sulfur reduced graphite oxide coating layer designed as a reasonable nanostructure can effectively promote the behaviors of the electrode material for LSBs.

SIBs have an extremely bright prospect to replace the LIBs in smart grid applications and large-scale energy storage because of the rich resource of sodium and resulting low cost. Lai et al. reported a two-dimensional (2D) SnNb₂O₆/amino-functionalized graphene (En-RGO) nanocomposite with a representative 2D–2D architecture constructed by an easy self-assembly approach and firstly investigated as anode materials for secondary SIBs [13].

The practical application of SMBs is hampered due to the inferior interfacial stability between Na metal and conventional electrolytes. Therefore, a high-concentration electrolyte is proposed to solve this issue. As reported by Fang et al. [14], a localized high-concentration electrolyte (LHCE) was formulated with 1 wt% SbF₃ as an interface-stabilized additive to protect the Na metal anode. This reformulated LHCE retains the special coordination structure in HCE with improved wettability and high ionic conductivity.

As a newly emerging excellent energy storage device, supercapacitors have been widely studied due to their

unique advantages. The electrode material is one of the key components that determine the performance of a supercapacitor. Wang et al. demonstrated a mulberry-like RuO₂ electrode material for supercapacitors synthesized by a facial hydrothermal method, which exhibited excellent electrochemical properties and a large specific surface area due to its unique morphology [15].

We are very grateful to all the reviewers and the authors for their outstanding contribution that ensured the high-quality researches to be published on this topic. We are looking forward to these articles to help readers with more knowledge of advanced energy storage and conversion materials and technologies.

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