Editorial for special issue on advanced materials for energy storage and conversion

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The ever-increasing environmental problems and energy challenges have called urgent demand for utilizing green, efficient, and sustainable energy, thus promoting the development of new technologies associated with energy storage and conversion systems. Amongst a wealth of energy storage devices, Li/Na/K/Zn/Mg ion batteries, metal-air batteries, and lithium–sulfur/all-solid-state batteries together with supercapacitors as advanced power sources have attracted considerable interest due to their conspicuous merits of high energy density, long cycle life, and good rate capability. In the energy conversion systems, solar cells and fuel cells can be considered as mainstream renewable energy resources once their manufacturing cost has decreased to an affordable level. However, the developments of advanced power sources depend critically on advances in materials innovation. Therefore, to promote the practical applications of these promising systems, developing high-performance electrode materials has been taken into the center stage in current research areas from chemistry, physics, and materials science fields.

Here we inspire a special issue focusing on the recent development and achievements in the design, synthesis, structure-engineering, and optimization of electrode materials for application in catalysis, battery, and supercapacitors, aiming to highlight the strategies and fundamental mechanisms for improving the electrochemical behaviors based on both the experimental studies and theoretical simulations.

This special issue includes 18 papers, namely, 15 research papers and 3 review papers on designing advanced electrode materials for applications in catalysis, supercapacitors, and batteries. Majority of papers mainly focused on the research development in realizing the optimization of electrode materials for electrochemical energy storage, which provide a guidance and improve our understanding of high-efficiency

materials for commercial applications in various electrochemical energy-related devices

Silicon (Si) anode has been considered as one of the main innovation pathways for improving the energy density of lithium-ion batteries (LIBs) because Si has ten times higher theoretical capacity ($3579 \text{ mAh}\cdot\text{g}^{-1}$) comparing with those of conventional graphite ($372 \text{ mAh}\cdot\text{g}^{-1}$). However, it suffers from dramatic volume expansion ($>300\%$) and low electronic conductivity. To address these issues, Du *et al.* [1] reported a new idea of using carbon dots (CDs) modification on Si (Si/CDs) to enhance the interaction between the Si particles and binders. The as-prepared Si/CDs electrodes showed good mechanical structure stability and electrochemical performance (64% capacity retention was achieved at 0.2 C for 150 cycles). Qiao *et al.* [2] designed a chain-like structure composite, in which ZIF-67 derived porous carbon acts as a shell structure to integrally encapsulate Si nanoparticles, and carbon nanotubes (CNTs) play a role in connecting carbon shells. In this composite, the carbon shell can cushion the volume expansion and CNTs can improve overall stability and conductivity. Benefitting from these structural superiorities, the as-fabricated composite electrode revealed superior rate capacity and cycling stability, which in particular achieves a capacity of $732 \text{ mAh}\cdot\text{g}^{-1}$ at $2 \text{ A}\cdot\text{g}^{-1}$ and shows a reservation rate of 72.3% after cycling 100 times at $1 \text{ A}\cdot\text{g}^{-1}$. To prevent the Si/C anode from cracking during the cycle, Yang *et al.* [3] used SrF_2 to coat the Si/C anode electrode. The SrF_2 coating layer is proven to be favorable to form a more stable and mechanically strong solid electrolyte interface (SEI), thus the Si/C electrode exhibited more excellent cycling stability. Moreover, Feng *et al.* [4] gave a comprehensive review on the research progress of Si-based alloy anode from three different systems, including Si/Li-active sys-

tem (Si–Mg, Si–Ge, Si–Zn), Si/Li-inactive system (Si–Fe, Si–Ni, Si–Ti, Si–Cu), and some controversial and original systems (Si–Ti–Ni system, Si–Li alloy, and Si-inactive NM system). Additionally, a three-dimensional Sb_2S_3 anode modified with CNTs interphase was reported by Wang *et al.* [5], which exhibited good cycling stability with a high capacity retention of 94.7% after 160 cycles at 0.5 C and a high reversible rate capacity of $760.8 \text{ mAh}\cdot\text{g}^{-1}$ at 10 C.

All-solid-state Li-ion batteries (ASSLIBs) have been widely studied to achieve LIBs with high safety and high energy density. It is well known that the development of high-performance ASSLIBs relies heavily on advances in solid-state electrolytes (SSEs) innovation. However, the current SSEs still have some disadvantages such as low ionic conductivity, poor interfacial compatibility with solid electrodes. To solve these problems, Wei *et al.* [6] prepared a novel solid composite electrolyte (SCE) that is consisted of nanostructured MOFs (UiO-66-NH_2), surface-functionalized metal oxide particles (S– ZrO_2), and PVDF-HFP polymer. It was found that the SCE can effectively immobilize anions by strong Lewis acid-based interaction, achieving a high Li-ion transference number and ionic conductivity. Moreover, garnet-structured $\text{Li}_7\text{La}_3\text{Zr}_2\text{O}_{12}$ (LLZO) is highly regarded an SSE with excellent application potential. In order to give an overview of LLZO for ASSLIBs, Zhang *et al.* [7] summarized recent developments on garnet-structured LLZO including the preparation, element doping, structure, stability, and interfacial improvement of LLZOs and provided comprehensive insights to guide the development of garnet-structured LLZO-type electrolytes. Interfacial issues in ASSLIBs include the electrochemical decomposition reaction at the electrode-electrolyte interface and the low effective contact area between the solid electrolyte and the electrode, and they have currently evoked a plethora of research. Wang *et al.* [8] provided a systematic summarization on the research activities of solid electrolyte interface treatment based on buffer layer therapy, especially the matching degree between different buffer layers and different interface issues, and what methods may improve buffer layer performance. This review could help to advance future research and development of ASSLIBs.

SSEs also demonstrate a bright application prospect in the commercialization of lithium–sulfur (Li–S) batteries. Li–S battery is identified as one of the most promising energy storage devices in the future because of its high energy density, portability, and cost effectiveness. However, the problems such as the low conductivity of sulfur, shuttle effect of soluble lithium polysulfide in organic electrolyte, and volume expansion of electrodes impede its further developments. To handle these challenges, Duan *et al.* [9] designed a hollow N-doped carbon coated CoO/SnO_2 ($\text{CoO/SnO}_2@\text{NC}$) composite to increase the sulfur loading. The nitrogen-doped carbon shell provides good conductivity, the hollow core-shell struc-

ture can relieve the volume expansion, CoO/SnO_2 cores can provide strong absorption of polysulfides and reduce the “shuttle effect” during charging and discharging. Therefore, the $\text{CoO/SnO}_2@\text{NC/S}$ composite as cathode material for Li–S batteries exhibited excellent lithium-storage performances with an initial discharge capacity of $395.7 \text{ mAh}\cdot\text{g}^{-1}$ at 0.2 C and $302.7 \text{ mAh}\cdot\text{g}^{-1}$ after 400 cycles. Wu *et al.* [10] synthesized porous $\text{g-C}_3\text{N}_4$ nanotubes (PCNNTs) as an efficient sulfur host material for high-performance Li–S batteries. PCNNTs with a tubular structure could alleviate the volume expansion caused by sulfur and lithium sulfide during charge/discharge cycling. High N contents could greatly enhance the adsorption capability of the carbon nitride for lithium polysulfides (LPSs). These synergistic effects contribute to the excellent cycling stability and rate performance of the PCNNTs/S composite electrode.

Sodium-ion batteries (SIBs)/potassium-ion batteries (PIBs) are considered as promising next-generation energy storage devices. However, a lack of appropriate high-performance anode materials has prevented further improvements. Antimony (Sb) with high theoretical capacity has attracted considerable interest as potential anodes in SIBs and PIBs, but it suffers from huge volume variation during cycling, which poses a critical challenge for stable battery operation. Wang *et al.* [11] synthesized an ultrafine Cu_2Sb nanoalloy confined in three-dimensional porous carbon material with freeze-drying followed by a high temperature sintering process. The 3D porous structure with large surface area offers sufficient interspace to accommodate the volume expansion of Sb and suppress nanoparticle aggregation. The inactive Cu with high conductivity further improved the structure stability. As a result, the composite shows superior cycling durability (the capacity can be maintained at $328.3 \text{ mAh}\cdot\text{g}^{-1}$ after 100 cycles for SIBs and $260 \text{ mAh}\cdot\text{g}^{-1}$ for PIBs). Moreover, organic electrode materials with high theoretical specific capacity as anodes for SIBs face many challenges in practical application, such as high discharge plateau and high solubility in organic electrolytes. Chen *et al.* [12] successfully synthesized tetrahydroxy benzoquinone tetrasodium salt ($\text{Na}_4\text{C}_6\text{O}_6$) as an anode for SIBs. The as-prepared $\text{Na}_4\text{C}_6\text{O}_6$ electrode with four –ONa electron donating groups added on structure of BQ (p-benzoquinone) reduces the discharge plateau from ~ 2.7 to ~ 1.2 V greatly with the decrease value of over 1.4 V, which can make BQ change from cathode to anode material for SIBs.

Battery technologies beyond LIBs, SIBs, and PIBs, such as zinc-ion batteries (ZIBs) and Mg-air batteries, have also been widely studied due to their high safety or high specific energy. Particularly, developing high-performance electrodes plays a critical role in the practical application of these promising battery technologies in the future. For example, Qin *et al.* [13] fabricated $\text{Ba}_{0.25}\text{V}_2\text{O}_5\cdot 1.1\text{H}_2\text{O}$ (BaVO) nanobelts as cathode materials of ZIBs. Benefiting from the in-

creased interlayer distance of 1.31 nm by Ba^{2+} and H_2O pre-intercalation, the obtained BaVO nanobelts showed an excellent initial discharge capacity of $378 \text{ mAh}\cdot\text{g}^{-1}$ at $0.1 \text{ A}\cdot\text{g}^{-1}$, a great rate performance ($172 \text{ mAh}\cdot\text{g}^{-1}$ at $5 \text{ A}\cdot\text{g}^{-1}$), and a superior capacity retention (93% after 2000 cycles at $5 \text{ A}\cdot\text{g}^{-1}$). Boroujeny *et al.* [14] investigated the microstructural properties and electrochemical performance of Zn sacrificial anodes during strain-induced melt activation. The electrochemical test results for the 50% cold-worked sample confirmed that the corrosion current density declined by 90% and the anode efficiency slightly decreased relative to that of the raw sample. Yang *et al.* [15] studied the discharge property of Mg-air batteries employing Mg–Sn–Y alloys with different Sn contents ($\leq 0.7\text{wt}\%$) as anode materials. The Mg–0.7Sn–1.4Y alloy possessed a high steady discharge voltage of 1.5225 V and a high anodic efficiency of 46.6% at $2.5 \text{ mA}\cdot\text{cm}^{-2}$. These good properties were related to its microstructure: small grain size of $3.8 \mu\text{m}$, uniform distribution of small second phase particles of $0.6 \mu\text{m}$, and a high content (vol%) of (1120)/(1010) orientated grains.

In addition, there are several works regarding the catalysis, graphite oxide, and supercapacitors in this special issue, which exhibit their respective advantages in energy storage and conversion applications. For example, Liu *et al.* [16] synthesized atom-precise silver nanoclusters (NCs) in high purity by a kinetically controlled strategy. The silver NCs were supported on the active carbon (AC) to form the Ag NCs/AC, which displayed excellent activity for the catalytic reduction of 4-nitrophenol with the kinetic reaction rate constant k of 0.21 min^{-1} . Besides, the catalytic activity of Ag NCs/AC kept almost constant after six times of recycle, suggesting its good stability. Atta *et al.* [17] successfully prepared the γ -ray-reduced graphene oxide samples (GRGOs) by using high absorbed doses of γ -rays. They found that radiation reduction is an ideal method for RGO preparation, especially when the resulting RGO is applied in devices such as supercapacitors and thermal resistors. Zhang *et al.* [18] fabricated the MnO_2 /biomass carbon nanocomposite by a facile hydrothermal reaction. The biomass carbon not only offered the high conductivity and good structural stability but also relieved the large volume expansion during the charge/discharge process. Therefore, the obtained MnO_2 /biomass carbon nanocomposite electrode exhibited a high specific capacitance ($238 \text{ F}\cdot\text{g}^{-1}$ at $0.5 \text{ A}\cdot\text{g}^{-1}$) and prolonged cycling stability (93% remaining after 2000 cycles).

The special issue summarized some of the latest advancement in the design, synthesis, structure-engineering, and optimization of electrode materials for application in catalysis, battery, and supercapacitors, which will provide helps for readers to explore new research directions in the interdisciplinary fields of metallurgy, materials, environment, energy, and so on. So, we are appreciated to all authors for their innovative works and all reviewers for their helpful comments.

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