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Research Highlight

Biomimetics: from biological cells to battery cells

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Biomimetics, a term defined by Schmitt in 1960s, has been accompanying the development of humanity in learning from nature to solve problems over billions of years. The nature-inspired artificial design has driven innovative research across various disciplines, especially materials science, which is the foundation for other biomimetic fields like medicine, robotics, bioelectronics, self-cleaning, catalysts and energy-related devices [1–3]. In the field of energy storage, lithium-ion batteries (LIBs) have been widely employed in portable electronics. However, with the expansion of battery market, especially driven by the rapid demand in electric vehicles, the limited geographically concentrated lithium and cobalt resources are raising concerns over long-term supply availability. Recently, potassium-ion batteries (PIBs) are attracting dramatical attentions owing to the merits like low cost, high crustal abundance of potassium resources, and weak Lewis acidity of K ions. Moreover, the feasibilities of using commercial graphite as anode and low-cost Al foil as current collector further highlight the cost advantage. However, the research of PIBs is still in its early stage with many critical issues unsolved, particularly, the undesired structural collapse of electrode materials induced by repeated insertion/extraction of large radius K ions (1.38 Å, ~82% higher than Li-ion) [4,5].

In a recently published article in the *National Science Review*, Lu's group [6] from Hunan University, and his collaborators conceive a new concept of biomimetic carbon shells (BCCs) simulating the functions of a biological cell (Fig. 1a). Briefly, a biological cell encompasses the cytomembrane, ion transporting channels across the cytomembrane, and organelles inside. As for the delicately designed BCCs, the amorphous carbon shell plays the role as the cytomembrane, which enables the formation of a stable solid electrolyte interphase (SEI) film on the surface and provides sufficient spaces for buffering the volume variations during K-ion insertion/extraction. The protruding carbon nanotubes across the carbon shell serve as the ion transporting channels, warranting fast K-ion diffusion and thorough electrolyte permeation. The highly graphitized carbon sheets and carbon nanotubes inside function like organelles, which deliver a low discharge plateau and thus indicate a higher energy density. Collectively, the BCCs electrode demonstrates high reversible capacity (302 mAh g^{-1} at 100 mA g^{-1}), superior rate capability (160 mAh g^{-1} at 1.0 A g^{-1}, Fig. 1b) and excellent cycle stability (226 mAh g^{-1} at 100 mA g^{-1} after 2100 cycles with running time over 15 mon, Fig. 1c). With advanced *in-situ* X-ray diffraction (XRD) technique, Lu and co-workers [6] illuminated the forming process of a stable SEI film on the surface of BCCs and underscored the excellent cycling stability of BCC electrode (Fig. 1d). Simultaneously, this also sheds light on the importance of electrolyte composition (a concentrated electrolyte of 4 mol L^{-1} bis(fluorosulfonyl)amide (KFSI) in 1,2-dimethoxyethane (DME) is adopted in this work), which is another critical issue in the field of K-ion storage [7–9]. Heart tied with the practical prospect, Lu and co-workers [6] evaluated the full-cell performance with widely used Prussian blue as the cathode. Surprisingly, the assembled full cells can maintain ultrahigh capacity retention after ~1000 cycles, verifying the promising prospect of BCCs in realizing commercial PIBs.

In closing, this work by Lu's group and his collaborators tactfully combined biomimetics and materials science, building better battery cells simulating biological cells. This strategy will also inspire the design and manufacture of biomimetic materials across multiple disciplines like nanoscience, chemistry, materials science, and energy storage. In the meantime, despite designing high-performance electrode materials, future research in PIBs should focus on (i) electrolyte optimization with low cost, high safety, and good chemical/electrochemical stability, and (ii) full-cell design with clear electrochemical mechanisms and optimizations of each individual electrode for better evaluating the practical and commercial prospects.

Conflict of interest

The authors declare that they have no conflict of interest.

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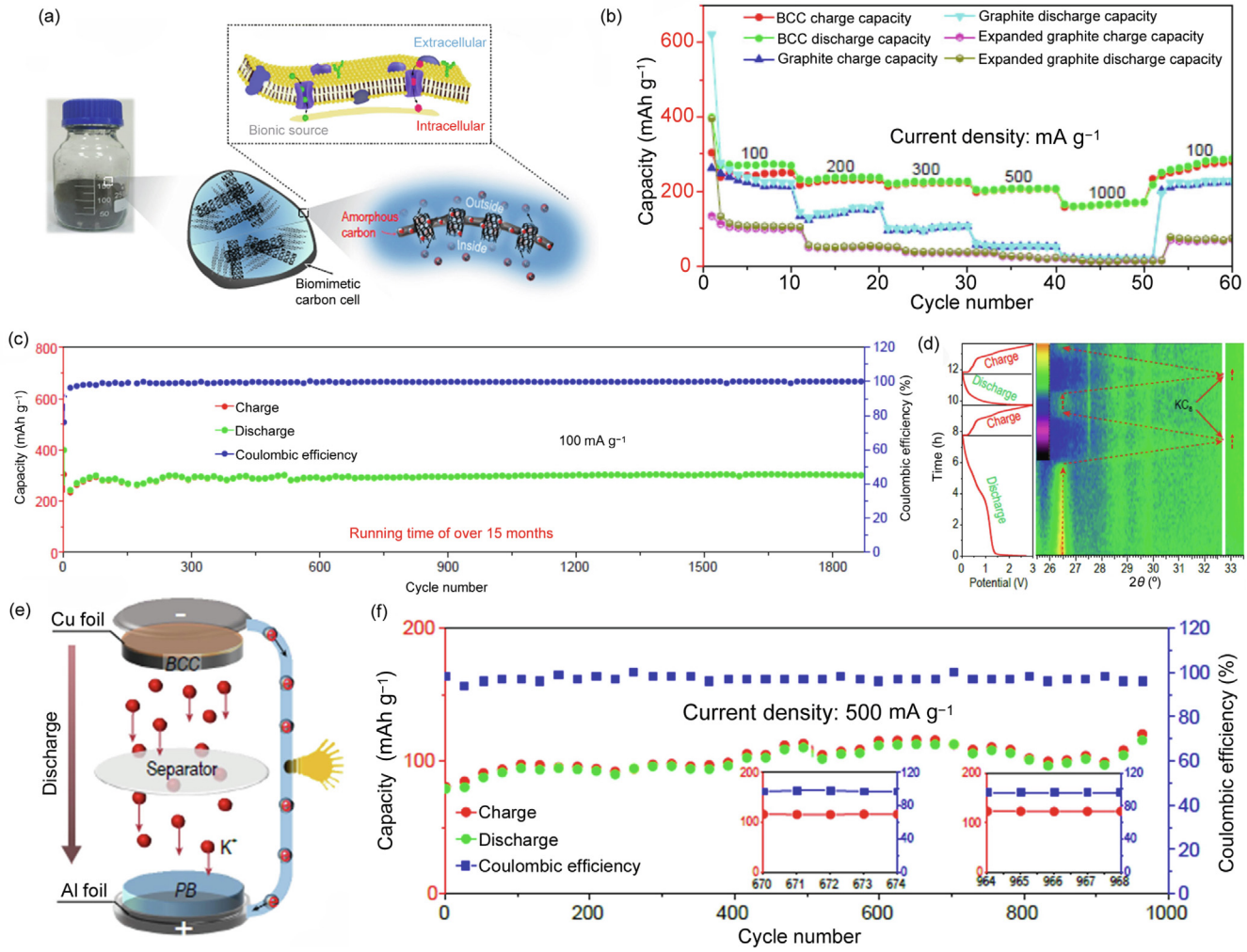

Fig. 1. (a) The structural and functional similarity of membranes in a biological cell and a BCC. (b) Rate performance of BCC, graphite, and expanded graphite at various current densities. (c) Long-term cycling performance at 100 mA g^{-1}. (d) Galavanostatic charge-discharge curves of BCC anodes for the first two cycles, and the related *in-situ* XRD patterns during cycling. (e) Schematic illustration of the K-ion full battery based on the as-prepared BCC and Prussian blue (PB). (f) Cycling stability at 500 mA g^{-1} [6].

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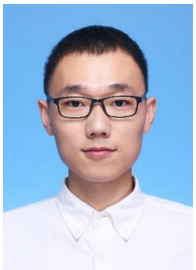

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