Science Bulletin 64 (2019) 76–77

Contents lists available at ScienceDirect

Science Bulletin

journal homepage: www.elsevier.com/locate/scib

Research Highlight

Rechargeable battery operates at a record low temperature

Ping He, Haoshen Zhou *

College of Engineering and Applied Sciences, National Laboratory of Solid State Microstructures, Collaborative Innovation Center of Advanced Microstructures, Nanjing University, Nanjing 210093, China

Commercialized lithium ion batteries (LIBs) using intercalation compounds as electrode materials have found wide applications in kinds of portable devices and electric vehicles (EVs). Nevertheless, there is a common problem that the LIBs will lose most capacity and power with the sharp decrease of the electrolyte's conductivity when the working temperature lowers down below 0 °C. As widely reported, only a low capacity retention of ~12% can be achieved for conventional LIBs at −40 °C compared to the normal capacity at room temperature. Although many efforts have been focused, the ultra-low temperature (below −40 °C) operation of Li-ion full cells has rarely been broken through up to present. Recently, Yongyao Xia, Yonggang Wang and co-authors [1] provided insight into the factor for the failure of rechargeable battery at low temperature, and achieved the successful operation of rechargeable battery at a record ultra-low temperature of −70 °C for the first time by taking an ethyl acetate (EA)-based electrolyte and organic electrodes materials.

One of the effective ways to ameliorate the low-temperature (low-*T*) performance of rechargeable battery is through externally heating/insulating [2]. This strategy can efficiently increase the local working temperature. However, both the auxiliary external devices/materials and the consumed time to heat would inevitably reduce the operation efficiency of battery systems.

In general, lacking ionic conductivity and the frozen liquid electrolyte at low temperature are believed to be the main factors for the poor performance of rechargeable battery. Accordingly, over the past years, many efforts have been paid to explore approaches for modifying the electrolytes, such as developing additives to construct binary/ternary/quaternary cosolvents system [3], decreasing the amount of solvent that exhibits low freezing point [4], exploring novel electrolyte solvents that have unique features for low temperature application [5]. Among all strategies, seeking a suitable solvent with a low freezing point for low-temperature electrolyte is a direct and effective way for the improvement of rechargeable batteries' performance at low temperature. Ethyl acetate (EA) stands out among many kinds of electrolyte solvent due to its freezing point of as low as −84 °C (Fig. 1), which needs further investigation on the low temperature performance of the ethyl acetate-based electrolyte.

It is well known that both the electrolyte and electrodes have great influence on the battery performance. Commercialized LIBs take intercalation compounds as electrodes, whose electrode reactions are based on the intercalation/de-intercalation of Li^+ into/out of electrode materials during the charge/discharge process. The electrode reaction involves the following steps: the solvated Li-ion diffuse from the bulk electrolyte the surface of the electrode, and then the charge-transfer reaction of the de-solvated Li^+-ions occurs at the electrode/electrolyte interface, followed with the Li-ion diffuse in the bulk of intercalated compound.

The de-solvation of solvated solvent molecules around Li^+-ions have to be thoroughly processed before the intercalation of Li^+ into crystalline framework of electrode materials. Obviously, the de-solvation/solvation rate became much difficult, even impossible at ultra-low temperature, which becomes another obstacle for the low temperature operation of conventional LIBs. The researchers come up with the employment of organic compound electrodes that exhibit special charge storage mechanism in the chemical bonds such as an n-type doping/de-doping or a p-type doping/de-doping mechanism. For example, the reversible enolization process of carbonyl group can be assigned to n-type mechanism, while the redox reactions accompanied with reversible adsorption/desorption of anions can be classified to the p-type mechanism. The charge storage process can be facilitated owing to the fast reaction on the organic functional groups, thus efficiently improving the slow de-solvation process at subzero temperature.

The researchers therefore come up with a battery design by taking advantage of the EA-based electrolyte and organic polymers electrodes [1], which can function well at the record low temperature of −70 °C (Fig. 2a). Furthermore, mixing polymer materials with intercalation compounds can behave synergy to improve the charge transfer within the hybrid materials, which effectively improves the energy density at low-*T* [6]. Such a rechargeable battery might be applied as an accessory power source to offer the instantaneous high power for the start-stop process, especially at ultra-low temperature.

Xia and colleagues' work indicates the realization of rechargeable battery at a record temperature as low as −70 °C, which is of great importance for their application under a greater span of temperature and climate such as aerospace, cold temperatures, some extreme climates and high altitude areas, and so on (Fig. 2b). Their study might shed light on the design of rechargeable batteries that can be operated at low-*T*. Obviously, in order

* Corresponding author.
E-mail address: hszhou@nju.edu.cn (H. Zhou).

https://doi.org/10.1016/j.scib.2018.12.026

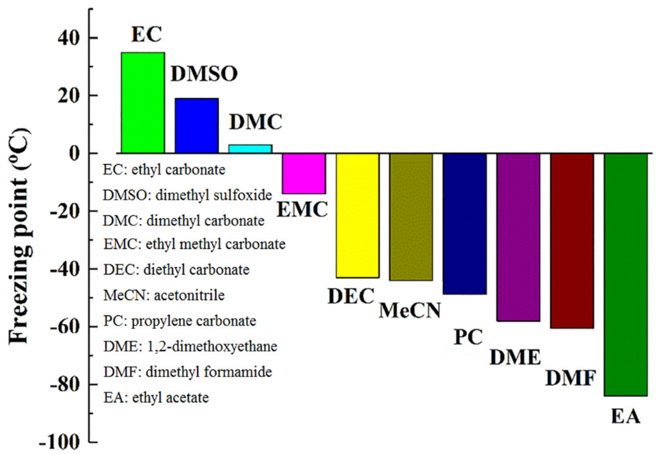

Fig. 1. Comparison of freezing point among the commonly-used solvents for rechargeable lithium-ion batteries electrolyte.

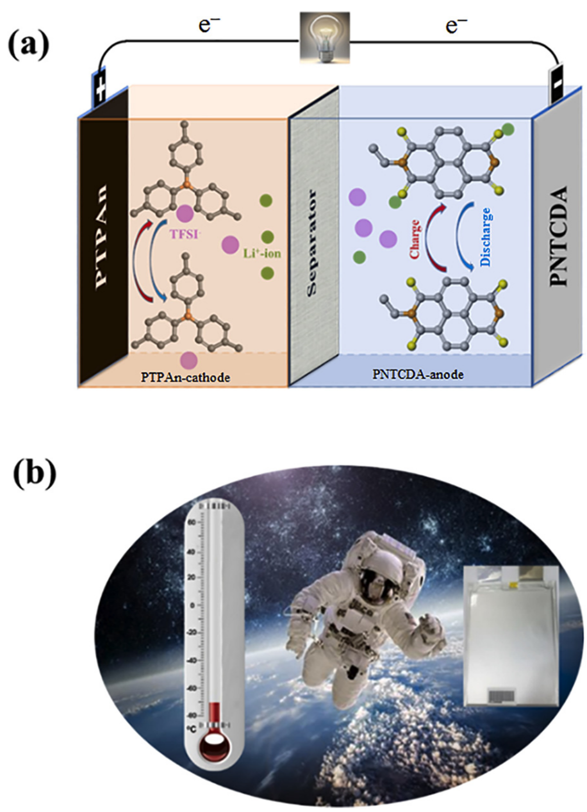

Fig. 2. Schematic illustration of working mechanism (a) and perspective for the potential application (b) of the rechargeable battery operated at the ultra-low temperature of −70 °C.

to exploit high performance rechargeable batteries at desired low temperatures, the solvation/de-solvation process at low temperature should further be clarified with in-situ and ex-situ characterizations in the future.

Conflict of interest

The authors declare that they have no conflict of interest.

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Ping He obtained his Ph.D. degree in Physical Chemistry from Fudan University in 2009, and later worked as a postdoctoral fellow at AIST, Japan. He currently is a professor of College of Engineering and Applied Sciences at Nanjing University. He focuses on the field of energy storage and conversion materials: functional materials electrodes for advanced batteries (Li-ion battery, Li-O_2 battery); electrochemical profile, structure stability, safety, processing – structure – property relation.

Haoshen Zhou obtained his B.S. degree from Nanjing University in 1985, and received his Ph.D. degree from the University of Tokyo in 1994. He is a professor in Nanjing University. His research interests include the synthesis of energy active materials and their applications in Li-ion batteries, Na-ion batteries, Li-redox flow batteries, metal–air batteries, and new type batteries/cells.