Lecture 14. Application of anode materials for alkali metal ion-batteries

LIBs are currently one of the most efficient devices for energy storage. These devices consist of an electrolyte and two electrodes, a cathode, and an anode, which are connected to an external circuit. The cathode is a lithium salt electrolyte placed on aluminium foil, and the anode is a carbon material deposited on a metal current collector. An electric current is created when charged particles move lithium ions to the cathode and electrons to the anode. When all the particles reach the electrode they need, the battery is discharged. When charging, the reverse process occurs. The main constituent materials of LIBs are electrolyte, separator, cathode, and anode. The cathode material occupies a large share (the mass ratio of cathode and anode materials is from 3:1 to 4:1). The most used anode materials are LTO (lithium titanate), surface functionalized silicon, powder graphite and high-performance graphene, conductive additives, activated carbon and carbon black. As cathode materials in LIBs, lithium cobalt ($LiCoO_2$) (J. Wang et al., 2022), spinel nickel-manganese ($LiMn_2O_4$) (Sharifidarabad et al., 2022; Nwachukwu et al., 2022), lithium ferro-phosphate ($LiFePO_4$) (Nwachukwu et al., 2022) are currently used, which are practical due to their increased energy density, high-capacity, and speed. The type of cathode material has a significant impact on the energy density, power density, safety, service life and cost of the battery, and the problem of developing new anode and cathode materials for LIBs does not lose its relevance.

Developments to improve the electrochemical characteristics of these materials are aimed at solving problems related to ensuring safety and reducing their cost. To solve these problems, the main research is aimed at the development of various materials with target properties and morphology. Xia et al. (Xia et al., 2021) successfully synthesized the chestnut shell fluff-NiS/C anode material, which is used as a superior performance anode for LIBs, shows fine cycling stability and rate performance and maintains a good specific capacity of 411.6 mAh/g after 100th cycle. Liang et al. (Liang et al., 2022) designed a composite material that porous ZnO crystals embedded on the surface of hollow carbon spheres derived from RH. The material had a high discharge specific capacity, e.g., 1111 mAh/g after 150 cycles. Zhao et al. (J. Zhao et al., 2022) fabricated the porous 3D-carbon framework@TiO_2 hybrids by using rape pollen as raw materials. The microstructure and morphology of obtained materials had been studied by scanning electron microscope (SEM) analysis and established that they had hierarchical porous hollow structure. That structure led to an increase in the SSA, which delivers high reversible specific capacity. He et al. (He et al., 2022) prepared a porous carbon framework using the grape stem as the biomass carbon source by facile approach. Moreover, the composite accommodated the Si NPs inside the matrix to further improve the capacity. The composites showed excellent lithium storage capability and high reversible charge capacities of 891 mAh/g after 400 cycles at 0.2 A/g.

There is also an intensive search for new electrochemical systems that could compete with LIBs. As an alternative to LIBs, KIBs hold great promise due to the prevalence of potassium. The main problems in the creation of KIBs remain their high flammability, limited charge, and discharge cycles, since not only potassium reacts with oxygen, but also carbon on the anode. Deng et al. (Deng et al., 2021) developed bagasse-derived Ni-doped 3D porous carbon materials as an anode material for use in KIBs. The obtained materials demonstrate that the formation of the porous structure activation with $NiCl_2$ and nitrogen doping is a key role. Moreover, the application of carbon materials as an anode material for KIBs are shown superior performance such as a reversible capacity of 100.4 mAh/g at a current density of 200 mA/g over 400 cycles. Wang et al. (D. Wang et al., 2022) prepared the N self-doped carbon quantum dots (N-CQDs) using soybean as the raw materials by the hydrothermal method. The obtained material was used as the anode materials in KIBs and the results with honeycomb carbon delivered a high specific capacity of 280.5 mAh/g at 0.1 A/g.

In Table 4, last year obtained biomass-derived anode materials used in lithium- and KIBs and their electrochemical performance are collected. The comparison of the electrochemical performance of the anode materials used for lithium- and KIBs are shown despite bagasse and soybean-based anode materials used for KIBs having a high surface area, the capacity of batteries is low. RH and rape pollen-based anode materials used for LIBs have a low surface area, and the capacity of batteries is high.

Table 1. Electrochemical performance of biomass-derived anode materials in batteries

Type of battery	Biomass	Microstructure	SSA, m^2/g	Current density, A/g	Cycle number	Capacity, mAh/g	Ref.
LIBs	RH	Porous carbon	94.375	0.2	150	1111	(Liang et al., 2022)
LIBs	Rape pollen	Hierarchical	69.6	0.1	200	687.3	(J. Zhao et al., 2022)
LIBs	Grape stem	-	-	0.2	400	891	(He et al., 2022)
LIBs	Chestnut shell fluff	3D interconnected microbelt structure	-	-	100	411.6	(Xia et al., 2021)
KIBs	Bagasse	Three-dimensional porous carbon	466.621	0.2	400	100.4	(Deng et al., 2021)
KIBs	Soybean	Honeycomb porous structures	242.6	0.1	100	280.5	(D. Wang et al., 2022)

Literatures

1. Lesbayev B., Auyelkhankyzy M, Ustayeva G., Yeleuov M., Rakhymzhan N., Maltay A., Maral Ye. (2023) Recent advances: Biomass-derived porous carbon materials. South African Journal of Chemical Engineering 43:327–336. DOI:10.1016/j.sajce.2022.11.012.

2. Lesbayev B., Auyelkhankyzy M., Ustayeva G., Yeleuov M., Rakhymzhan N., Maral Y., Tolynbekov A. (2023) Modification of Biomass-Derived Nanoporous Carbon with Nickel Oxide Nanoparticles for Supercapacitor Application, Journal of Composites Science, 7:20, doi.org/10.3390/jcs7010020