Lecture 11. Application of carbon aerogels as electrode materials for high-performance supercapacitors

Supercapacitors are devices in which the accumulation of electrical energy occurs due to the formation of an electrical double layer at the interface between an electrolyte solution with ionic conductivity and an electrode with electronic conductivity. According to the energy storage mechanism, supercapacitors are divided into double-layer supercapacitors with ideally polarizable highly porous electrodes, hybrid supercapacitors with asymmetric electrodes, and pseudocapacitive supercapacitors, on the electrodes of which redox interactions occur during the charge/discharge process. In an electrical double layer, as in a conventional capacitor with two flat plates, the capacitance is proportional to the area of the plates and inversely proportional to the distance between them. In a double electric layer in supercapacitors, the distance between the charged surface of the electrodes and the layer of ions in the electrolyte is measured in angstroms, therefore, by increasing the specific surface of the electrodes, it is possible to create supercapacitors with a huge capacity. Thus, one of the important criteria for achieving a high capacitance of supercapacitors is the use of electrodes with a high SSA. It can distinguish the following main criteria that an electrode material intended for supercapacitors should have:

- ideal polarizability in the range of potentials limited by the potentials of the electrochemical decomposition of the solvent.
- a high surface area for high specific capacitance.
- high conductivity in the electronic component to ensure high values of power density.
- be indifferent (neutral) concerning the electrolyte solution.

These criteria are best met by porous carbon materials, which have a high SSA, stable frame structure, and mass productivity. Biomass-based carbon is promising for the creation of porous electrode materials for supercapacitors (Wang et al., 2020), especially the developments related to the utilization and use of vegetable raw materials wastes remain topical problems due to environmental and economic factors (Väisänen et al., 2016; Azat et al., 2019; Daulbayev et al., 2022). Biomasses attract attention not only because they are available, renewable, and cheap raw materials, but also because they have a ready-made homogeneous highly developed structure, which makes it possible to obtain porous carbon material with a high SSA with a uniform distribution of pores on its basis. Hence, in recent years there has been a sharp increase in the number of research works (Zhan et al., 2021; Zou et al., 2022; Feng et al., 2021; Li et al., 2022), devoted to the production of porous carbon materials based on plant wastes intended for supercapacitors.

In (Wan et al., 2020) studies on obtaining a nanoporous carbon material from orange peels using an unconventional activating agent, copper carbonate was carried out. The authors note that the orange peel was chosen because it contains large amounts of carbon, oxygen, nitrogen, and sulfur. The nanoporous material was obtained by one-stage heat treatment at temperatures of 700-900 °C by pyrolysis in an argon atmosphere. The best samples with a hierarchical structure and doped with a significant quantity of nitrogen, oxygen, and sulfur heteroatoms with SSA of 912.4 m^2/g were obtained at an activation temperature of 800 °C. The authors explain the preference for a temperature of 800 °C by the optimal regime of the etching effect of copper carbonate. The resulting nanoporous carbon has a specific capacity of 375.7 F/g at 1 A/g. The symmetrical supercapacitor assembled based on the obtained material provides a high energy density of 31.3 Wh/kg at a specific power of 499.5 W/kg and retains 92.7% capacity after 50.000 charge/discharge cycles.

The authors of (Ning et al., 2022) used succulent leaves as the raw material for obtaining nanoporous carbon. The nanoporous material was obtained by one-stage carbonization at a temperature of 800 °C in a nitrogen atmosphere. Thermochemical activation was carried out using a double activating agent, which is a mixture of magnesium nitrate ($Mg(NO_3)_2 \cdot 6H_2O$) and zinc chloride ($ZnCl_2$). To dope the nanoporous material with heteroatoms of sulfur and nitrogen, thiourea was added to the initial mixture. The obtained N-S-HPC material has a three-dimensional hierarchical porous structure with SSA 2136.2 m^2/g and is doped with oxygen atoms (6.8%), nitrogen (9.5%) and sulfur (2.21%). Electrodes based on N-S-HPC achieve specific capacitance up to 455.3 F/g at 1 A/g. Symmetric supercapacitors assembled based on N-S-HPC, when using 1 M H_2SO_4 electrolyte, have a maximum specific energy of 10.3 W h/kg at 250 W/kg, and when using 1 M Na_2SO_4 electrolyte, the maximum specific energy almost doubles and reaches 19.89 Wh/kg at 450 W/kg.

Literatures

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