Electrochemical energy storage with nanoporous carbons

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During the last decade, the societal demand for reducing green-house gas emissions has boosted the research on electrochemical energy storage devices. Owing to their high electrical conductivity, relatively low cost and various morphologies, carbons are recognized to be electrode materials of choice for lithium batteries (LIBs), electrochemical capacitors (ECs) and others. The most popular type of EC based on the formation of an electrical double-layer (EDL) on the surface of nanoporous carbon (mostly activated carbon in case of industrial ECs) electrodes delivers high specific power, yet relatively modest specific energy, while implementing environmentally unfriendly and unsafe organic electrolytes. Therefore, strategies to develop safer and better performing ECs are mandatory.

The presentation will first demonstrate the attractiveness of nanoporous carbons in combination with neutral aqueous electrolytes to develop “green” ECs with enhanced specific energy. Hydroxyl anions may be trapped in the pores of carbon (and hydrogen simultaneously chemisorbed), which results in an increase of local pH and enhanced cell voltage. It will also be shown that interfaces with various redox couples can be created at the surface of carbon nanopores, and lead to hybrid ECs constituted of battery-like and EDL electrodes. When an interface is created by trapping polyiodides in the pores of carbon, the capacitance of the hybrid cell is twice higher than for a typical EDLC. Both OH^- ions and polyiodides can even be trapped in the pores of negative and positive carbon electrodes, respectively, when employing a bifunctional electrolyte, which gives rise to a hybrid capacitor showing an energy density in the same range as conventional EDLCs in organic electrolyte. Moreover, the hydrogen chemisorption mechanism can be controlled by implementing highly concentrated solutions, so-called water-in-salt electrolytes, which enable to circumvent the undesired freezing of aqueous electrolytes at sub-ambient temperatures. In sum, when all these “ingredients” are combined, the realized ECs constitute a highly cost-effective and green alternative to the traditional systems in organic electrolyte.

The second part of the presentation will show that the specific energy of electrochemical capacitors can be boosted by combining a metal-ion battery-type anode, using for example graphite, and an EDL porous carbon positive electrode in so-called metal-ion hybrid capacitors. The lithium-ion and sodium-ion capacitors realized with composite electrodes including carbonaceous active materials display the same specific power as EDL capacitors and 4 to 5 times higher specific energy, which makes them very promising for applications in electric vehicles.