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Electrochemical energy storage with carbons

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Energy management is an unavoidable strategy in the panel of solutions to reduce fossil consumption and green-house gases emissions. To manage the fluctuations of renewables and on-board energy in vehicles, electrochemical energy storage can be used to adapt the delivery to the demand. Two main systems may be applied, batteries and electrical double-layer capacitors (EDLCs), which store energy through faradaic and electrostatic processes, respectively. Due to these mechanisms, batteries store high amount of energy, whereas EDLCs are perfectly adapted to harvest energy in small amount during short periods of time, for example during braking of vehicles. Presently, all the research efforts are guided by enhancing the electrochemical performance of both systems, while implementing environmentally friendly materials and reducing the production costs.

Graphite has been early recognized as the material of choice for anodes of Li-ion batteries. To enhance the power delivery of these systems, hard carbons have been implemented, especially for the sodium-ion systems where graphite displays a poor performance. Fashionable materials, such as carbon nanotubes (CNTs) have been also proposed, yet their large mesopore volume favours a high irreversibility of metal insertion, leading to a poor cycle life of the batteries. Nonetheless, CNTs added in small proportion in the formulation of electrodes might be very useful to enhance their conductivity and thereof power of the devices.

Nanoporous carbons (especially activated carbons – ACs) owing to their versatility of structure/texture, morphology, low cost and highly developed surface area are the basic electrode material for EDLCs [1]. New forms of carbons, e.g., carbon nanotubes and graphene, as well as carbon black are applied for the percolation of electrodes or as support for electroactive materials. In all cases, these various carbon forms are designed to enhance the specific energy of EDLCs, while developing safe and environment friendly solutions. High energy EDLCs can be realized with ionic liquids by the implementation of hierarchical porous carbons having i) mesopores produced by silica templating carbonization of glucose and ii) micropores simultaneously created in the pore walls by $ZnCl_2$ activation. Appropriate glucose/SiO_2/$ZnCl_2$ proportions enable to optimise simultaneously the micro-/mesopore volume ratio and the density of carbons, and develop high volumetric energy EDLCs able to operate at high power with ionic liquid from -40 to 100 °C.

Despite their interesting features, EDLCs come nevertheless with limitations, such as notably low specific energy and a significant rate of self-discharge compared to other types of energy storage systems. These disadvantages may hinder their application as a primary power source in hybrid vehicles and their integration into the electrical power grid. Therefore, metal-ion capacitors (MICs) combining an electrical double-layer positive electrode and a battery-type negative electrode have emerged as a promising energy storage technology [2] due to two notable features: i) the negative carbon electrode operates at low potential, thus, the maximum operative voltage of MICs is significantly higher than that of an AC//AC capacitor, reaching generally 3.8 V; ii) the EDL positive porous carbon electrode operates in a wider potential range than the positive electrode of an EDLC, typically between e.g., 2.5 V and 4.1 V vs Na/Na^+ for a sodium-ion capacitor [2], thus the capacity/capacitance of the device is larger than in a conventional EDLC. This unique configuration enables MICs to achieve up to ca. four times higher specific energy than EDLCs at comparable power levels, which makes them very promising for applications in electric vehicles. The *operando* track of ion population changes in the EDL carbon electrode of a lithium-ion capacitor will be presented during its charge/discharge.

References

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