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Flexible Hybrid Battery/Pseudocapacitor

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Project Description

Batteries keep devices working by utilizing high energy density, however, they can run down and take tens of minutes to hours to recharge. For rapid power delivery and recharging, high-power density devices, i.e., supercapacitors,[1] are used. The electrochemical processes which occur in batteries and supercapacitors give rise to different charge-storage properties. In lithium ion (Li+) batteries, the insertion of Li+, which enables redox reactions in bulk electrode materials, is diffusion controlled and can be slow. Supercapacitor devices, also known as electrical double-layer capacitors (EDLCs) store charge by adsorption of electrolyte ions onto the surface of electrode materials. No redox reactions are necessary, so the response to changes in potential without diffusion limitations is rapid and leads to high power.[2] However, the charge in EDLCs is confined to the surface, so the energy density is lower than that of batteries.[3]

The redox reactions in batteries store more energy per unit mass due to faradaic processes in which charge is transferred across interfaces between a battery's electrodes and the electrolyte leading to reduction and oxidation reactions (redox) of species at the interface.[4] When a battery is charged or discharged, the redox reactions change the molecular or crystalline structure of the electrodes which can often affect their stability. EDLCs show no major changes in the properties of the electrode materials during operation so can be cycled millions of times.[4]

Current in a Li-ion battery is generated when Li ions migrate from the negative electrode (anode) to the positive anode (cathode) through the electrolyte during discharge. Reversing the process results in intercalation of Li ions back into the anode and removal from the cathode to produce the charged state.

Common battery electrode materials include; $LiCoO_2$, $LiMn_2O_4$, and $LiFePO_4$ which are used as the cathode and graphite and $Li_4Ti_5O_{12}$ used for the anode.

In a supercapacitor or EDLC, a double-layer charge is developed at the interface between the electrolyte and electrodes. Thus, the larger the surface area of the electrode, the more charge that can be created. Thus, highly porous carbon is the normal selection for both EDLC electrodes. Activated carbon is commonly used due to its high specific surface area (1,000–2,000 m^2/g), however, they have a limited capacitance due to low mesoporosity (<2–50 nm) and poor electrolyte accessibility. One would therefore like a balance between mesoporosity and specific surface area in order to optimize the supercapacitor performance. Carbon nanotubes (cnts) are being actively studied as electrode materials for EDLCs. Cnts have high specific surface area, lower than activated carbons, but show a mesoporous structure providing a highly electrolyte accessible network.[5] Table 1 is a comparison between a commercial activated-carbon-based EDLC and a Li-ion battery.

Table 1: Li-ion battery versus EDLC.

Attribute	Li-Ion Battery	EDLC
Power Density (kW/L)	3	10
Energy Density (Whr/kg)	100	5
Rate Capacity X (XC)	<40	>1,800
Minimum T (°C)	0	−40
Maximum T (°C)	+40	+65
State-of-Change Excursion (%)	50	100

Electrolytes for Li-ion batteries consist of lithium salts such as $LiPF_6$ and $LiBF_4$ dissolved in an organic solvent such as ethylene carbonate or dimethyl carbonate. Electrolytes for EDLCs consists of inorganic chemicals disassociated into ions in a solvent. Typical solvents include water, propylene carbonate, tetrahydrofuran, and diethyl carbonate.

Ionic liquids, which have been studied more recently as electrolyte solutions, show great promise primarily due to the ability to tailor the properties of these liquids. There are a large number of ionic liquids available commercially.

Anticipated Benefits

If successful, the device will combine the best of Li-ion batteries and electric double-layer capacitors. Our target is 100 kW-hr/kg specific energy and 1,000 W/kg specific power. The target values are shown in the Ragone plot in figure 1. These values plus a flexible package will make for a device that is conformable to any surface area.

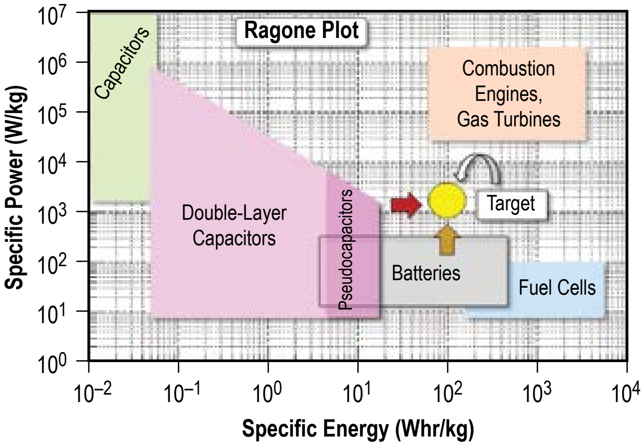

Figure 1: Ragone plot of specific power versus specific energy.

Potential Applications

Applications for NASA include power for small satellites as well as small load applications in spacecraft and habitats on the Moon and Mars. Department of Defense applications include missile systems and rolling equipment. Commercial applications include cell phones, laptops, and tablets.

Notable Accomplishments

Accomplishments include designing and constructing the electrochemical cell, measuring the electrochemical window of three ionic liquids, testing bare CNT sheets and silicon-coated CNT sheets as electrodes, and producing one NTR.

References

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