Energy storage: EDLC & Pseudo – Capacitors

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Energy is found everywhere, we just need to harvest and store it.

Supercapacitors can be used for load leveling applications.

We lack good storage technologies.

We want to move ASAP to sustainable energy.
Supercapacitors (EDLC) fill the energy and power densities gap between batteries and capacitors.

A typical Ragone plot, of common Faradaic electrochemical energy storage cells (time constants in red)

- Specific Power ($W \cdot kg^{-1}$)
- Specific Energy ($Wh \cdot kg^{-1}$)

- Capacitor
- ECs (2008)
- 1s
- 1 min
- 1h

- Comm. Li-ion
- 5V. Li-ion
- Ni/MH
- Ni/Cd
- Primary Li
- Lead acid

Overview - Material design - Aqueous SC - High voltage SC - PsC - Summary
What is Capacitor?

- A capacitor (originally known as condenser) is a passive two-terminal electrical component used to store energy in an electric field.
- When there is a potential difference across the conductors, a static electric field develops across the dielectric, causing positive charge to collect on one plate and negative charge to accumulate on the other plate. Energy is formed in terms of electrostatic field.
What is Supercapacitor?

Supercapacitor (SC) also known as electric double-layer capacitor (EDLC) or Ultracapacitor, is electrochemical capacitor. The capacitance value of an electrochemical capacitor is determined by two storage principles, which both contribute indivisibly to the total capacitance:

• **Double layer capacitor** – Electrostatic storage achieved by separation of charge in a Helmholtz double layer at the interface between the surface of a conductive electrode and an electrolyte. The separation of charge is of the order of a few angstrom (0.3–0.8 nm), much smaller than in a conventional capacitor.

• **Pseudocapacitor** - Faradaic electrochemical storage with electron charge transfer, achieved by redox interaction, intercalation or electrosorption.
Up to $10^9$ V/m potential fall exist on charged interfaces

Electrical Double Layer (EDL)

- Water molecule
- Counter ion
- Co-ions

OHP

Outer Helmholtz plane
The difference between Supercapacitor and Battery:

- **Supercapacitor**: More power is required for short time interval in 200m race.
- **Battery**: Constant but less power required for long time in 20km race.
Charged species can be stored electrostatically by the EDL

\[ C = \frac{A \cdot \varepsilon_0 \cdot \varepsilon_r}{d} \]

A = Surface area (very high in Activated carbon).

d = Dielectric thickness, single solvent molecule.

\( \varepsilon_r \) = limited by the solvent properties.

Possible electrolytes:

1. Aqueous electrolyte, high rates small ions high ionic conductivity, limited voltage.

2. Organic electrolyte, moderate conductivity and capacity up to 3V.

3. Ionic liquids- Low conductivity, lower capacity, high voltage, safe.

www.youtube.com/watch?v=FJZKm5khaAA
From dead leaves till energy storage devices

![Image of a Neem tree, dead leaves, and crushed powder]

**Fig. 1** Schematic diagram for the synthesis of functional carbon from dead leaves and the supercapacitor based measurements thereupon.

<table>
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<th>Current density (A g⁻¹)</th>
<th>0.5</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>10</th>
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<tr>
<td>Specific capacitance (F g⁻¹)</td>
<td>401</td>
<td>302</td>
<td>285</td>
<td>268</td>
<td>259</td>
<td>258</td>
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<tr>
<td>Areal capacitance (µF cm⁻²)</td>
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<td>24.5</td>
<td>23.17</td>
<td>21.7</td>
<td>21.05</td>
<td>21.0</td>
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<td>Power density (W kg⁻¹)</td>
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<td>1191</td>
<td>2526</td>
<td>3620</td>
<td>6480</td>
<td>11 685</td>
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<td>Energy density (W h kg⁻¹)</td>
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<td>42</td>
<td>40</td>
<td>37</td>
<td>36</td>
<td>35.8</td>
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</table>

High capacitance graphene SC

Fig. 10. Specific capacitance of G-POT in different electrolytes, 2 M H$_2$SO$_4$, 0.1 M LiClO$_4$ and ionic liquid.

Fig. 1. (a) Emeraldine salt form of graphene–polyanilines nanocomposite, (b) emeraldine base form of graphene–polyaniline nanocomposites, (c) formation of CPs wrapping around graphene.

Increasing the electrochemical window using neutral electrolyte solutions

Fig. 7 Three-electrode cyclic voltammograms (CVs, 2 mV s⁻¹) of ACH in 2 mol L⁻¹ Li₂SO₄. The loops are obtained by stepwise shifting of the negative potential limit to more negative values. The vertical line at −0.35 V vs. NHE corresponds to the thermodynamic potential for water reduction.

Electrodeposition of Mn-Mo oxide film on CNT/ITO

Figure 11. Plots of the specific capacitance of the optimized Mn-Mo/CNT composite electrode as a function of the number of cycles, based on the CV data in 0.5 M Na₂SO₄ at

Figure 4. FE-SEM images of the CNT films (a) before and (b) after electrodeposition of Mn-Mo oxide, along with (c) that of Mn-Mo oxide deposited on a bare ITO substrate.

Activated carbons possess unique physicochemical properties:

Activated carbon (AC)

General features:
- Highly disordered
- Electrically conductive
- High surface area (up to $\sim 3000 \text{m}^2/\text{g}$)
Using CNTs as a conductive additive and as a reinforcing agent in novel electrodes

Rolling up a graphene sheet to form a tube. Properties:

• Very strong and flexible molecular material due to the C-C covalent bonding and seamless hexagonal network architecture.
• Thermal conductivity ~ 3000 W/m·K in the axial direction
• Electric conductivity six orders of magnitude higher than copper

**CNTs grow methods:**

a) Arc-discharge  
b) Laser ablation  
c) Catalytic chemical vapor deposition (CCVD)
Carbon precursor

Stirring

Carbonization under inert atmosphere

Carbon material

Oxidizing agent

Activated carbon

CNT dispersion

Overview

Material design

Aqueous SC

High voltage SC

PsC

Summery