# Coating technologies for Ultracapacitor components

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The 15th International Coating Science and Technology Symposium
September 12-15, 2010 in St. Paul, Minnesota[1]

Energy storage devices are gaining more importance as current social economic trends battle for various "Green" energy sources. Ultracapacitors possess both relatively high energy densities and high power densities. Applications range from consumer electronics to hybrid vehicles. In order for ultracapacitors to become a viable business, manufacturing-friendly coating technologies are necessary for success.

The construction of an ultracapacitor device starts with the electrodes. Each electrode comprises of an active material which is attached to a metal current collector by an electrically conductive adhesion layer (Figure 1 – left). Coating technologies such as spray, slot die, gravure, metered rod, reverse roll, or curtain coating could be combined with extrusion or doctor blade techniques in order to fabricate these electrode structures. In terms of manufacture ability and cost control, coating and conversion technologies, in particular roll-to-roll, are a solution.

Balance between the materials formulation and the coating technique utilized determines certain dry film attributes: thickness, uniformity, composition, microstructure, coated-edge alignment, and front-side-to-back-side alignment (for double-sided electrodes). Most of the time, these strict requirements will push the boundaries of traditional coating technologies. Additionally, web guide and handling complicates high throughput.

In general, an ultracapacitor or electrochemical double layer capacitor (EDLC) is composed of two electrodes within an electrolyte liquid containing ions. A porous separator material prevents the electrodes from electrical short-circuit, while allowing ions to readily pass through. Electrons conduct to and from each electrode, through an external circuit, while ions flow in between the electrodes (completing the circuit).

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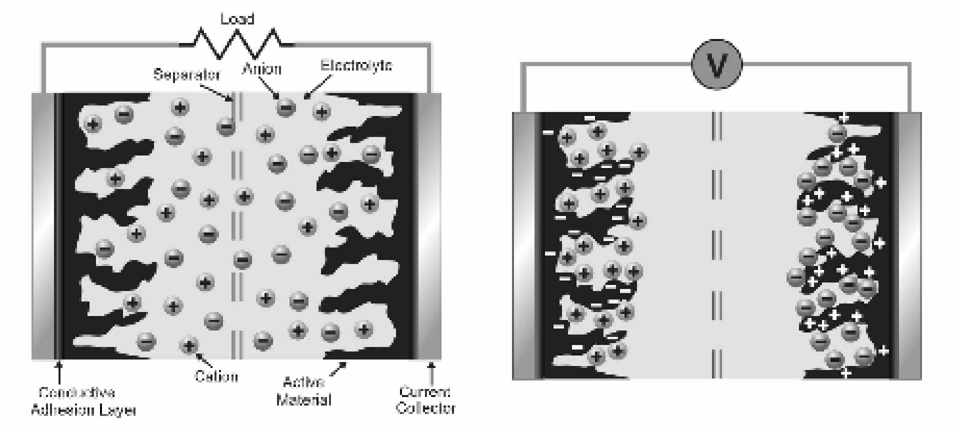

**Figure 1. Illustration of an Ultracapacitor or also known as an electrochemical double layer capacitor (EDLC). Left – discharged state of ultracapacitor. Right – charged state of ultracapacitor. Depicted at both electrodes, the electrochemical double layer is defined by a layer of charge built up at the electrode interface and a layer of counter ions formed at the solution interface.**

Ultracapacitors utilize active materials and an ionic electrolyte to store charge at the electrochemical double layer. Upon application of a voltage, a layer of charge builds up at the electrode interface and a layer of counter ions form at the solution interface (Figure 1 – right). The electrochemical double layer capacitance ($C_{dl}$) is defined by equation 1.

$$C_{dl} = \frac{\varepsilon A}{4\pi t} \qquad (1)$$

$A$ is the surface area of the electrode, $\varepsilon$ is the dielectric constant of the electrical double-layer region, and $t$ is the thickness of the double layer.[2]

Energy ($E$)[3] and power ($P_{Max}$, matched impedance)[4] of ultracapacitors are represented by the following equations.

$$E = \frac{1}{2} C V^2 \qquad (2)$$

$$P_{Max} = \frac{V^2}{4R} \qquad (3)$$

$C$ is the capacitance in Farads, $V$ is the nominal voltage, and $R$ is the equivalent series resistance (ESR) in ohms.

By the mechanism of simple electrostatic forces, ultracapacitors store relatively large amounts of energy and quickly release this energy on the time scale of seconds. More importantly, the double layer phenomenon allows ultracapacitors to be cycled hundreds of thousands to even a million times. With more effective active electrode material (increased capacitance) and more parallel resistances (lower ESR), energy and power (equations 2 and 3) will increase proportionally. Moreover, with more efficient packaging, energy and power densities will increase.

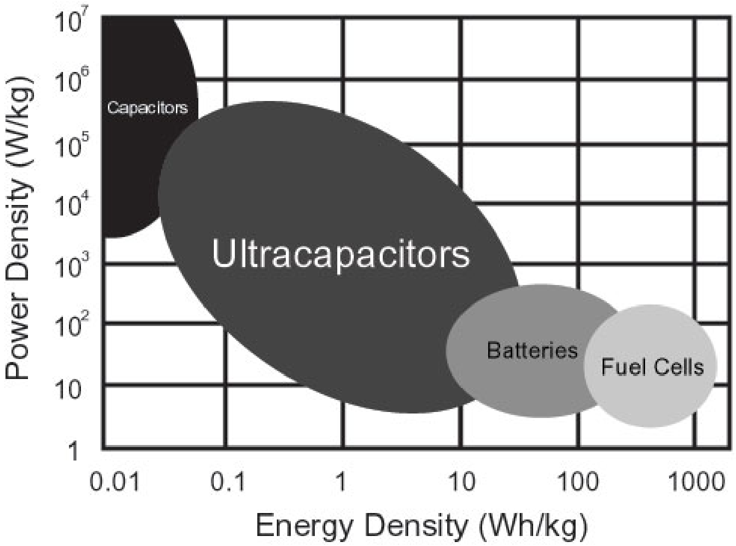

**Figure 2. Ragone plot for different energy storage and power delivery devices.**

Ultracapacitors reside in between the energy and power densities of traditional capacitors and batteries (Figure 2), allowing for a wide range of applications.[1] Corning is interested in the versatility of ultracapacitors. Currently, one marketing focus has been in stop-start with regenerative braking or what is called the Micro-2 space of hybrid electric vehicles (HEVs). Micro-2 HEV participation is projected to be around 30 million vehicles worldwide by 2025.

Corning has demonstrated Ultracapacitor devices with advantaged energy densities while maintaining power density levels (Figure 3).

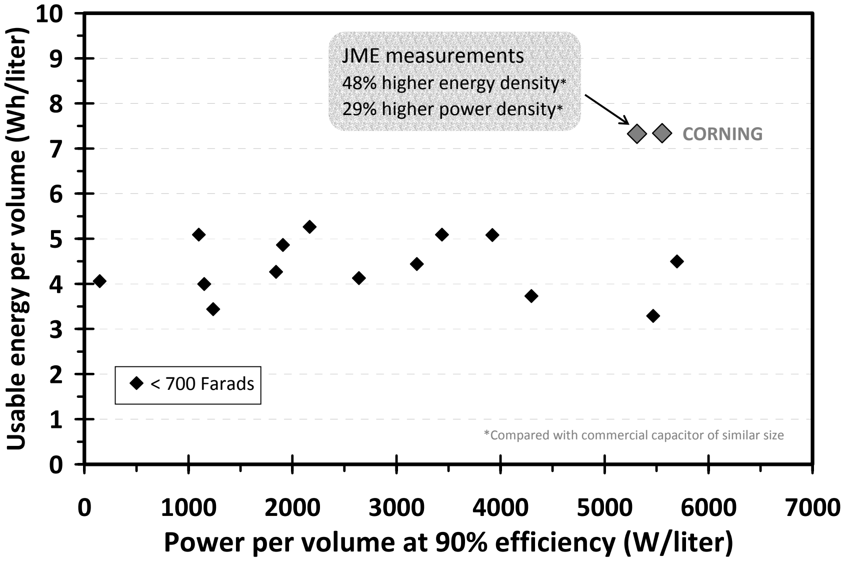

**Figure 3. Ragone plot of Corning ultracapacitors versus commercially available ultracapacitors and ultracapacitors within open literature.**

## ***References***

1. Kotz, R. & Carlen, M. Principles and applications of electrochemical capacitors. *Electrochimica Acta* 45, 2483-2498 (2000).
2. Conway, B.E. *Electrochemical Supercapacitors - Scientific Fundamentals and Technological Applications* (Kluwer Academic / Plenum Publishers, New York, page 74, 1999).
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