CAPACITOR SCIENCES

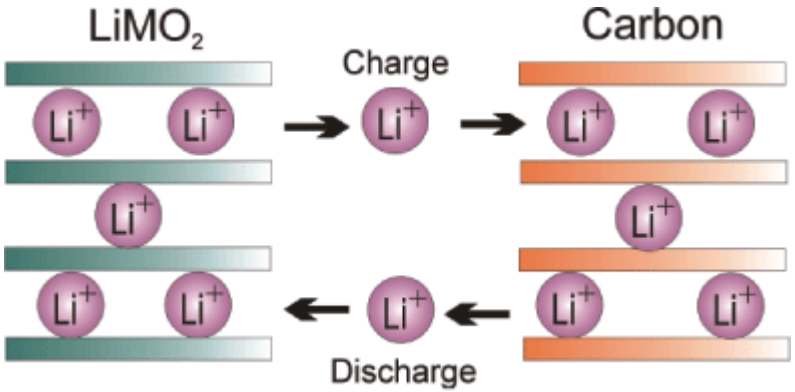
Beyond Lithium Ion

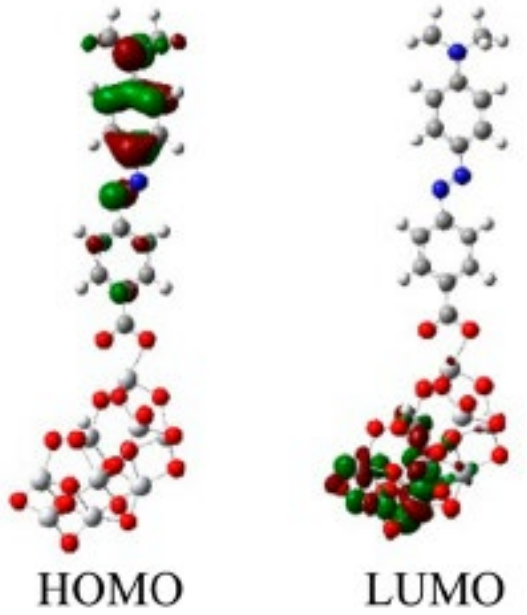
Electrochemistry or Molecular Polarizability

Batteries vs Capacitors for Energy Storage

Battery - Electrochemistry
Reduction – oxidation reaction in two reactors – cathode and anode - causes movement of Lithium ions

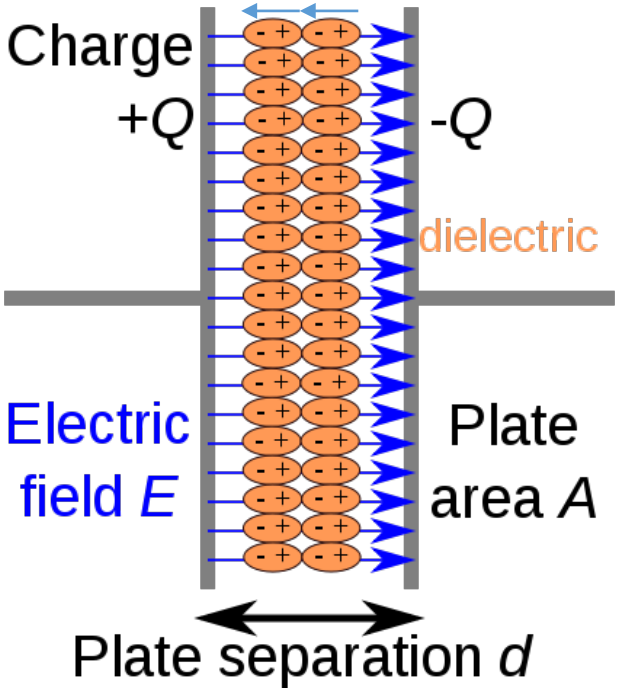
Capacitor - Molecular Polarizability
Influence of an external electric field causes movement of electrons in polarizable molecules or complexes





Capacitor Fundamentals

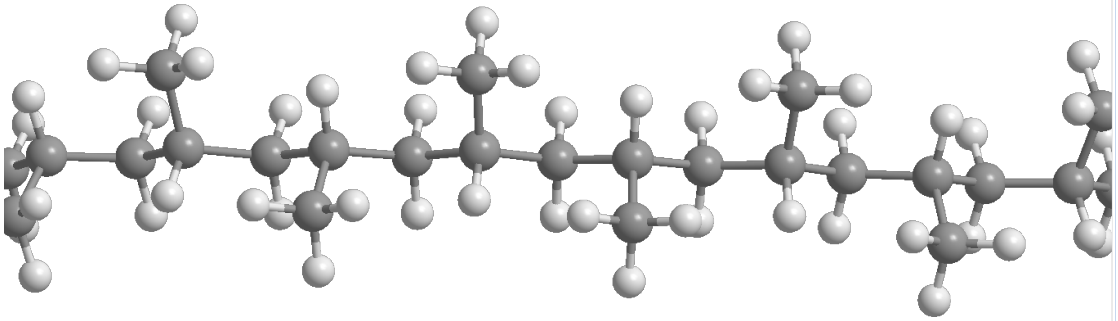
- High Polarizability, High Voltage For High Energy Density
- High Resistivity for Charge Storage Longevity



Why Not Use Capacitors For Energy Storage Today?

Polypropylene film is not very polarizable (W = 0.5 Wh/kg)

- Highly resistive hydrocarbon
- Low polarizability (no polarizable core)
- Ideal for short bursts of power

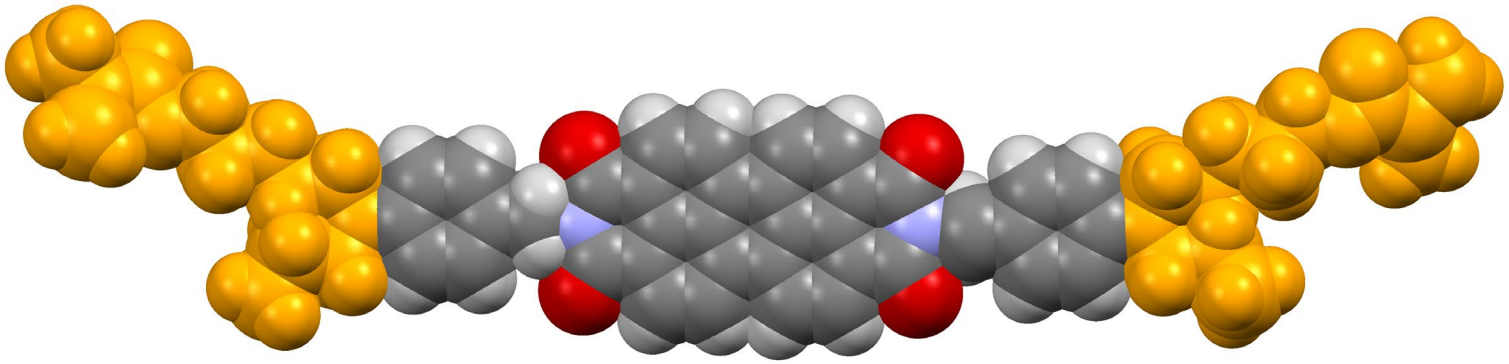


Polypropylene Polymer

What Needs to Change?

Meta-dielectric materials with polarizable cores and resistive envelopes

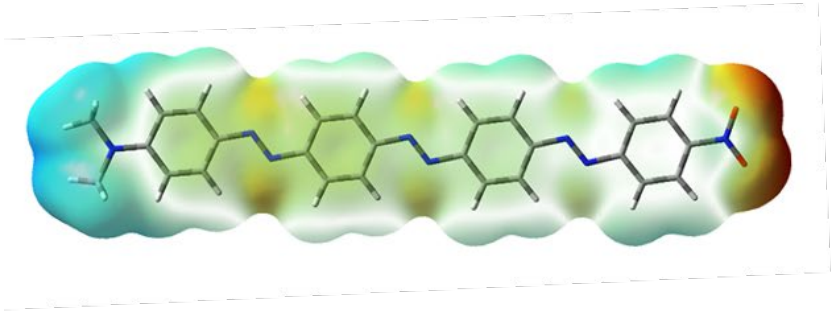
- Polarizable cores to store energy
- Insulative tails to hold stored energy



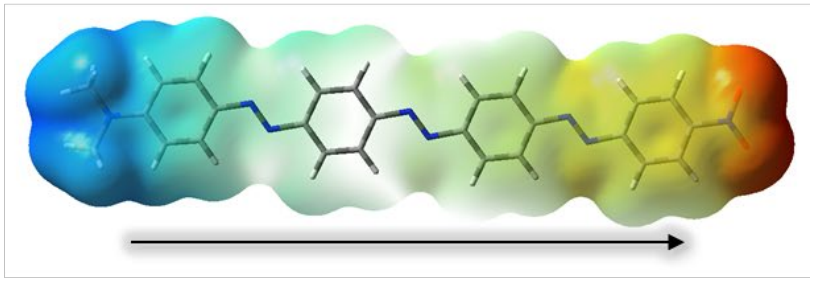
Resistive Tails | Polarizable Core | Resistive Tails

Electrostatic Energy Storage

Energy is Stored by Polarizing Molecules with an External Electric Field



Electron Cloud at Zero Electric Field (Discharged State, Not Polarized)



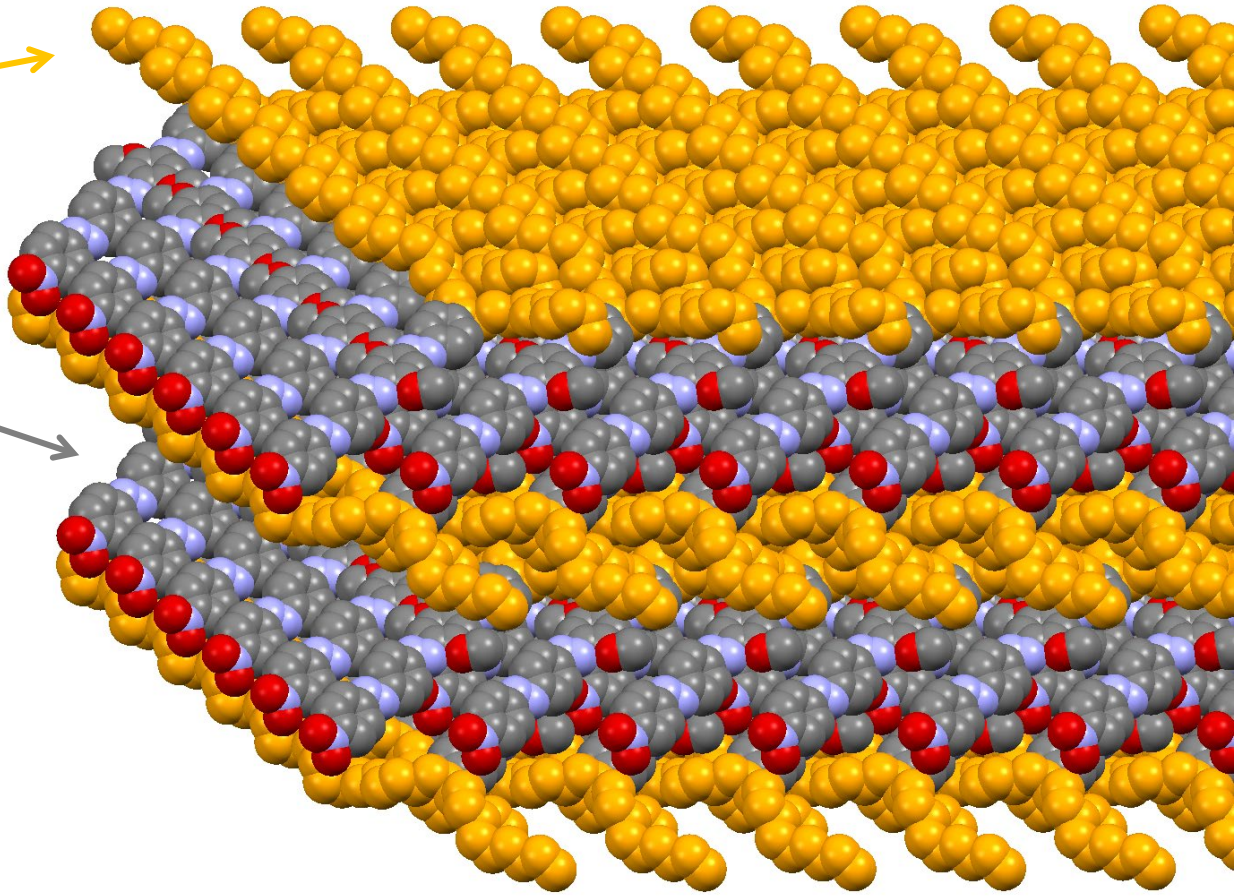
Electron Cloud at High Electric Field (Charged State, Polarized)

X-Ray Diffraction Image of CSI Material

Actual Structure: Polarizable, Resistive and Structured Films

Insulative Tails:
High resistivity

Polarizable Cores:
High energy density



Energy Storage Cost-Performance >10X of Li Ion Batteries

Specific Energy, Materials Supply & Cost Required for Global Energy Storage:

- Energy storage pack capacity of more than 1 kWh/kg (Tesla S 85 = 0.16 kWh/kg)
- Materials supply of more than $10E^{10}$ kg/year (2017 lithium production $50E^{6}$ kg)
- Energy storage pack cost of less than $50/kWh (BNEF 2017 Average = $209/kWh)

[A New Era of Functional Plastic Films Made From Oil to Store Electricity]

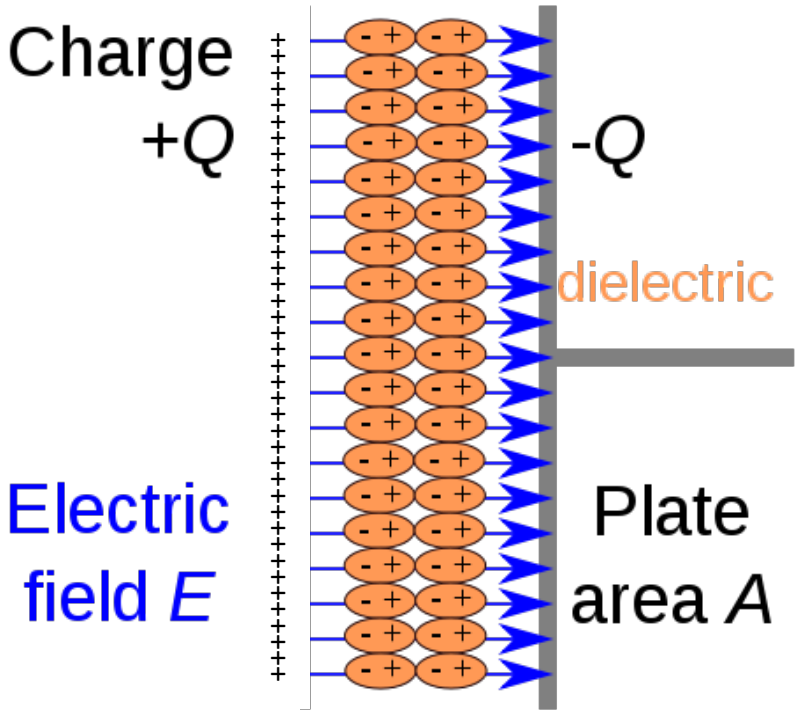
Energy Storage Beyond Li-Ion

Nano-structured capacitive energy storage devices:

- Electrostatic energy storage, no electrochemistry
- High energy density, no capacity fading
- Non-flammable & non-explosive
- Rapid charge and discharge
- Low-temperature operation
- Solid-state, virtually unlimited lifetime

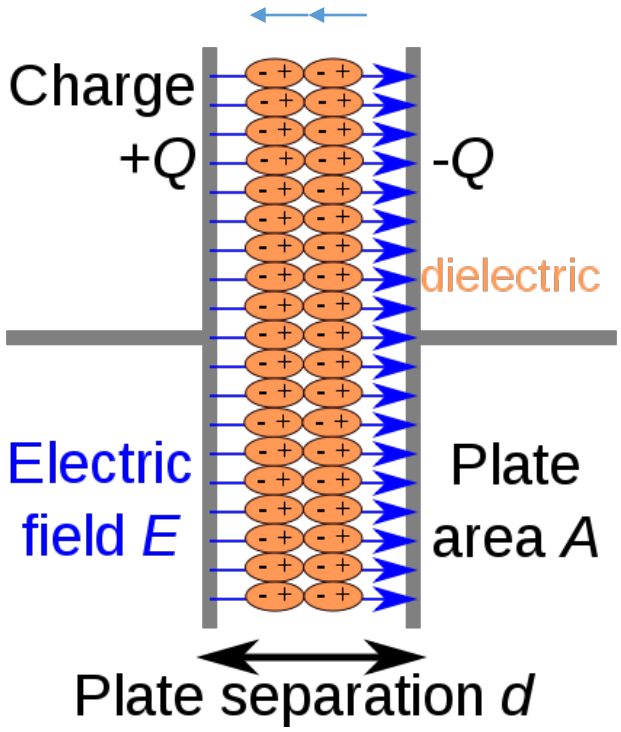
Ion Deposition for Testing of Dielectric Materials

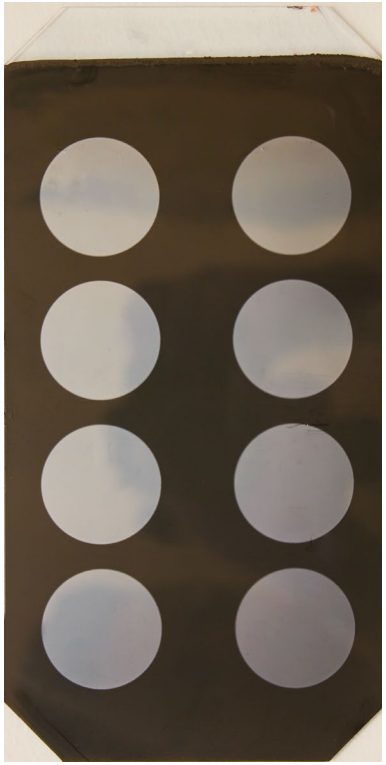
- Deposited ions forms virtual top electrode



Coin Cell Prototypes

- Dielectric material between two metal electrodes





Testing Results

Specific Energy of Between 4X to 8X Lithium Ion Batteries

- Material basis: 2.2 to 4.2 kWh/kg
- Projected device: 1 to 2 kWh/kg

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