NUS National University of Singapore | College of Design and Engineering

ME5205 CA1 Presentation:

Short-Review of Supercapacitors – Classifications, Theory, Recent Advances, and Potential Applications *(Group 5)*

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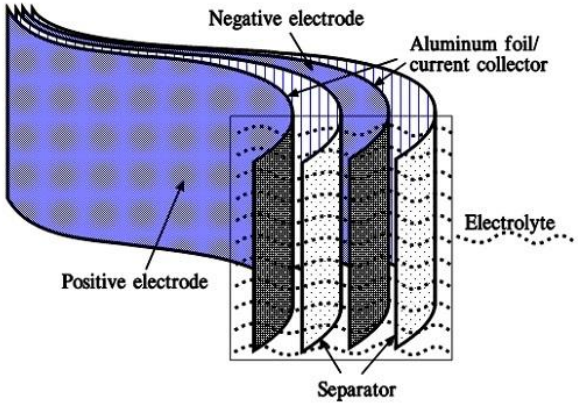
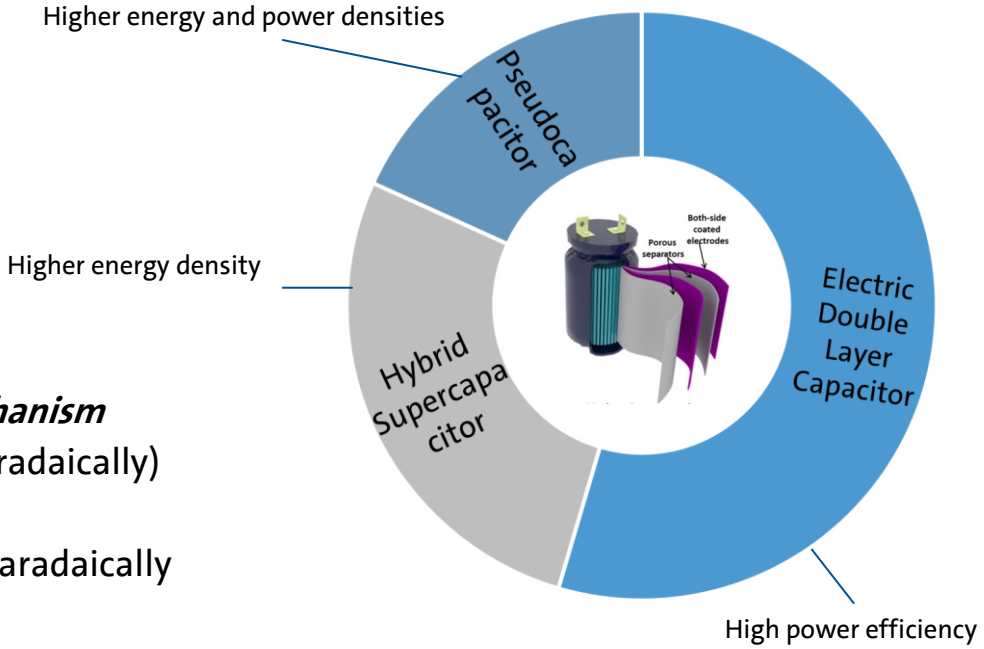
Types of Supercapacitors: *Three Basic Categories*





Classification Criteria : Energy storage mechanism

EDLC: store charge electrostatically (non-Faradaically)

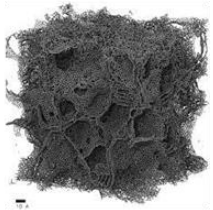
PC: store charge Faradaically

HSC: utilize both non-Faradaically and Faradaically processes to store charge

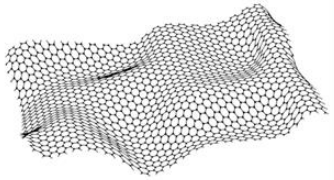
Types of Supercapacitors: *Subclass: EDLC*

Carbon foams

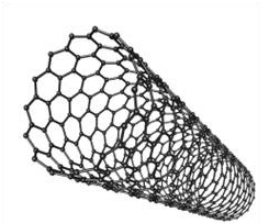
Carbon aerogels



Carbide-derived carbon



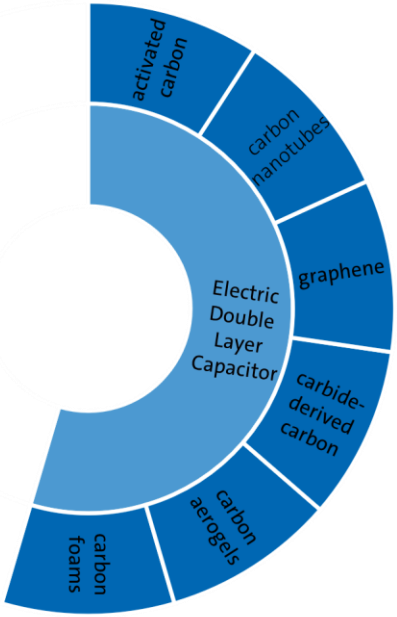
Graphene



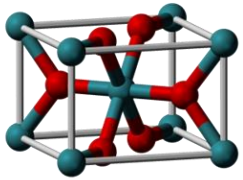
Carbon nanotubes

Activated carbon

- 1, 2, and 3: the lightest materials on the planet
- 4 and 5: electrical and mechanical capabilities
- 6: high surface area and oxidation ability, superior electrochemical efficiency



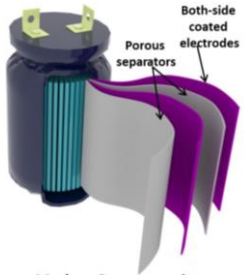
Types of Supercapacitors: *Subclass: PC*



RuO_2

Platinum

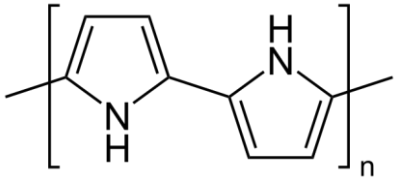
Palladium



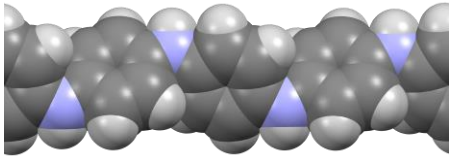
Metal oxides
Relatively high capacitance and conductivity

Conductive polymers
High capacity with low current density and high energy levels

Noble mental
Inclusion with other sustainable and cheap materials lower the cost



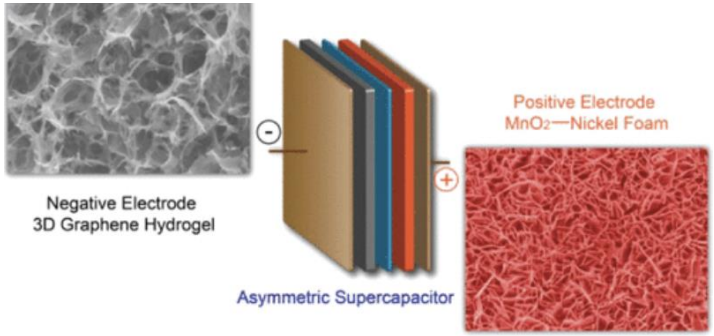
Poly pyrrole



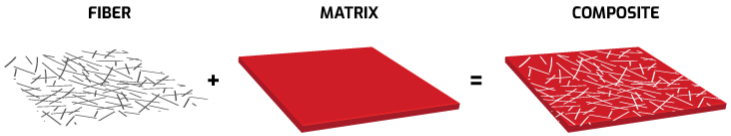
Poly aniline

Types of Supercapacitors: *Subclass: HSC*

This is the situation with a nickel foam carbon and MnO2 electrode



- Higher energy and power densities (compared w/ EDLC)
- Better cycling stability (compared w/ PC)



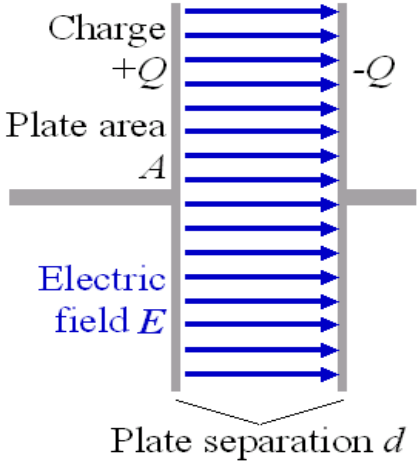
- Cycling stability (compared w/ EDLC)

Surface modification, comprehensive nanocomposite material creation, and microstructure optimization are just a few covered topics.

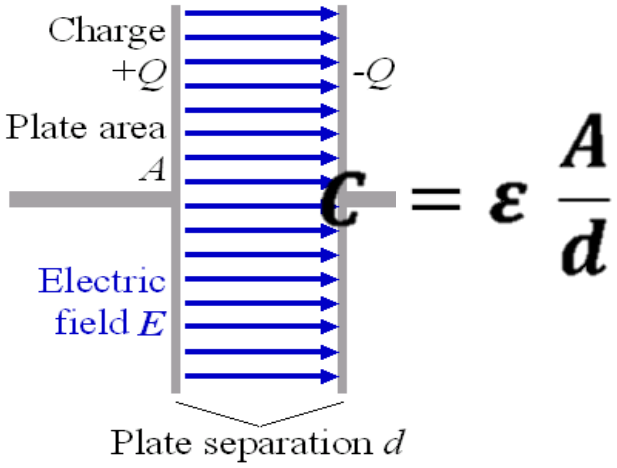
Working Principles: *Capacitor*

A capacitor consists of two conductive plates separated by an insulating material.

The process of capacitor energy storage is the result of gradual accumulation of charge under the action of electric field force

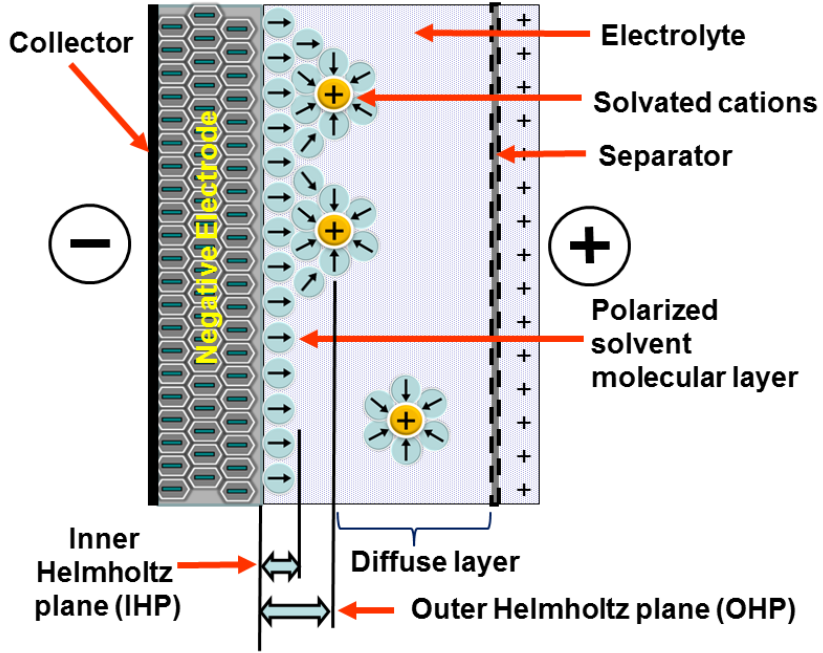


Working Principles: *Capacitance of parallel plate capacitor*



$$C = \varepsilon \frac{A}{d}$$

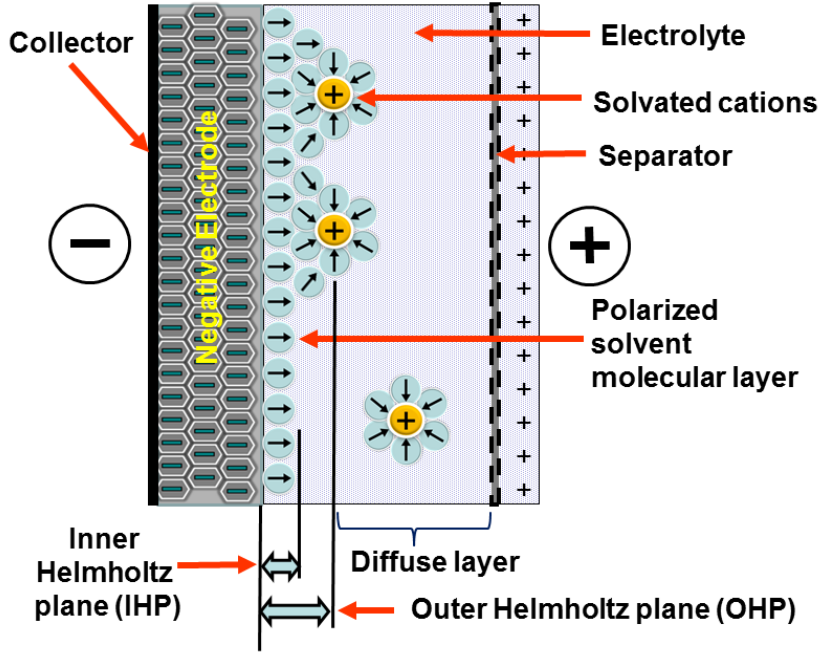
Working Principles: *Electrostatic double-layer capacitor*

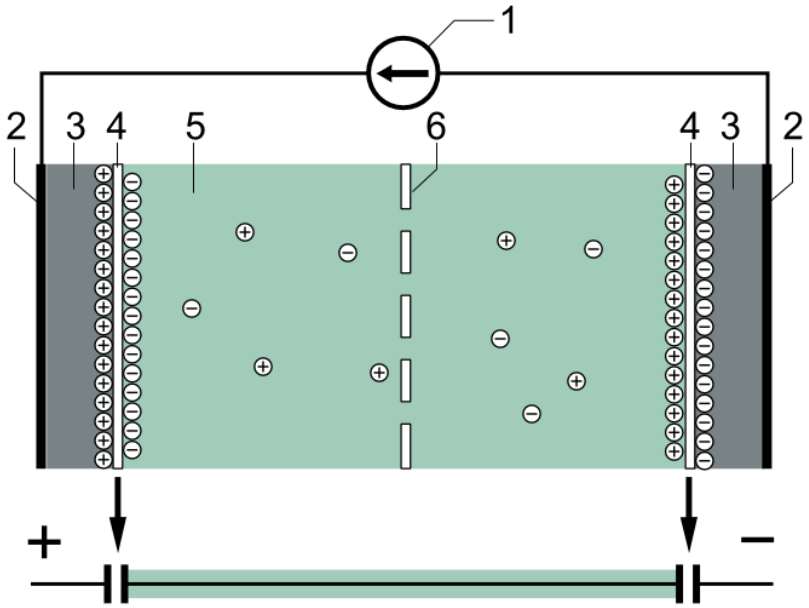


The solvent molecules are held on the surface of the porous carbon coating by physical adsorption, forming an internal Helmholtz plane (IHP).

The positively charged ions inside the electrolyte are attracted to the negative charges stored on the electrodes,, forming an outer Helmholtz plane (OHP).

Working Principles: *Electrostatic double-layer capacitor*





Working Principles: *Pseudocapacitor*

- The prefix “Pseudo” means fake.
- Reversible redox reactions
- When electric field is applied, fast redox reactions will happen at respective electrode to store energy.
- When voltage is removed, reverse redox reactions will happen to release stored energy.
- The separator in electrolyte separates anode electrode and cathode electrode apart to prevent short circuits from happening, while still allowing ions to pass through it .

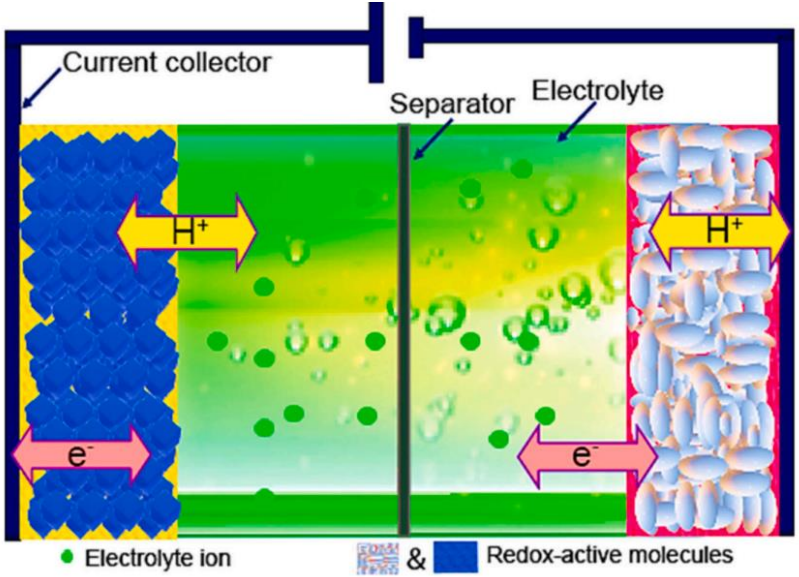
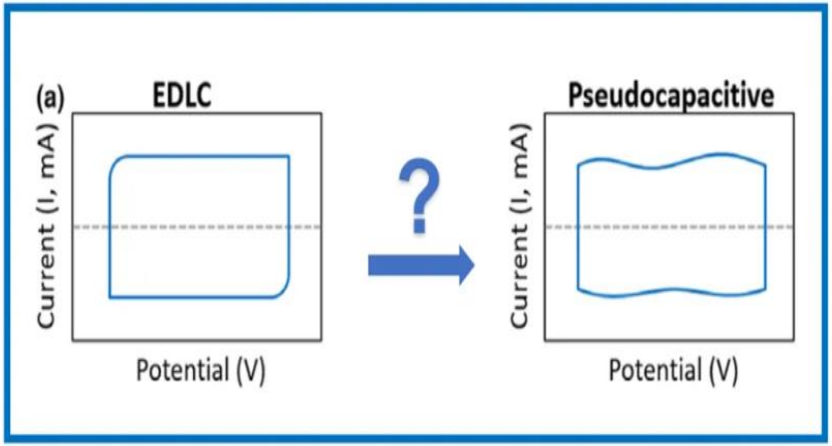


Illustration of Pseudocapacitor Mechanism

Working Principles: *Cyclic Voltammetry*

- The prefix "pseudo" implies that a pseudocapacitor isn't a conventional capacitor, yet we still refer to it as a supercapacitor. Why?
- It is shown in this voltammetry graph that the fast redox reactions happening on the electrodes gives the pseudocapacitor quasi-rectangular shapes curve in voltammetry graph.
- This shape resembles the shape of a supercapacitor.



The Cyclic Voltammetry Graph of Supercapacitor

Working Principles: *Hybrid Supercapacitor*

- The characteristic of a hybrid supercapacitor combines both supercapacitors mentioned above.
- Operating in both faradic and non- faradic modes.
- On one side of the electrodes, the materials exhibit electrical double-layer capacitance.
- On the other side of the electrodes, the materials demonstrate pseudocapacitive behavior.
- Relatively high energy density and power density.

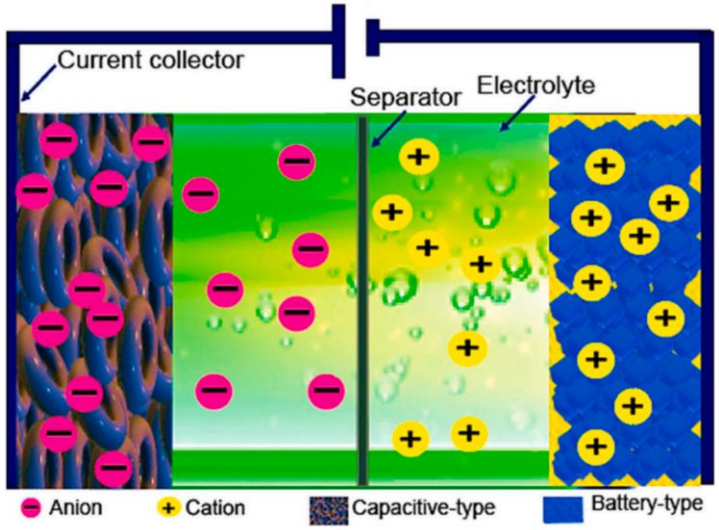


Illustration of a hybrid supercapacitor mechanism

Recent Advances: *Materials and Structure*

High energy density

Long lifetime

High reliability

318 F/g

760 F/cm^3

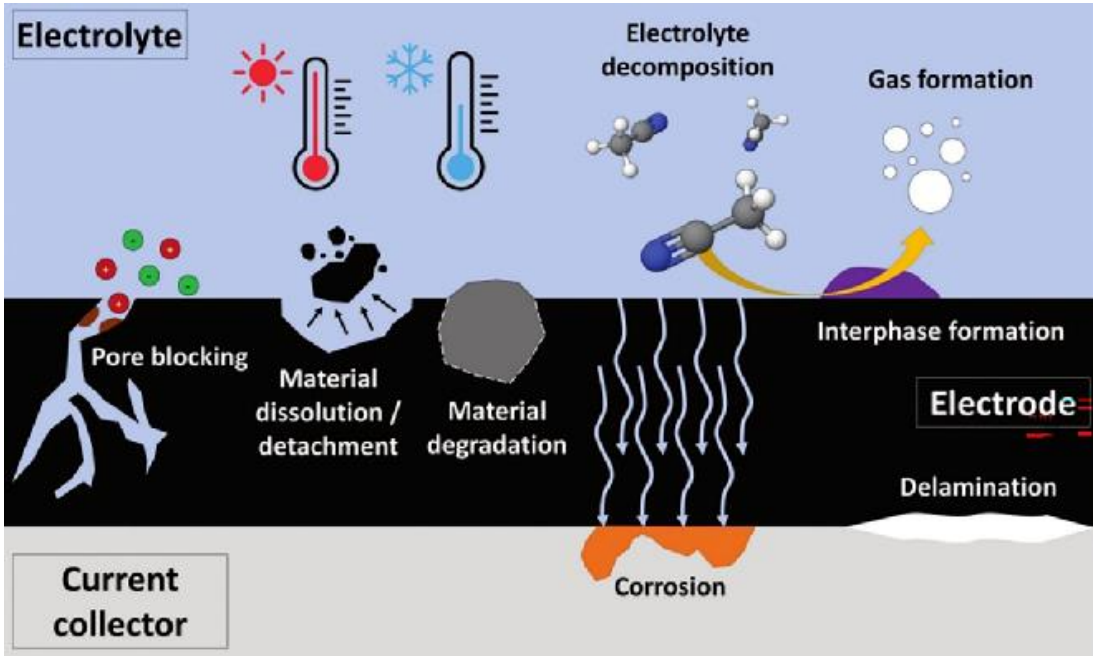
32.4 mF/cm^2

90% at 12000 cycles

94% retention at 5000 cycles

1.6 V in blood condition

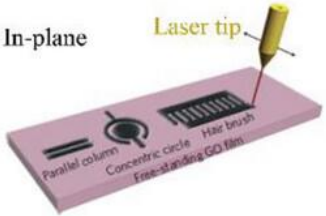
Recent Advances: *Degradation Mechanisms*



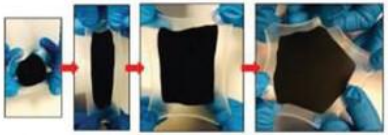
1. From materials
2. From mechanical
3. Intelligent monitoring

Recent Advances: *Flexible Supercapacitors*

Pioneer of flexible supercapacitor



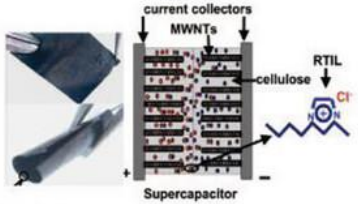
FSCs by laser technique



An omni-directionally stretchable electrode of flexible supercapacitor

FSCs by spray coating

2006 2007 2011 2013 2016 2017 2020



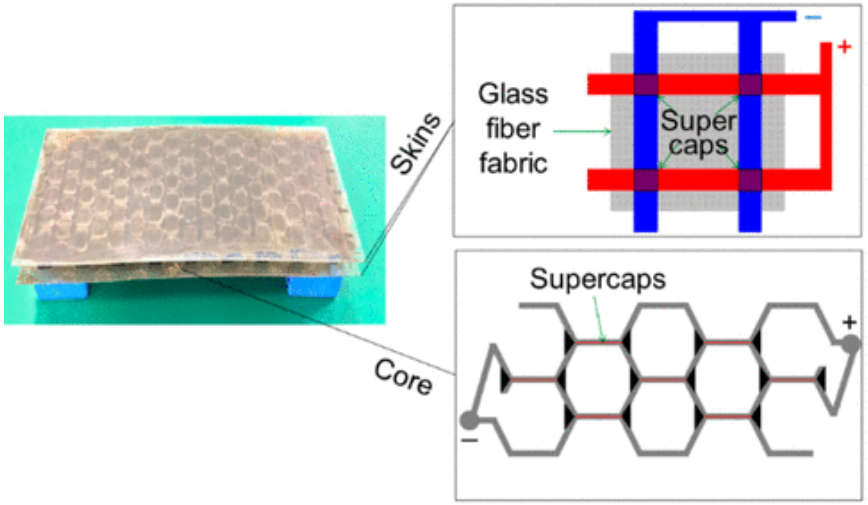
FSCs based on nanocomposite paper

Fiber-shaped FSCs

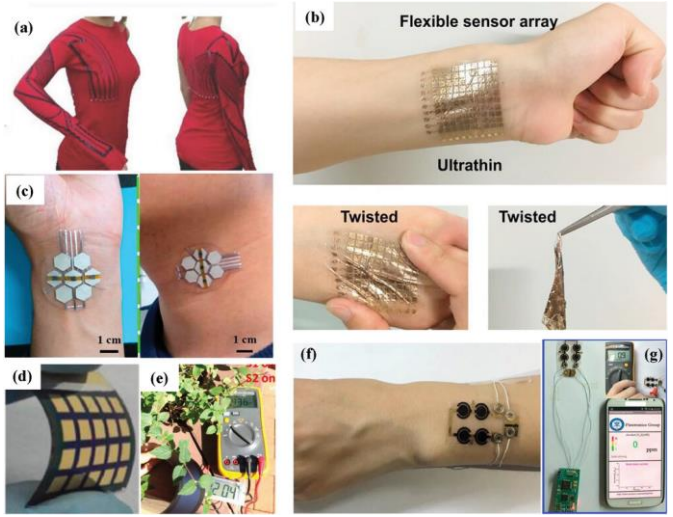
Biopolymer-based biodegradable supercapacitors

High-performance FSCs with excellent mechanical properties

Recent Advances: *Flexible Supercapacitors*

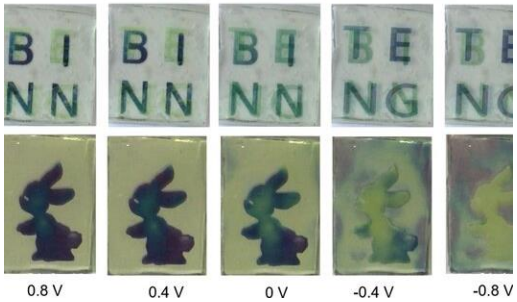


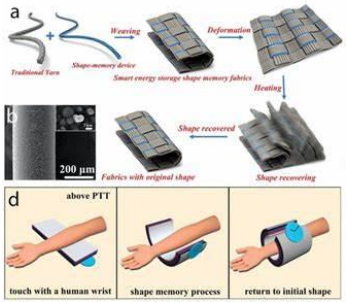
Flexible supercapacitor prototype with innovative sandwich-structured composites.

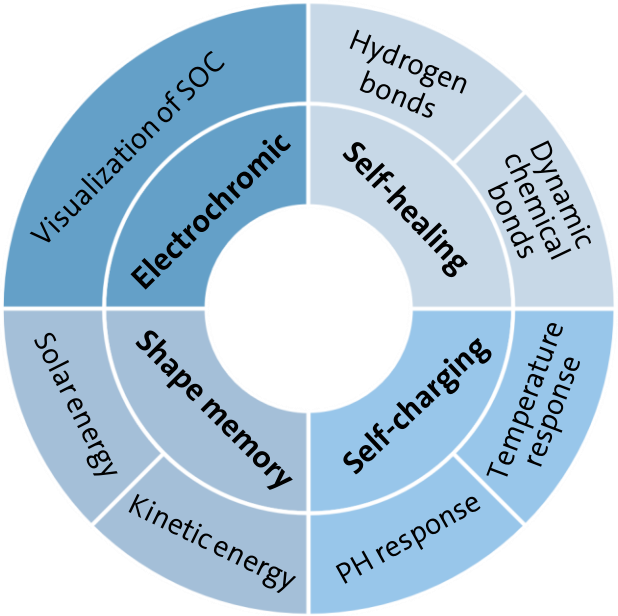


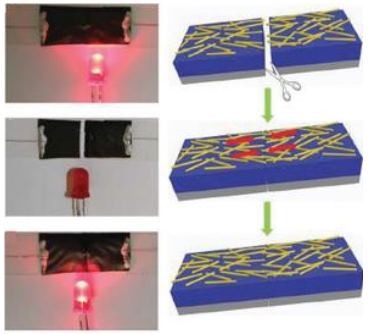
Flexible supercapacitor applications in wearable devices.

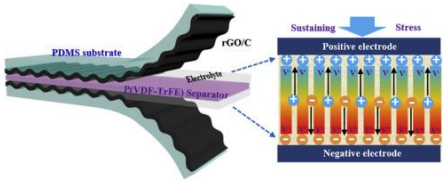
Recent Advances: *Innovations*











Current & Potential Applications

Automobile (EV/HEV)

- Hybrid energy storage system (HESS)
- Store energy when decelerate
- Use for acceleration, in-vehicle electronics

Municipal Transportation Vehicle (EV/HEV)

- Regenerative braking energy (RBE) recovery
- Economic for larger scale
- Also for industrial equipment

Light Rail/Tram

- Eliminates overhead/catenary lines
- Recharge during stops at stations

Current & Potential Applications

Microgrid (EV/HEV)

- Isolated grid from main grid
- For renewable energy
- Solve intermittent issue

Energy Storage

- High power density, low energy density
- Cannot replace conventional battery
- Work in progress

Thank you for your listening !

Questions?

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