# Fundamental requirements of Materials development for Energy Storage Devices

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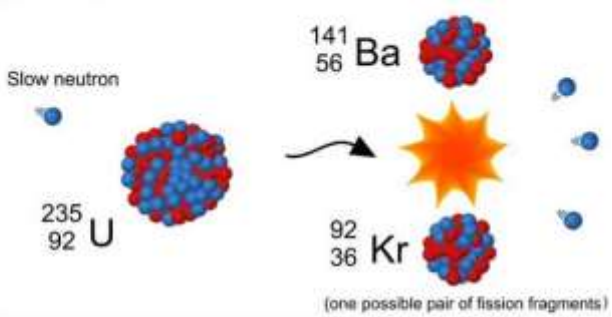
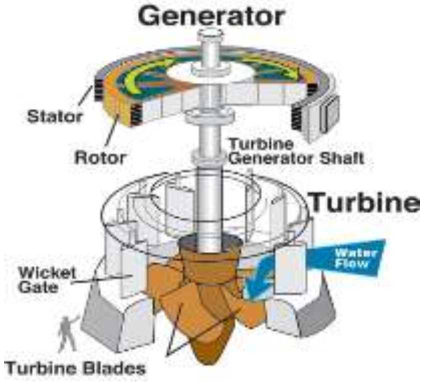
# Introduction





Today, we can convert energy from many different forms into usable electricity.

# Background

But the main problem for electricity is how we store it from the generation source?

# Background

In the 1600’s, scientists did not really know much about electricity or how to use it. The spark generators were mostly used by scientists to study the nature of the sparks

In 1745, scientists (Musschenbroek and Cunaeus) noticed that one could “charge” up a glass filled with water and get a shock by touching a metal nail.

Simplified version

Metal foil wrapped around the inside and outside of a jar with a chain connecting the inner layer

Lyden Jar – Named after a city Lieden

First Capacitor

We know these devices as capacitors, but they work by storing charge ELECTROSTATICALLY

# Current Needs For Energy Storage

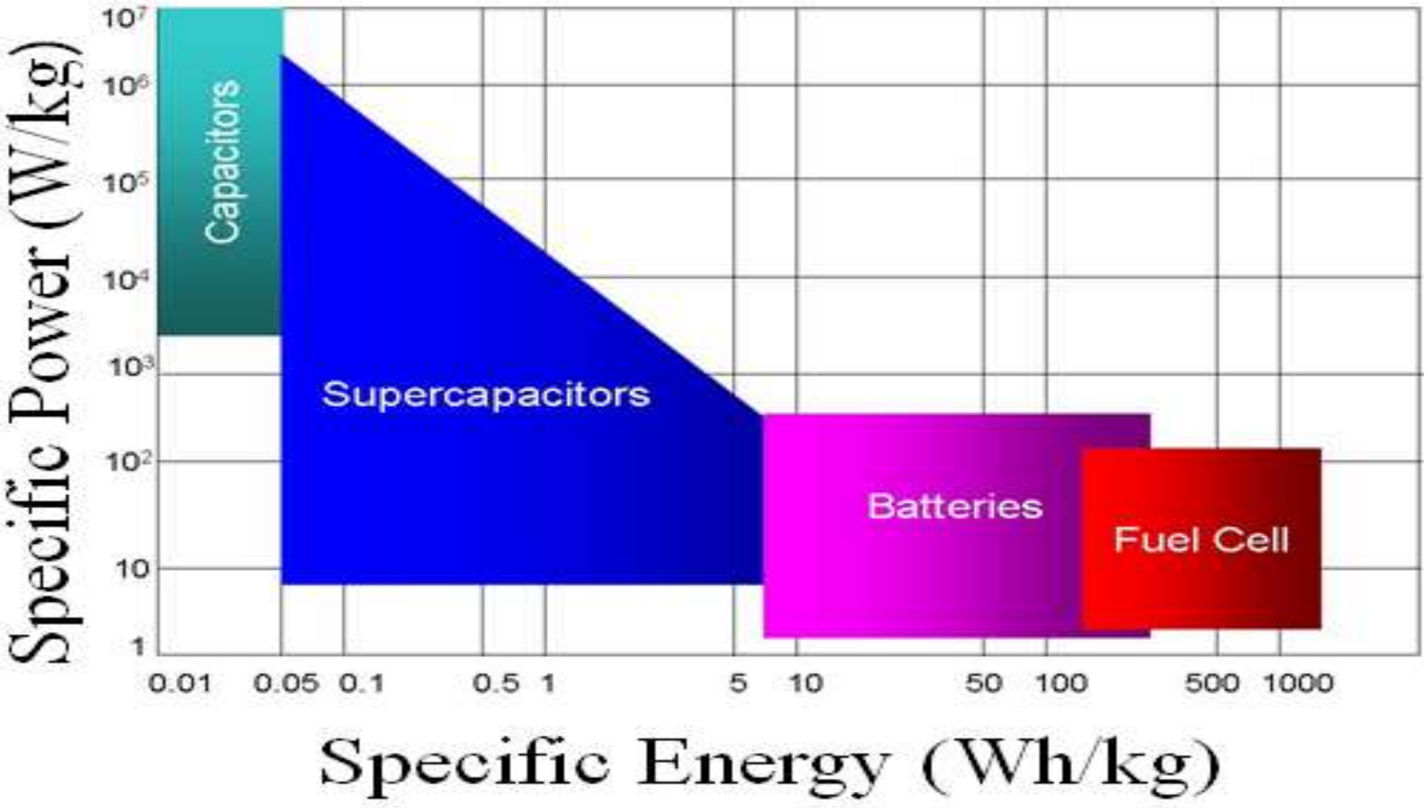
Portable Electronics

20-30% $CO_2$ Emission

# Current Needs For Energy Storage

Large Scale Energy Storage

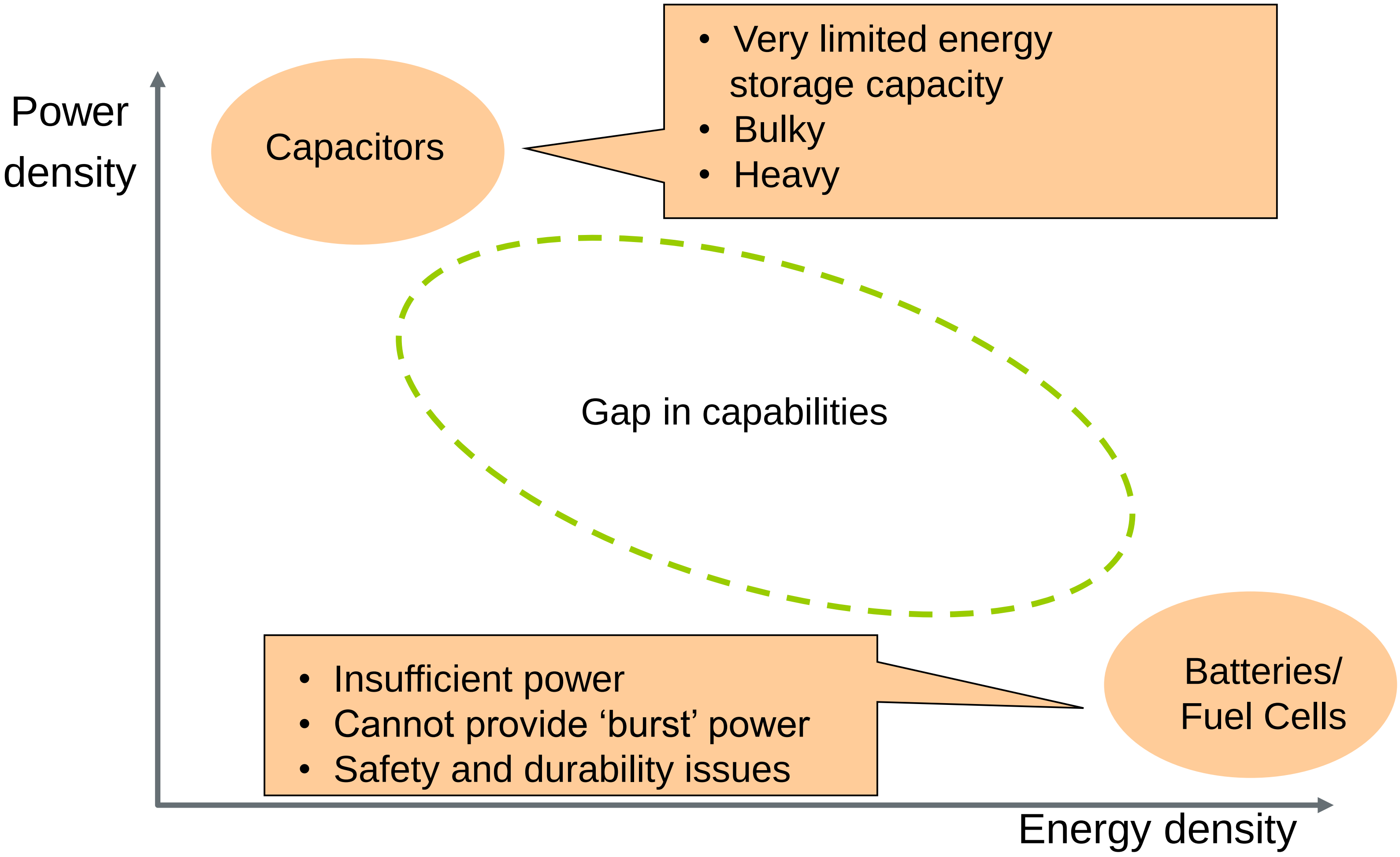
# Current Energy Storage Devices



**Important Parameters**

1. Energy Density (Energy per Weight or volume)
2. Power density (Power per Weight or volume)
3. Safe with long cycle life
4. Cost

# Current Energy Storage Devices

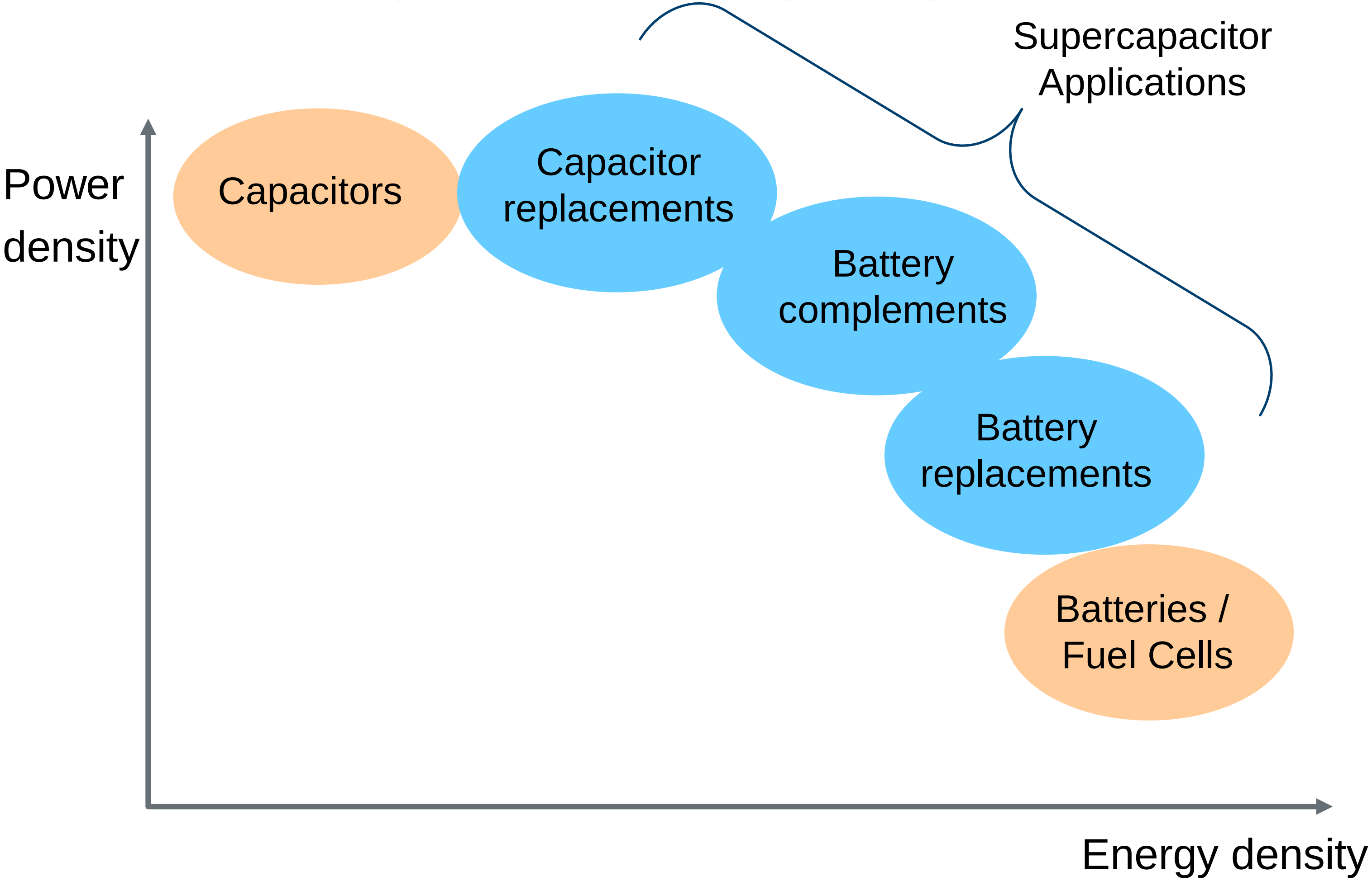


- Very limited energy storage capacity
- Bulky
- Heavy

- Insufficient power
- Cannot provide ‘burst’ power
- Safety and durability issues

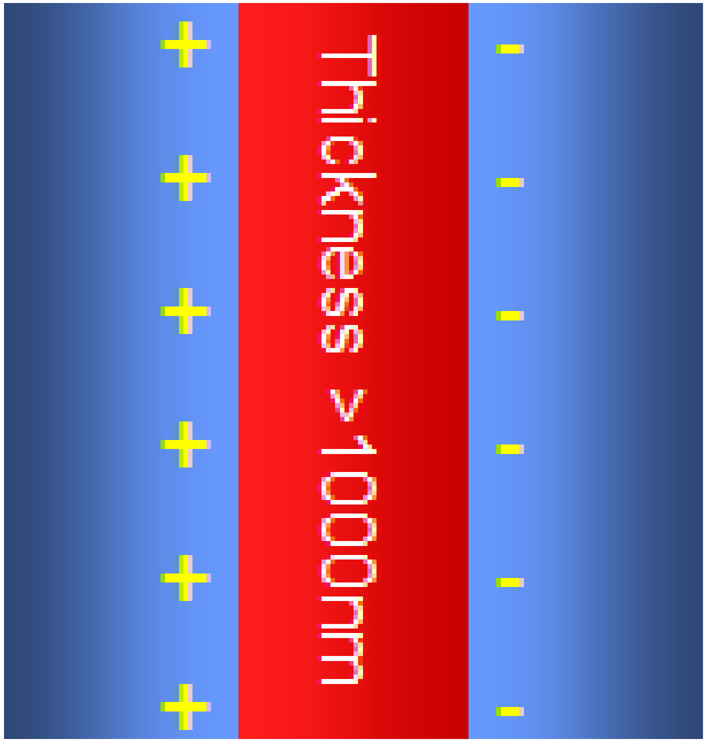
# Current Energy Storage Devices

*Supercapacitors have a unique ability to provide a solution that is small, lightweight and has the power to fill the gap in capabilities*



# Energy Storage Devices

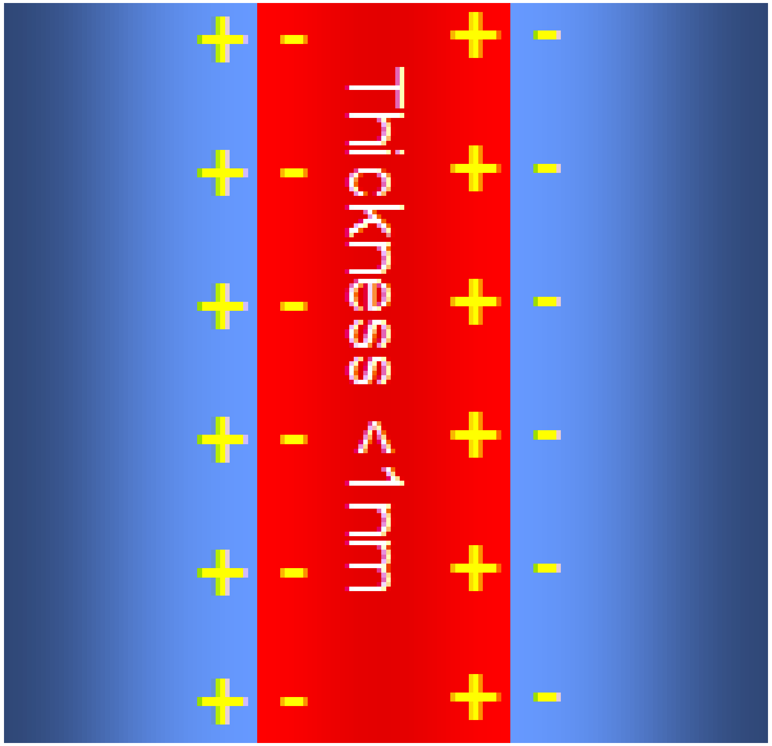
Capacitor



$C \alpha 1/\text{thickness}$

$E = \frac{1}{2} CV^2$

Supercapacitor



Electrolyte solution

# Materials Challenges

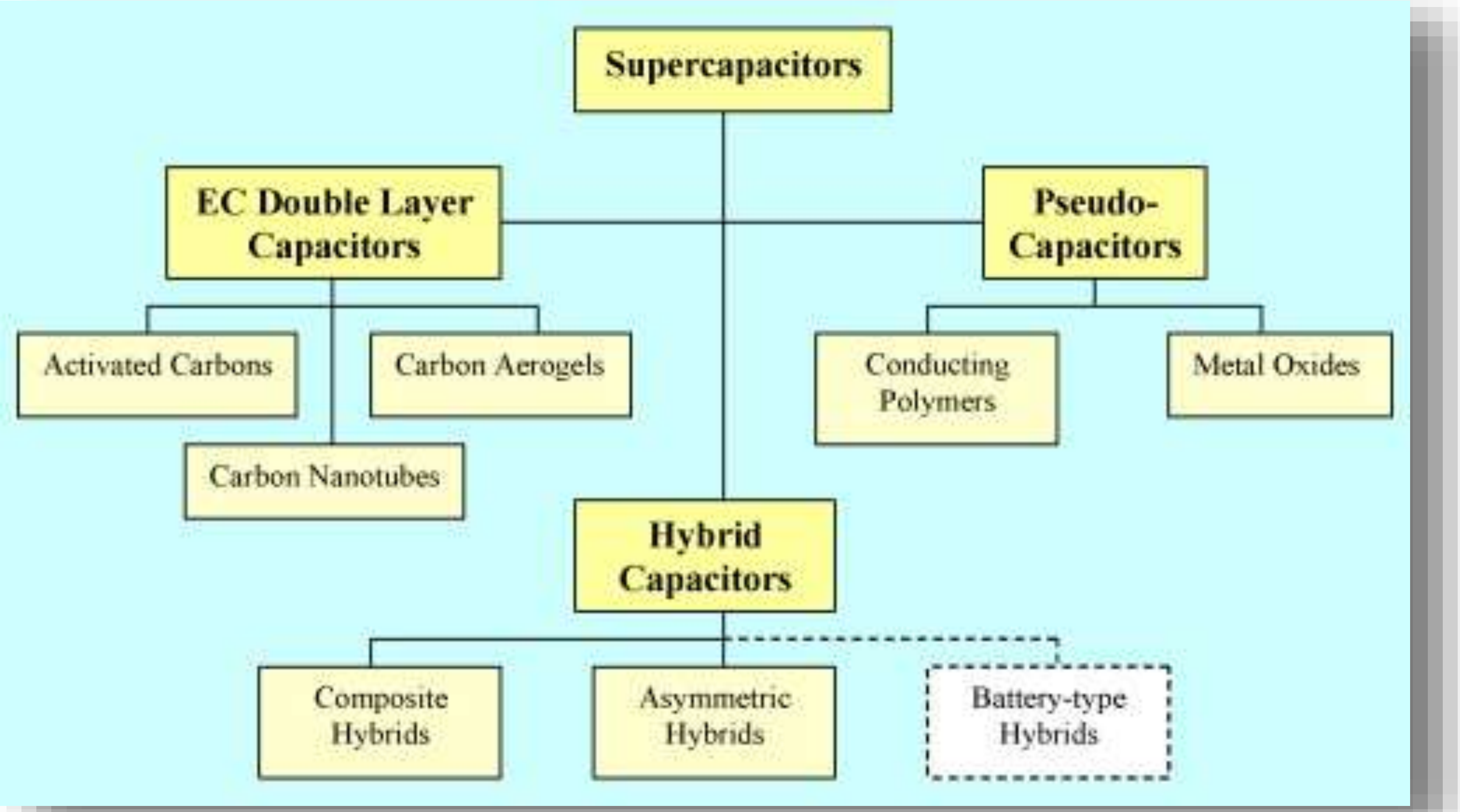
Reactions occur at the electrode surfaces

- ✓ We want to get as high a surface area as possible
  - Need to have ions and electrons together for reactions to occur
  - However
  - e.g. Nanoparticles behave differently than bulk materials
    - Energy of the reactions also depend on the surface properties
- ✓ Electrons must still be able to get outside the cell
  1. Electron resistance cannot be too high
  2. Separator must be robust and allow rapid transfer of ions
  3. Fundamental materials properties need to be understood

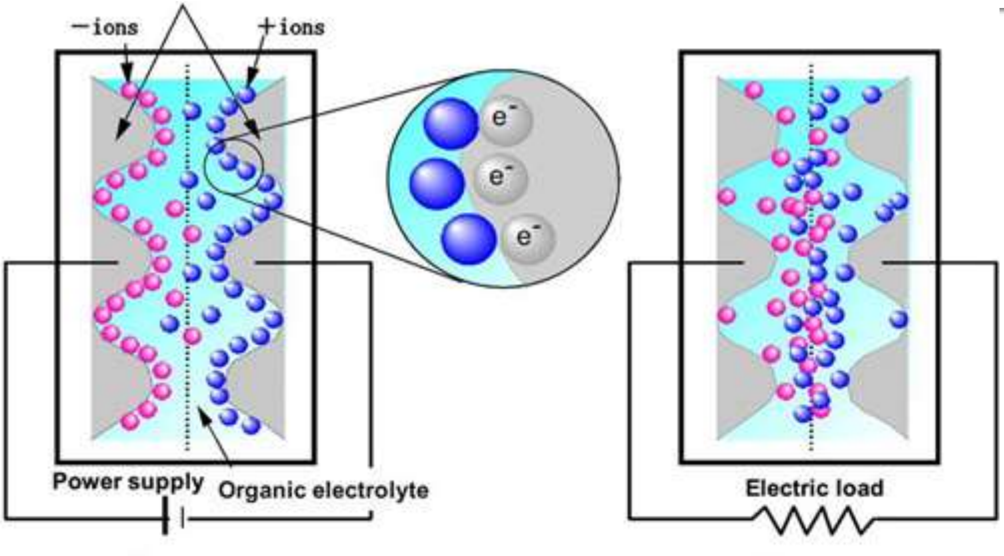
# Materials for Supercapacitors

# Supercapacitors

# Taxonomy of Supercapcitors

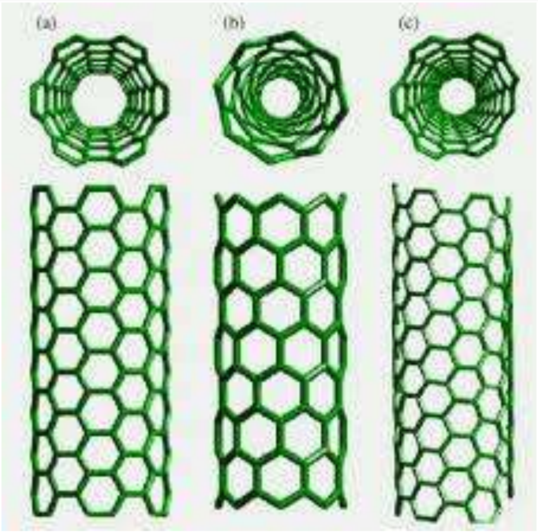


# Double Layer Capacitors



Charging

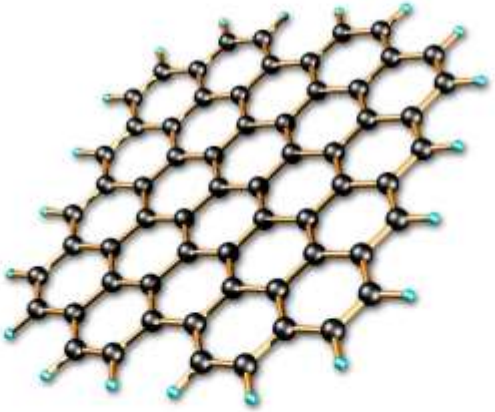
Discharging



$\text{CNT}_\text{S}$

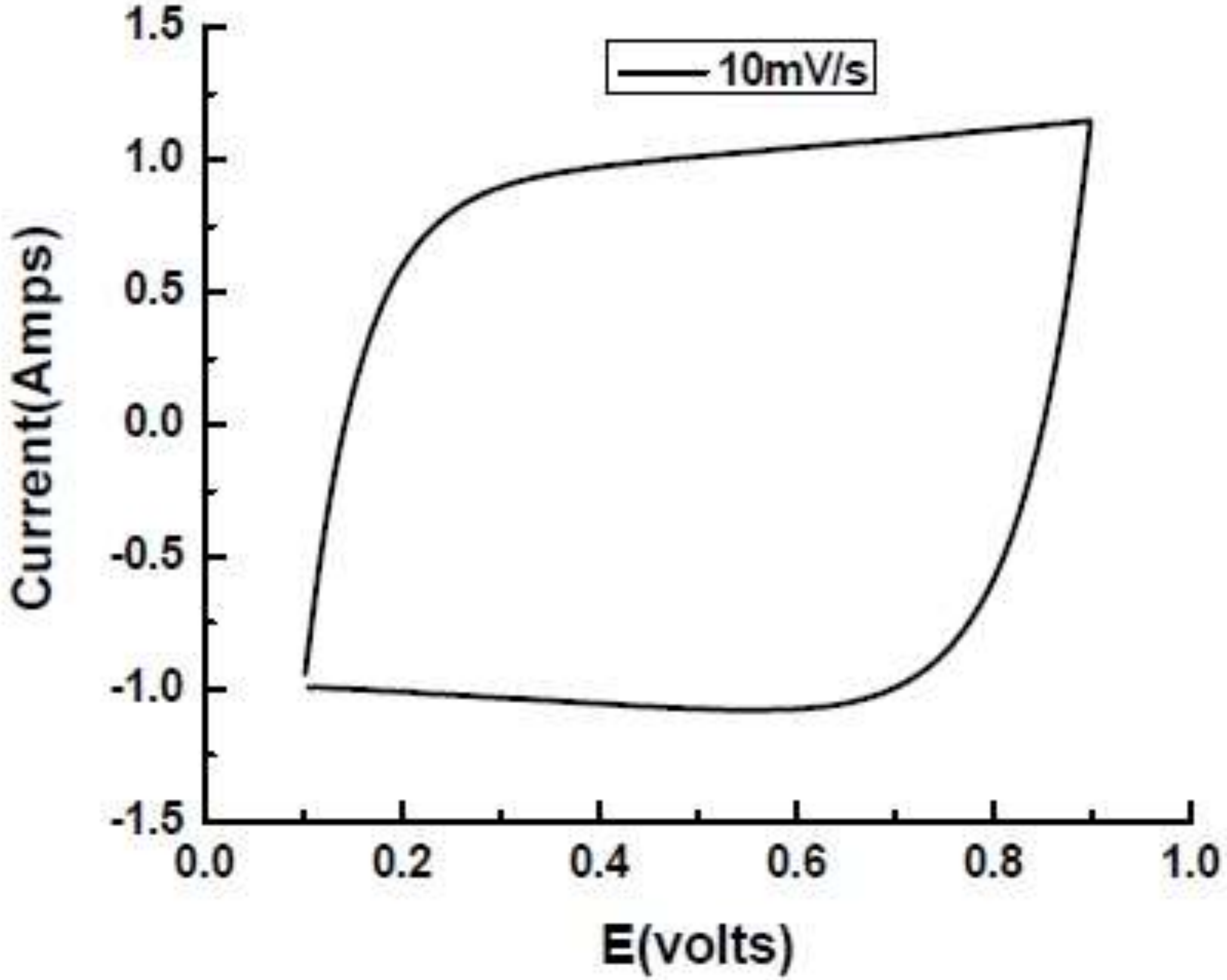
Carbon Aerogel

Activated Carbon

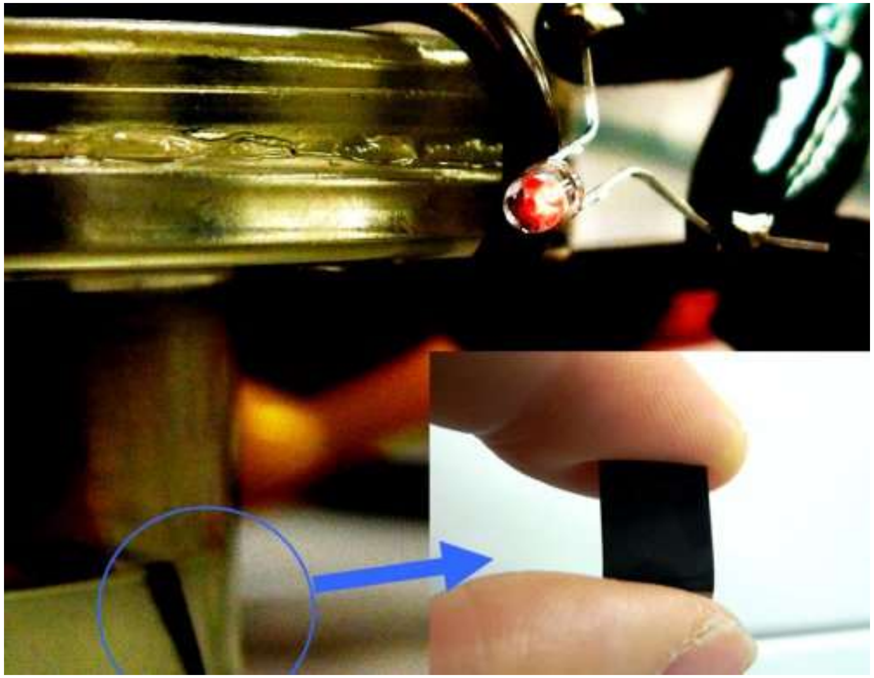


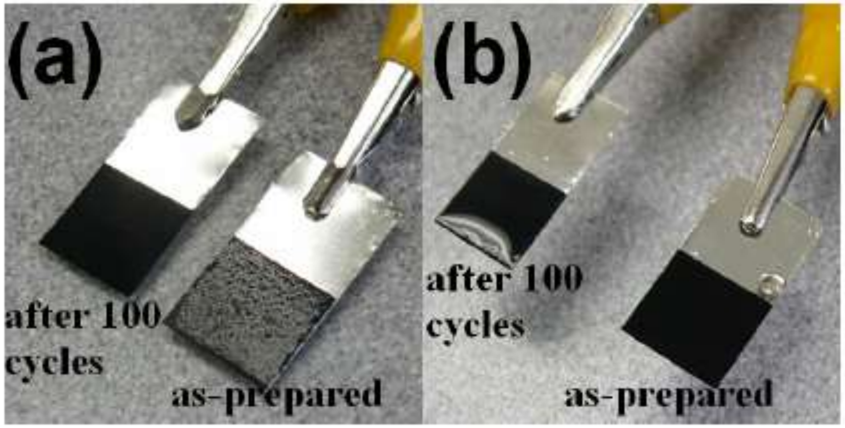
Graphene

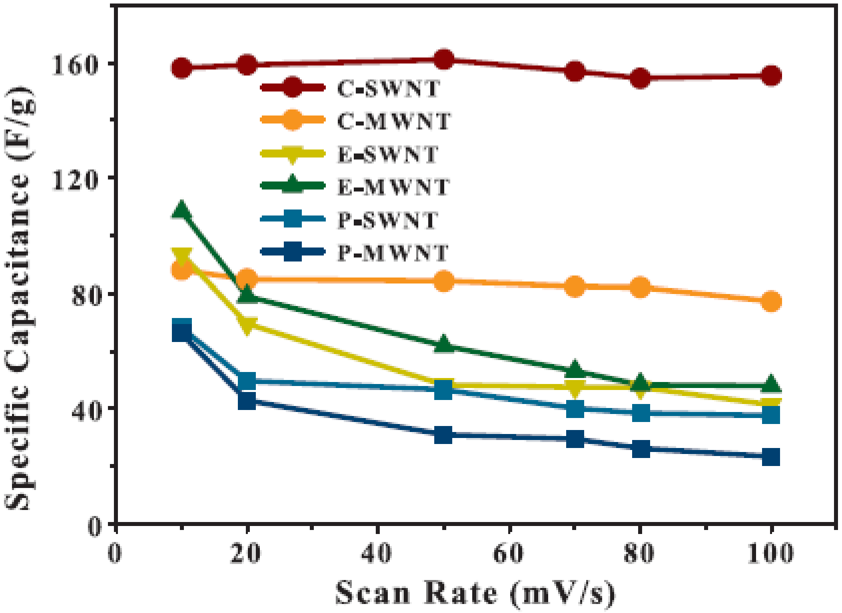
# Typical CV curve for DLCs



# Carbon Nanotubes

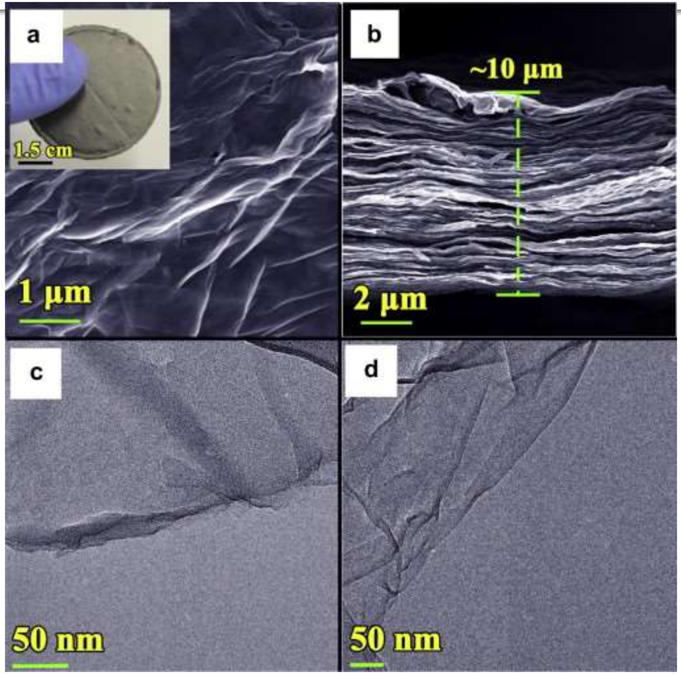


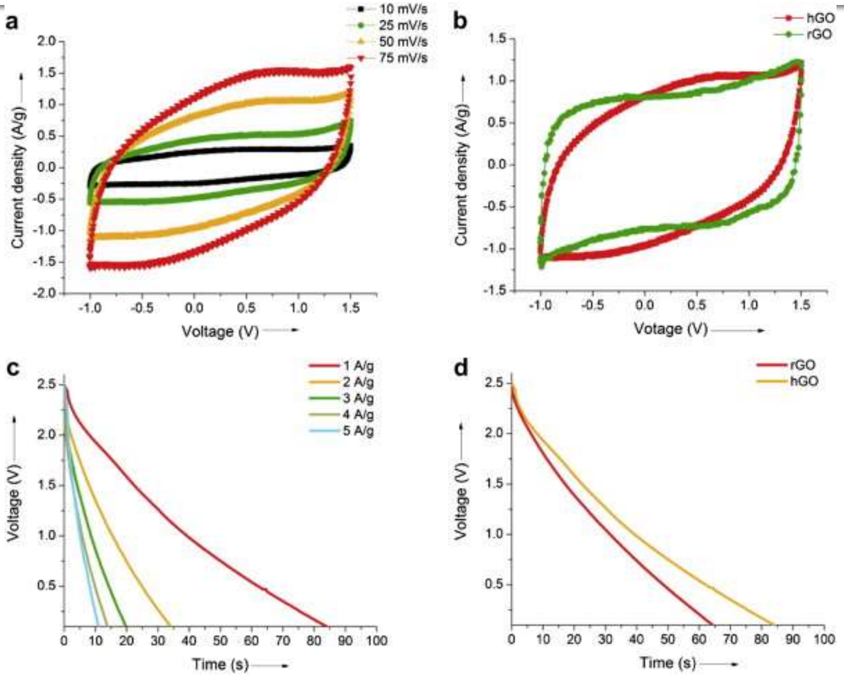


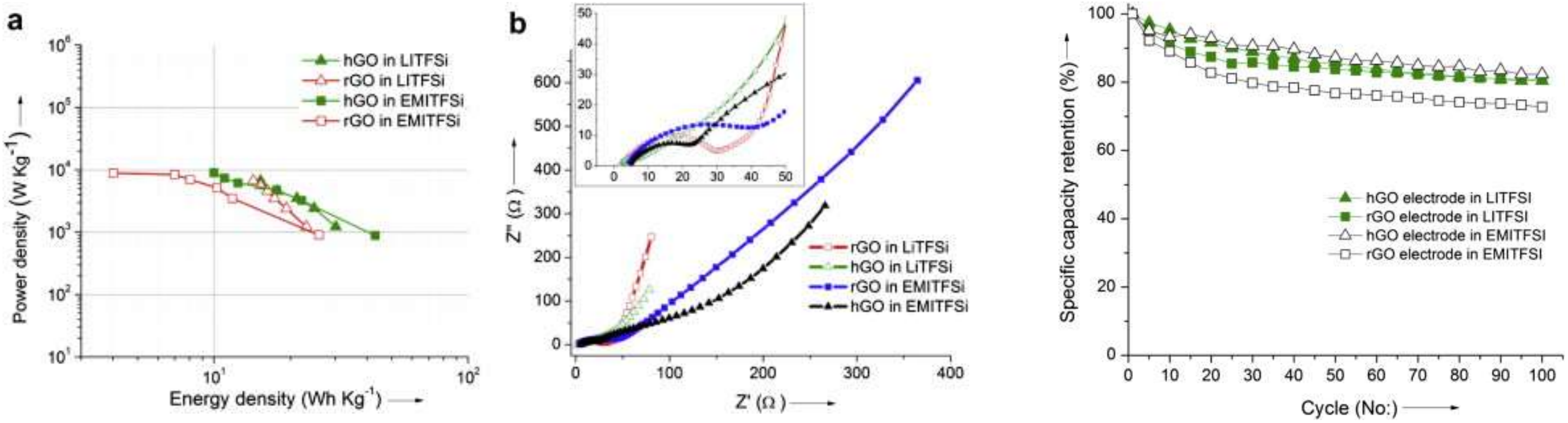


C – carboxylic
E – Easter
P - Purified

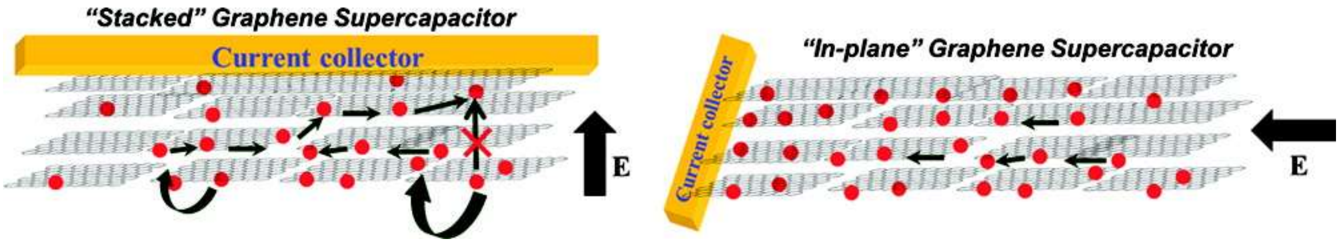
# Graphene Nanosheet for EDLC

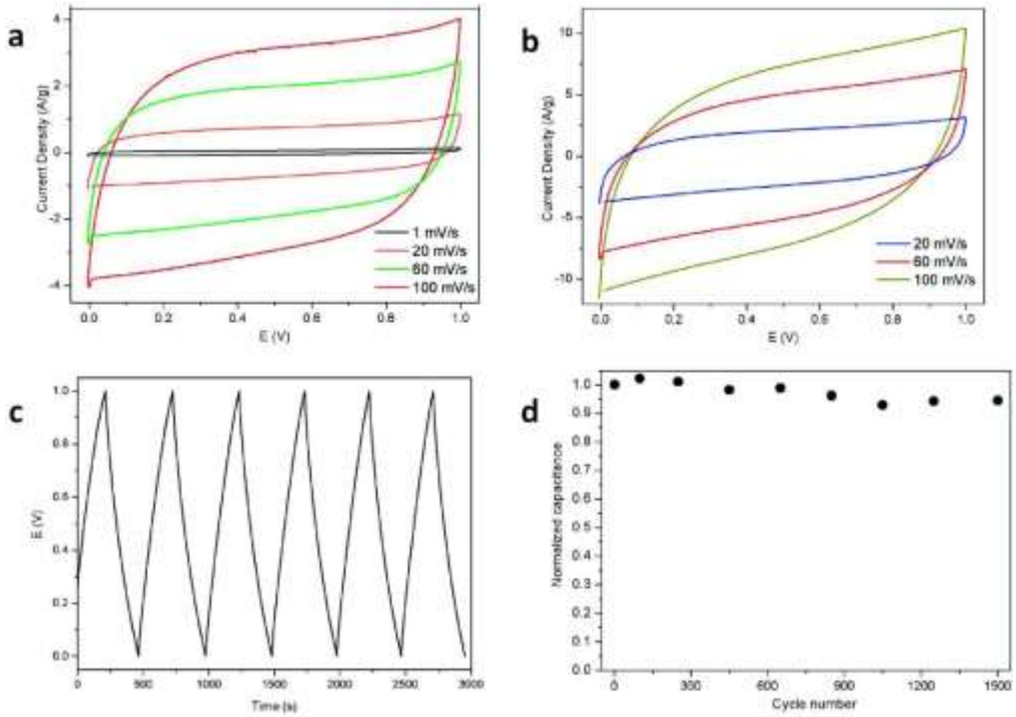






# Ultrathin Planar Graphene Supercapacitors

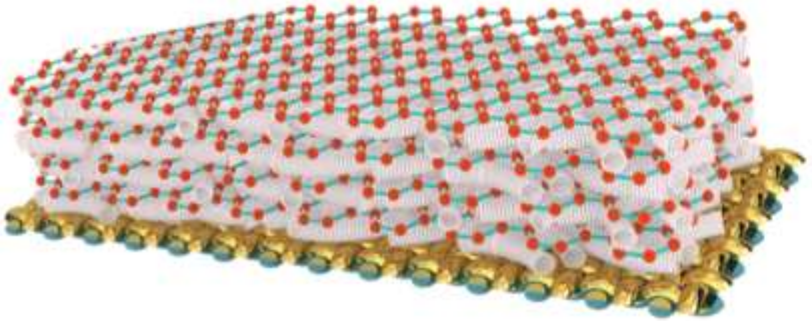




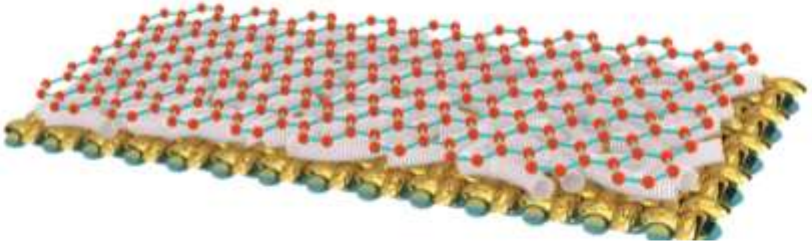
# Preventing Graphene Sheets from Restacking for High-Capacitance Performance

Ni/Cu/Ni/Au Coated Textile Fiber Substrate

Deposition of metal oxide coated MWCNTs layer



Repeat the steps to obtain the desired number of layers

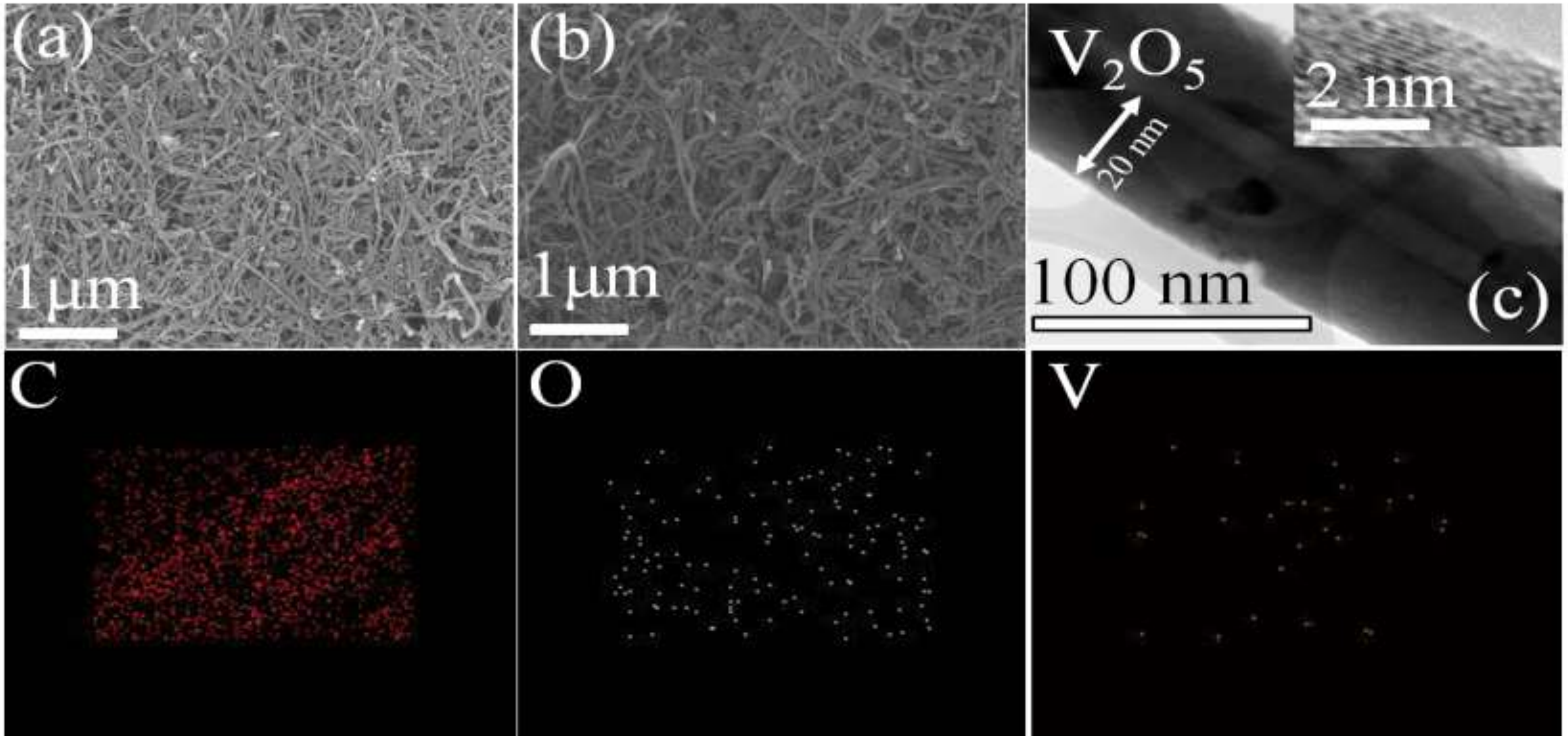


Transfer of Graphene on the Layer of metal oxide coated MWCNTs

Imran Shakir, *et.al* Nanoscale 6 (8), 4125-4130

Imran Shakir, Electrochimica Acta 129, 396-400

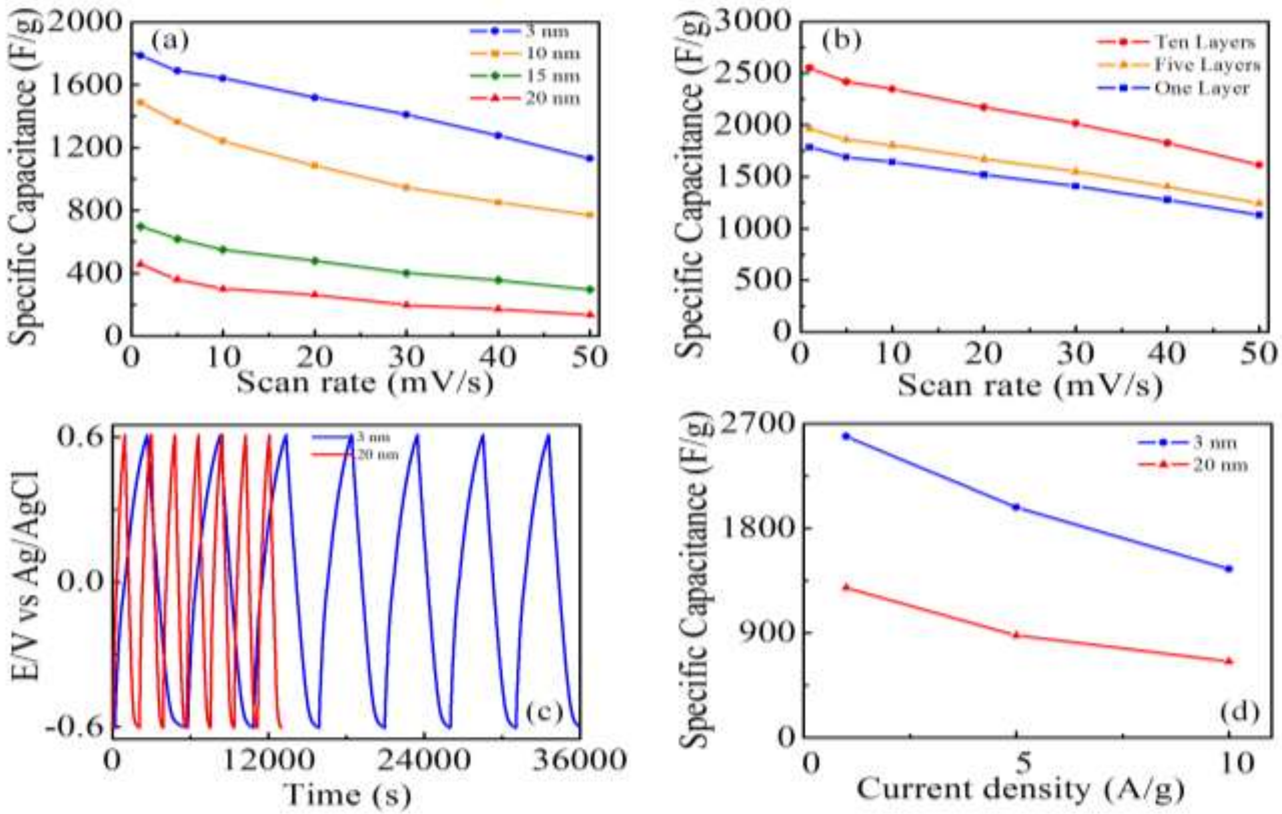
# Preventing Graphene Sheets from Restacking for High-Capacitance Performance



- HRTEM images confirm the uniform and ultrathin 3 nm deposition of $V_2O_5$ on MWCNTs for the 0.1 mM $VOSO_4$ sample, on the other hand if we use 10 mM $VOSO_4$ the uniform 100 nm coating of $V_2O_5$ was obtained as shown in figure.

Imran Shakir, *et.al* Nanoscale 6 (8), 4125-4130

# Preventing Graphene Sheets from Restacking for High-Capacitance Performance



- The specific capacitance of metal oxide with thickness of 3 nm sandwich between graphene was found to be higher than that of higher thickness (2590F/g).

Imran Shakir, *et.al* Nanoscale 6 (8), 4125-4130

# Pseudocapacitors

Store energy using fast surface redox reactions

Metal oxides:

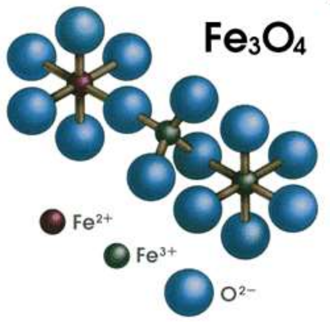
Capacity 1300 F/g ($RuO_2$)

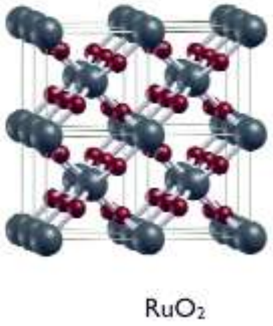
Nominal voltage 1.2 V

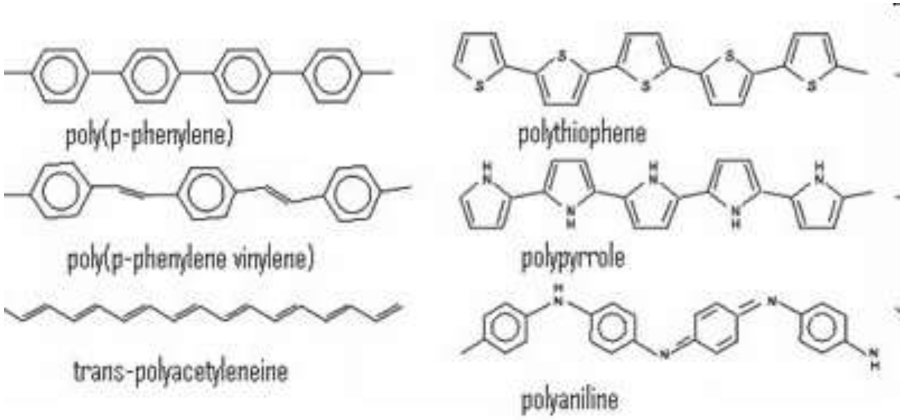
Conducting polymers:

Capacity 30 – 40 mAh/g

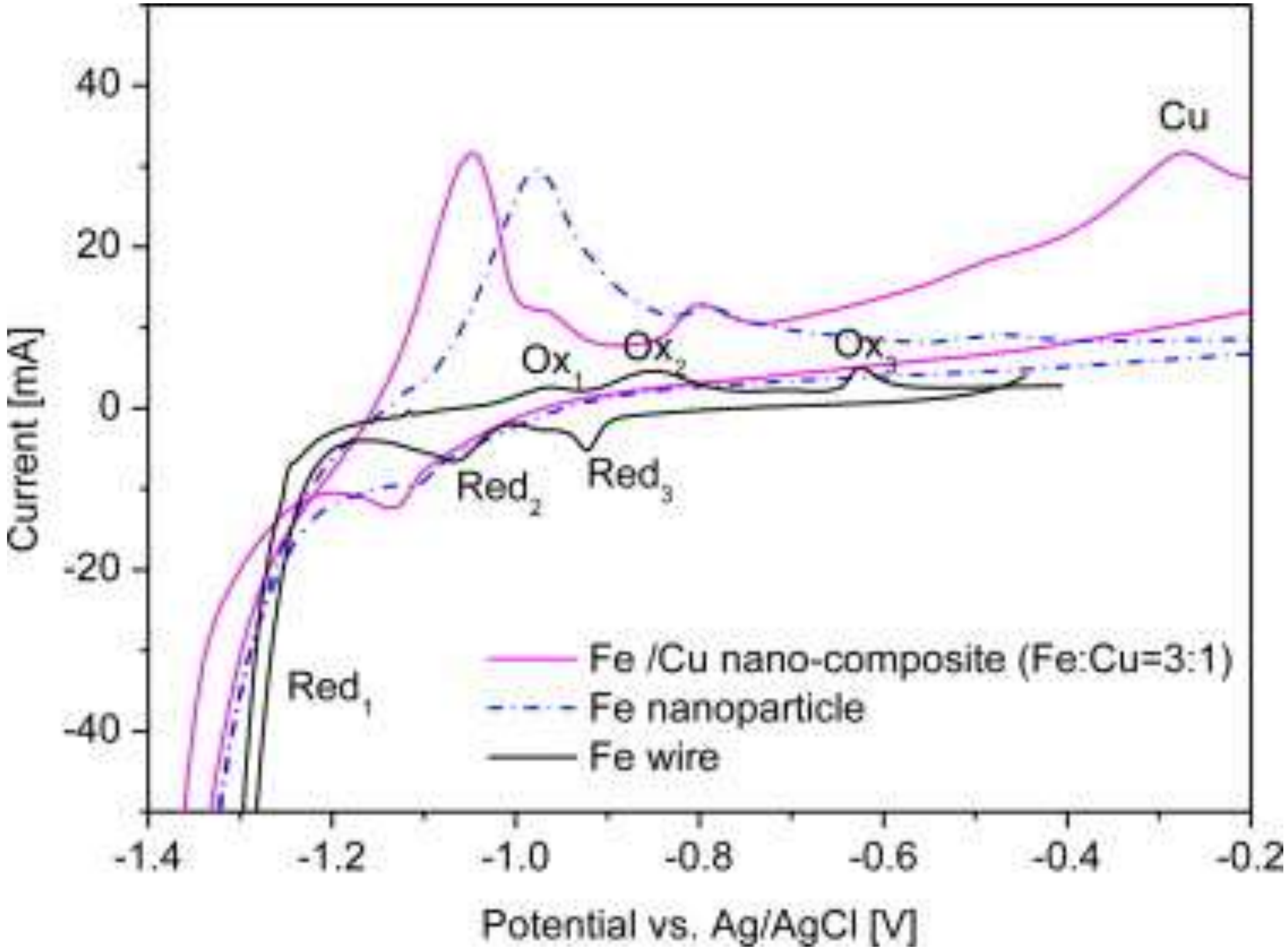
Nominal voltage 1.0 V



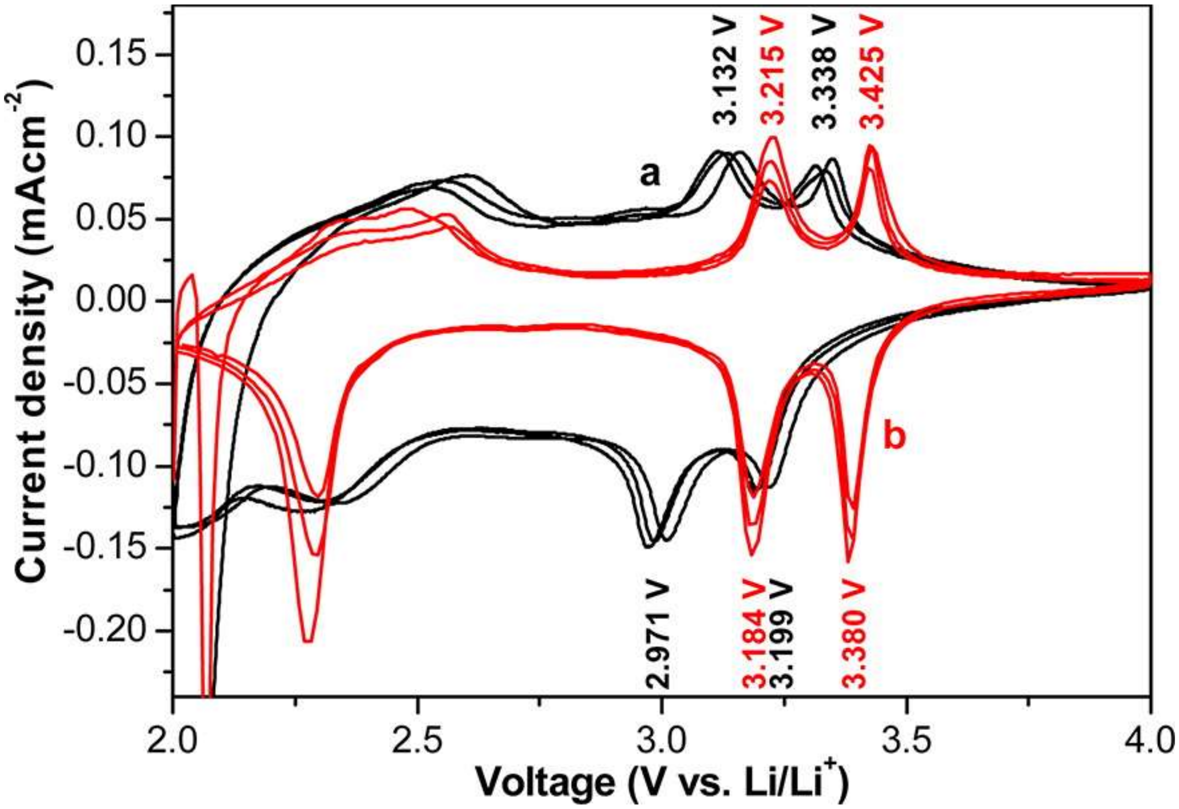




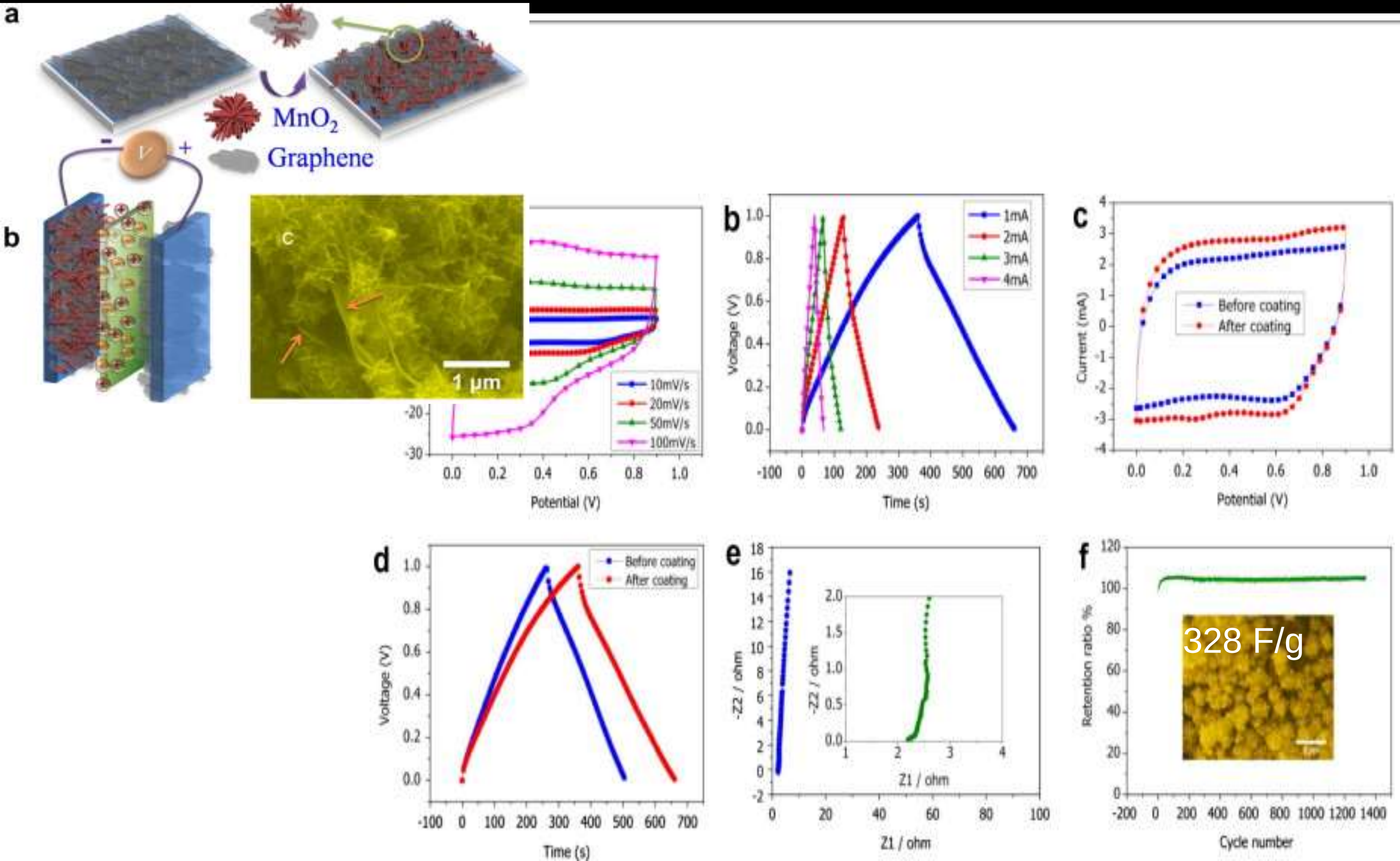
# Oxidation and Reduction peaks



# $V_2O_5$ a typical example

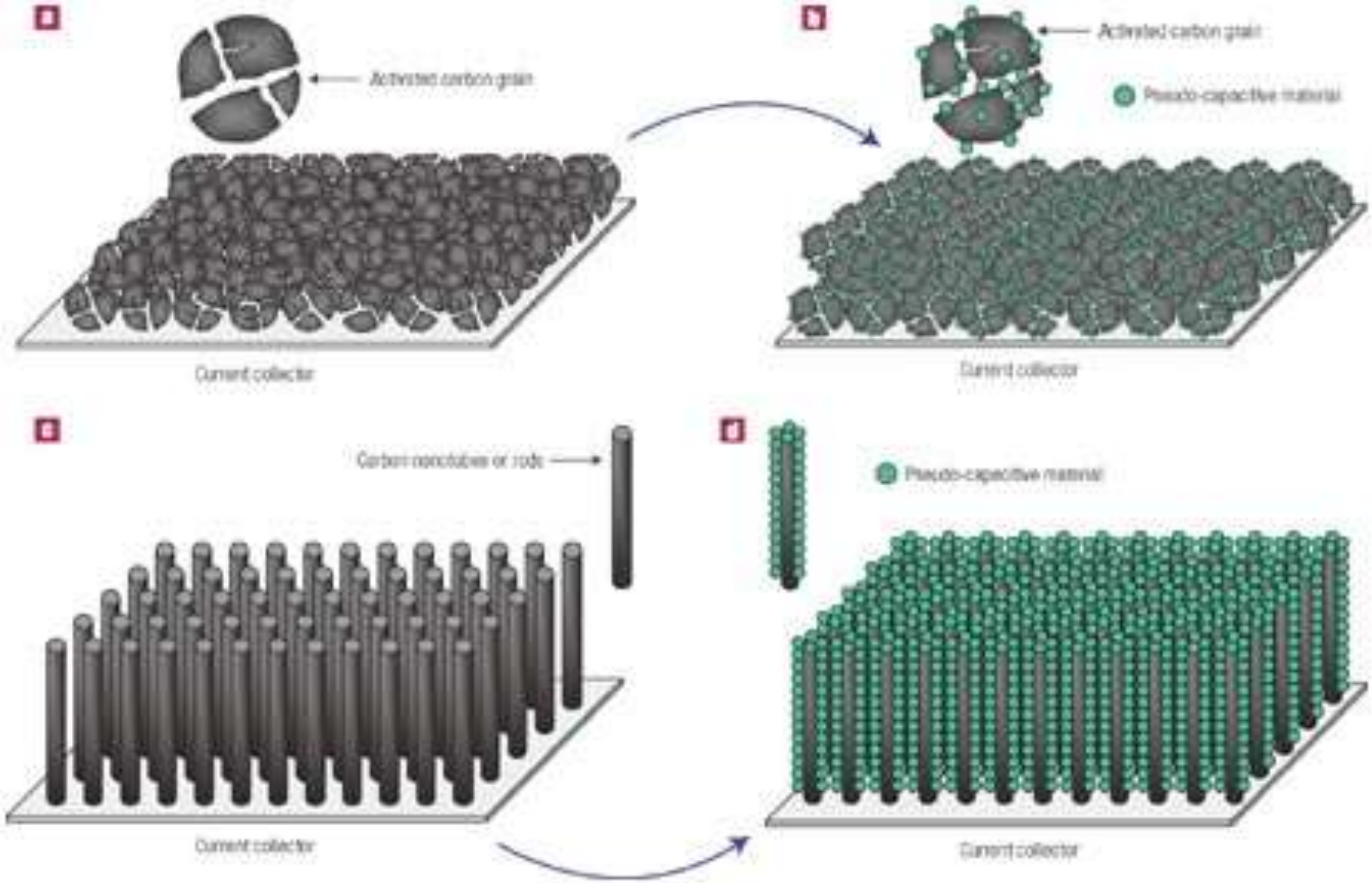


# Hybrid Capacitors

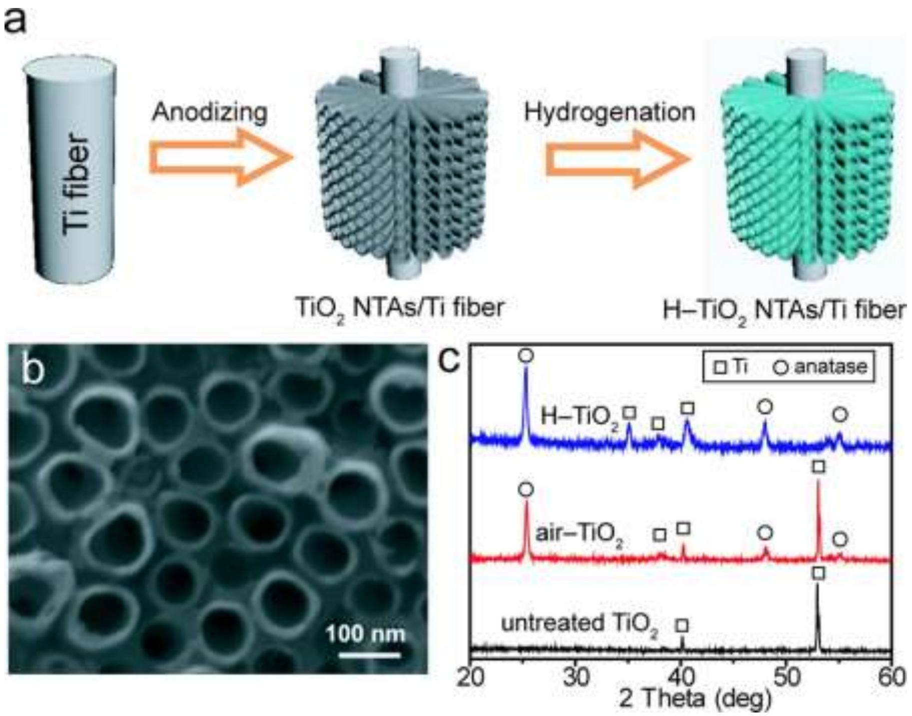


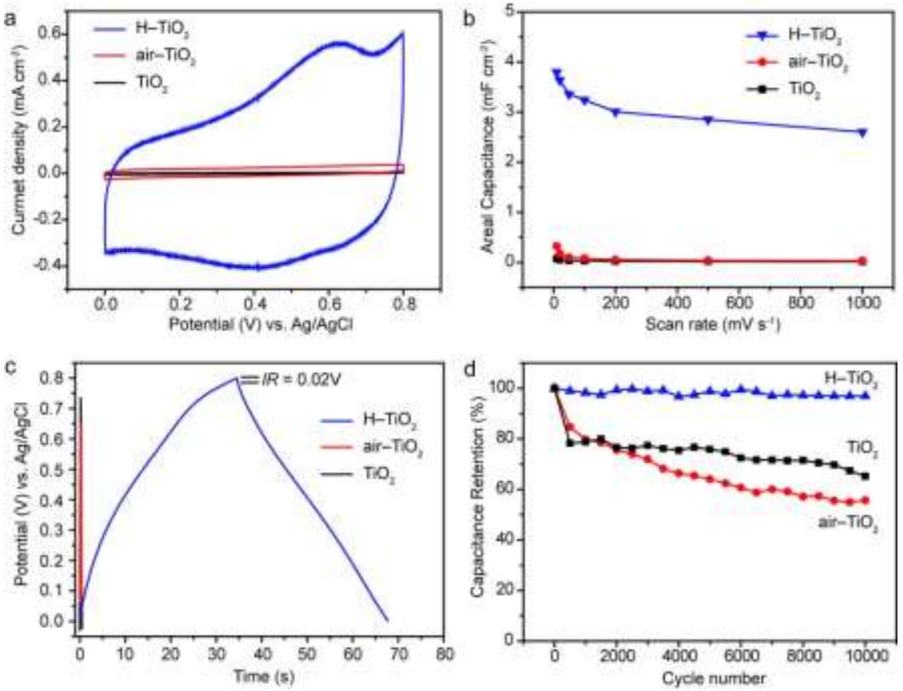
328 F/g

# Possible Strategies for Improvement

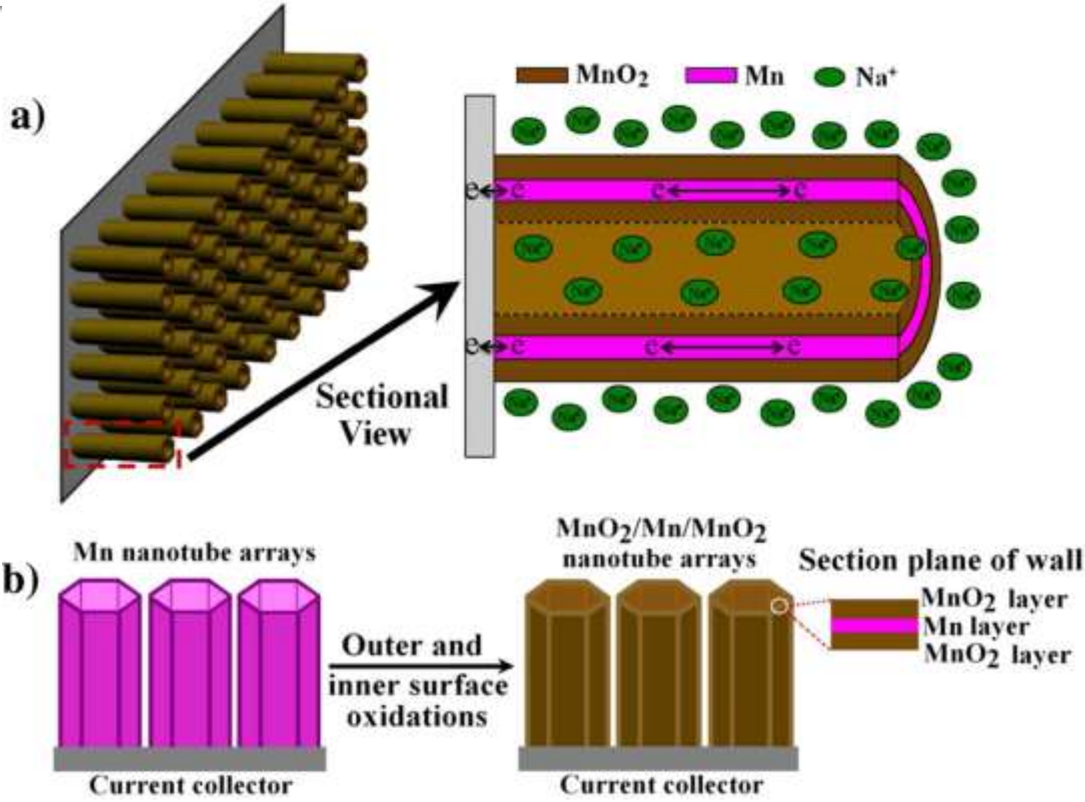


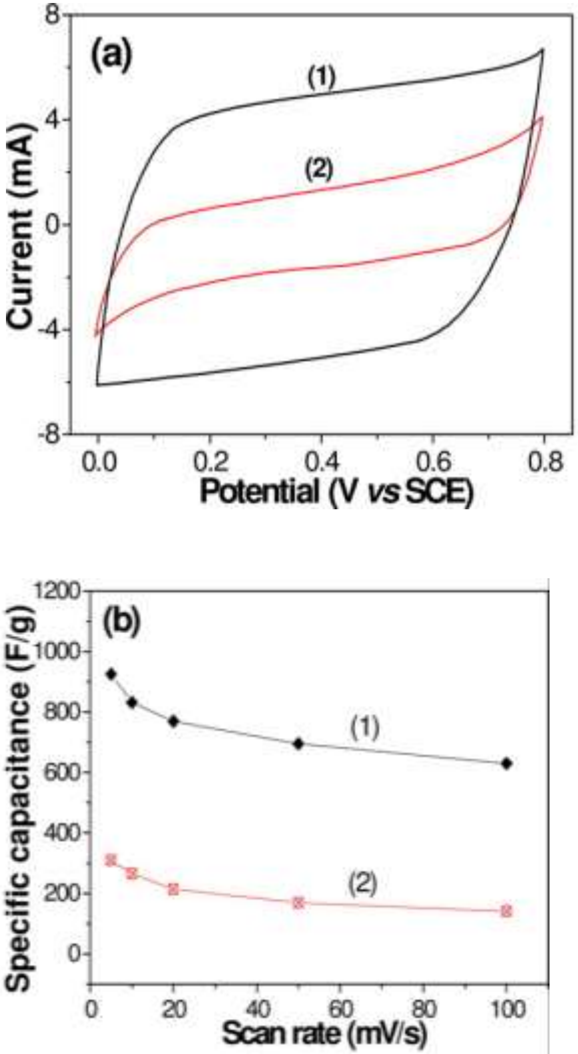
# Hydrogenated $TiO_2$ as Supercapacitors



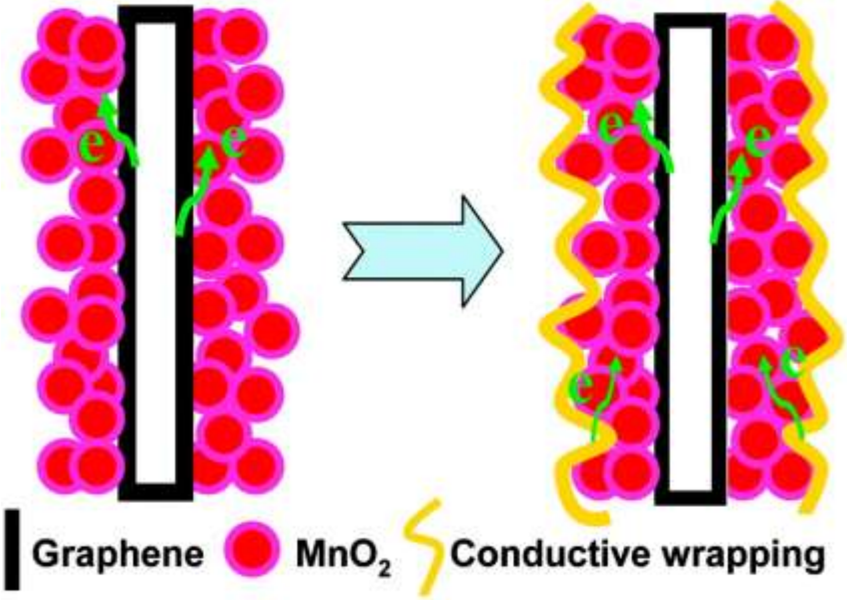


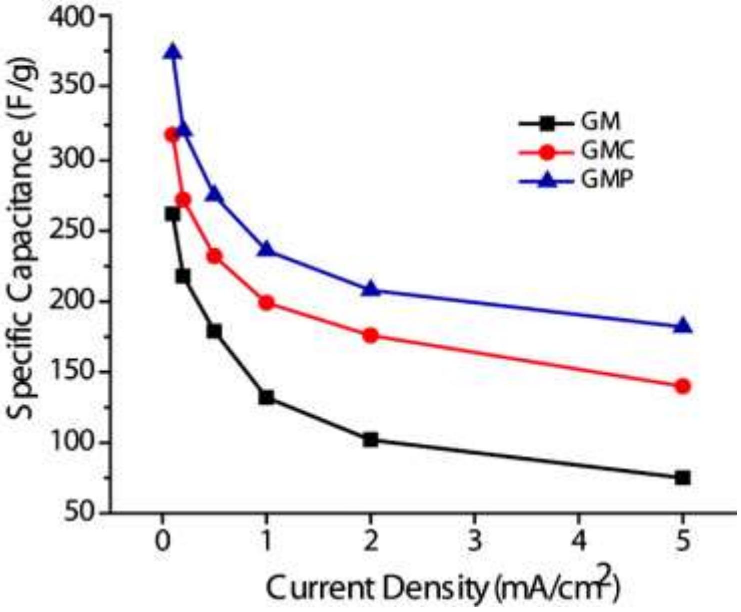
# $MnO_2$/Mn/$MnO_2$ Sandwich-Structured Nanotube Arrays



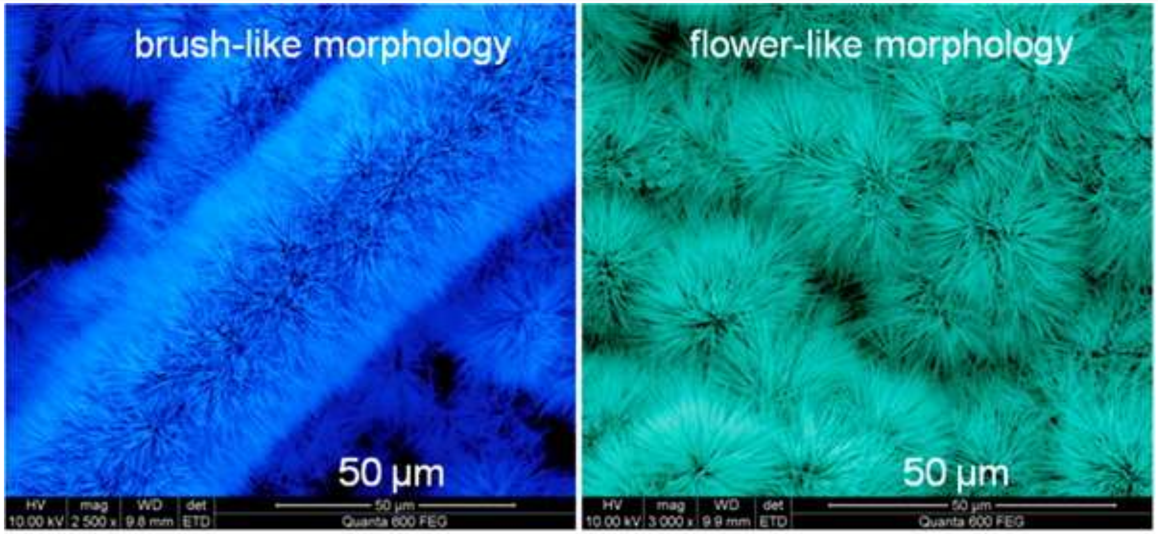


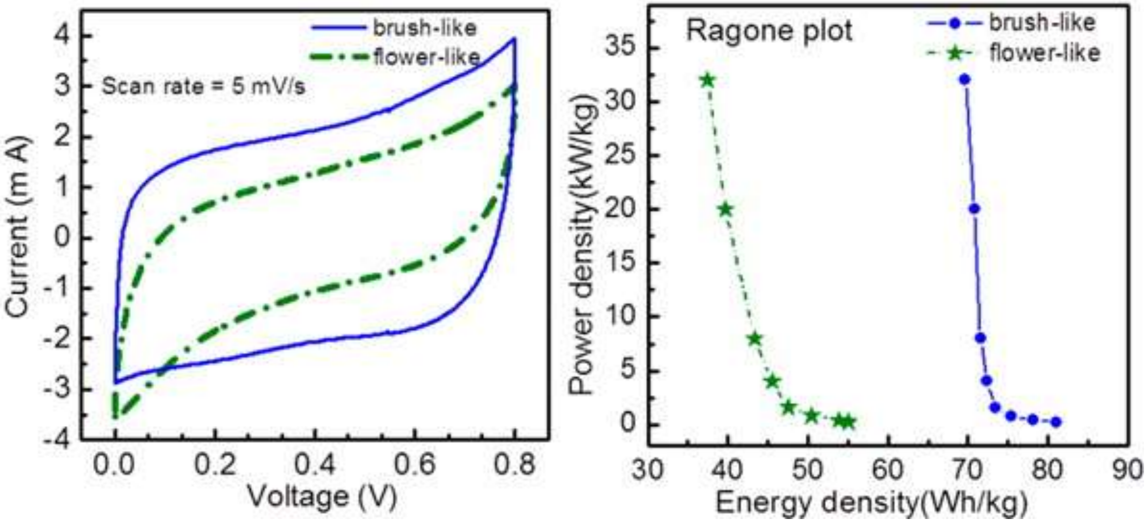
# Enhancing the Supercapacitor Performance of Nanostructured Electrodes by Conductive Wrapping



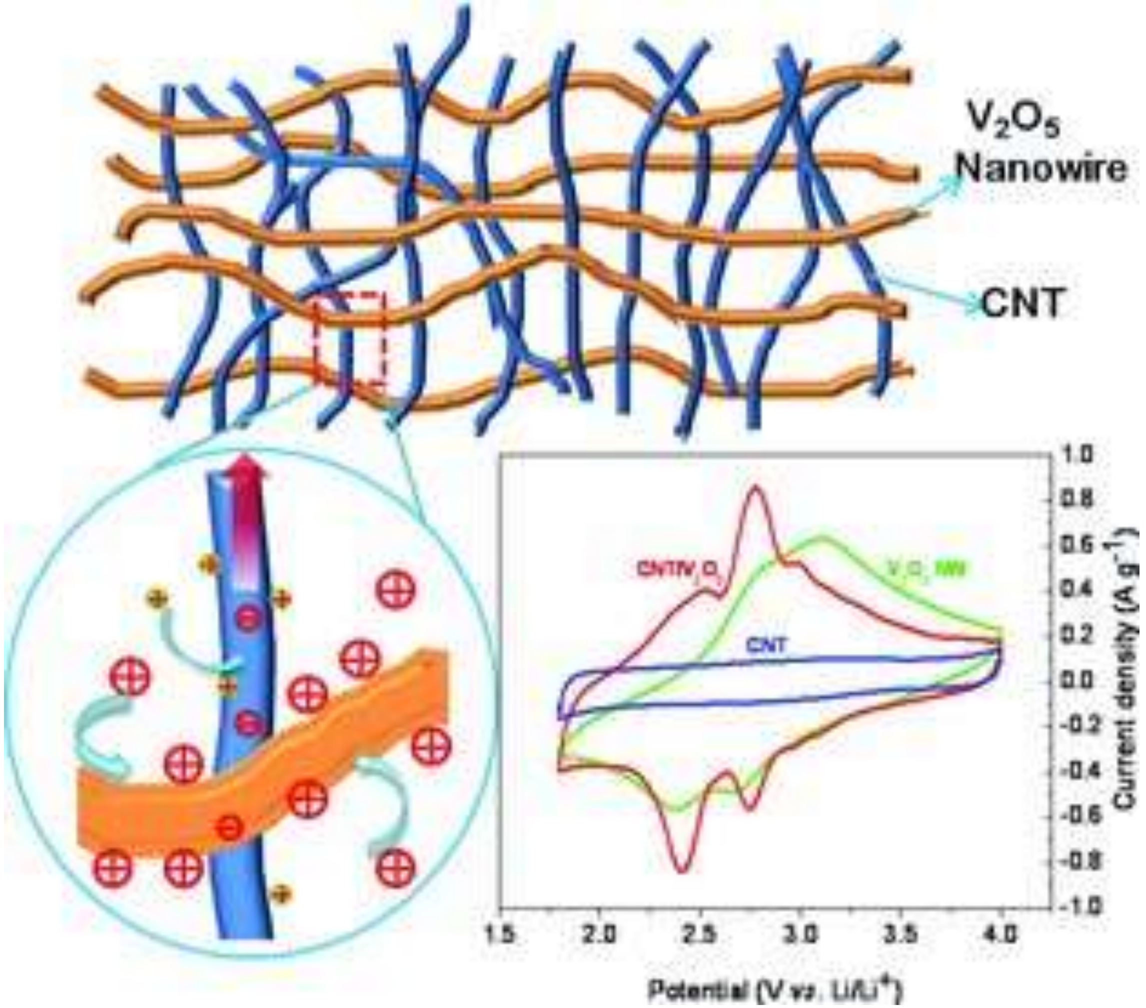


# Mesoporous Cobalt Oxide Nanowires

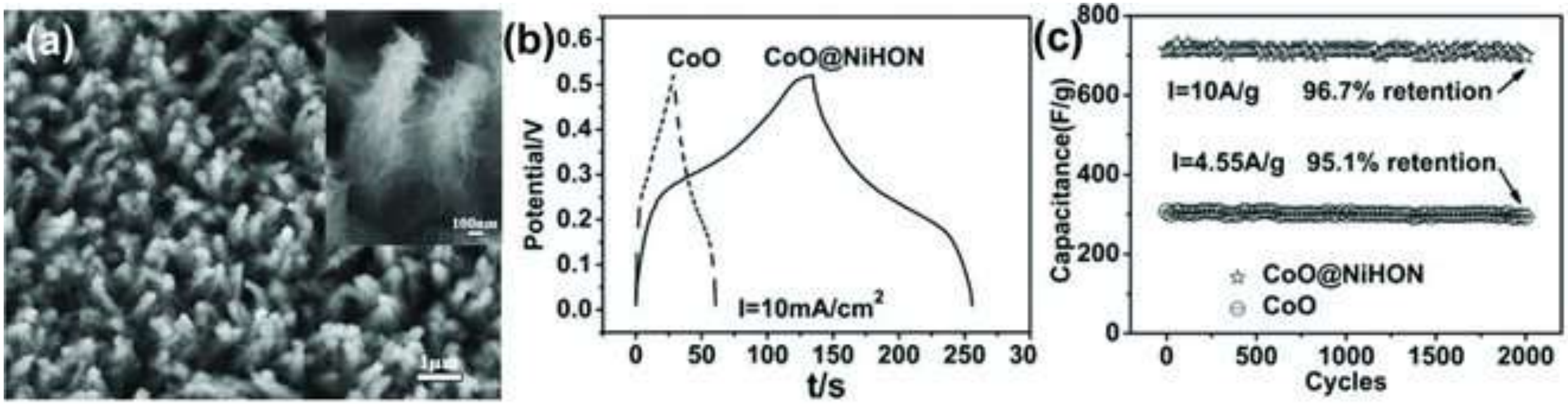


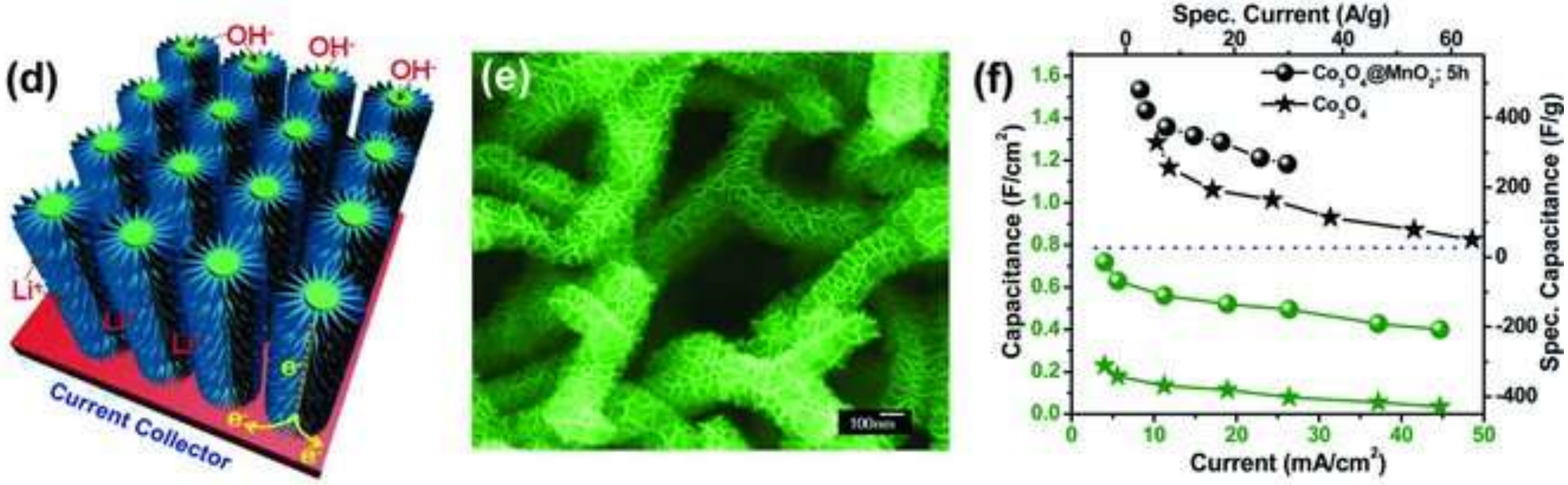


# Intertwined structures

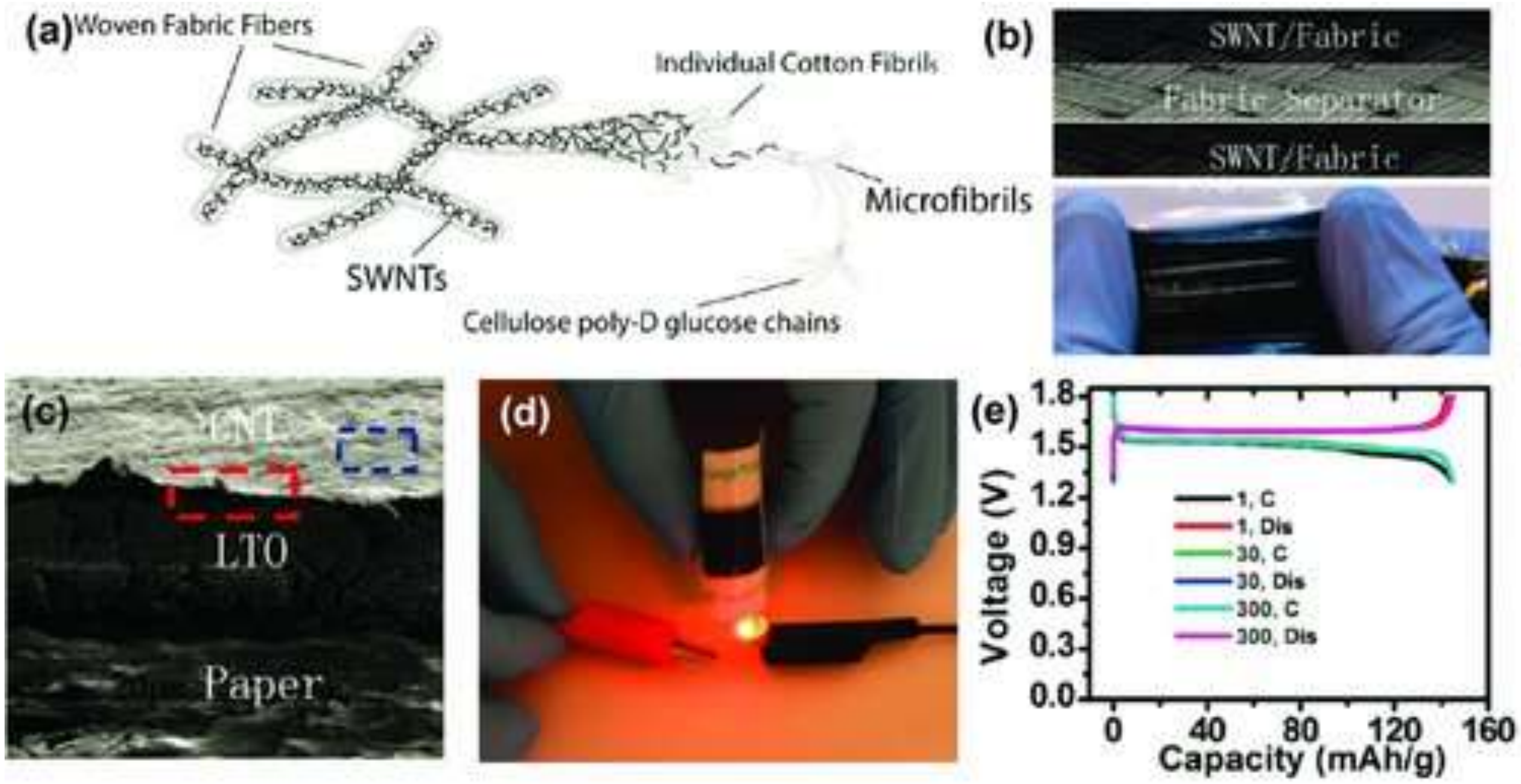


# Recent Advances in MO based Supercapacitors

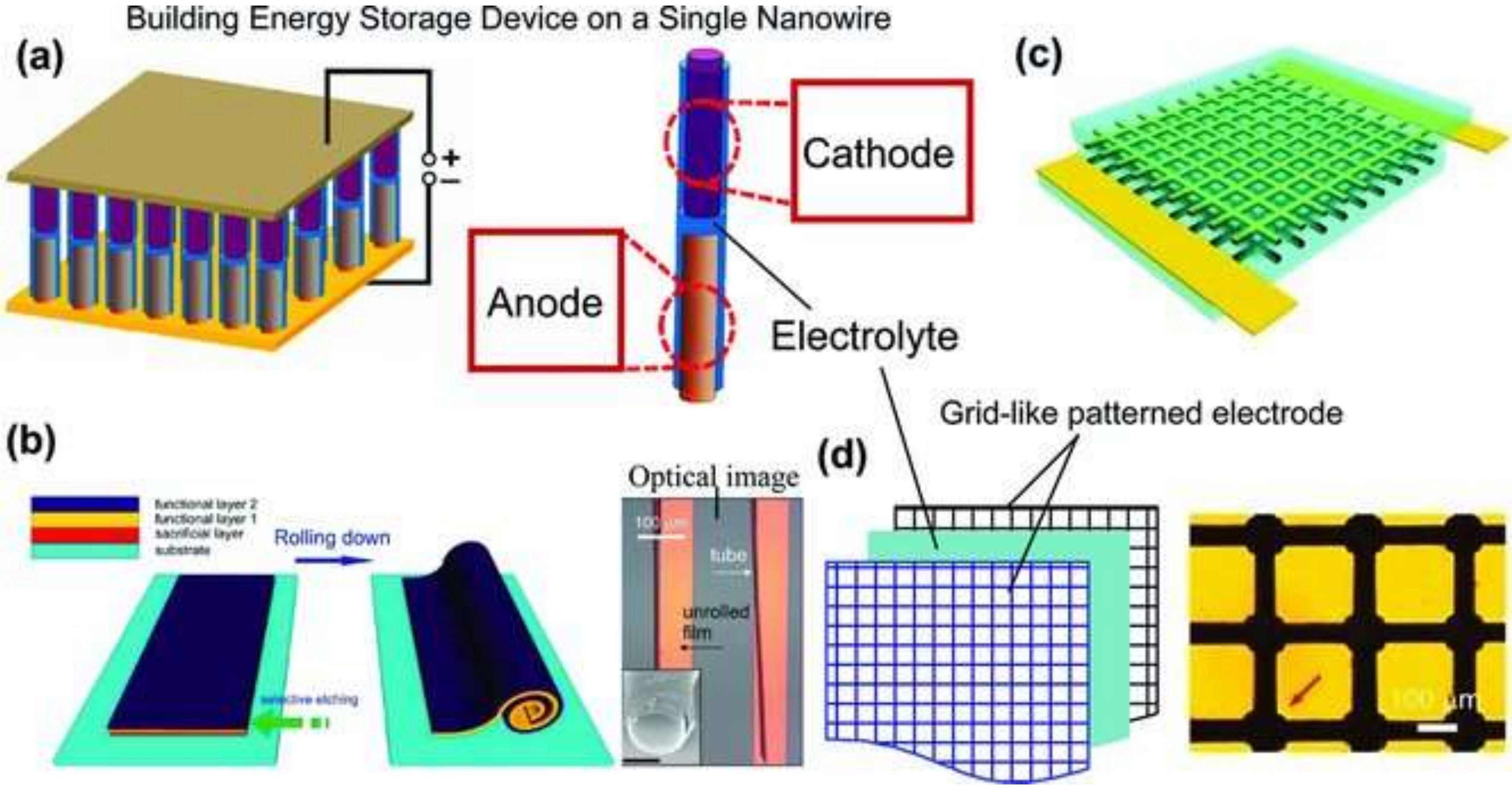




# Flexible paper/textile current collectors



# New design Architectures for Electrodes



# Conclusions

- The first direction is to integrate active/synergetic nanomaterials
- The second direction is to improve the overall electrical conductivity of metal oxide films/arrays to the largest extent by integrating with diverse conducting agents
- The third direction is the innovation in electrode structure design. For some future applications, good electrodes are expected to be lightweight, full of porosity, mechanically flexible but still robust enough to maintain the power supply.

Thanks for your attention !