NACK NETWORK

Building College-University Partnerships for Nanotechnology Workforce Development

Nanotechnology, Energy, and Energy Storage

Friday, April 10th, 2015

The webinar will begin at 1pm Eastern Time

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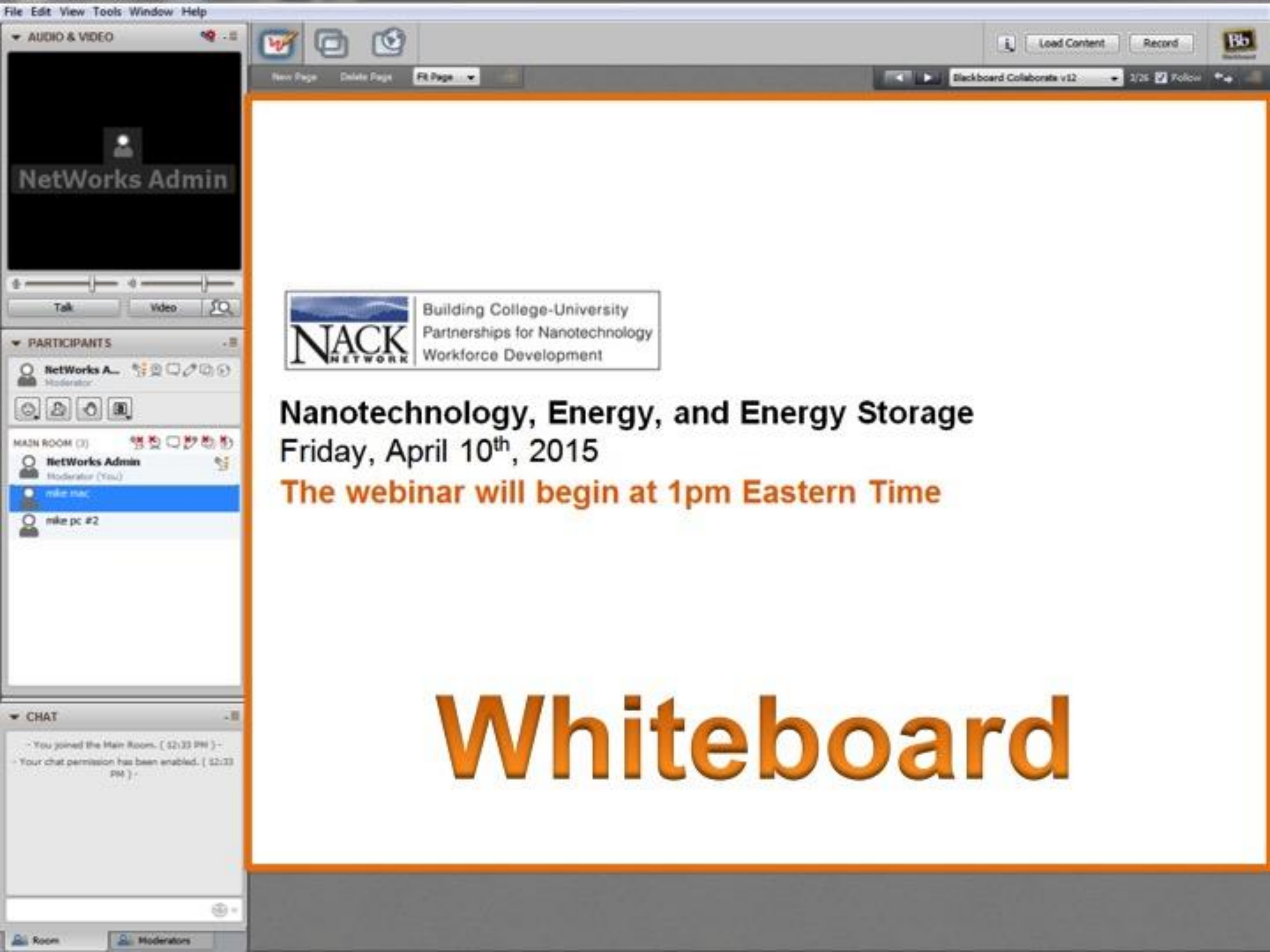
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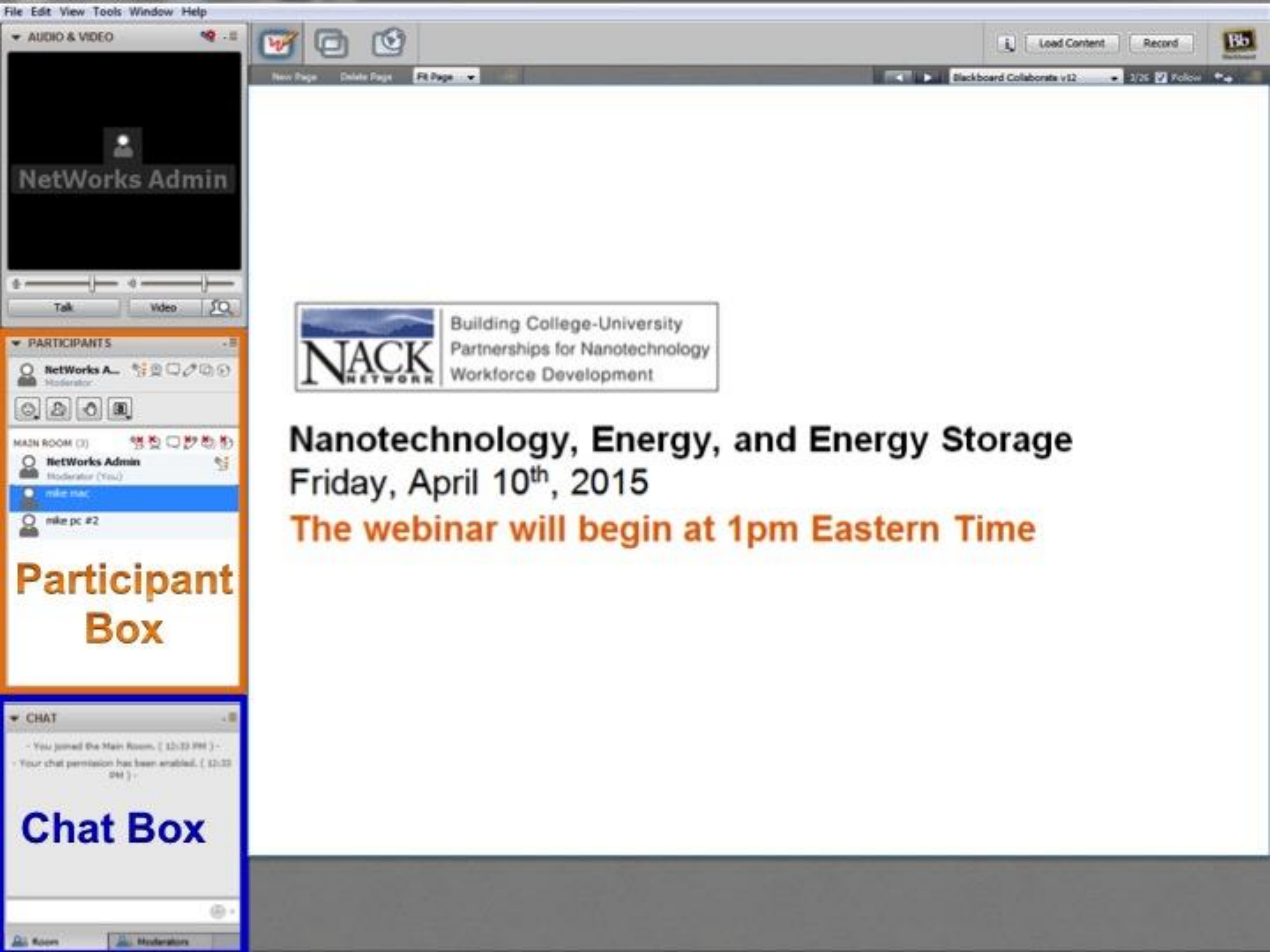
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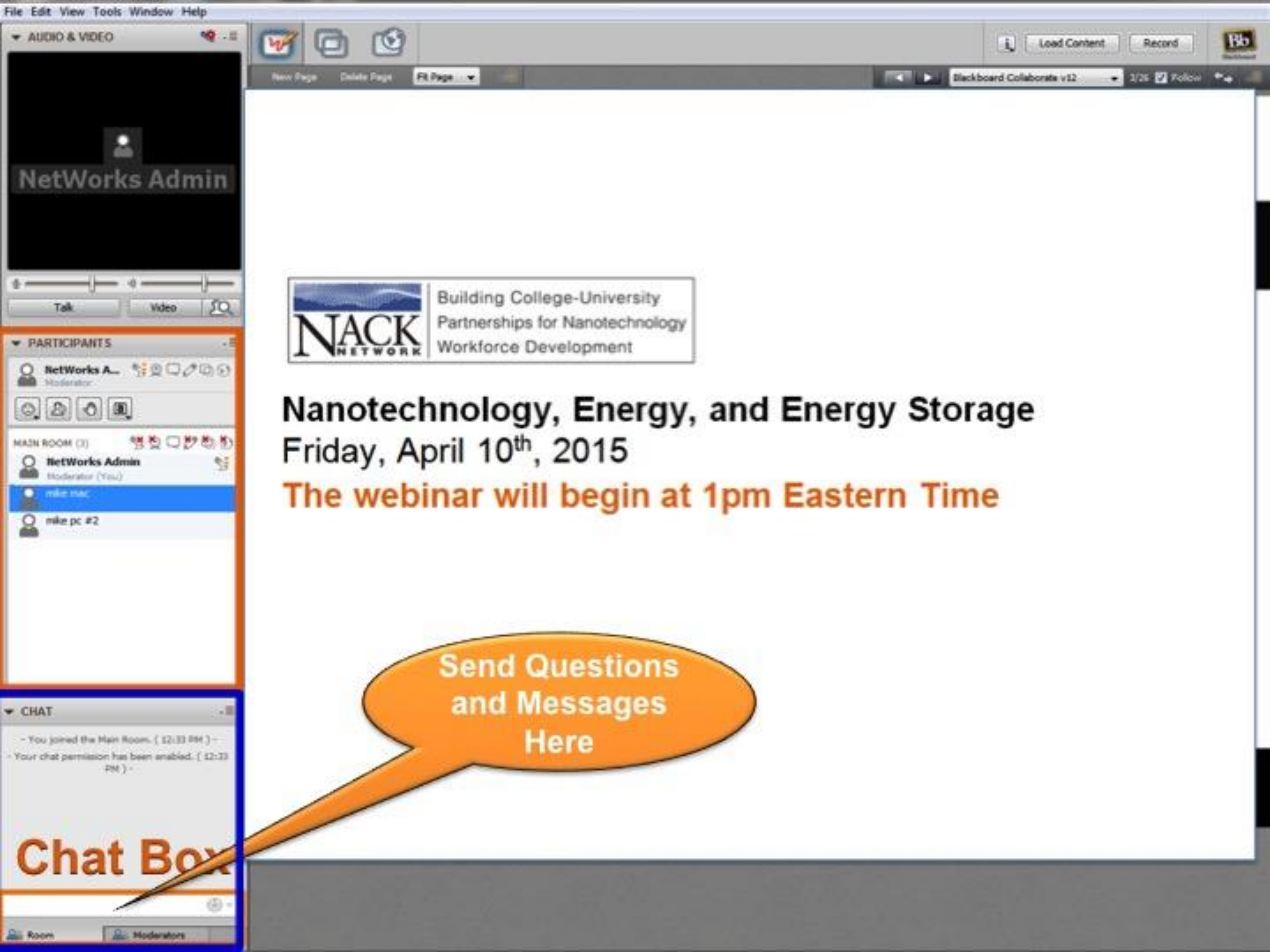
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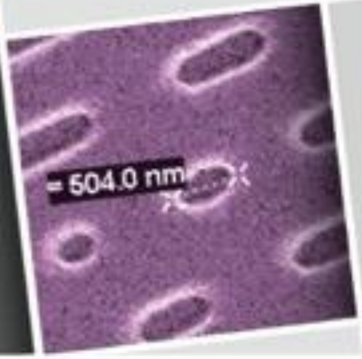

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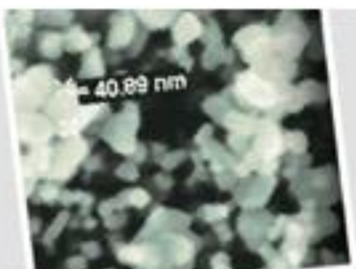

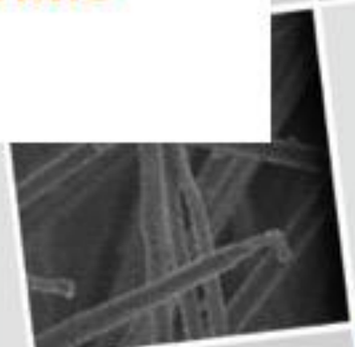

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The NACK Network, established at the Pennsylvania State College of Engineering, and funded in part by a grant from the National Science Foundation (DUE 1205105).

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Today's Presenter

Dr. Hongli Zhu

Dr. Zhu is currently a postdoctoral research associate at the Energy Research Center of University of Maryland. Her work focuses on the research of environmentally friendly green biomaterials, electronics, energy storage and energy harvesting, including: 1) sodium- / lithium- ion battery and super capacitor; 2) design and application of novel transparent nano-structured paper for flexible electronics including solar cells, transistor, touch screen, antenna, actuator, and organic LED et al; 3) Nanomanufacturing, device manufacturing, multifunctional paper and fiber manufacturing.

Moderator: **Mike Lesiecki, MATEC**

Host: Roxanna Montoya MATEC

Grid Scale *Energy* Storage for Sustainable Future

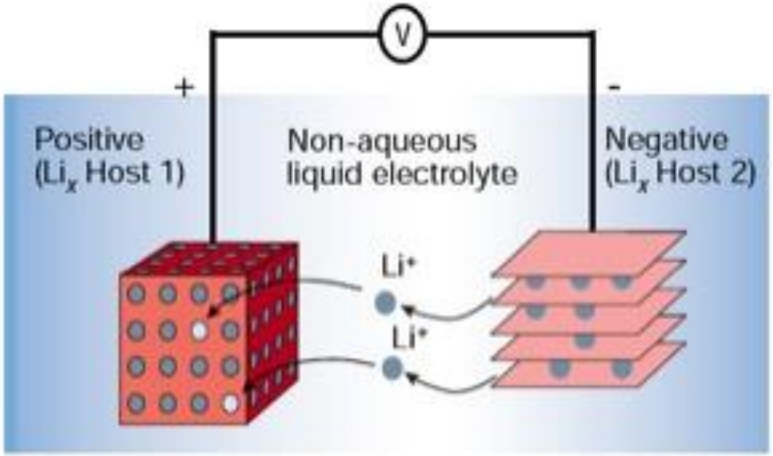
Production
- Wind
- Heat
- Solar …

Transmission
- Electrical grid

Usage
- Lighting
- Building
- Electric Vehicle …

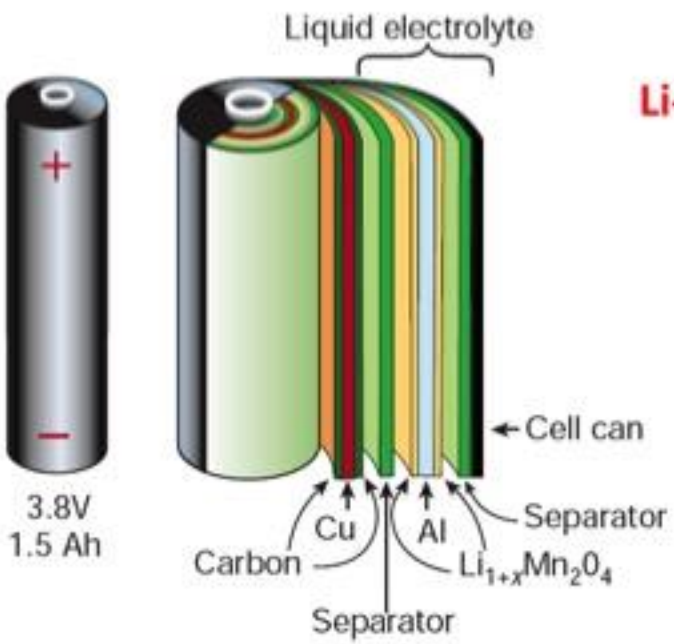
Large scale energy storage:
Low Cost!
Longer Cycling!

Common Structures



Supercapacitors
Ultracapacitor

Electrons ⇄ Ions

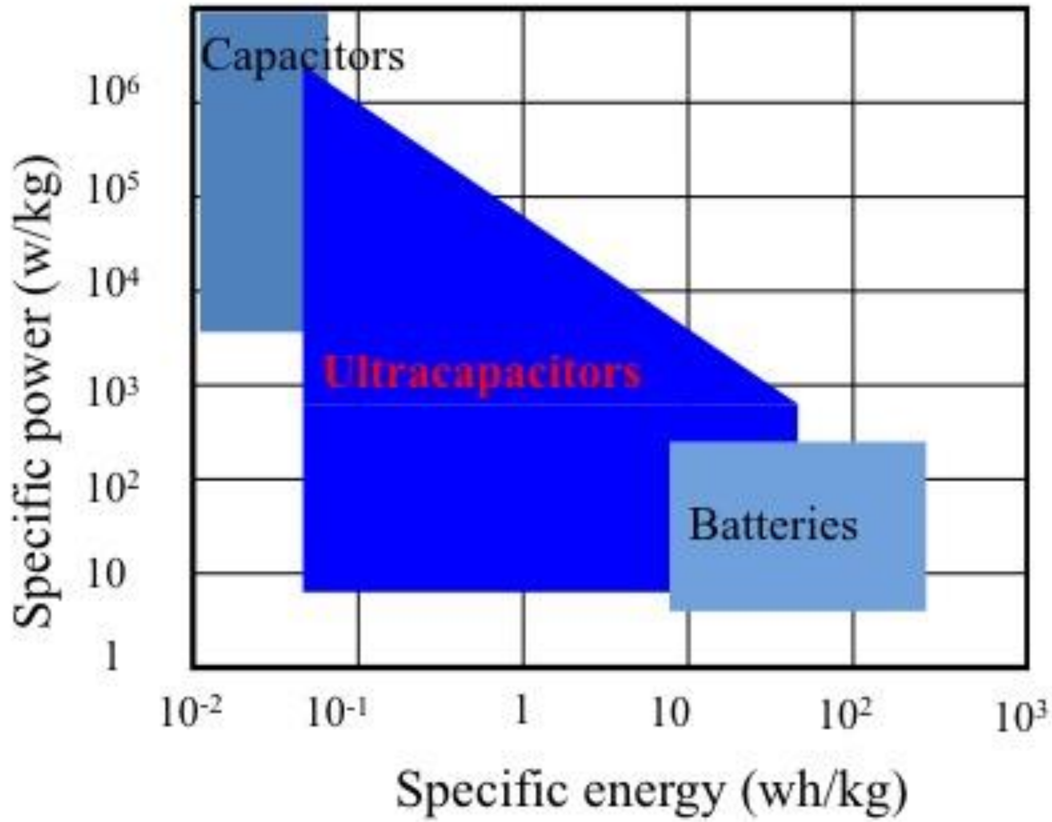


Li-ion Batteries

Terminology

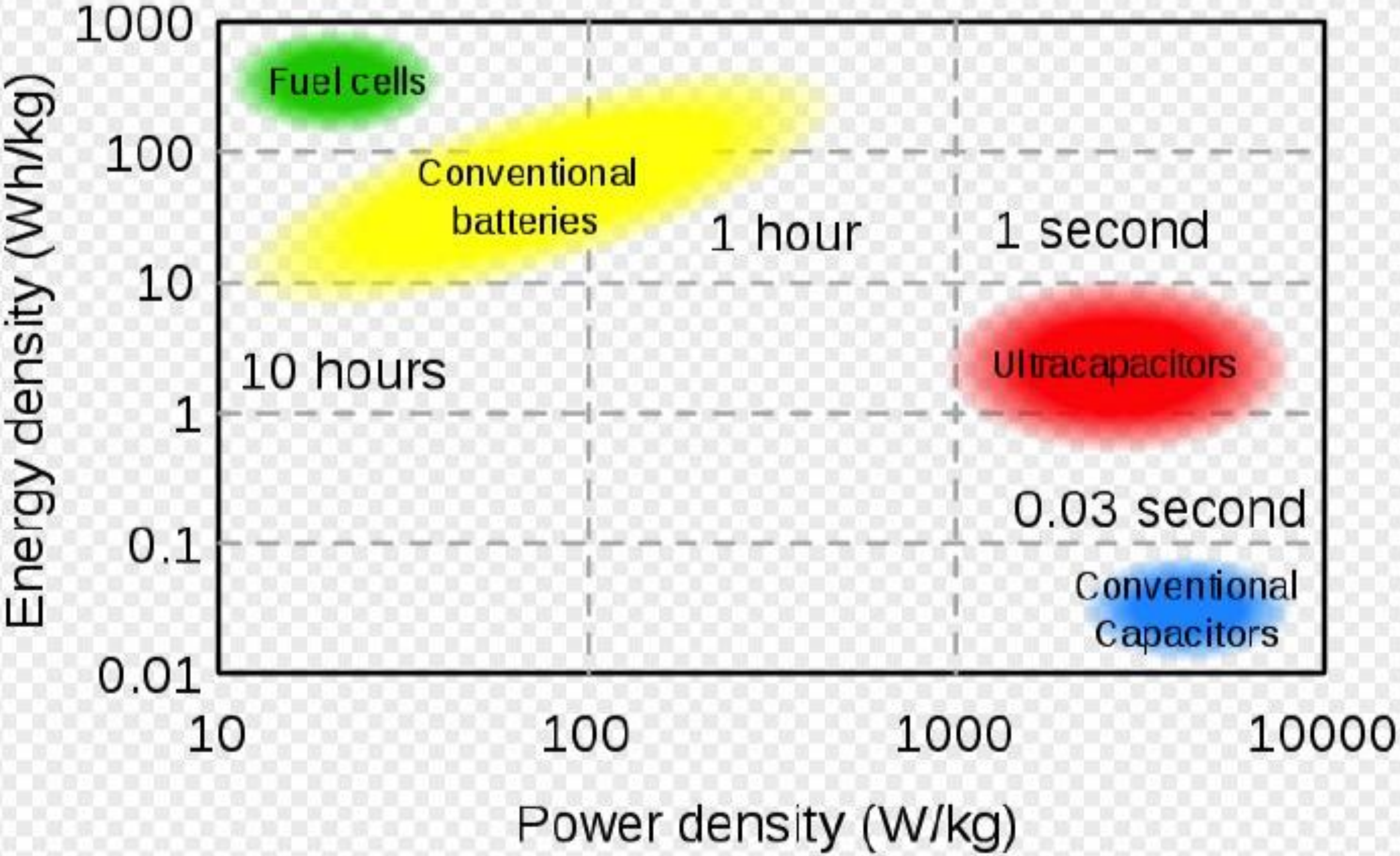
Current collector
Electrode materials
Separator
Electrolyte
Conductive addtive
Polymer binder

Comparison in Energy and Power Density



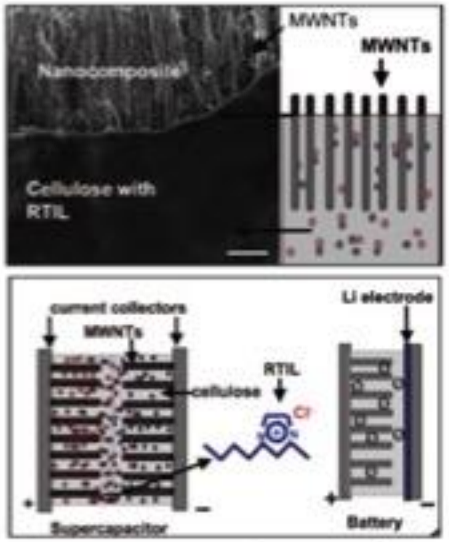
Battery: bulk storage

Ultracapacitor: surface storage
(high power, long cycling)



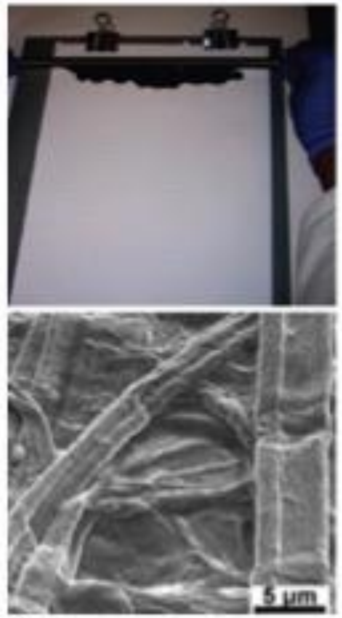
1000
100
10
1
0.1
0.01
Energy density (Wh/kg)
Fuel cells
Conventional batteries
1 hour
1 second
10 hours
Ultracapacitors
0.03 second
Conventional Capacitors
10
100
1000
10000
Power density (W/kg)

Previous Paper Energy Devices

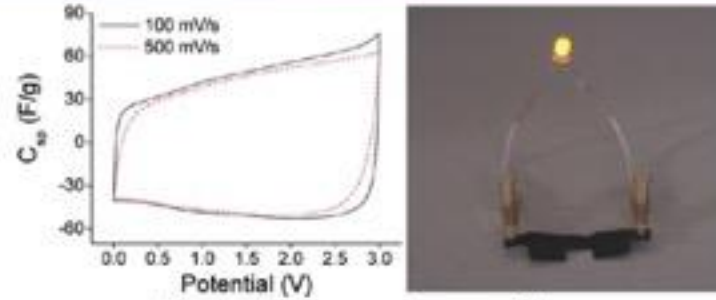


Paper Supercapacitor

Ajayan et al. *PNAS* , 2007



Hu et al. *PNAS* . 2009

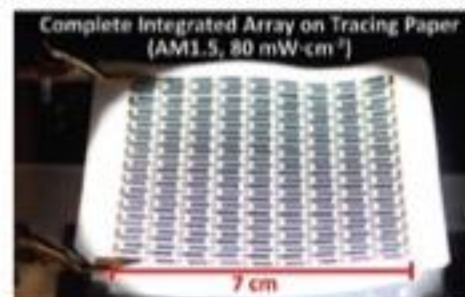


Paper Supercapacitor

Kim et al. ACS Nano 2012

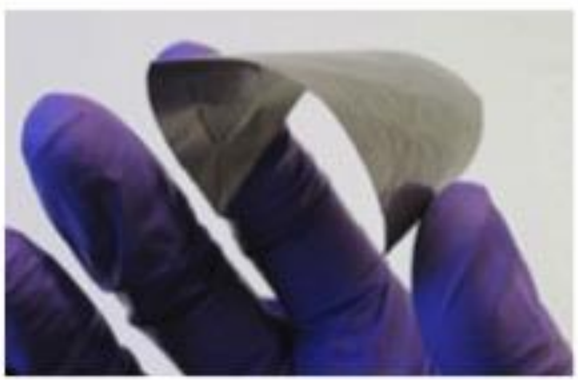
Battery Separator

Kim et al. J. Mater Chem. 2012



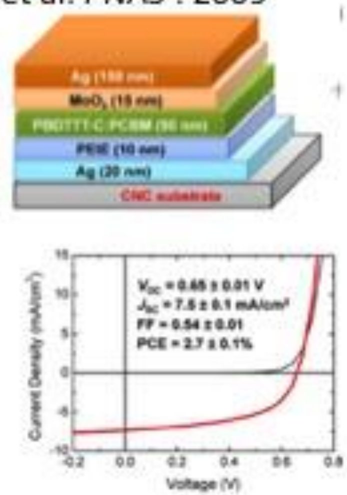
Paper Solar Cells

Bulovic, Gleason et al. Adv Mater. 2011



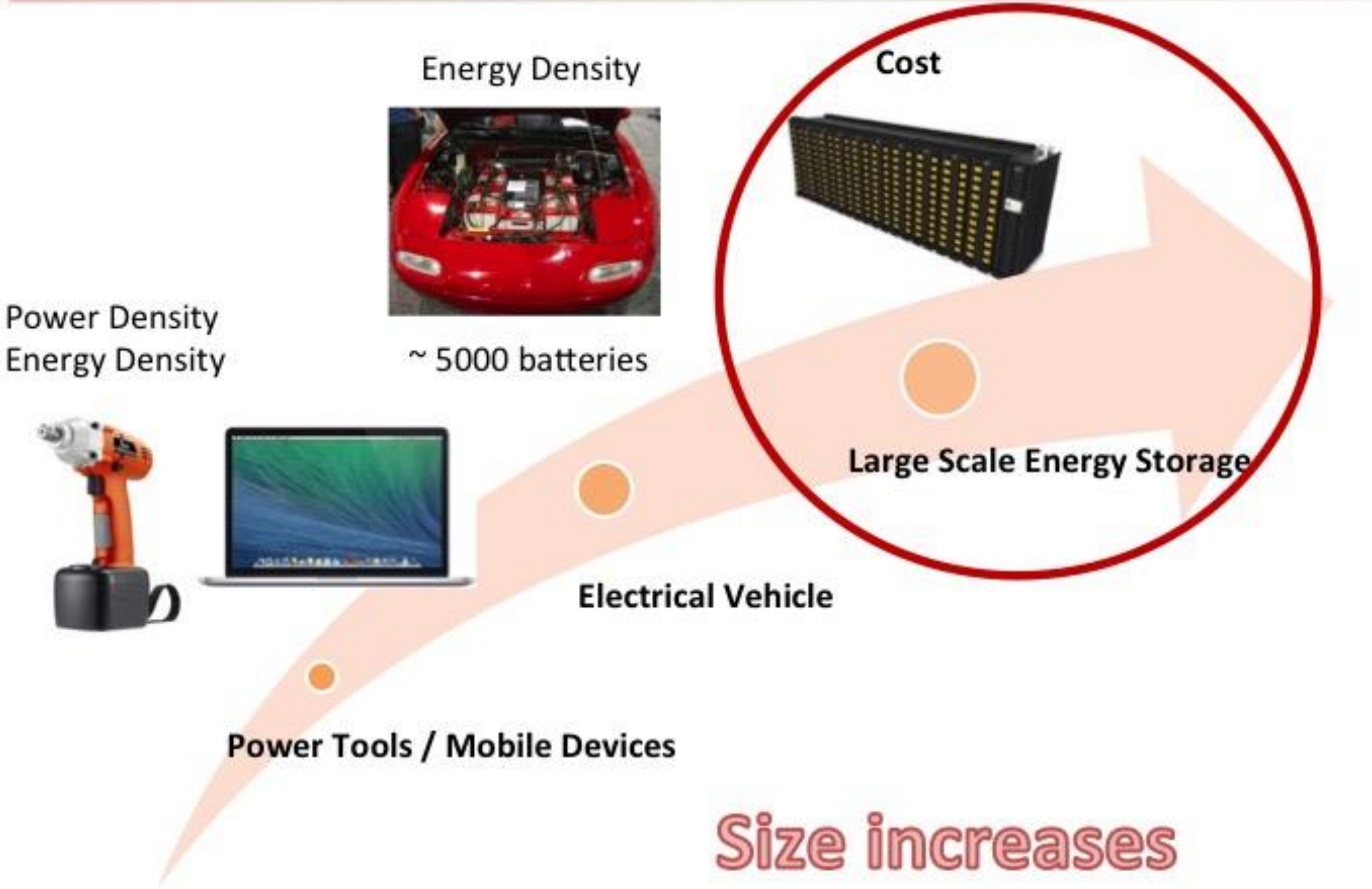
http://www.paperbatteryco.com/

Paper Battery



Kippelen et al. , Scientific Report, 2013

Batteries: Opportunities and Challenges



Na Ion and Na Ion Batteries (Why & What)

Table 1 The comparison between Na and Li elements[9–12]

	Na	Li
Cation radius	97 pm	68 pm
Atomic weight	23 g mol^{-1}	6.9 g mol^{-1}
E_0 *vs.* SHE	−2.7 V	−3.04 V
A–O coordination	Octahedral or prismatic	Octahedral or tetrahedral
Melting point	97.7 °C	180.5 °C
Abundance	23.6×10^3 mg kg^{-1}	20 mg kg^{-1}
Distribution	Everywhere	70% in South America
Price, carbonates	~2 RMB per kg	~40 RMB per kg

R: 97pm
W: 23 g/mol

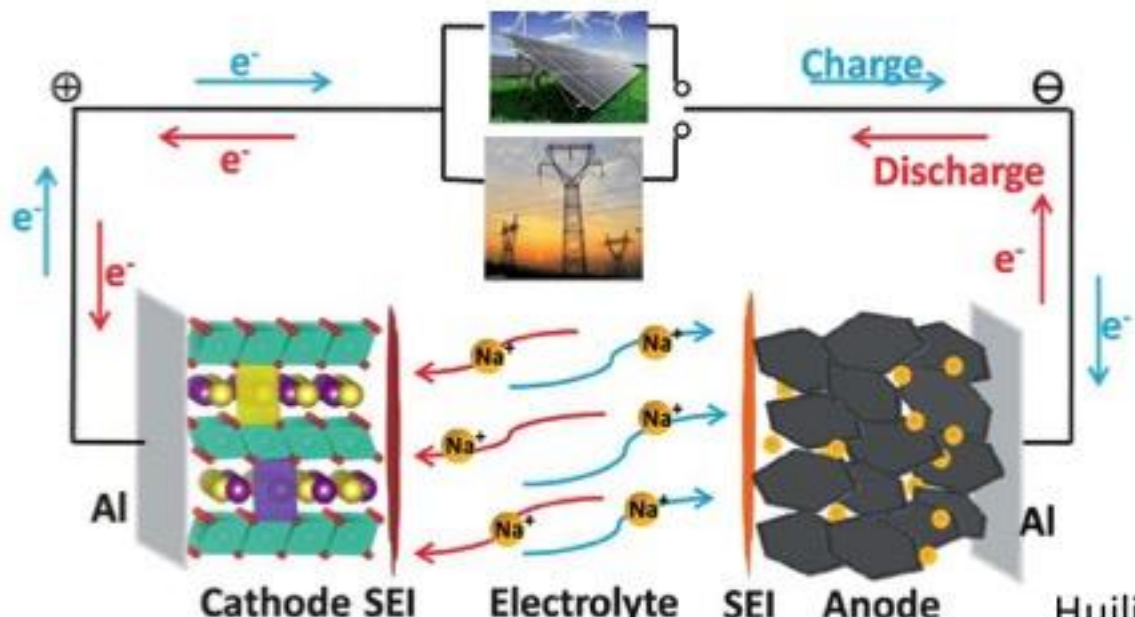
R: 68pm
W: 6.9 g/mol

- **Volume Expansion**

➡ **Stress release**

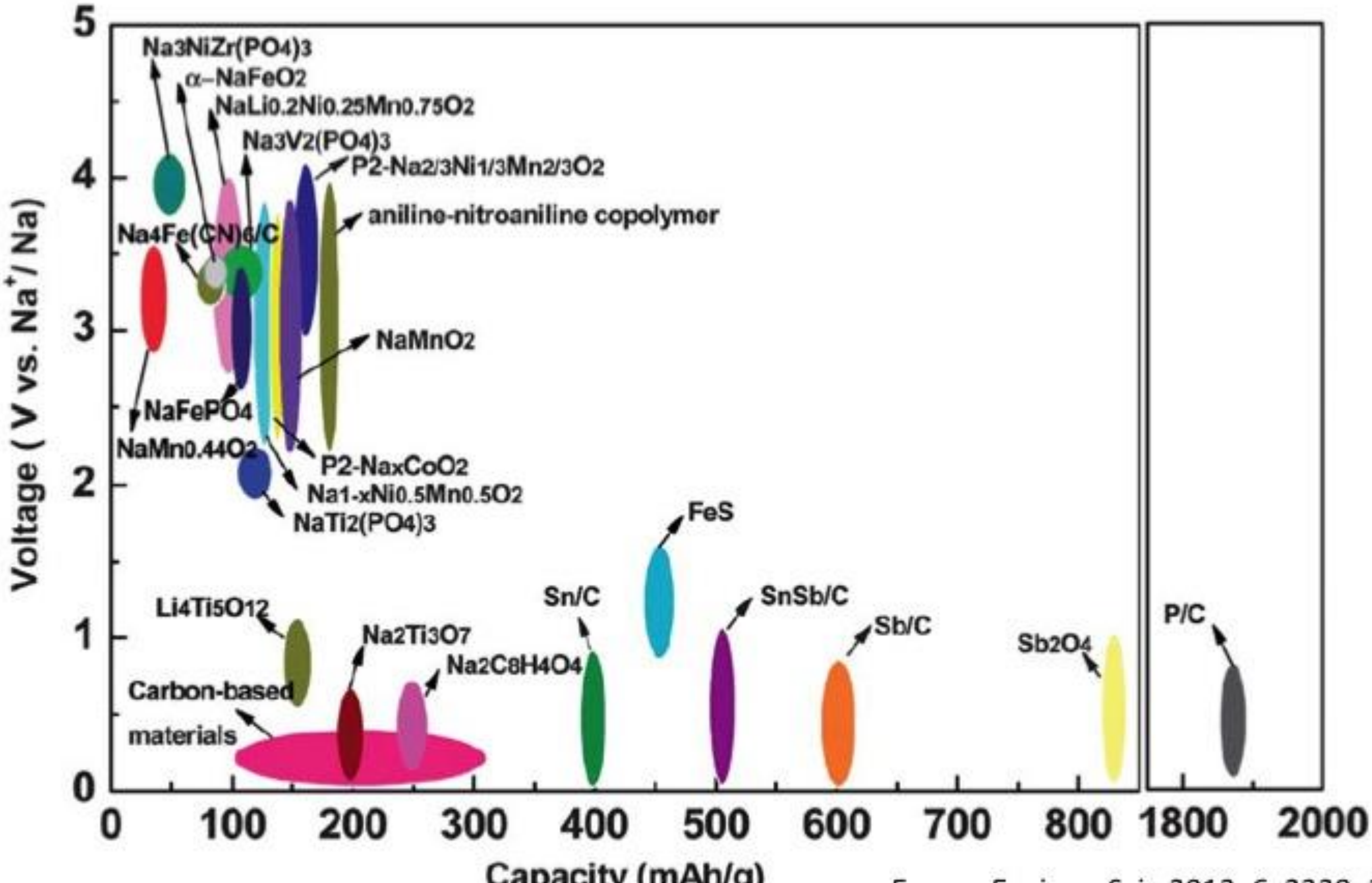
- **Slow Ion Diffusion**

➡ **Diffusion channel**



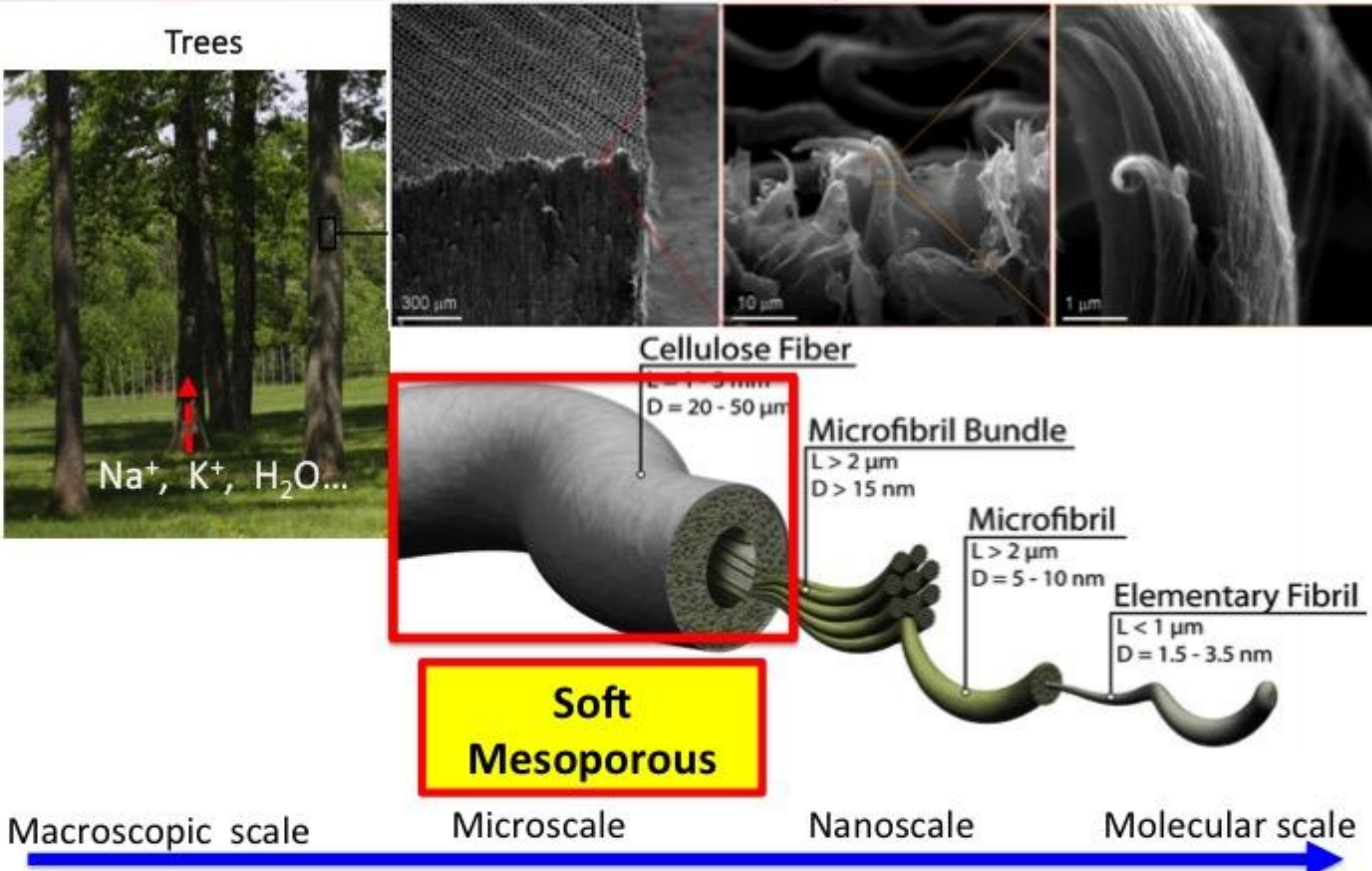
Huilin Pan et al.Energy Environ. Sci., 2013.

Current Development for Cathode and Anode



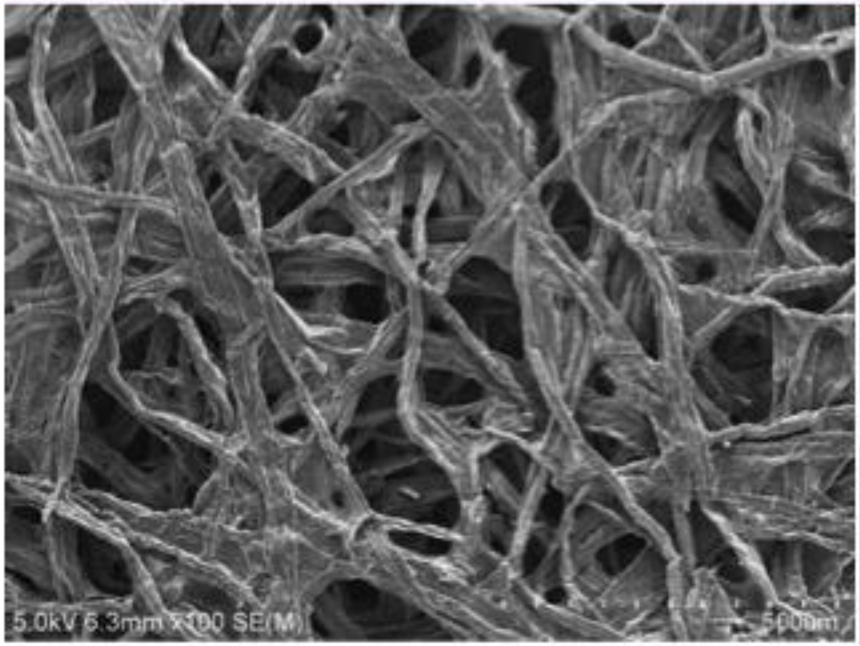
Energy Environ. Sci., 2013, 6, 2338–2360

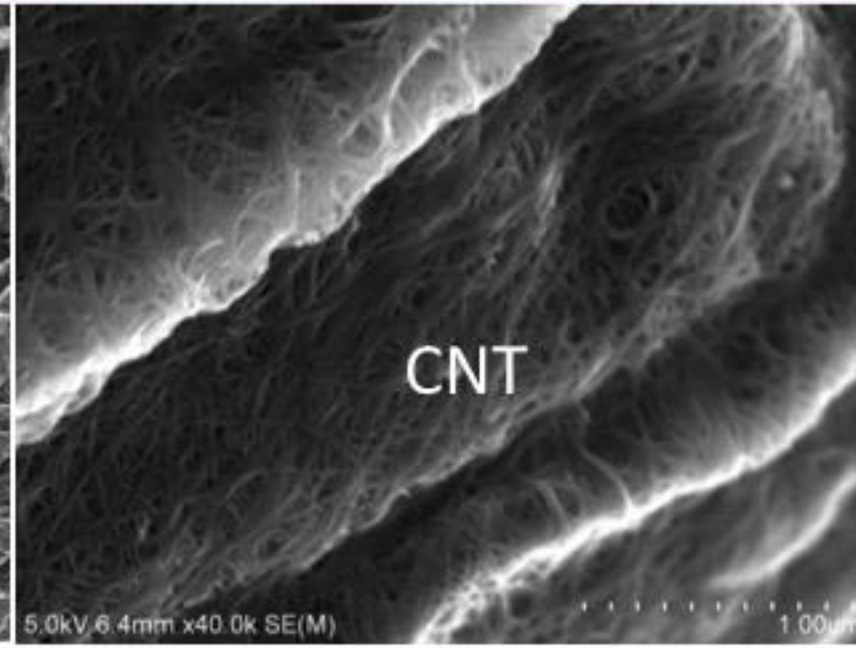
Nature-Made Hierarchical Structure

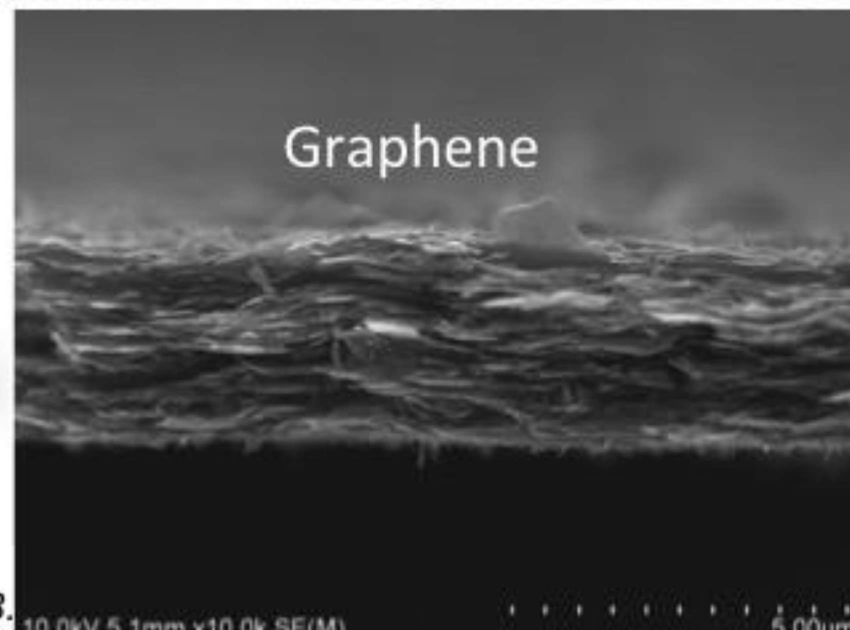


q *Zhu, H. et al.* ***Nano Letters***, *2013, 13 (7).*

Conductive Wood Fibers as Current Collectors



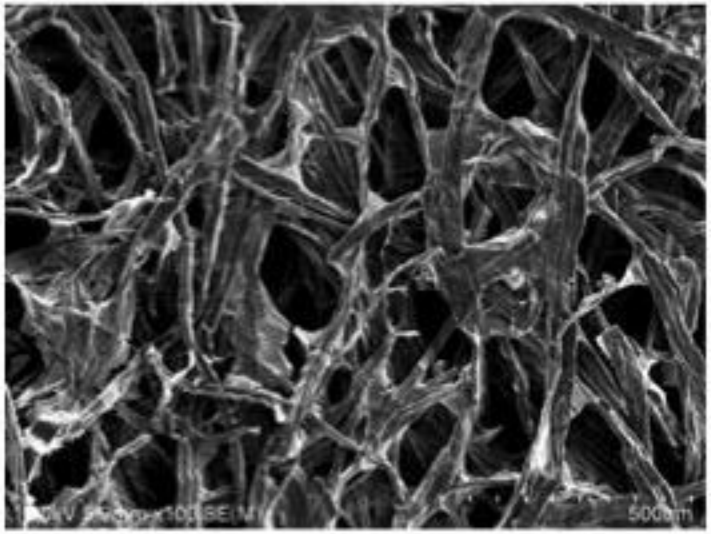


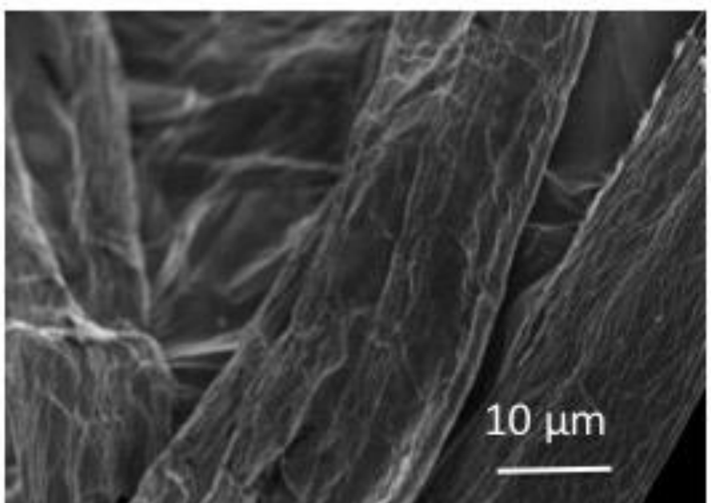


- *X. Han, Y. Chen, H. Zhu., et al.* ***Nanotechnology****, 2013.*

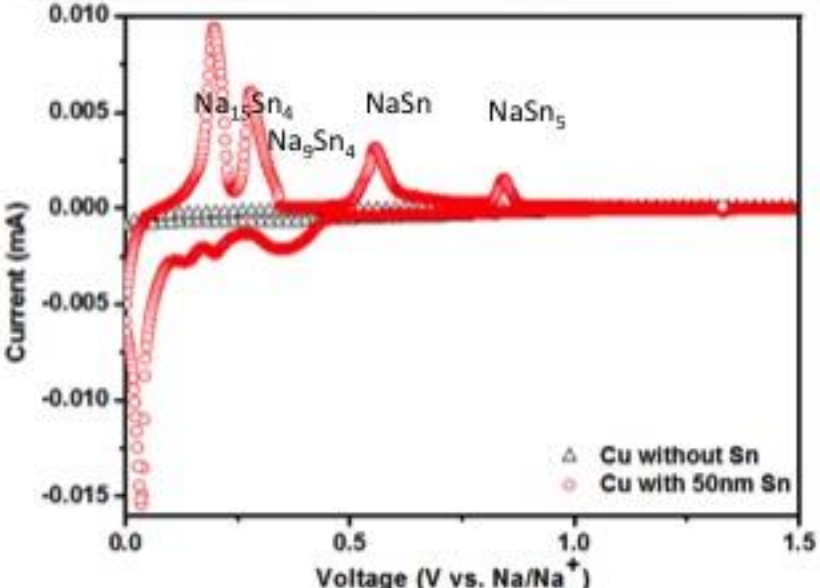
Sn Anode Preparation

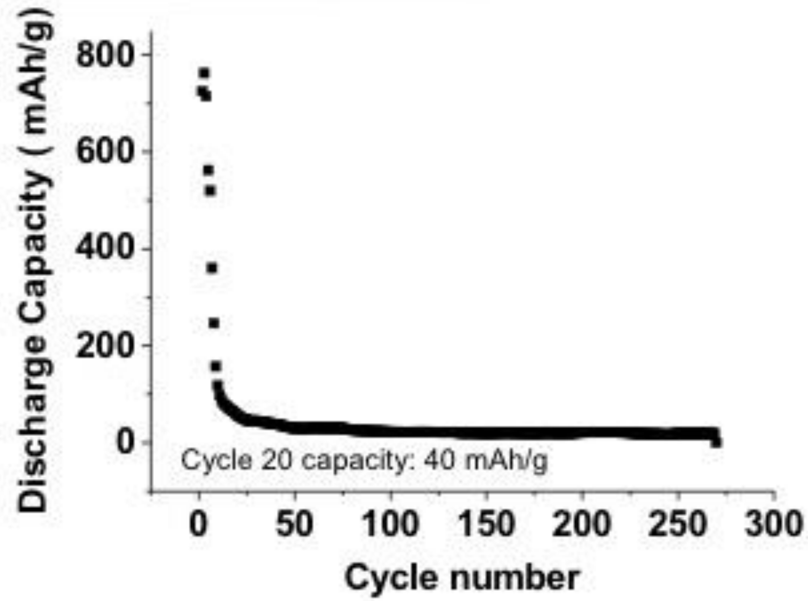
- Electrodeposition (Scalable)



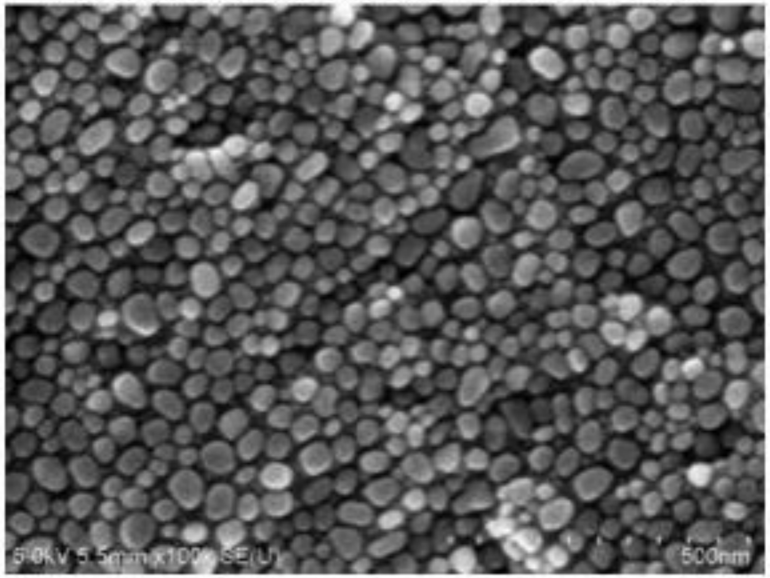


Control Experiment: Stiff Copper Foil as Substrate

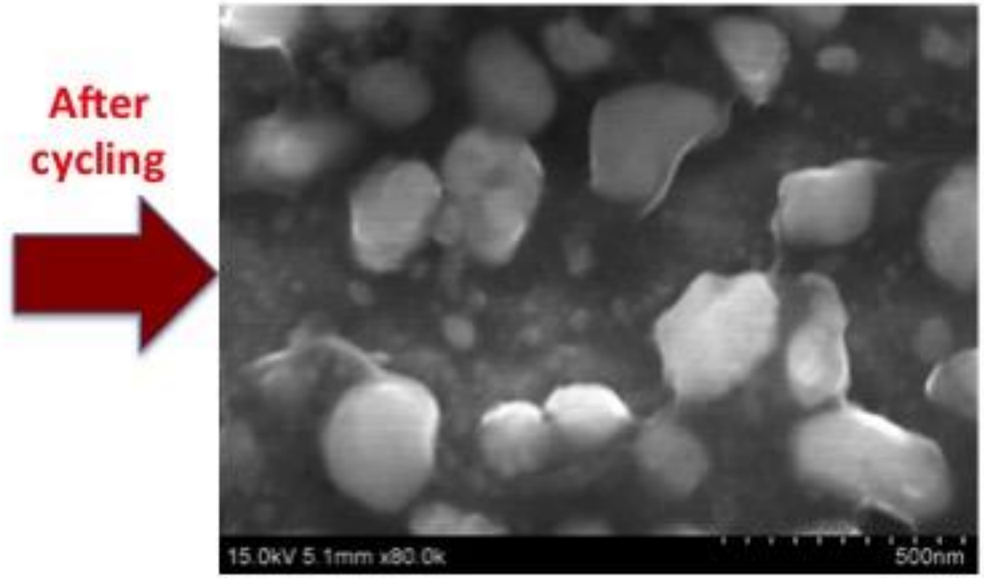




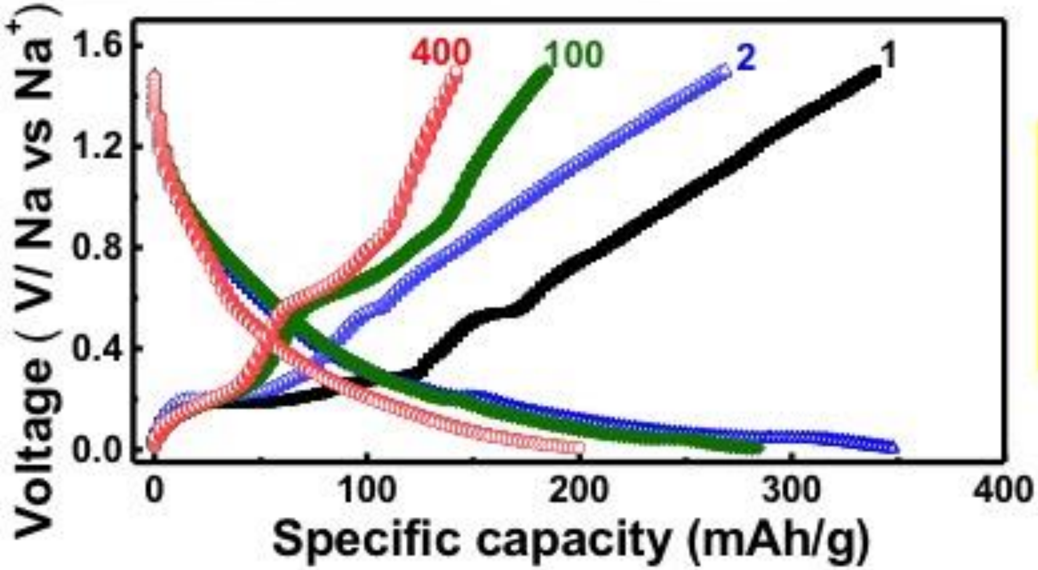
Electrolyte 1 M NaPF6 in EC:DEC, Rate C/10



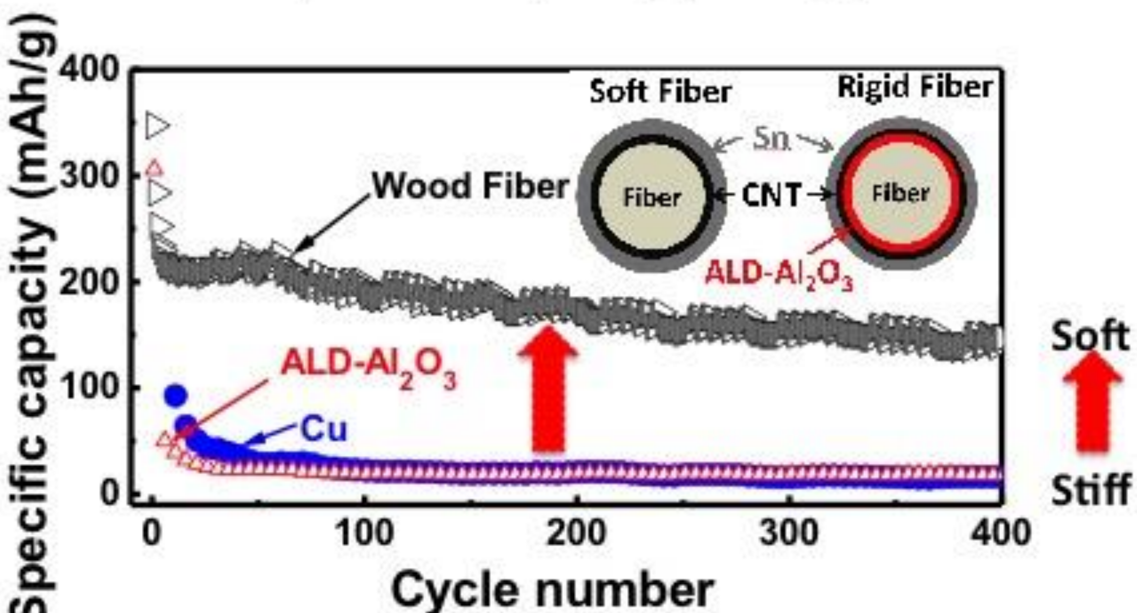
After cycling



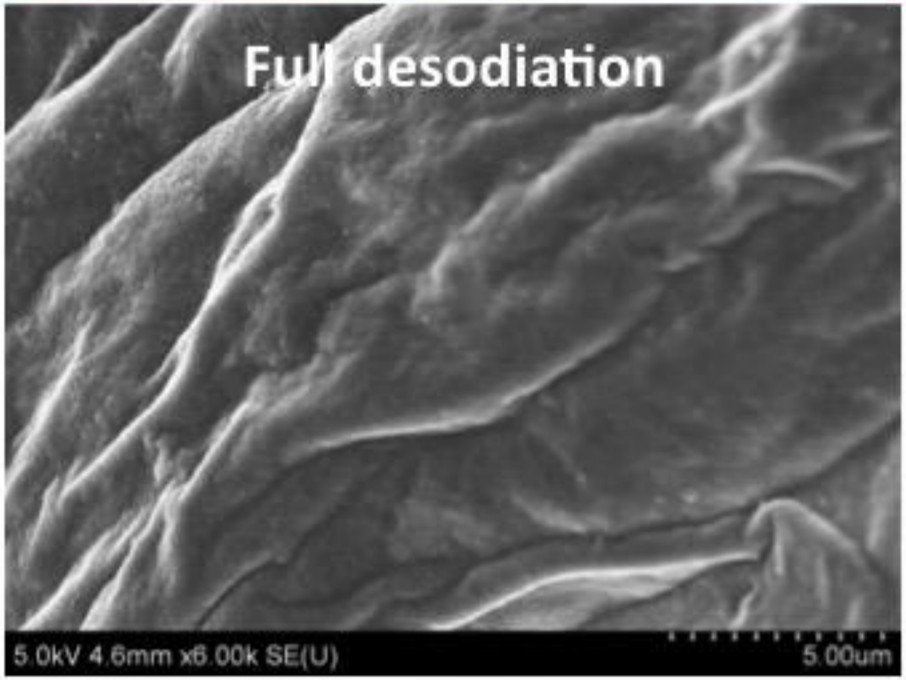
Compared with Stiff Cu Thin Film and Rigid Fiber

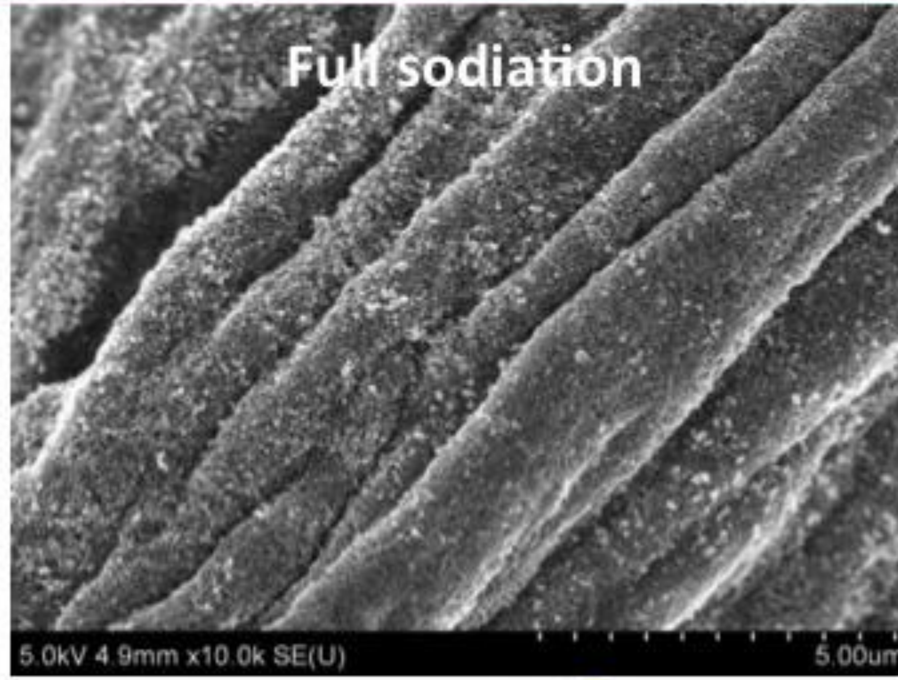


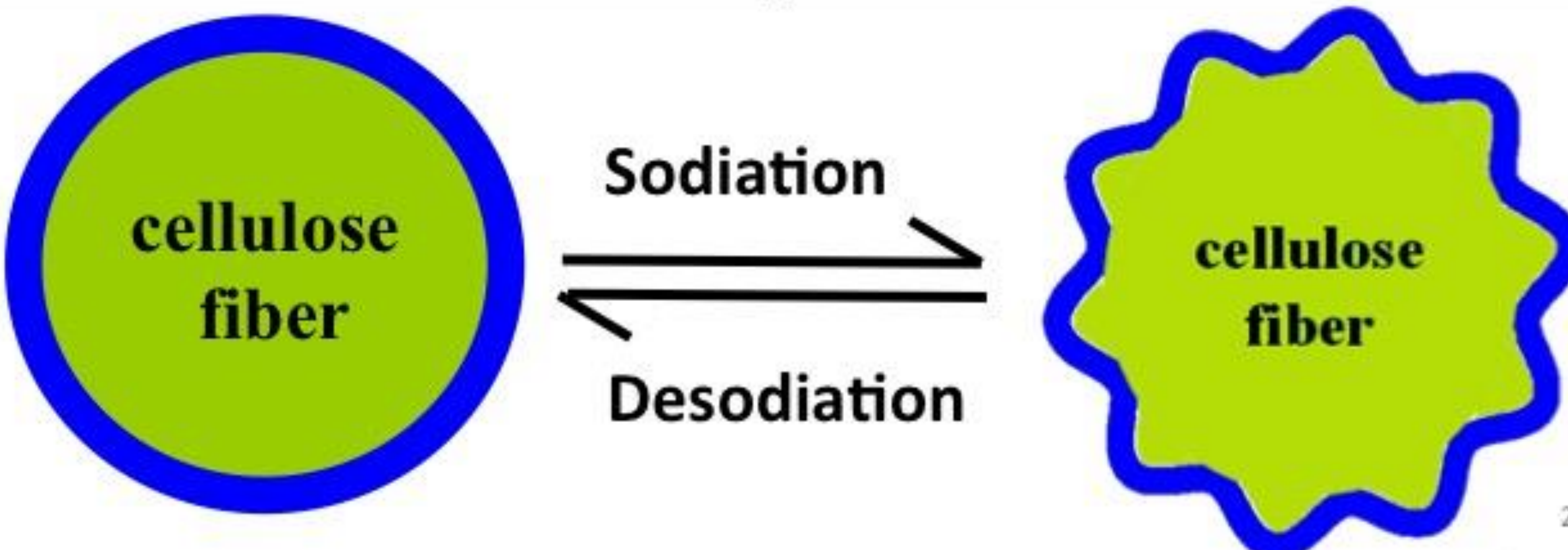
Stable electrode,
Stable cycling,
Longer cycling life.



Wrinkling to Release Mechanical Stress

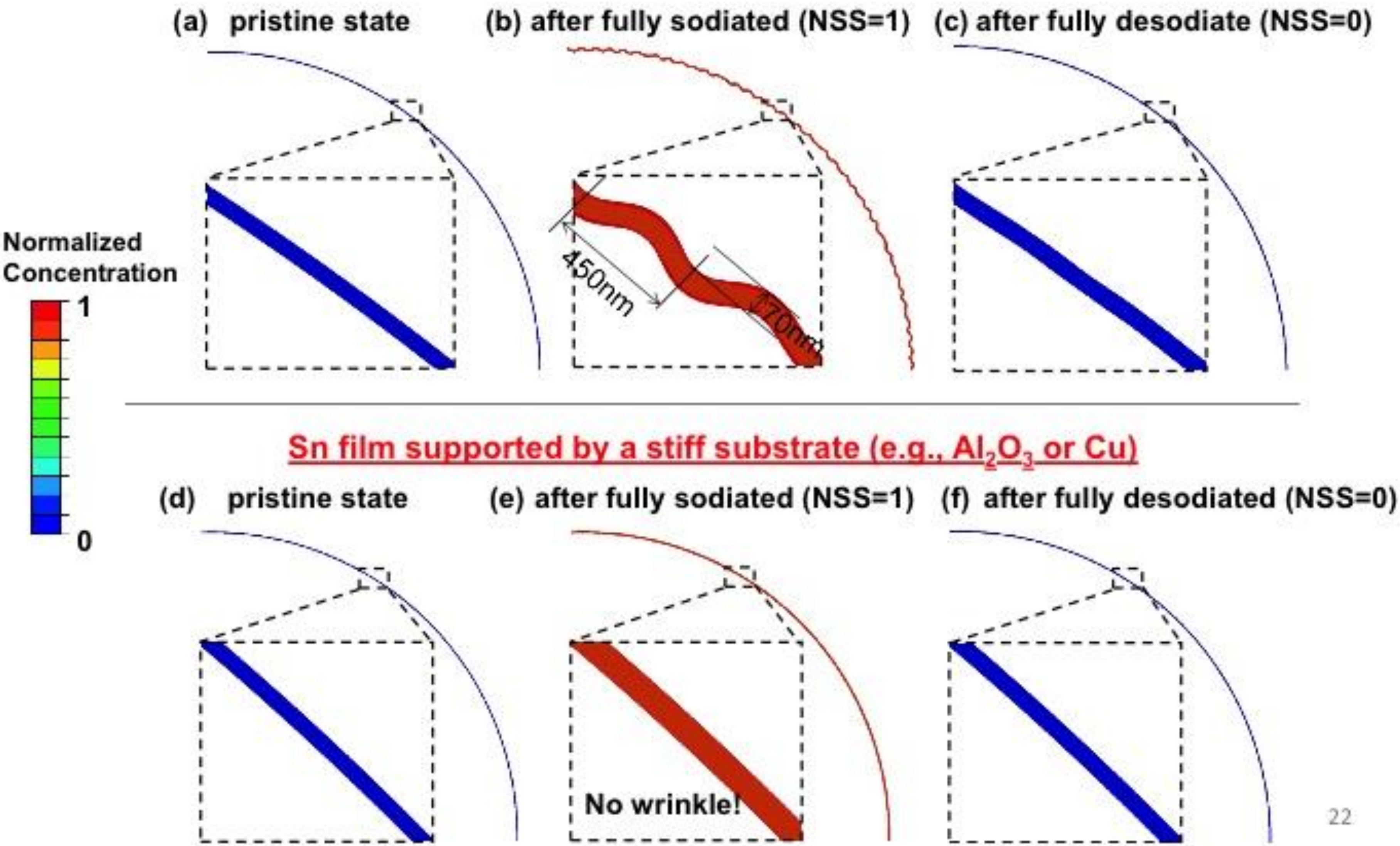




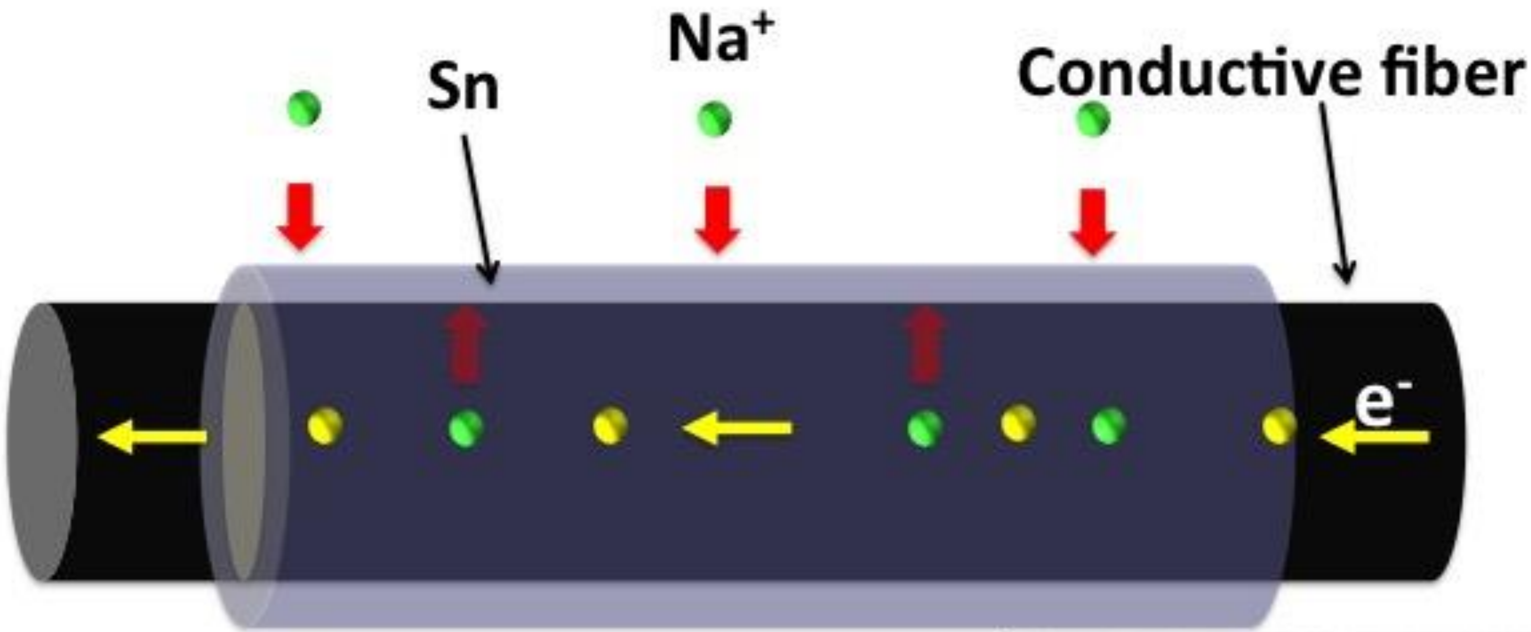


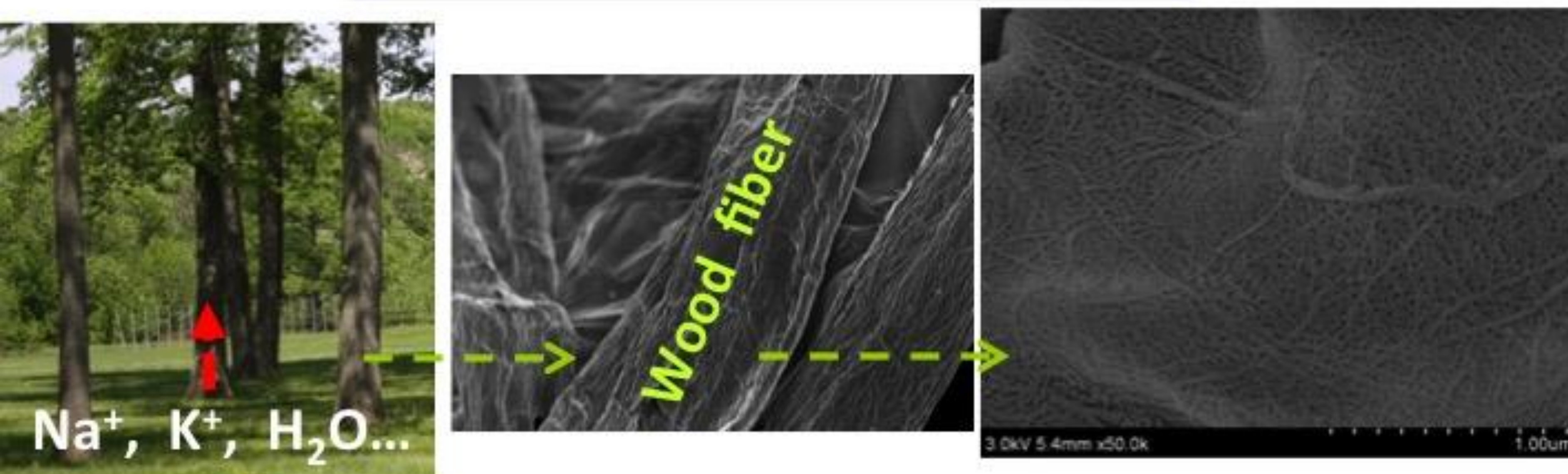
Wrinkling to Release Mechanical Stress

Sn film supported by a cellulose fiber

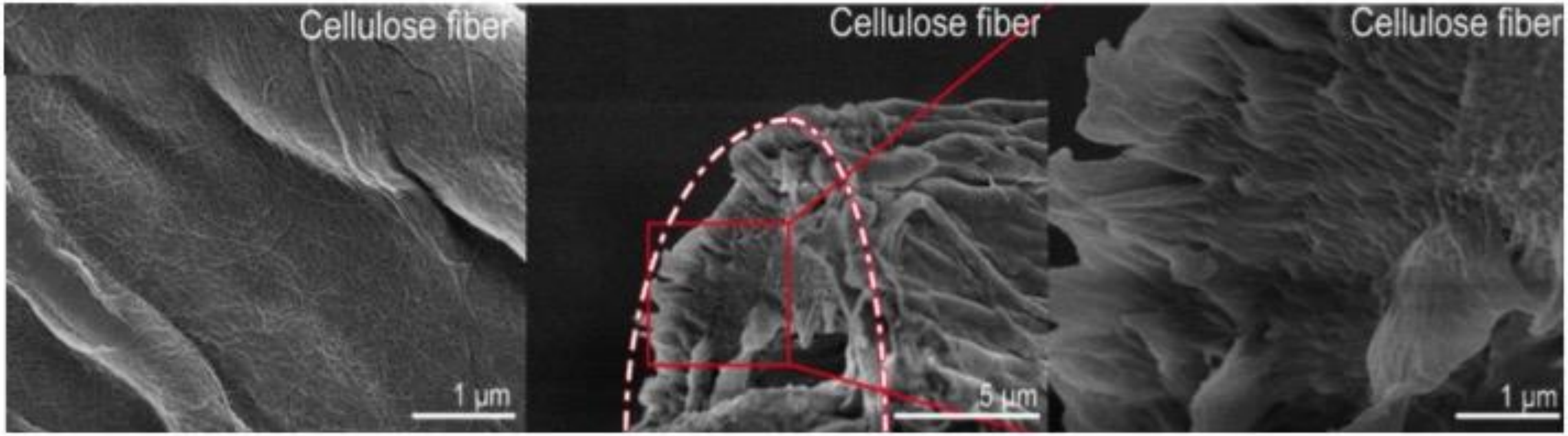


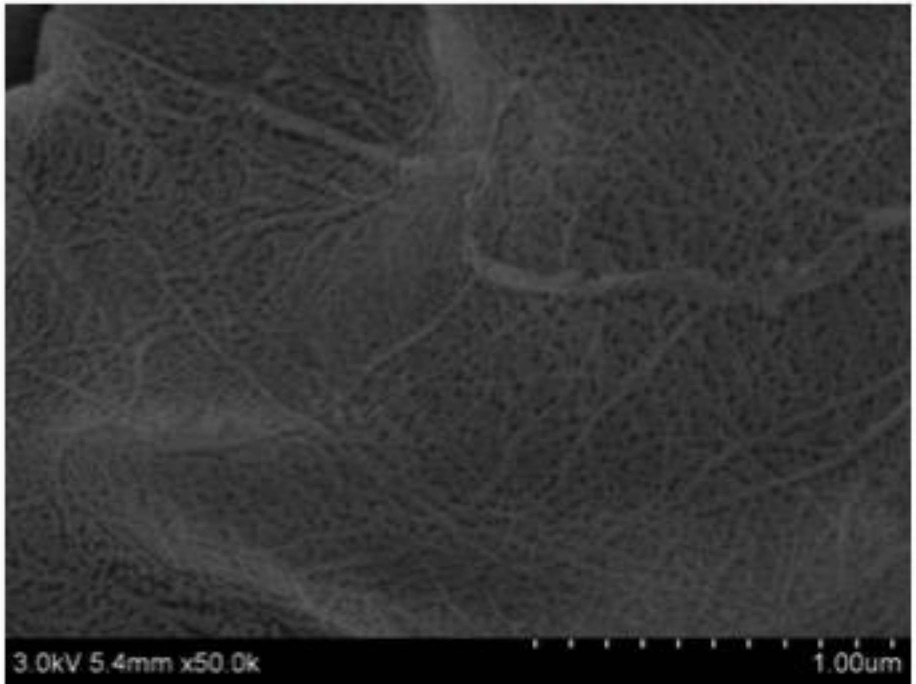
Mesoporous Structure for Improved Rate Performance



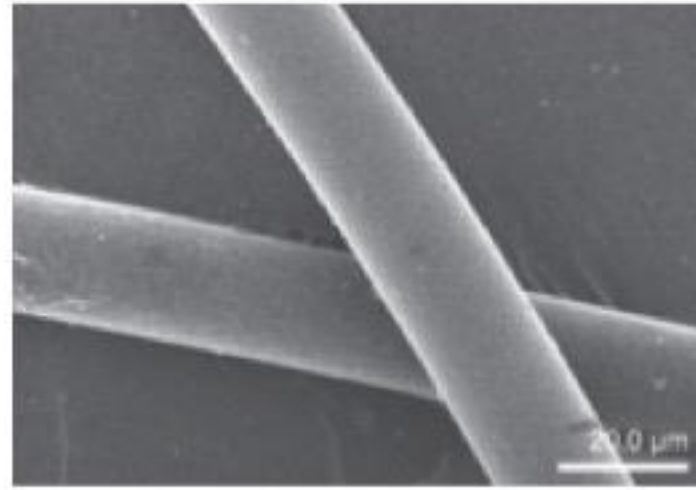


Nanoporous Cellulose Fibers



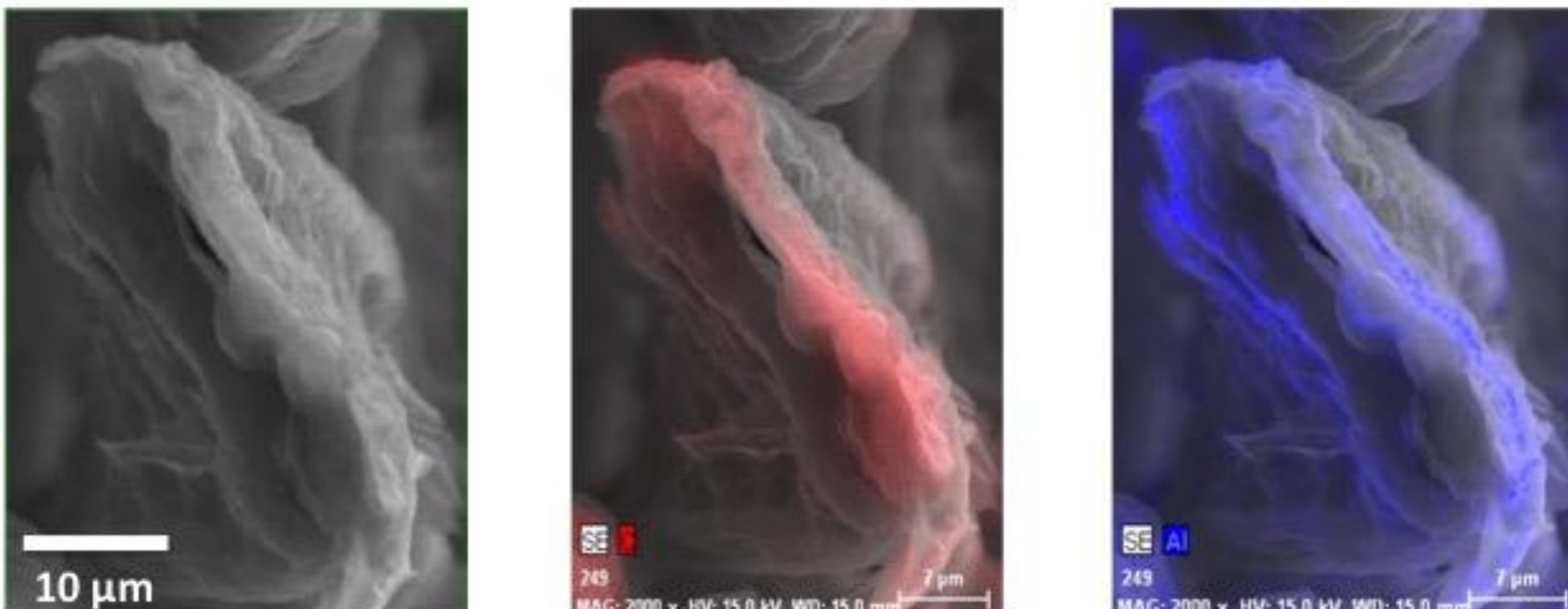


Two Control Experiments (no internal channels)



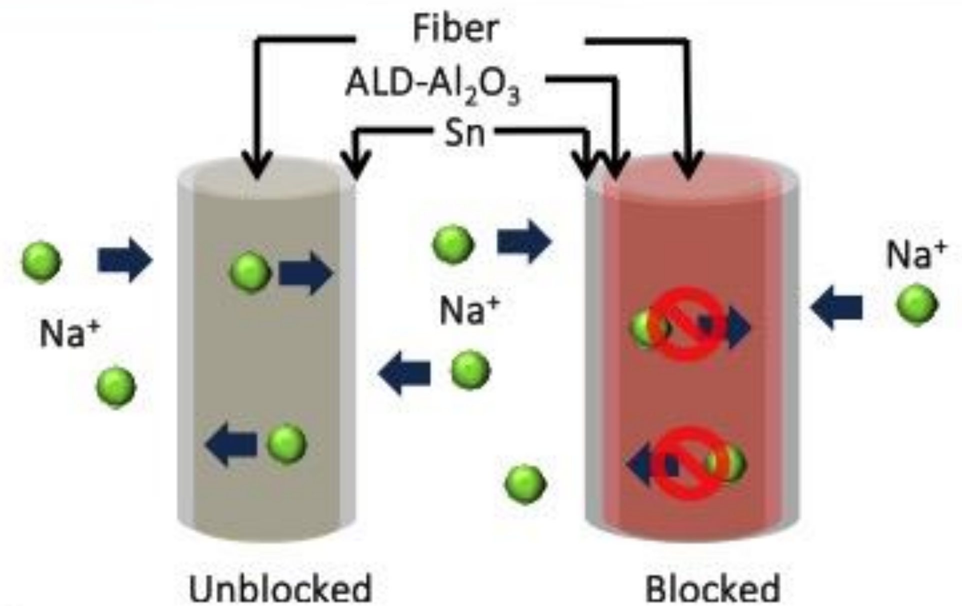
Control 1: Synthetic fibers

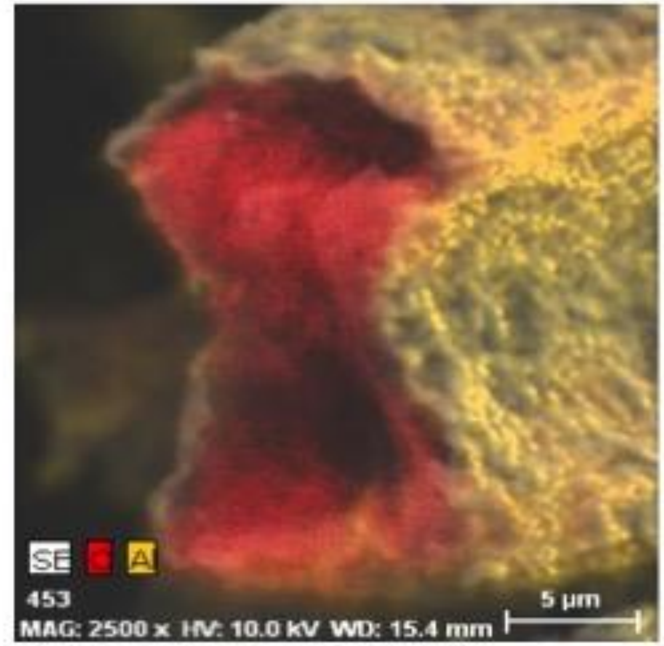
Control 2: ALD blocked cellulose fibers

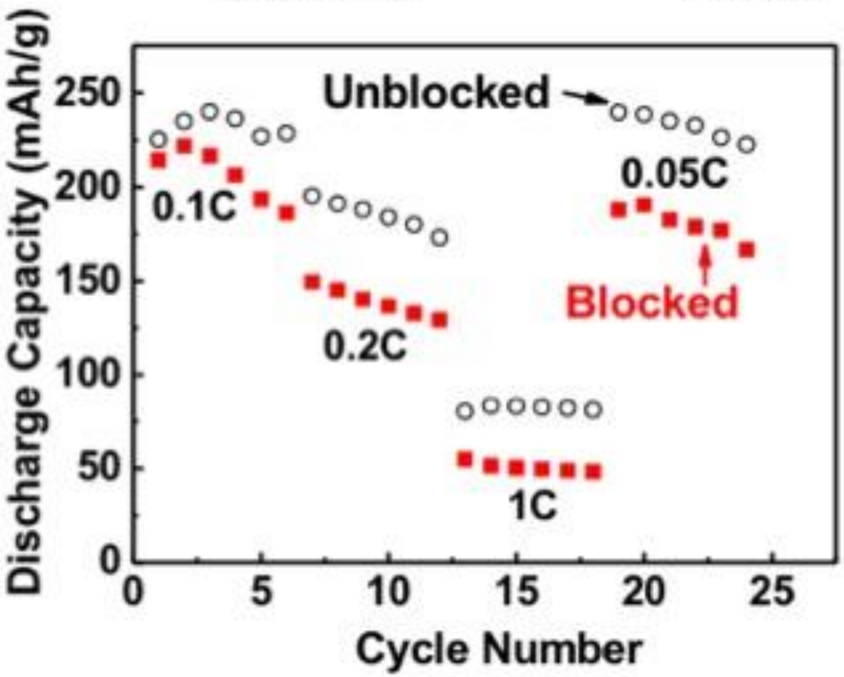


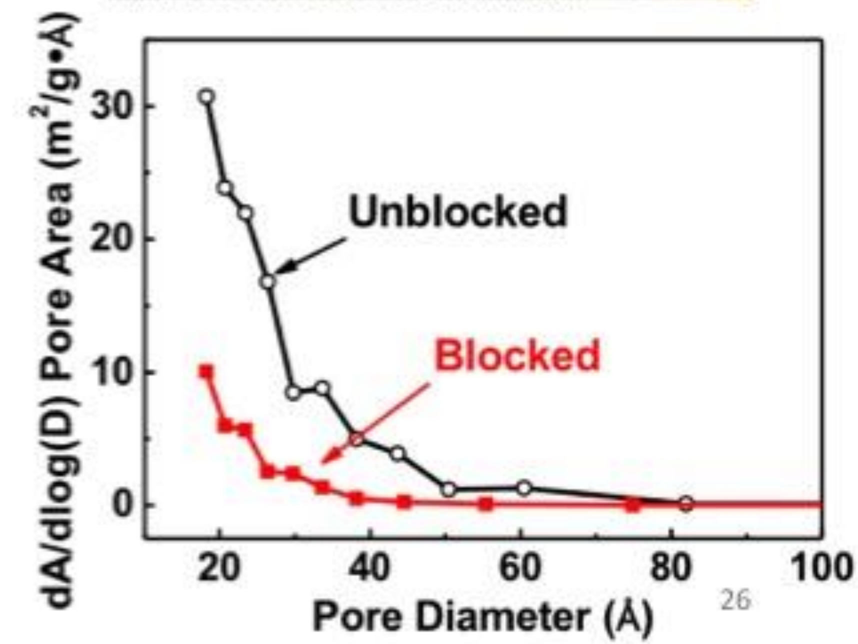
160oC with trimethyl aluminum [TMA, Al(CH3)3] and DI water precursors

Mesoporous Structure for Improved Rate Performance

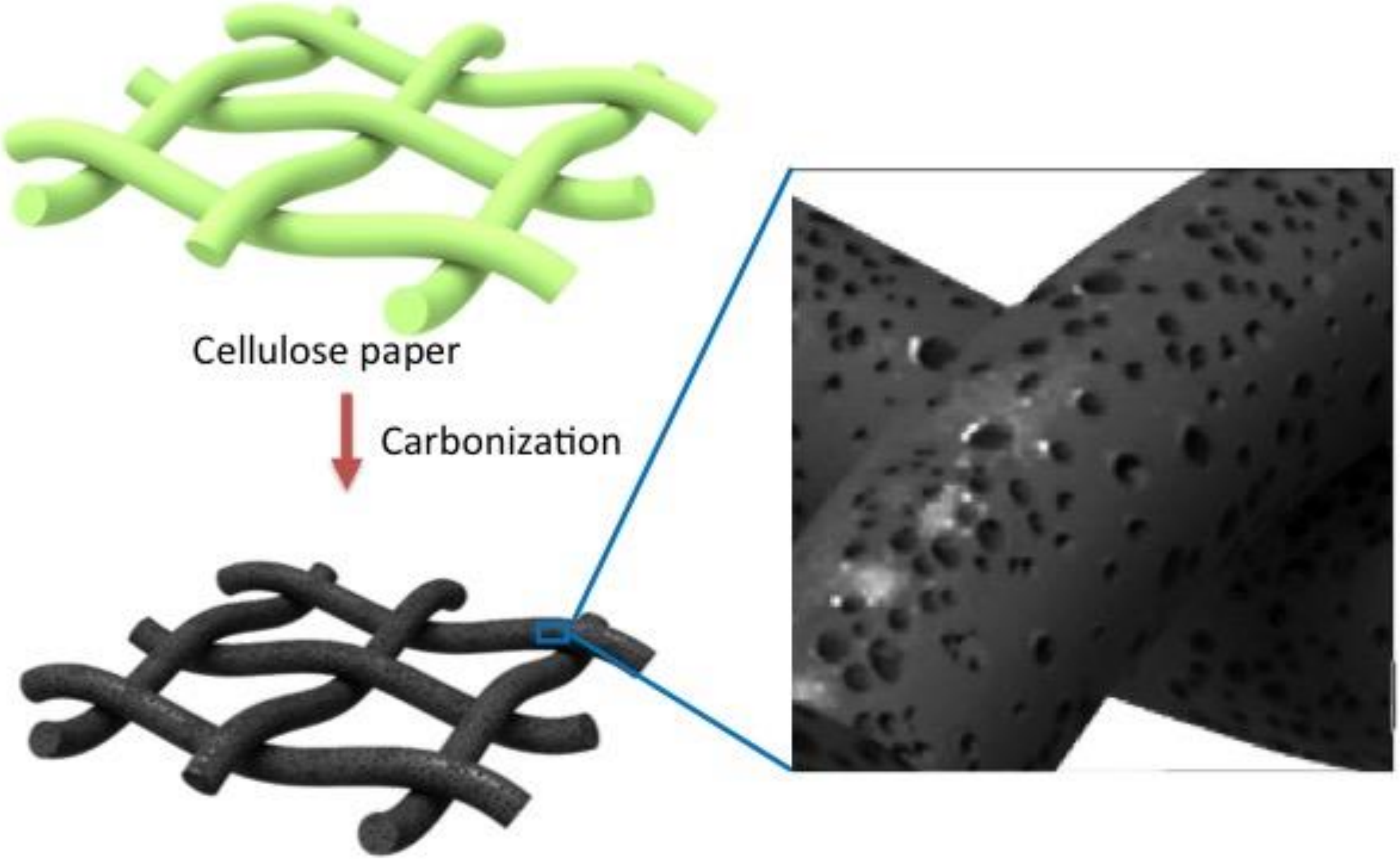






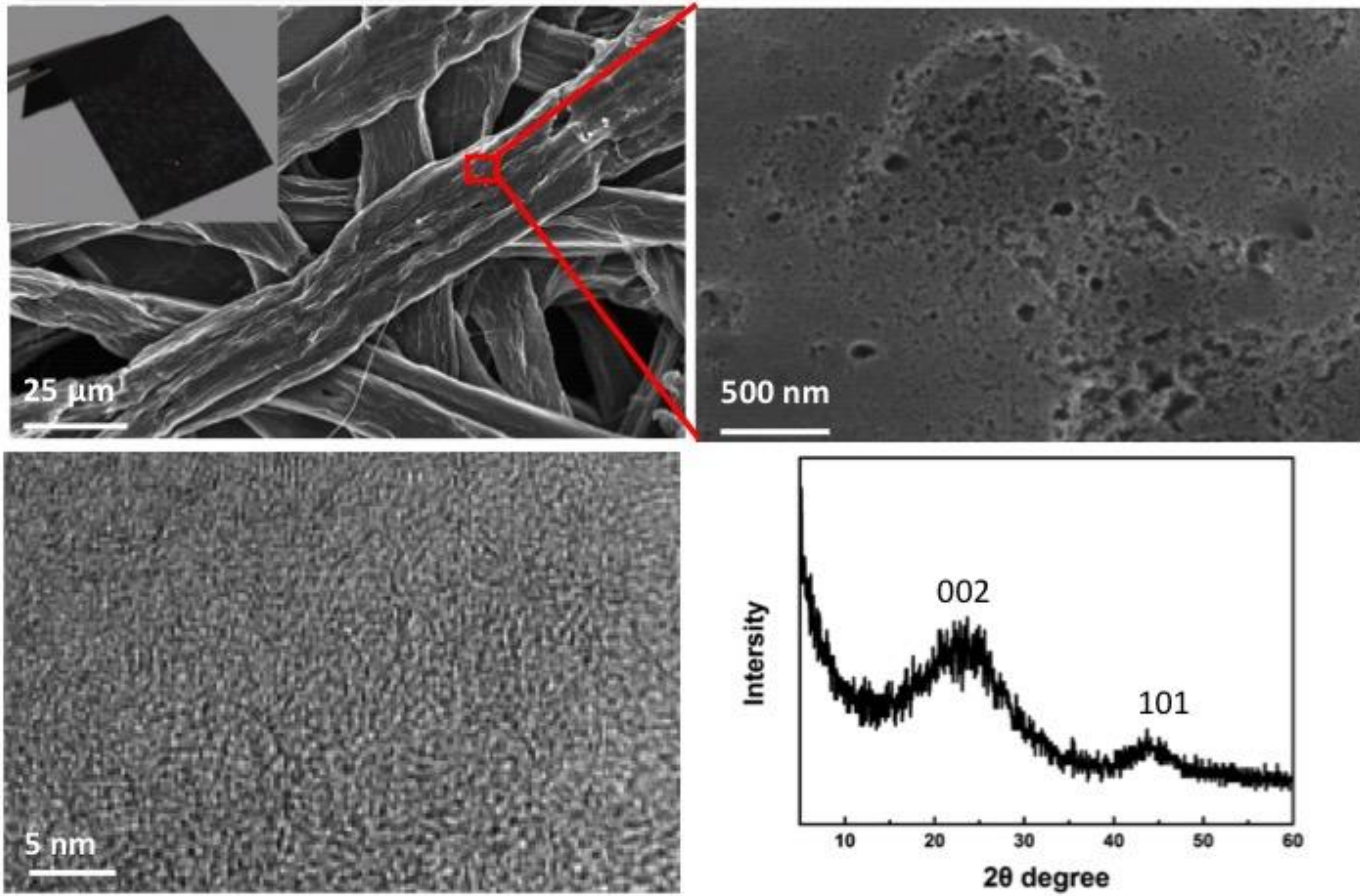


Carbonized Cellulose Paper for Na-ion Batteries

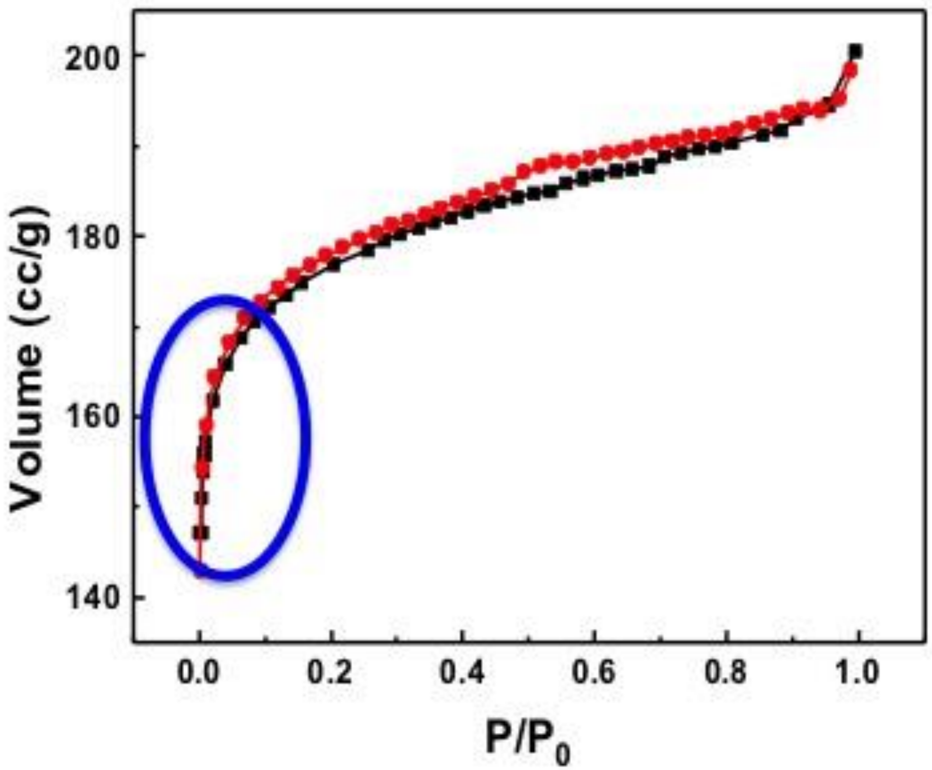


Conductive paper with nano-sized pores

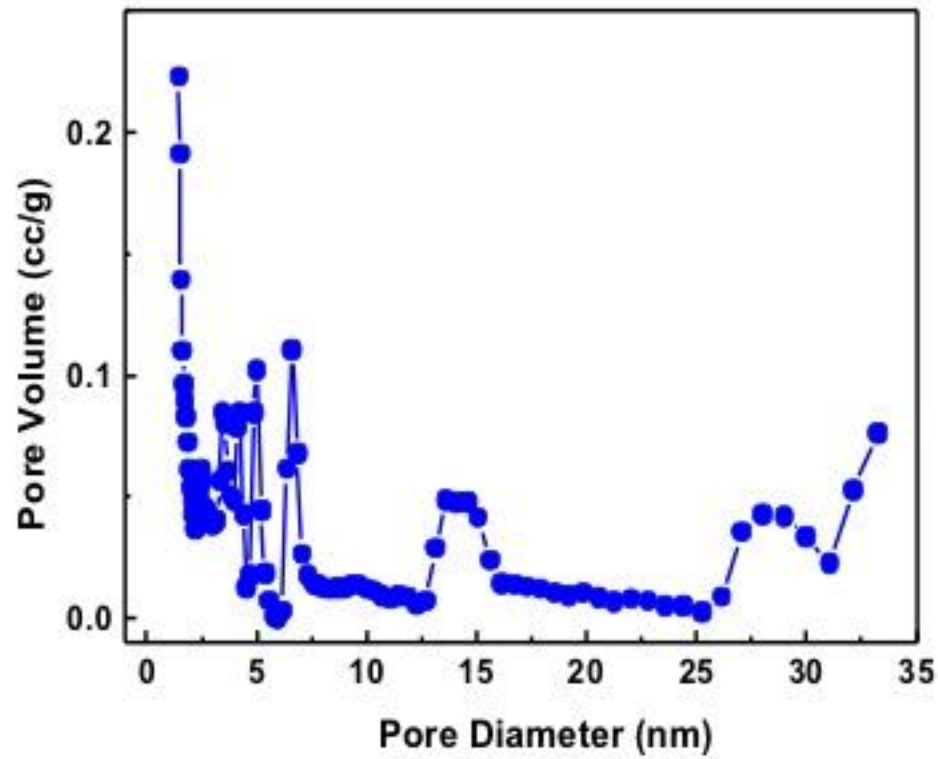
Morphology of Carbonized Paper



Nitrogen Adsorption–desorption



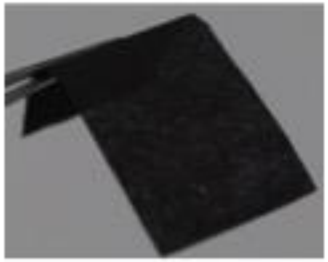
Isotherms



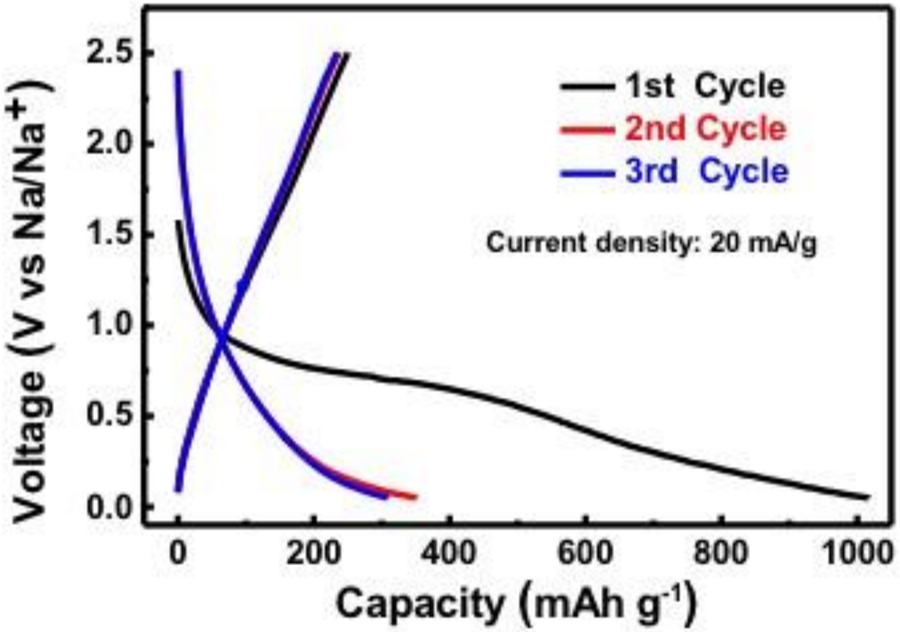
Pore size distribution(the DFT model)

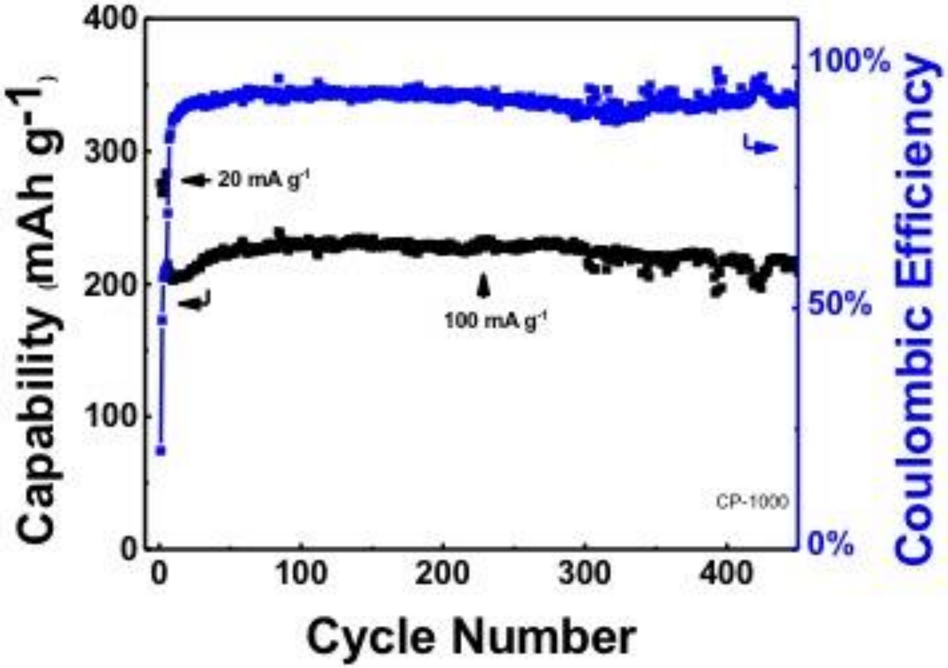
The specific Brunauer-Emmett-Teller (BET) surface area is 701m^2 g^{-1}.
High porosity and surface area can provide much more active reaction sites during sodiation and de-sodiation

Electrochemical Performances



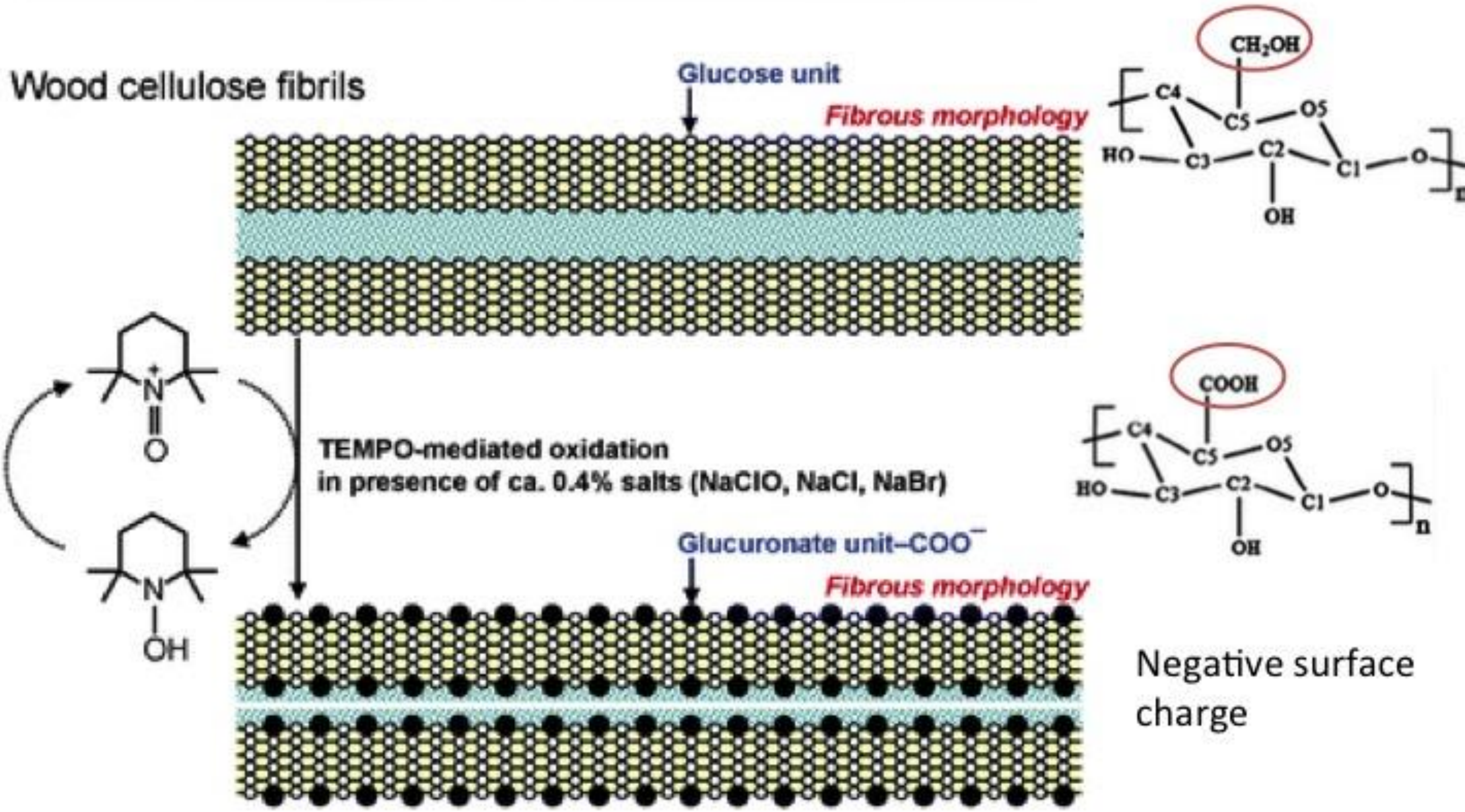
3/8'' round discs were directly punched out of carbonized paper for use as binder free anode. Electrolyte 1M $NaClO_4$ in EC:PC (1:1).





25% for the initial coulombic efficiency

TEMPO-mediated Oxidation Process

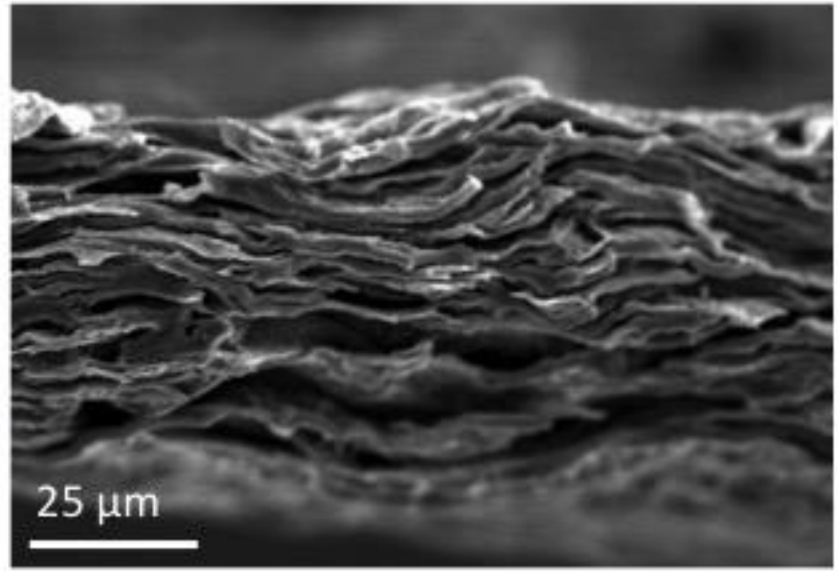


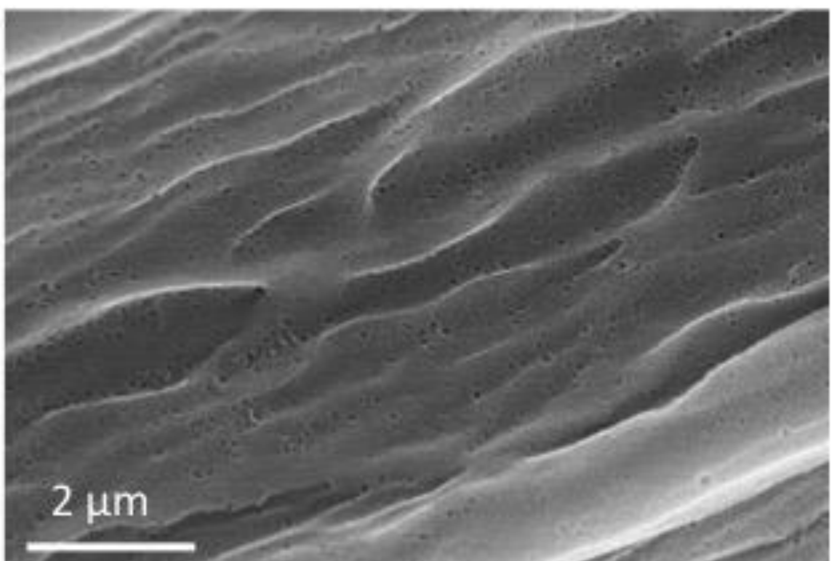
Negative surface charge

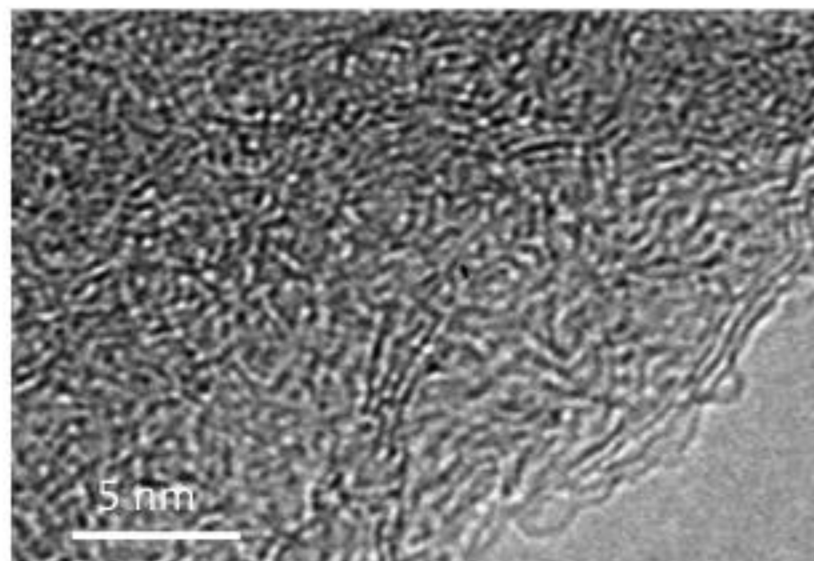
To weaken hydrogen bond

Nanoscale, 2011, 3, 71–85.

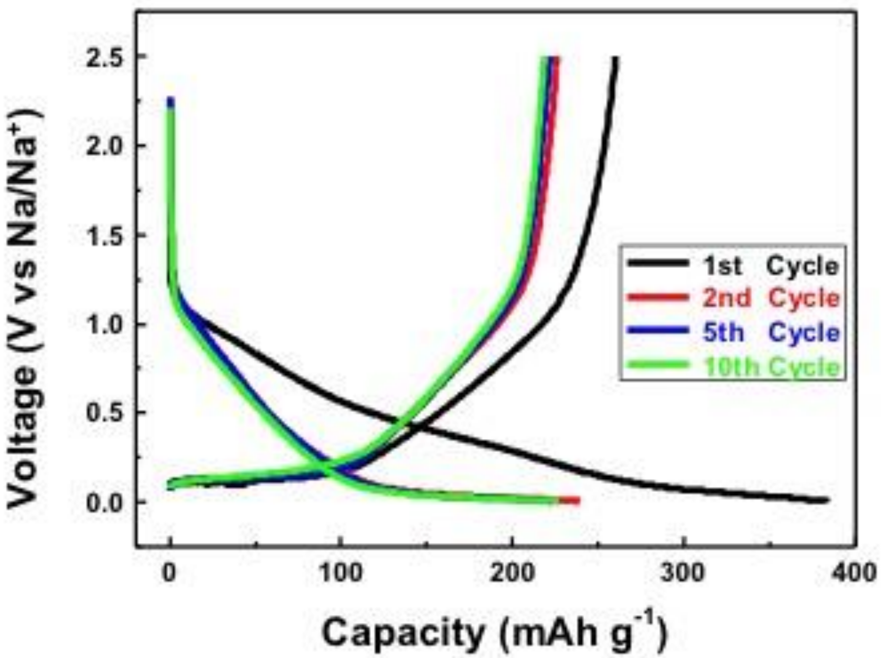
Carbonized TEMPO Treated Paper--Much Denser!

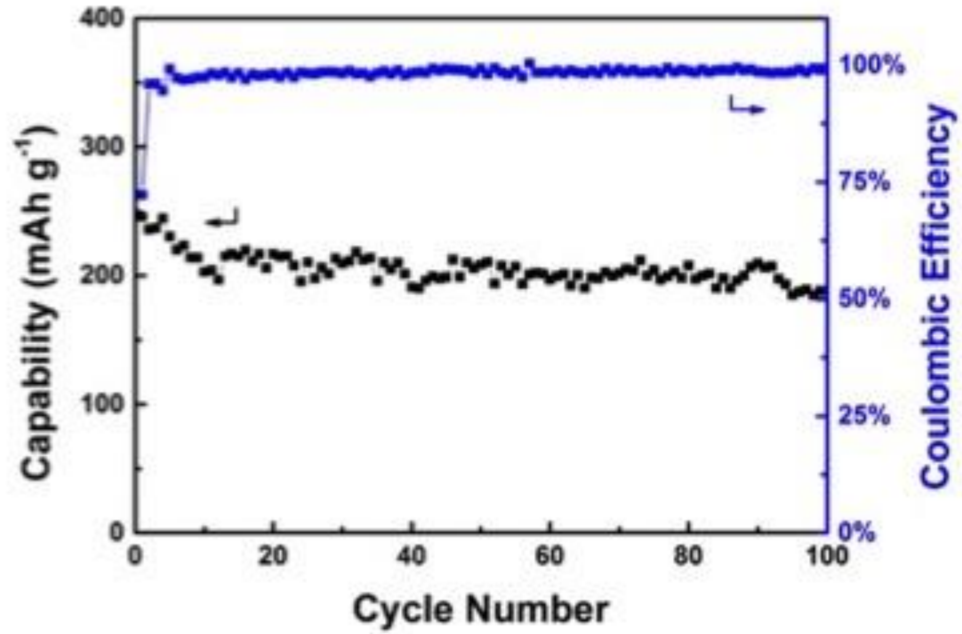






Electrochemical Performances

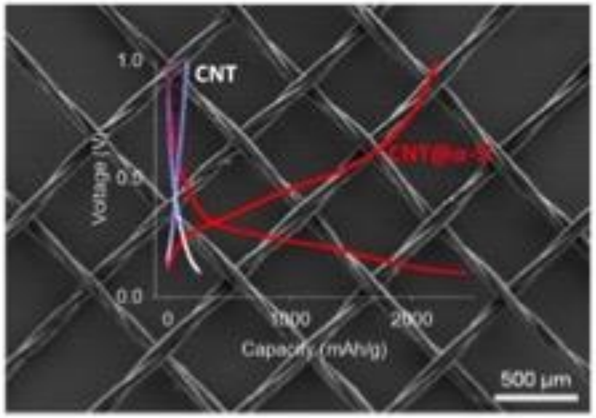


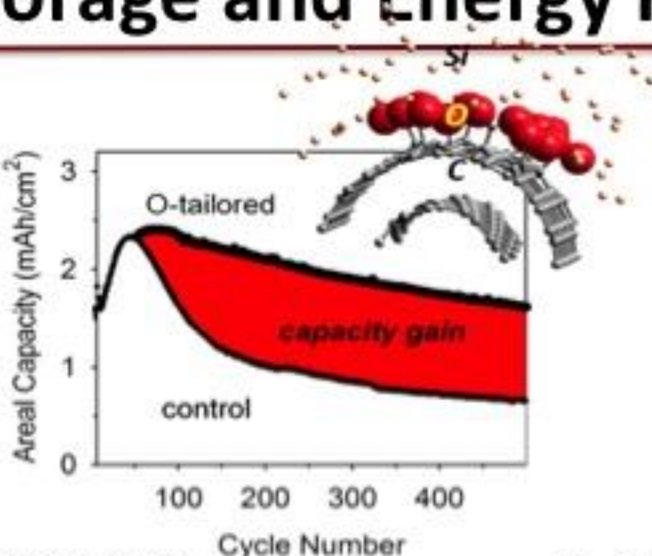


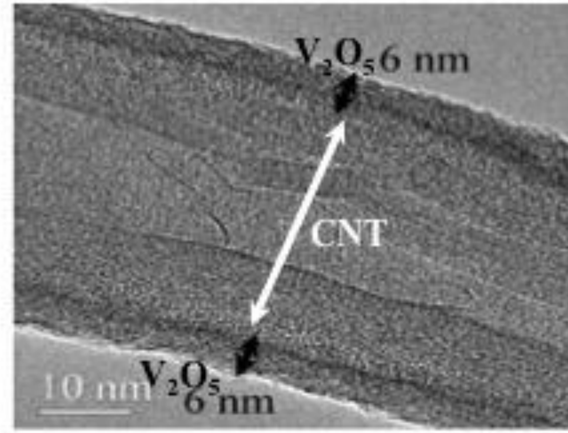
Initial coulombic efficiency 72%

In the subsequent, the CE raised to 95% for the 2nd cycle.

Energy Storage and Energy Harvesting







q *Sun, C., Zhu, H., et al.* ***Nano Letters****, 2015, 15 (1).*

q *Gui, Z.,* Zhu, H.,* et al.* ***ACS Nano****, 2013, 7(7).*

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q *Chen. X., Zhu, H. et al.* ***ACS Nano****, 2012, 6(9).*

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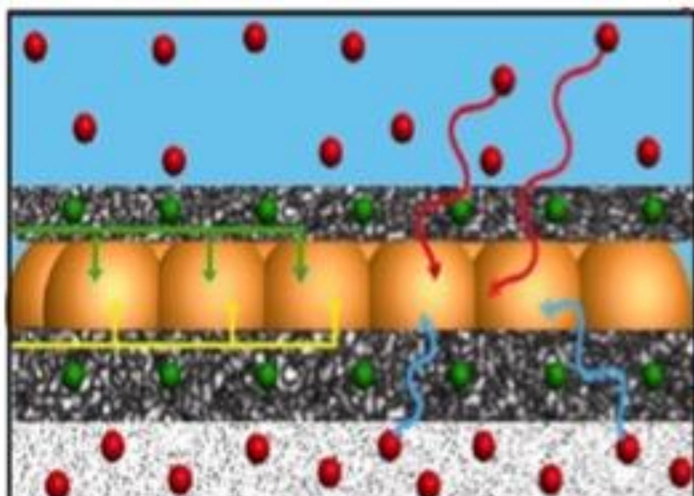
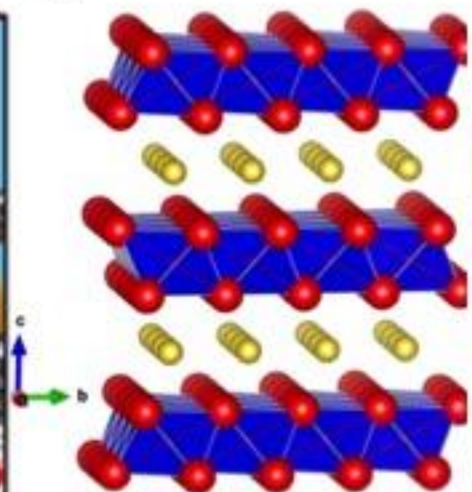
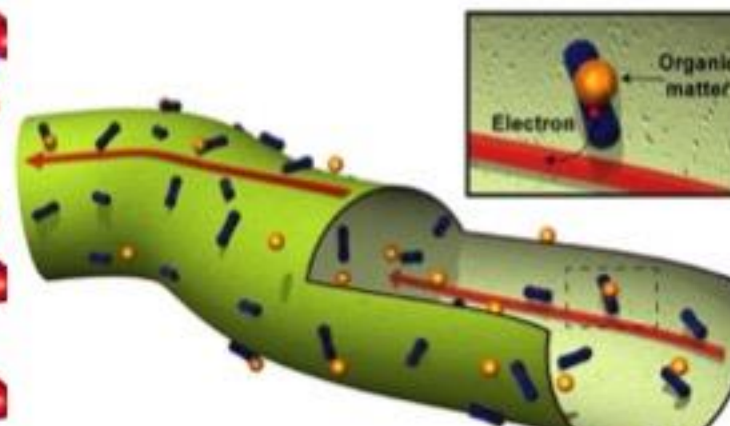


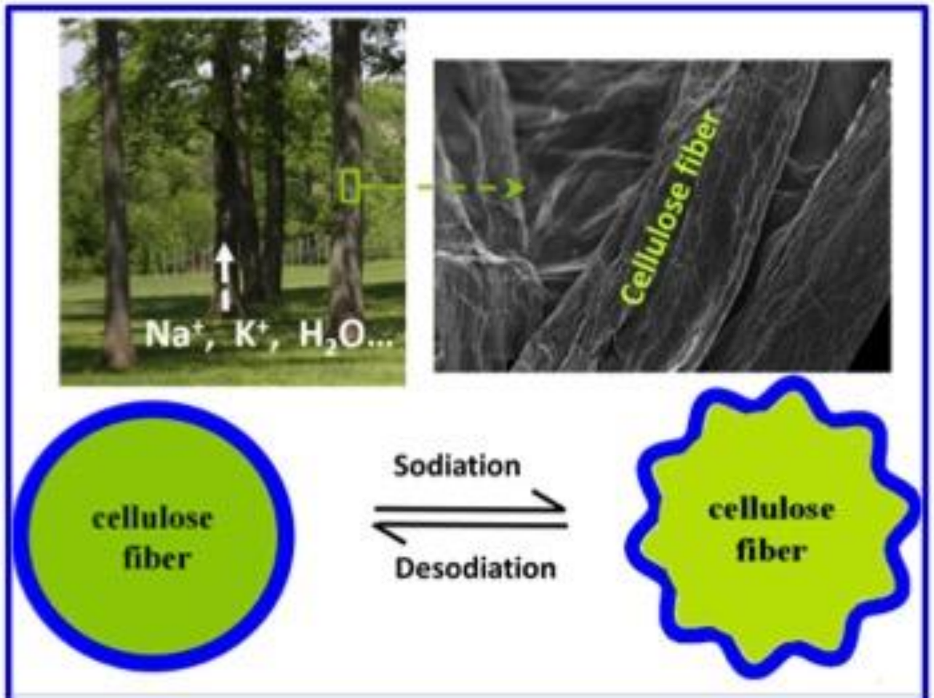




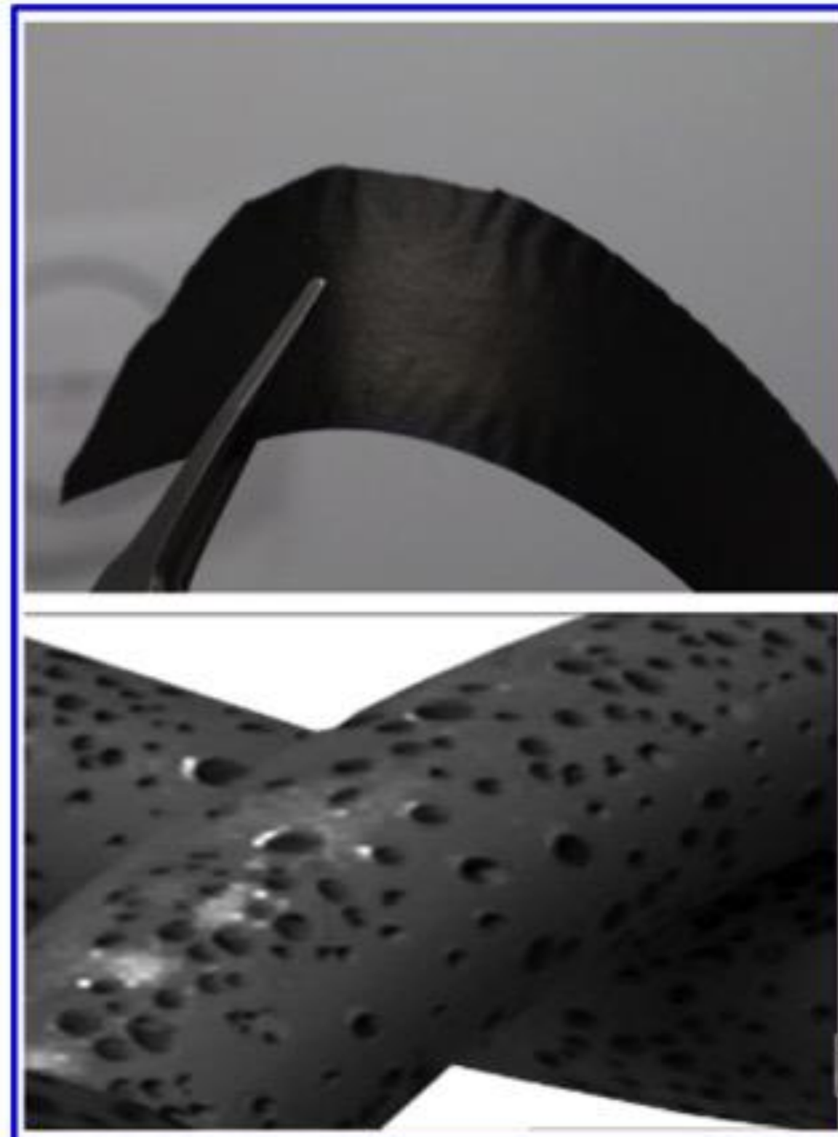
q *Zhu, H. et al.* ***ACS Applied Materials and Interfaces****. 2014, 6(6).*

Conclusions

Ø Natural wood fiber as ***mechanical buffer*** and ***electrolyte reservoir for Tin anode in sodium ion battery***



Ø Carbonized Cellulose Paper as a free standing anode for Sodium ion battery



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- **Co-workers in Hu's group, University of Maryland, College Park**

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