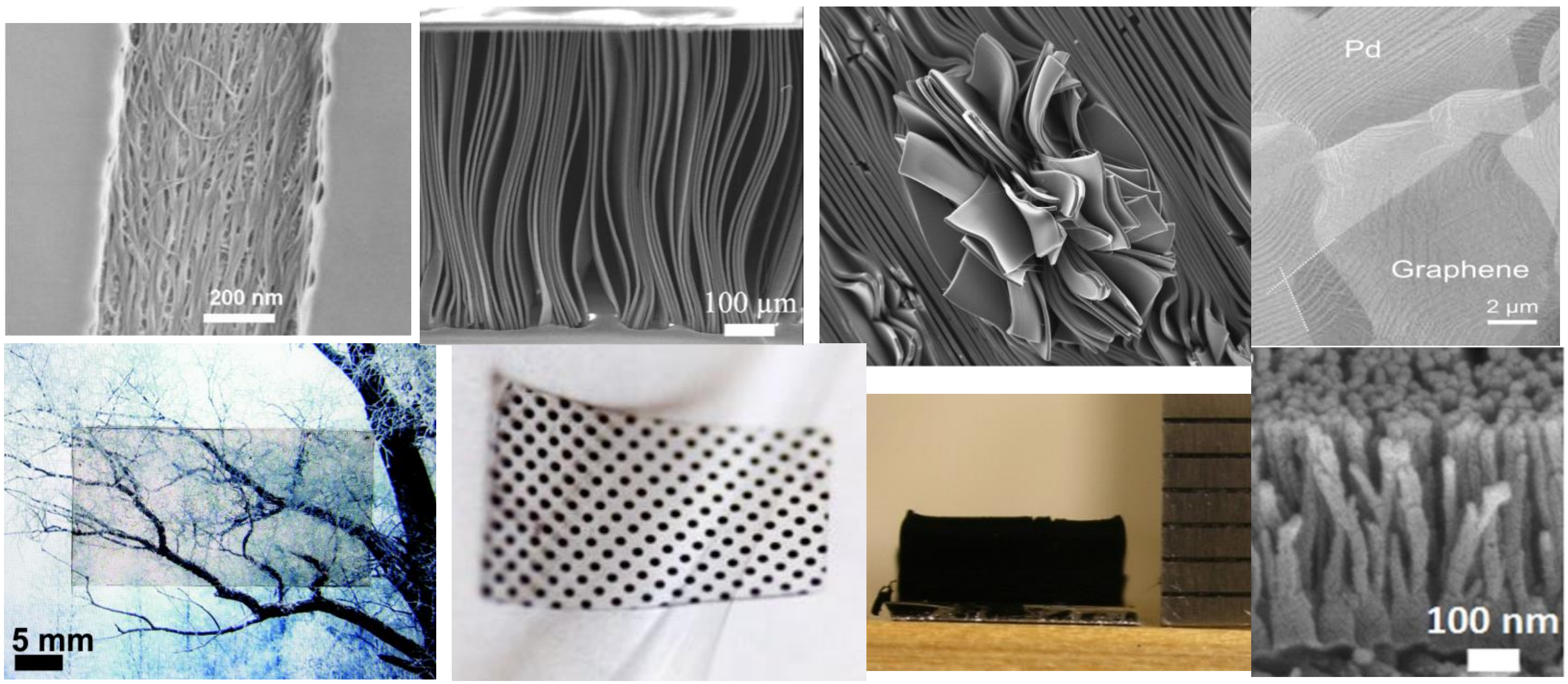
Engineering Carbon Nanostructures and Architectures for High Performance and Multifunctional Electrodes

Yung Joon Jung

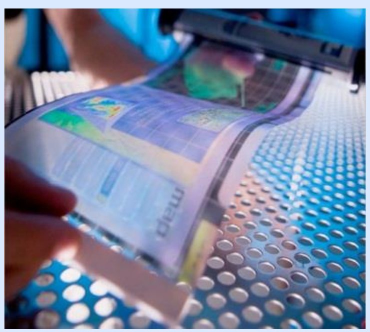
Department of Mechanical & Industrial Engineering
Northeastern University, Boston, MA 02115



Northeastern UNIVERSITY

High Performance and Multifunctional Electrodes

Multifunctional Electronics



Flexible and transparent smart phone, flexible computer, Flexible electronic newspaper (Wearable Electronics)

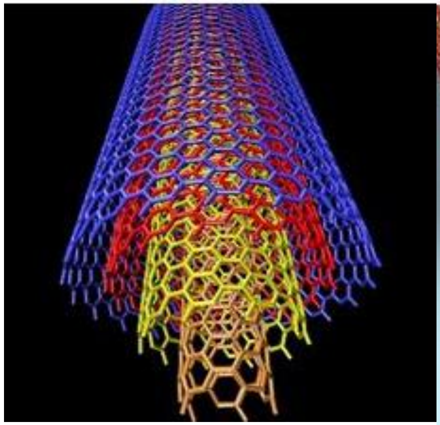
Devices require mechanically flexible, functional, and high performance energy storage systems

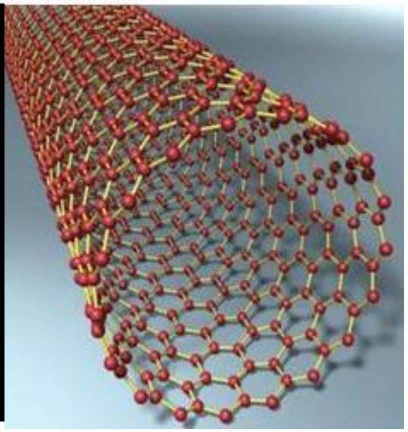
Electrode Materials

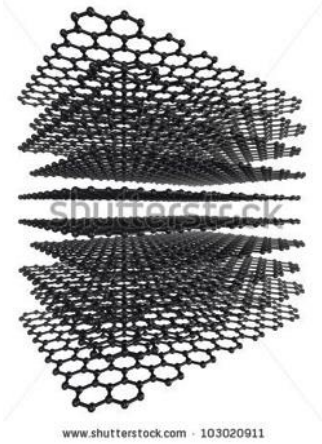
- 3D Nanostructures
- Electro-Mechanical Stability
- Optical Transparency etc.

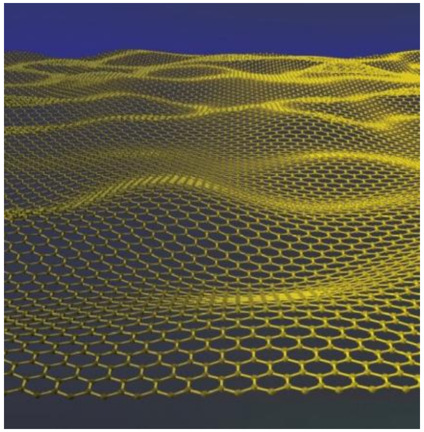
Northeastern University

SP^2 Carbon Nanostructured Materials









- ***Mechanical Properties***
  - *Strong sp2 Carbon-Carbon covalent bonding*
  - *High elastic modulus (1 TPa) and High strength*
- ***Electrical and Optical Properties***
  - *High Mobility*
  - *Highly conductive w/wo mechanical deformation*
  - *High current density (10^9 A/cm^2)*
  - *Optically Transparent*
- ***In-plane Properties of Graphitic Carbon***
  - *Good thermal conductivity (<3000W/mK)*
  - *Good chemical stability*

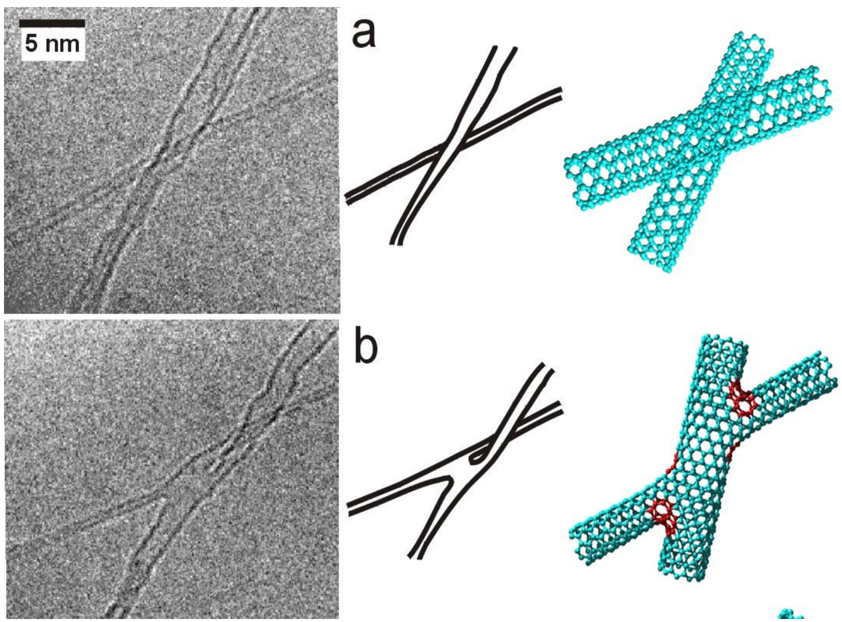
Northeastern
UNIVERSITY

Engineering SP2 Nanostructure

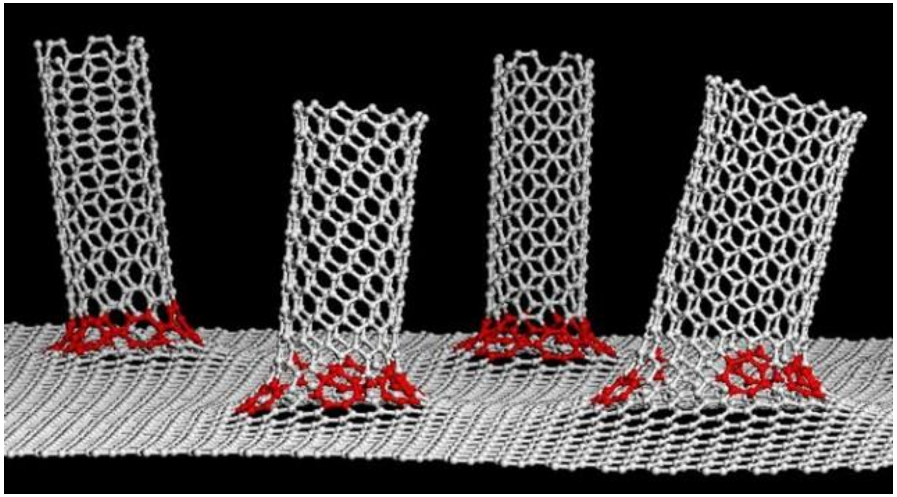
Limitation of current CNT/graphene based networks

- *Built on weak van der Waals interactions between CNTs, CNTs-Graphene*
- *Lower mechanical strength, electrical and thermal conductivities due to a lower pulling resistance, electron and phonon scatterings at these "**unconnected**" junctions*

Transforming physical Junctions into covalently bonded sp^2 Chemical Junctions



Terrones, Ajayan et al., PRL, 2002



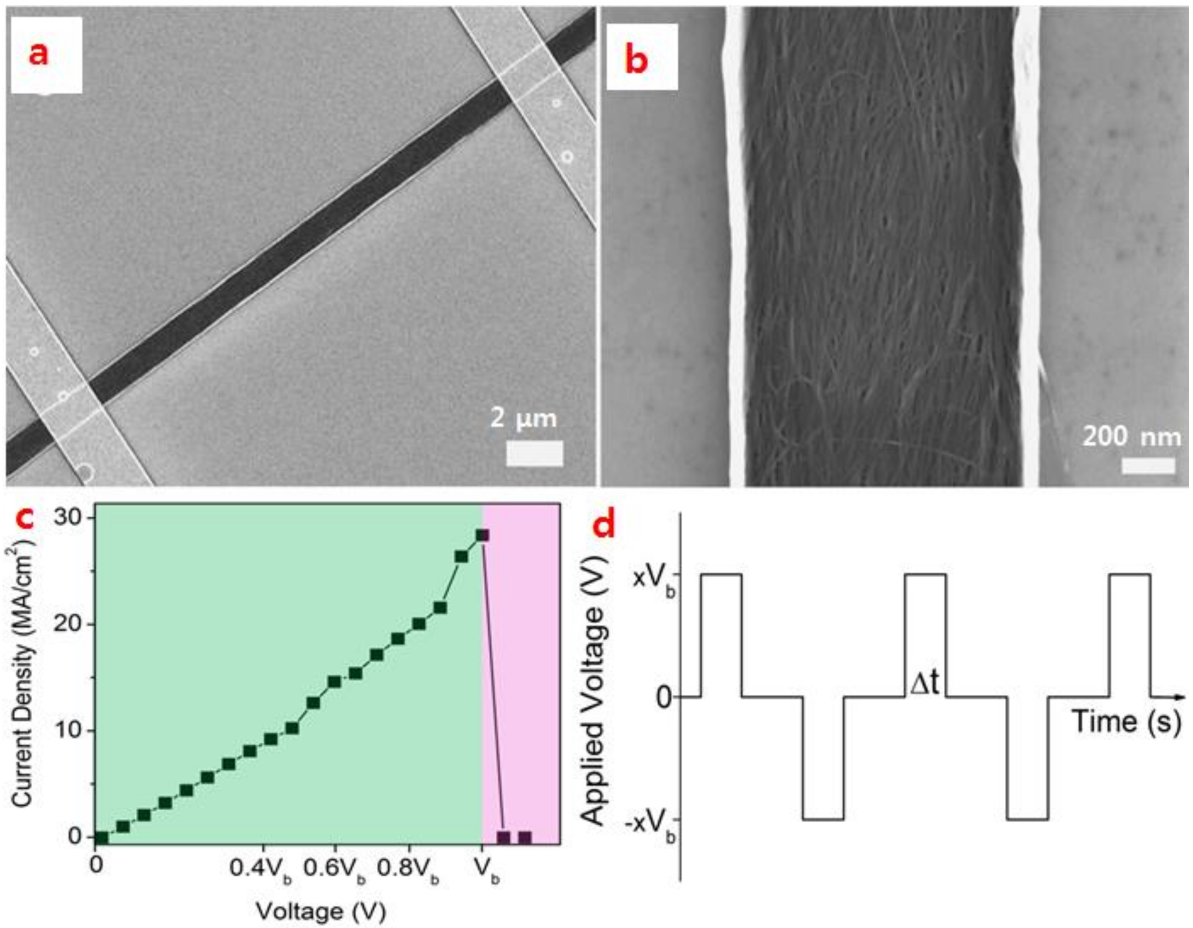
J. Tour et al., Nature Communications, 2012

Northeastern UNIVERSITY

Engineering SP2 Nanostructure

Restructuring sp^2 Lattice and Network Structure

A voltage-induced *electrical fusion* of SWCNTs

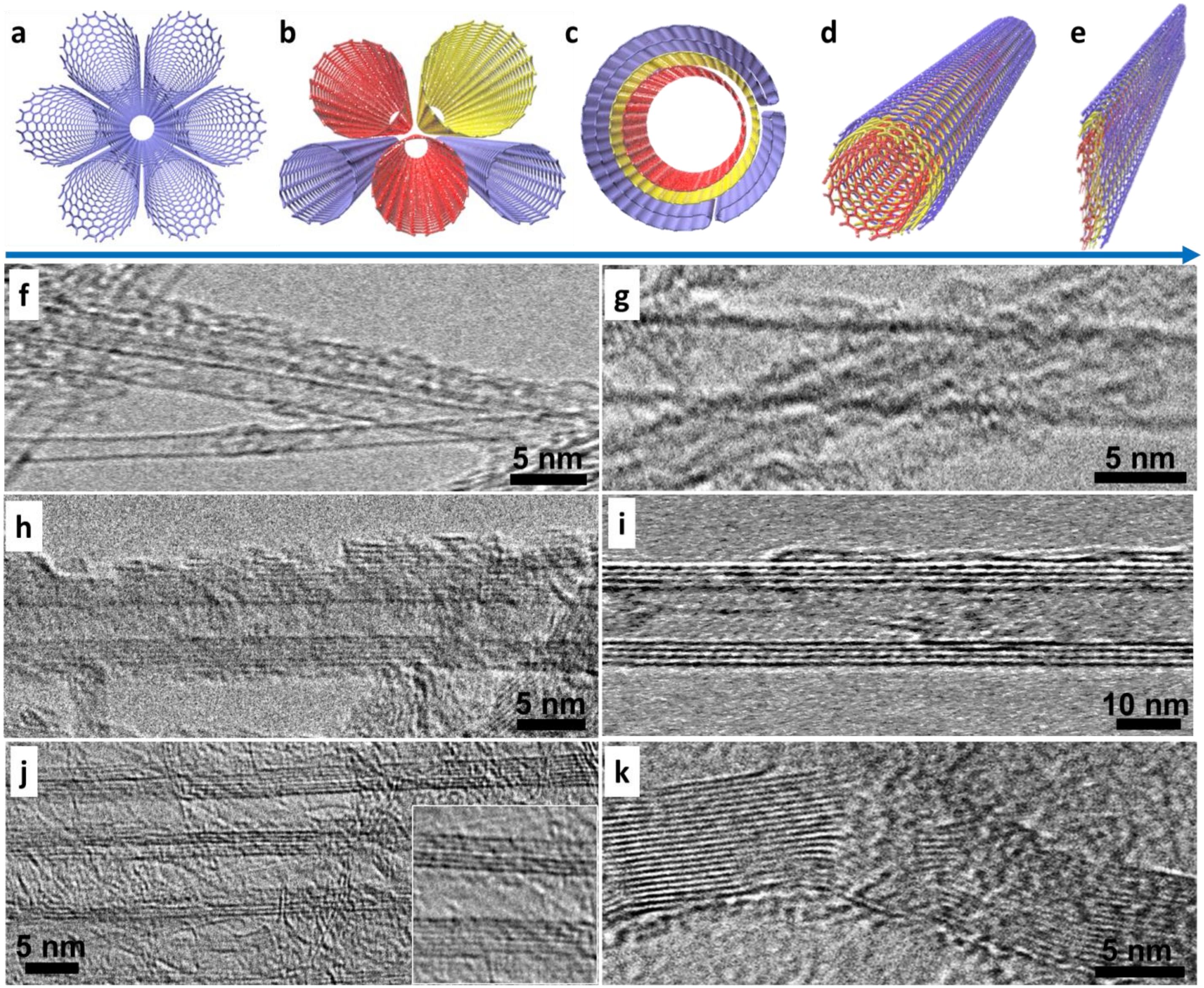


1
p
n
b
2
s
r

H. Jung et al, Nature Communications, 2014

UNIVERSITY

Engineering SP2 Nanostructure



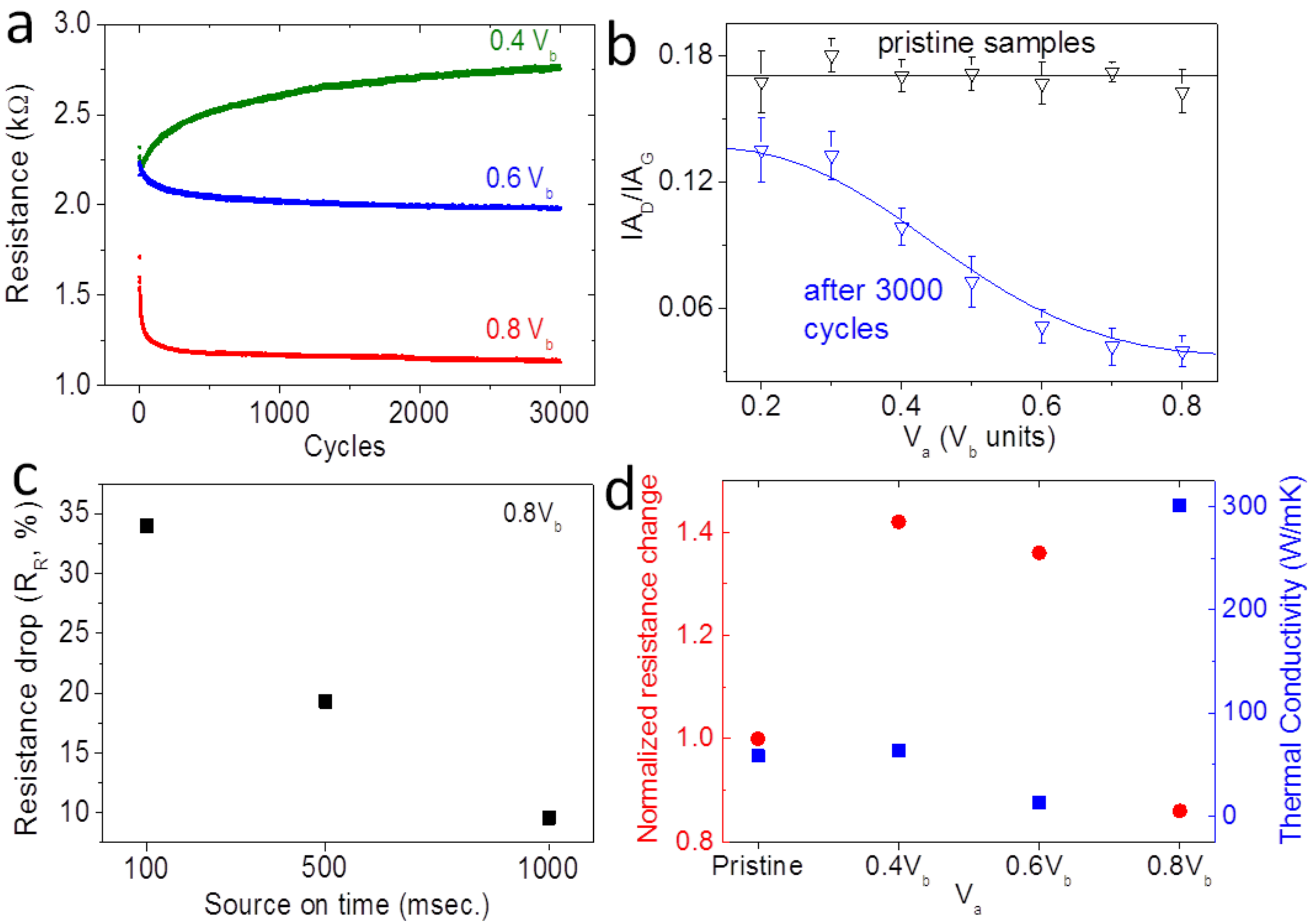
Restructuring sp^2 Lattice Structure

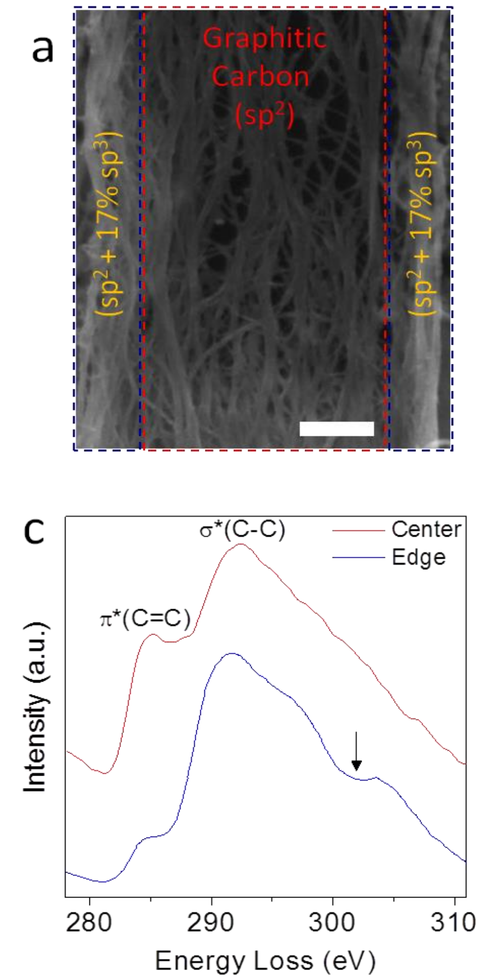
H. Jung et al, Nature Communications 2014

Jung's Research Group

Northeastern University

Engineering SP2 Nanostructure

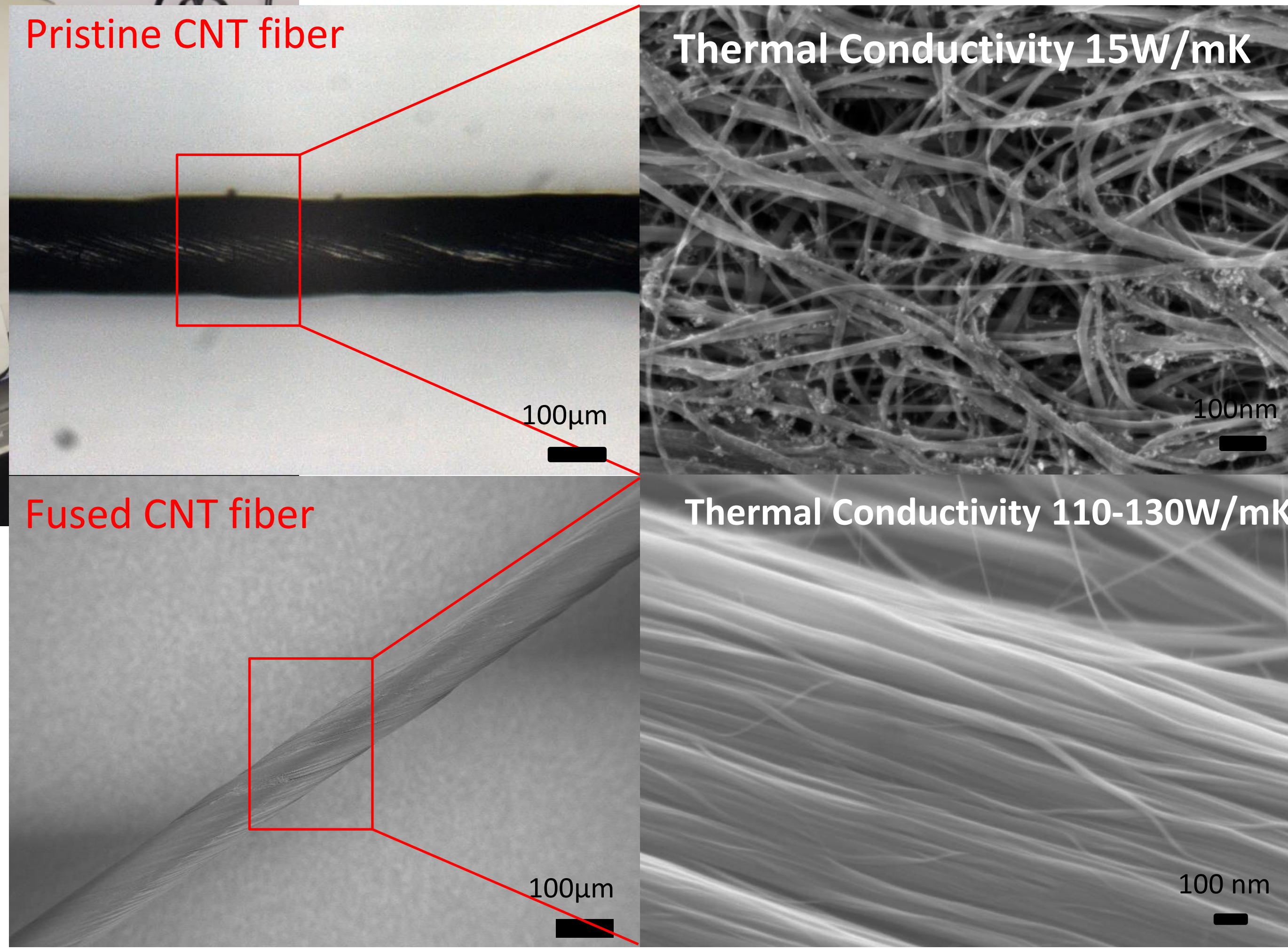




Jung's Research Group

Northeastern University

Engineering Nanostructure and Morphology



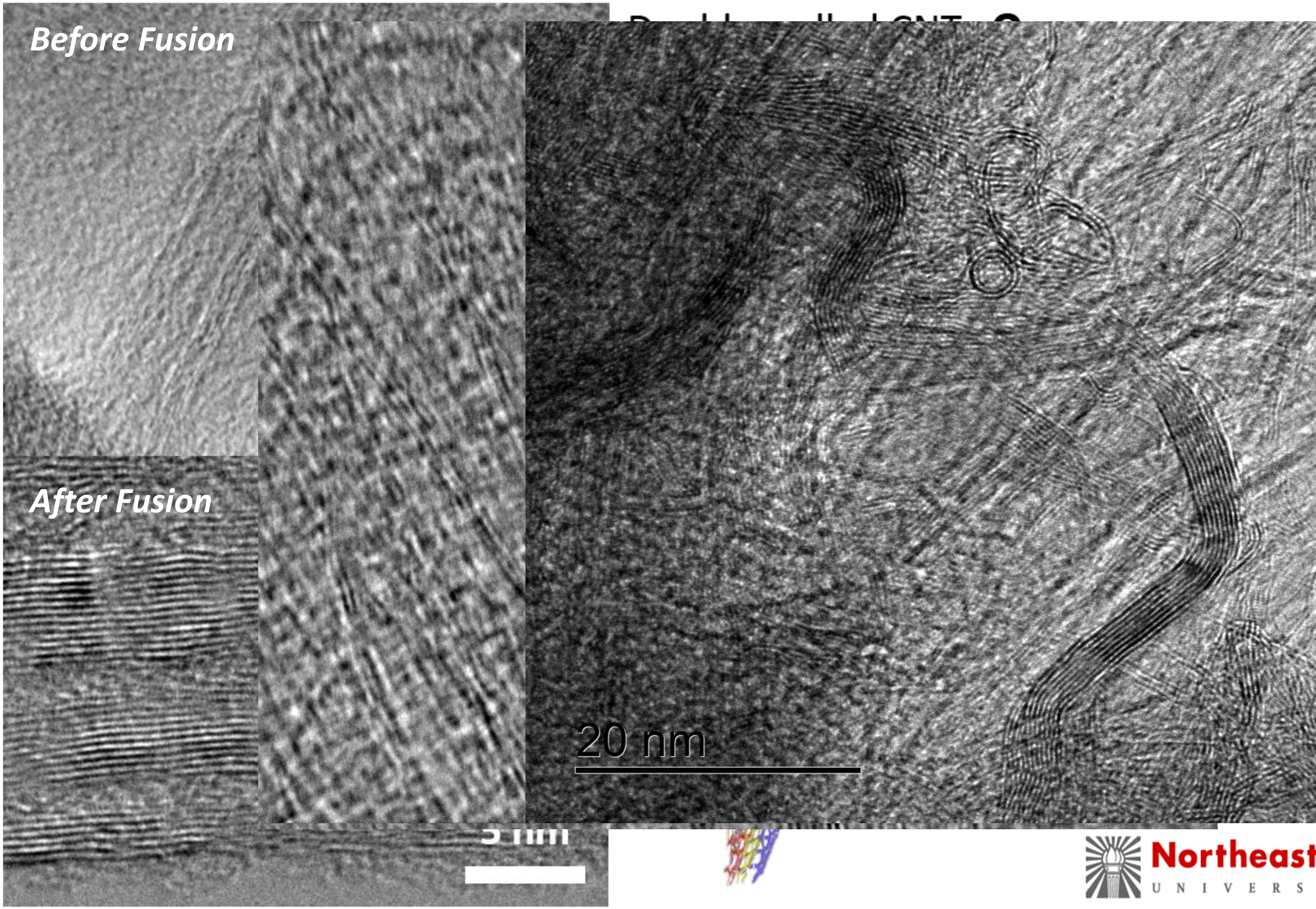
Supported by
NSF-DMREF Program
(Materials Genome Initiative)

J. Hao et al, Unpublished

JRG Jung's Research Group

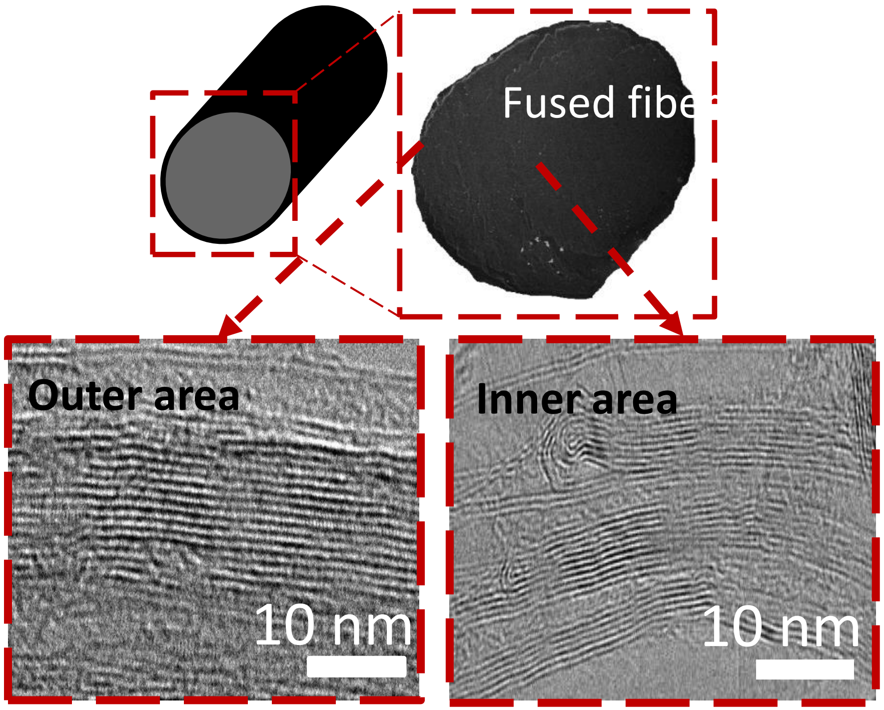
Northeastern University

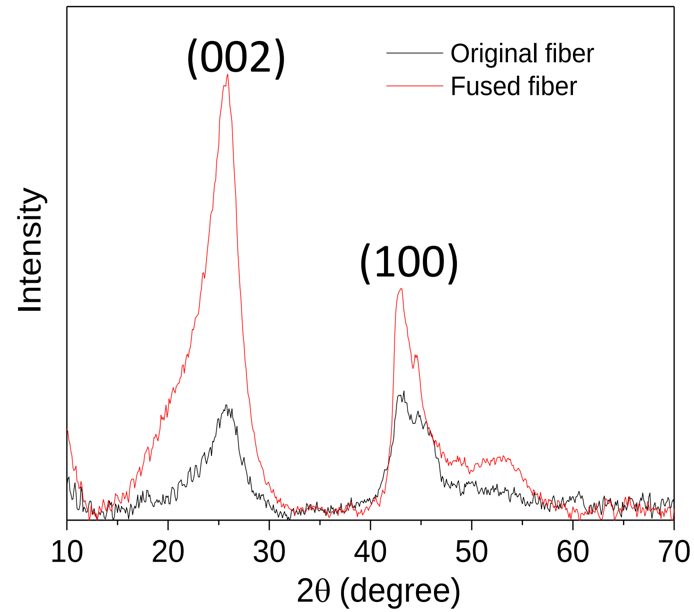
Engineering Nanostructure and Morphology

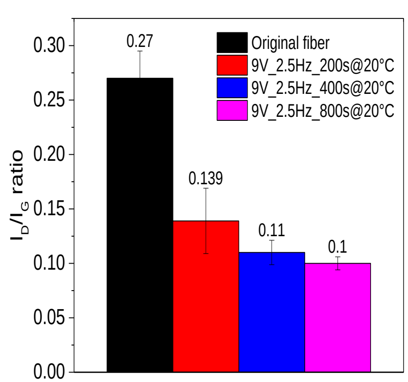


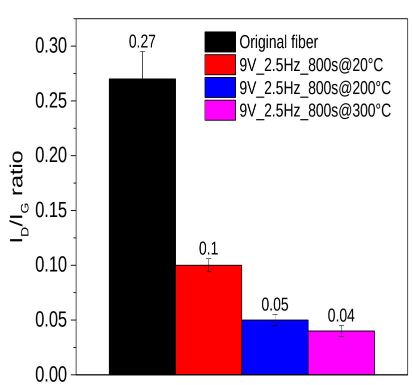
Northeastern University

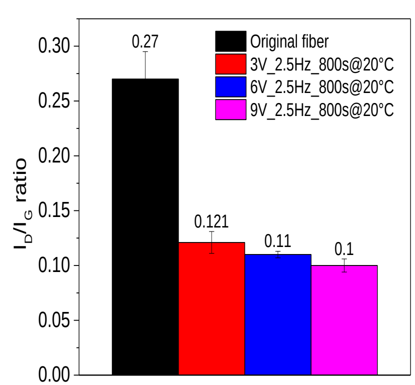
Engineering Nanostructure and Morphology









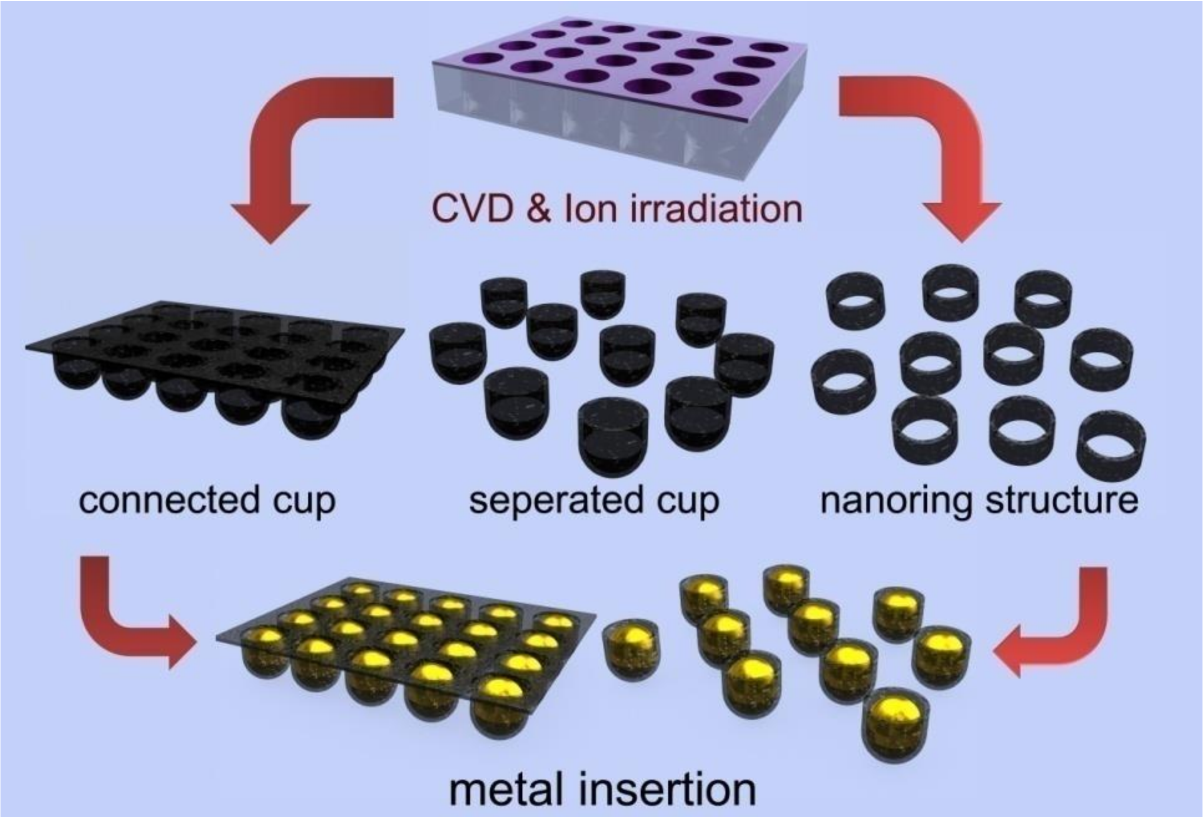


Northeastern
UNIVERSITY

Engineering 3D Nanoscale Architecture

Carbon Nanocups

Graphitic nanostructures having smaller length/diameter (L/D) aspect ratio, ***nanoscale cup morphology***, can effectively contain other nanomaterials and polymers, leading to multi-component hybrid nanostructures.



Multifunctional Nanosystems

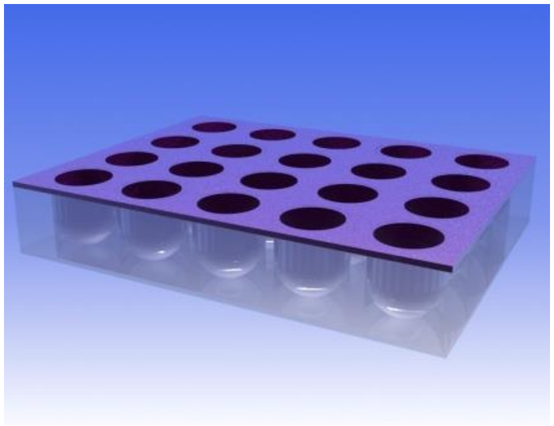
- ❑ *Energy Storage*
- ❑ *Nanogram Quantity Container*
- ❑ *Multifunctional Sensors*

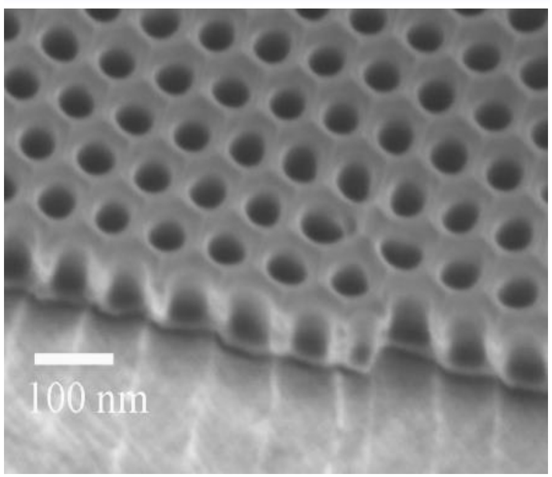
Northeastern UNIVERSITY

Engineering 3D Nanoscale Architecture

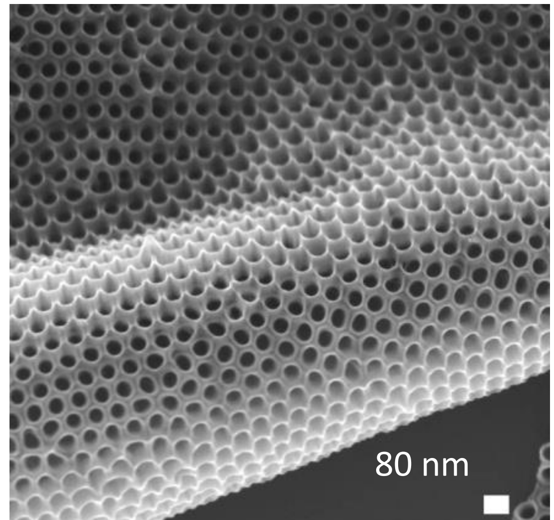
Fabrication Process

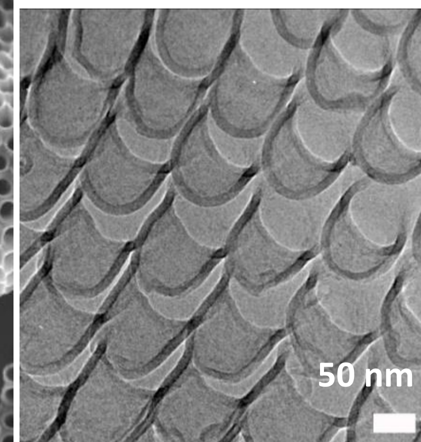
The length of nanochannels are controlled by second anodizing time.

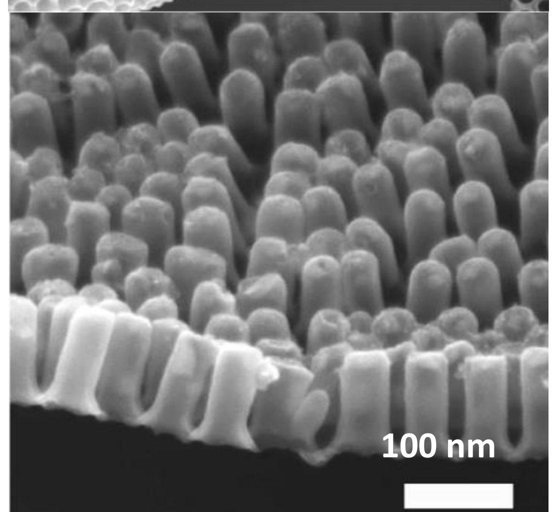


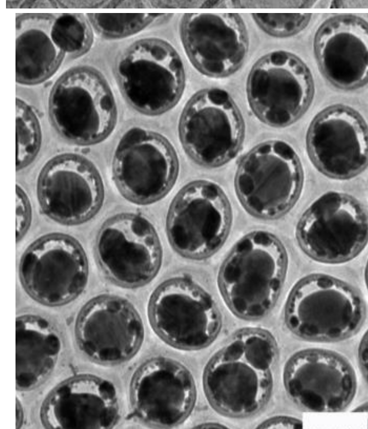


Thermal CVD of Carbon







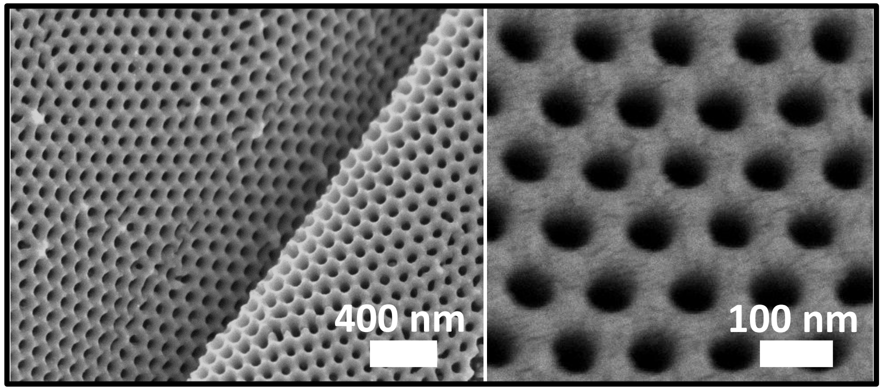


H. Chun, et. al., ACS Nano (2009)
H. Jung et al. Scientific Reports (2011)

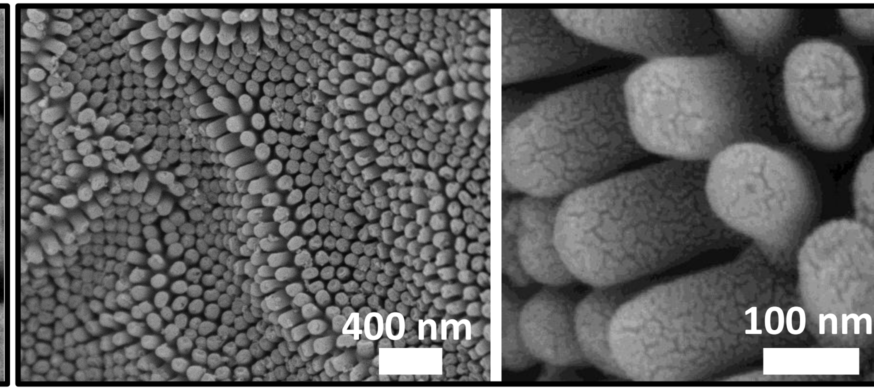
Northeastern UNIVERSITY

Engineering 3D Nanoscale Architecture

TOP view



BOTTOM view

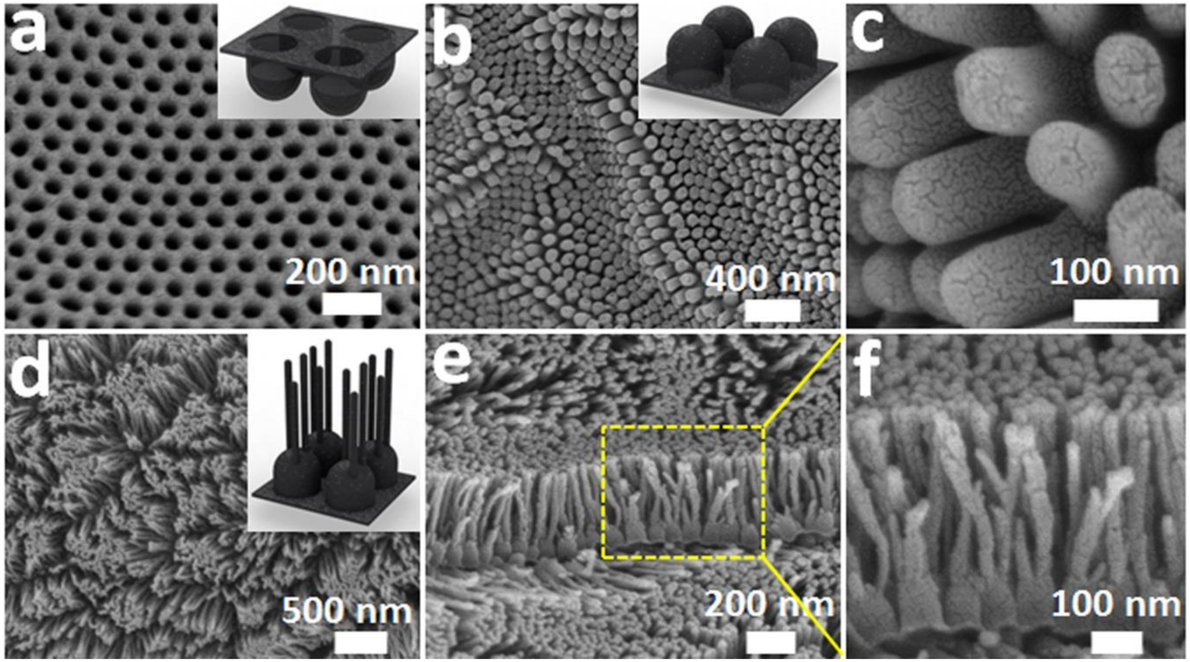


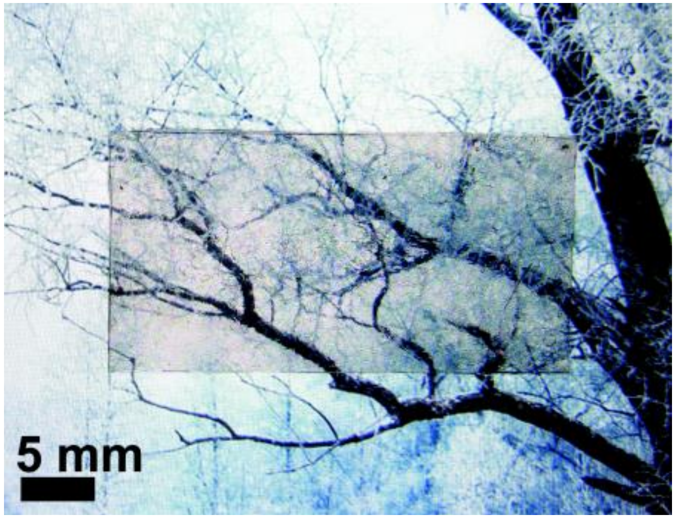
3D Carbon Nanostructured Film for Supercapacitor Electrodes

- Electrically Conductive: Surface Conductivity: 117 S/m
- High surface area and highly disordered graphitic layers provides the effective permeation of the polymer electrolyte and their conformal packaging with electrodes.
- Unique nanoscale cup feature enables the easy access and faster transport of ions at the electrode/electrolyte interface resulting in higher power capability.
- High current carrying capability, substantial mechanical strength, and small effective electrode thickness (5-10 nm: *80-85% Transmittance at 550nm wavelength*) allow us to build ***optically transparent*** and ***mechanically flexible*** reliable thin-film (solid state) energy storage devices.

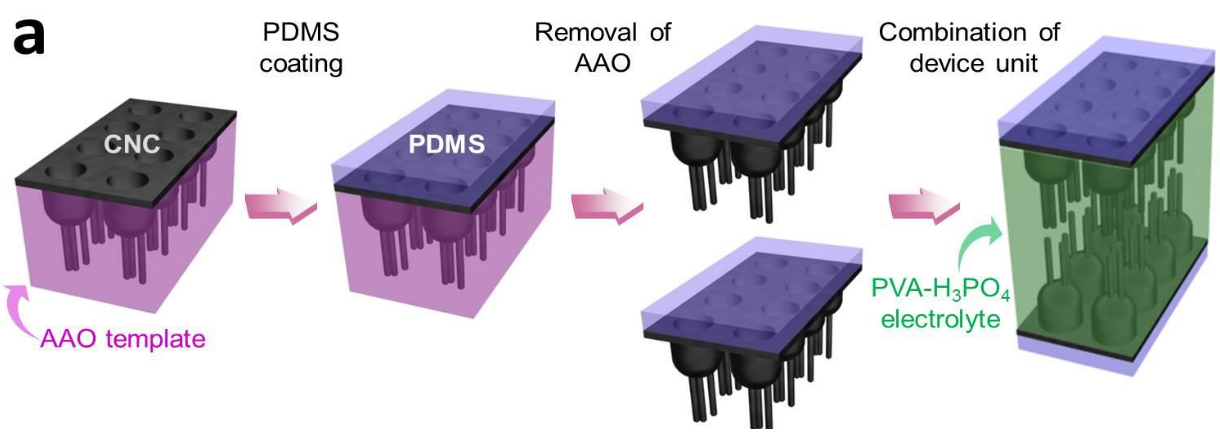
Northeastern UNIVERSITY

Flexible and Transparent Supercapacitors





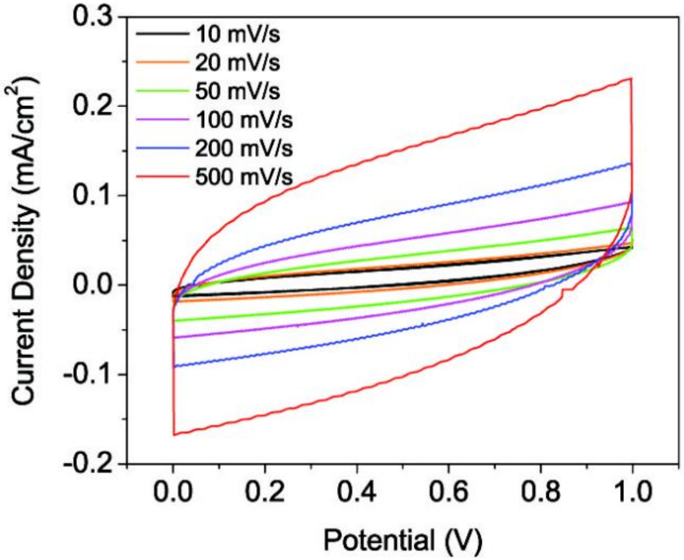
(a) concave and **(b, c)** convex and (**d-f**) branched nanocup films (*H. Jung et al. Scientific Reports 2012*)

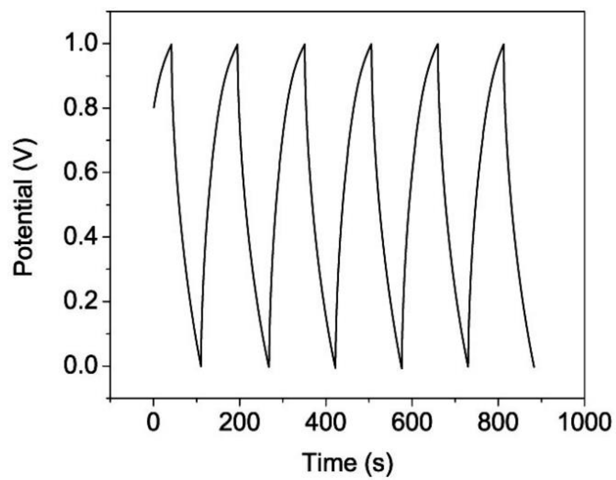


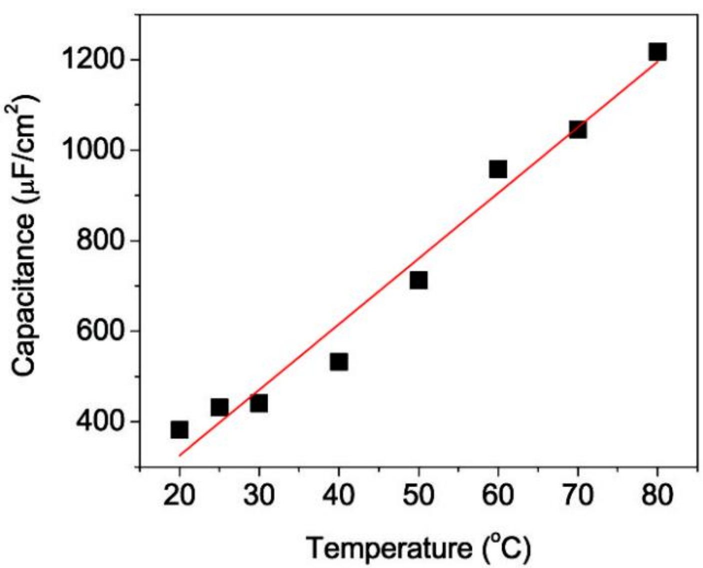
- **CNC films: Outer graphene layers are acting as current collectors and the Innermost layer exposed electrolyte is acting an electrode.**
- **Polymer electrolyte (PVA-H_3PO_4) is acting as both electrolyte and separator.**

Northeastern UNIVERSITY

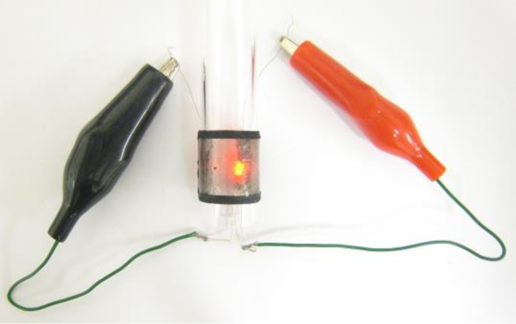
Flexible and Transparent Supercapacitors

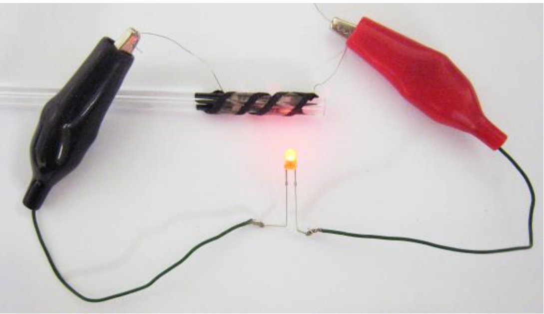






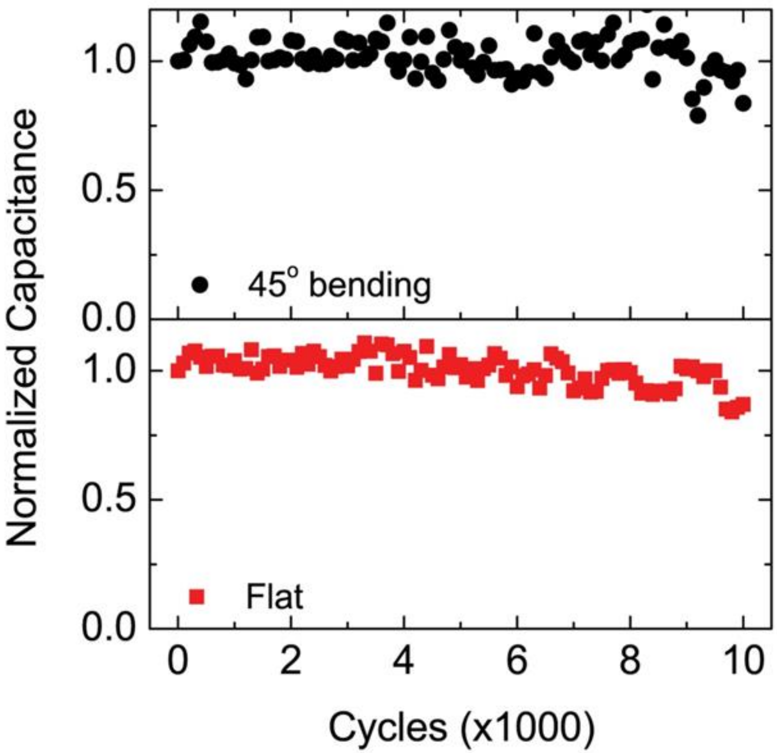
(**a**) Cyclic voltammetry (CV) measured with 10 – 500 mVs^{-1} scan rates. (**b**) Galvanostatic charge/discharge (CD) results measured at a constant current density of 5 μAcm^{-2}. The capacitances by the geometrical area calculated from CD curves are 409 μF cm^{-2}. (**c**) The capacitance change as a function of temperature

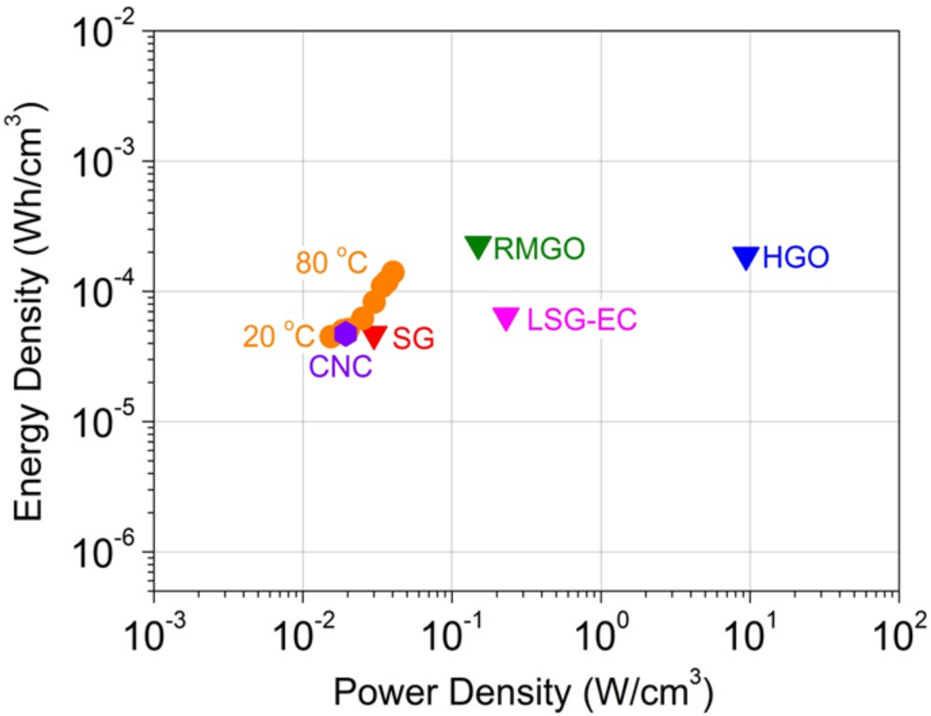




Northeastern
UNIVERSITY

Flexible and Transparent Supercapacitors





Normalized capacitance as a function of cycle-number (10,000) and w/wo the mechanical deformation (45° bending).

(SG: single layer graphene, RMGO: reduced multilayer graphene oxide, HGO: hydrated graphitic oxide, LSG-EC: laser-scribed graphene electrochemical capacitor)

Jung, Ajayan et al. Scientific Reports 2012

Northeastern University

Acknowledgement

- **NSF-**Designing Materials to Revolutionize and Engineer our Future (DMREF 1434824-*Materials Genome Initiative*)
- **NSF** ECCS-1202376
- NSF CHN-Center for Highrate Nanomanufacturing, NEU
- **US Army** under grant W911NF-10-2-0098, subaward 15-215456-03-00.
- Ministry of Energy, Industry, and Trade (MOEIT) Republic of Korea

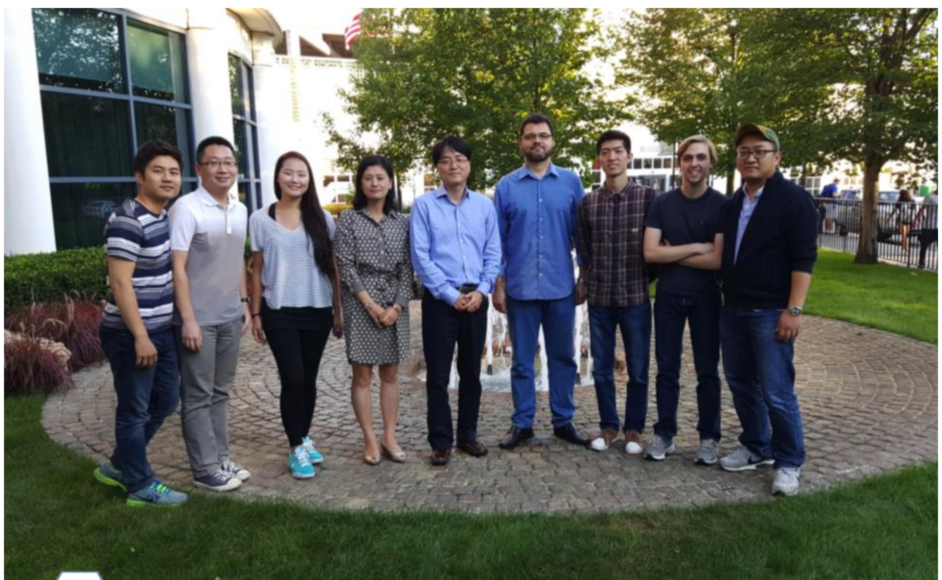
산업통상자원부
MINISTRY OF TRADE, INDUSTRY & ENERGY

Northeastern
UNIVERSITY

Acknowledgement

Contributions from Our Group Members

Prof. Hyunyoung Jung (KNUST, Korea)
Prof. MyungGwan Hahm (Inha University, Korea)
Dr. Younglae Kim (Intel, Portland)
Prof. Bo Li (Villanova Univ. PA.)
Prof. Rodrigo Lavall (Federal Univ. of Minas Gerais, Brazil)
Sanghyun Hong (PhD)*, Ji Hao (PhD), Heyhee Kim (PhD),*
Sen Gao (PhD), Jeonghoon Nam (PhD)
Zane Gavin (UG), Alexander Keklak (UG)



Collaborators

Prof. S. Kar (NEU), Prof. P. Ajayan (Rice Univ.), Prof. A. Busnaina (NEU), Prof. Y. Homma (Tokyo Univ. Science)
Dr. C. Ahn (KAIST-NanoFab)*, Dr. Ann Chiramonti (NIST), Prof. G.H. Gilmer (CSM)*
*Prof. Dongsik Kim (POSTECH)****, Prof. M. Upmanyu (NEU), Prof. C. Livermore (NEU)***
Prof. Jonghwan Suhr (SKKU), Dr. Sung Lee (KRICT), Prof. Y. Kwon (KyungHee Univ.), Dr. Jeremy Robinson (Naval Research Lab.) Prof. David Luzzi (NEU)

JRG Jung's Research Group

Northeastern UNIVERSITY