Tailoring Carbon Nanomaterials for Emerging Applications

presented by

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School of Chemical and Biomedical Engineering

23 June 2015 @ 東京大学

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Carbon Materials

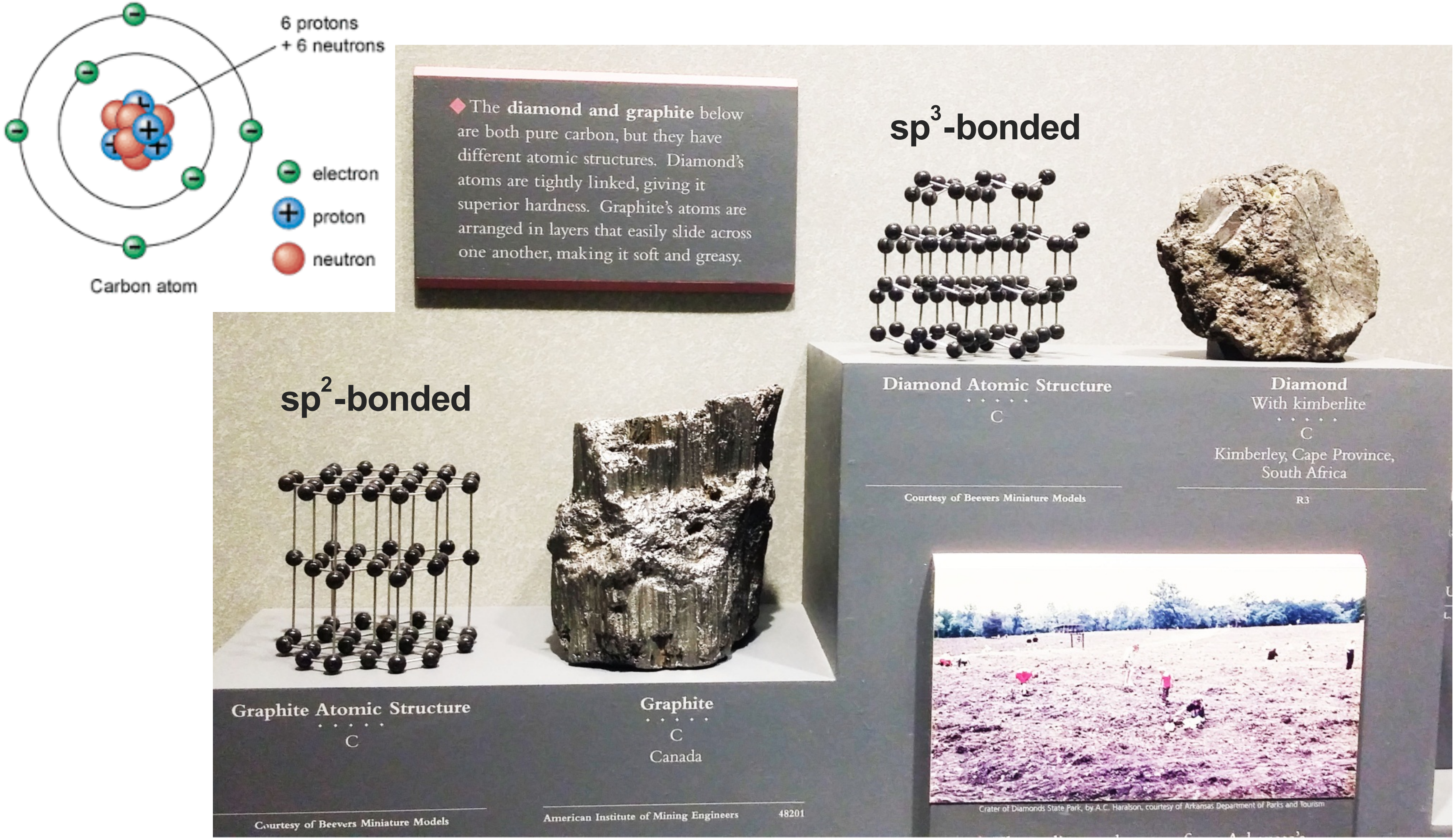
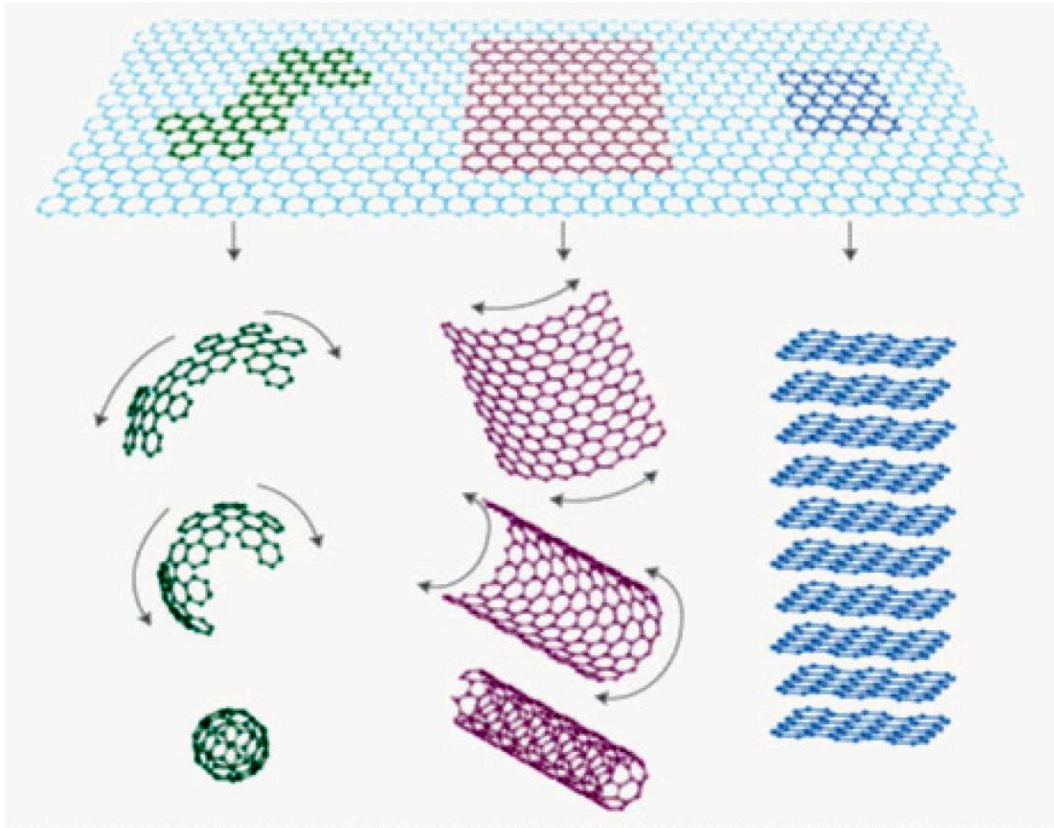
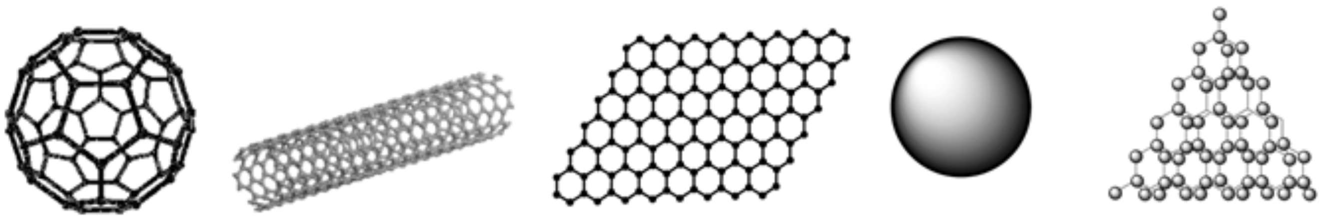


Photo from Smithsonian National Museum of Natural History

Carbon Nanomaterials



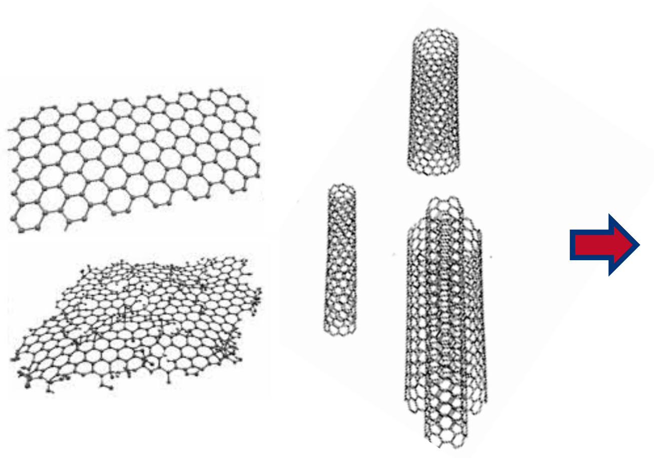


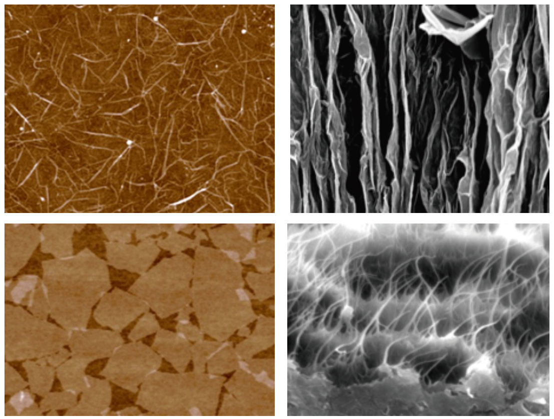
Images from wikipedia.org and thno.org

My Research Scope

Fundamental understandings

Nanoscale structures | *Macroscale architectures* | *Performance evaluations*





- *Macroelectronics*
- *Supercapacitors*
- *Smart textiles*
- *Electrocatalysts*
- *Membranes*
- *Antibacterial coatings*

Synthesis methods | *Assembly techniques* | *Application design*

Chemical process design and development

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Three Case Studies

- **Chirality selective synthesis of single-walled carbon nanotubes (SWCNTs)**
- Assembly of carbon nanotube/graphene hybrid carbon fibers for fiber supercapacitors
- Antibacterial activity of carbon nanotubes and graphene

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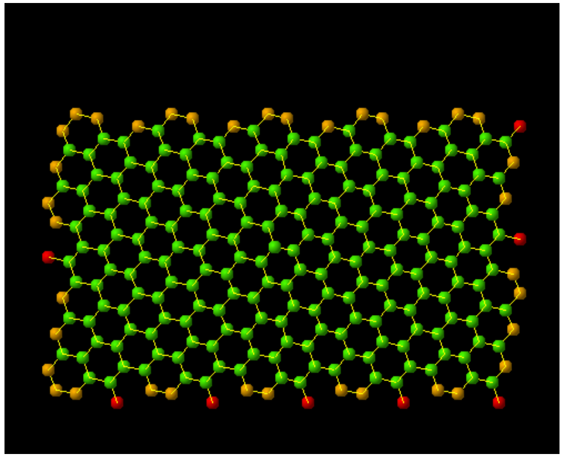
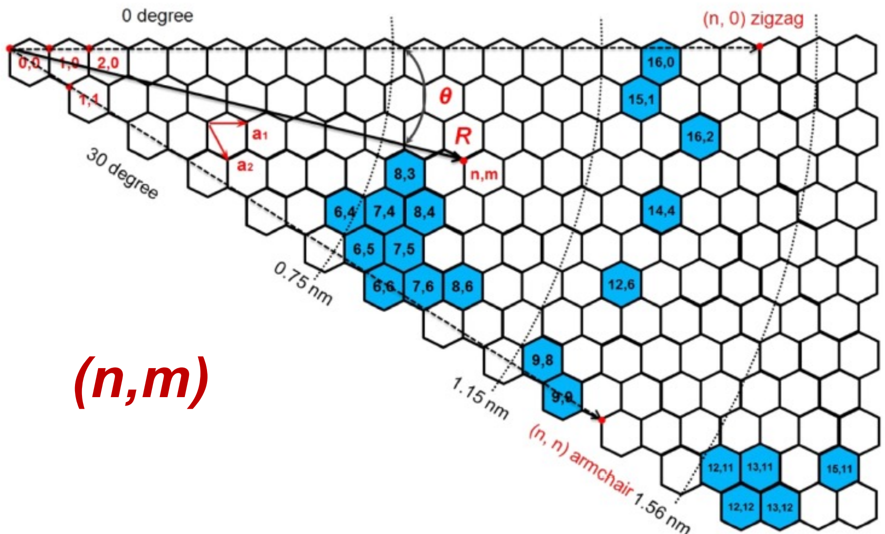
Chirality of SWCNTs





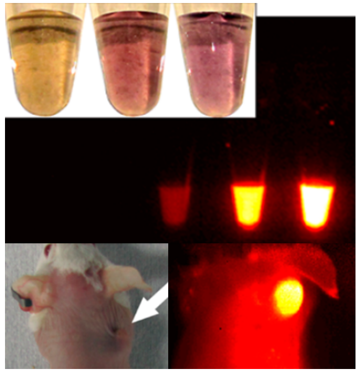
Metallic (n-m = 3j)

Semiconducting (n-m = 3j+1 or 3j+2)

Conductive films

Electronic transistors

Photovoltaics



Bioimaging/phototherapy

Images from Prof. Maruyama; Carbon, 2015, 81, 1; and JACS, 2013, 7, 3644

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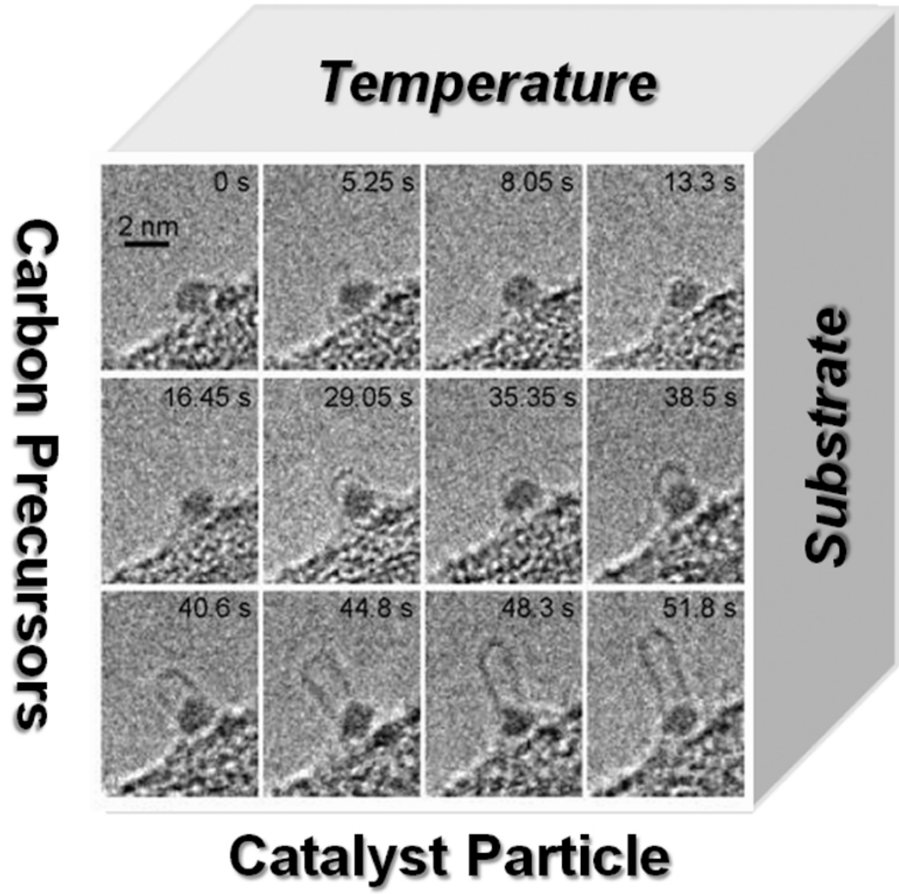
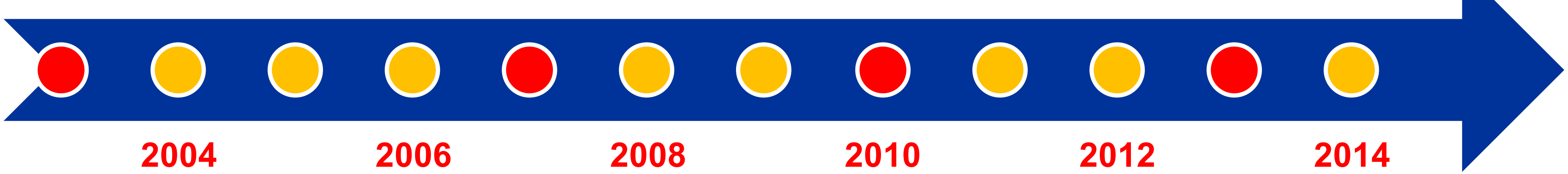
Catalysts in Chemical Vapor Deposition of SWCNT Synthesis



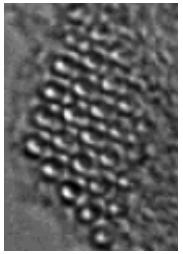
Nano Letter, 2008, 7, 2082 ; Carbon, 2015, 81, 1

Efforts on Chirality Selective Synthesis

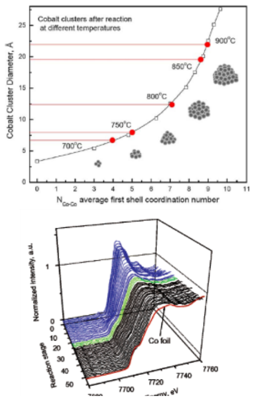


2003

Co-MCM-41
(JPCB, 107, 11048; 108, 503)



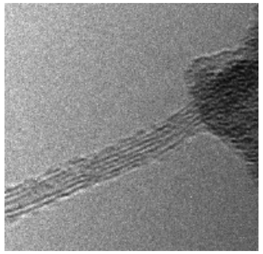
2004



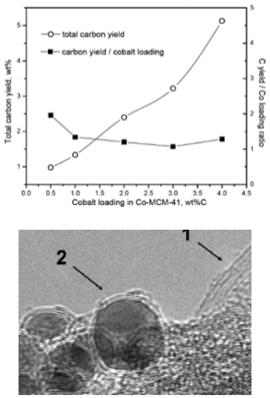
T/P effects
(JOC, 225, 453; 226, 351; JPCB, 108, 15565)

2005

Ni-MCM-41
(Nanotechnology, 16, S476)



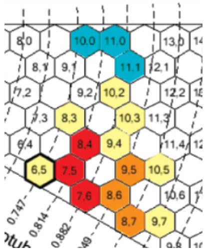
2006



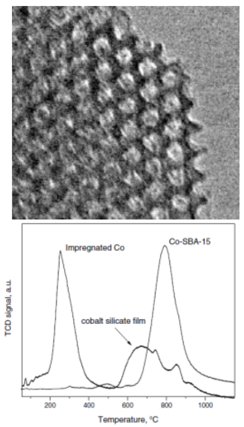
Metal loading
(Carbon, 44, 67)

2007

Carbon feeds/P
(JACS, 129, 9014; Carbon, 45, 2217, JPCC, 111, 14612)



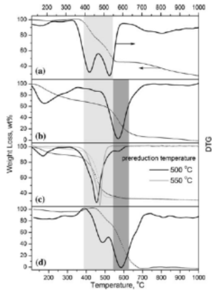
2008



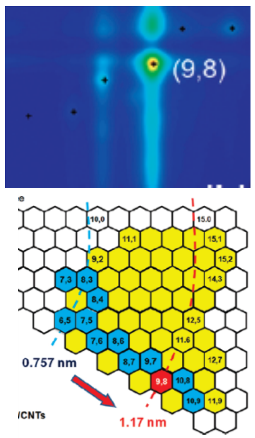
Co-SBA-15
(MMM, 110, 347)

2009

Supports (JMS, 44, 3285 Nano, 4, 99)



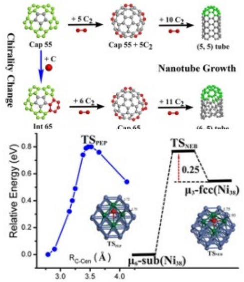
2010



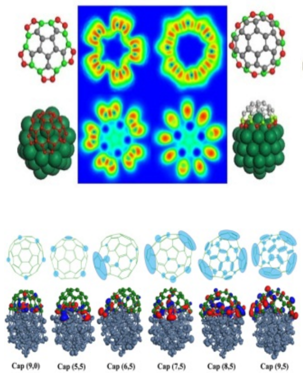
Co-TUD-1
(JACS, 132, 16747)

2011

Carbon dimer
(ACS Nano, 4, 939 TCA, 128, 17)



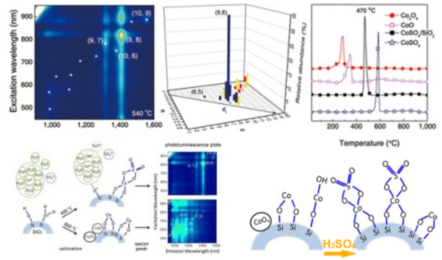
2012



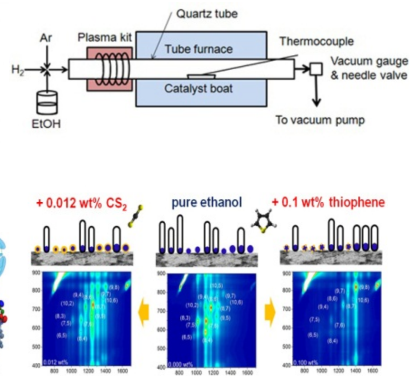
Reactive sites
(JPCL, 2, 1009; JPCA, 116, 11709)

2013

$CoSO_4$/SiO2
(ACS Nano, 7, 614; JOC, 300, 91; CC, 49, 2031)



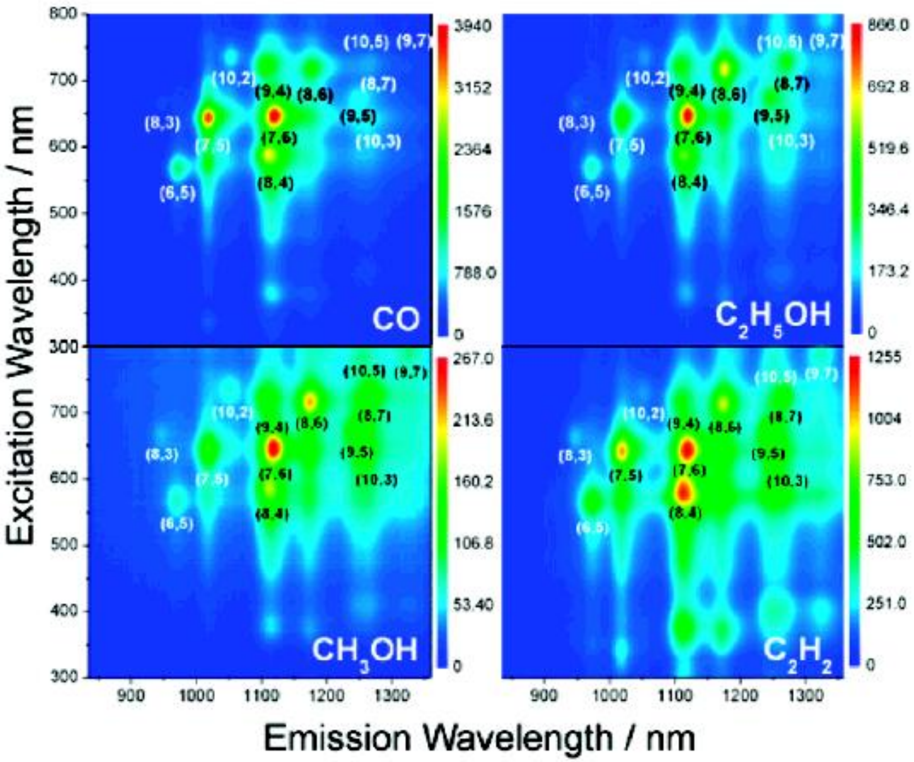
2014

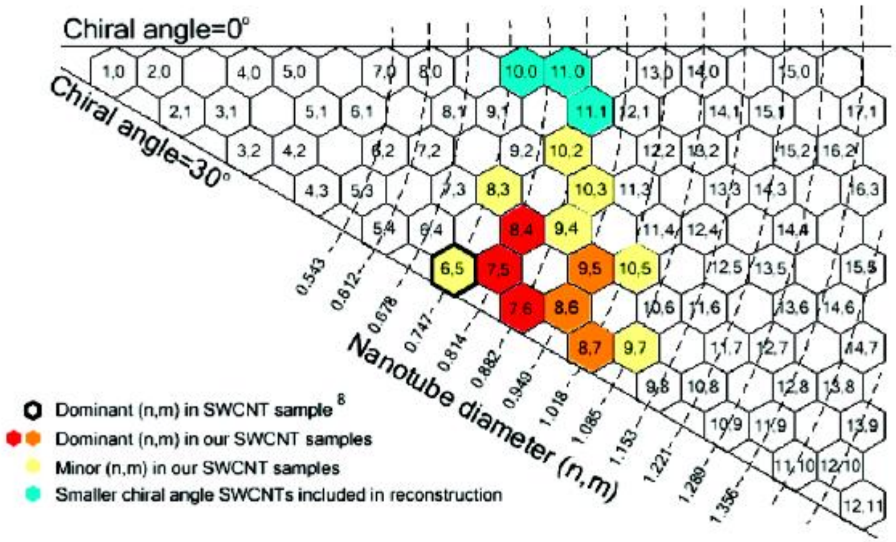


Plasma/S
(Carbon, 66, 134; JMCA, 3, 3310)

Effect of Carbon Precursors

- Similar chirality distribution can be obtained using different carbon precursors
- Predominantly in the same high chiral angel region





JACS, 2007, 129, 9014

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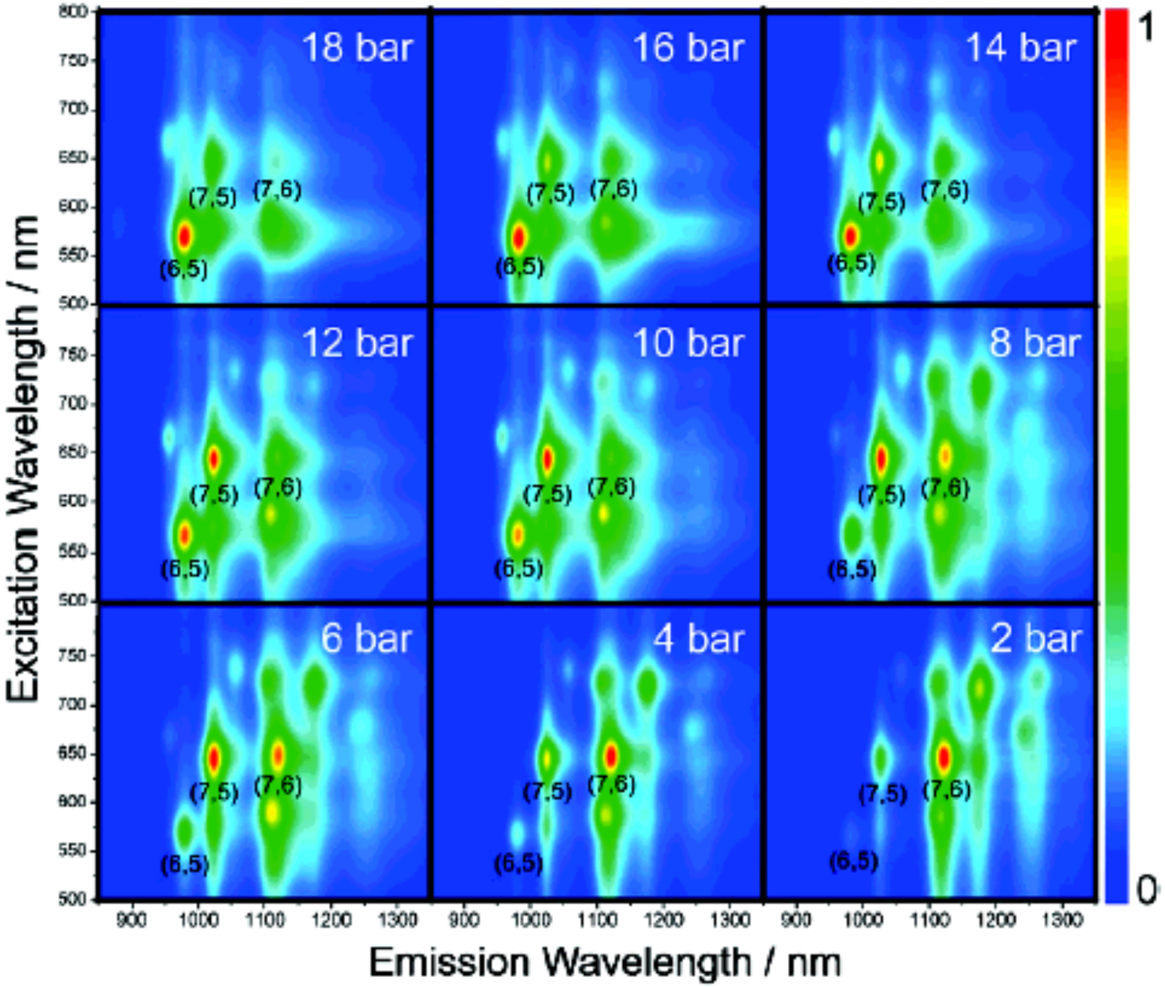
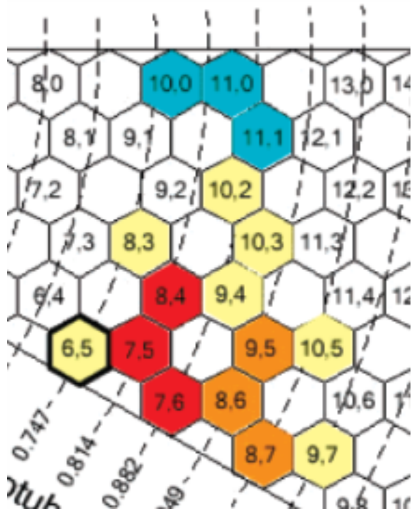
Pressure Induced Chirality Selectivity Changes





Journal of Physical Chemistry C, 2007, 111, 14612

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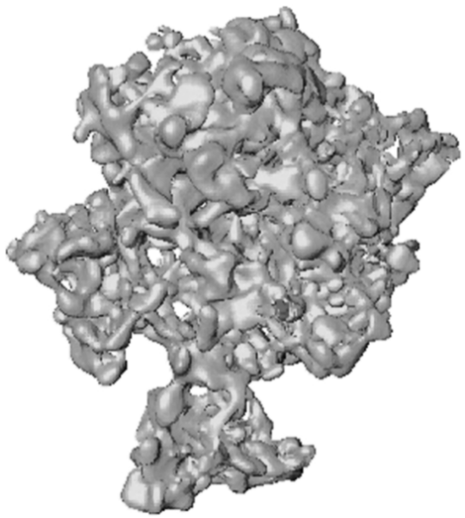
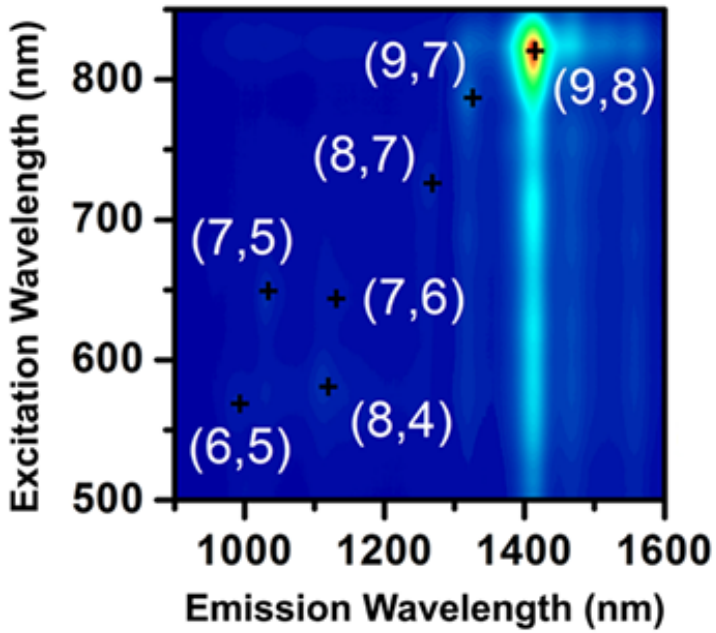
Co-TUD-1 Catalyst

- SWCNTs with narrow (n,m) distribution at about 1.2 nm



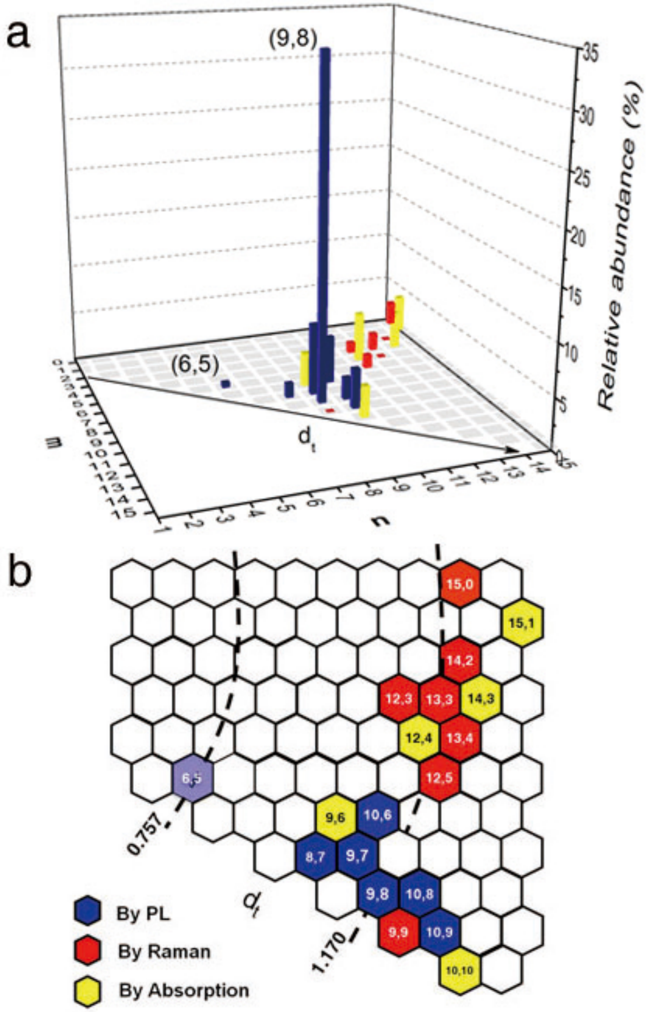
3D amorphous structure
with random and
interconnecting pores

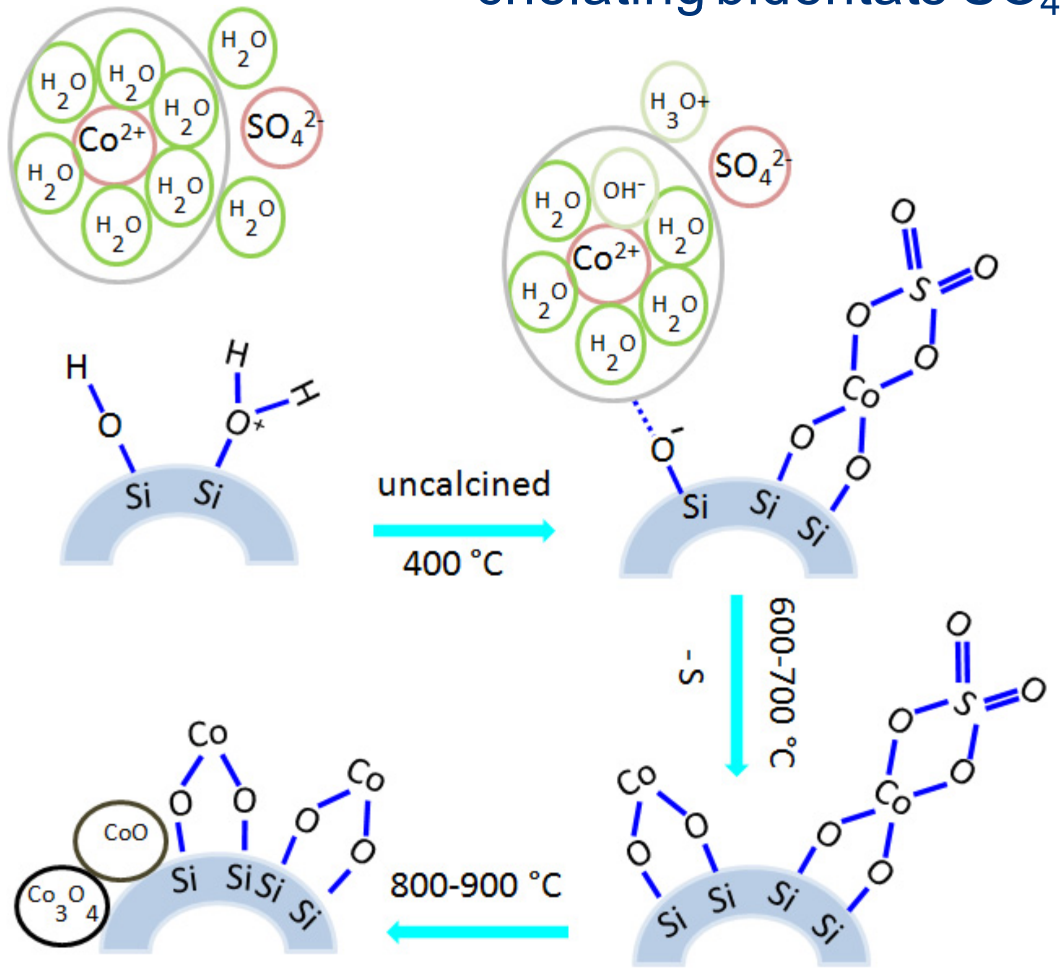


JACS, 2010, 132, 16747

$CoSO_4/SiO_2$ Catalyst

Oxolation reaction
chelating bidentate SO_4^{2-}





ACS Nano, 2013, 7, 614 ; Journal of Catalysis, 2013, 300, 91

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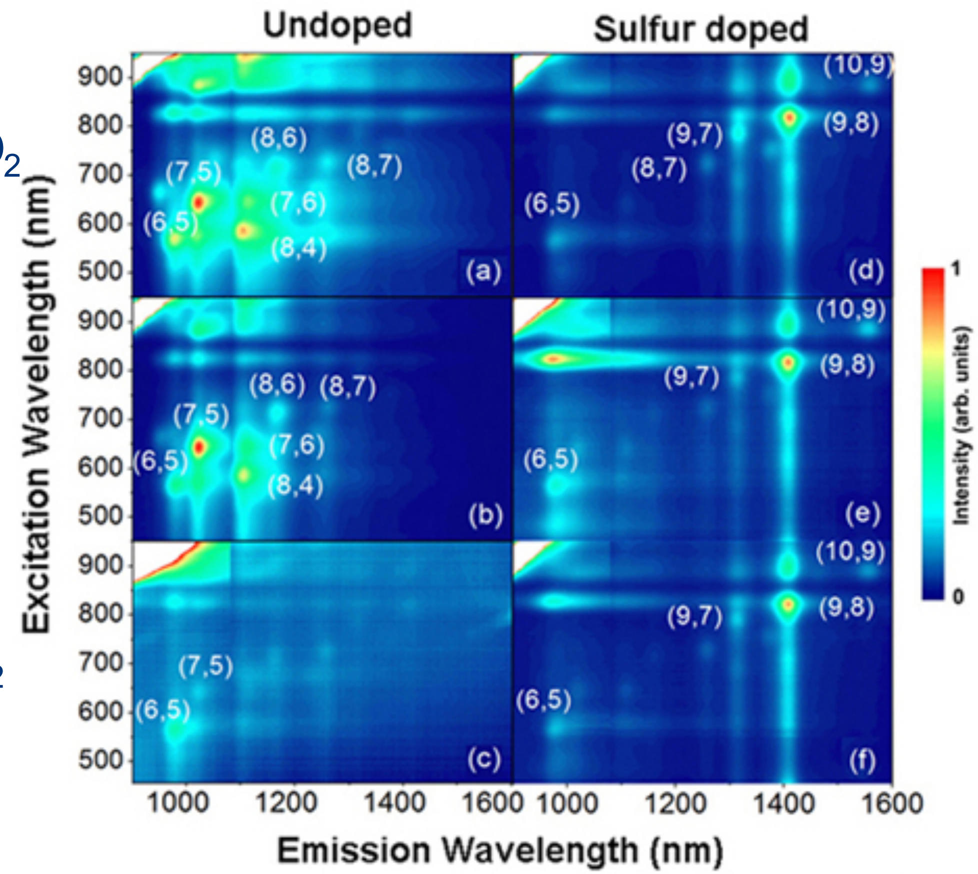
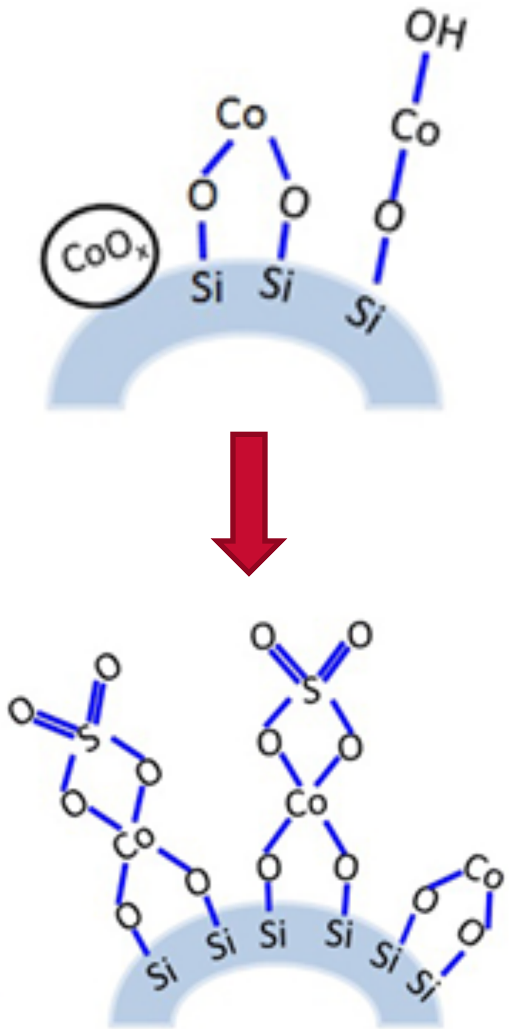
Sulfur Induced Chirality Selectivity

$Co(acac)_2/SiO_2$

$CoCl_2/SiO_2$

$Co(NO_3)_2/SiO_2$





Chemical Communications, 2013, 49, 2031

Catalysts for Chirality Selective Synthesis of SWCNTs

CARBON 81 (2015) 1–19

Available at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/carbon

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Review

Catalysts for chirality selective synthesis of single-walled carbon nanotubes

CrossMark

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A R T I C L E I N F O

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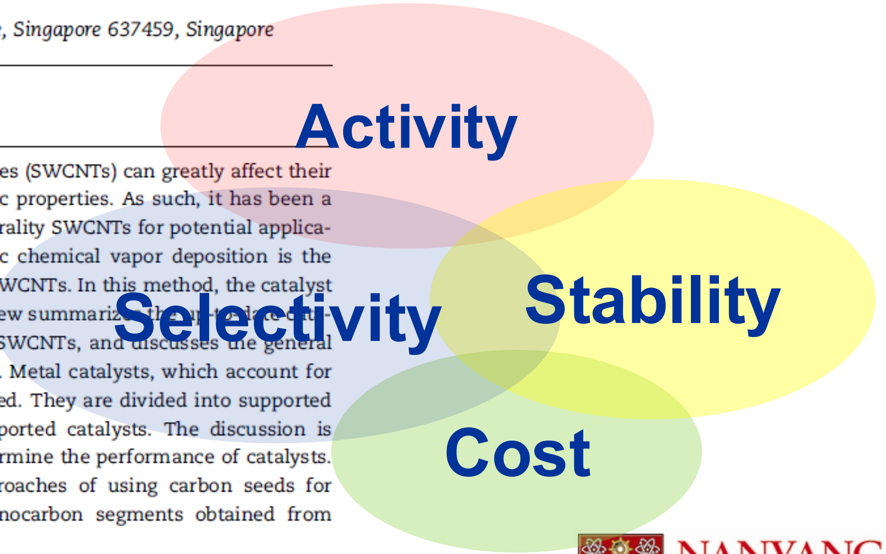
A B S T R A C T

The chiral structures of single-walled carbon nanotubes (SWCNTs) can greatly affect their electronic, optical, thermal, mechanical and magnetic properties. As such, it has been a long-standing goal to selectively synthesize single chirality SWCNTs for potential applications ranging from electronics to medicine. Catalytic chemical vapor deposition is the prevalent method for chirality selective synthesis of SWCNTs. In this method, the catalyst plays a critical role in the chirality selection. This review summarizes the up-to-date catalyst development for chirality selective synthesis of SWCNTs, and discusses the general principles in current state-of-the-art catalyst designs. Metal catalysts, which account for the majority of catalysts used so far, are first reviewed. They are divided into supported catalysts on porous and flat substrates and unsupported catalysts. The discussion is focused on catalyst preparation methods, which determine the performance of catalysts. Next, non-metal catalysts are examined. New approaches of using carbon seeds for SWCNT "cloning" are also summarized. Lastly, nanocarbon segments obtained from organic synthesis for SWCNT growth are discussed.



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Three Case Studies

- Chirality selective synthesis of single-walled carbon nanotubes (SWCNTs)
- **Assembly of carbon nanotube/graphene hybrid carbon fibers for fiber supercapacitors**
- Antibacterial activity of carbon nanotubes and graphene

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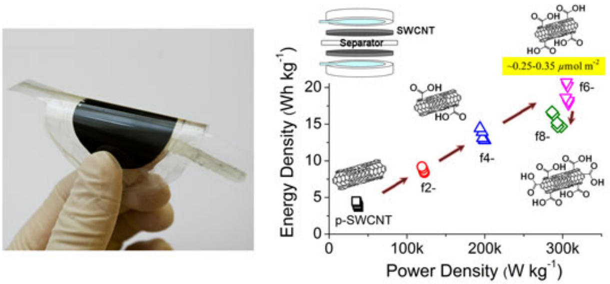
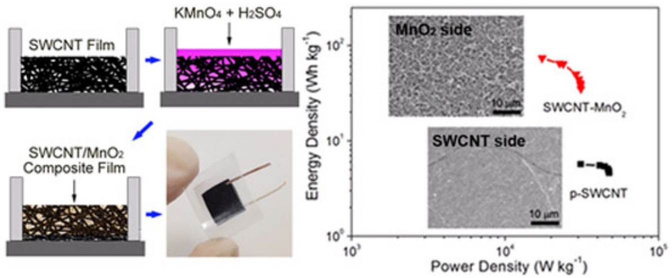
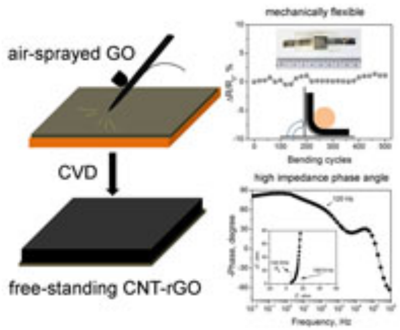
Carbon Based Electrodes/Electro-Catalysts



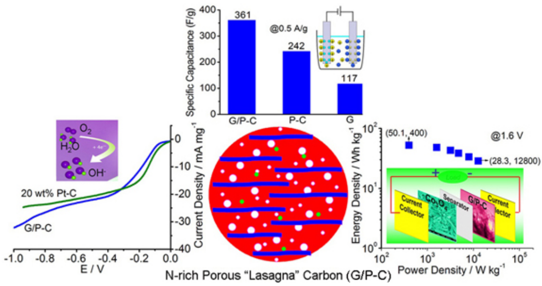
Energy & Environmental Science, 2011, 4, 4220



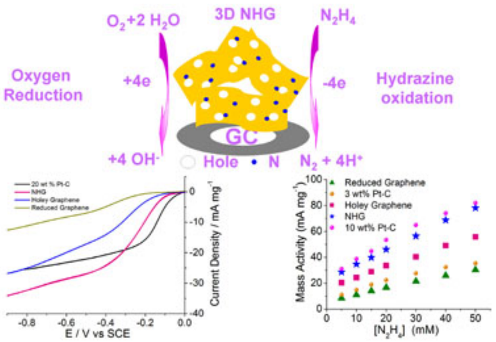
Electroochimia Acta, 2012, 78, 122-132



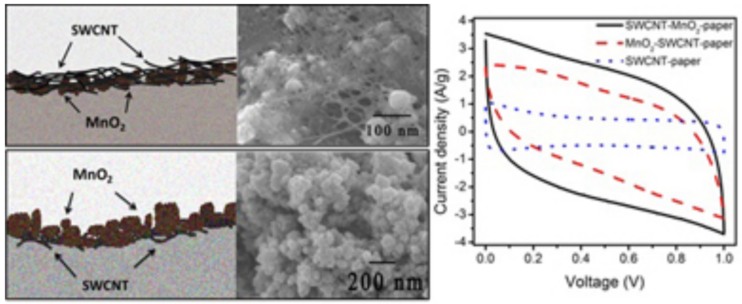
Journal of Solid State Chemistry, 2015, 224, 45



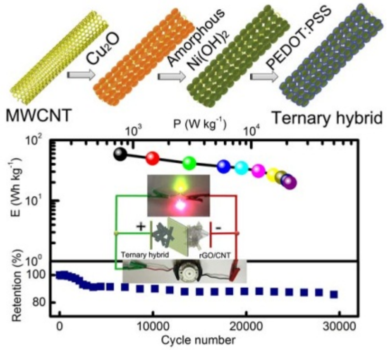
Journal of Materials Chemistry A, 2013, 1, 11061



Nanoscale, 2013, 5, 3457

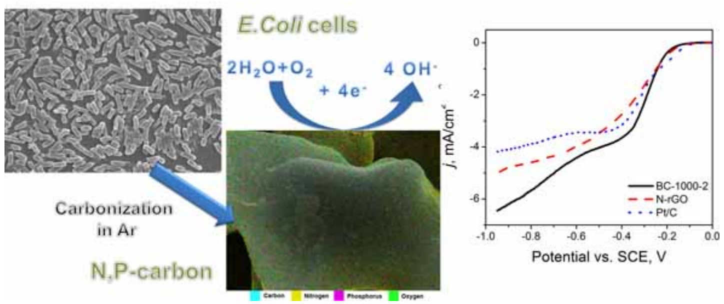


Nansocale, 2013, 5, 11108

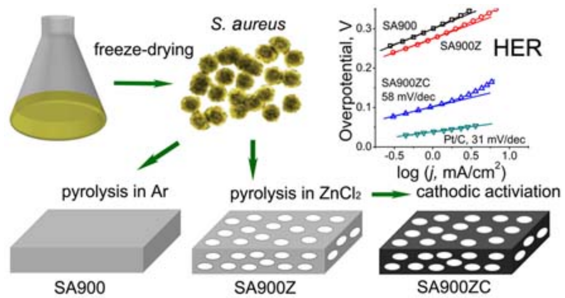


Advanced Functional Materials, 2015, 25, 1063

16



Catalysis Today, 2015, 249 228-235



Journal of Materials Chemistry A, 2015, 3, 7210-7214

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Emergence of Fiber Supercapacitors

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TUTORIAL REVIEW

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Cite this: DOI: 10.1039/c4cs00286e

Emergence of fiber supercapacitors

Dingshan Yu,[a] Qihui Qian,[a] Li Wei,[a] Wenchao Jiang,[a] Kunli Goh,[a] Jun Wei,[b] Jie Zhang[c] and Yuan Chen*[a]

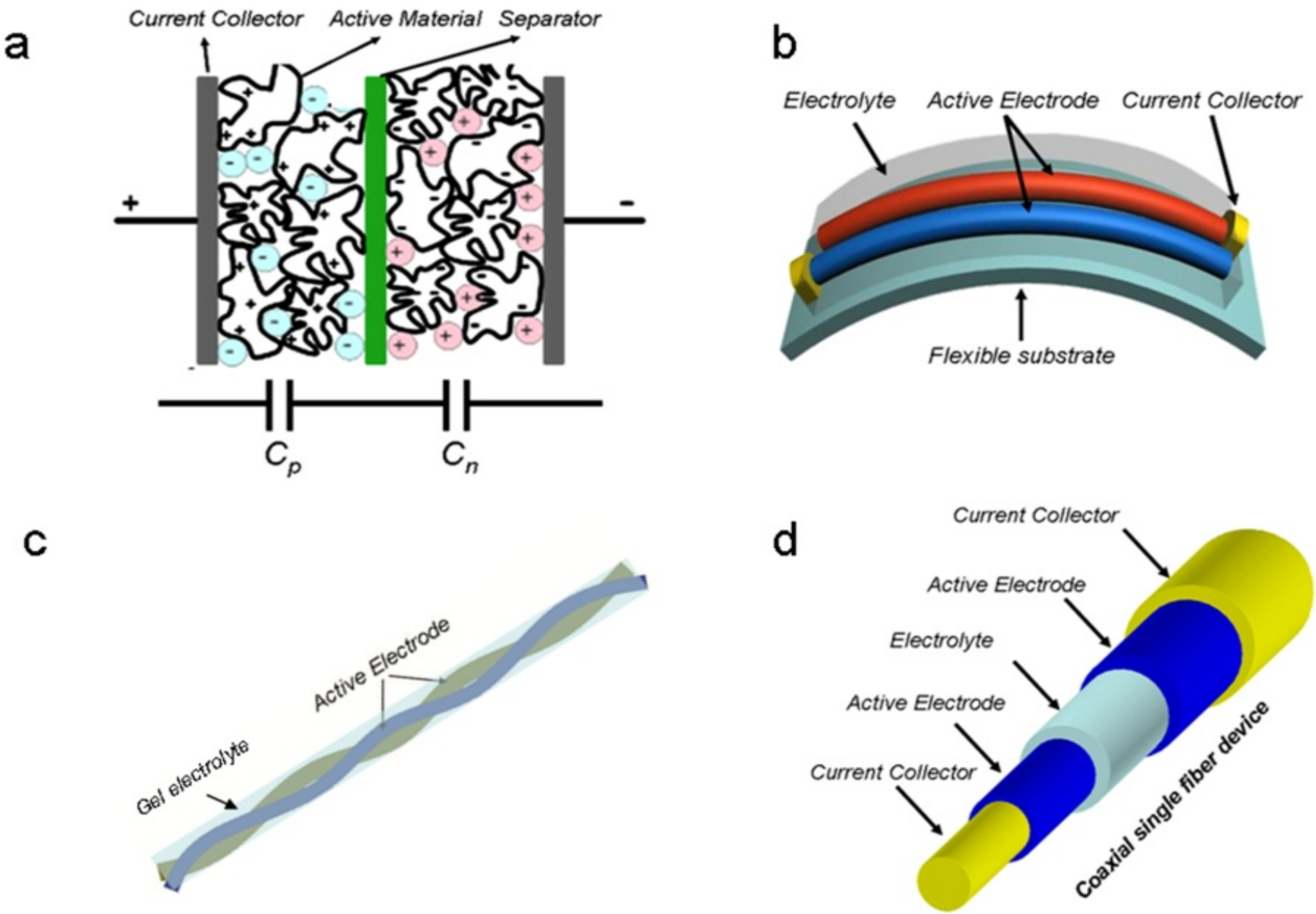
Supercapacitors (SCs) are energy storage devices which have high power density and long cycle life. Conventional SCs have two-dimensional planar structures. As a new family of SCs, fiber SCs utilize one-dimensional cylindrically shaped fibers as electrodes. They have attracted significant interest since 2011 and have shown great application potential either as micro-scale devices to complement or even replace micro-batteries in miniaturized electronics and microelectromechanical systems or as macro-scale devices for wearable electronics or smart textiles. This tutorial review provides an essential introduction to this new field. We first introduce the basics of performance evaluation for fiber SCs as a foundation to understand different research approaches and the diverse performance metrics reported in the literature. Next, we summarize the current state-of-the-art progress in structure design and electrode fabrication of fiber SCs. This is followed by a discussion on the integration of multiple fiber SCs and the combination with other energy harvesting or storage devices. Last, we present our perspectives on the future development of fiber SCs and highlight key technical challenges with the hope of stimulating further research progress.

Received 28th August 2014

DOI: 10.1039/c4cs00286e

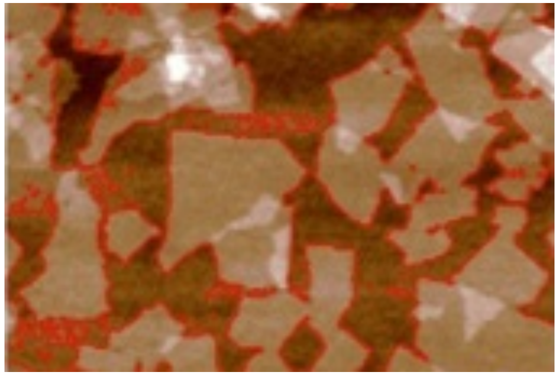
www.rsc.org/csr

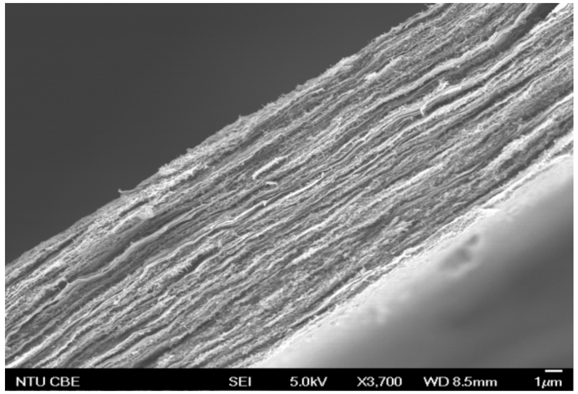
Emergence of Fiber Supercapacitors



Synthesis of Carbon Composites

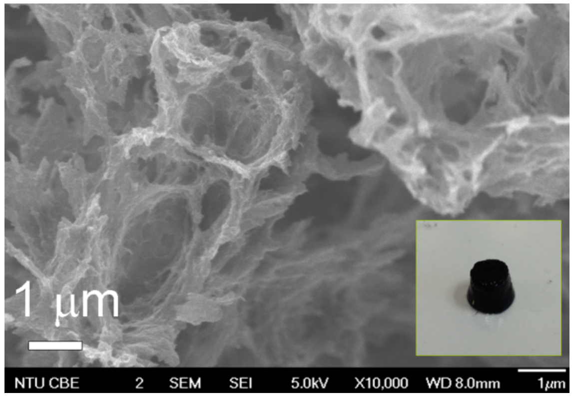
Graphene oxide sheets
Specific surface area: 2630 m^2/g





Stacked GO films: 20-50 m^2/g

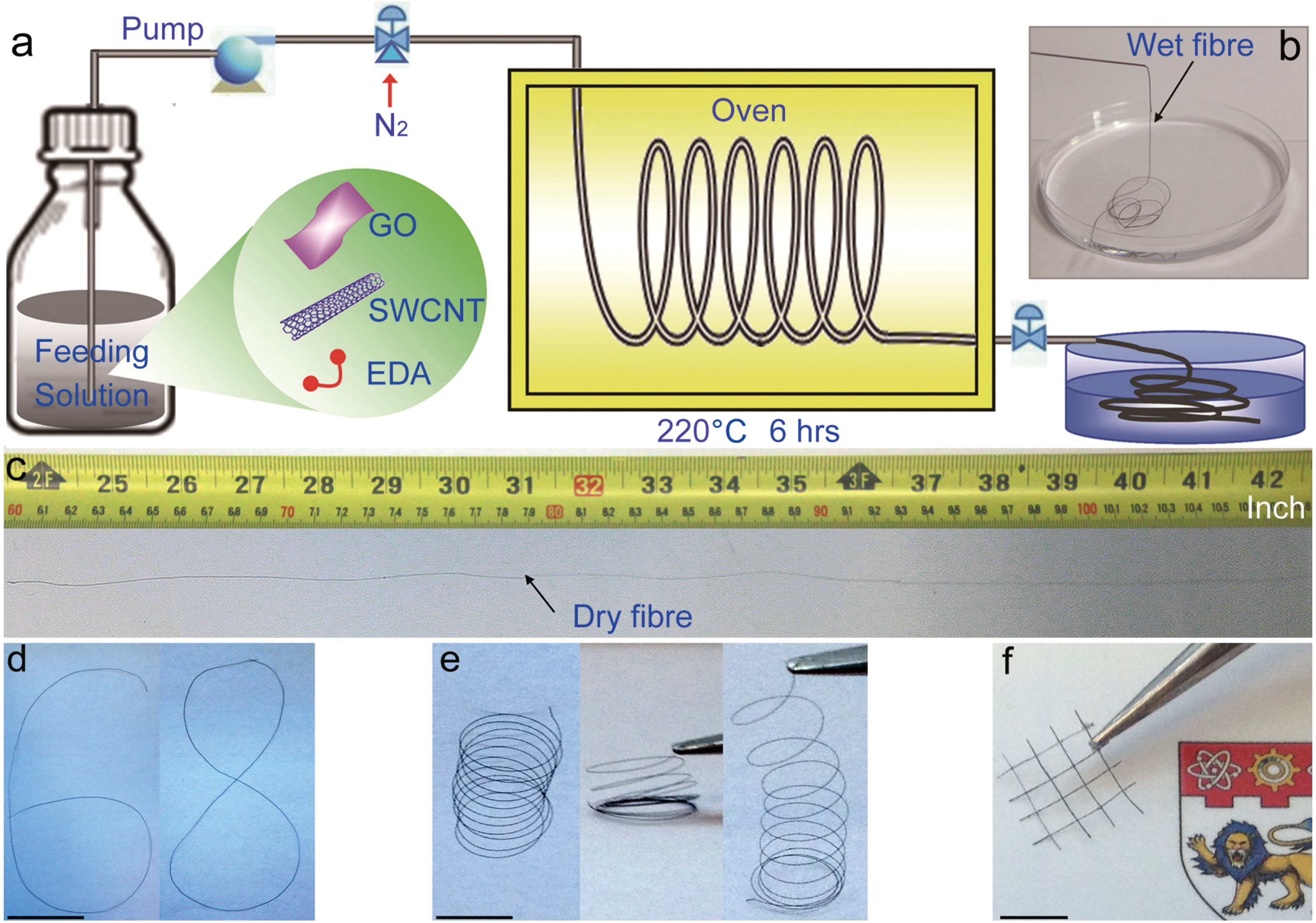
Hydrothermal synthesis in autoclaves



3D GO composites: 800 m^2/g
Density: < 1 mg/cm^3

***Nanoscale*, 2013, 5, 3457; *Journal of Materials Chemistry A*, 2013, 1, 11061**

Synthesis of Carbon Hybrid Fibers



Nature Nanotechnology, 2014, 9, 555

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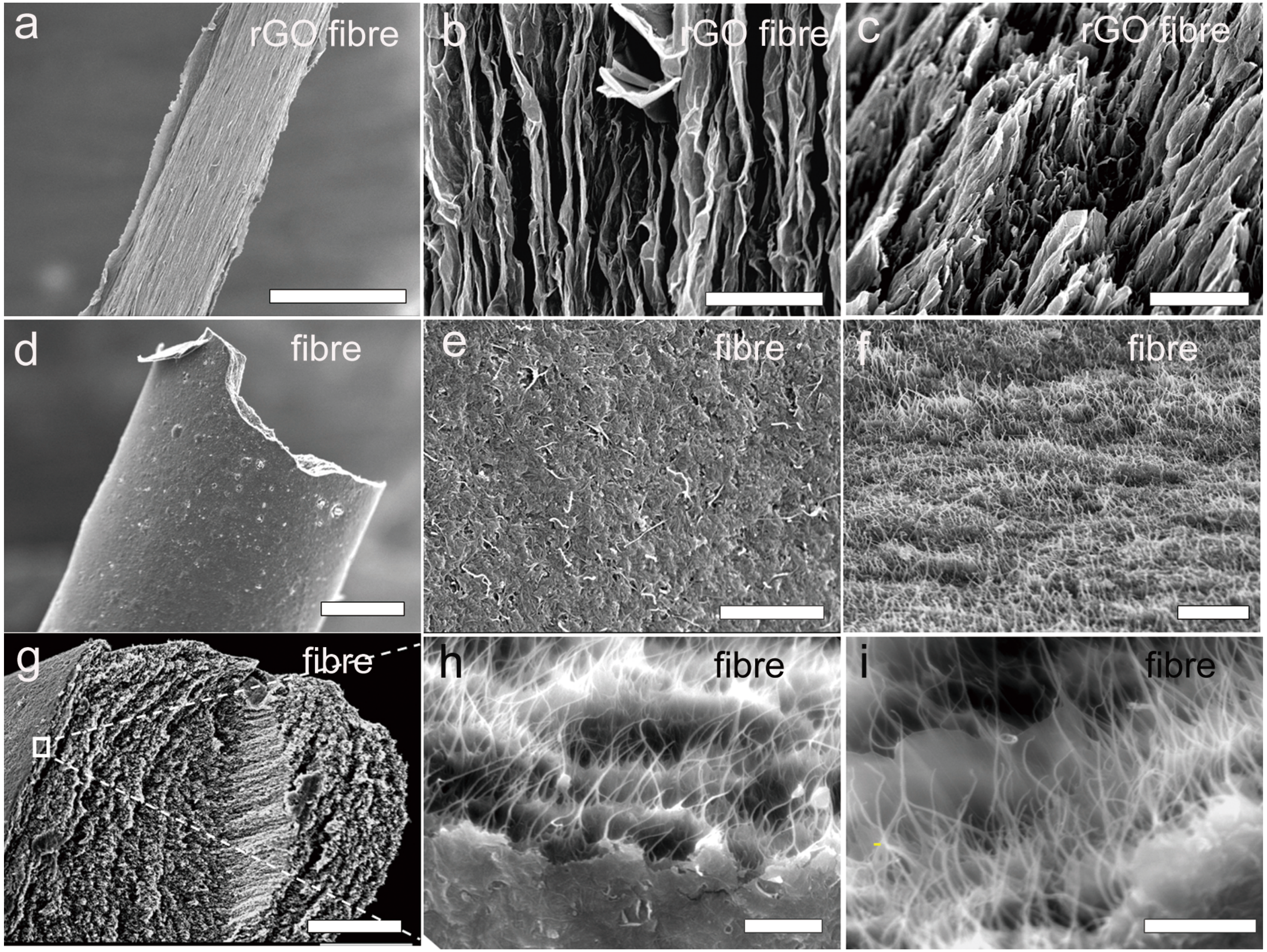
3D Composite Confined within 1D Fiber



Nature Nanotechnology, 2014, 9, 555

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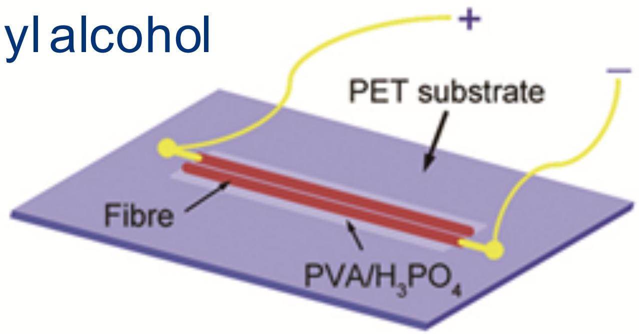
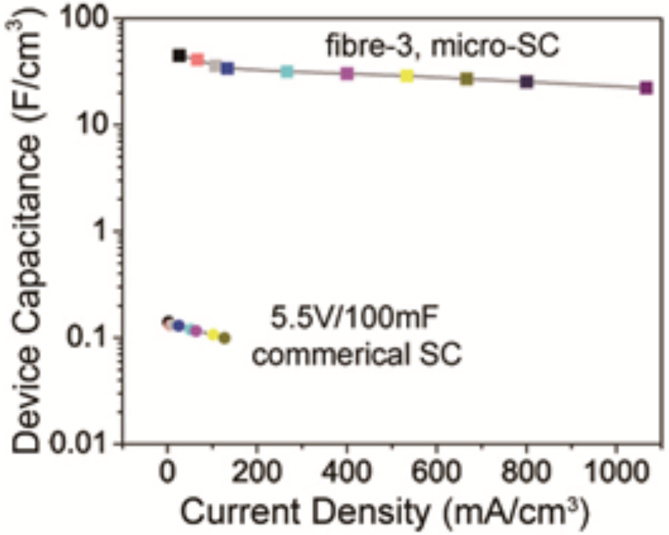
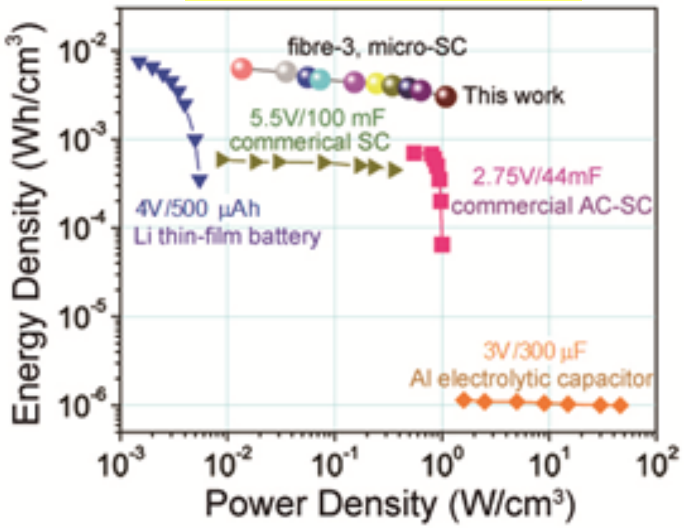
All-Solid-State Flexible Fiber Capacitors

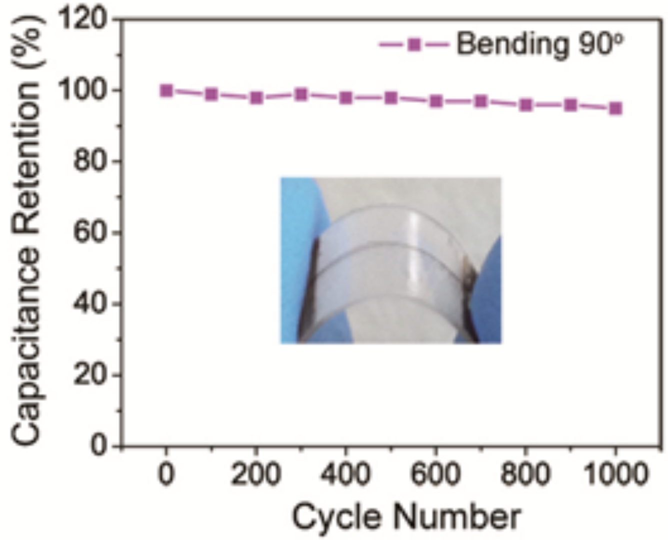
polyvinyl alcohol





6.3 mWh/cm3





Nature Nanotechnology, 2014, 9, 555

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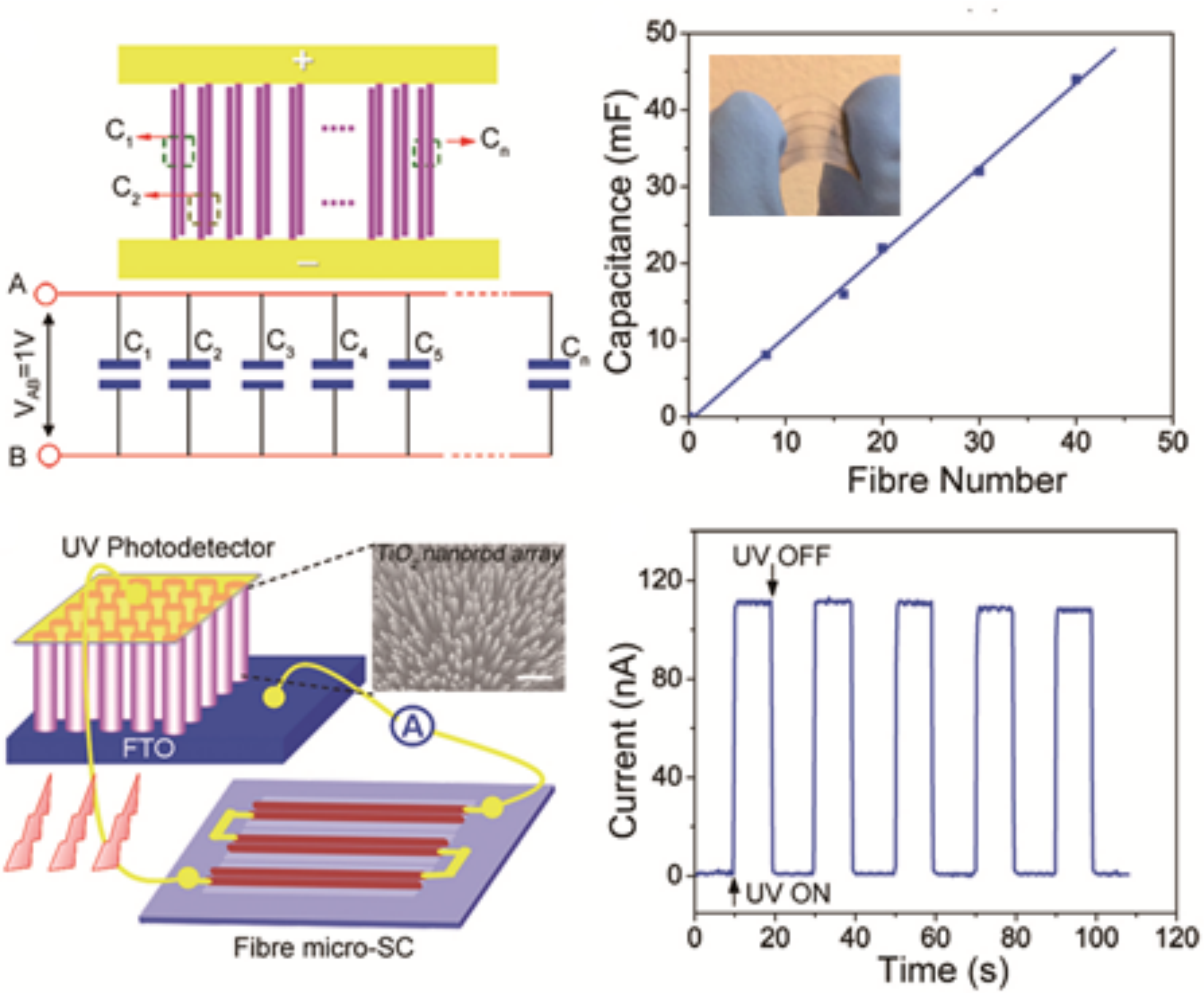
Integration in a Self-Powered Nanosystem



Nature Nanotechnology, 2014, 9, 555

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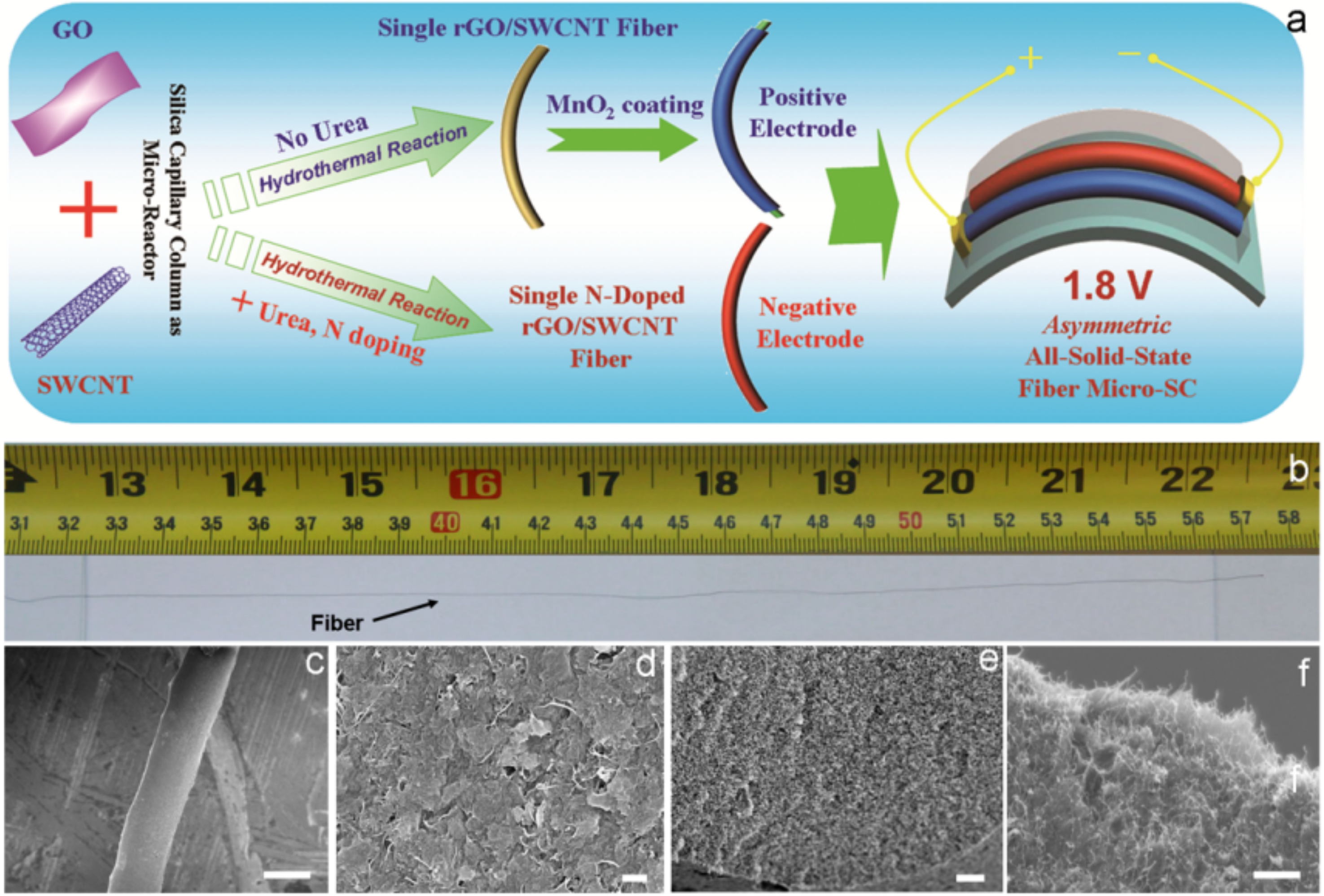
Controlled Functionalization of Carbon Hyrbid Fibers



Advanced Materials, 2014, 26, 6790

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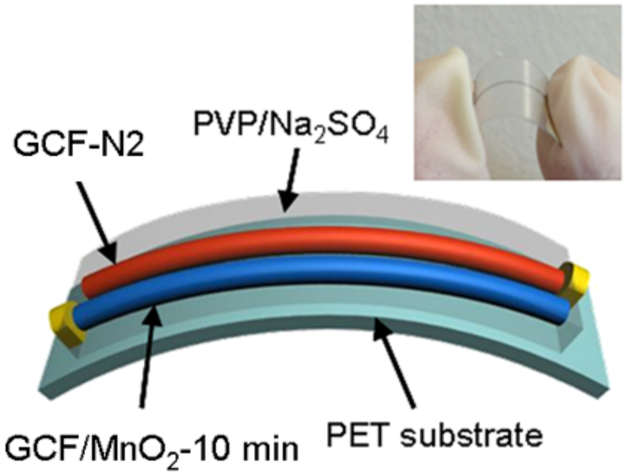
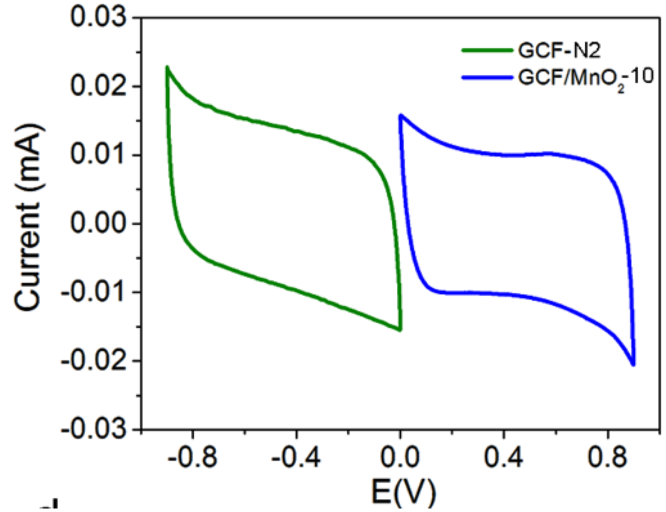
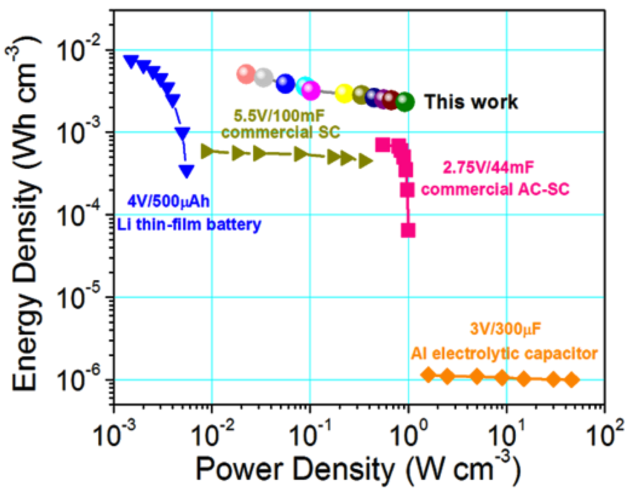
Asymmetric Solid-State Micro-Supercapacitors



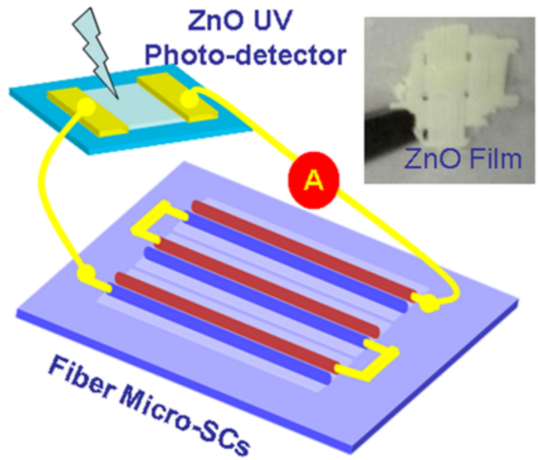
Neutral Electrolyte



Wider voltage window: 1.8 V



High energy/power density



Integratable in nanosystem

Advanced Materials, 2014, 26, 6790

Three Case Studies

- Chirality selective synthesis of single-walled carbon nanotubes (SWCNTs)
- Assembly of carbon nanotube/graphene hybrid carbon fibers for fiber supercapacitors
- **Antibacterial activity of carbon nanotubes and graphene**

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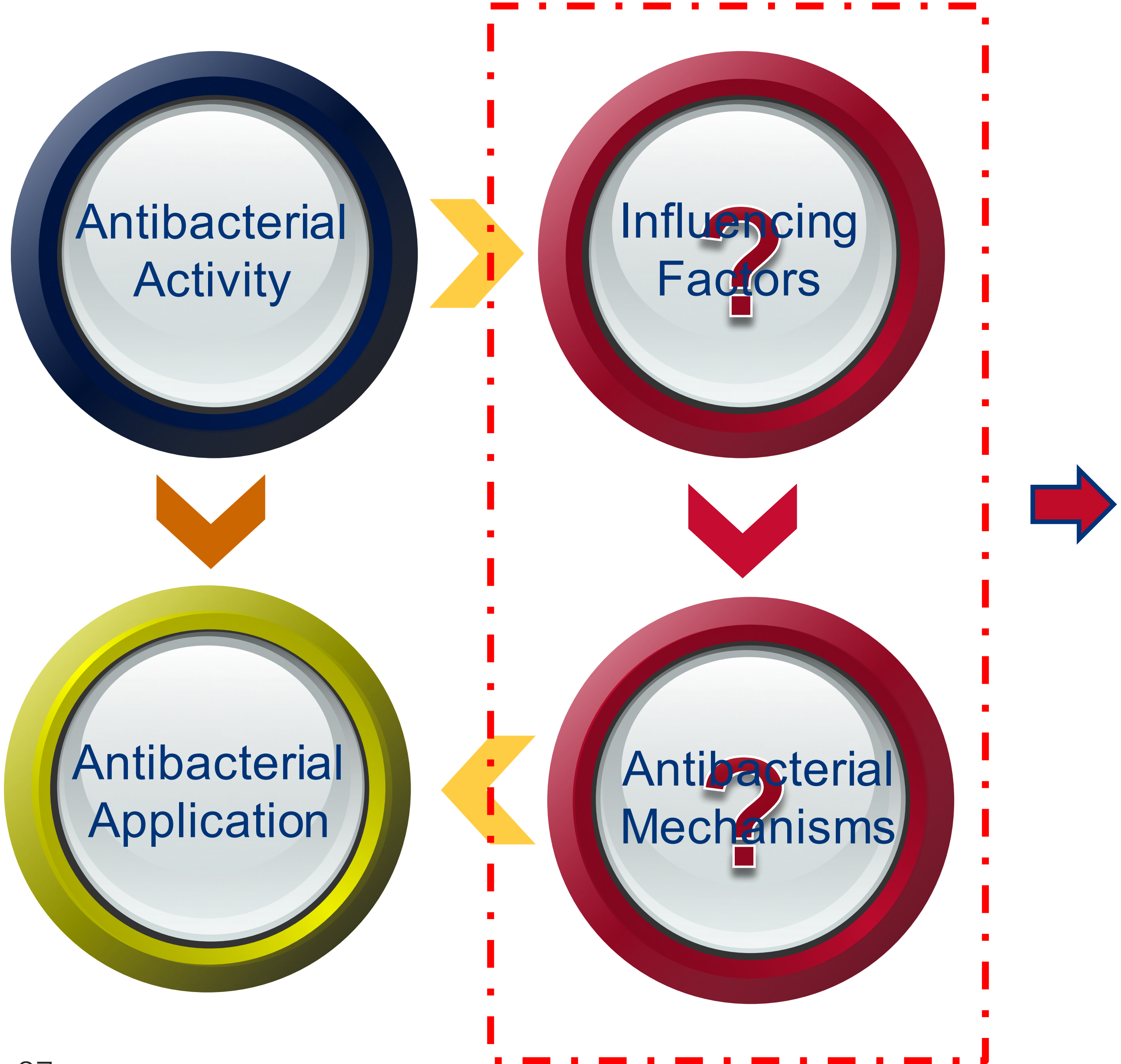

maximize the CNM antibacterial application potentials and minimize risks

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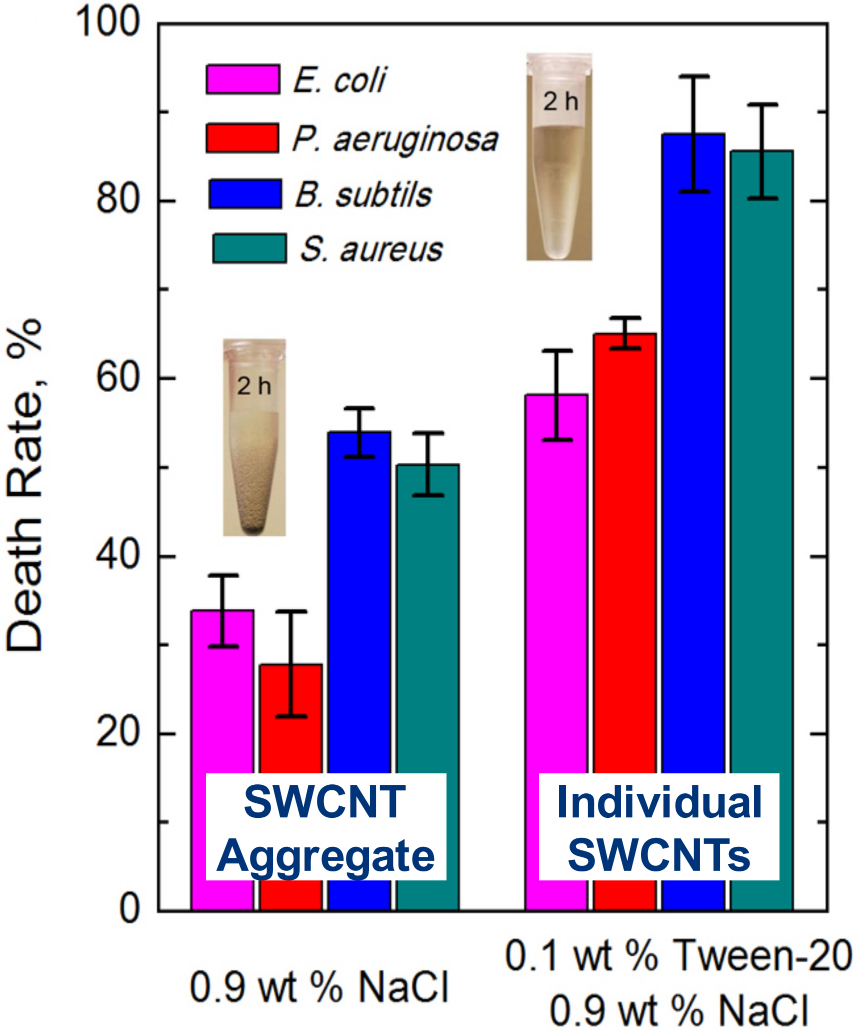
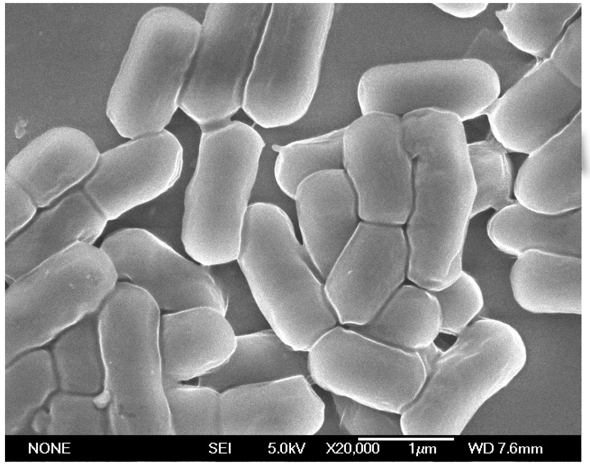
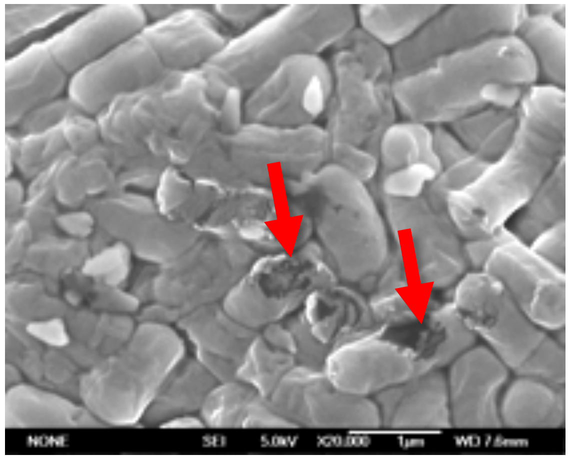
Dispersed SWCNTs Kill More Bacteria







ACS Nano, 2009, 3, 3891

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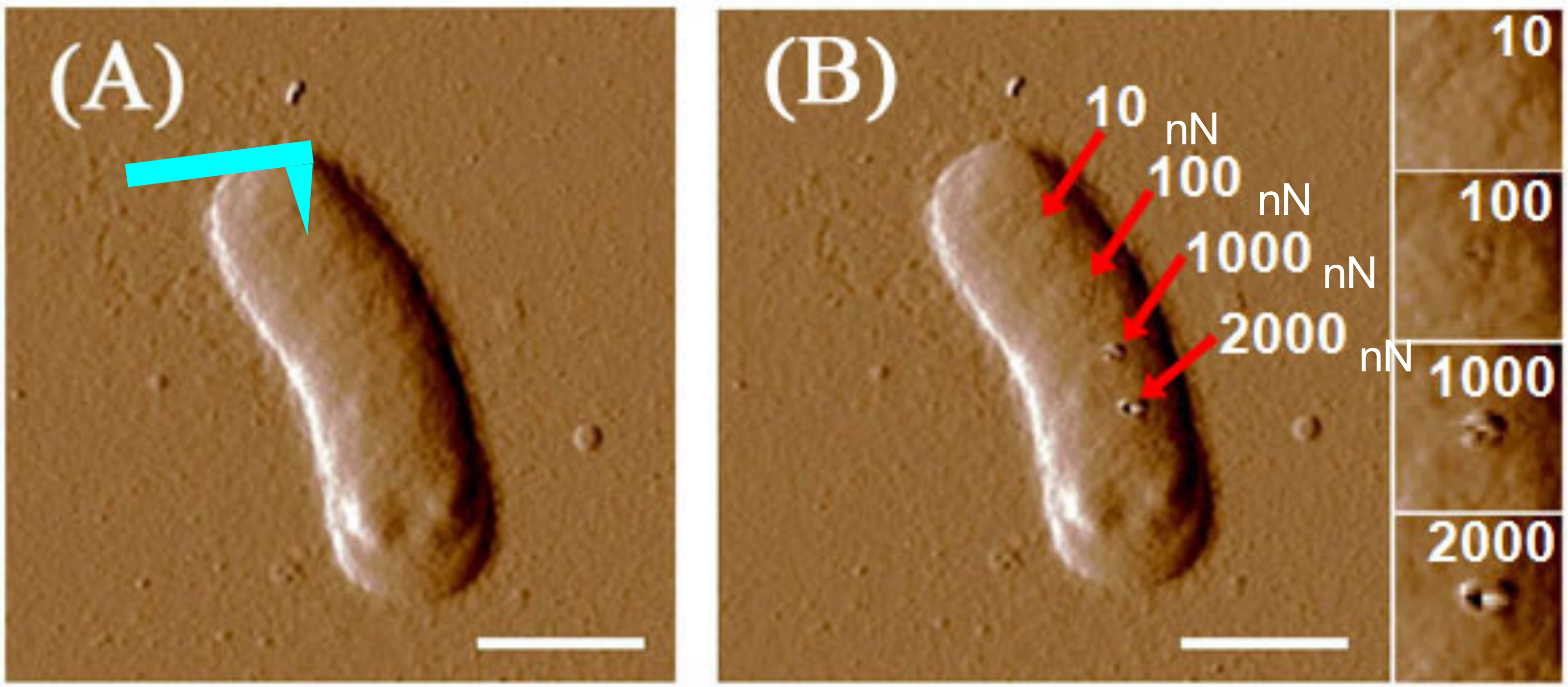
Atomic Force Microscopic Study of Cells

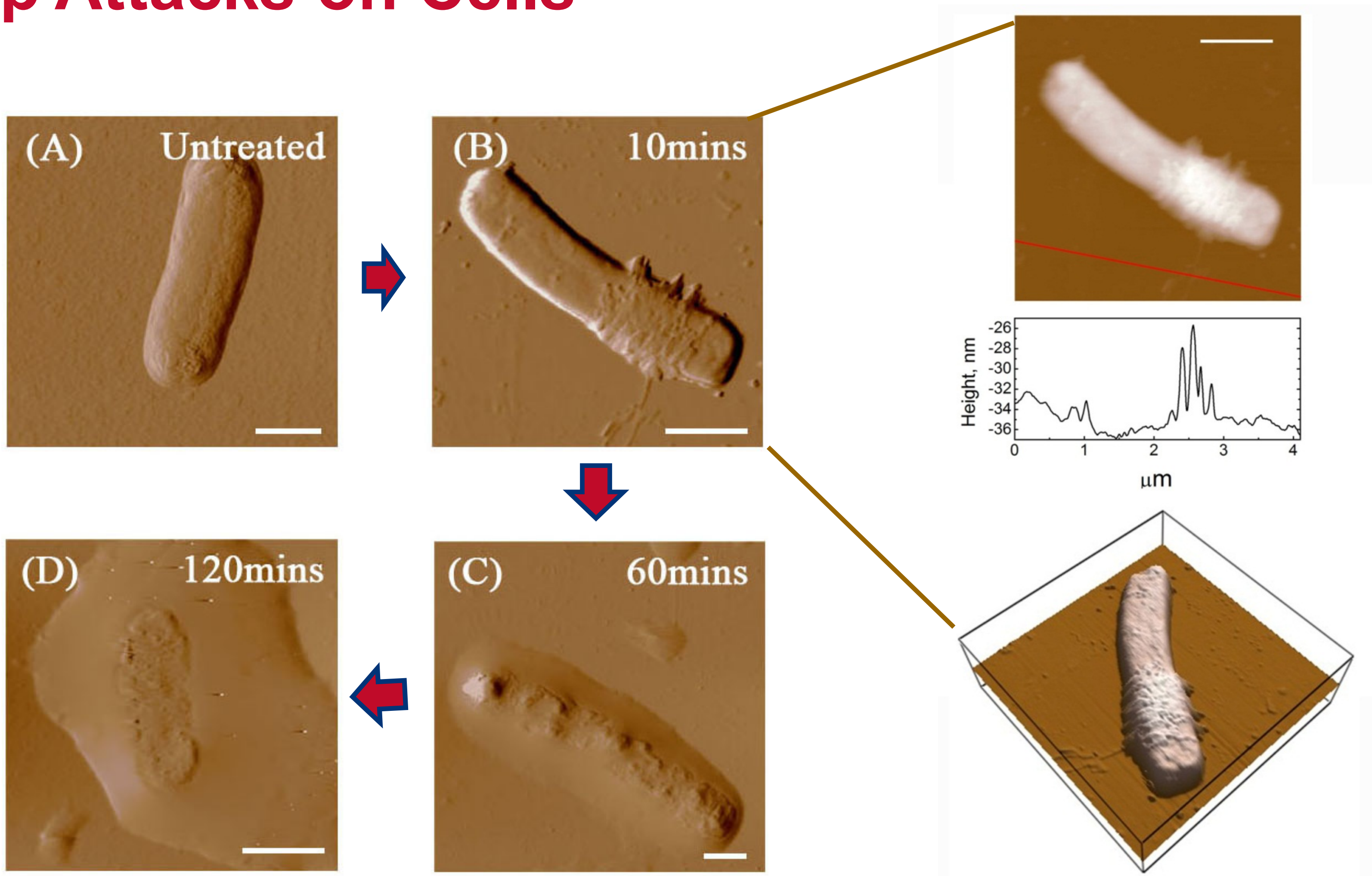


AFM amplitude images of (A) E. coli and (B) E. coli after piercing by a 2 nm AFM tip for 200 times at different locations.

SWCNTs dispersed in solution cannot induce large forces (> 10 nN)

Nanoscale, 2010, 2, 2744

Group Attacks on Cells

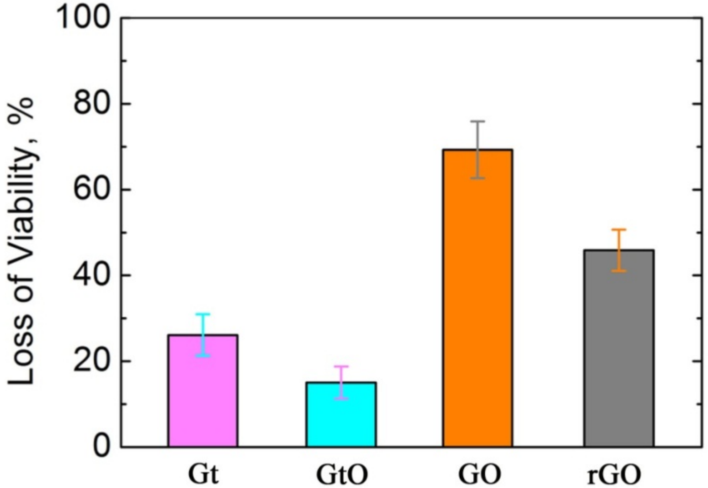


The antibacterial activity of SWCNTs is the accumulation effect of large amount of nanotubes through interactions between SWCNT networks and bacterial cells.

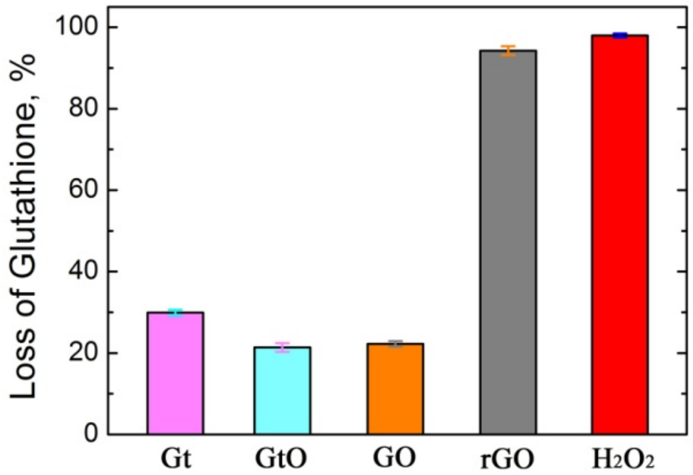
***Nanoscale*, 2010, 2, 2744**

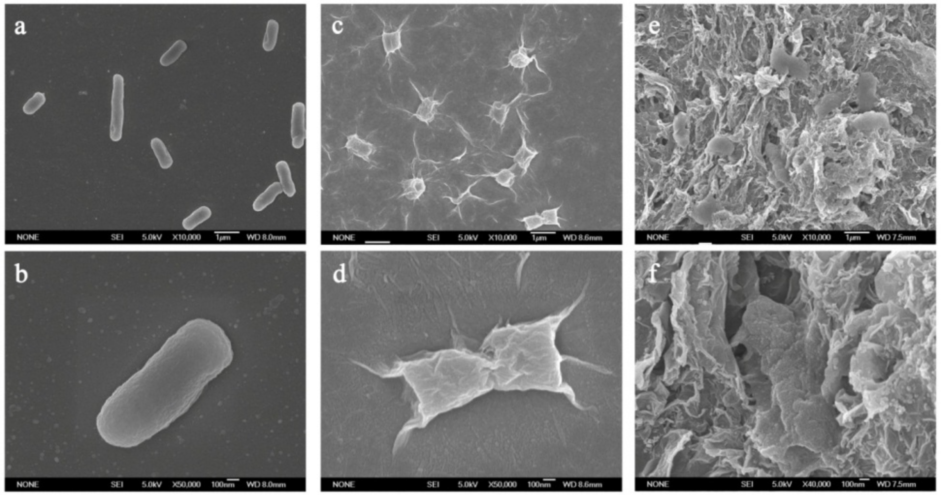
Antibacterial Activity of Graphene Based Materials

Antibacterial activity
GO > rGO > Gt > GtO



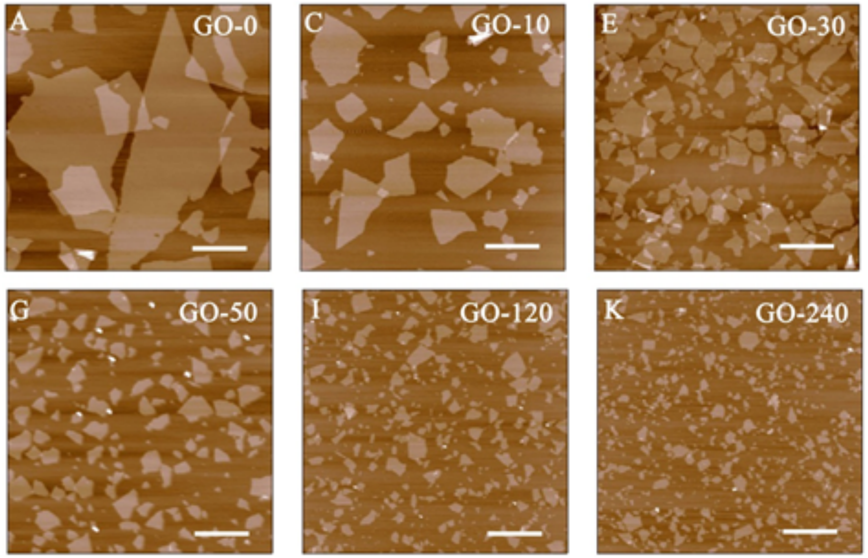
Oxidative stress
rGO > Gt > GO ≈ GtO

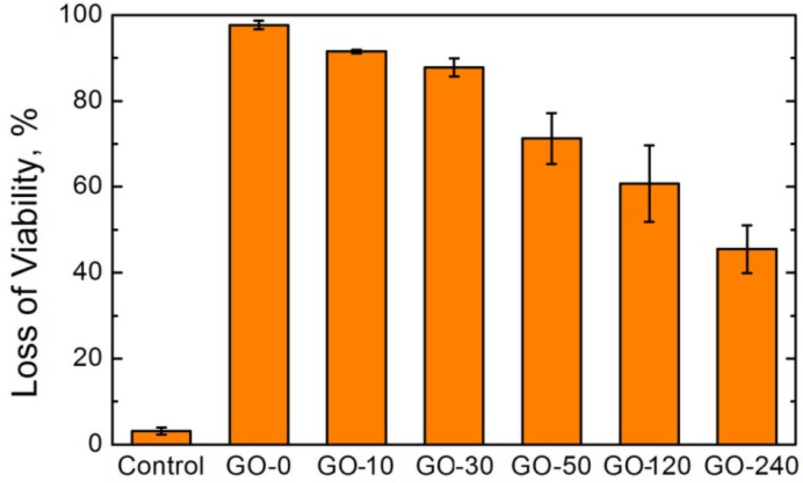


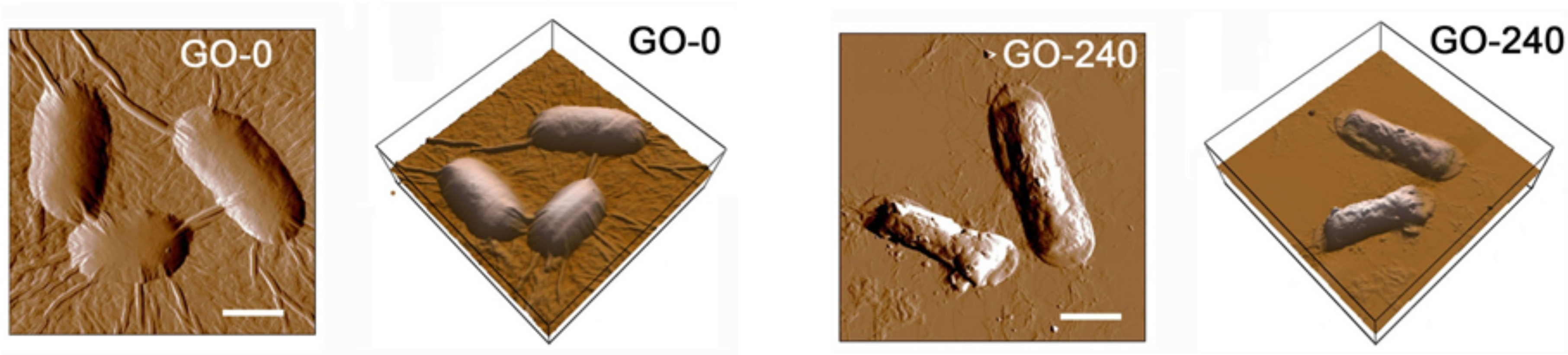


ACS Nano, 2011, 5, 6971

Size Effect on Antibacterial Activity of GO







Langmuir, 2012, 28, 12364

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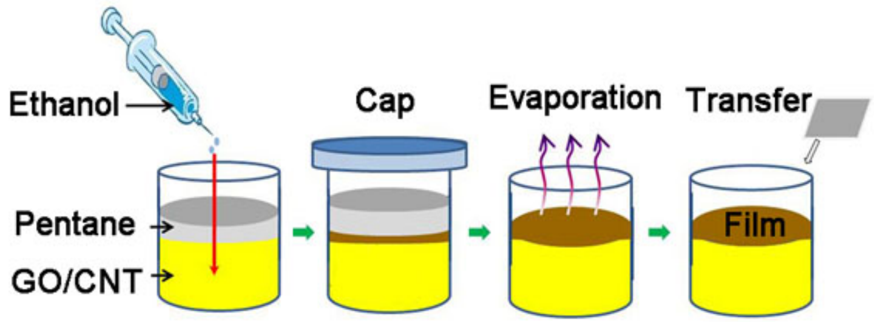
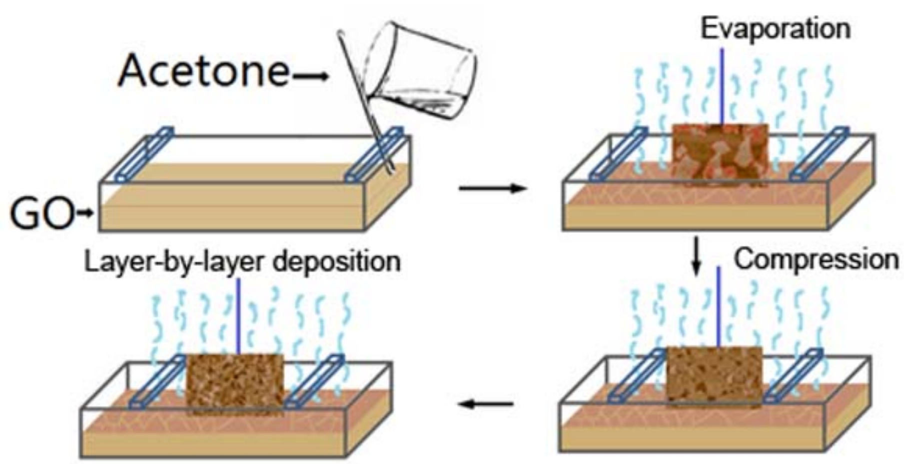
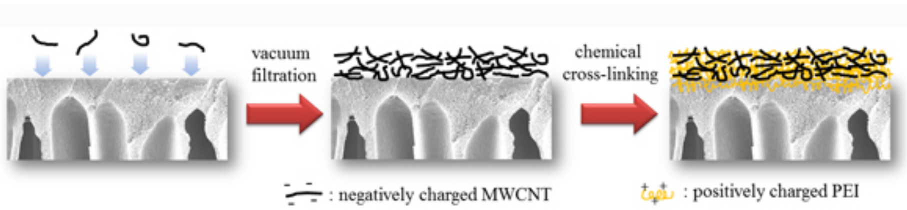
Exploring Potential Antibacterial Applications



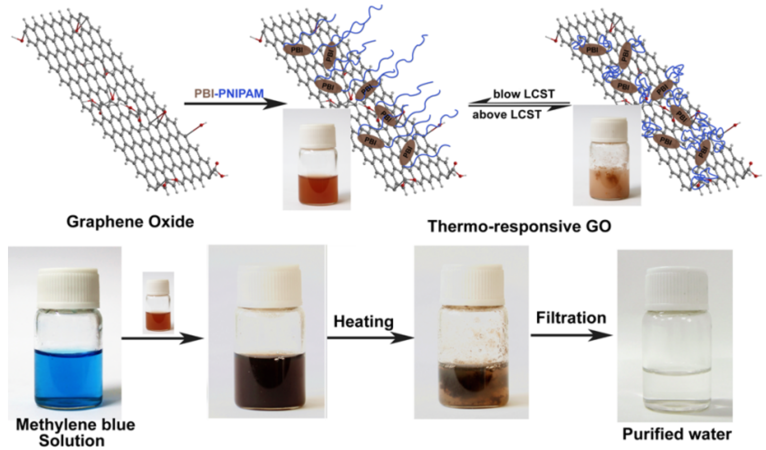
Langmuir, 2011, 27, 9174

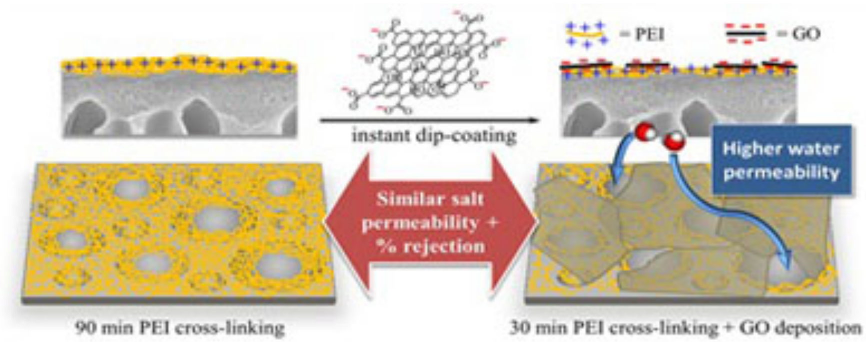


Chemistry - An Asian Journal, 2013, 8, 437



Journal of Membrane Science, 2013, 446, 244





Journal of Membrane Science, 2015,474, 244

Journal of Colloid and Interface Science, 2014, 430, 121

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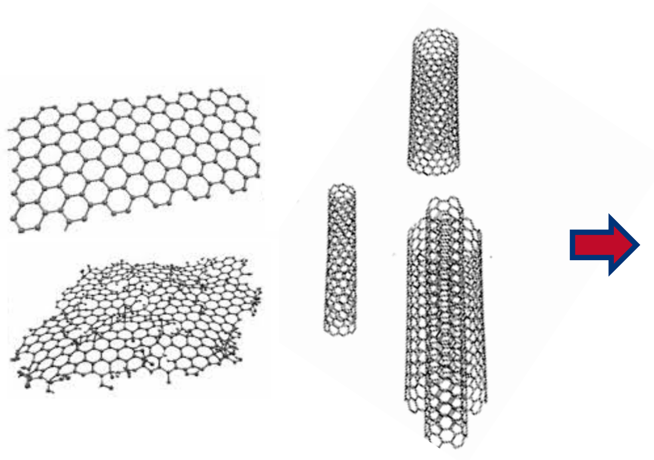
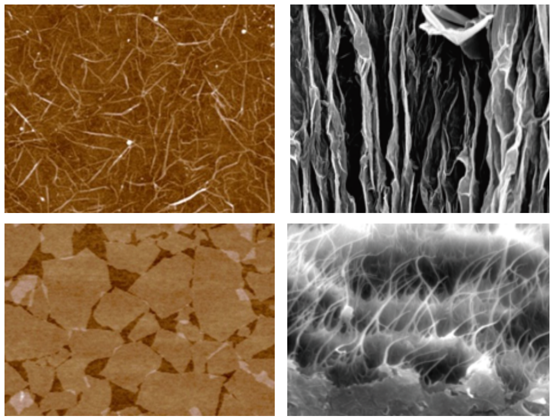
My Research Scope

Fundamental understandings

Nanoscale structures	*Macroscale architectures*	*Performance evaluations*



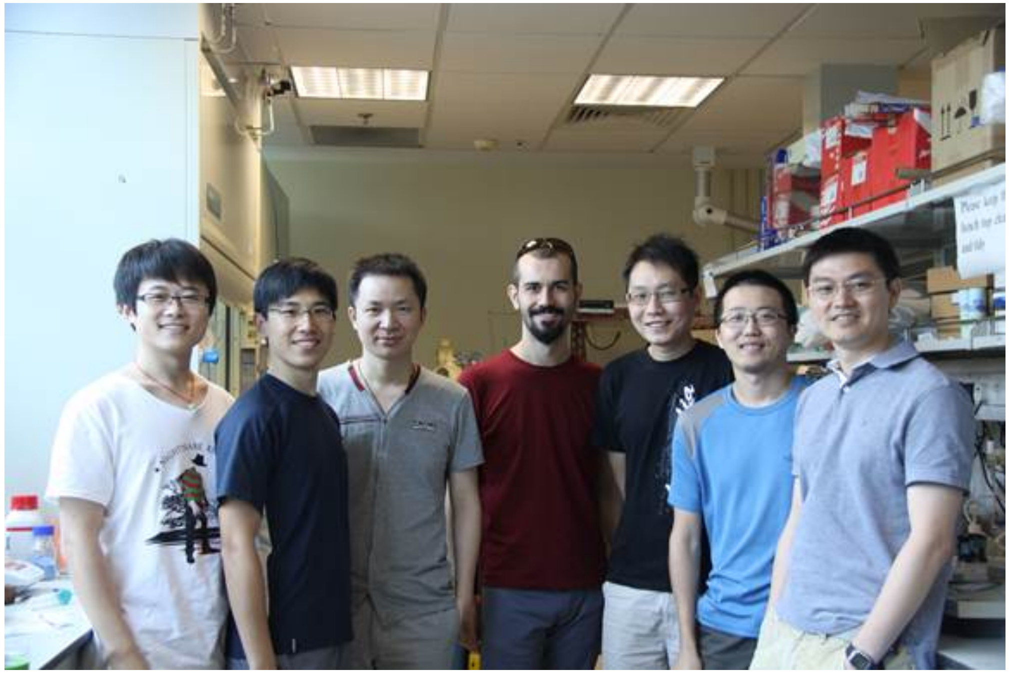


- *Macroelectronics*
- *Supercapacitors*
- *Smart textiles*
- *Electrocatalysts*
- *Membranes*
- *Antibacterial coatings*

Synthesis methods	*Assembly techniques*	*Application design*

Chemical process design and development

Acknowledgements



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