Application of graphene-based composites in environmental protection and its industrialization progress

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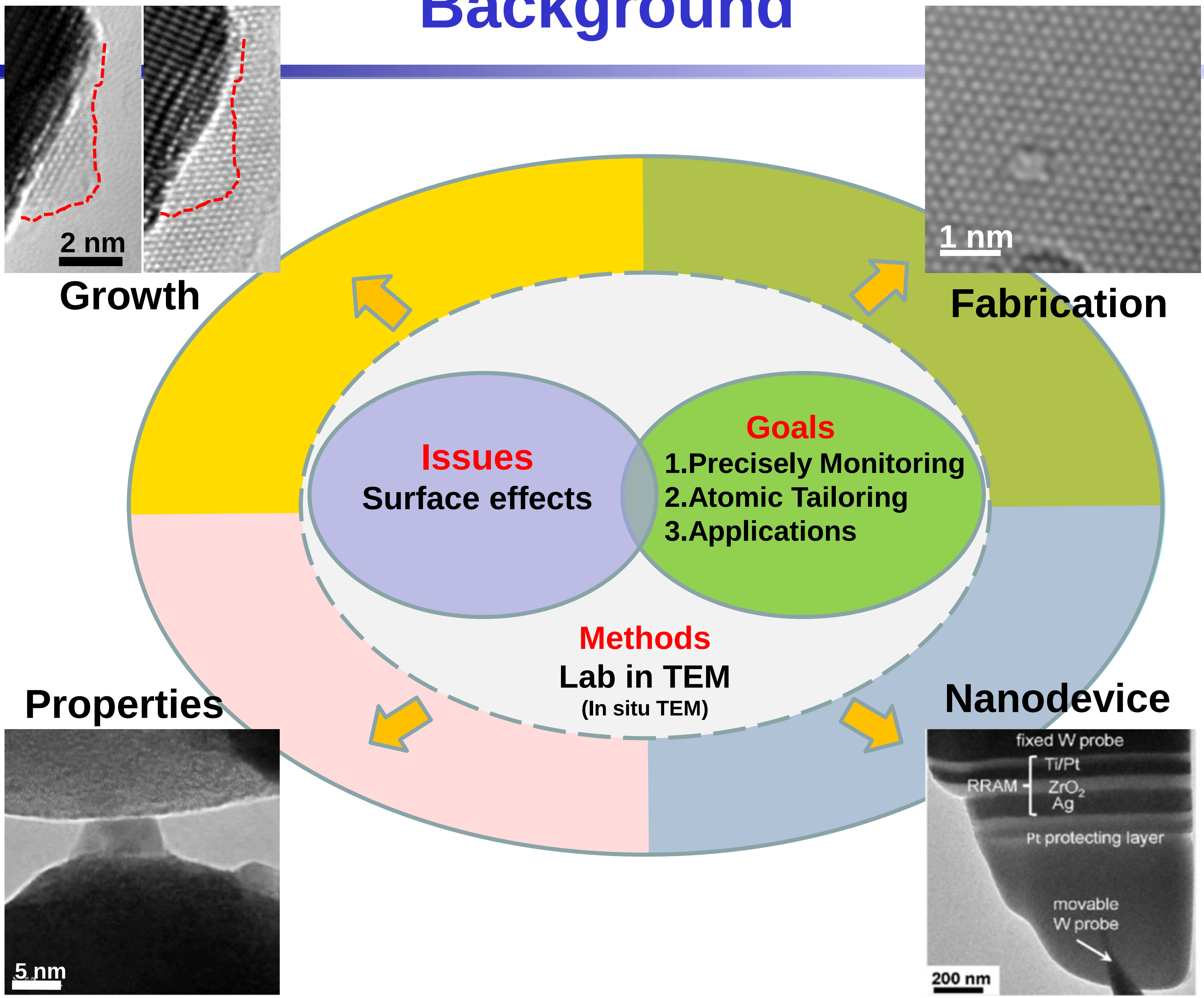
Outline

- **Background:**
- **Precisely monitoring surface structures**
- **Tailoring the surface structures**
- **Applications based on the surface effects**

Background

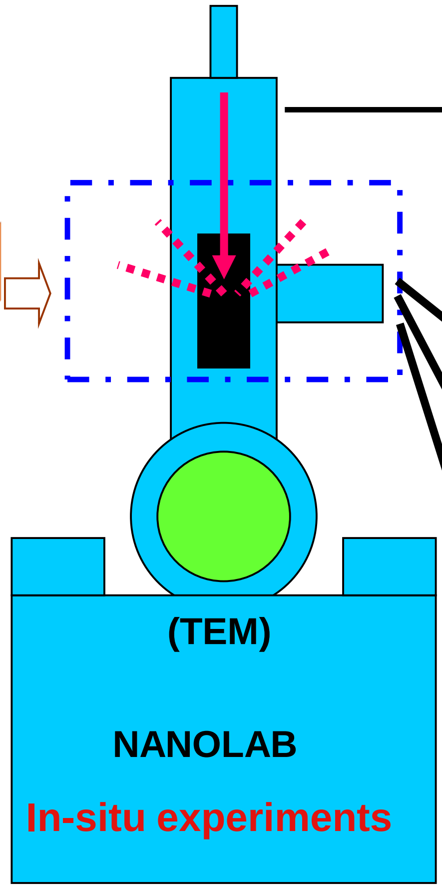

2 nm
Growth
1 nm
Fabrication
Issues
Surface effects
Goals
1.Precisely Monitoring
2.Atomic Tailoring
3.Applications
Methods
Lab in TEM
(In situ TEM)
Properties
5 nm
Nanodevice
fixed W probe
Ti/Pt
RRAM
ZrO2
Ag
Pt protecting layer
movable
W probe
200 nm

How to set up a lab inside a TEM?

Manipulating

Probes: Mechanical, electrical ...

Electron irradiation



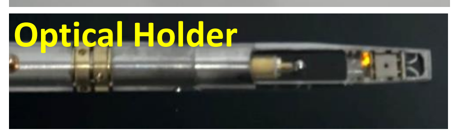
Lab in TEM

Cs-corrected TEM (Titan 80-300™)
Resolution ≤ 80pm

Current : 0-5 mA
Bias : +/-10 V;140V
Piezo resolution X, Y: 20 pm

Load range: 0-2000 nN;
Force sensitivity: 10 nN;

Input Voltage=12V DC
Temperature： 20-1300℃

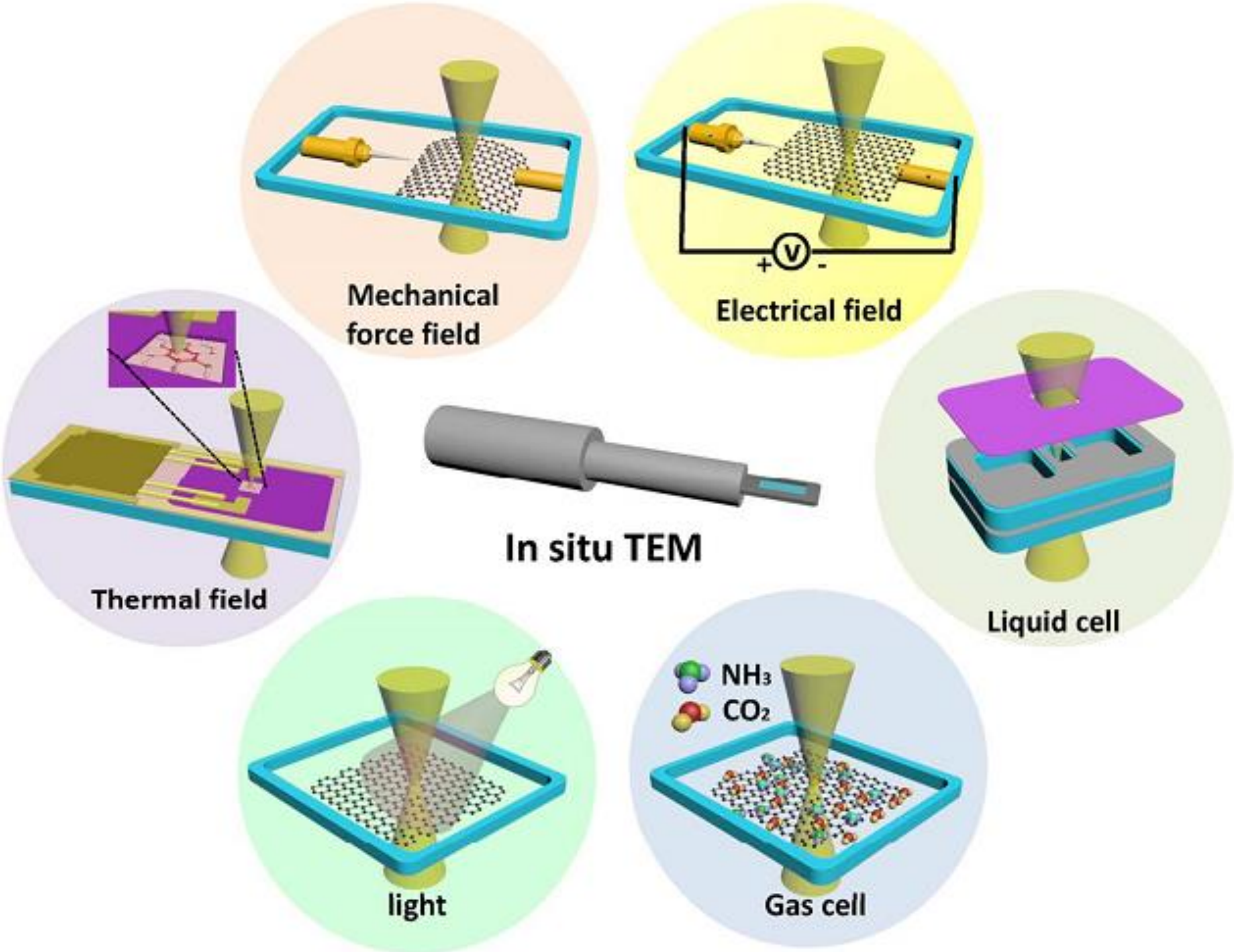


Wavelength: 365-950nm

Imaging, manipulation and measurement… at atomic scale

Simultaneously?

A lab inside TEM

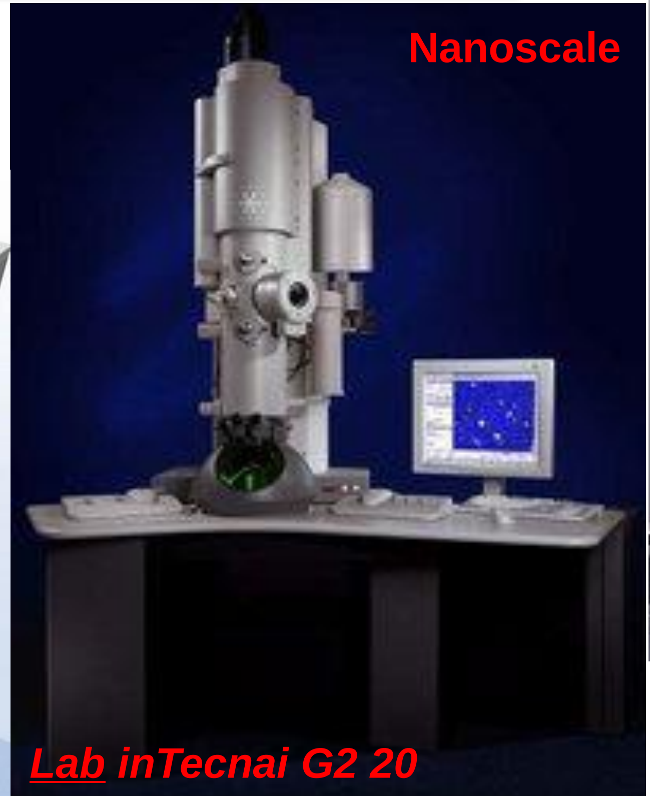


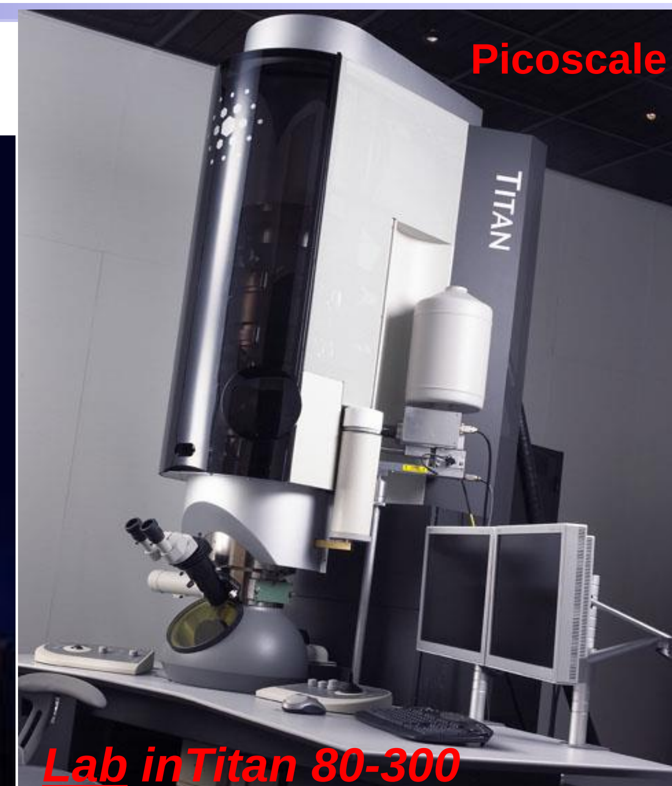
In situ TEM could simulate complicated environments (gas, liquid) with multiple stimuli (e.g., electrical, thermal field, light, and mechanical stress).

How to set up a lab inside a TEM

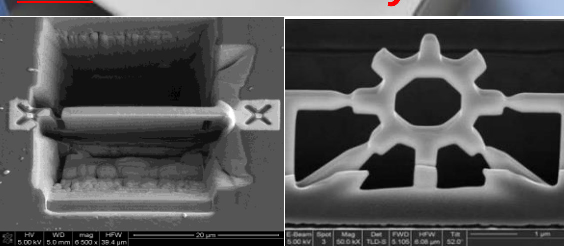
Multiscale dynamic characterization

Microscale





First Commercial Cs-corrected TEM in our lab

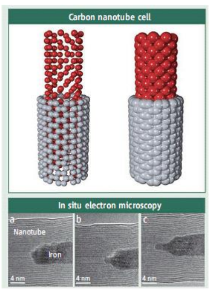


Basic (Nano, Pico)←—→Application (Micro)

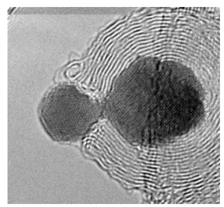
SEU-FEI Nano-Pico Center (Nanjing)

A lab inside a TEM

Development of in-situ microscopy in our group

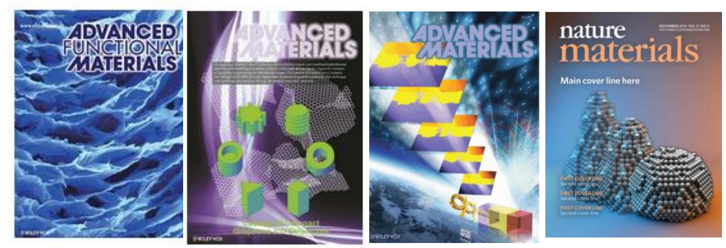


Science 312, (2006)



*PRL*101, (2008)

Property

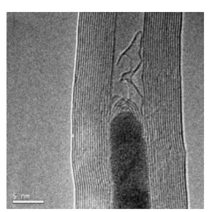


Nature 528,(2015); ***Science*** 344, (2014); ***Nature Mater.***(2014)

Device and Application

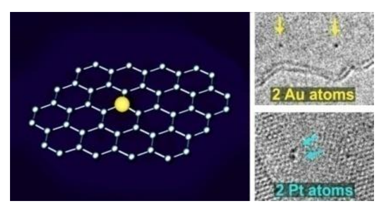
2006 | 2008 | 2010 | 2012 | 2014 ···

Dynamic Characterization



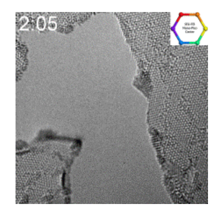
Nature Nanotech. 2, (2007)

In-situ growth



PRL 105, (2010)

Manipulation

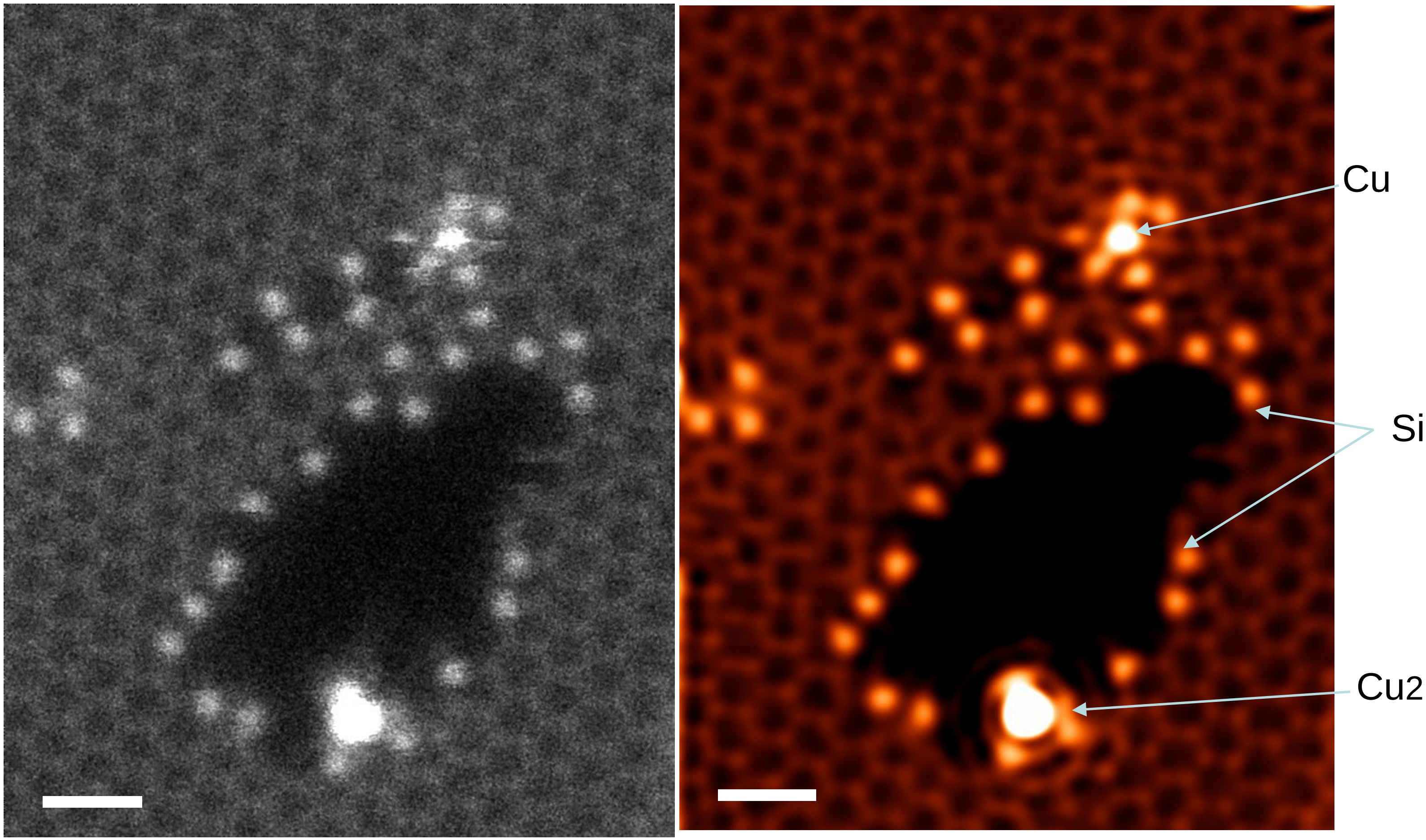


Nature Comm.4, 1776 (2013);

Nanofabrication

Precisely Monitoring surface

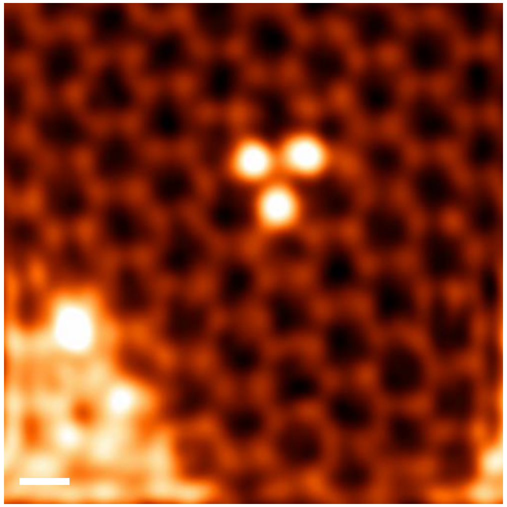
Si and Cu doping at graphene nanopore



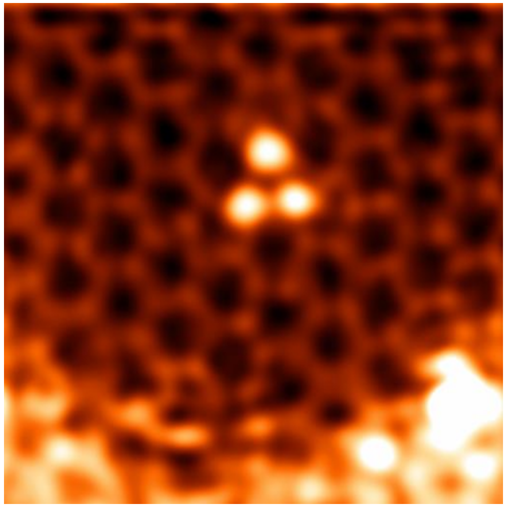
(left: original; right: processed)

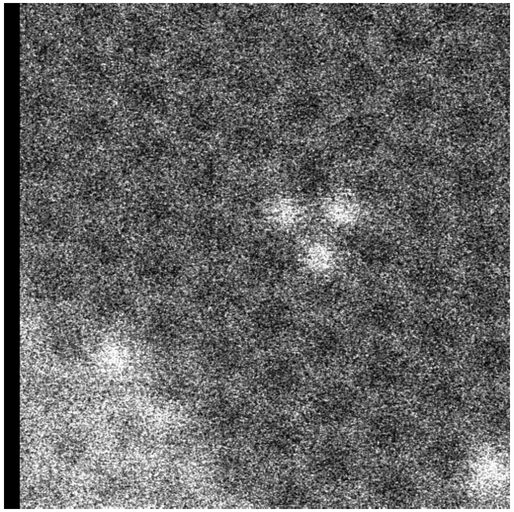
Precisely Monitoring surface

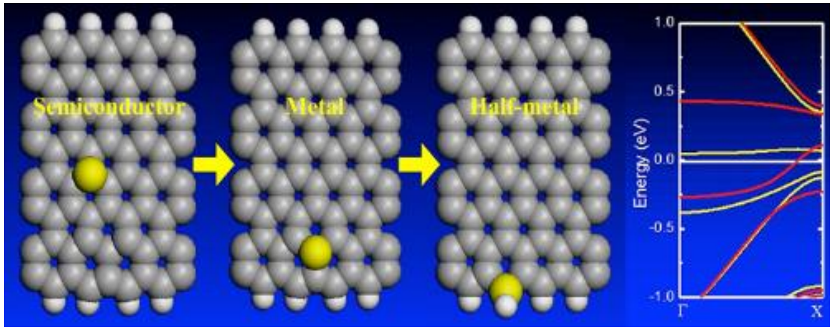
Si trimer in monolayer graphene



rotation





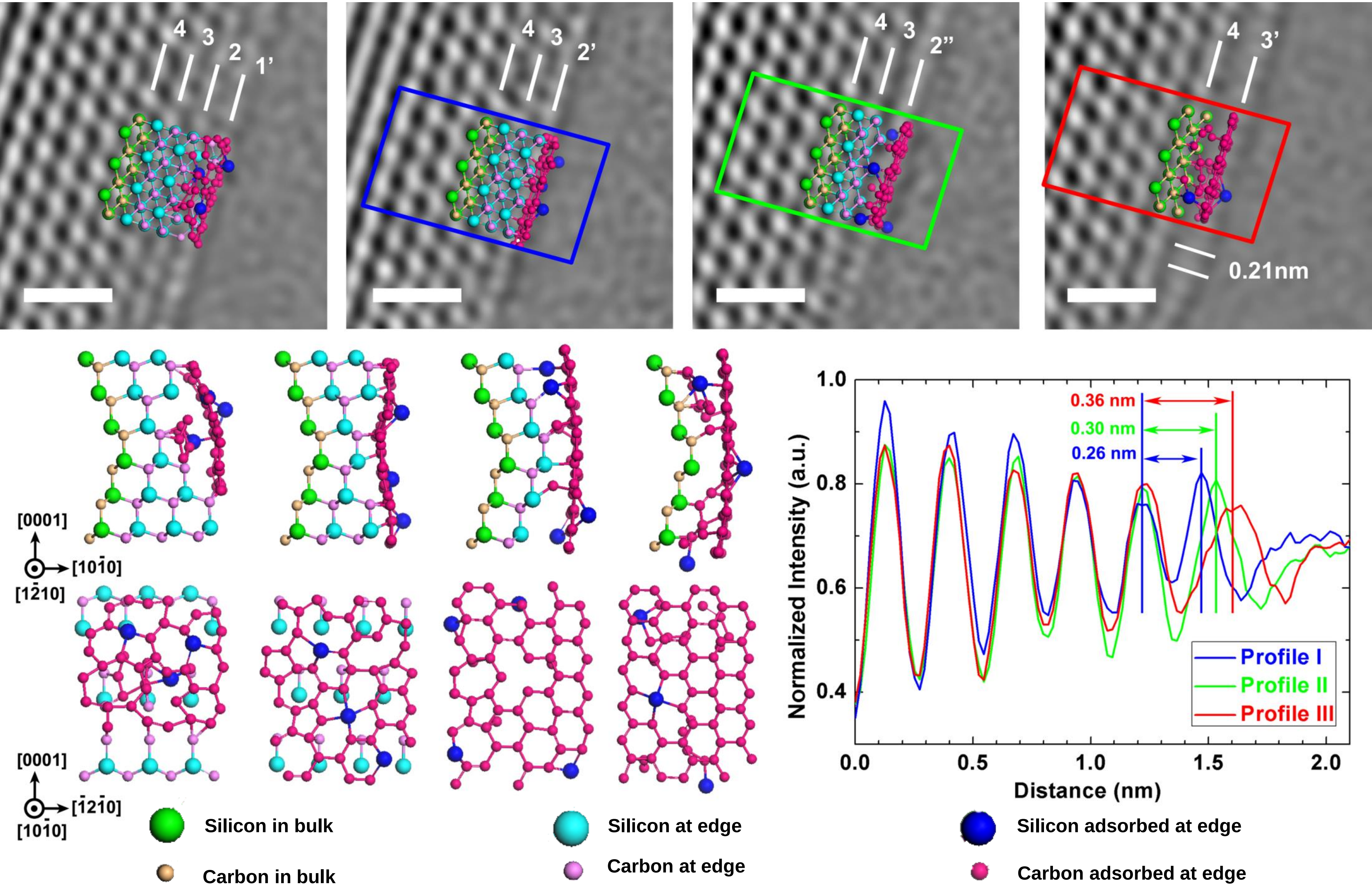


Speed: x20

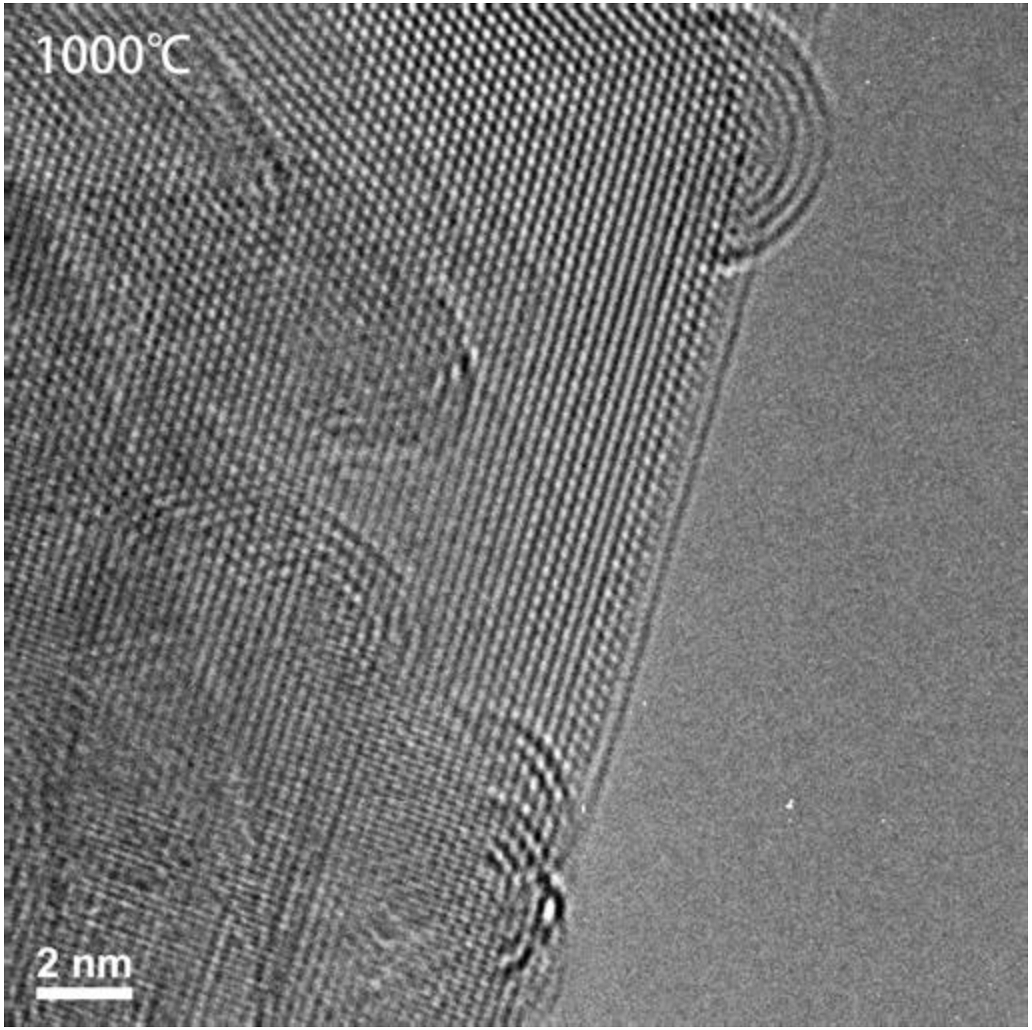
Dynamic Chracterization

Watching How Three-layer SiC Transforms to Monolayer Graphene

Unpublished results

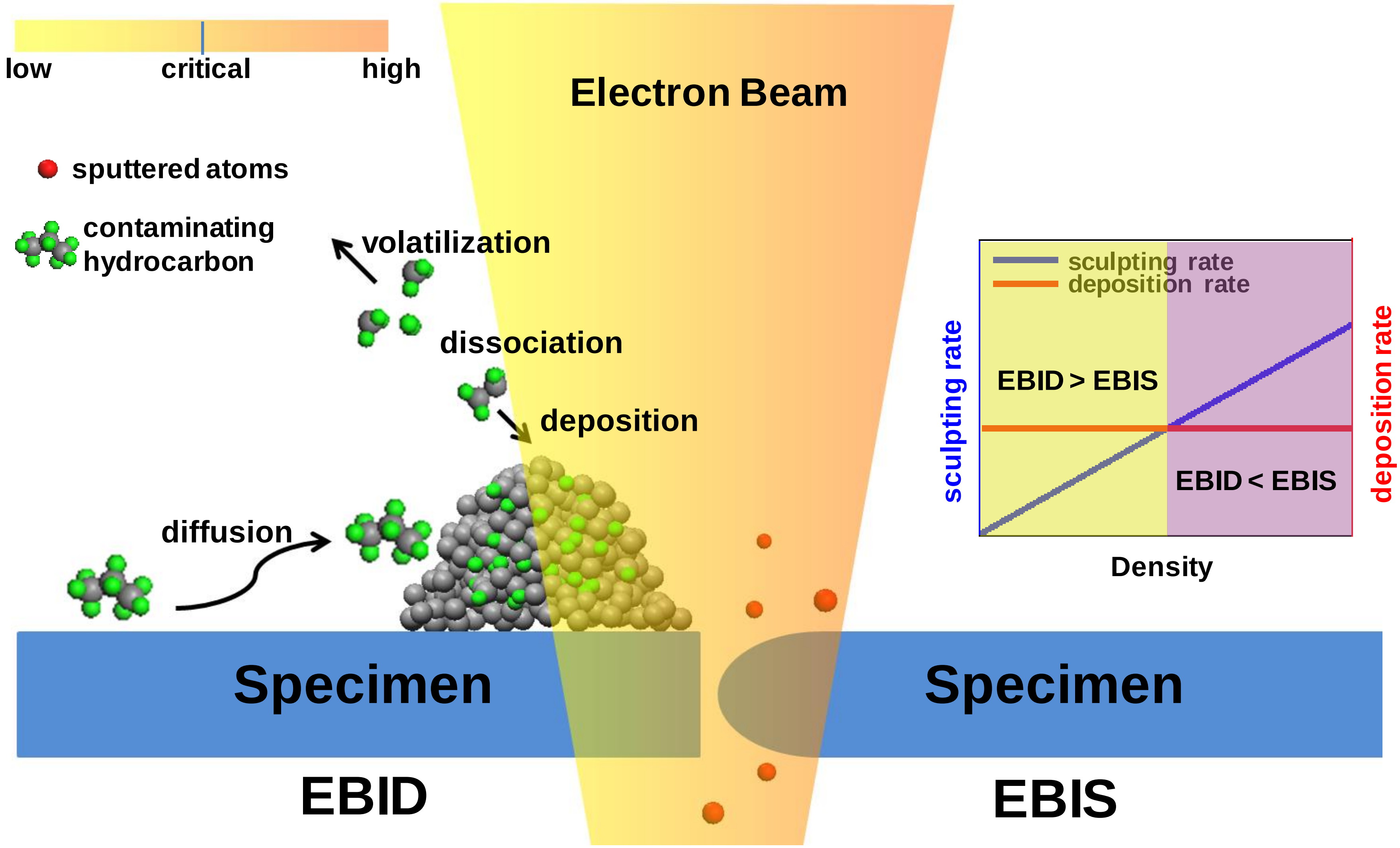


Graphene growth from SiC



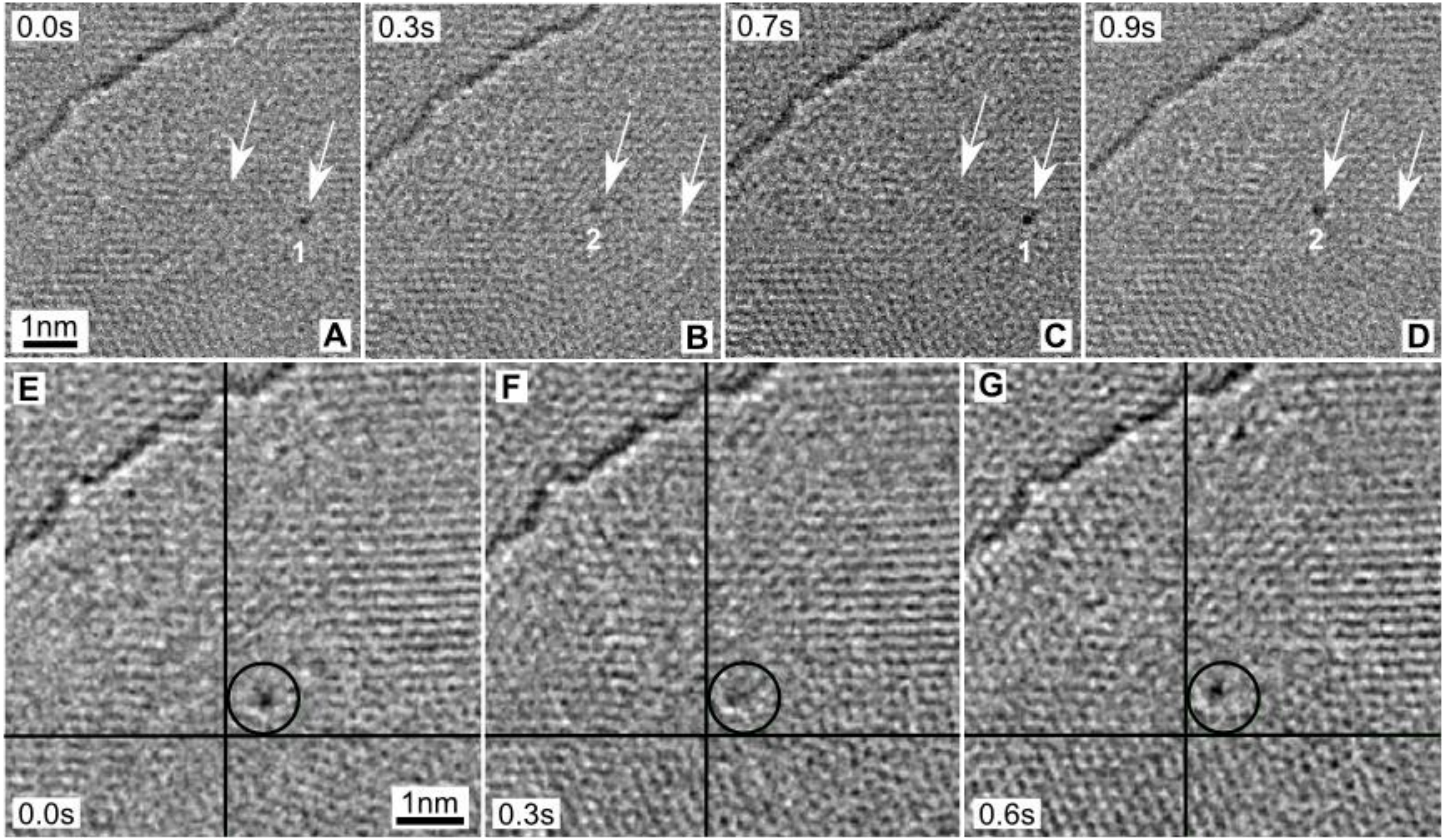
Unpublished results

◆ Tailoring structure: mechanism– by irradiation



T. Xu/ L.T. Sun, *et al*., **Small** 2014

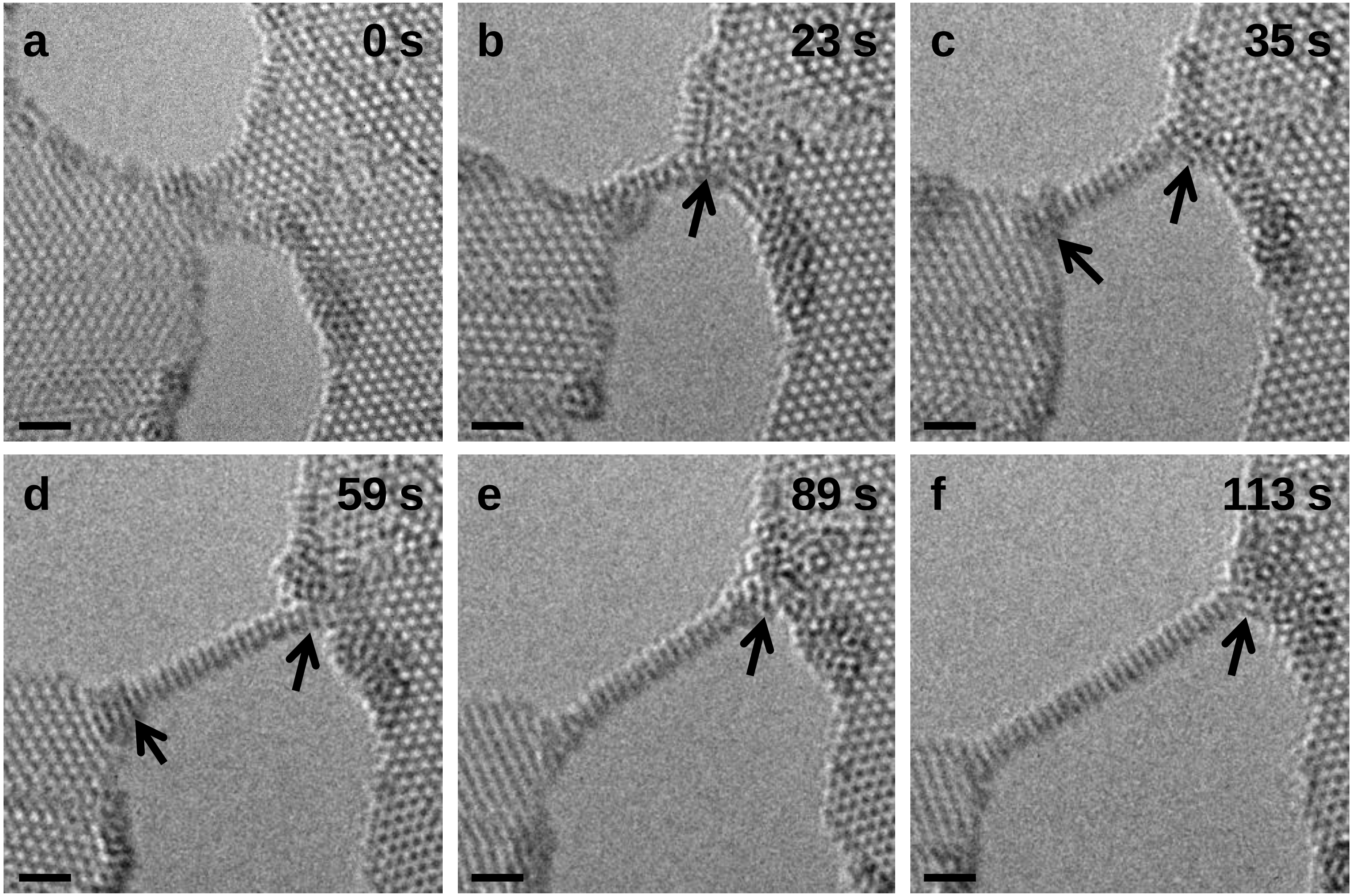
Tailoring structure: sculpting--create defects—manipulating atoms



Migration and Trapping of metal atoms on graphene

PRL 105, 196102 (2010)

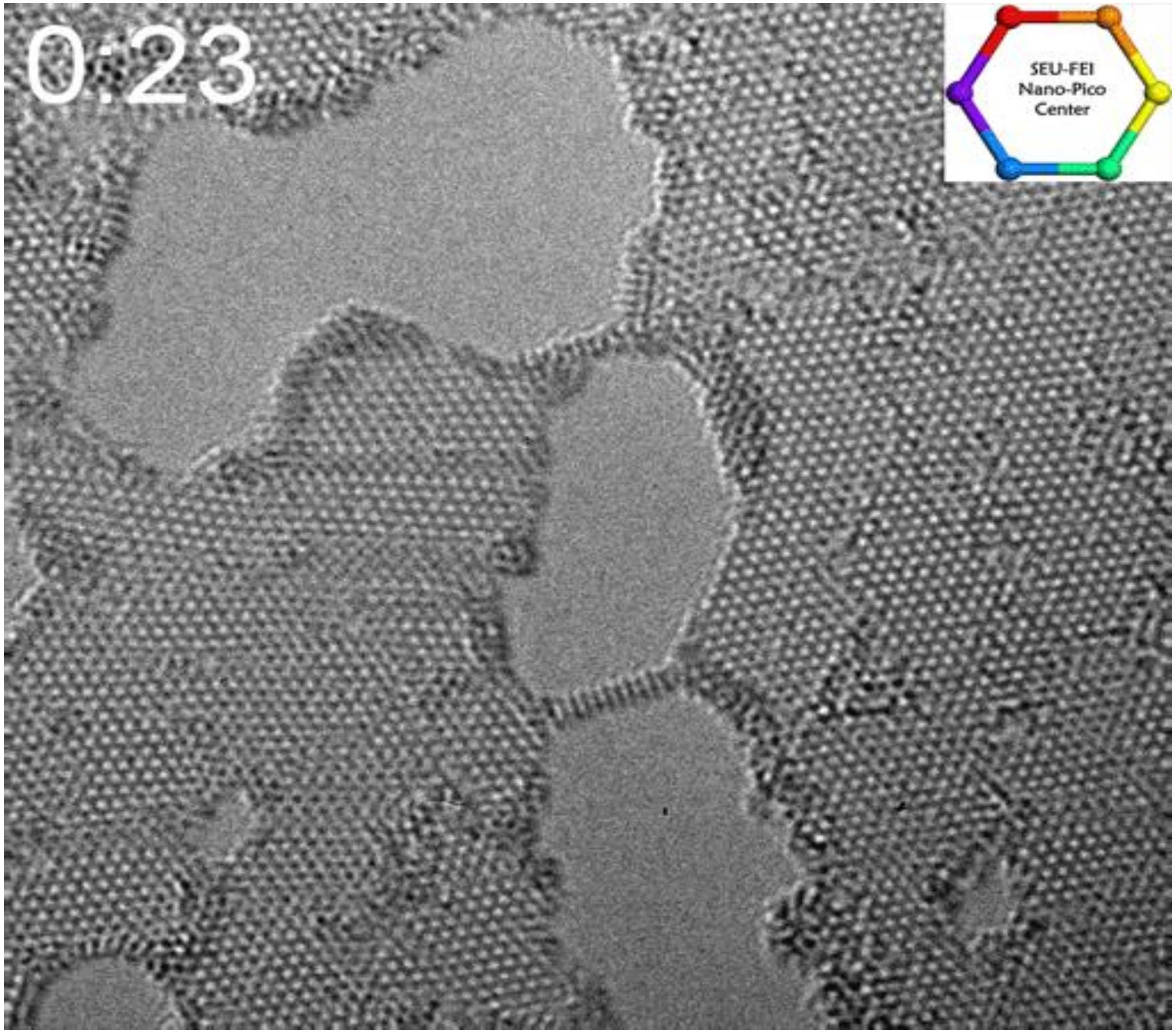
Tailoring structure: mechanism--energy difference



Possible narrowest molybdenum sulfide nanoribbon

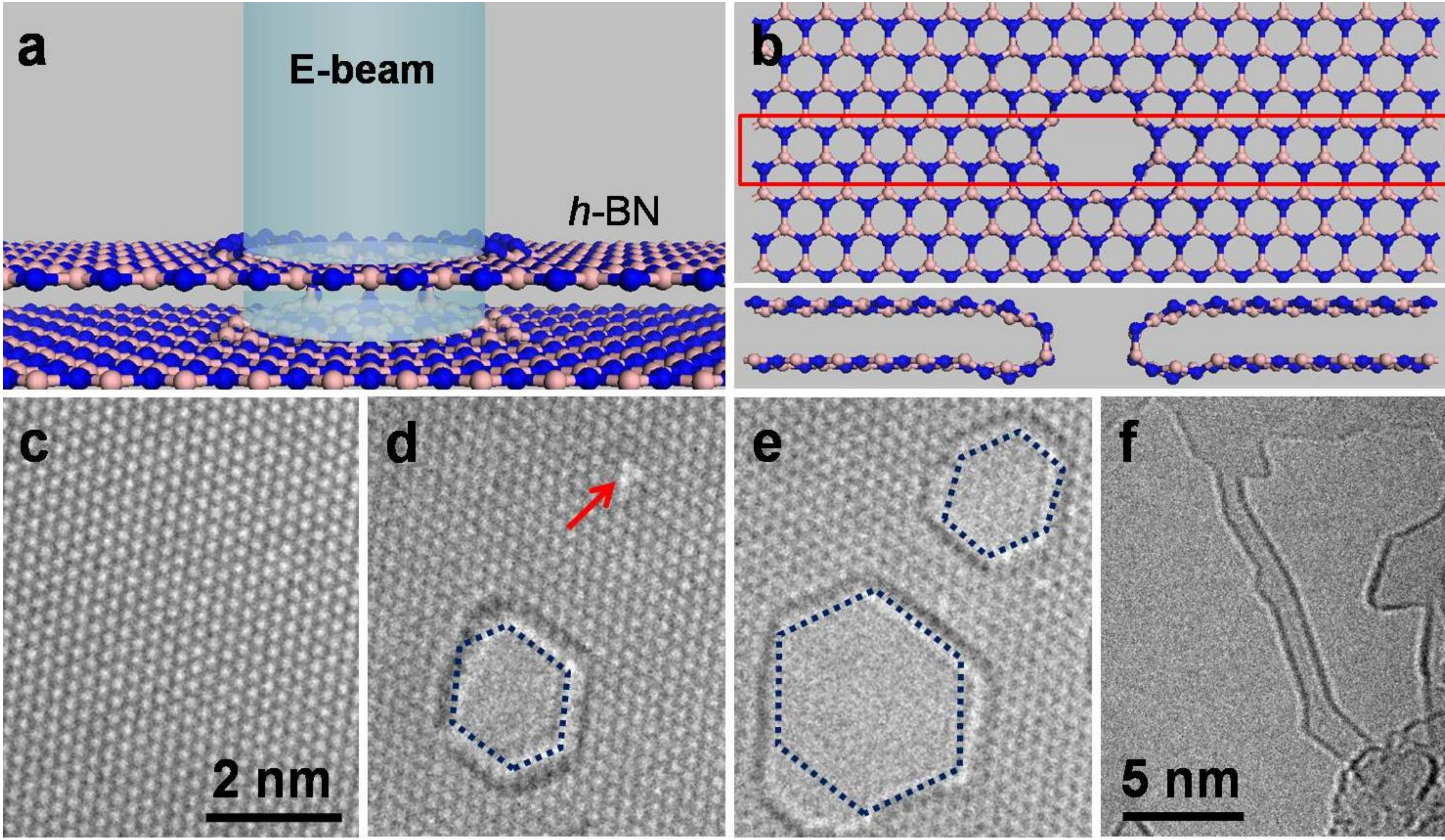
Nature Communications 4:1776 **(**2013)

Tailoring structures by energy difference



Nature Communications 4:1776 (2013)

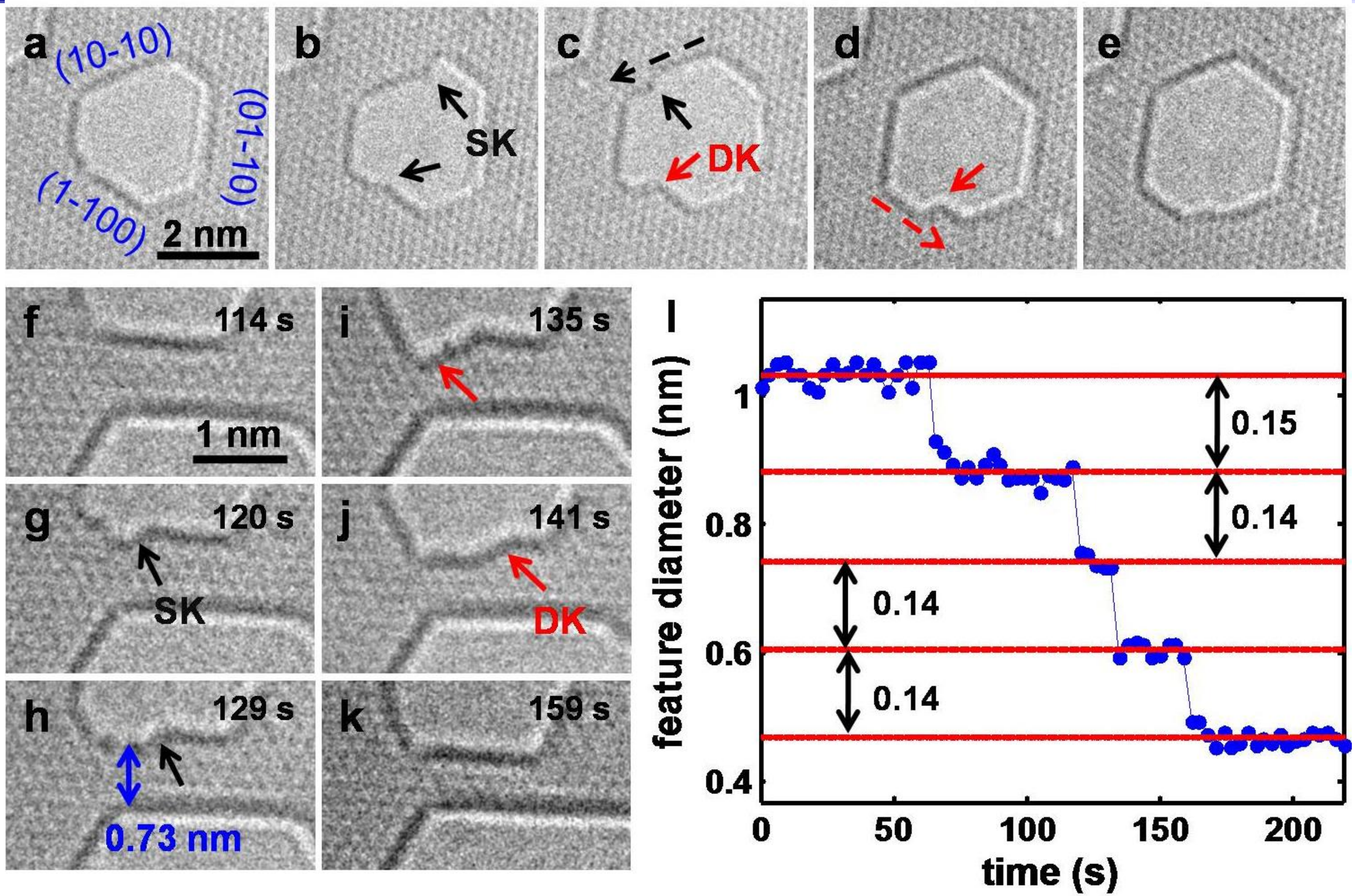
Nanofabrication at atomic scale



BN tubular structure from bilayer structures

Adv. Funct. Mater. in press

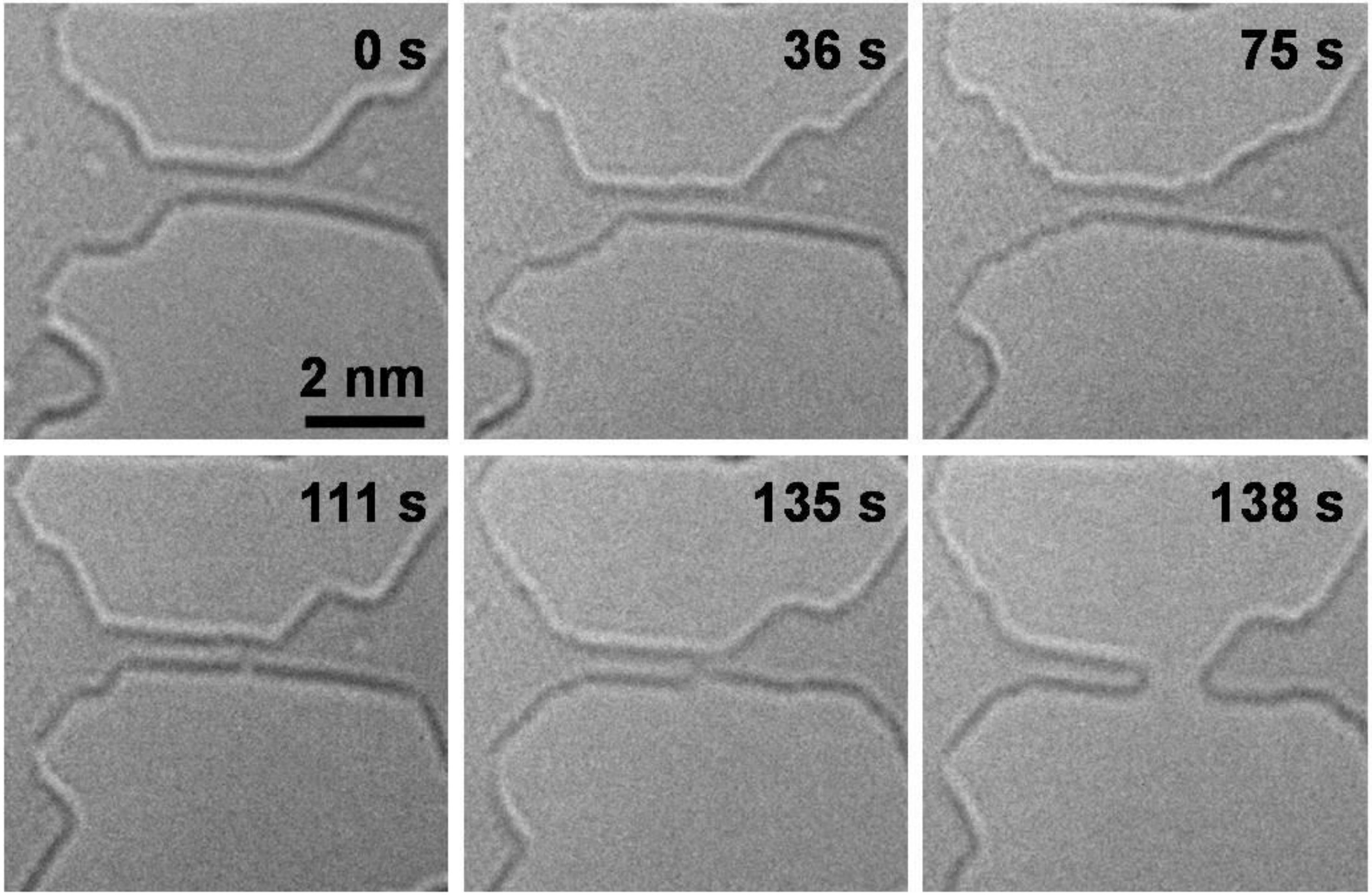
Nanofabrication at atomic scale



Precisely thinning of the tubes: **0.14nm**

Adv. Funct. Mater. in press

Nanofabrication at atomic scale

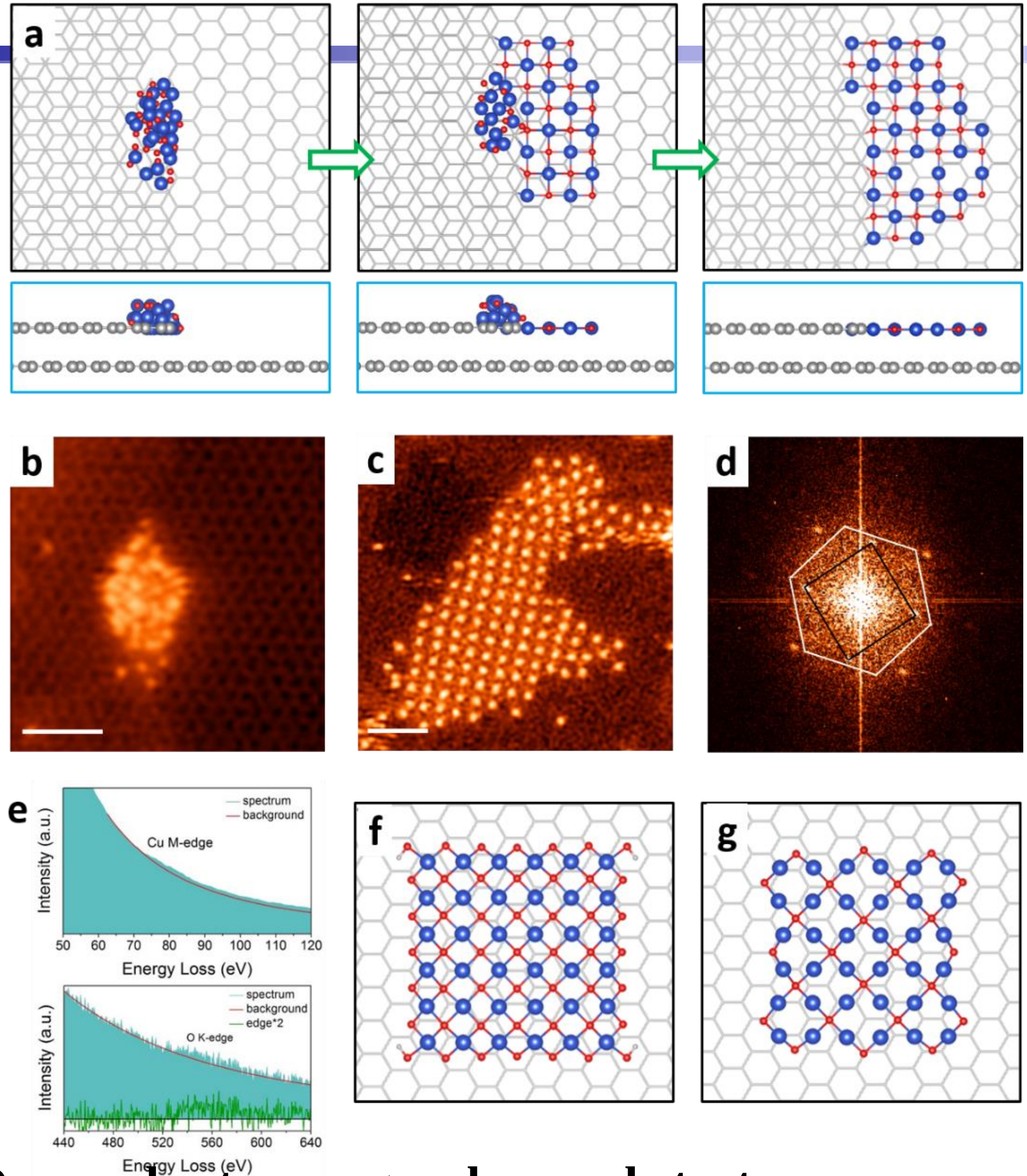


BN tube with diameter of ~ 0.45 nm is the smallest stable tube.

Adv. Funct. Mater. in press

Nanofabrication at atomic scale: new 2D materials

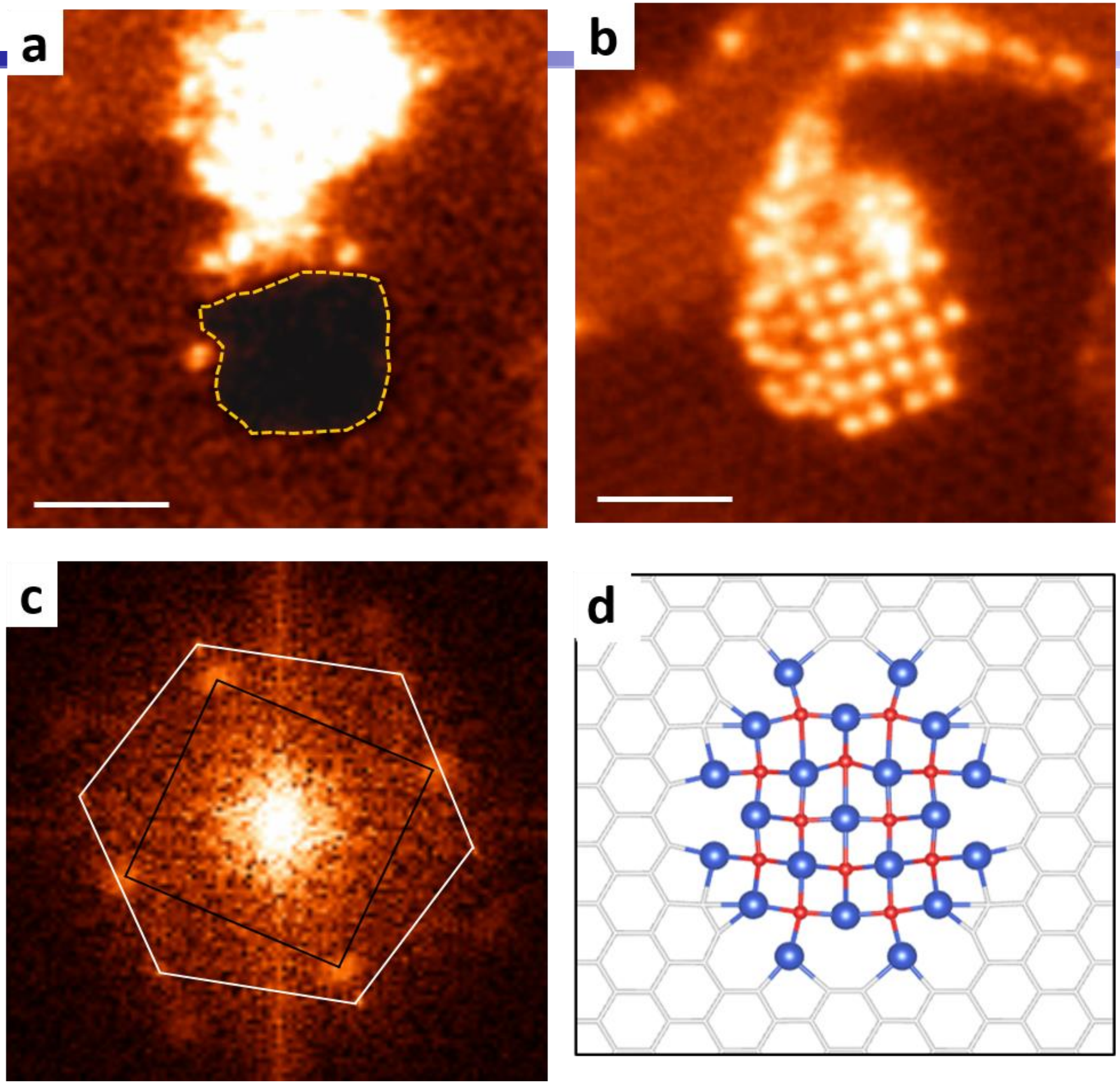
Kuibo Yin



Monolayer CuO nanosheets on a graphene substrate

2D Materials, *in press*

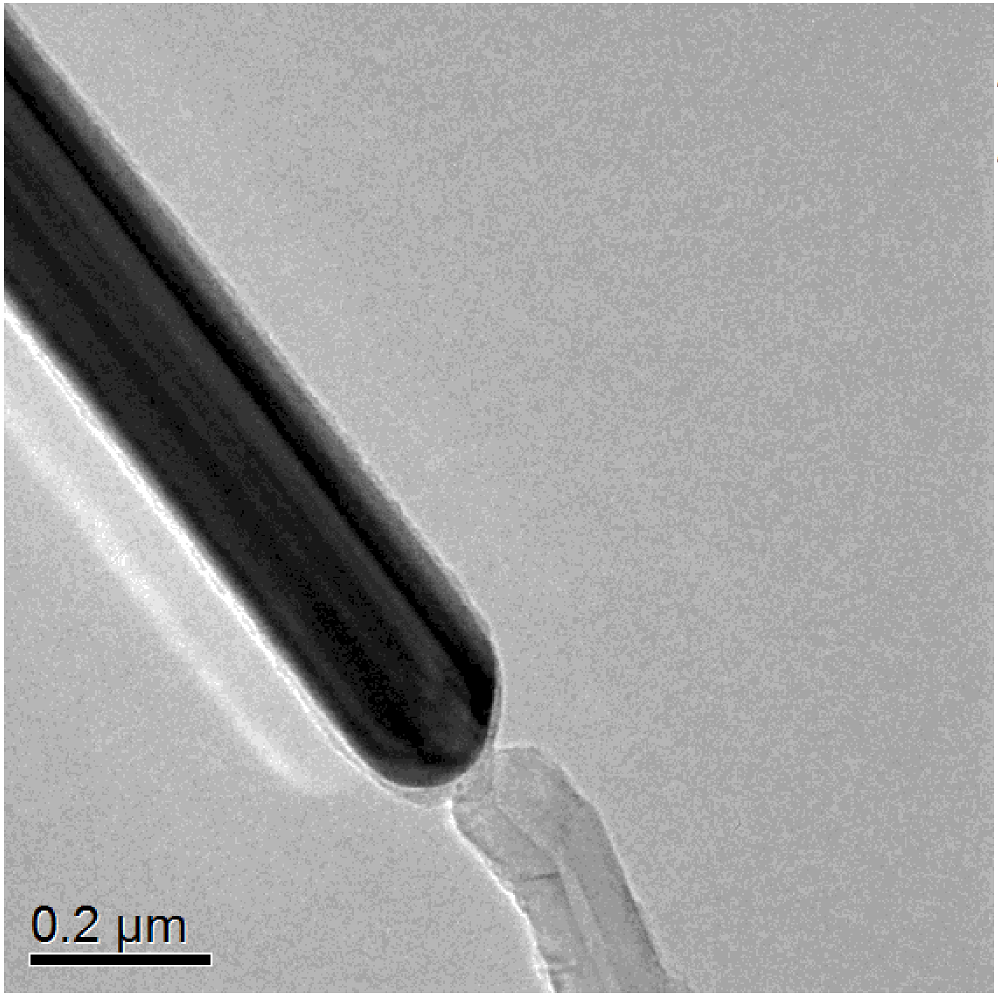
Nanofabrication at atomic scale: new 2D materials



An unsupported monolayer CuO in a graphene pore

2D Materials, *in press*

Tailoring structures -for new structure design--deposition



Acquisition date: 7/25/2011

Acquisition time: 9:46:16 PM

Exposure time: 0.1 s

Indicated Magnification: 9900.0

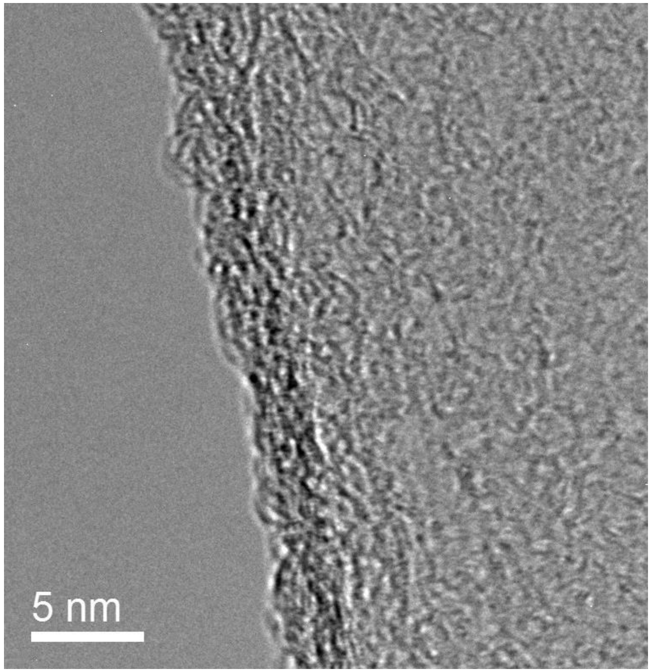
Investment casting of graphene-based structures

Joule heating can also drain away the silver to form graphitized single carbon nanotube with the STM-TEM platform

Carbon 50, 2845(2012)

Tailoring structures -for new structure design

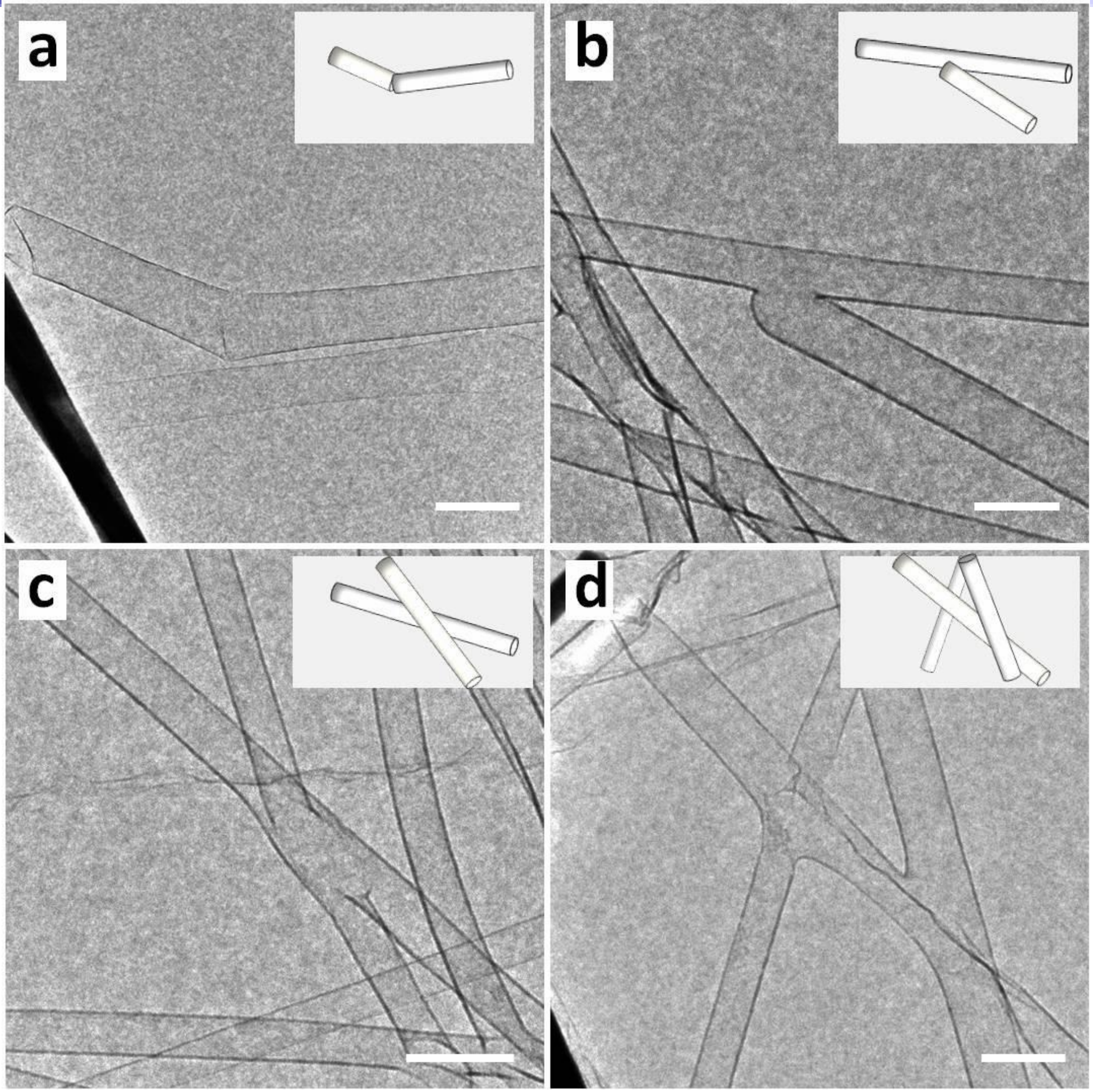
May find applications in nanofluidics, graphene-based devices



partially graphitized

compact graphene structures

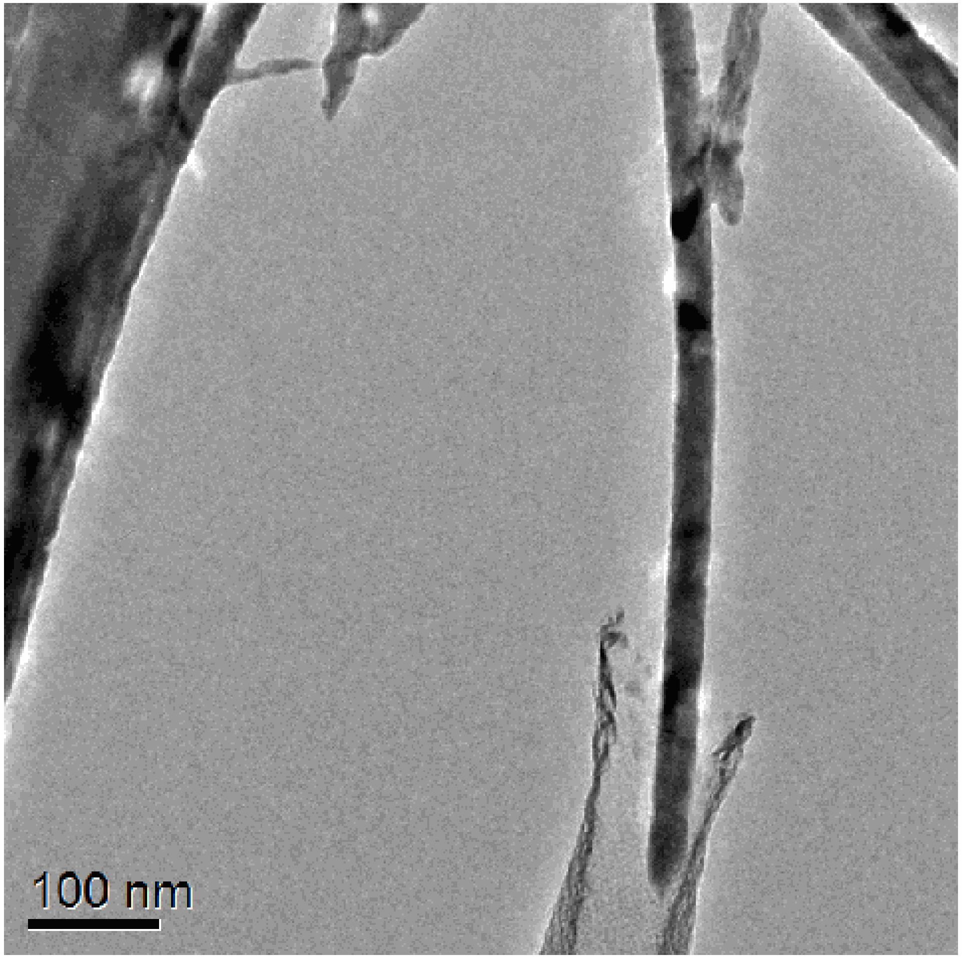
***Carbon 50,* 2845(2012)**

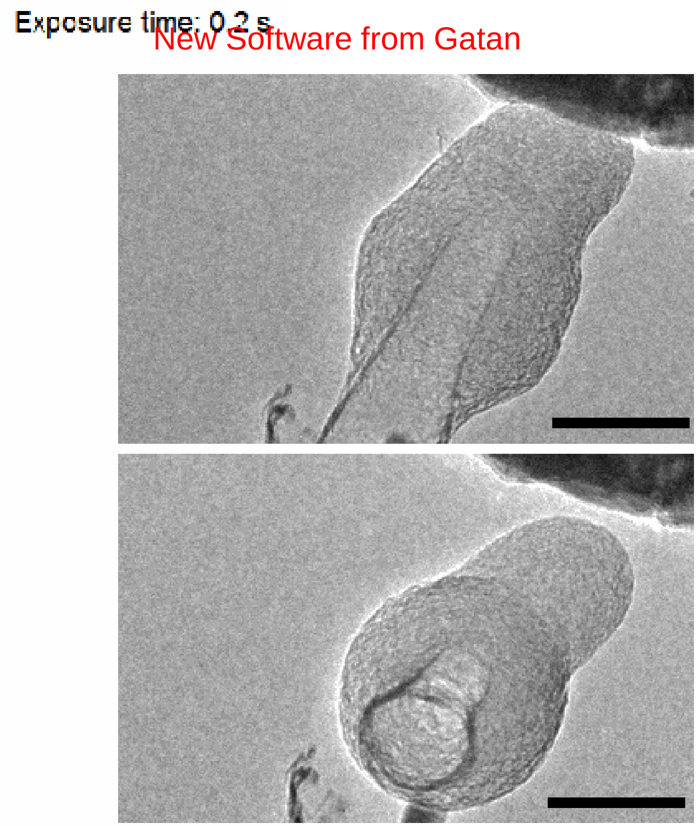


(a) head-to-head connection. (b) A ‘Y’ shape connection. (c) A ‘X’ shape connection. (d) Complex connections.

Tailoring structures -new structure design

Mechanical property of Graphic structures



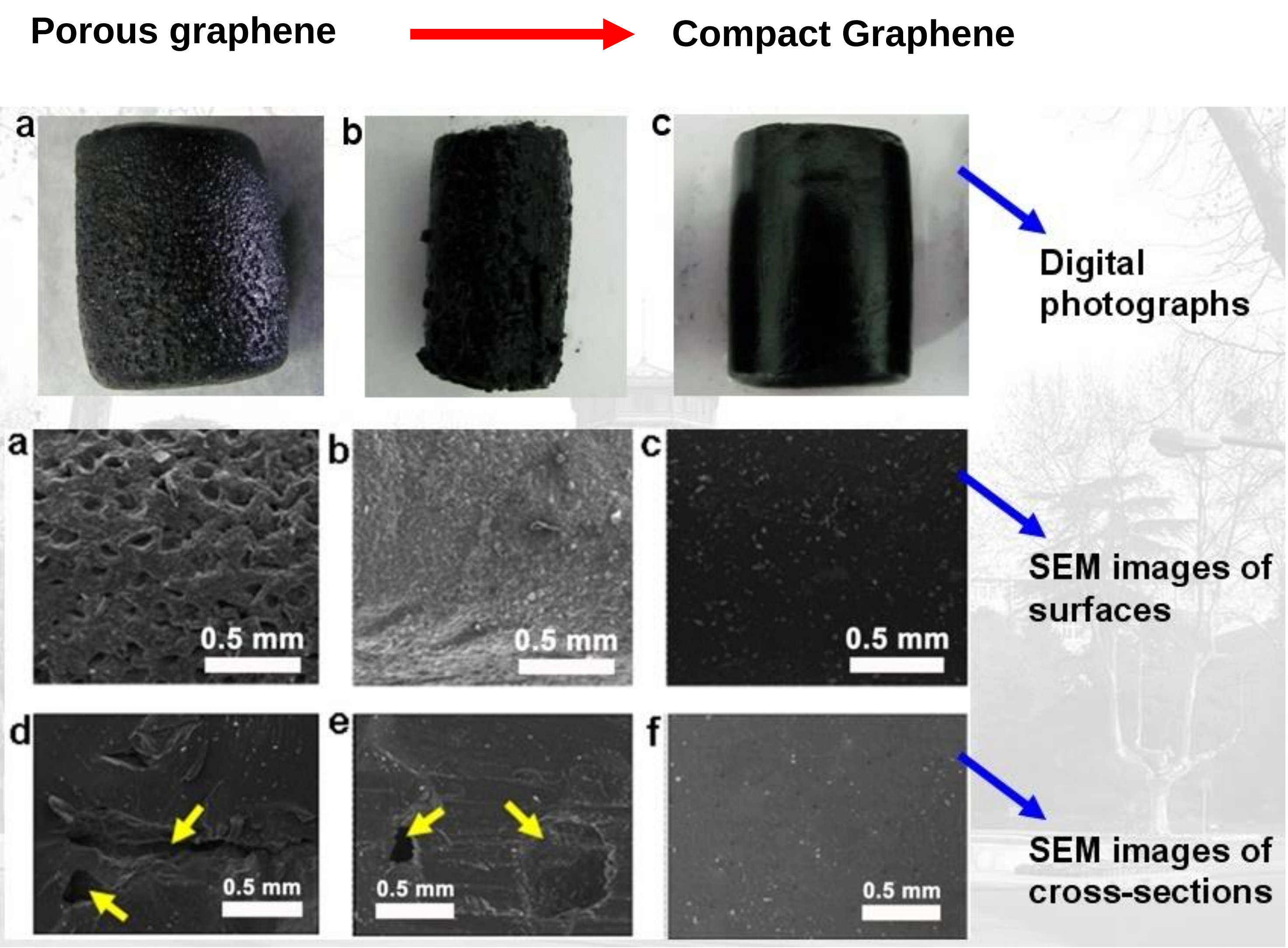


New Software from Gatan

Nice mechanical behavior of graphene-based structures

L. B. He/ L. T. Sun et al., ***Carbon*** *50*, 2845(2012)

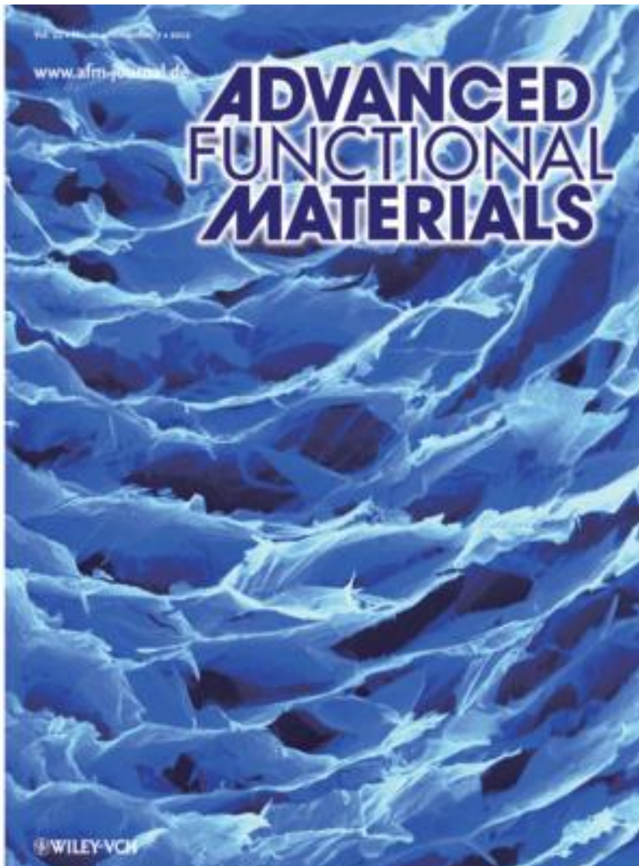
In situ property characterization --for application

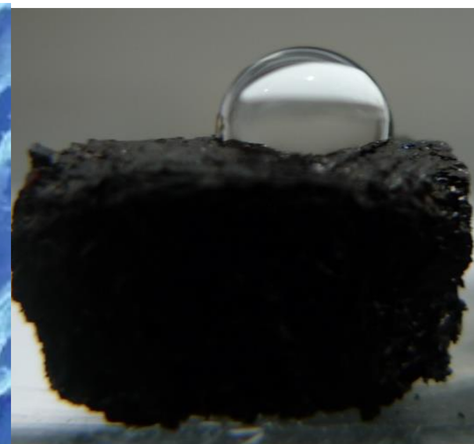


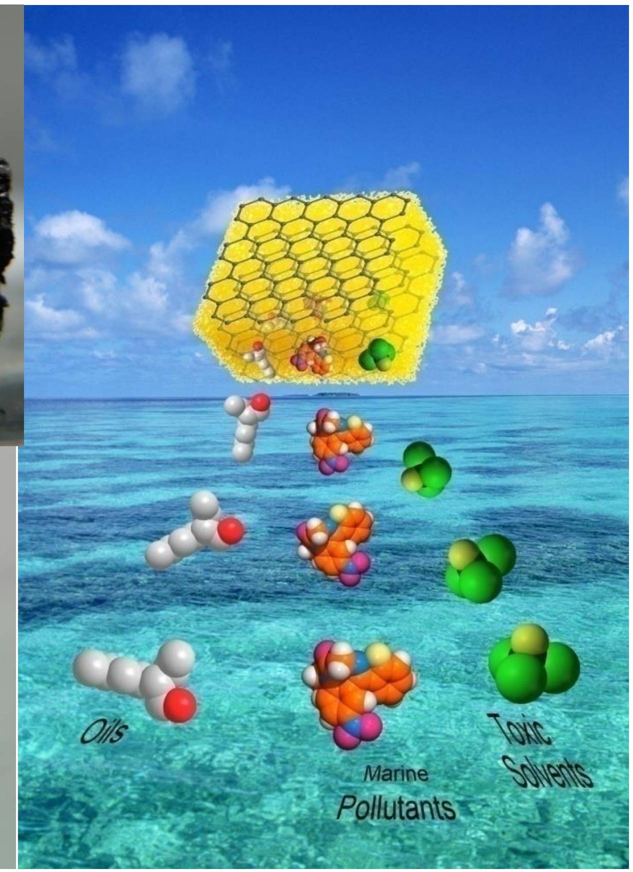
Tailoring 3D graphene structures

In situ property characterization --for application

Spongy graphene (SG) as a highly efficient and recyclable sorbent for oils and organic solvents (<u>first time report)</u>







Adv. Funct. Mater. 22, 4421 (2012) **Cover article**

Superhydrophobic property

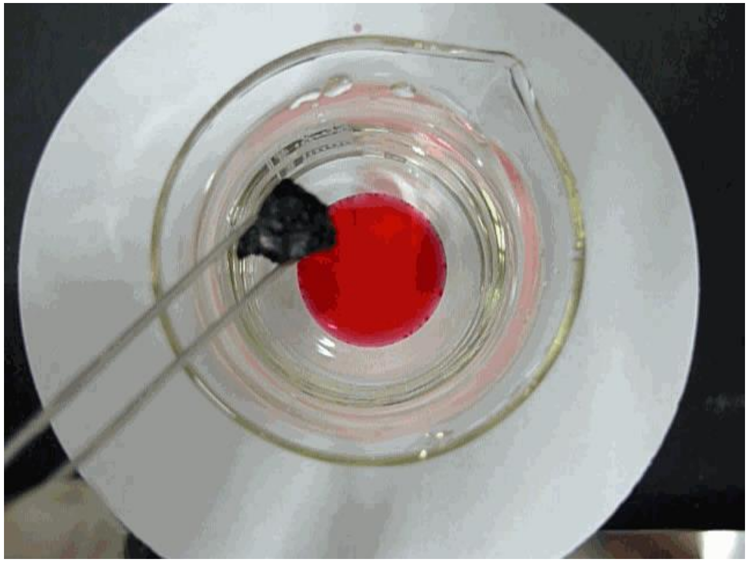
Scientific Reports *3,* 2117 (2013)

In situ property characterization --for application

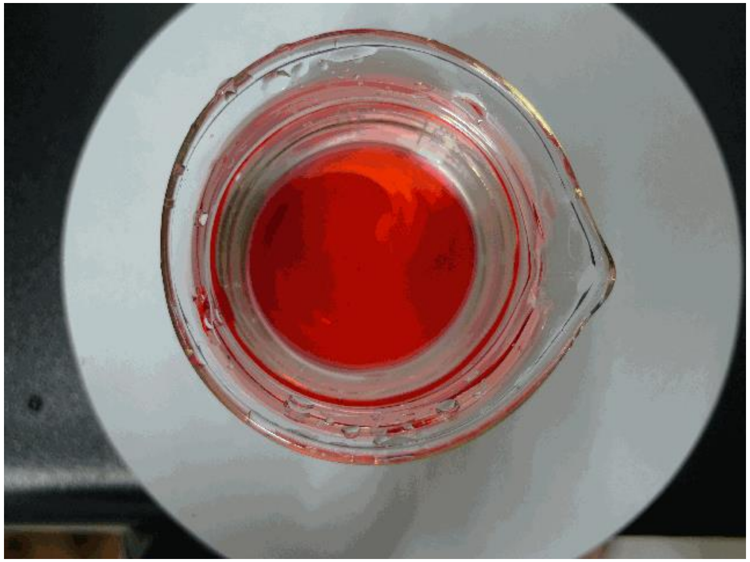
Superhydrophobic property

Dynamic adsorption process

oil on artificial seawater



Toluene on artificial seawater



Absorb: Petroleum products and fats + toxic solvents(toluene and chloroform)

(absorb up to 800 times its own weight)

Scientific Reports** 3,* 2117 (2013)   ***Adv. Funct. Mater. 22, 4421-4425 (2012)

SEU-JGRI Joint Center for Advanced Carbon Materials

Lab

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Xinli Guo

Z. X. Shi

Jinlan Wang

Zhenhua Ni

Principal Investigators

Meeting room

office

Joint Center between Southeast University and Jiangnan Graphene Research Institute

JGRI 江南石墨烯研究院
JIANGNAN GRAPHENE RESEARCH INSTITUTE

東南大學

In situ property characterization --for application

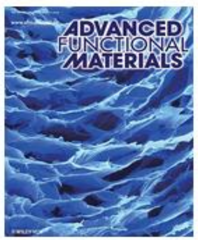
Dynamic adsorption process

highly efficient and recyclable

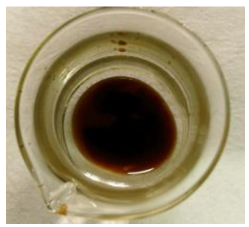
Research History- Spongy graphene as sorbent for oils/organic solvents

Progress of the environmental application in our group

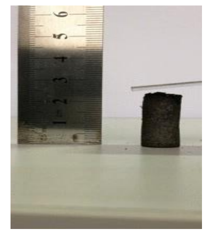
First Paper published
(AFM2012, Cover)



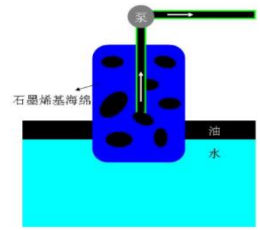
High efficiency
(J. Mater. Chem. A)



Compressible sponge



Continuous separation

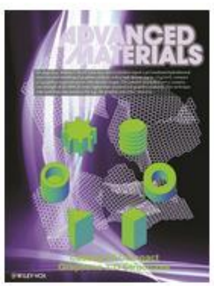


Sorption for trace oil

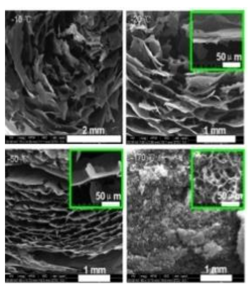
First Patent

2010 2011 2012 2013 2014 2015 2016

First-time Observed

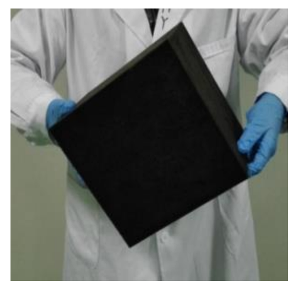


Shape control



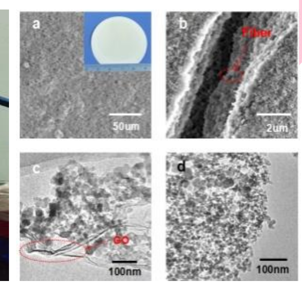
Structure control
(Sci. Rep.)

Low cost
Adv. Mater.; Small



Large scale sponge

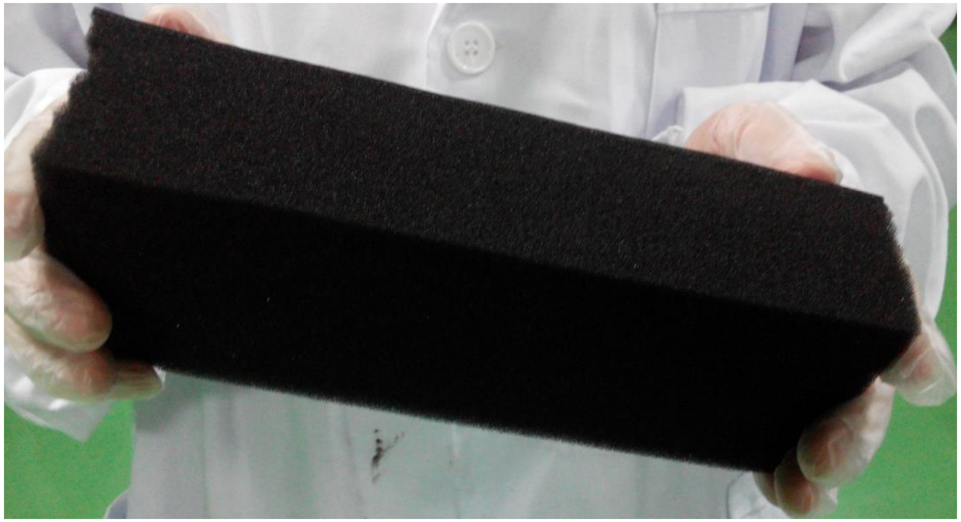
Metal mesh combined



Separation for micro emulsion

40+ Patents: 201010607317.3, 201110312393.6, PCT/CN2012/078045 and others

Industrialization progress：graphene based sponge

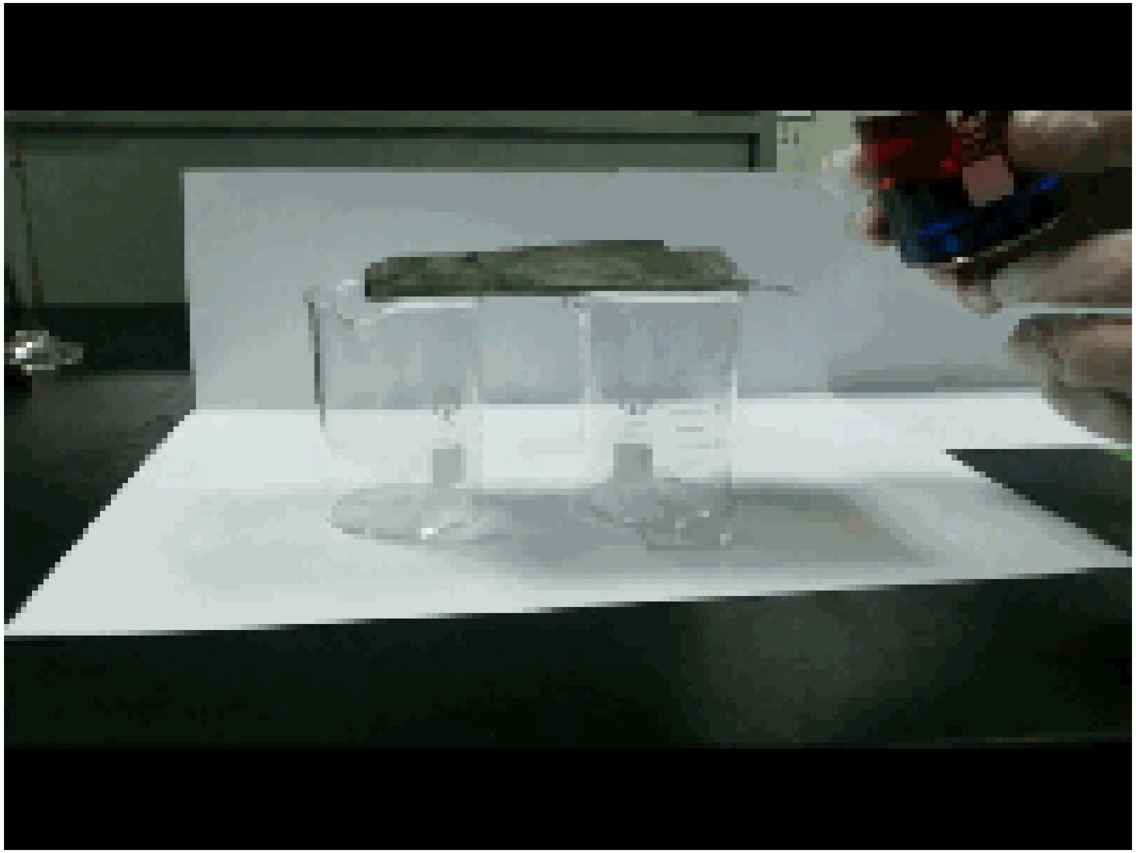


- Large-scale production
- Low cost
- High sorption capacity
- Good recyclability

Continuous separation

Industrialization progress： separation mesh

Application based surfaces



Graphene-based film for separating the oil and water

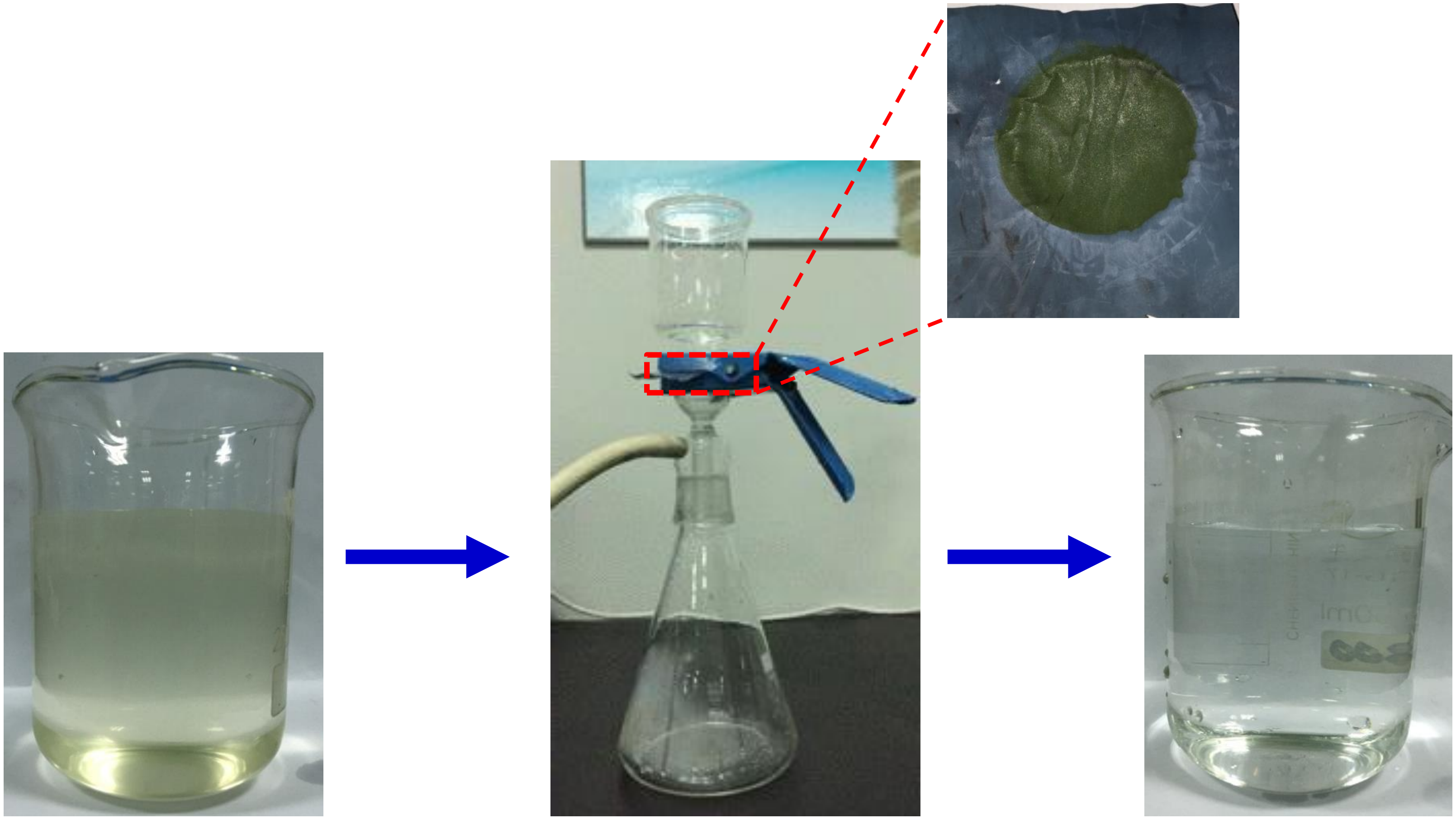
Industrialization progress： separation mesh

Superhydrophobic and superoleophilic

Superhydrophilic and superoleophobic

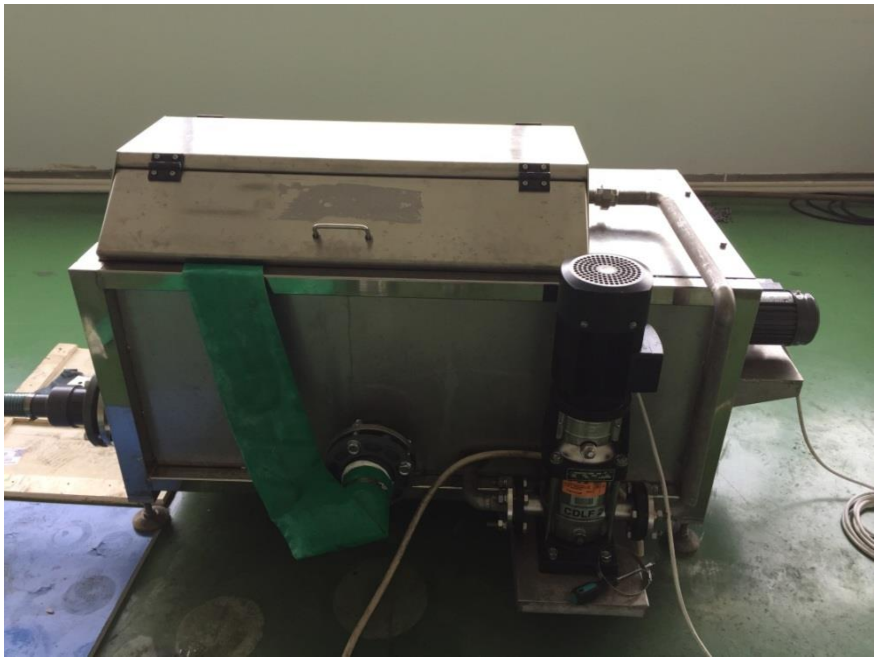
Red: oil; blue: water

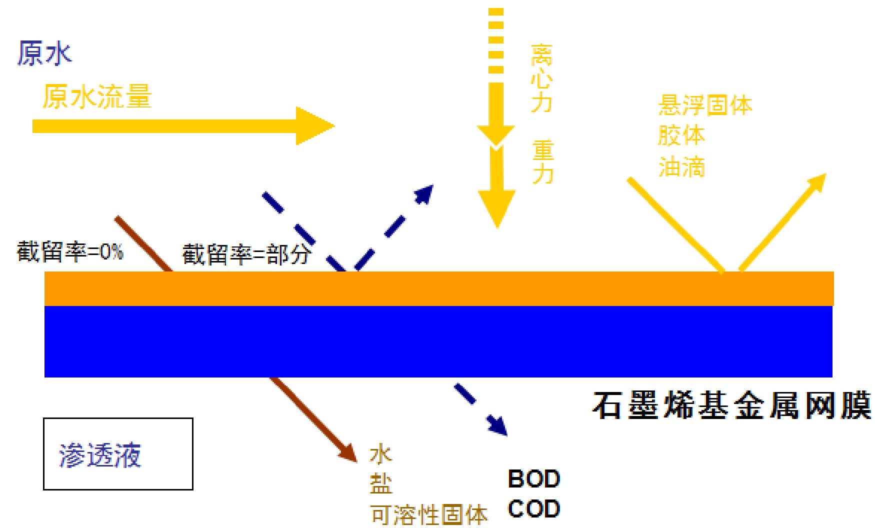
Industrialization progress： separation mesh



blue green algae
过滤蓝藻

Application based surfaces

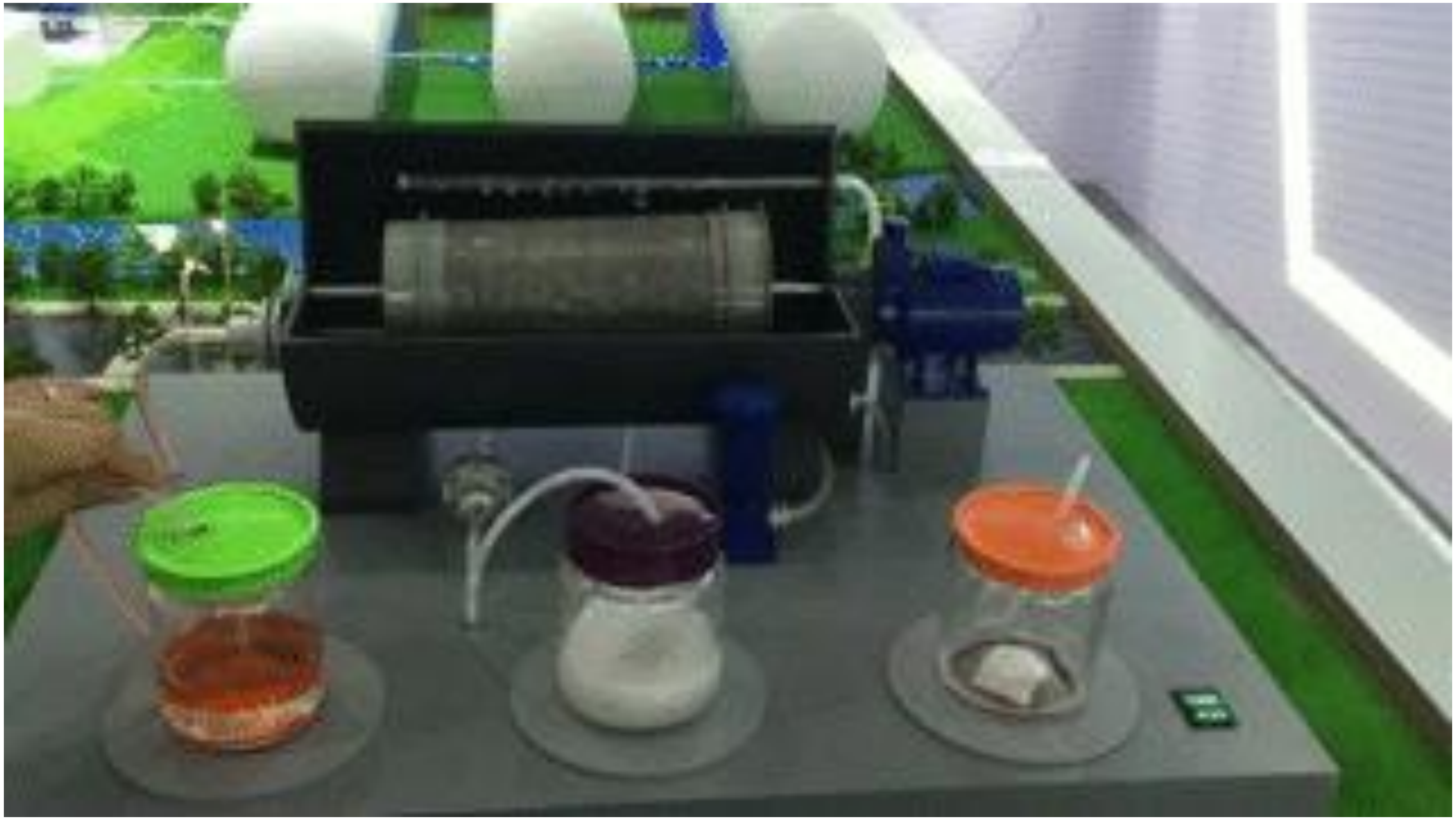




石墨烯基金属网膜功能示意图

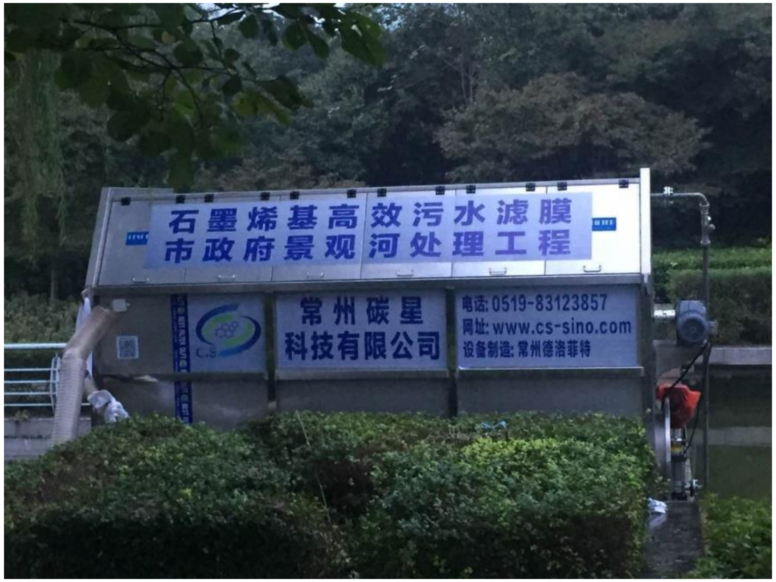
Equipment for separate oil, water and solid particles

Equipment for separate oil, water and solid particles



Equipment for separate oil, water and solid particles

APPLICATIONS



常州市政府景观河，
10000t/d

惠州 52000t/d

泸州 20000t/d

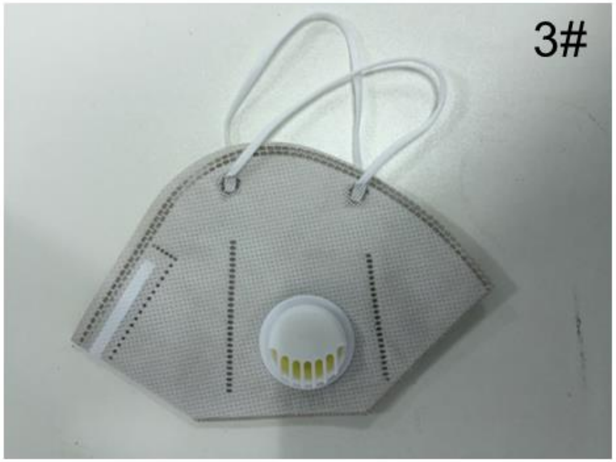
Industrialization progress： separation mesh

Building product line for separation metal mesh 10000 m^2/y

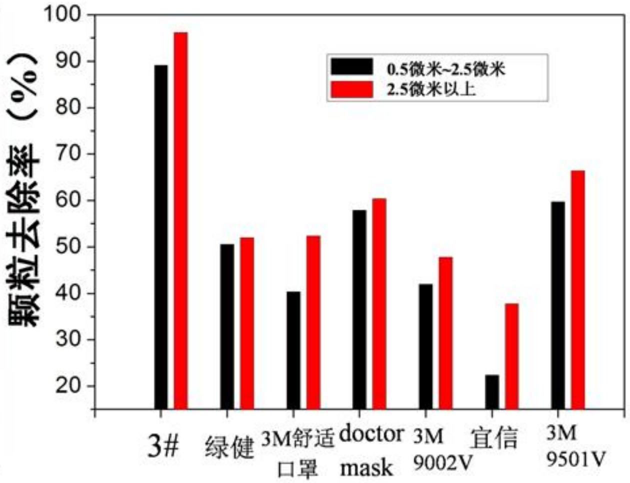
APPLICATIONS

Other application – graphene based filter materials

Filter materials



Gauze mask sample

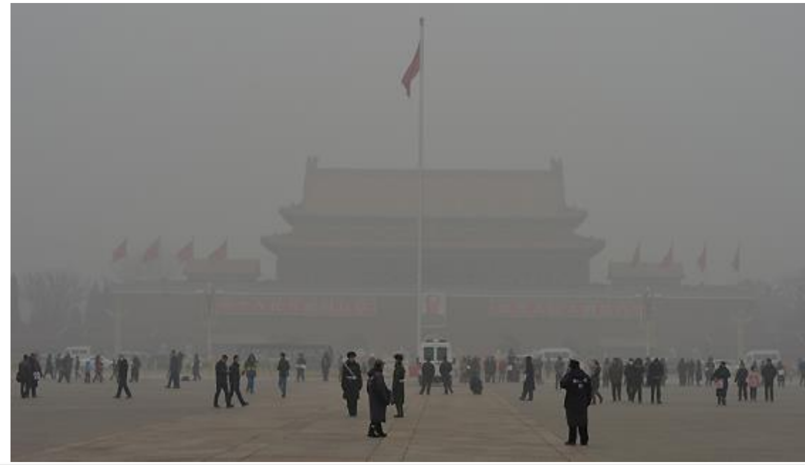


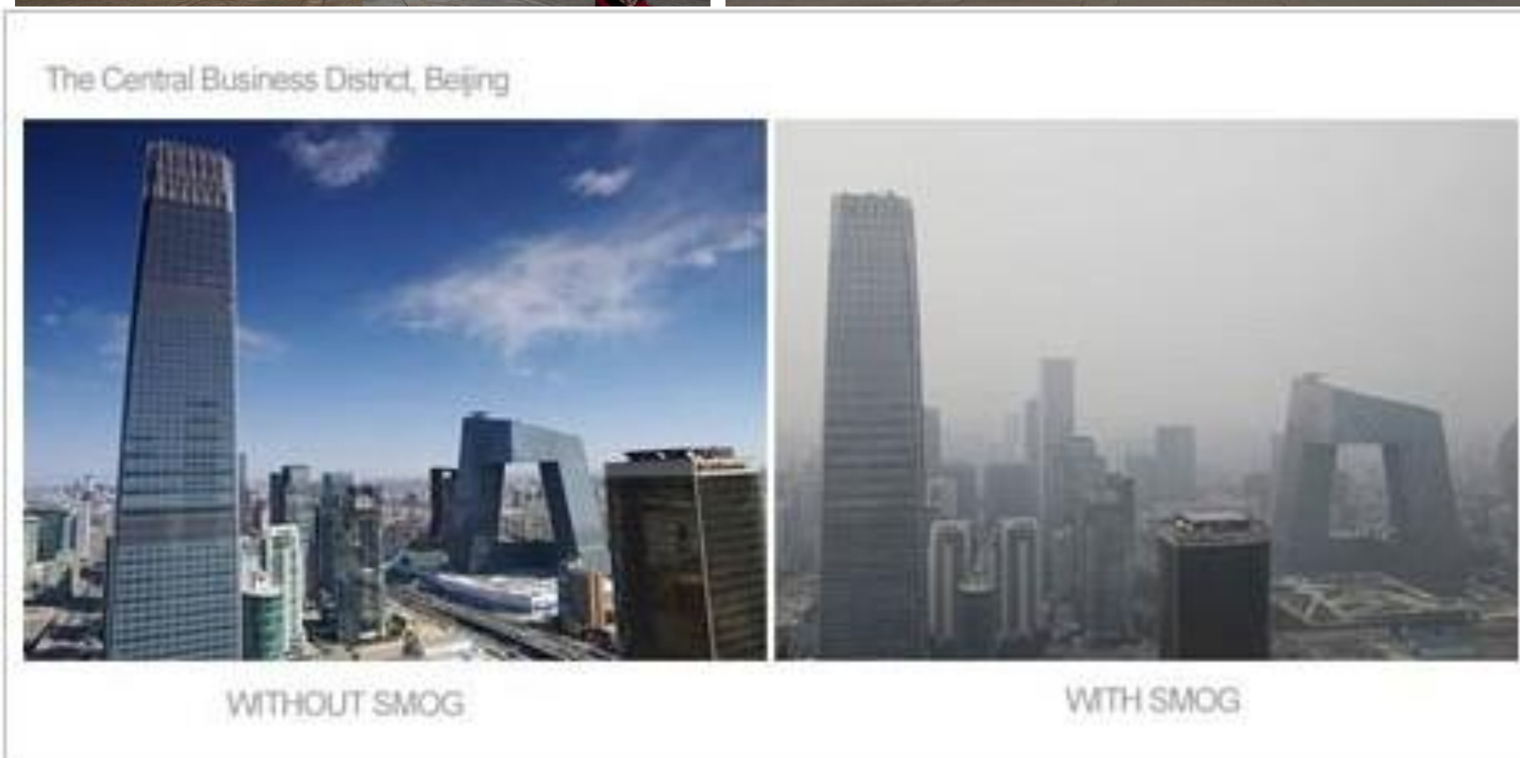
Comparison

Other application—graphene based filter materials

Product line for filter materials: 200000 m^2/y

Application based surfaces--Anti smog mask



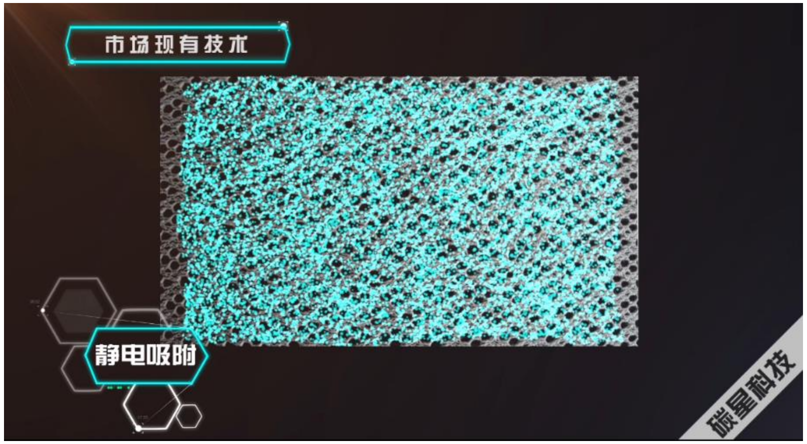


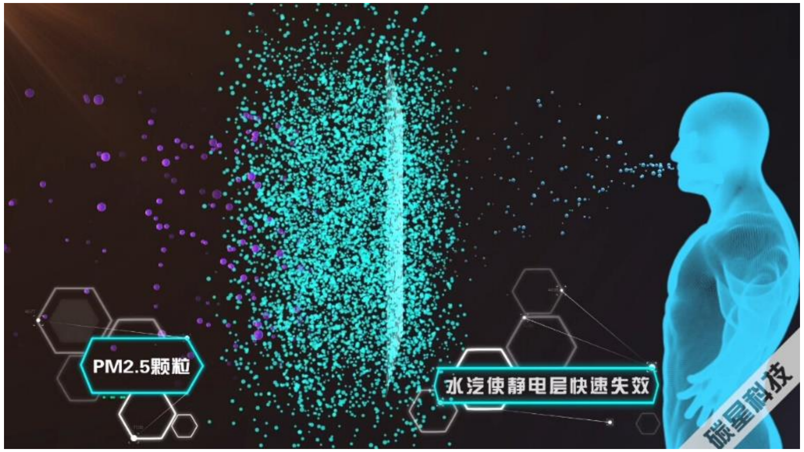
Application based surfaces--Anti smog mask

Anti amog masks

Application based surfaces--Anti smog mask

Anti smog mask: current technology





Mechanism：block big particles + adsorb small particles

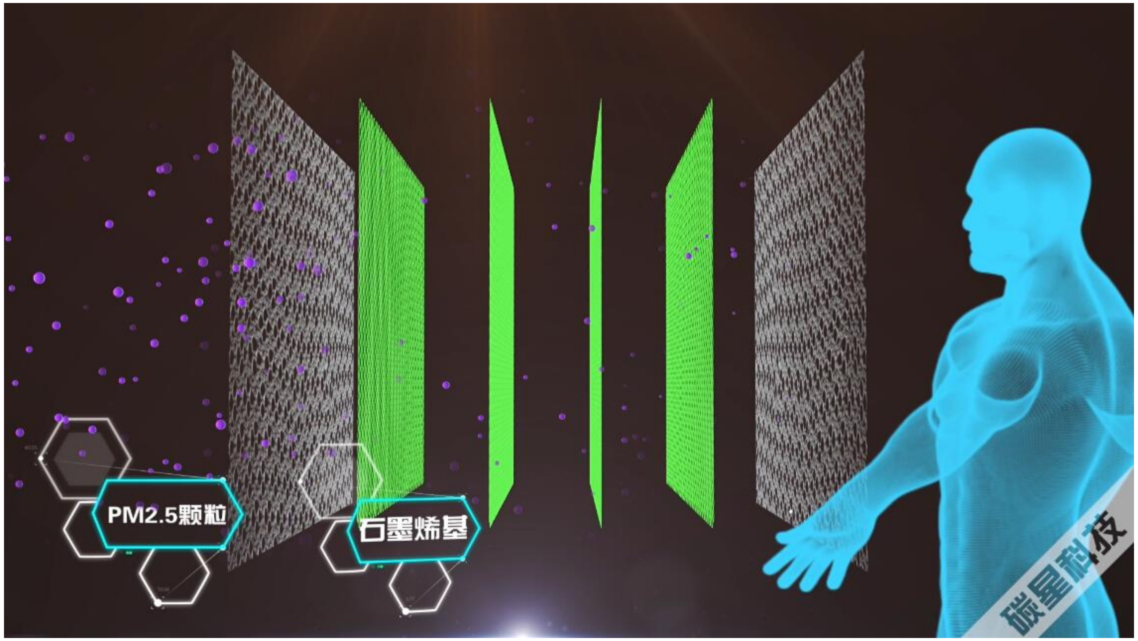
(Melt-blown Nonwoven Fabric) (electrostatic charges)

Problem：disappear of electrostatic charges

under moisture condition or meet vapor (short-time available:<1h)

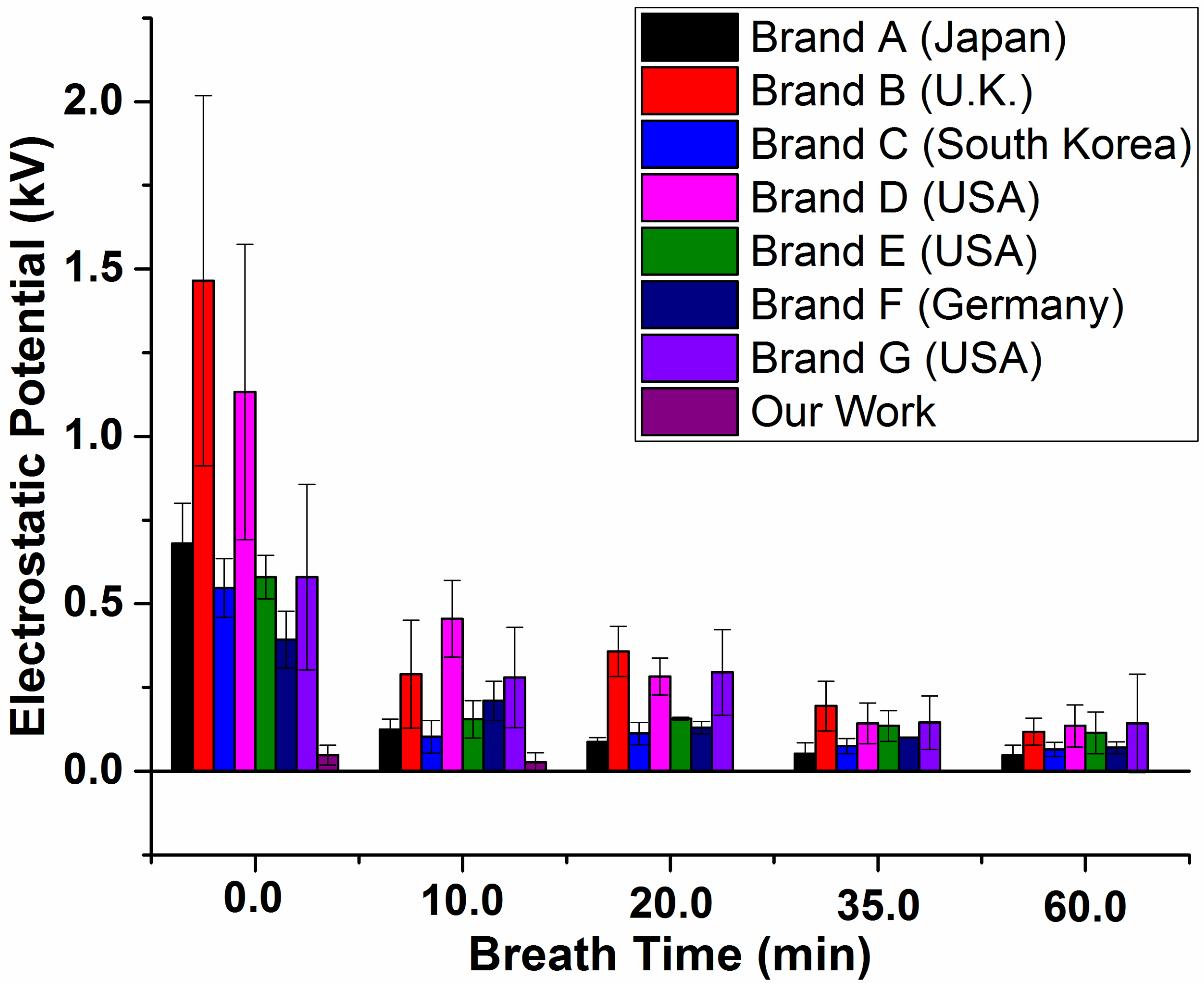
Application based surfaces--Anti smog mask

Functionalized graphene-based anti-smog mask

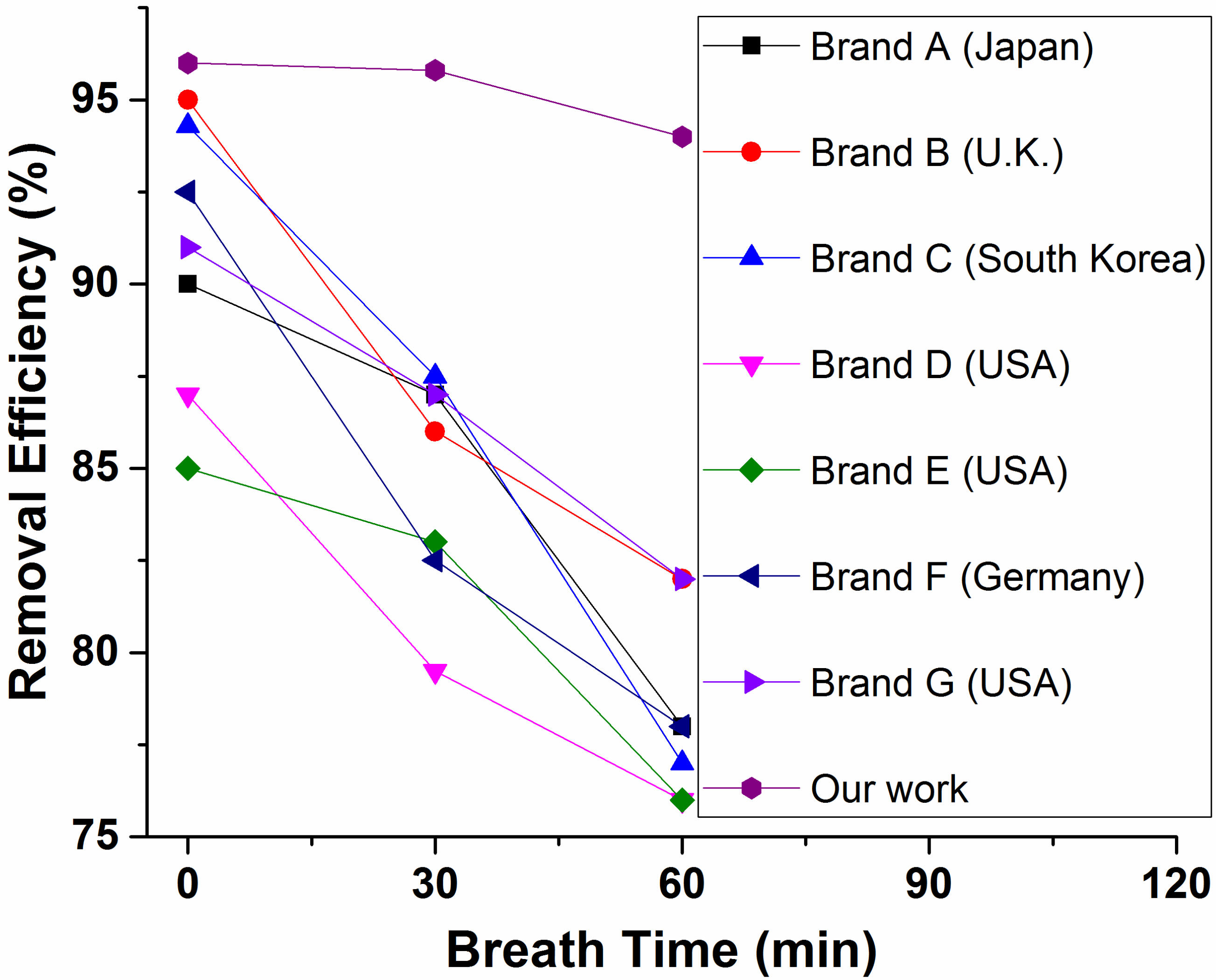


Advantage： **large surface area of functionalized graphene with many defects (**adsorption property for small particles)
(long-time available: around 1week)

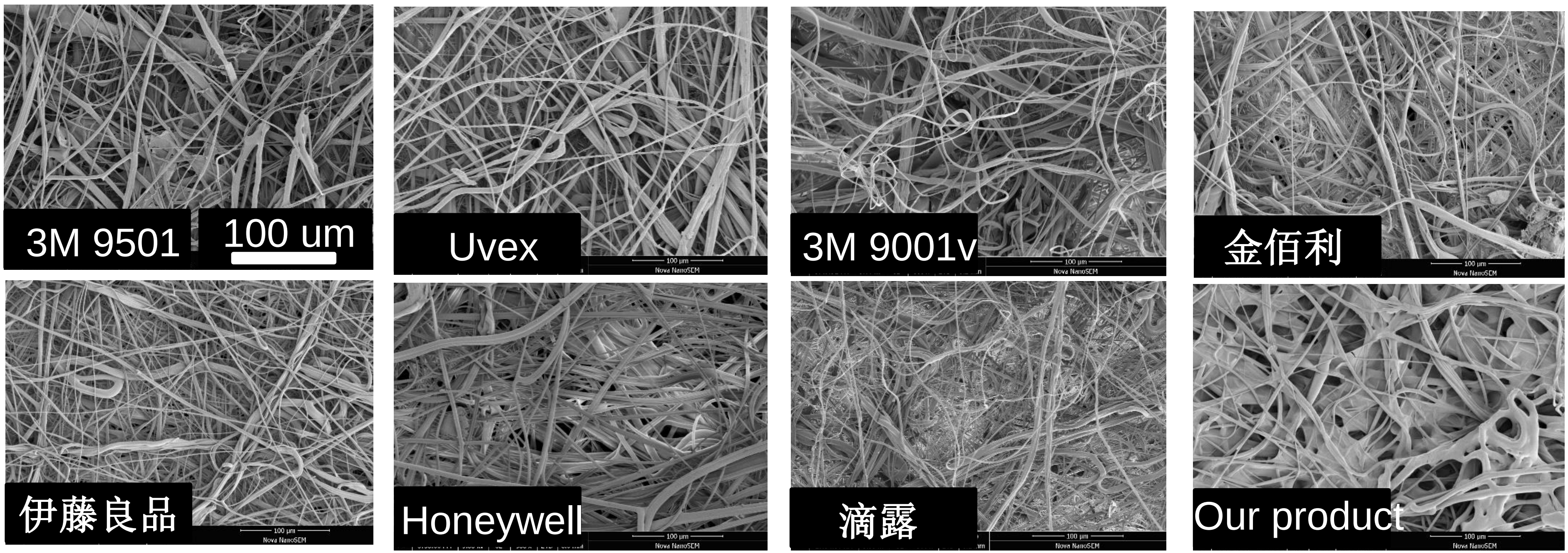
Application based surfaces--Anti smog mask



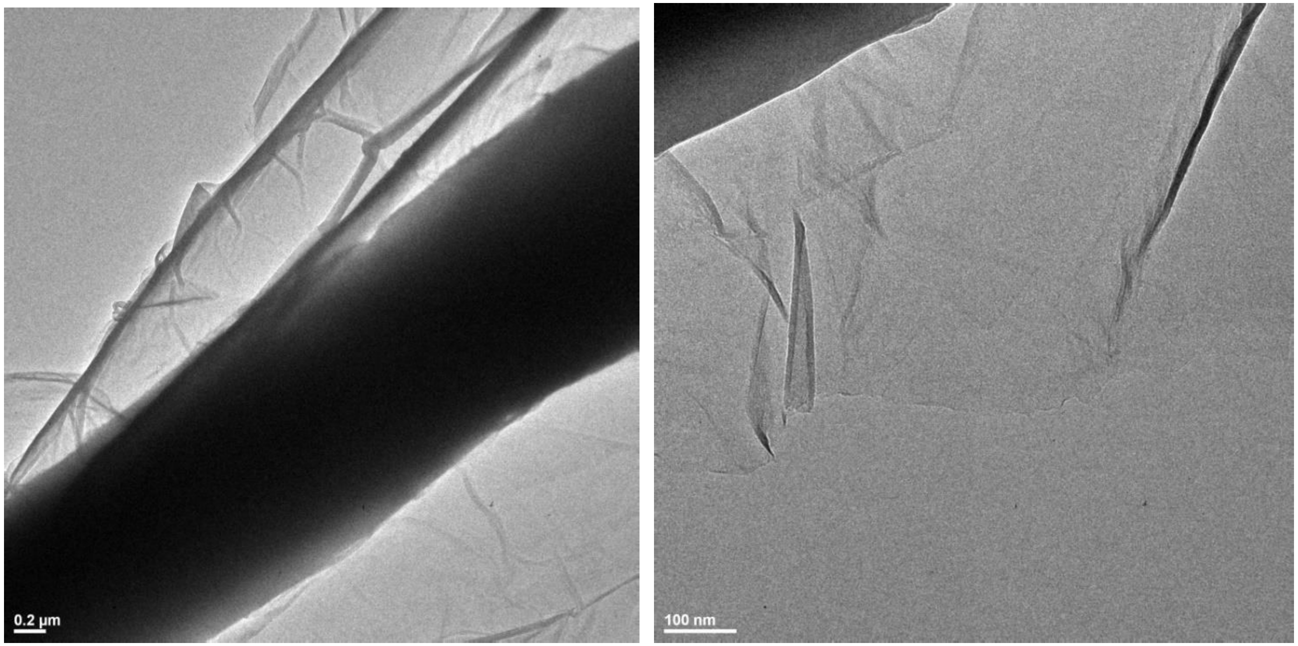
Application based surfaces--Anti smog mask



Application based surfaces--Anti smog mask

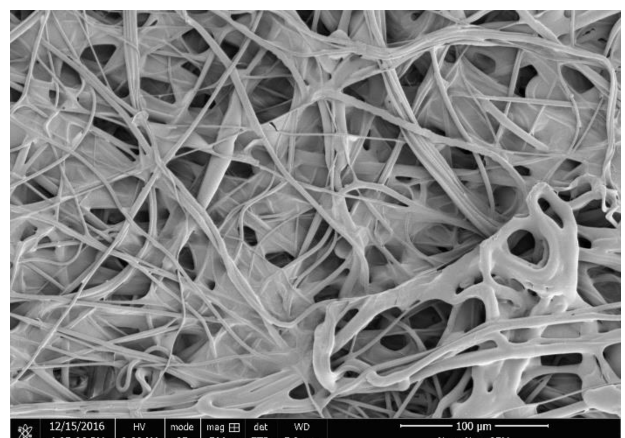


Application based surfaces--Anti smog mask



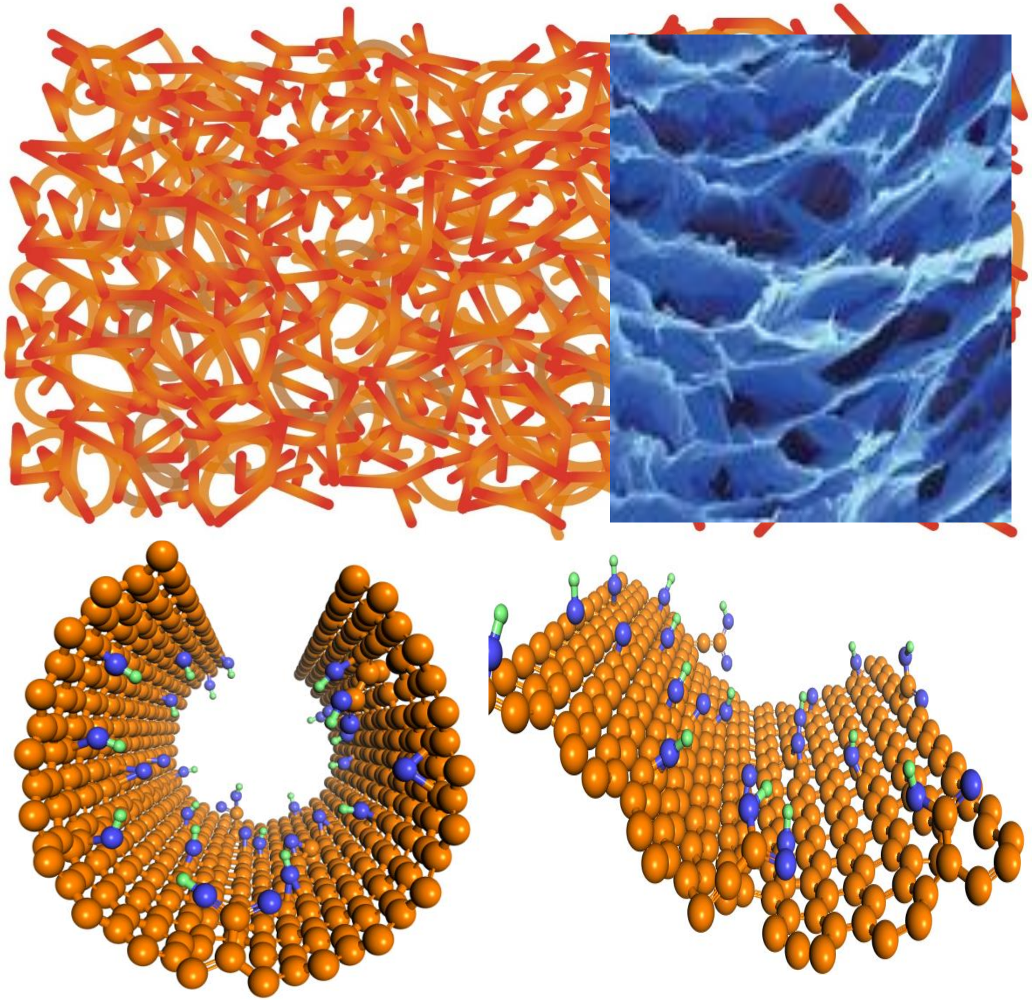
TEM images of filter materials with graphene

ununiform distribution

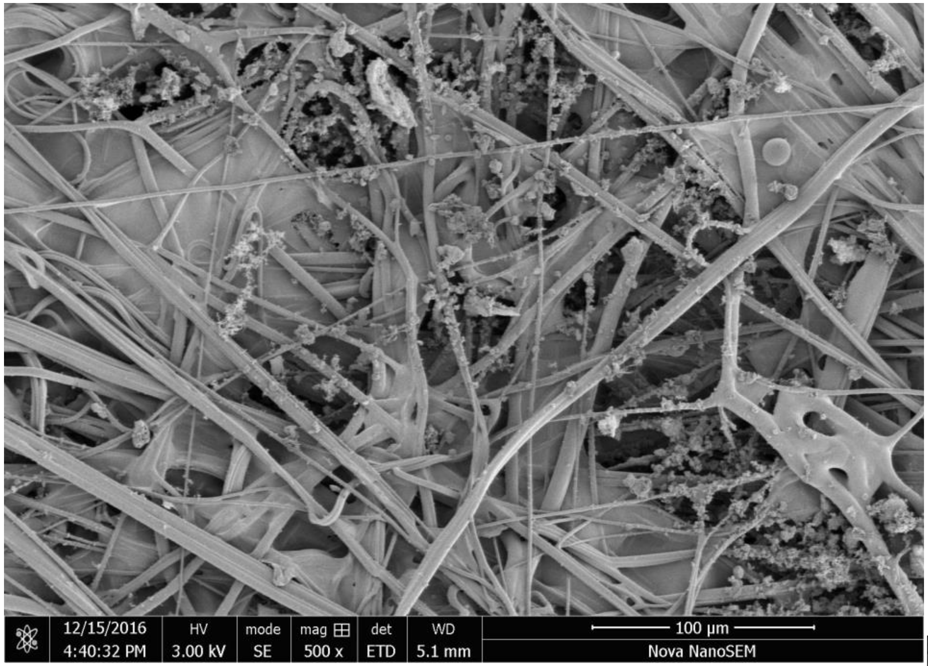


uniform distribution

Application based surfaces--Anti smog mask

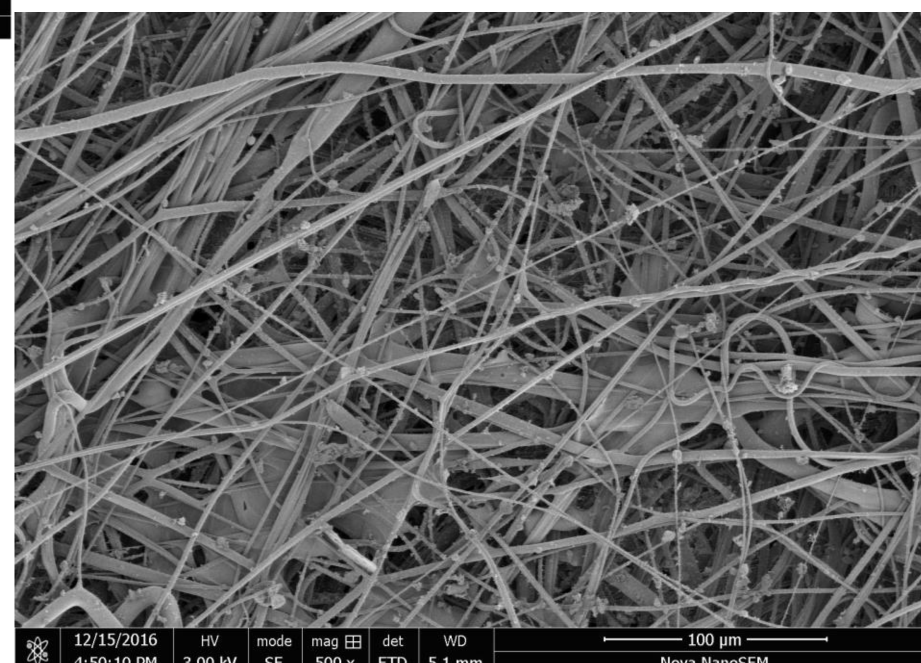


Functionalized graphene-based mask for fog and haze/smog

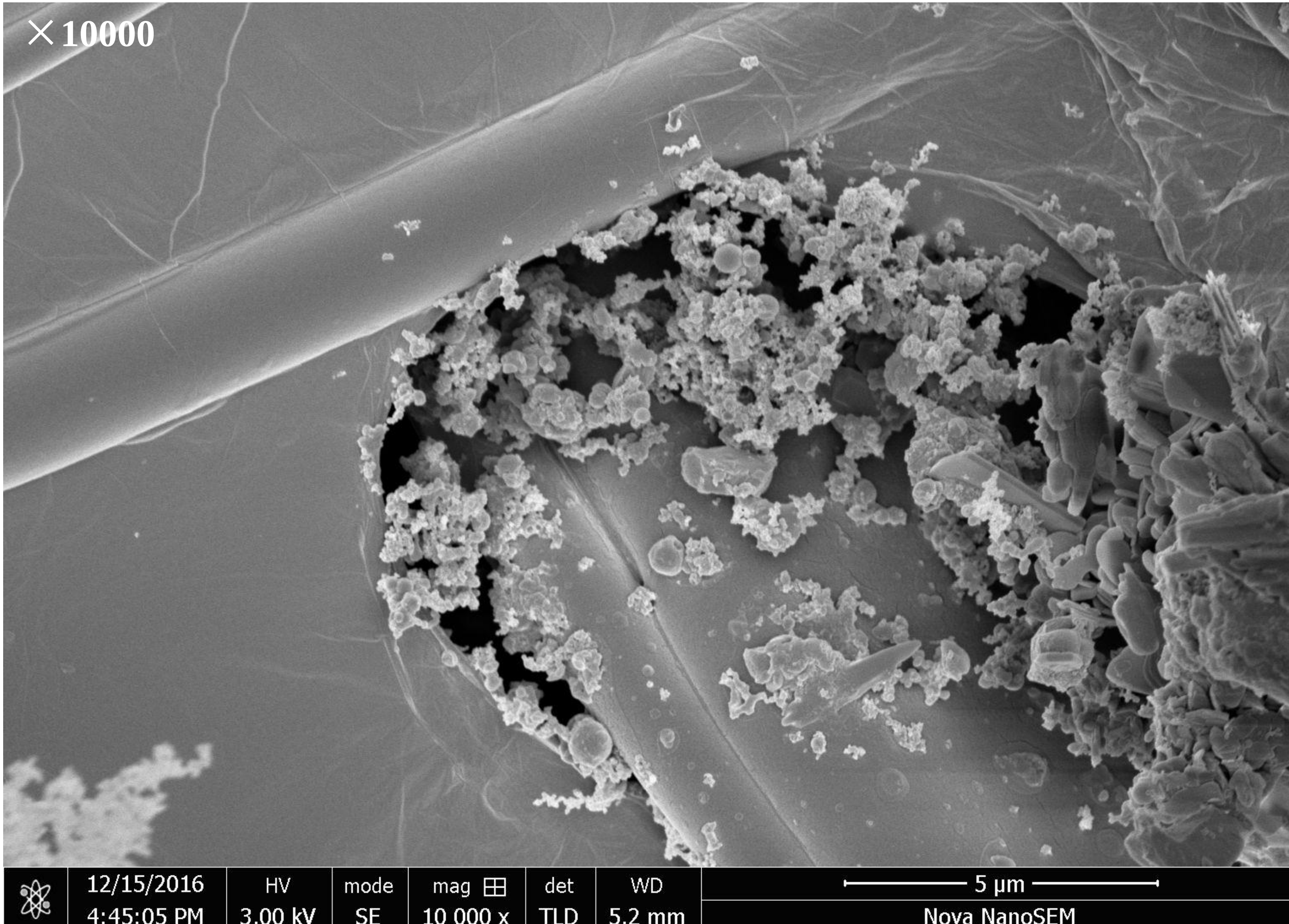


Used after 2h
Filter materials with graphene

Used after 15h
Filter materials without graphene



Used after 2h
Filter materials with graphene

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无纺布外层
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石墨烯基
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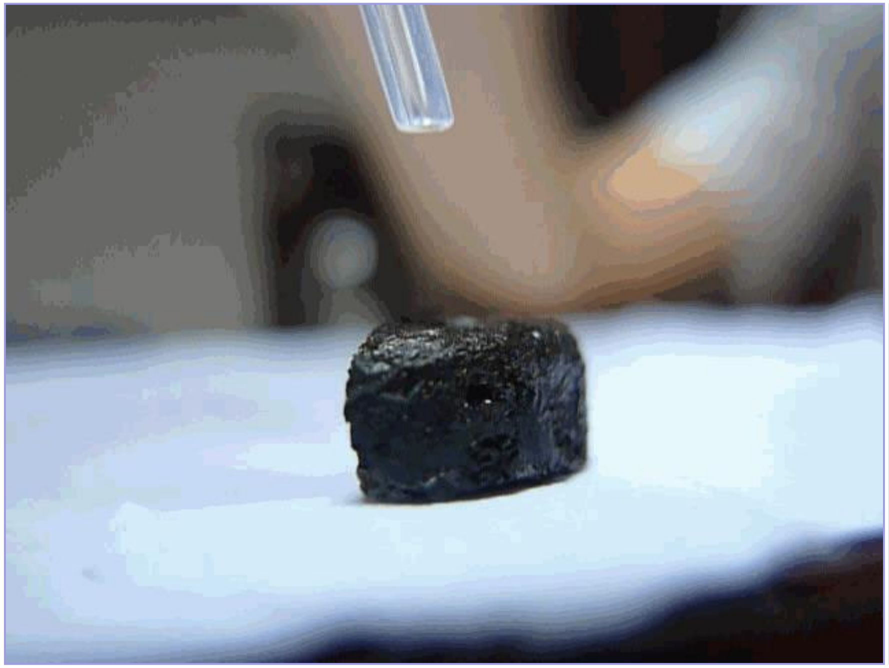
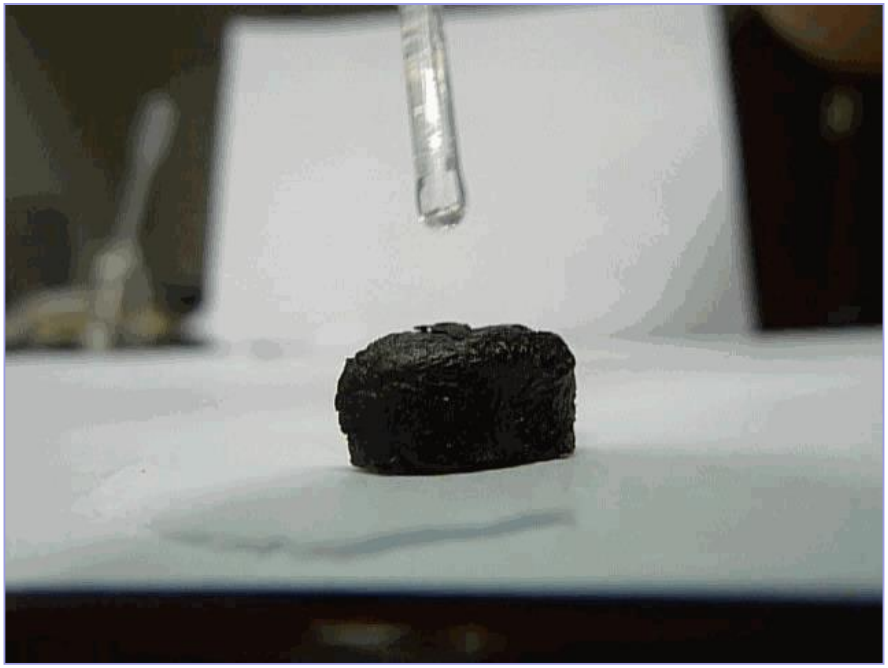
In situ property characterization --for application

Interface between the liquid and graphene?



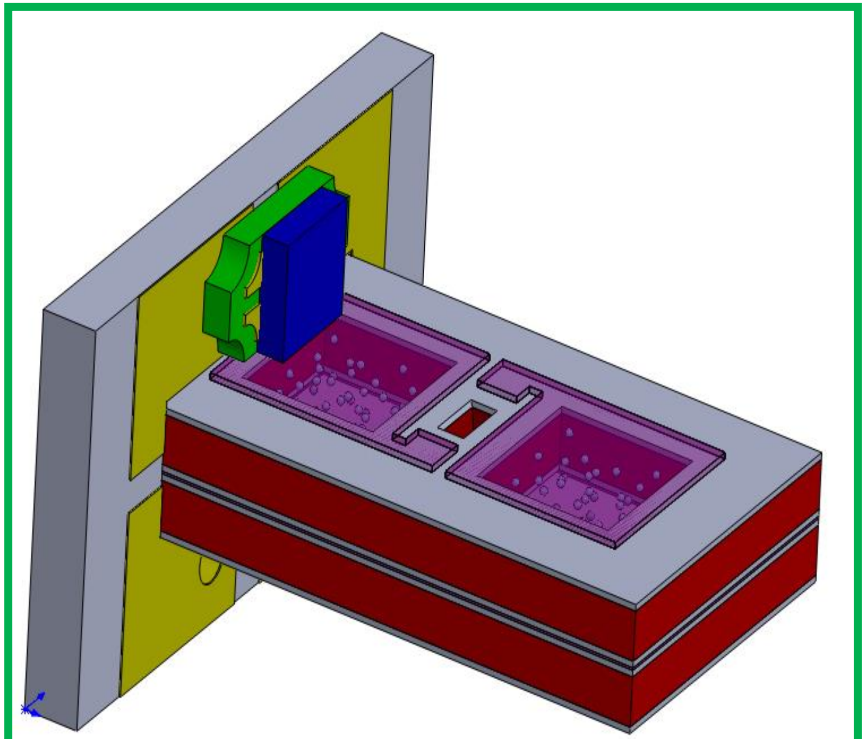


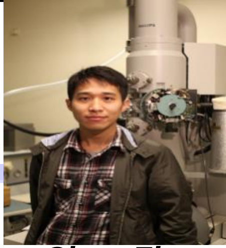
Water Oil

Selectivity, why?

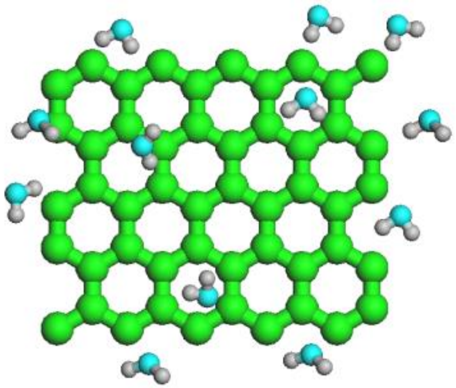
Nature: Scientific Reports 3, 2117 (2013)
Advanced Materials 25, 5916 (2013)

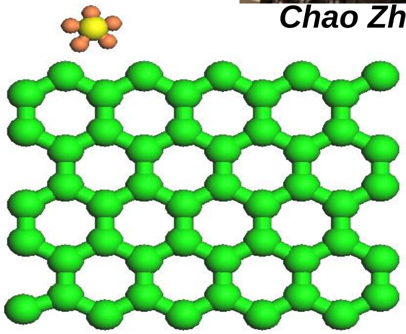
Interface between the liquid and graphene



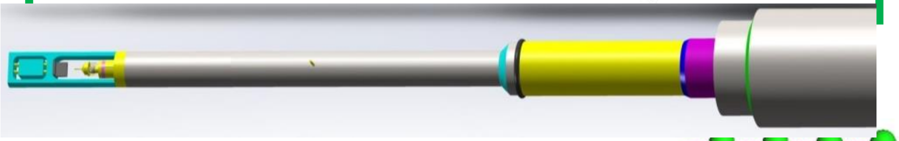


Chao Zhu

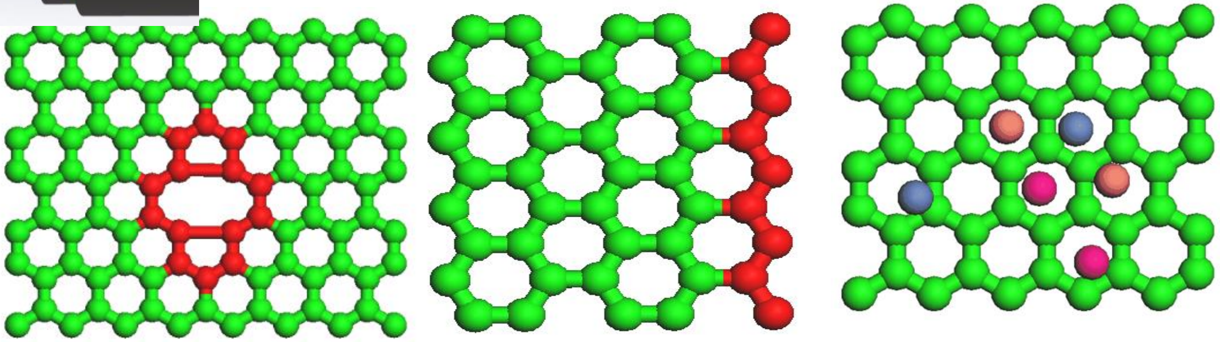




Different liquids

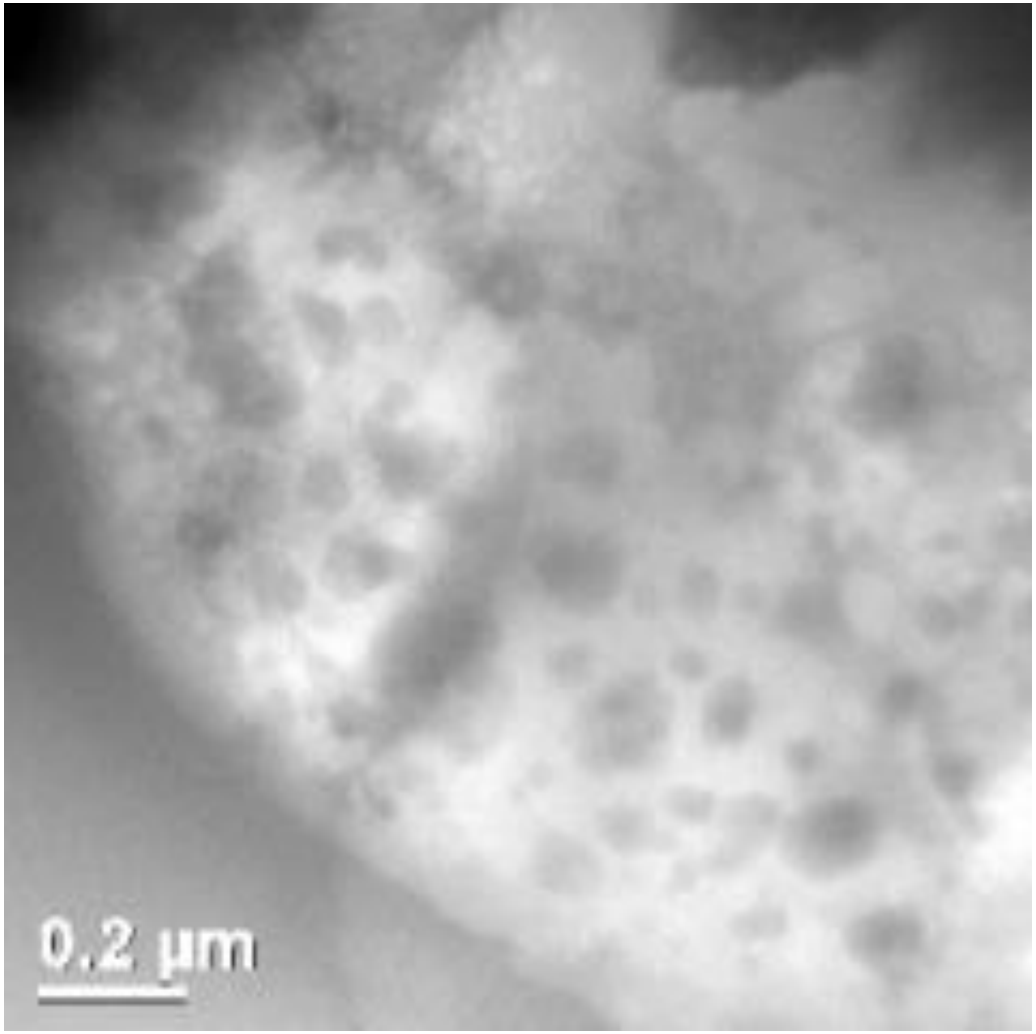


Different surface structures



Liquid inside TEM

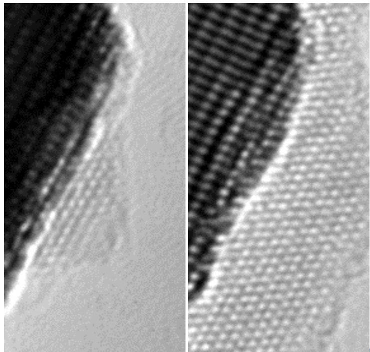
In situ property characterization --for application



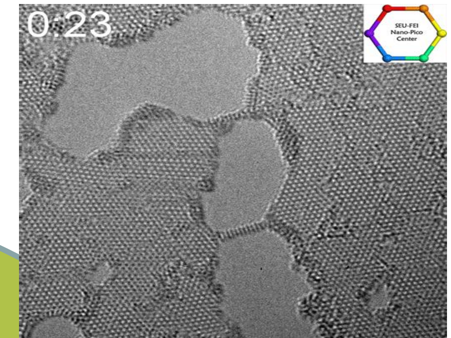
Growth of oil droplet

Unpublished results

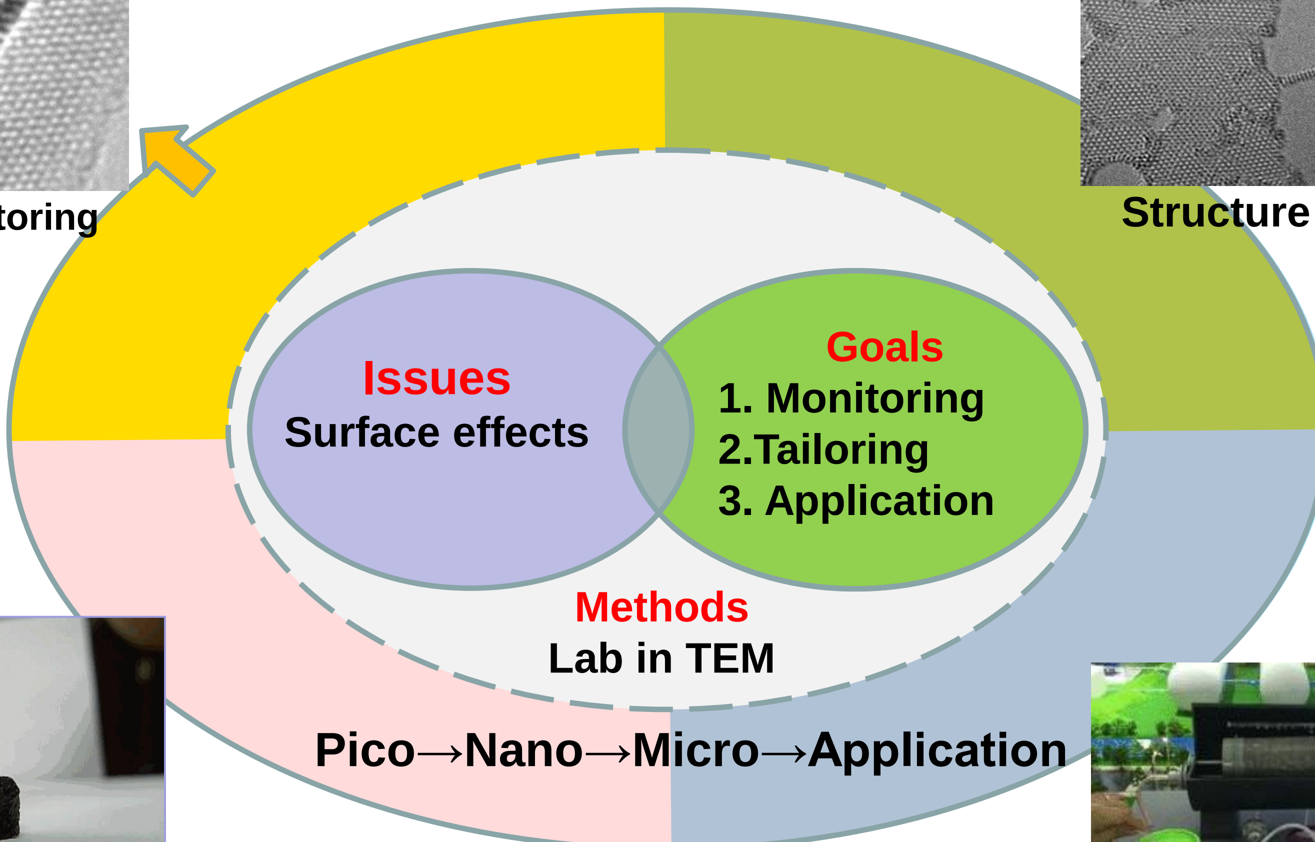
Summary

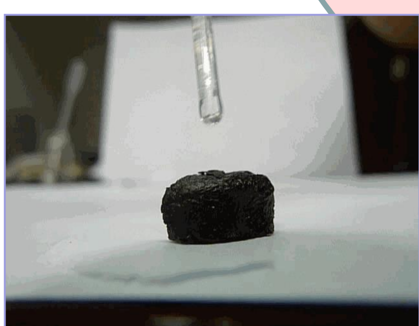


Growth Monitoring



Structure Tailoring





Novel Properties

Potential applications

Acknowledgement

Collaborators

International: F. Banhart, M. Terrones, Rod Ruoff, A. Krasheninnikov, P. M. Ajayan, Harold Kroto...

National: Z Zhang, DP Yu, XH Bao, M Liu, XR Wang, WL Gou, CH Jin, JL Wang, ZH Ni, J Li...

Group Members:


Neng Wan


Kuibo Yin


Feng Xu

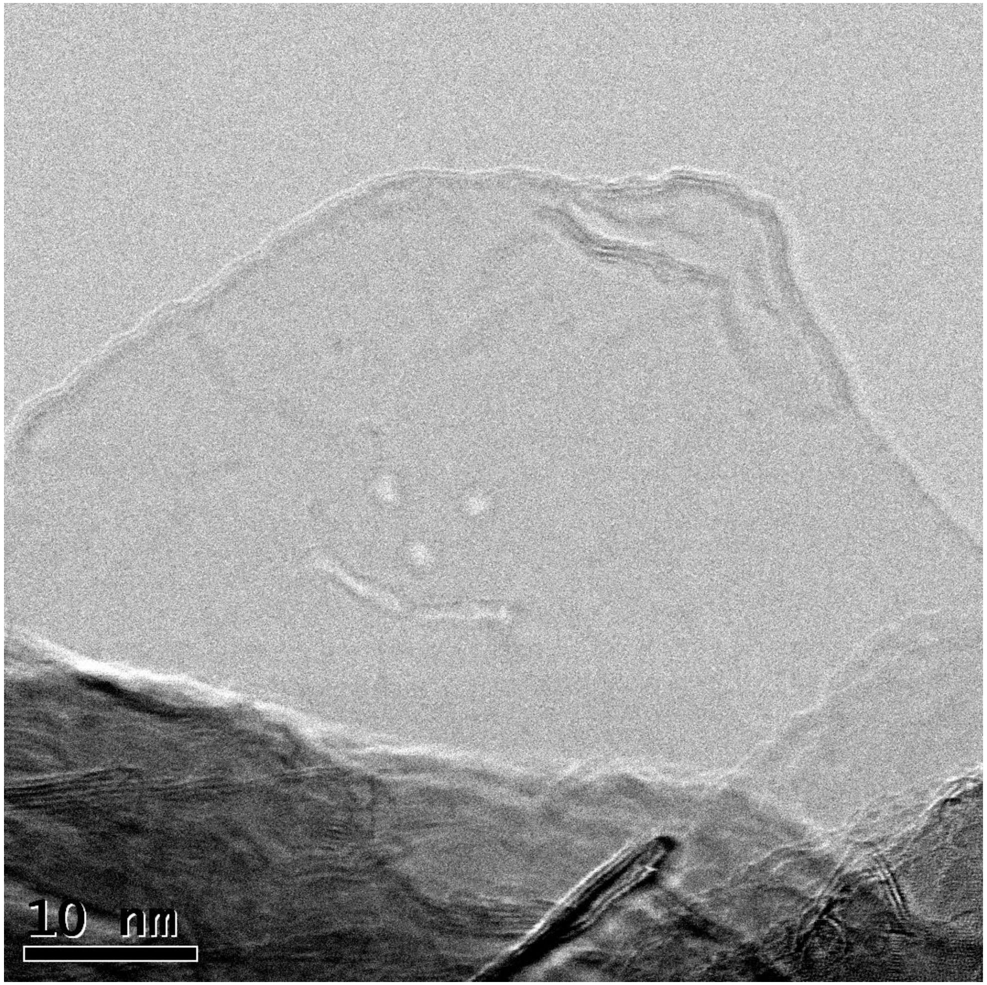

Longbing He


Xing Wu


Binjie Wang


Xiao Xie

Thanks for your attention



A happy graphene nanobear