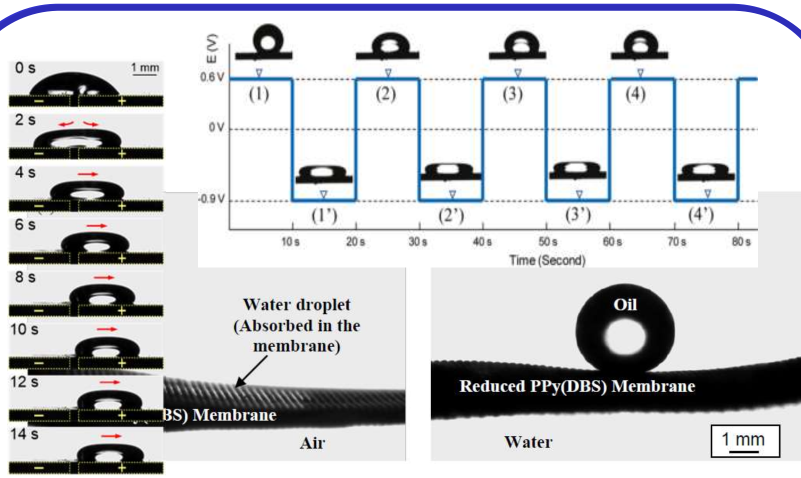
Research on Microfluidics and Graphene/CNTs in EH Yang Group

Dr. E. H. Yang
Professor, Mechanical Engineering Department
Stevens Institute of Technology

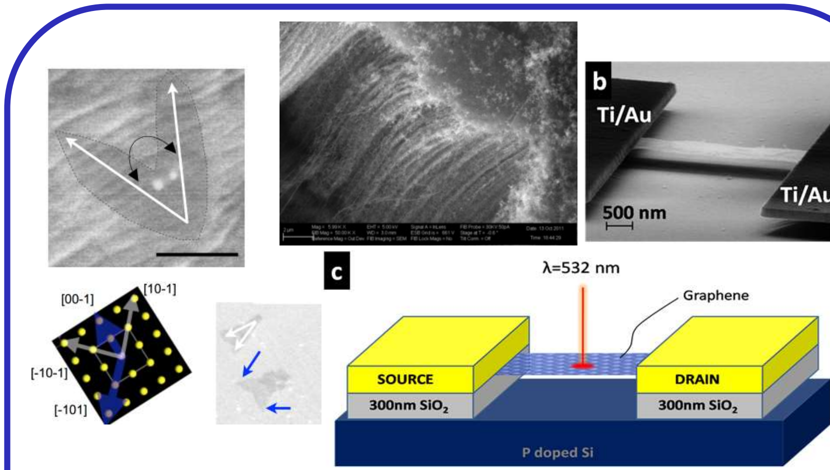
Presentation at NASA Goddard Space Flight Center
December 17th, 2013

EH Yang Group: Research Areas

Fundamentals and device applications



Smart polymers microfluidics



1D and 2D atomic layers

Strauf

Fisher

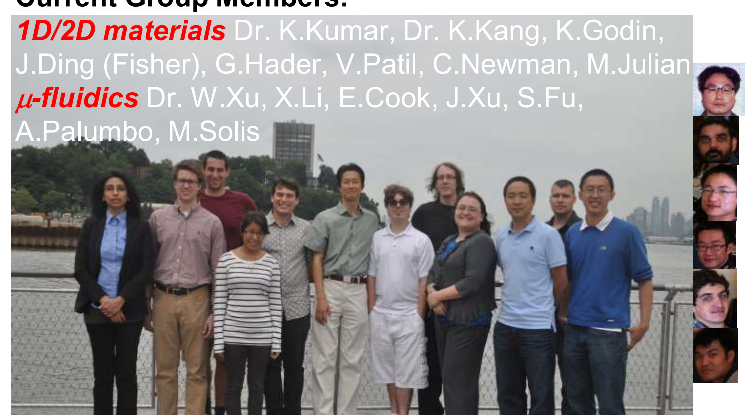
Choi

Major Collaborators @ Stevens

Current Group Members:

1D/2D materials Dr. K.Kumar, Dr. K.Kang, K.Godin, J.Ding (Fisher), G.Hader, V.Patil, C.Newman, M.Julian

μ-fluidics Dr. W.Xu, X.Li, E.Cook, J.Xu, S.Fu, A.Palumbo, M.Solis



Outline of Presentation

- **Smart Polymer Microfluidics**
  - Overview: *Wetting, PPy, EWOD*
  - Droplet Manipulation on PPy(DBS): *DCM Droplets, Magrangoni effects*
  - Applications: *Lab on a Chip, Oil/water Separation*

- **Graphene and CNT Architectures**
  - CVD Growth and Characterization: *Domain Growth Mechanism, Annealing Effect*
  - Photodetection using CVD Graphene: *Suspension of Graphene; Enhanced Photoelectric Effect*
  - Graphene-CNT Composites for Energy Storage: *Seamless Growth; Suppressed Graphene Etching*

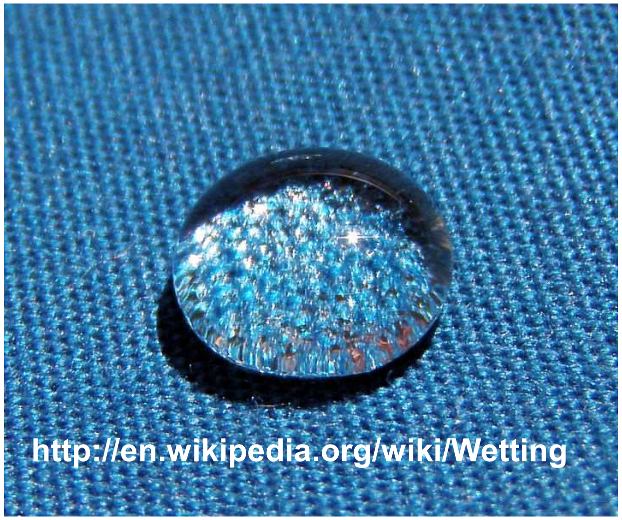
Outline of Presentation

- **Smart Polymer Microfluidics**
  - Overview: *Wetting, PPy, EWOD*
  - Droplet Manipulation on PPy(DBS): *DCM Droplets, Magrangoni effects*
  - Applications: *Lab on a Chip, Oil/water Separation*

- **Graphene and CNT Architectures**
  - CVD Growth and Characterization: *Domain Growth Mechanism, Annealing Effect*
  - Photodetection using CVD Graphene: *Suspension of Graphene; Enhanced Photoelectric Effect*
  - Graphene-CNT Composites for Energy Storage: *Seamless Growth; Suppressed Graphene Etching*

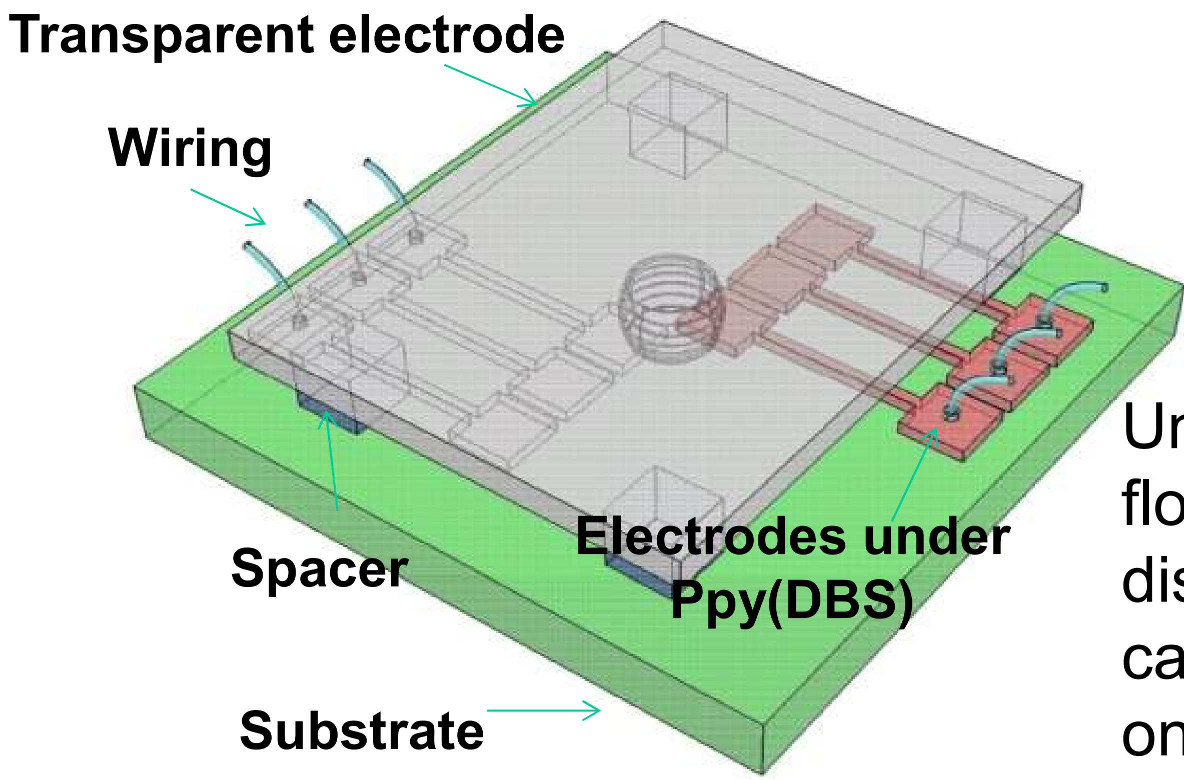
Wetting

- Wetting: The ability of a liquid to maintain contact with a solid surface.
- The wettability is determined by a force balance between adhesive and cohesive forces.
- At the interface between a liquid and a gas, forces develop in the liquid surface that causes the surface to behave as if a “membrane” were stretched over it.



Water beads on a fabric that has been made non-wetting by chemical treatment.

Droplet Microfluidics



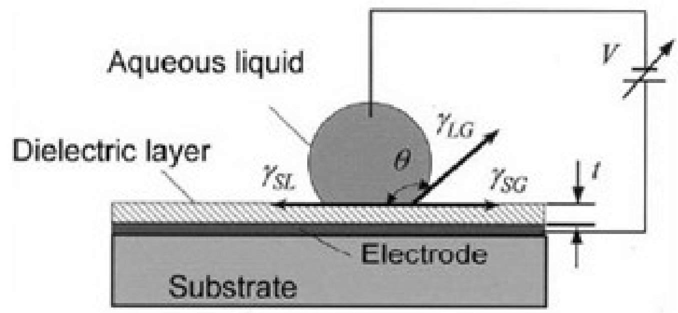
Unlike continuous-flow systems, discrete droplets can be manipulated on a substrate: *Valves and tubes are completely removed.*

Electrowetting for Droplet Manipulation

- In electrowetting on dielectric (EWOD), an externally added electrostatic charge modifies the surface tension at the fluid-surface interface.

- The effect of a potential *V* on the contact angle is then determined by the following:

$$\cos\theta(V) - \cos\theta_o = \frac{\varepsilon_r \varepsilon_o}{2\gamma_{LG} t} V^2,$$



where

θ (theta) is the contact angle,

θ_o (theta-nought) is the equilibrium contact angle at $V = 0$,

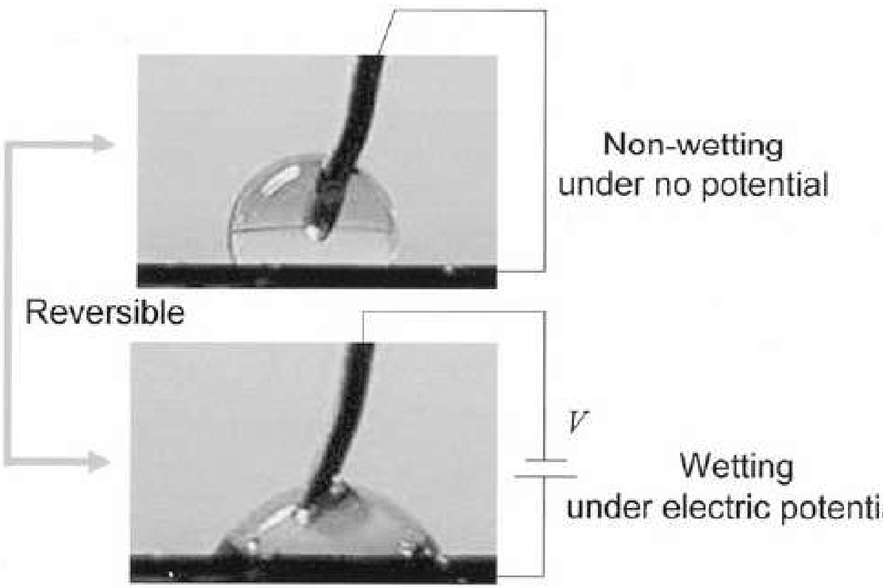
V is the electric potential across the interface (V),

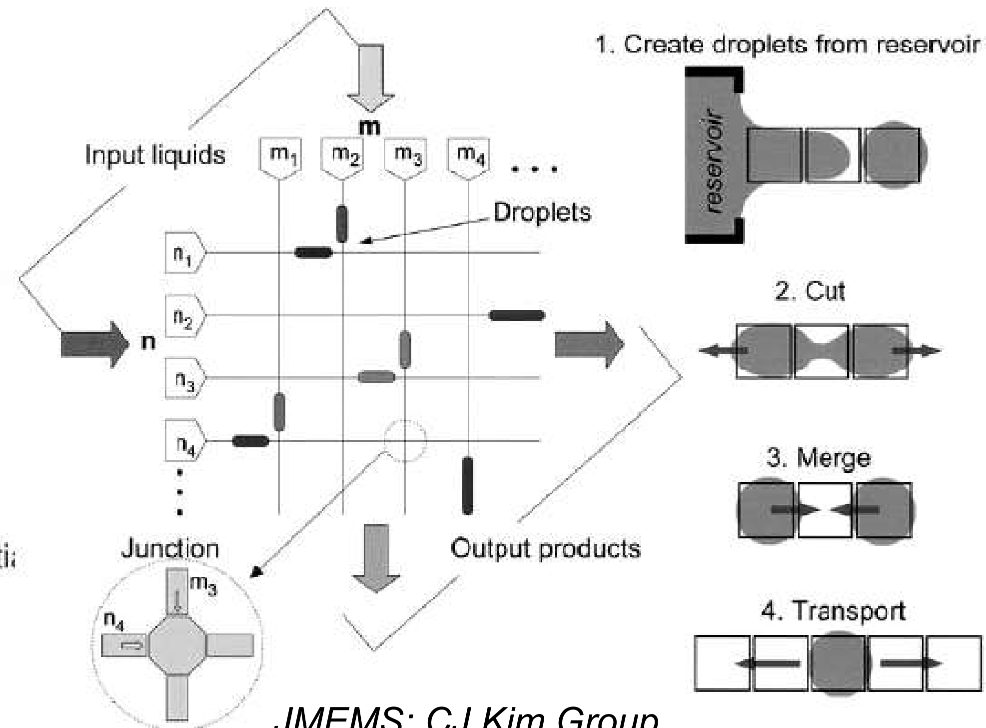
ε_r (epsilon) the dielectric constant of the dielectric layer,

ε_o (epsilon) is the permittivity of a vacuum (8.85×10^{-12} F/m), and

t is its thickness (m).

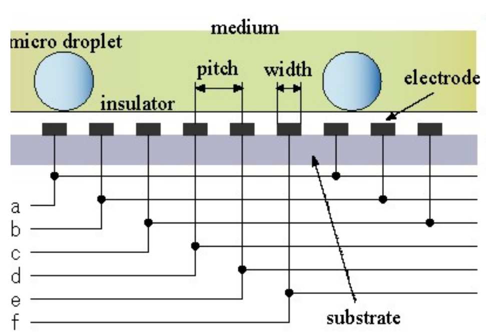
Electrowetting on Dielectric





JMEMS: CJ Kim Group

Electrowetting



Digital Microfluidic Circuit

Electrowetting on Dielectric

http://microfluidics.ee.duke.edu/

Advanced Liquid Logic, Inc.

Advanced Liquid Logic
powered by Digital Microfluidics

Home | Applications & Products | Technology | About Us | Contact Us

Home › Newborn Screening

Newborn Screening

Advanced Liquid Logic has developed the LSD-100, an automated newborn screening system capable of rapidly and simultaneously performing 5 assays on 40 dried blood spot extracts along with 4 controls & 4 calibrators.

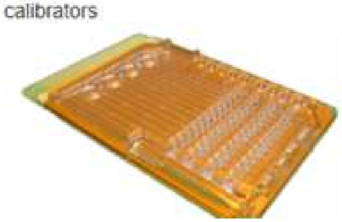
Components of the LSD-100 Newborn Screening System

The Newborn Screening Analyzer

- A small form-factor (8"x13"x20") bench-top instrument
- Houses electronics, thermal components and optical detection systems
- Up to four instruments controlled from one PC, providing scalability

Digital microfluidic cartridge

- Capable of rapidly and simultaneously performing 5 assays on 40 dried blood spot extracts along with 4 controls & 4 calibrators
- Minimal hands on time for reagent loading
- Disposable under standard biohazard procedures
- Reagents for each assay type are formulated at Advanced Liquid Logic under controlled manufacturing practices.



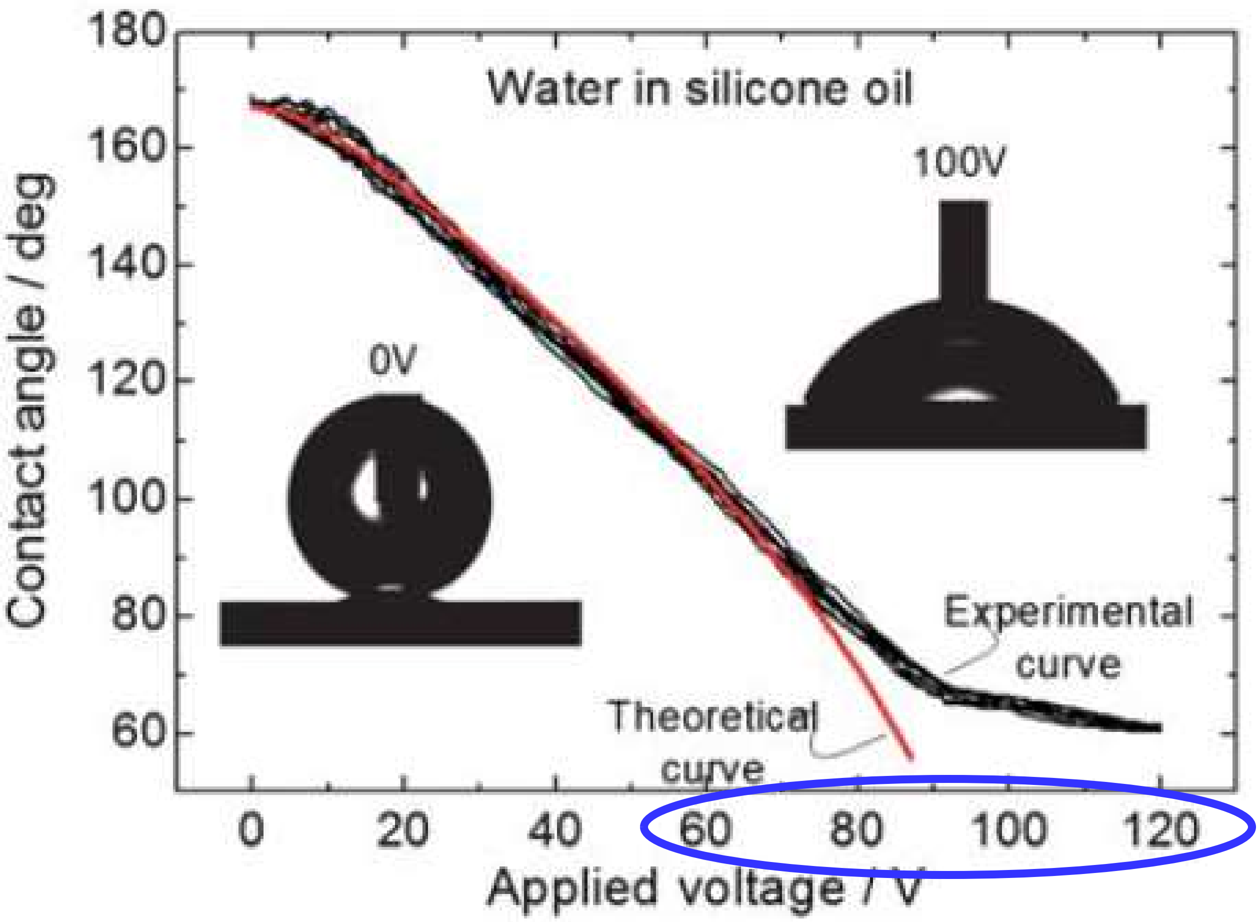
More Information

For additional information on the LSD-100 please contact Advanced Liquid Logic.

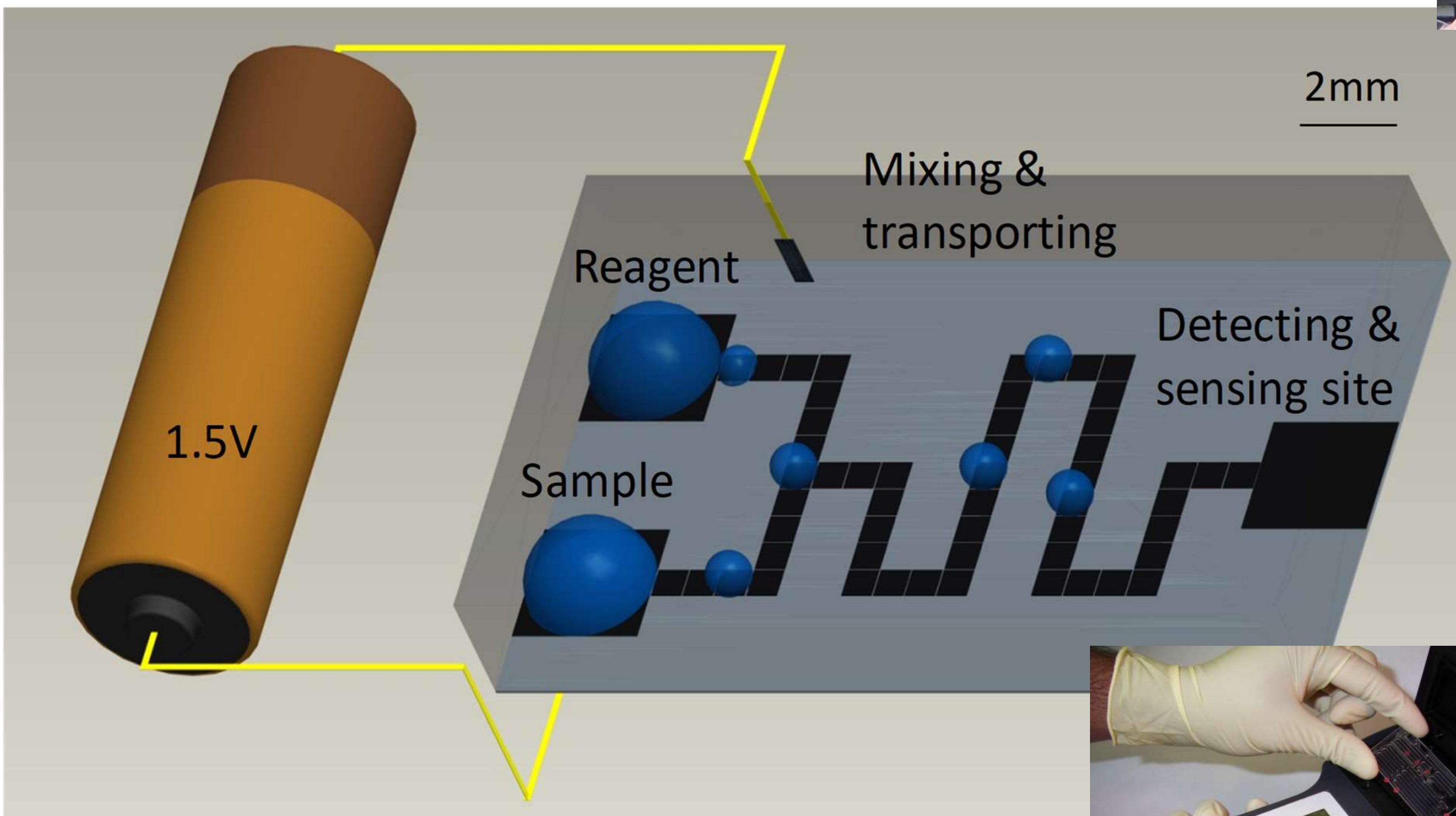
Contact Us

http://www.liquid-logic.com/lsd-100

Voltage issues



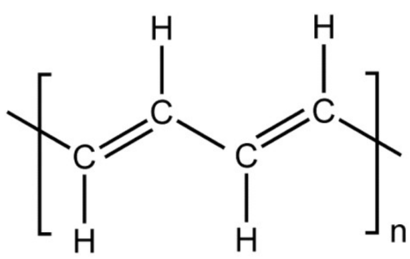
Operating with a AAA Battery?



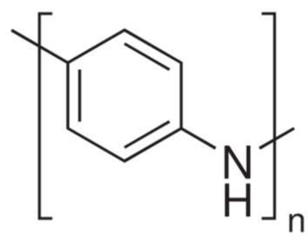
Hand-held device powered by a AAA battery

Conjugated Polymer

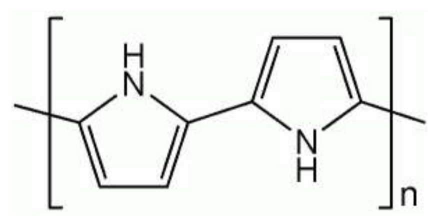
- Conjugated polymer has alternating single and double bonds between carbon atoms on the polymer backbone.
- Conductive (1 to 10^5 S/cm) when doped
- Chemical/electrochemical oxidation or reduction facilitates reversible doping.



Polyacetylene



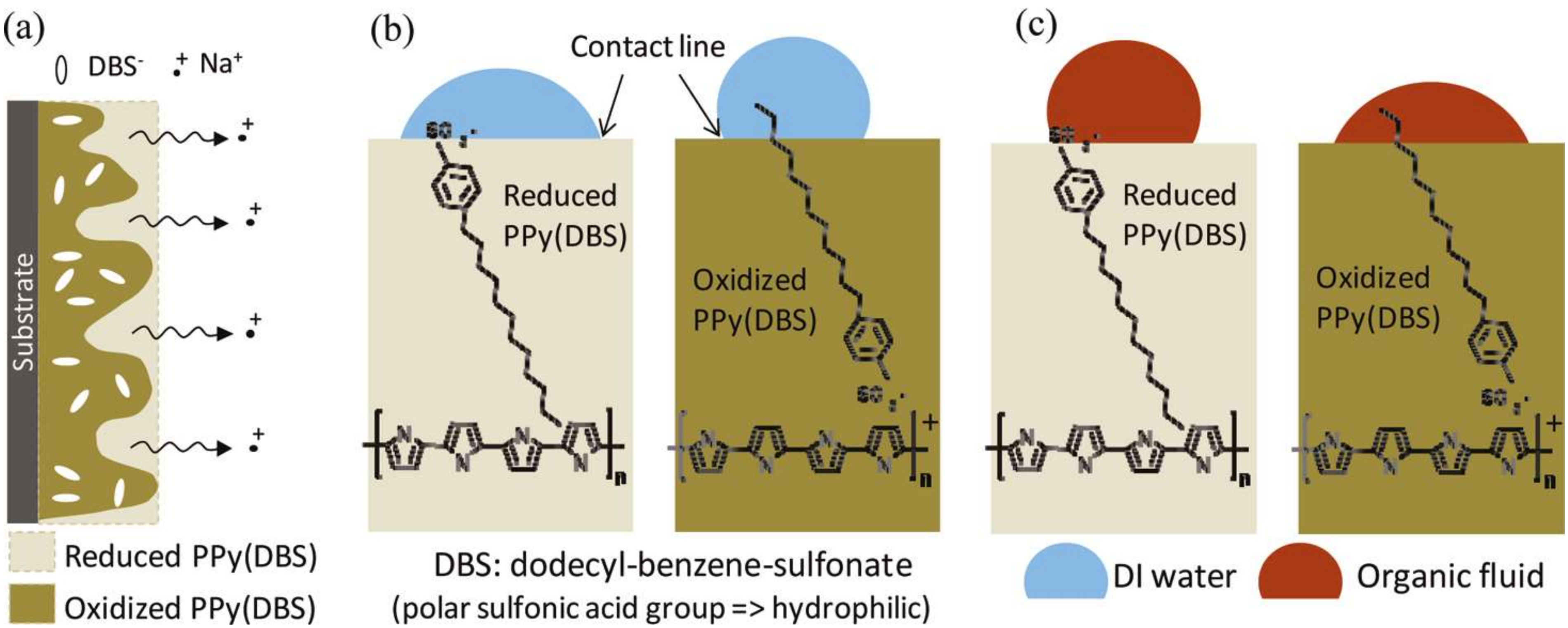
Polyaniline



Polypyrrole

Tunable Wetting on PPy(DBS)

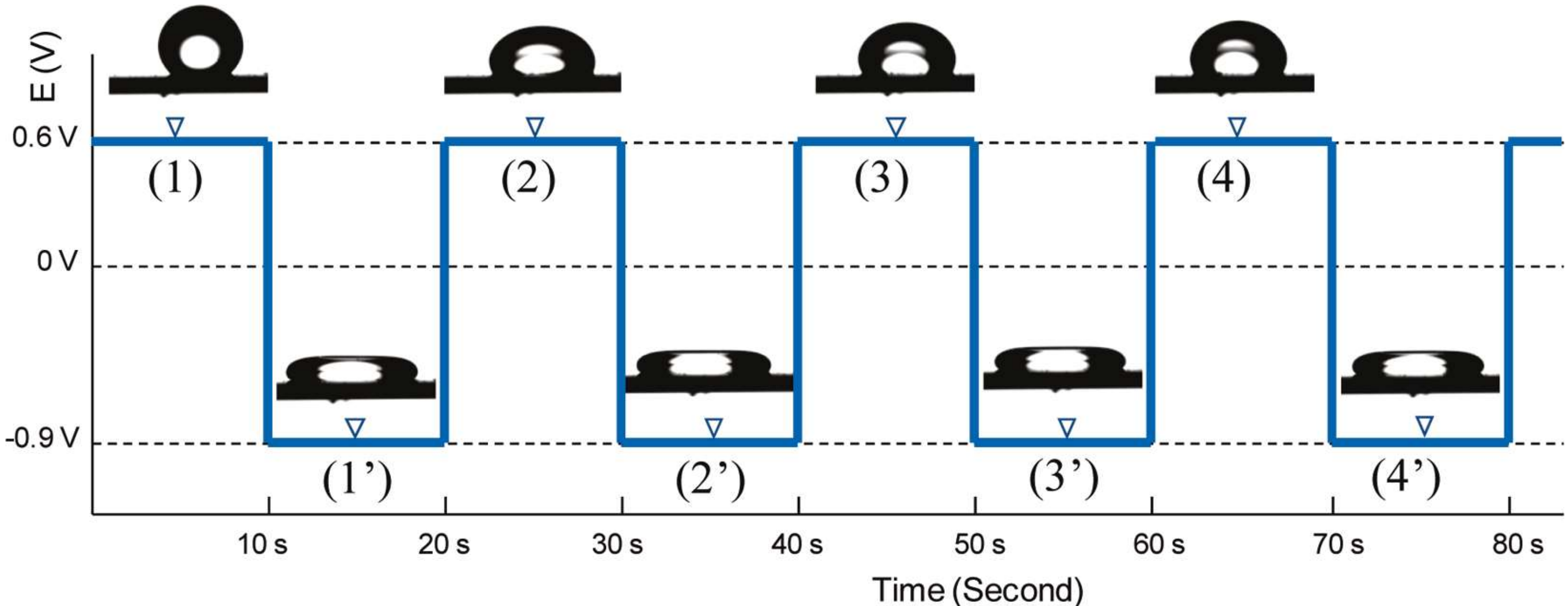
$$PPy^{+}(DBS)^{-} + Na^{+} + e^{-} \underset{\text{Oxidization}}{\overset{\text{Reduction}}{\rightleftharpoons}} PPy(DBS)^{-}Na^{+}$$

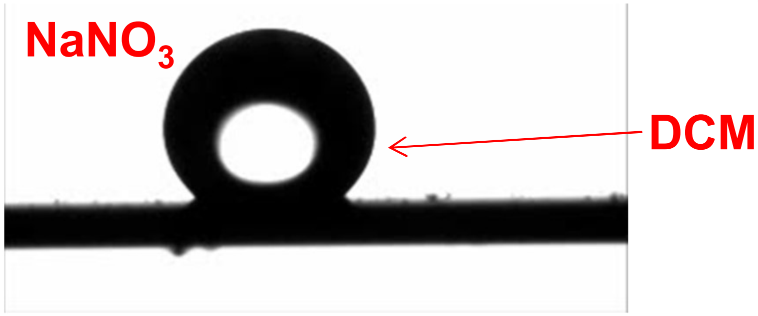


Reduced PPy(DBS) surface exhibits higher surface energy than the oxidized case.

Langmuir, 2011, 27, 4249–4256

Striking Dynamic Behavior!

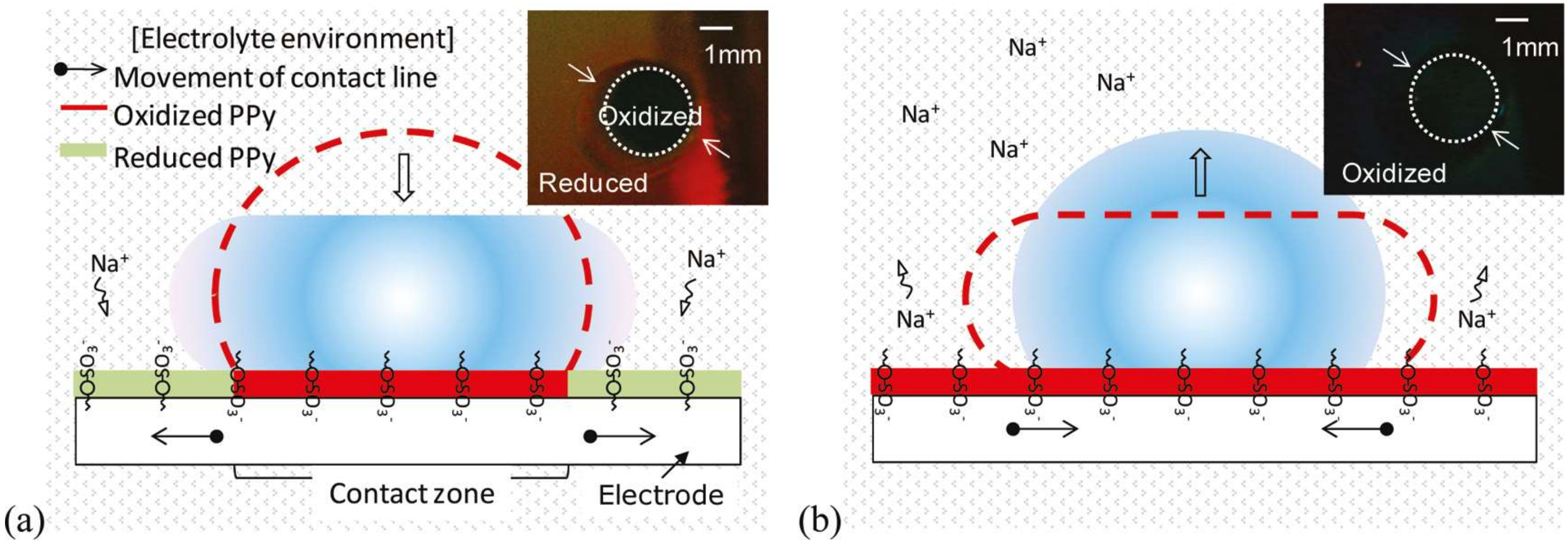




Langmuir, 27(7), 4249-4256 (2011).

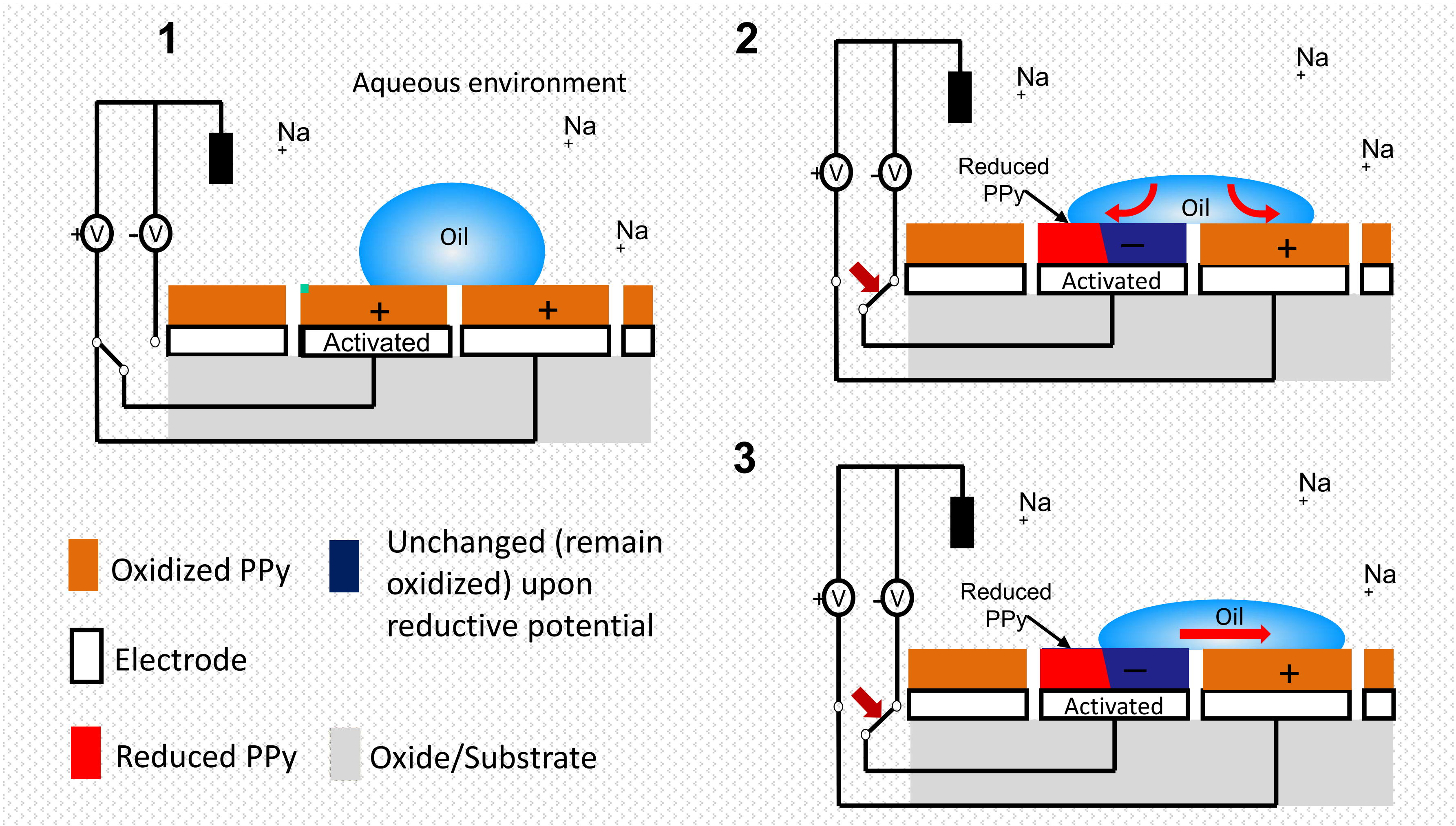
Droplet Flattening: Why?

$$PPy^{+}(DBS)^{-} + Na^{+} + e^{-} \underset{\text{Oxidization}}{\overset{\text{Reduction}}{\rightleftharpoons}} PPy(DBS)^{-}Na^{+}$$

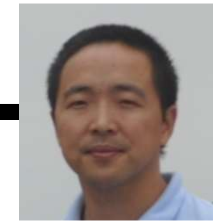


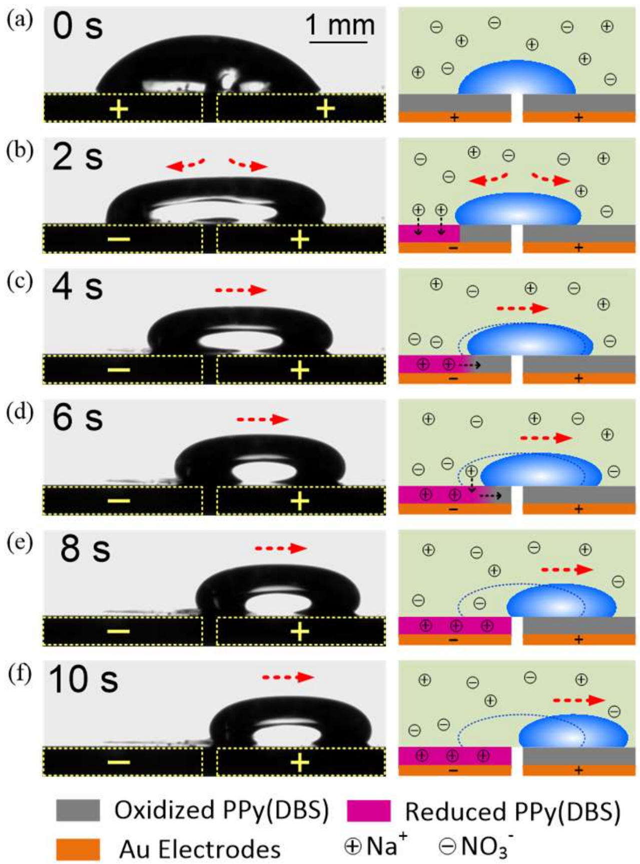
Reduced PPy(DBS) surface exhibits higher surface energy than the oxidized case.

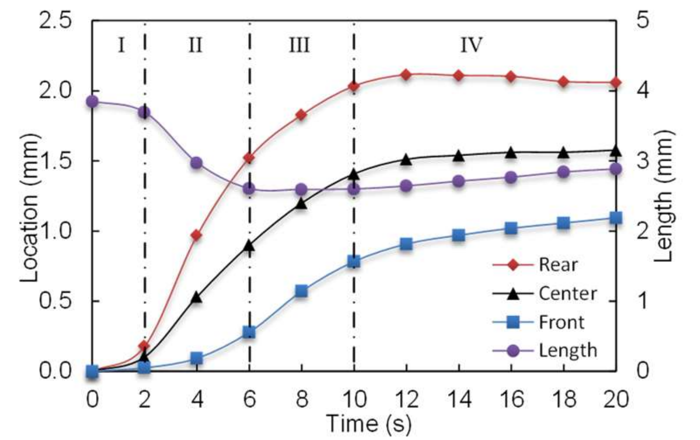
Marangoni Effect and Oleophobicity

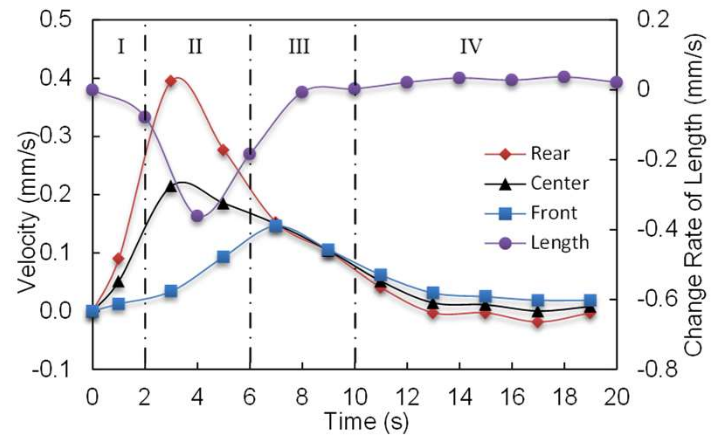


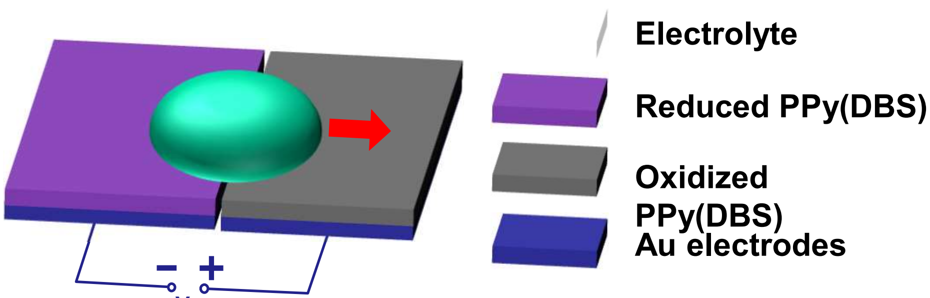
Droplet Transportation on Two Electrodes





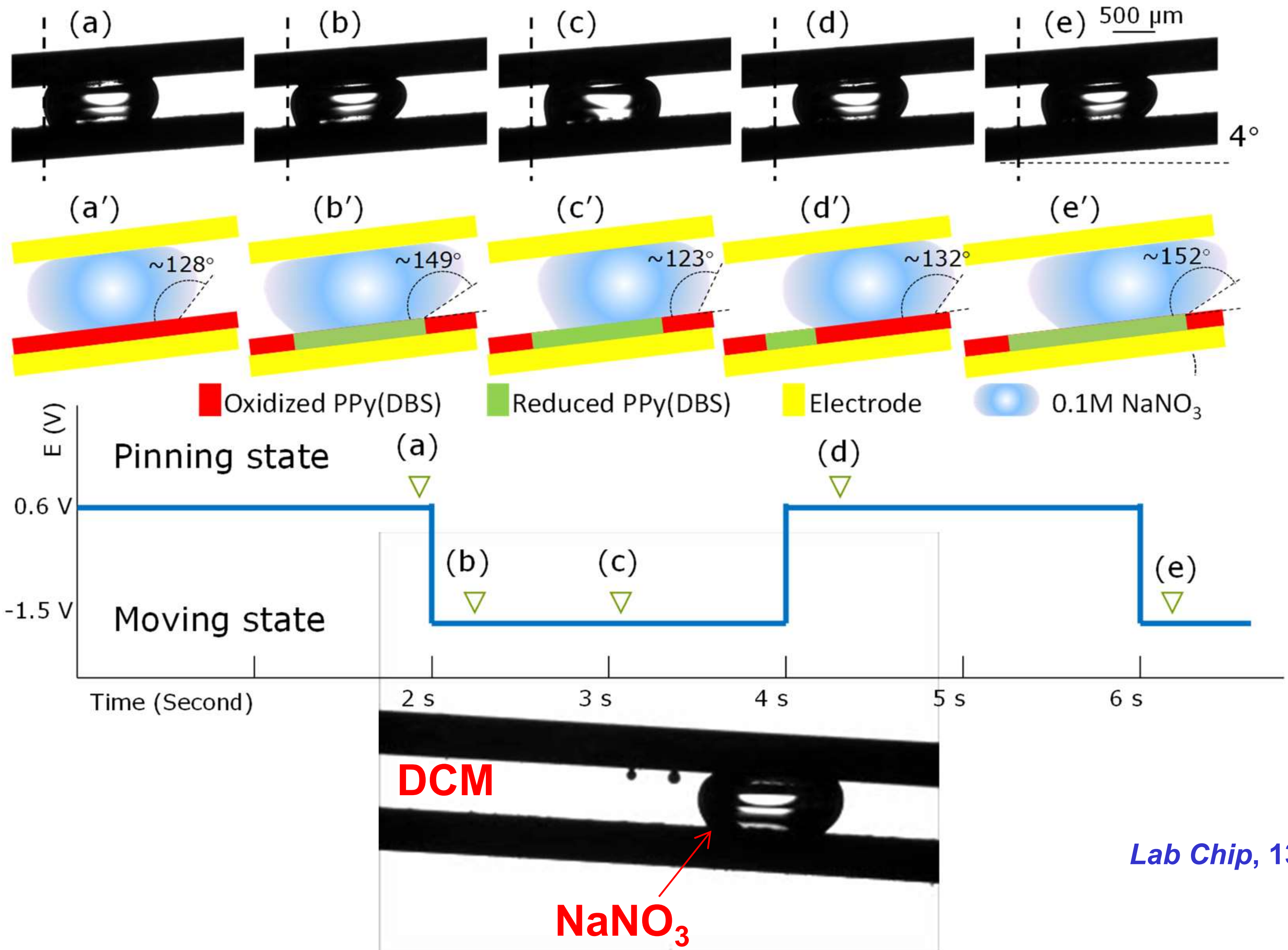






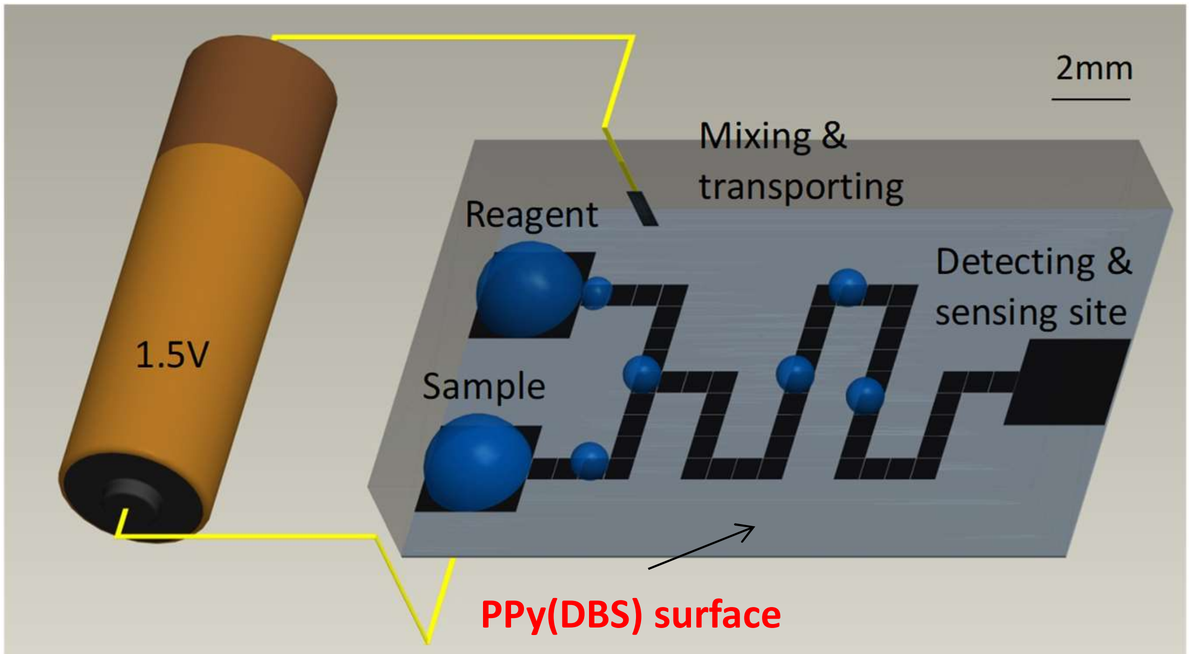
Manuscript in preparation

Controlled Stop and Go (Tilted)



Lab Chip, 13, 302 (2013)

Low Voltage LOC Device

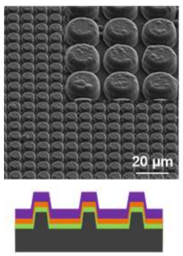


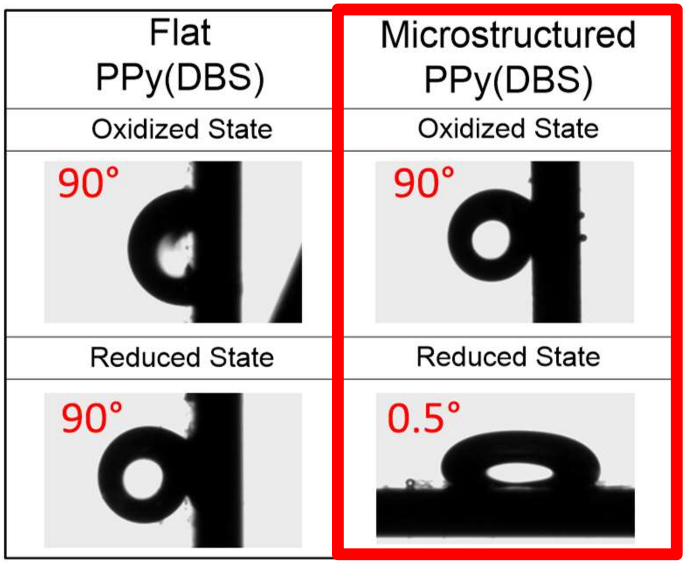
Low-cost, hand-held device (powered by a AAA battery) containing complex liquid handling assays.

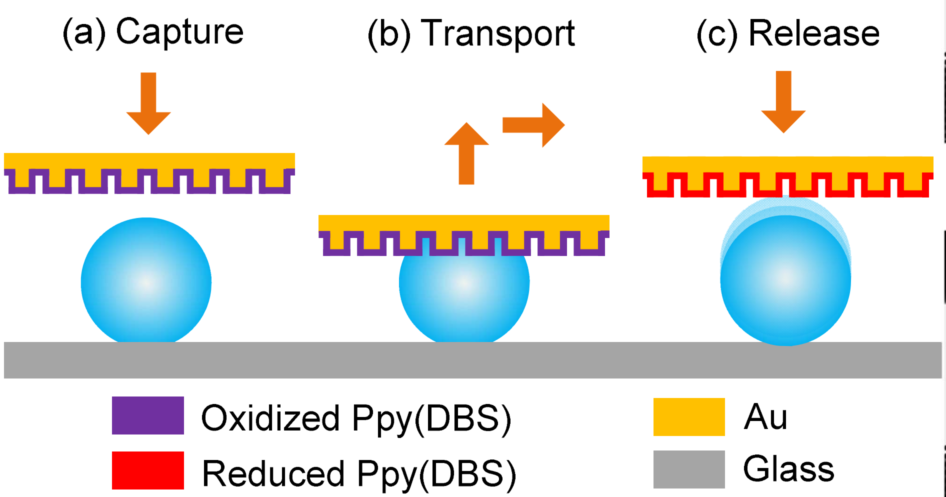
Portable Devices for…

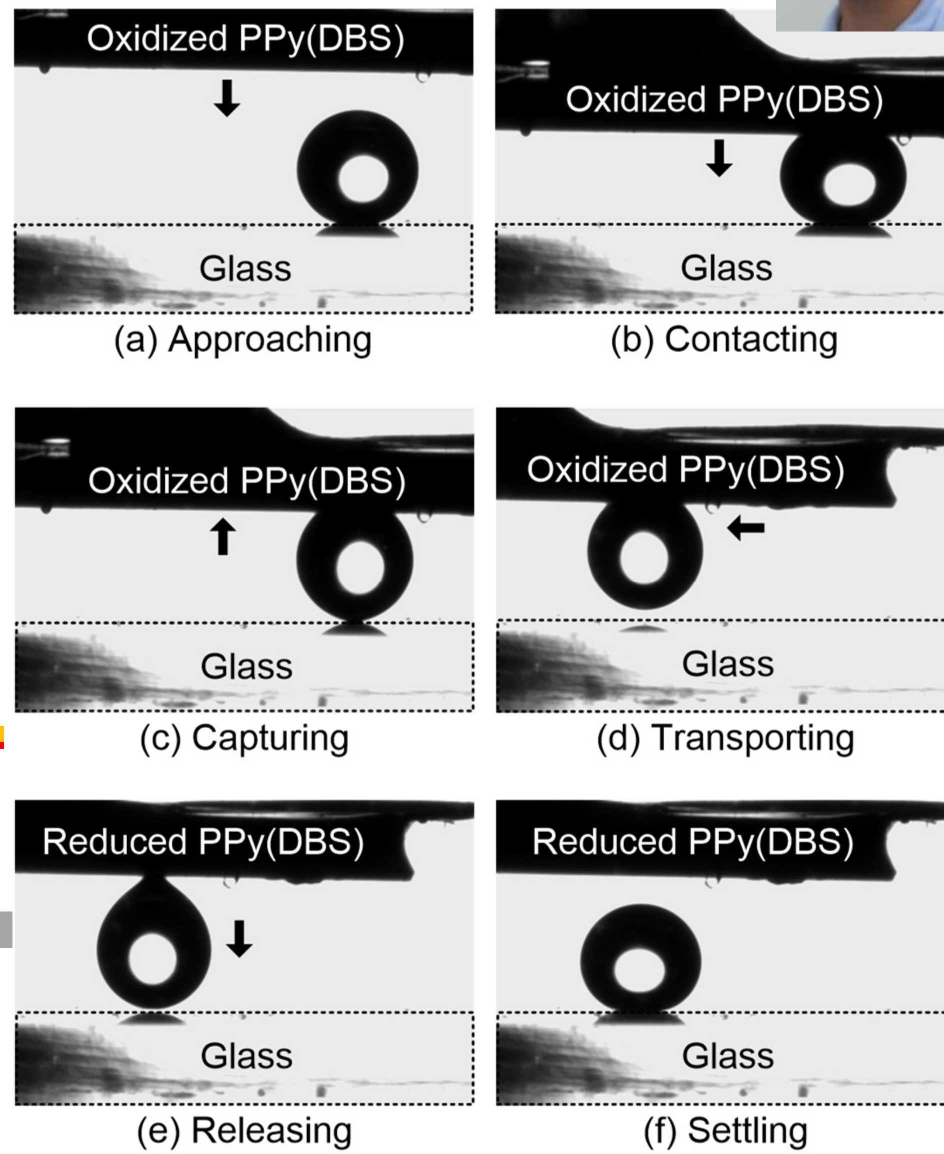
- Sample dilution and purification
- Molecular separation
- DNA/RNA analysis
- Particle sensing and detection
- Biomolecule synthesis

Capture and Release



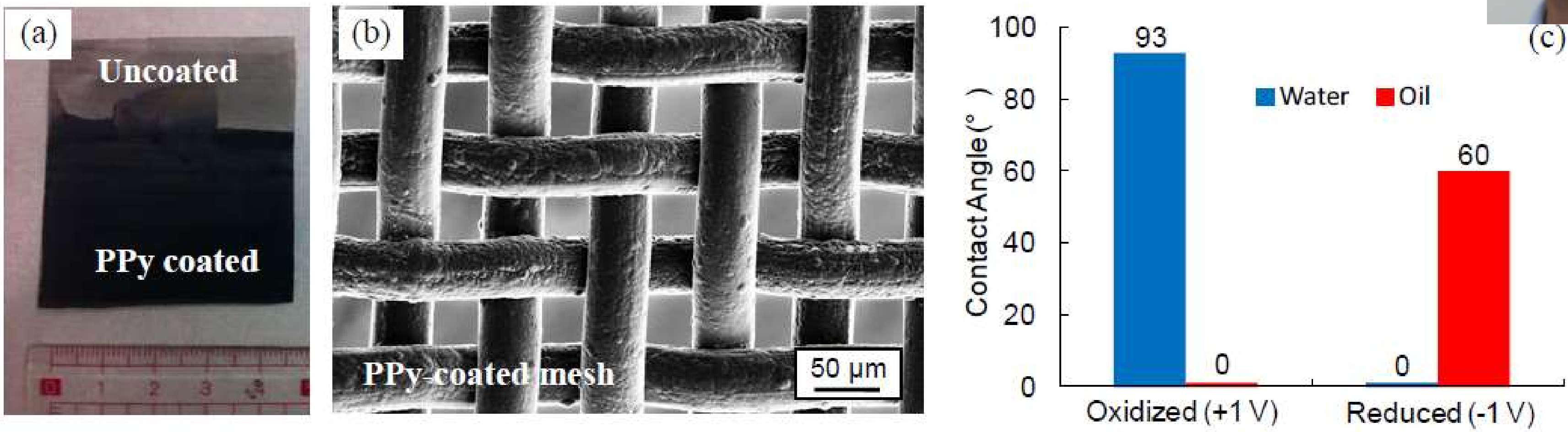


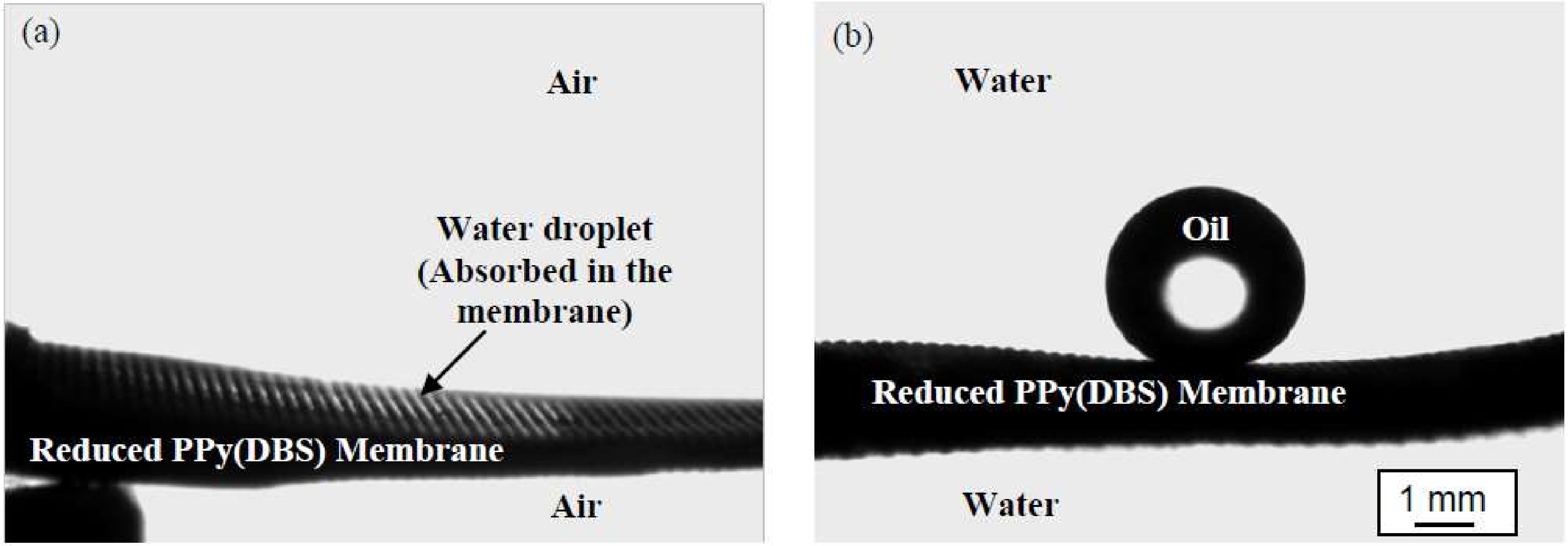




Manuscript in preparation

Underwater Superoleophobicity





Outline of Presentation

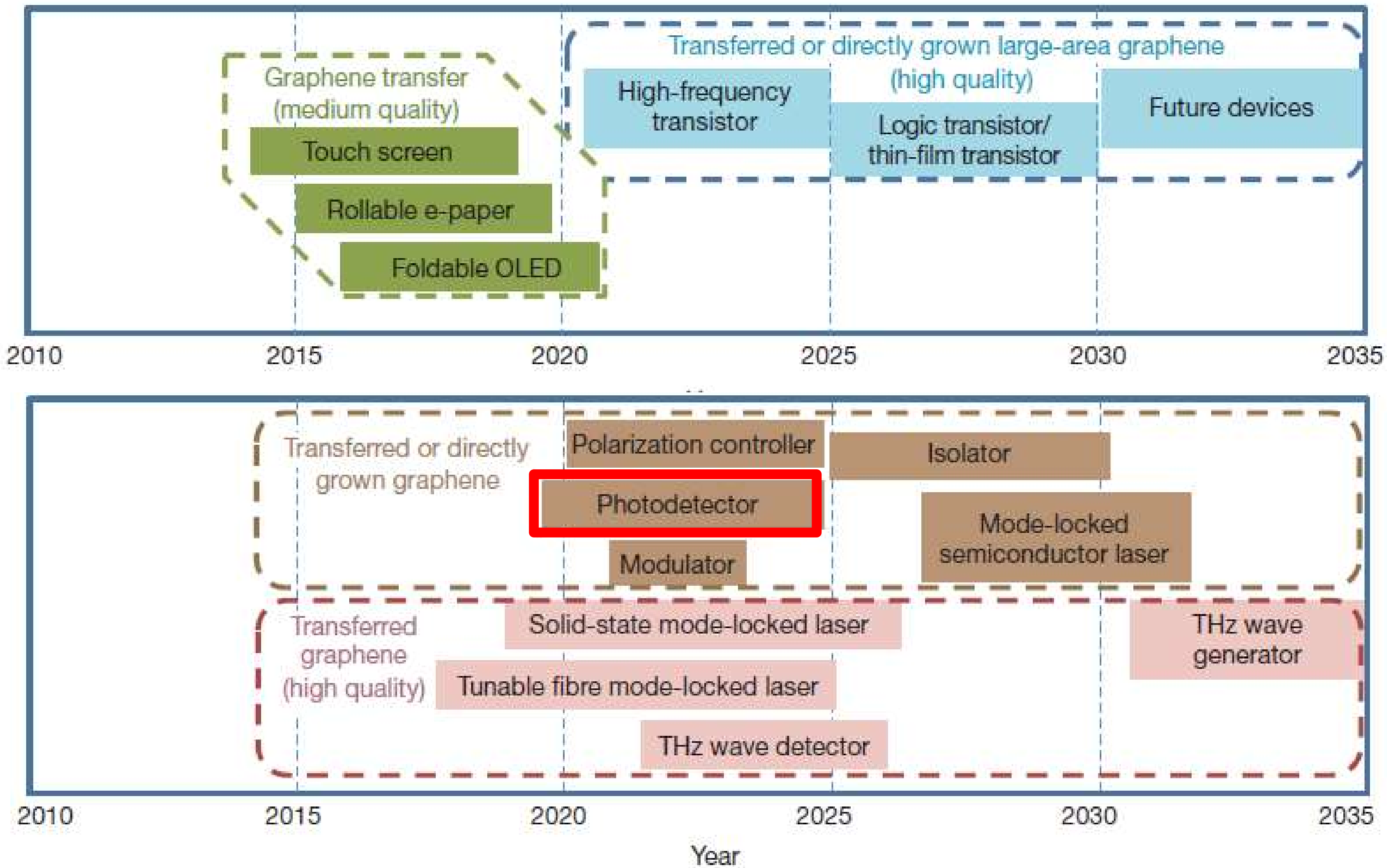
- **Smart Polymer Microfluidics**
  - Overview: *Wetting, PPy, EWOD*
  - Droplet Manipulation on PPy(DBS): *DCM Droplets, Magrangoni effects*
  - Applications: *Lab on a Chip, Oil/water Separation*

- **Graphene and CNT Architectures**
  - CVD Growth and Characterization: *Domain Growth Mechanism, Annealing Effect*
  - Photodetection using CVD Graphene: *Suspension of Graphene; Enhanced Photoelectric Effect*
  - Graphene-CNT Composites for Energy Storage: *Seamless Growth; Suppressed Graphene Etching*

Material Properties

Property	Graphene	CNT	Compare to..
Elastic Modulus	**1060 GPa**	~1000-5000 GPa	1220 GPa (Diamond)
Intrinsic Fracture Strength	**130 GPa**	13-53 GPa	6.8 GPa (UH-MW-Polyethylene)
Charge Mobility	**2,000-200,000 cm^2/V-s**	100,000 cm^2/V-s	8,500 cm^2/V-s (GaAs) or 1,000 cm^2/V-s (Si)
Resistivity	**10^{-2}-10^{-8} Ω-cm**	~10^{-2} Ω-cm	1.59 x 10^{-8} Ω-cm (Ag)
Thermal Conductivity	**5000 W/m-K**	200 W/m-K (SWNT) or >3000 W/m-K (MWNT)	400 W/m-k (Cu) or 2,200 W/m-K (Diamond)
SSA	**2630 m^2/g**	50-1315 m^2/g	XX
Transmission	**97.7%**	N/A	85-92% (ITO)

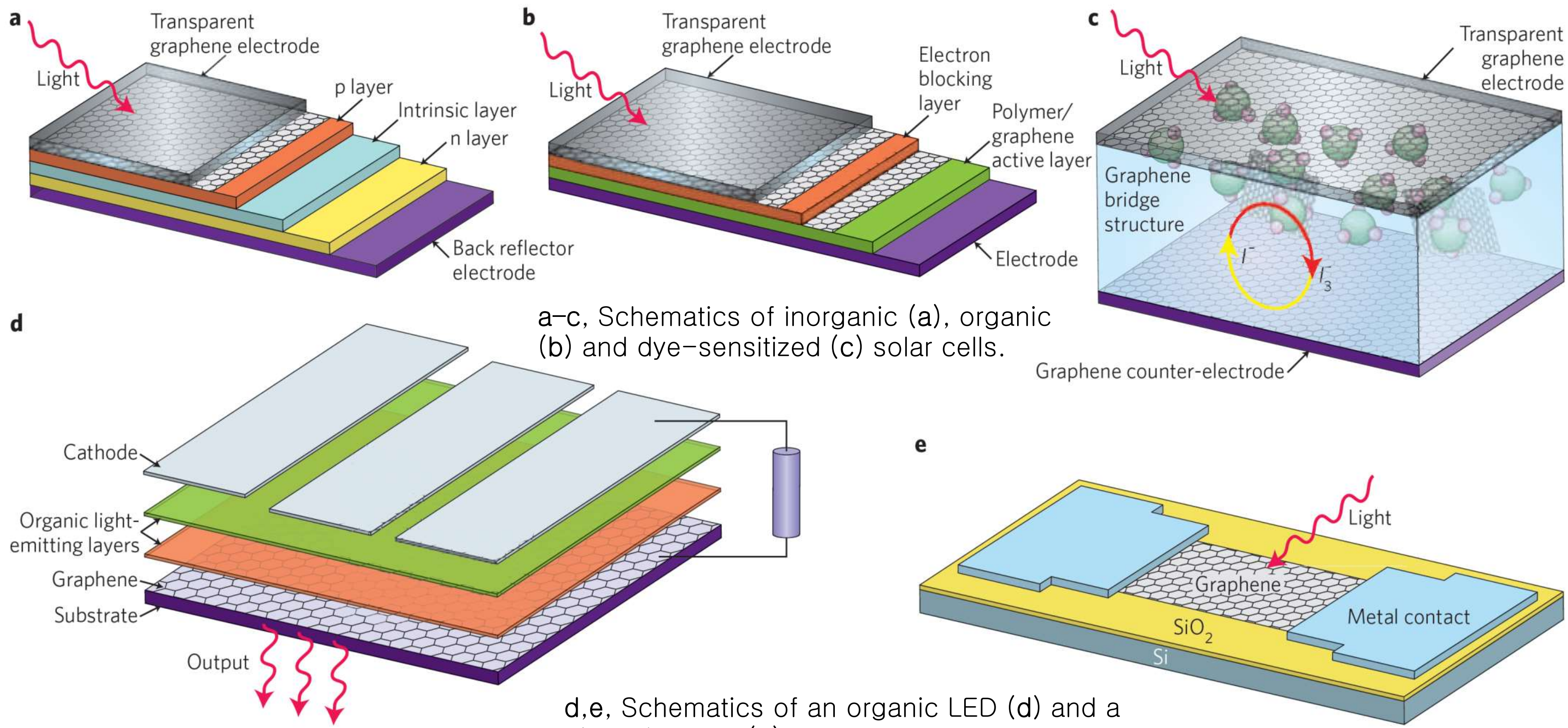
Graphene Development Roadmap



NATURE | VOL 490 | 11 OCTOBER 2012

Graphene Optoelectronics – Device Concepts

REVIEW ARTICLE NATURE PHOTONICS DOI: 10.1038/NPHOTON.2010.186



a–c, Schematics of inorganic (a), organic (b) and dye-sensitized (c) solar cells.

d,e, Schematics of an organic LED (d) and a photodetector (e).

Chip-Integrated Graphene Photodetector

LETTERS NATURE PHOTONICS DOI: 10.1038/NPHOTON.2013.253

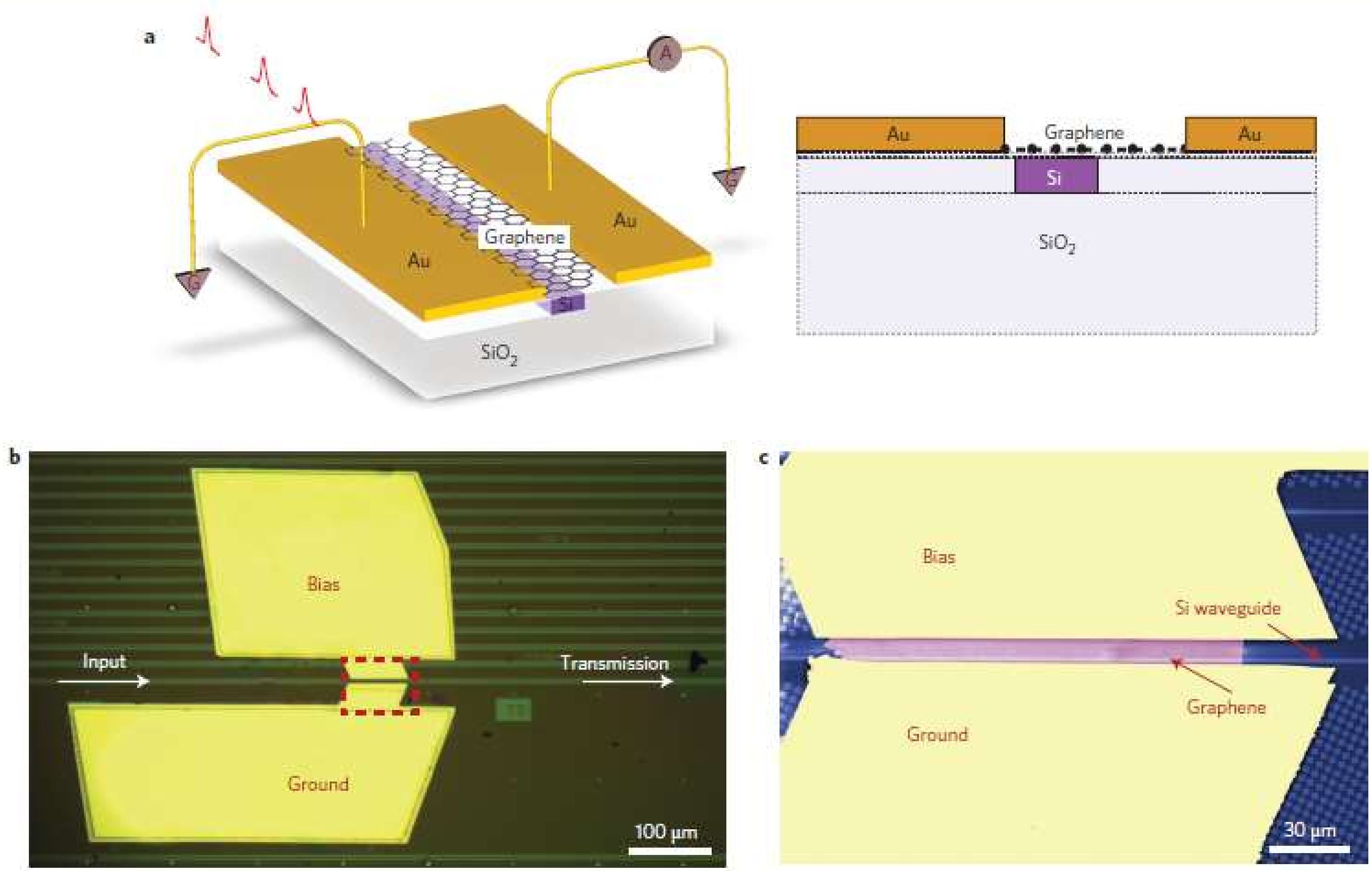


Figure 1 | A waveguide-integrated graphene photodetector. a, Schematic of the device. The silicon bus waveguide fabricated on an SOI wafer is planarized

CVD Graphene Growth

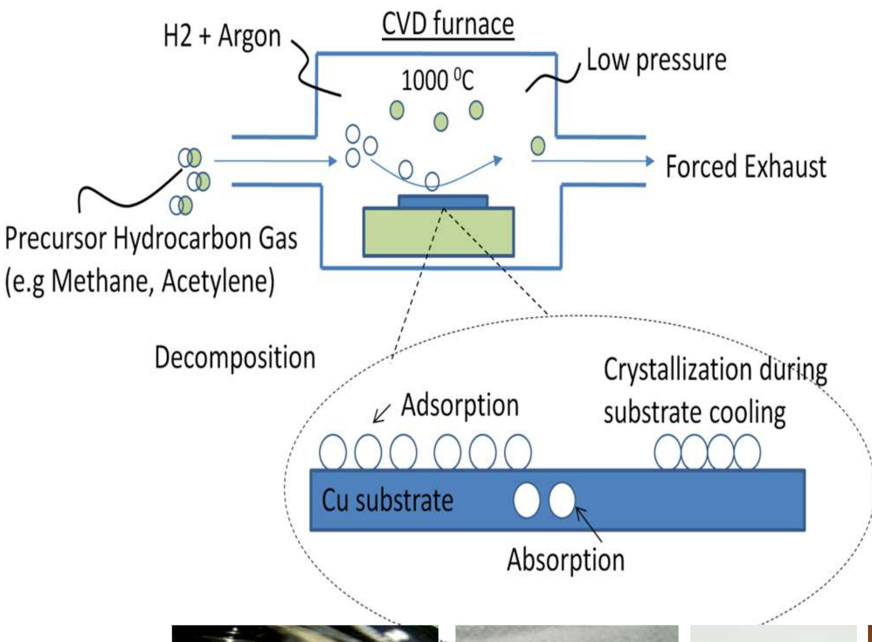
Cu Substrate

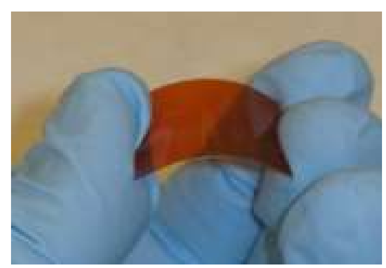
⇩

Ar+H_2+CH_4 flow

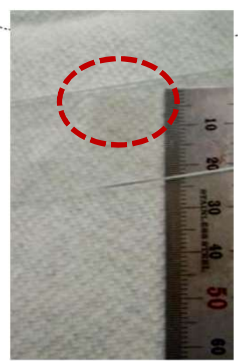
⇩

Computerized Precise heating and cooling cycles

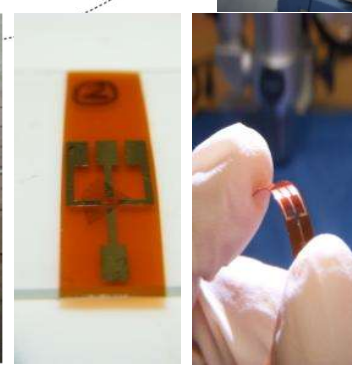




Graphene on water

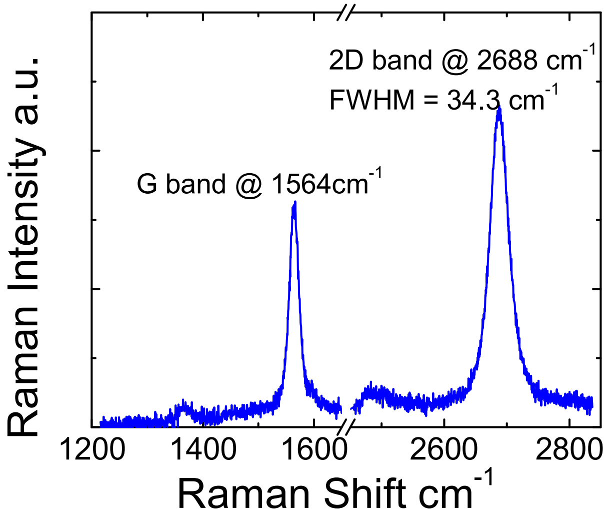


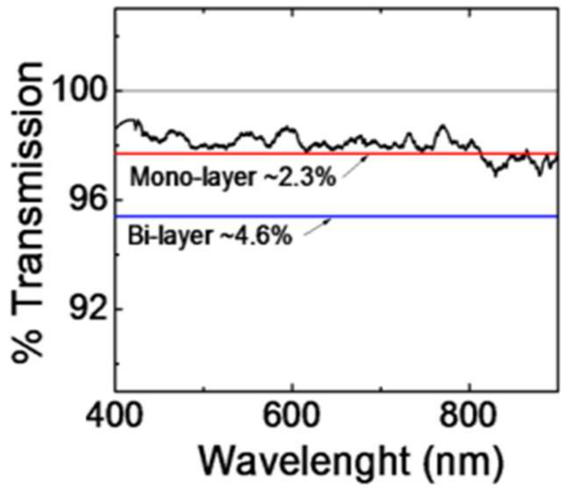
Transferred graphene on glass

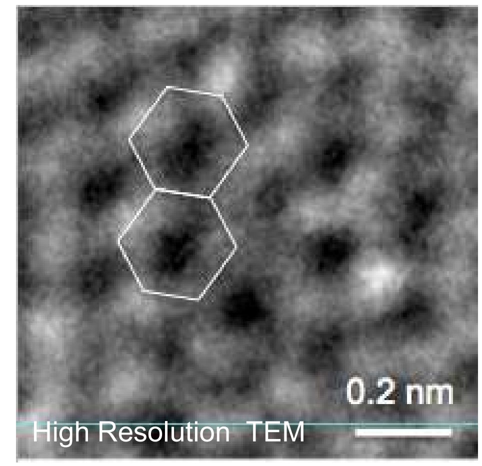


Transferred graphene on flexible substrate

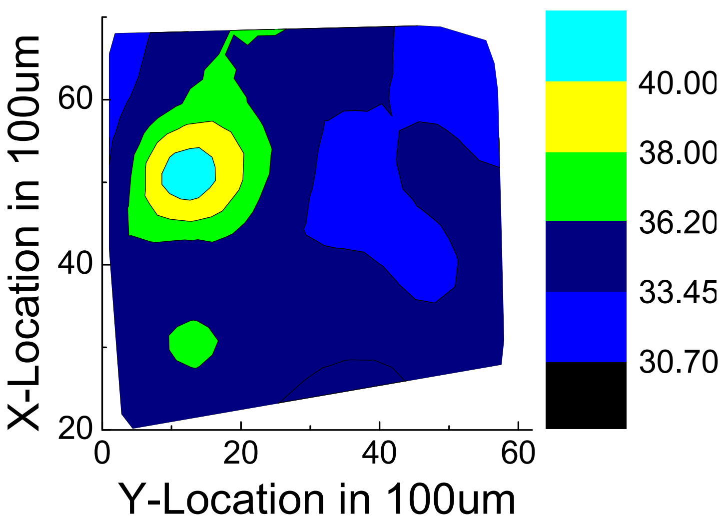
Monolayer Growth

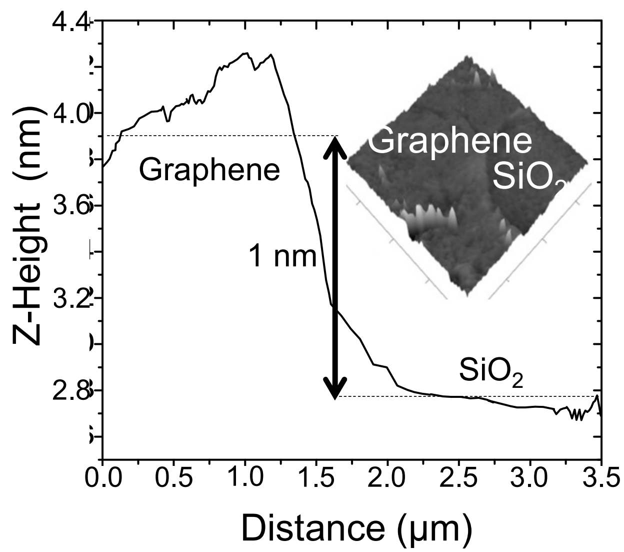


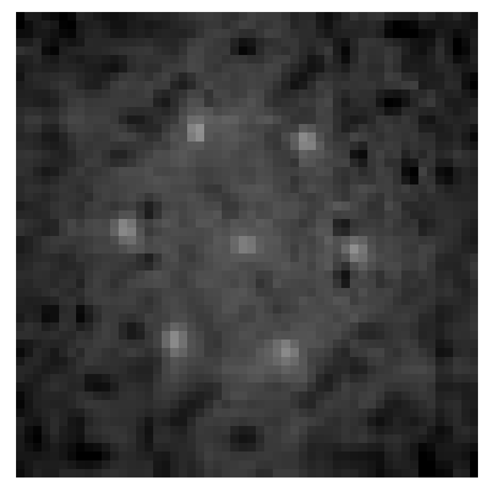




2D Intensity mapping



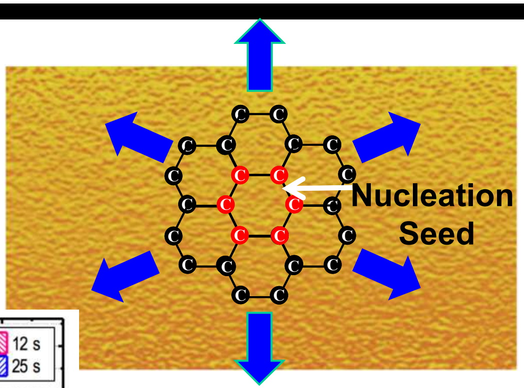


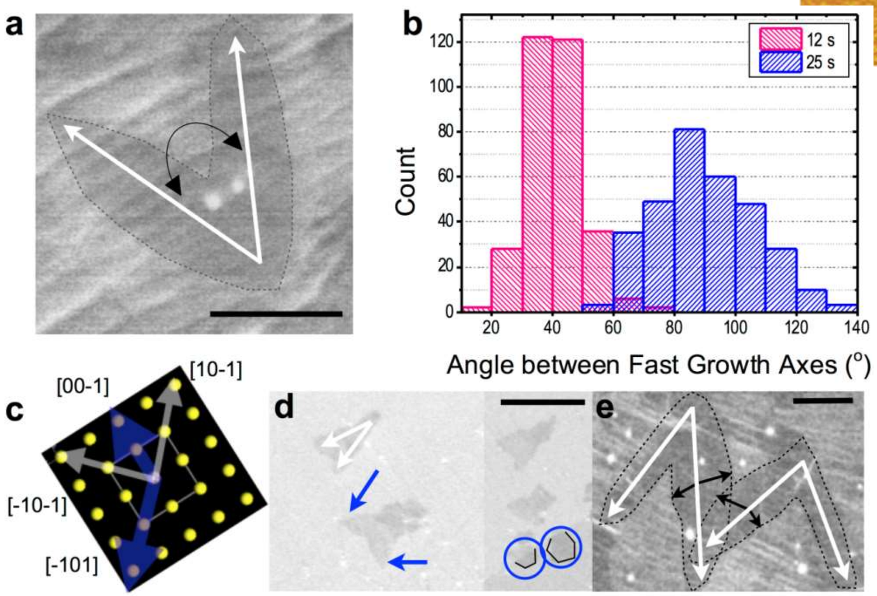


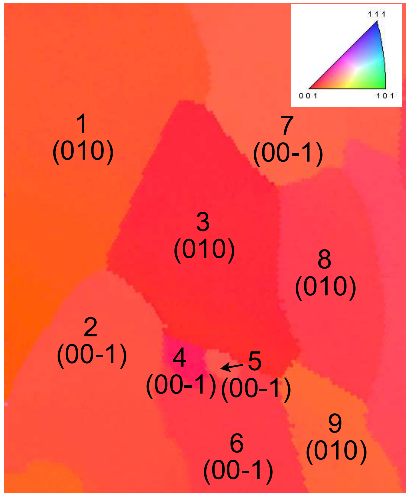
Fast Fourier Transform

Domain Study

- CVD graphene → **Polycrystalline**
- **Electronic** and **mechanical** properties affected by presence of **grain boundaries**.
- **Key challenge** → control of domain
  - Shape
  - Orientation
  - Size



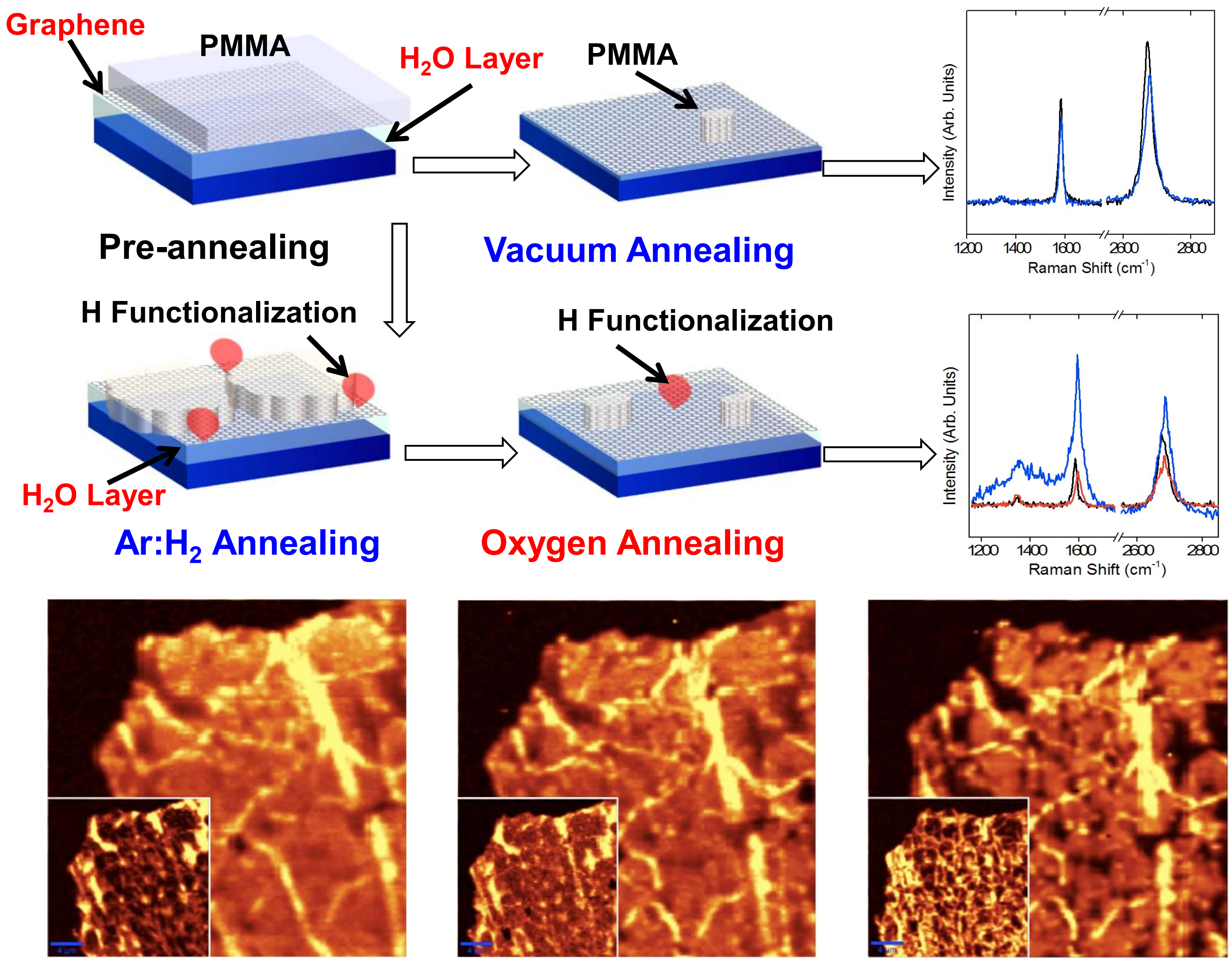




2-lobed symmetrical curvilinear graphene domains specifically on Cu{100} surface orientations; its growth and morphology are dependent on the underlying Cu crystal structure ➔ *important towards tailoring graphene properties via substrate engineering*

Scientific Reports, (3) 2571 (2013)

Graphene - Annealing Effect

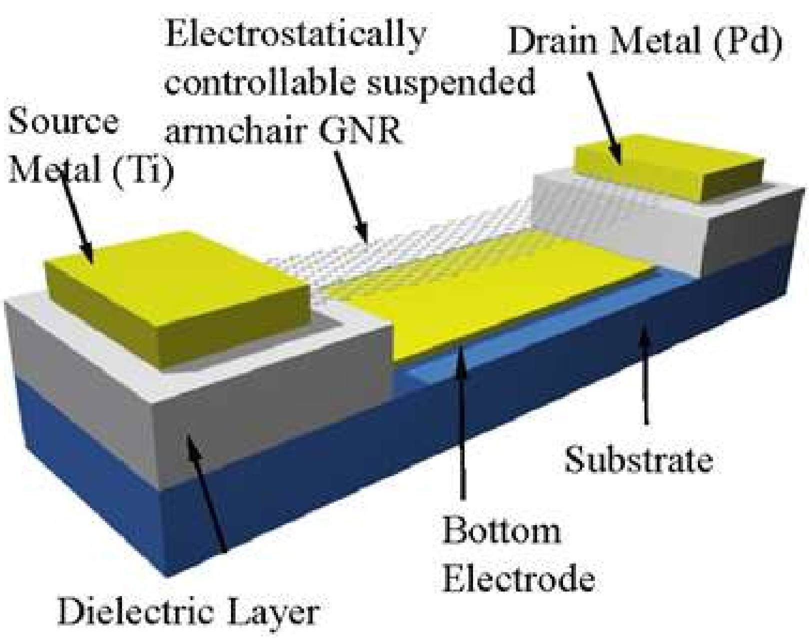


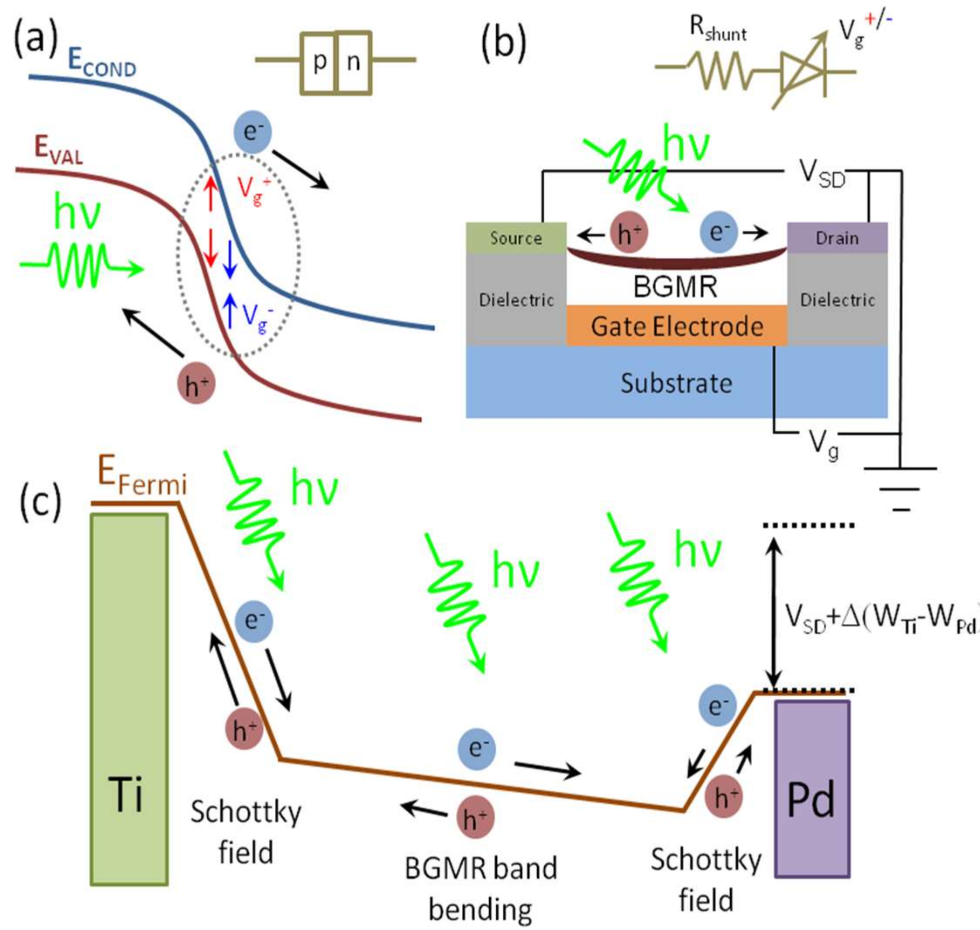
Pre-Annealing | Ar:H_2 annealing | Oxygen annealing

Annealing-based processes *create morphological changes and directly influence doping and strain*

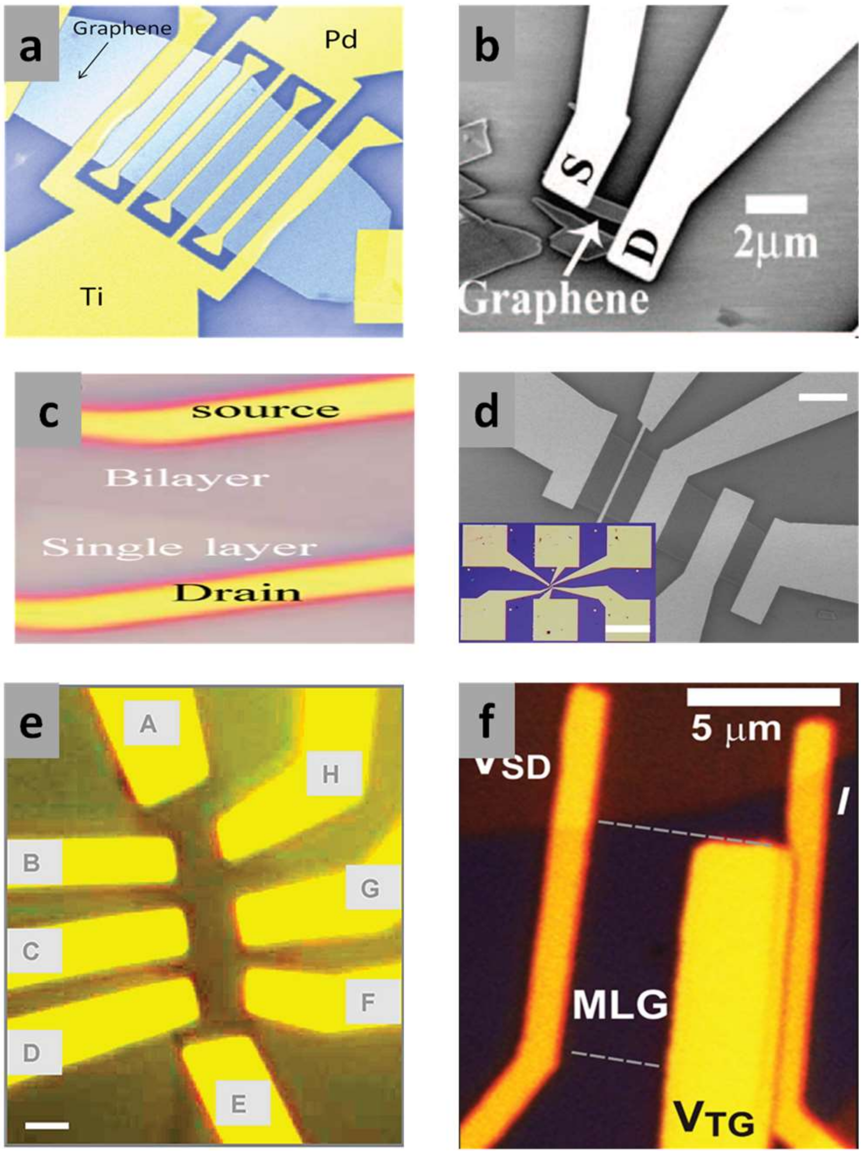
Carbon, (64), 35, (2013)

Graphene Photodetectors





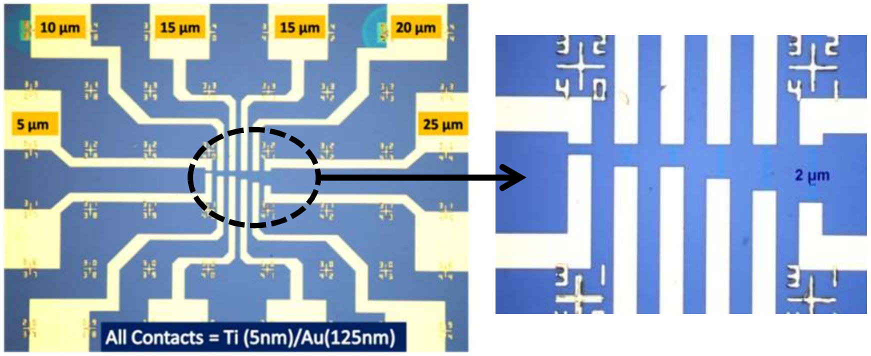
Graphene Photodetector Research

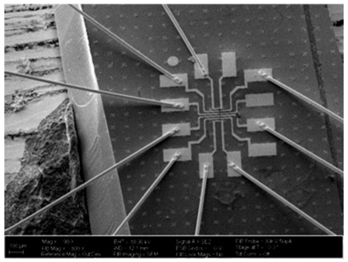


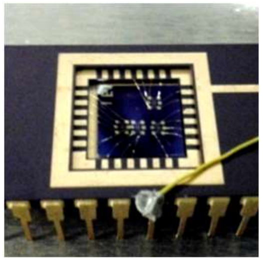
- Study of
  - Fermi-level modulation at metal contacts,
  - Electrical doping
  - ***Photo-thermoelectric mechanism***
  - Top-gated photo-transistors
  - Hot electron generation

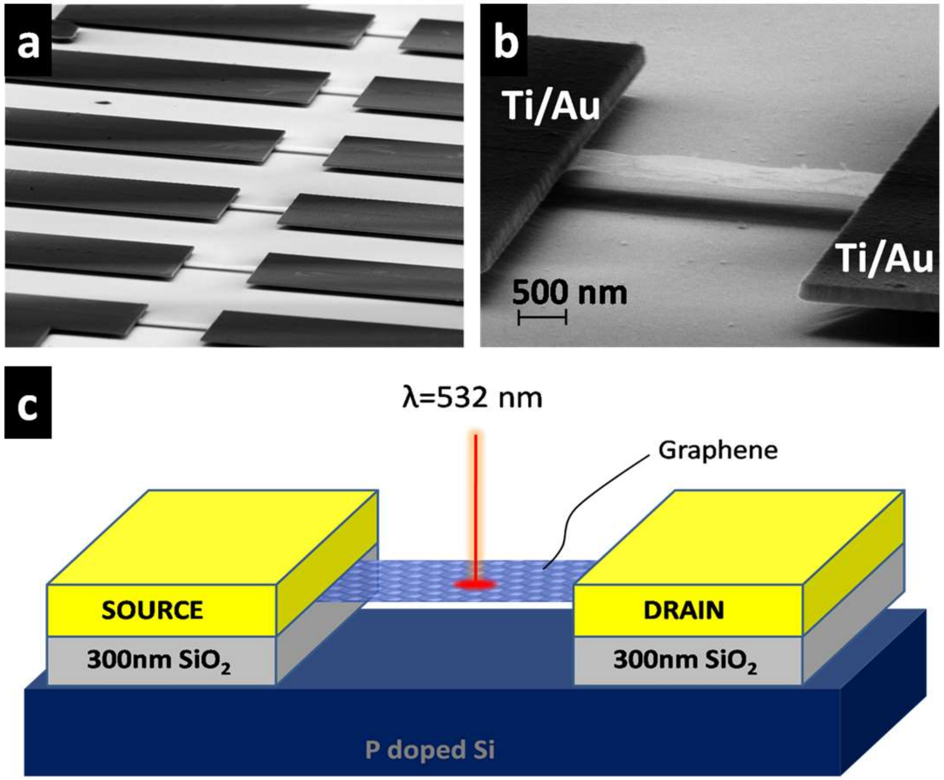
a. *Nat. Nano* 4, 839-843 (2009).
b. *Nano Letters* 9, 1039-1044 (2009).
c. *Nano Letters* 10, 562-566 (2009)
d. *Nat. Photon.* 4, 297-301 (2010).
e. *Nano Letters* 9, 1742-1746 (2009)
f. *Nat. Photon.* 7, 53-59 (2013)

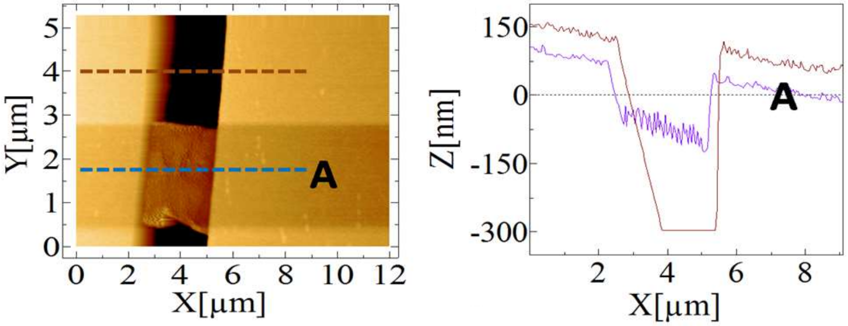
Graphene Micro Ribbons for Photodetectors





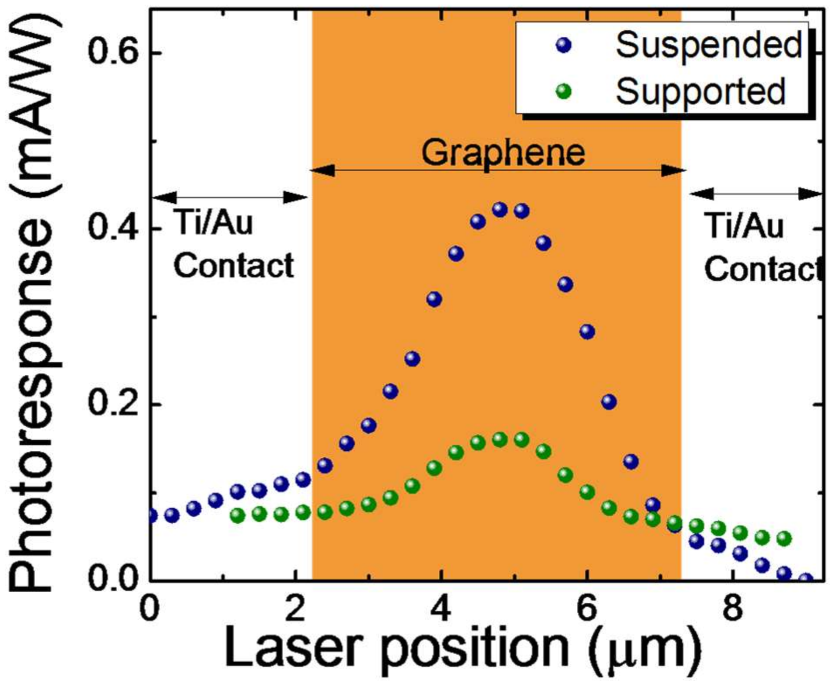


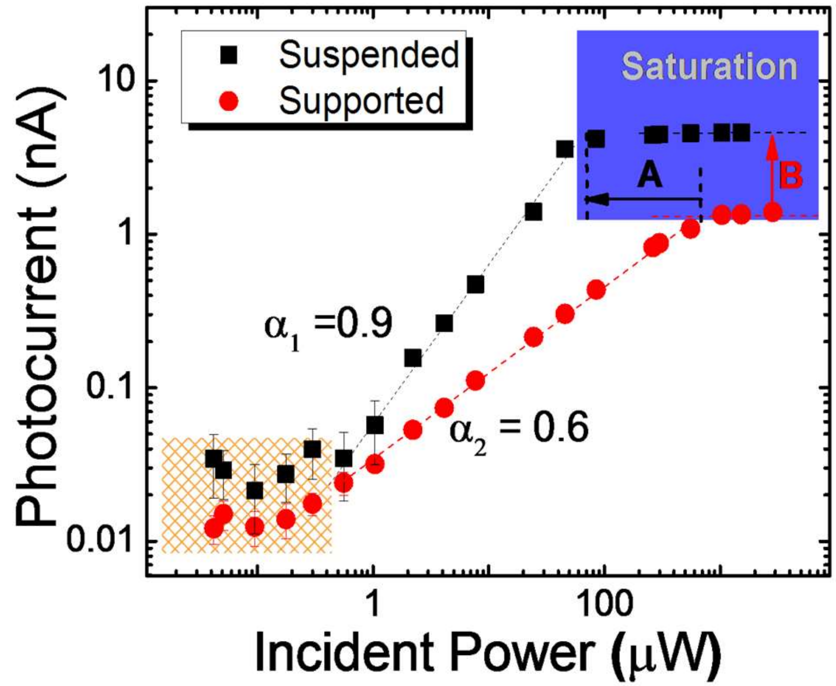




Scientific Reports, (3), 2791 (2013)

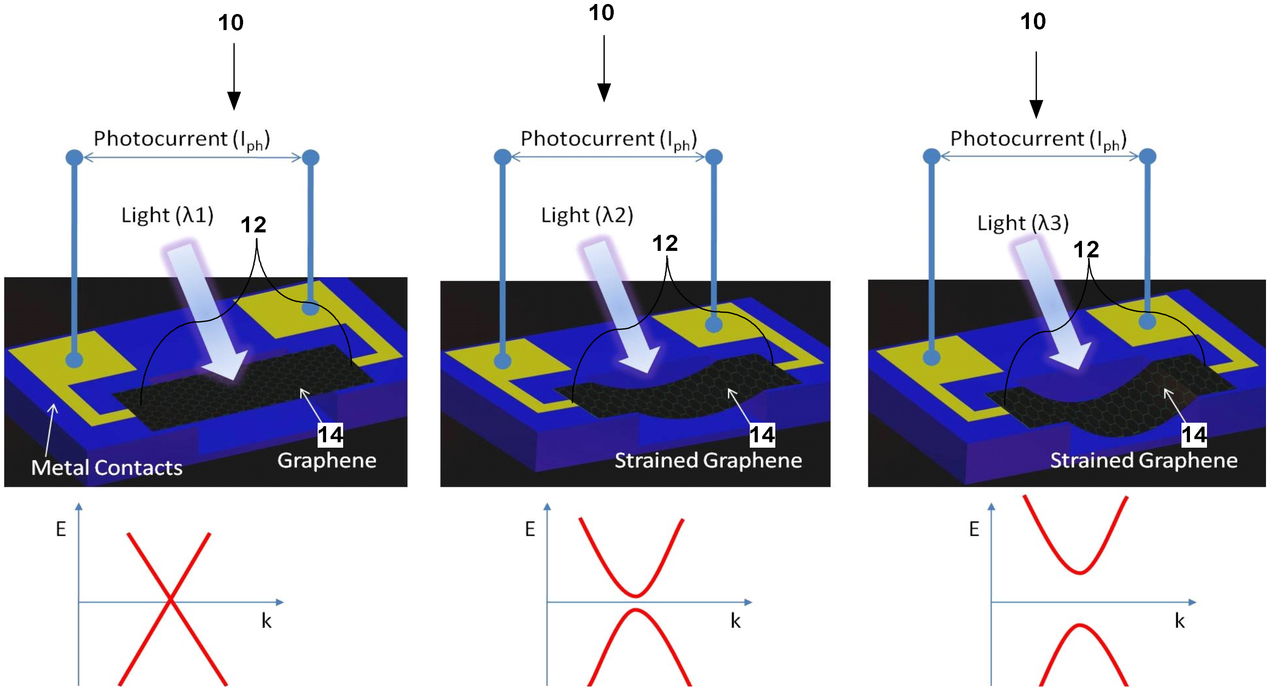
Photoelectric Effect vs. Photo-Thermoelectric Effect



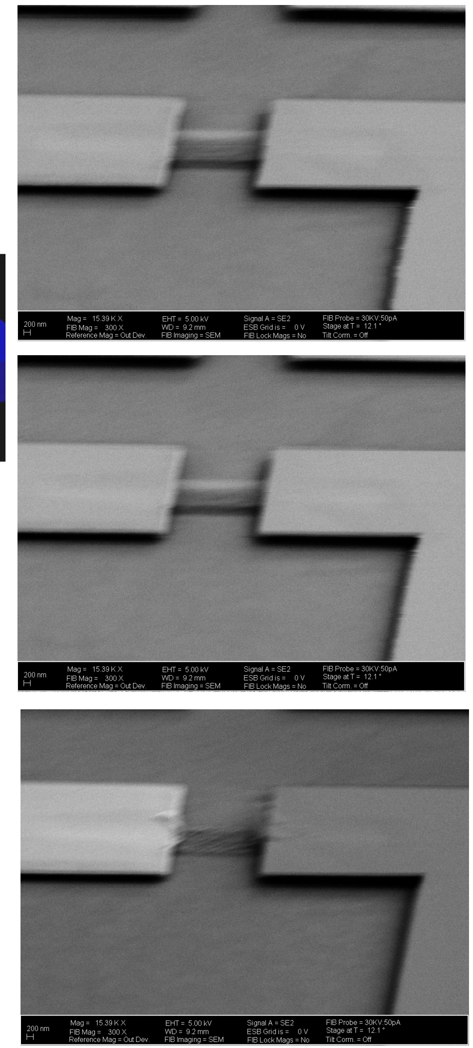


- **The fully-suspended CVD graphene is *dominated by the faster photoelectric effect.***
- **These findings are promising towards wafer-scale fabrication of graphene photodetectors approaching THz cut-off frequencies.**

Wavelength Tunable Photodetector?



US Patent Pending



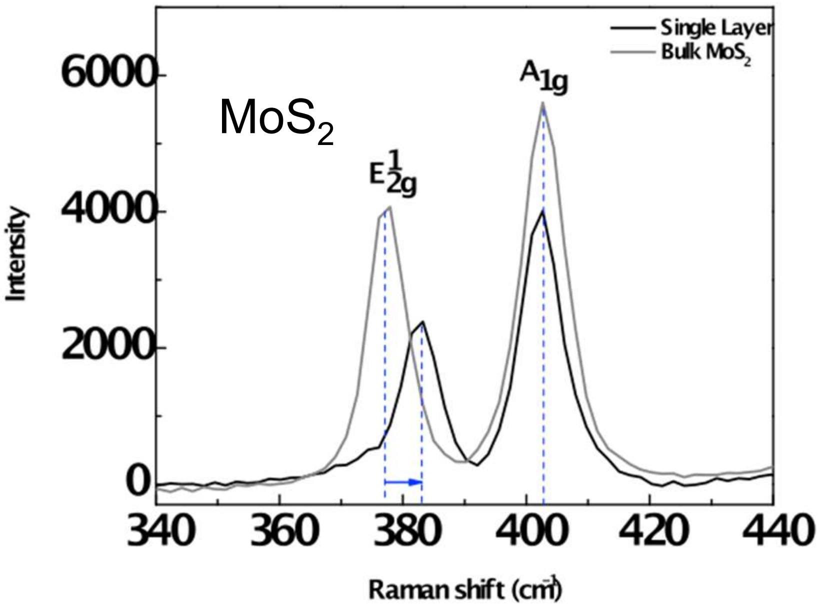
For strain tuning, we need

1) controlled electrostatic actuation of suspended graphene microribbons.
2) *In situ* SEM imaging of the actuation.

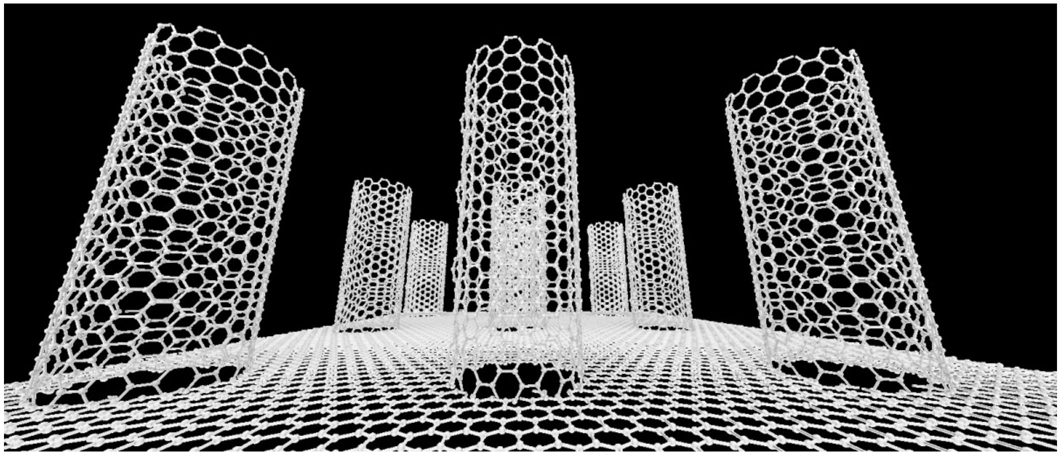
Future: Tunable Photodetector

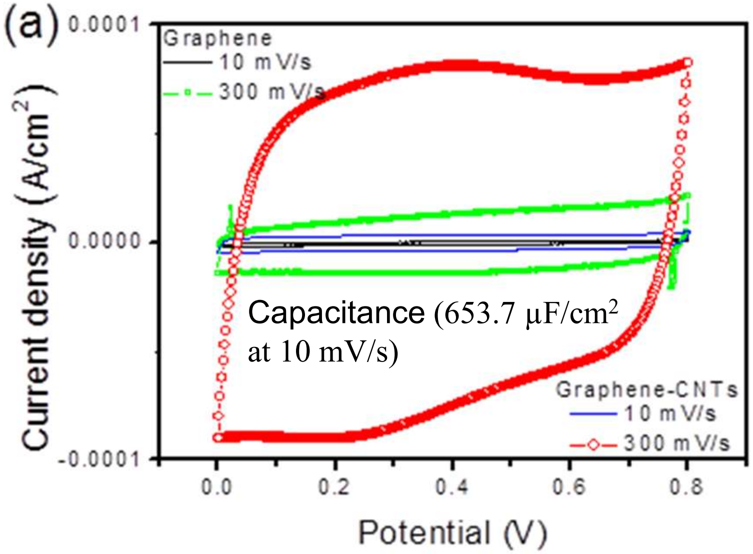
- Develop microactuators to induce in-plane strain in a suspended graphene, MoS_2, or WS_2 microribbon:

  ➔ *Toward a photodetector with strain-tuning capability for opening/closing of the bandgaps.*



Graphene-CNT Architecture

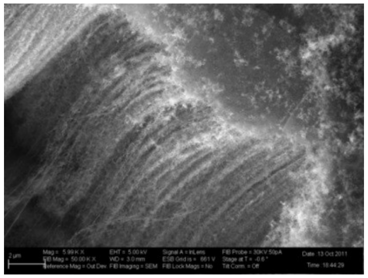


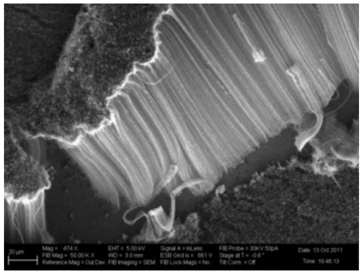


•Avoid self-aggregation

•Maximize the energy storage capacity

Nanotechnology, 23, 015301 (2012)



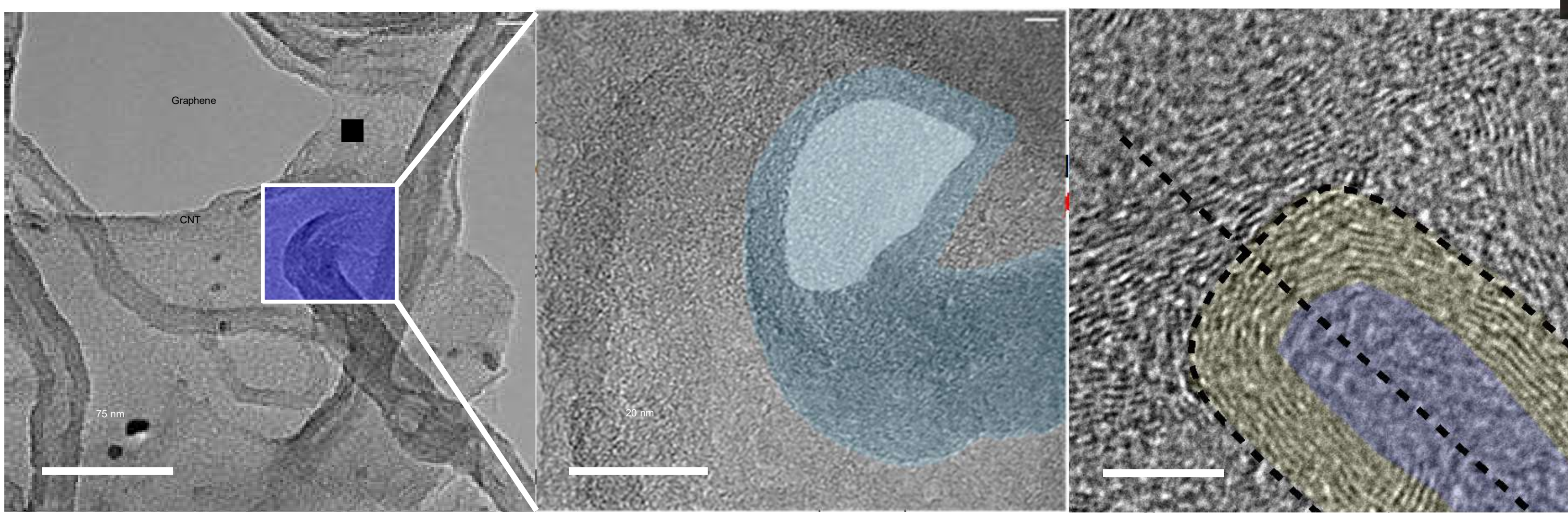


Supercapacitor: An electrochemical capacitor with

- High power density (~14 kW/kg)
- Long cycle life (over 100,000 cycles)
- Fast charge storage

Ideal for energy storage that undergoes frequent charge and discharge cycles at high current.

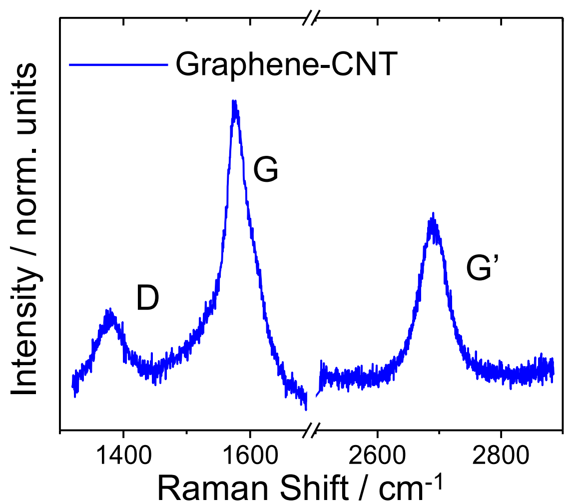
Seamless Growth of CNTs from Graphene

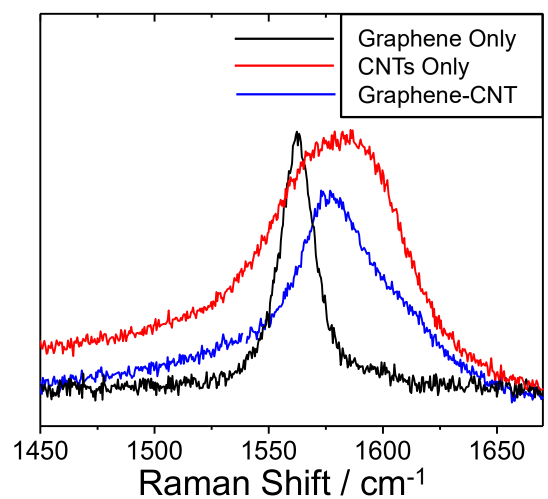


CNT Root in Graphene

Graphene Planes

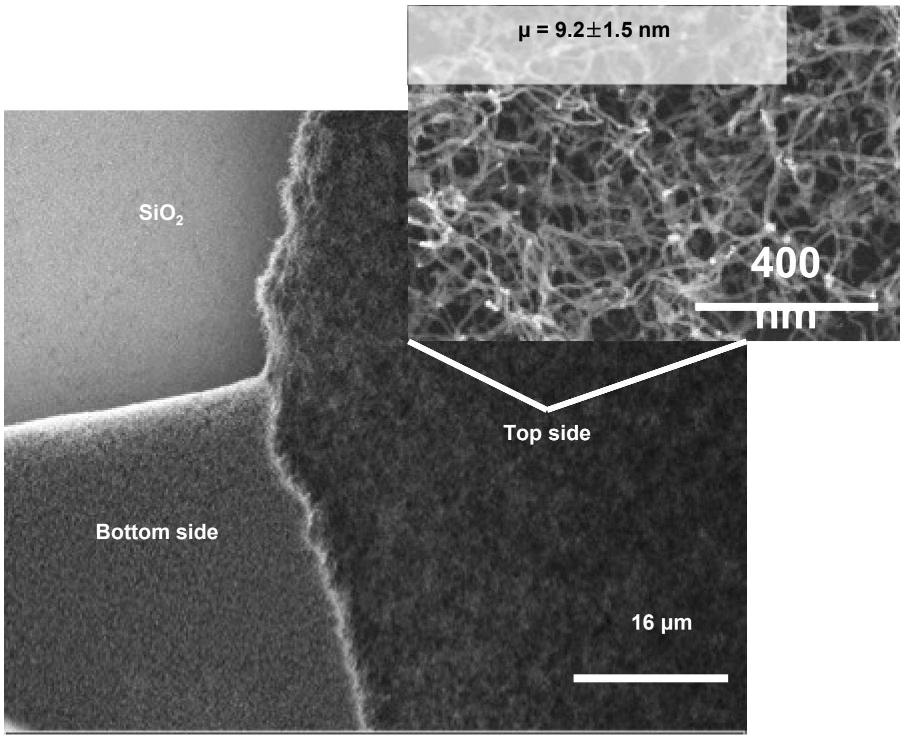
Chemistry of Materials, 25(19), 3874–3879 (2013)



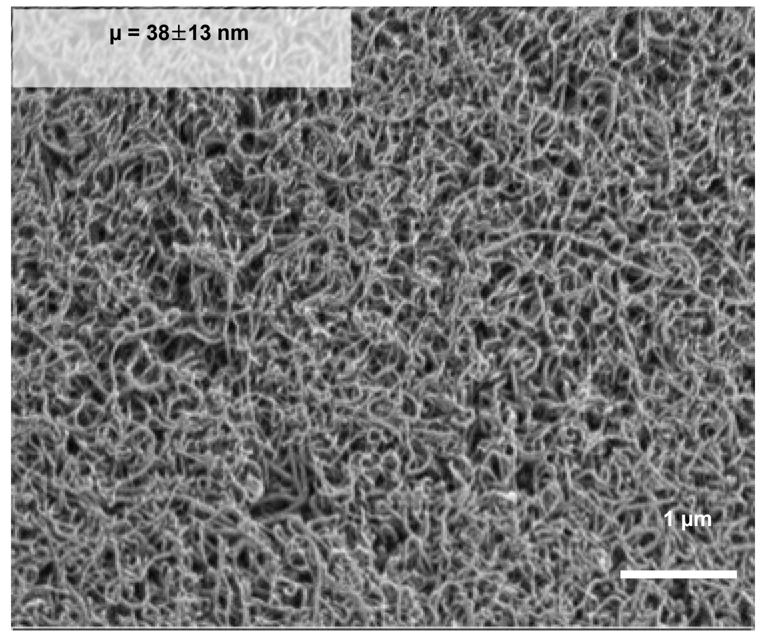


Carbon Feedstock: C_2H_4

Thermal Treatment: 800˚C
CNT Growth: 800˚C



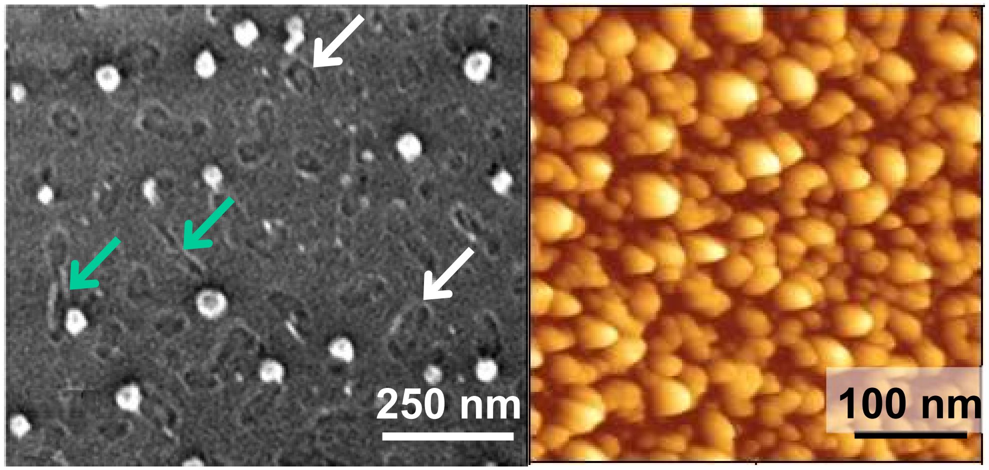
Two stage growth
1. C_2H_4 and graphene → bottom side
2. C_2H_4 → top side

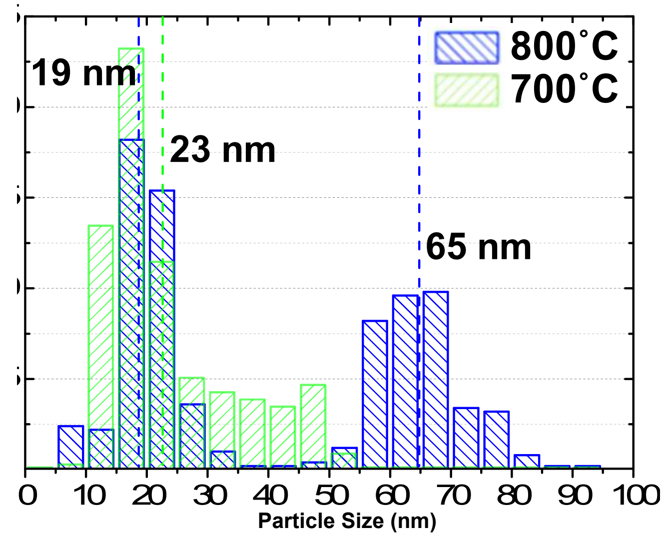


Bottom Side

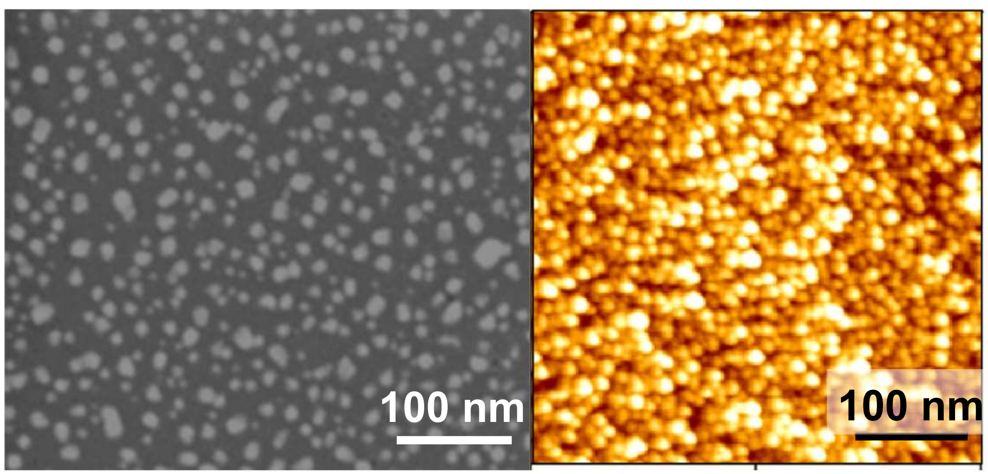
CNT Catalyst Thermal Treatment

800˚C





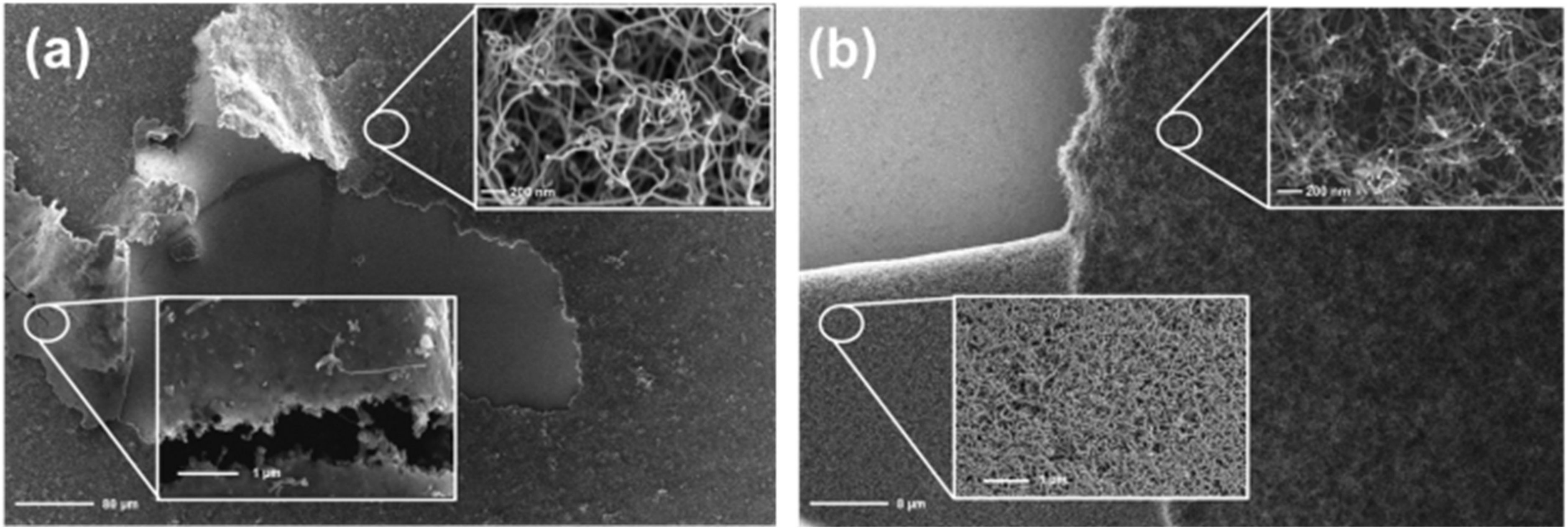
700˚C



800˚C
Hydrogenation active
Low density nanoparticles

700˚C
Hydrogenation suppressed
High density nanoparticles

Suppressed Graphene Etching During CNT Growth

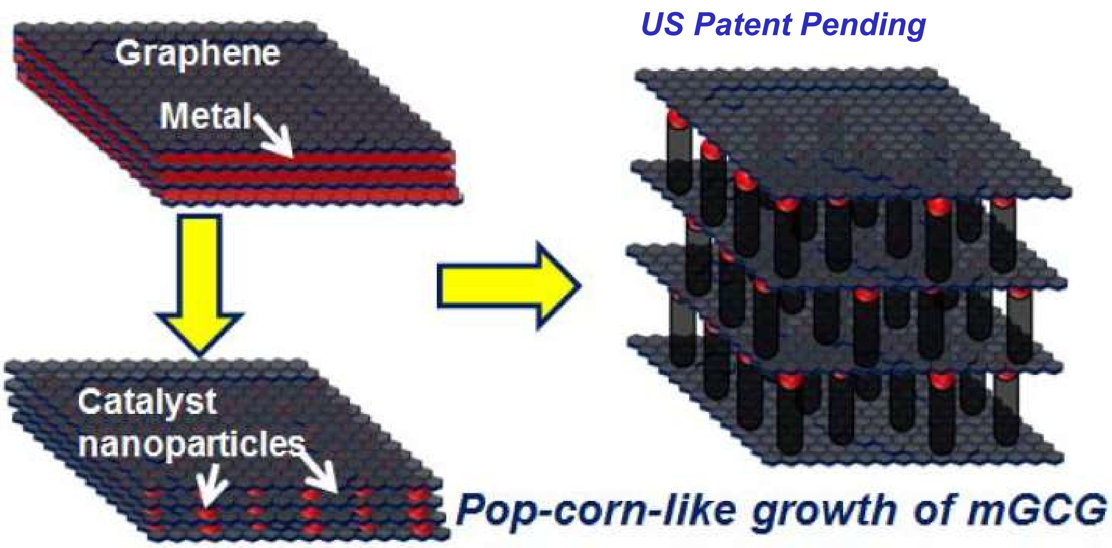


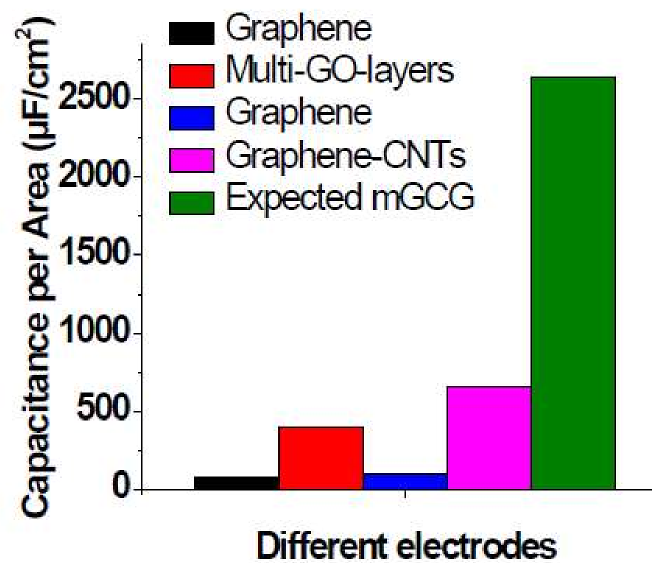
(a) intact graphene substrate and (b) without graphene (etched away)

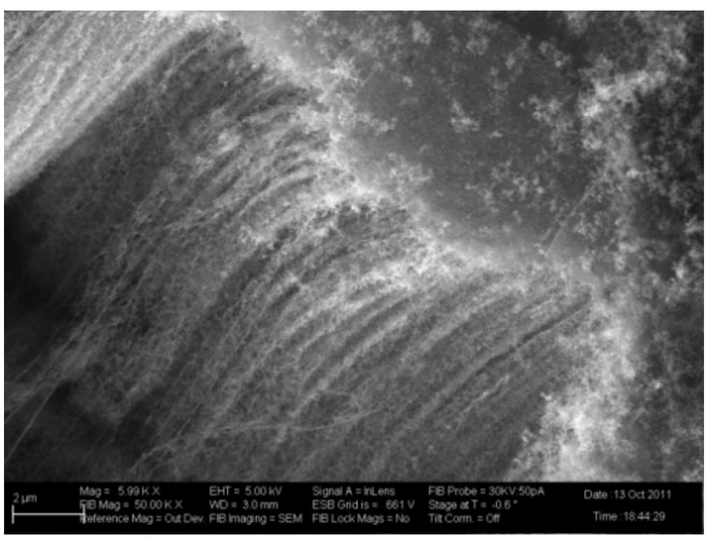
By using C_2H_4 gas as a hydrocarbon source for CNT growth under low temperature (700°C) and controlled gas ratio conditions, the catalytic hydrogenation reaction was dramatically suppressed to avoid etching of graphene during the CNT growth process.

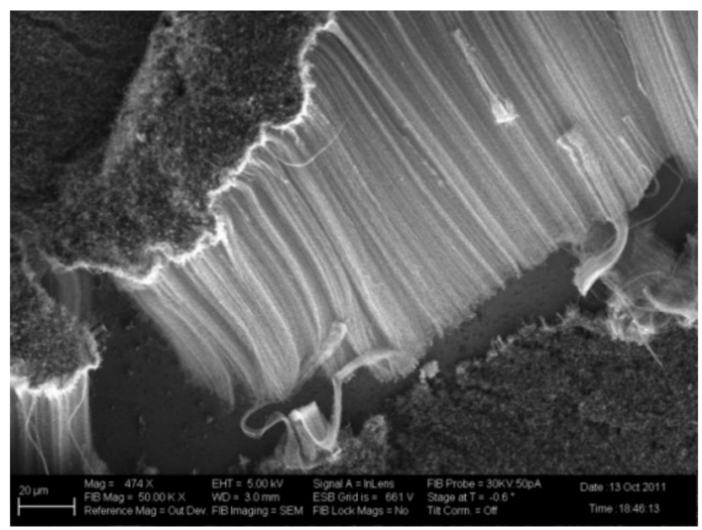
Chemistry of Materials, 25(19), 3874–3879 (2013)

Multi-stack GCG Supercapacitors



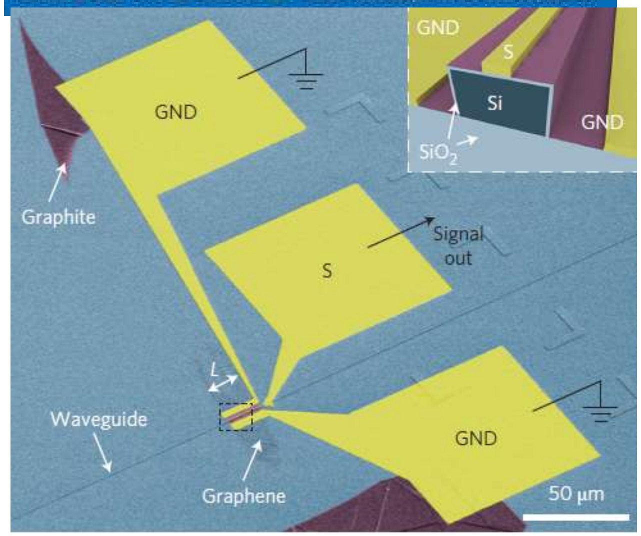






Future: MX_2/Graphene or Si Hybrids

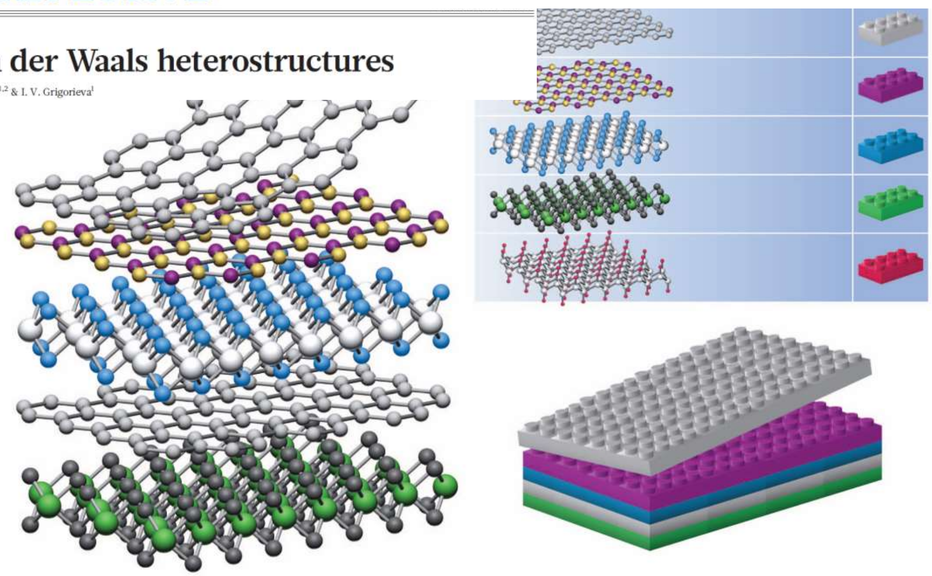
NATURE PHOTONICS DOI: 10.1038/NPHOTON.2013.240



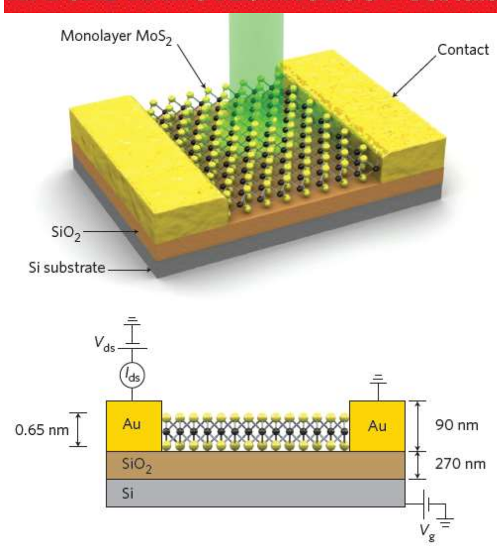
PERSPECTIVE 5 JULY 2013 | VOL 499 | NATURE | 419

Van der Waals heterostructures

A. K. Geim[1,2] & I. V. Grigorieva[1]



NATURE NANOTECHNOLOGY DOI: 10.1038/NNANO.2013.100



NATURE MATERIALS DOI: 10.1038/NMAT3386 LETTERS

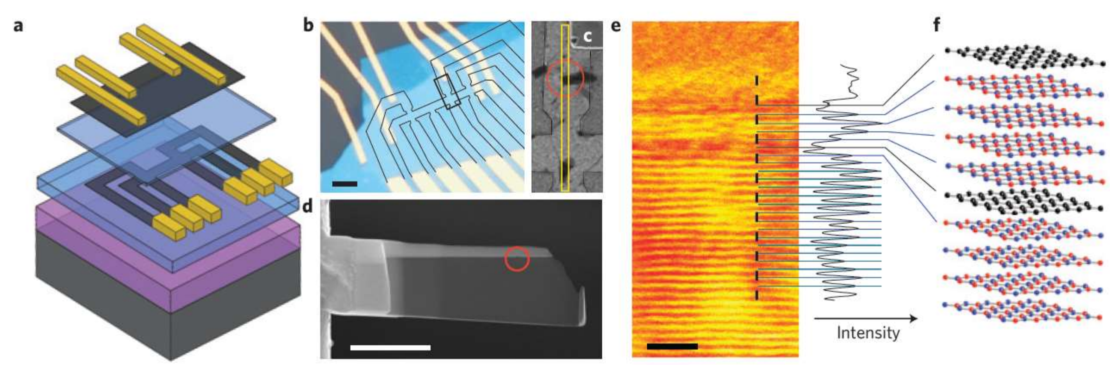


Figure 1 | Cross-sectional TEM of graphene–hBN heterostructures. a, Schematic of one of our devices: two graphene monolayers (dark grey) are interlaid

Summary

❑ Graphene/CNTs and 2D van der Waals layers

- Investigate graphene and carbon nanotubes, seeking light-harvesting and energy storage applications.
- With further improvement in fabrication techniques and using graphene's springboard, new 2D materials are expected to create new scientific frontiers.

❑ Droplet Microfluidics / Conjugated Polymers

- In microfluidic devices where surface effects are important, liquid droplets can be manipulated by tuning the surface properties.
- This tunable wetting technology is a pathfinder for next generation digital microfluidics, oil separation and antimicrobial surfaces.


Question?