Nanotechnology *for* Future Electronics and Photonics

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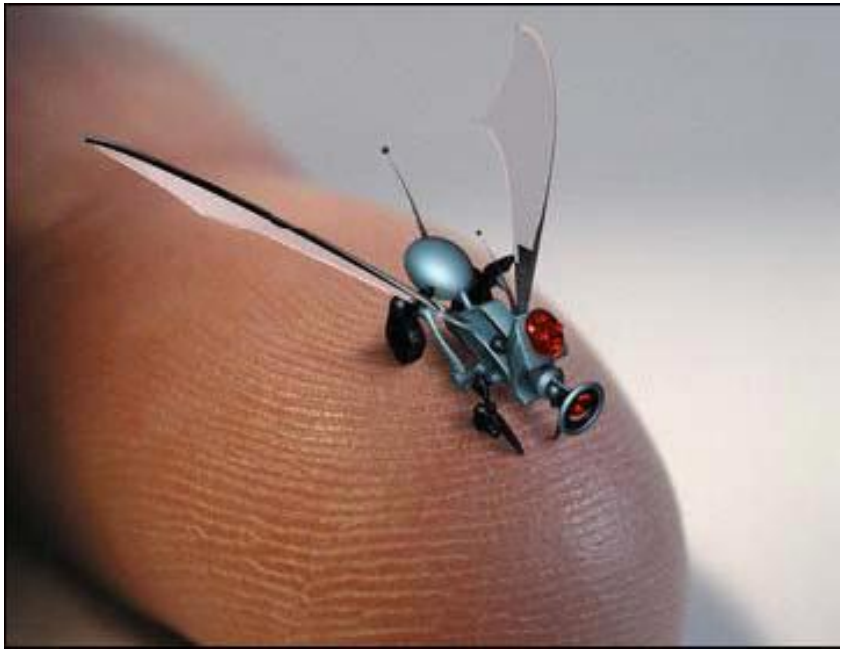
6th AURA Workshop
Hanoi, 18 October 2016

Summary of Presentation

Introduction of Nanotechnology



Nanotechnology is the art and science of manipulating matter at the nanoscale (down to 1/100,000 the width of a human hair) to create new and unique materials and products.

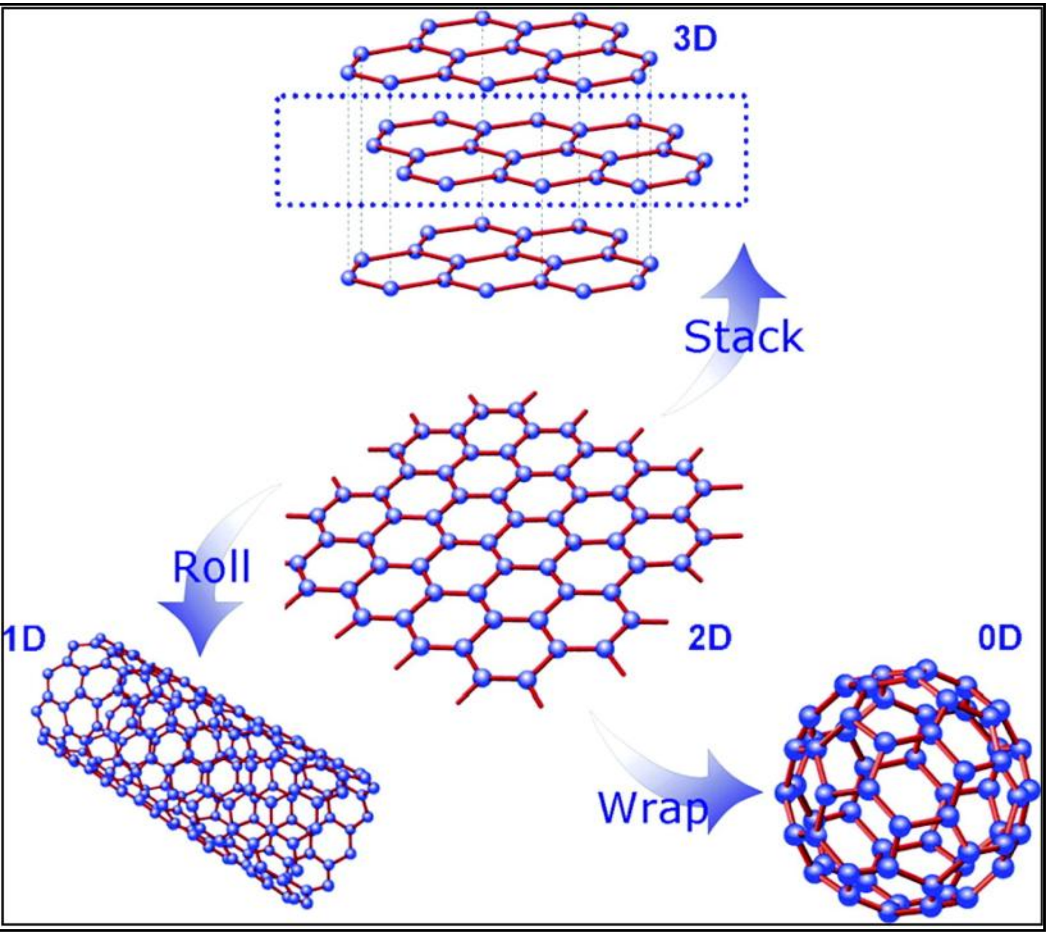
Nanotechnology has enormous potential to change society.

An estimated global research and development investment of nearly $9 billion per year is anticipated to lead to:

- new medical treatments and tools;
- more efficient energy production, storage and transmission;
- better access to clean water;
- more effective pollution reduction and prevention;
- and stronger, lighter materials and many other uses.

http://www.nanotechproject.org/topics/nano101/introduction_to_nanotechnology

Why Size Matters?



0D fullerene ● 1D CNTs ● 2D graphene ● 3D foam

A U.S. silver dollar contains **26.96 grams** of coin silver having diameter of about **40 mm**, and has a total surface area of approximately 27.70 cm^2 (square centimeters).

If coin silver diameter ~ 1 mm:
the total surface area ~ 11,400 m^2

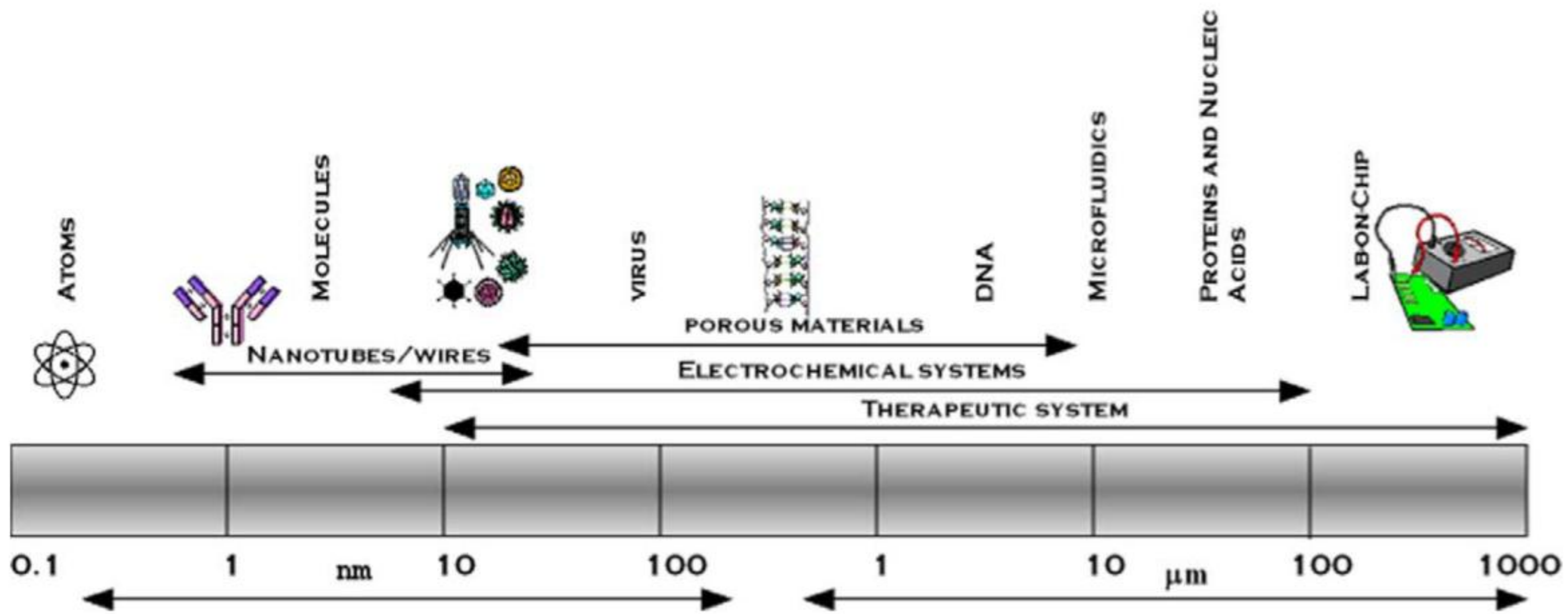
If now having 1 nm particles of silver:
the total surface area of those particles is ~ 4.115 million times greater than the surface area of the silver dollar…!

http://www.nanowerk.com

Introduction of Nanotechnology

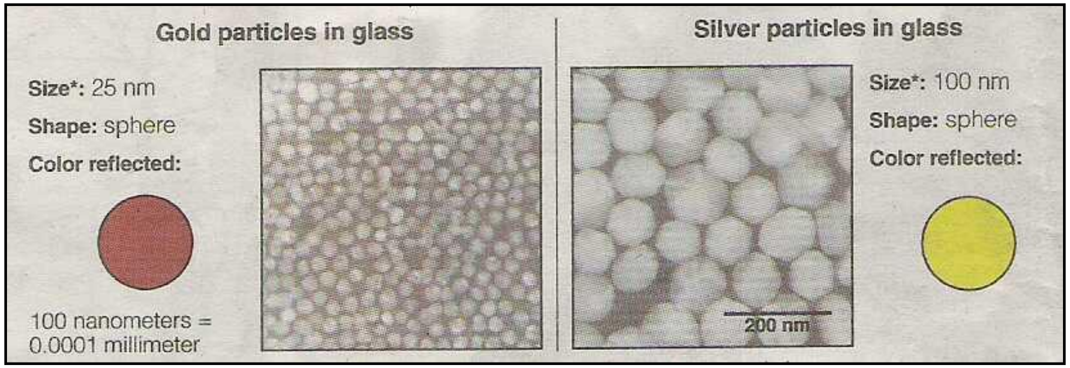
Nanotechnology is being applied to almost every field imaginable, including:

• Electronics • Magnetics • Optics
• Information technology
• Materials development • Biomedicine

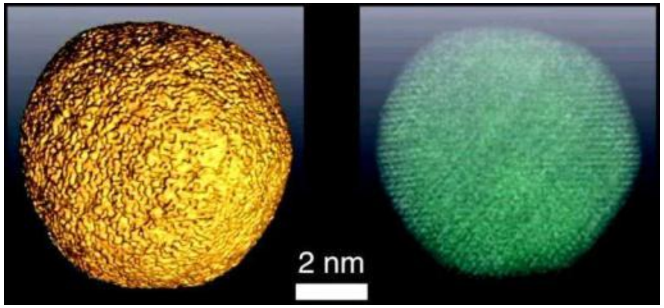


Stained Glasses

The “first nanotechnologists” worked in the middle ages:



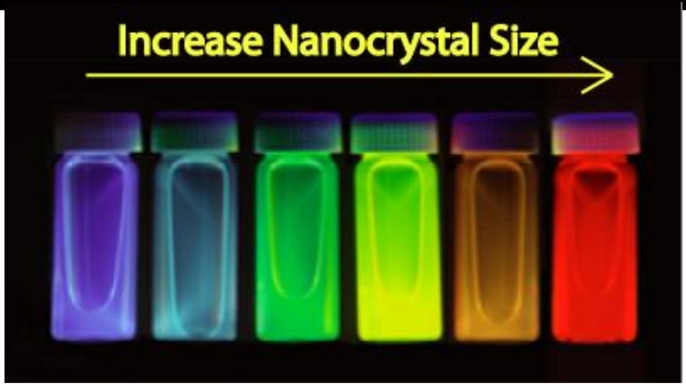
→ stained glass: nanoparticles of gold and silver in glass



Creation of Nanowire a new challenge in modern age!

http://nano--tech.blogspot.sg/p/history.html

Nanocrystals



$$E_g(QD) \approx E_{g0} + \frac{\hbar^2 \pi^2}{2 m_{eh} R^2}$$

$$m_{eh} = \frac{m_e m_h}{m_e + m_h}$$

m_e = effective electron mass

m_h = effective hole mass

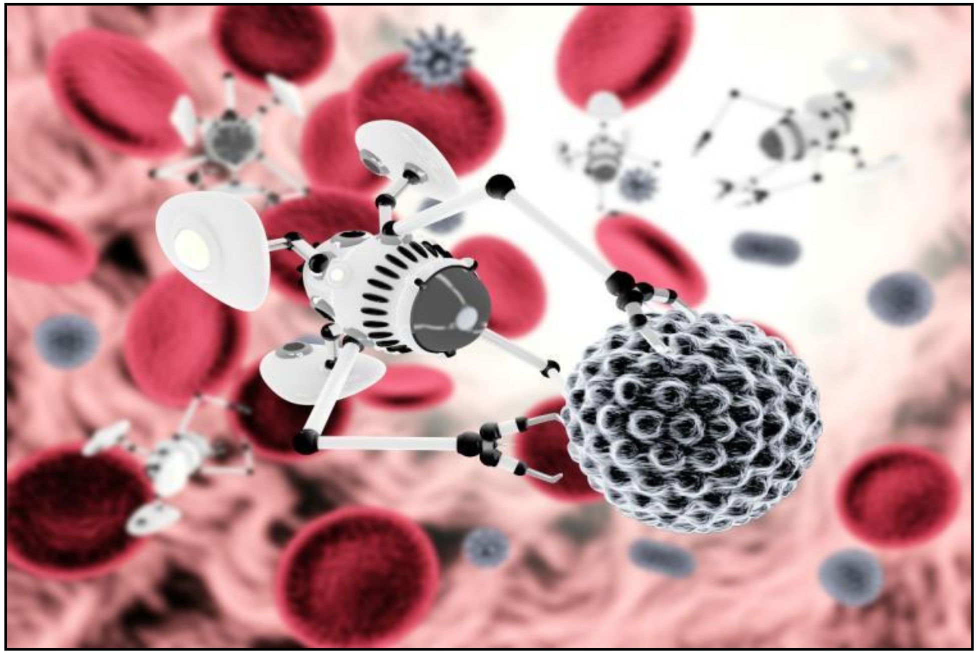
Nanocrystals:
Band-gap Engineered
Semiconductor Materials

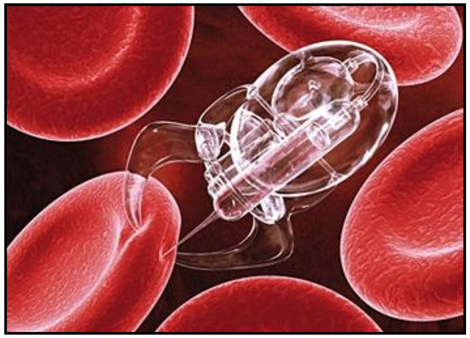
http://nano--tech.blogspot.sg/p/history.html

Summary of Presentation

CINTRA Nanotechnology UMI 3288 CNRS-NTU-THALES

Example of what could be achieved: Smart Pill or Smart Drug





Pictures from: http://www.deluxebattery.com

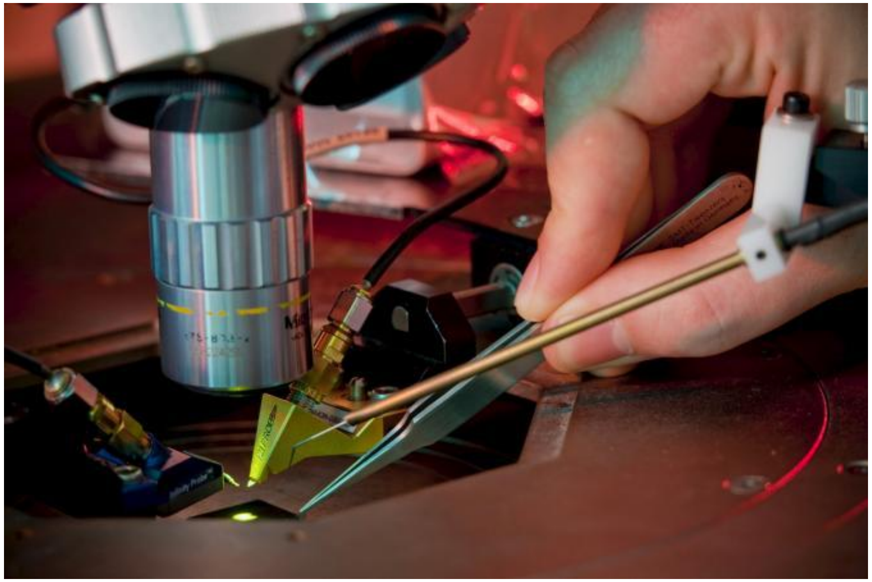
This is an instrument that can be swallowed and tracked by another computer or electronic device. They have TV cameras to capture images of our insides that we can then see from the computer connected with the pill. Magnets can also guide the pills. This could help the pill locate tumors or polyps that could be harmful to humans.

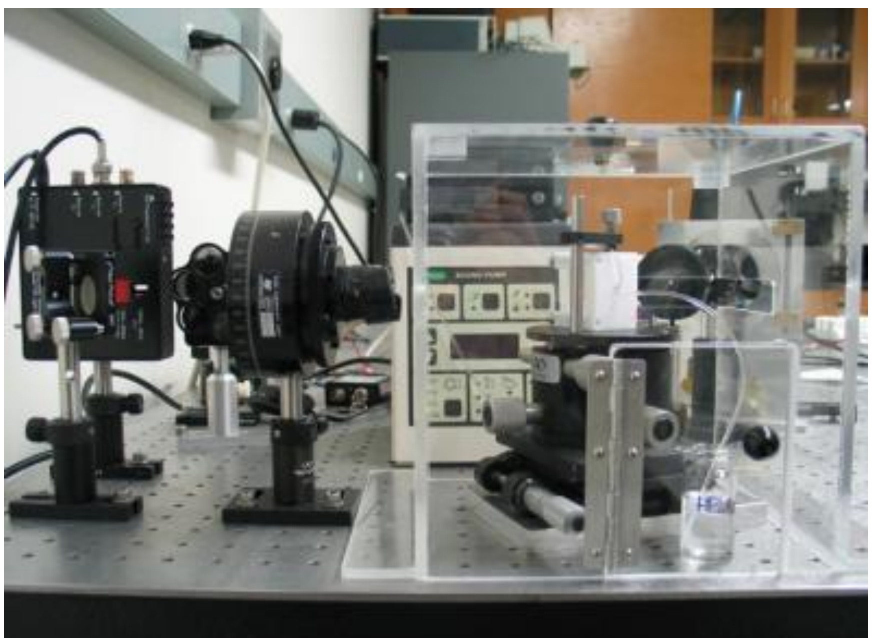
Summary of Presentation

CINTRA Nanotechnology UMI 3288 CNRS-NTU-THALES

- Introduction
- History
- Application
- **Activities of CINTRA**
- Q & A

CINTRA work





Work developed in CINTRA:
1D Carbon Based Materials

CiNTRA Nanotechnology UMI 3288 CNRS-NTU-THALES

TECHNOLOGICAL EXPERTISE IN CARBON NANOTUBES (CNTS) GROWTH

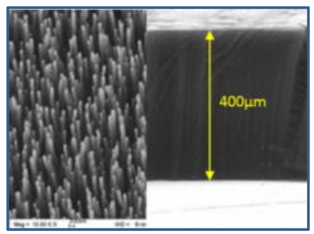
- MWCNT and SWCNT growth capabilities on different substrates (eg. Si, SiO_2, metals, etc)
- CNT diameter (~1-350nm), CNT density ($1x10^{14}$CNTs/m^2 TCVD, $1x10^{12}$CNTs/m^2 PECVD)
- High aspect ratio (1:25) CNTs growth on patterned surface

Growth Methods

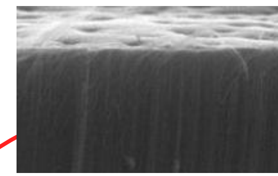
- PECVD
- TCVD

Materials

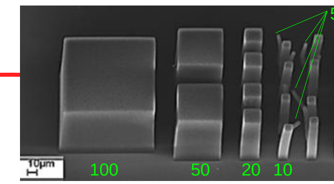
Vertical Aligned CNTs growth Length 25µm(PECVD), 400µm (TCVD)



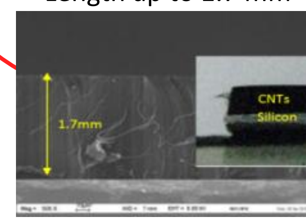
SWCNTs Length ~ 220 µm



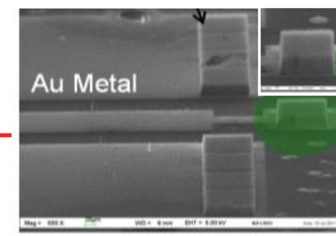
High Aspect Ratio CNTs



Ultralong MWCNTs Length up to 1.7 mm



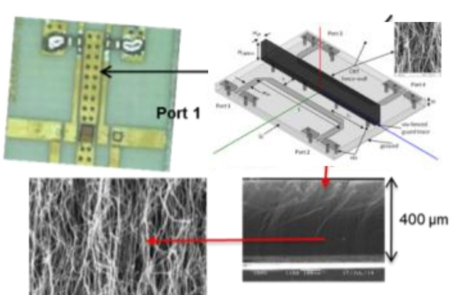
CNTs on Metals - Au, Al, Cu, Pt



PIs: Tay Beng Kang, Shen Zexiang

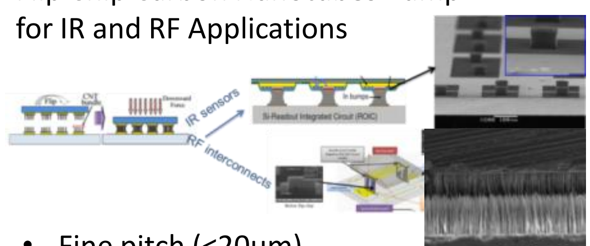
APPLICATIONS

CNT Fence-wall for RF Isolation



- Size and weight reduction

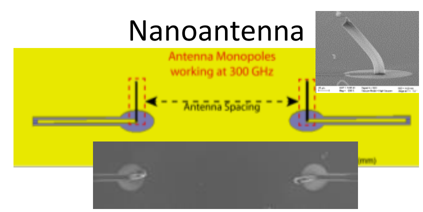
Flip Chip Carbon Nanotubes Bump for IR and RF Applications

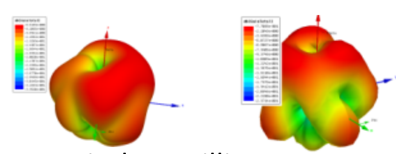


- Fine pitch (<20um)
- Low Temperature CNT growth (400°C)

Collaboration: III-V lab and XLIM

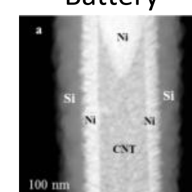
Nanoantenna





- Wireless millimeter wave interconnect

Si@Ni@CNT for Lithium Ion Battery



- Anode material
- Accelerated charge transport

2D Nano Materials

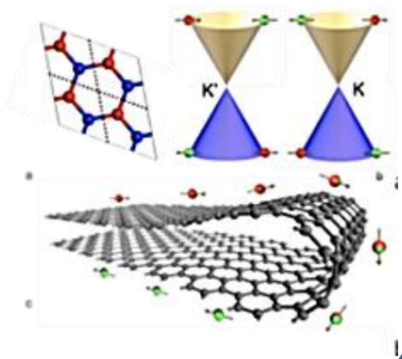
Nanotechnology UMI 3288 CNRS-NTU-THALES

- Graphene, h-BN, MoS_2, WS_2, WSe_2
- **Possible integration of 2D materials into Van der Waals Solids – VdW eg. Graphene on h-BN, WS_2 on MoS_2**

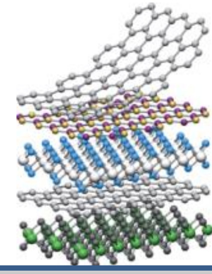
PIs: Liu Zheng, Edwin Teo, Tay Beng Kang

Materials

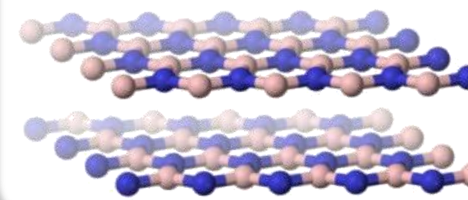
Graphene
(CVD and chemical synthesis)



MoS_2, WS_2, WSe_2, etc (CVD)

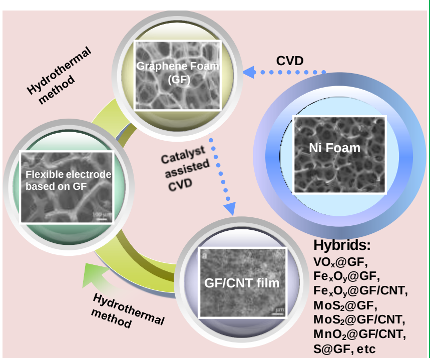


Hexagonal Boron Nitride (CVD)



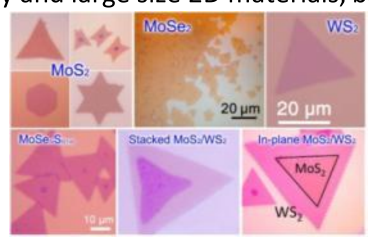
Applications

Graphene and its hybrids for
<u>Energy Storage</u>



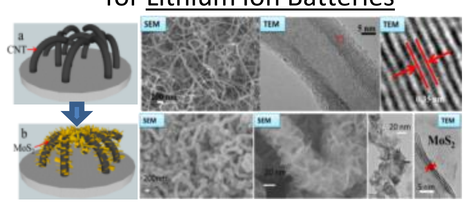
- High energy density and capacity
- Long cycle life

High quality and large size 2D materials, bandgap tuning



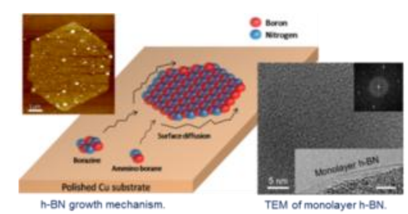
- <u>For Gas and Infra-red Sensors</u>
- High sensitivity, small size and low power

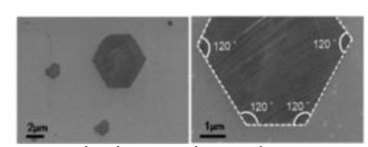
MoS_2@CNT network Anode material
for <u>Lithium Ion Batteries</u>



- Enhanced structural stability of anode
- Superior rate capability

Ultra large single crystalline domains
2D Boron Nitride Hexagons for
<u>Thermal Interface Material</u>





- High thermal conductivity
- Light weight and flexible
- High dielectric potential

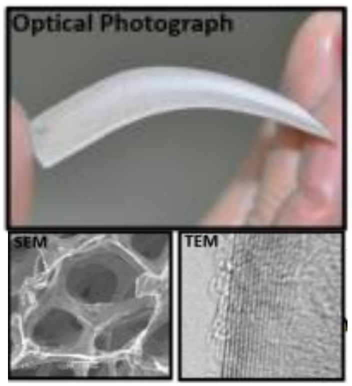
3D Nano Structures

CiNTRA
UMI 3288
Nanotechnology CNRS-NTU-THALES

Architecting 3D nano structures from 1D and 2D nano-materials

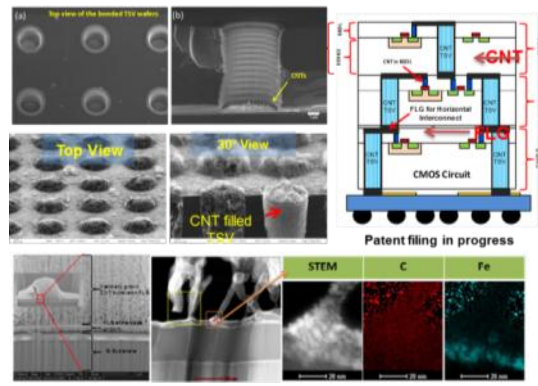
PIs: Edwin Teo, Shen Zexiang, Tay Beng Kang, Liu Zheng

3D Boron Nitride for <u>Heat Spreader</u> and <u>Thermal Interface Material</u>



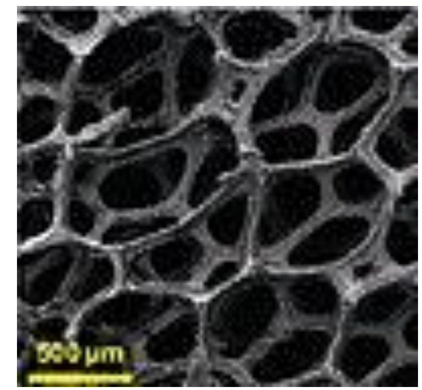
- High thermal conductivity
- EM compliance for RF components

3D <u>Heat Channeling</u> via Through-Silicon-Vias in Device Packaging



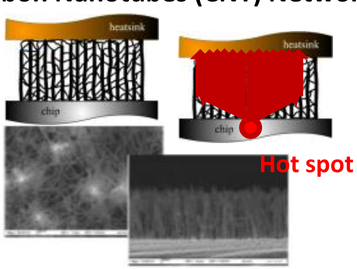
- Reduced electrical / thermal contact resistance
- 3D electrical and thermal channeling

3D Metal-Graphene-Nanotubes Multifunctional Hybrid Material for <u>Energy Storage</u>



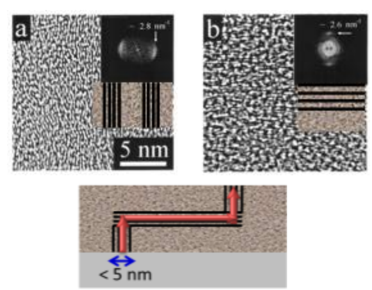
- Unique structure electrodes

Next Generation <u>Thermal Interface Material</u> 3D Carbon Nanotubes (CNT) Network



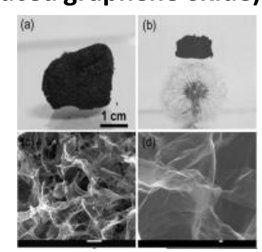
- 6 times higher thermal conductivity than copper
- Improved array strength
- Multi channel for thermal conduction

Nano-Crystalline Graphitic (NCG) Carbon <u>3D nanosteering</u>



- Combination of electrical and thermal excellence in a single material

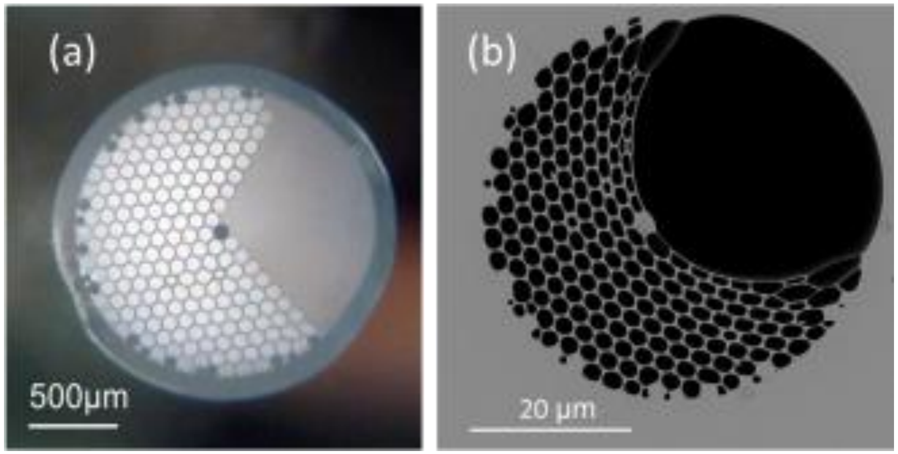
rGO (reduced graphene oxide) Aerogel

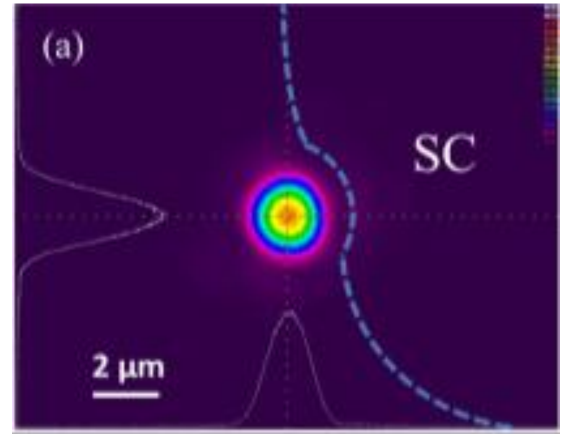


- Extremely low density, ultra light
- High strength and flexible
- High thermal conductivity and electrical insulator
- Light weight heat spreader

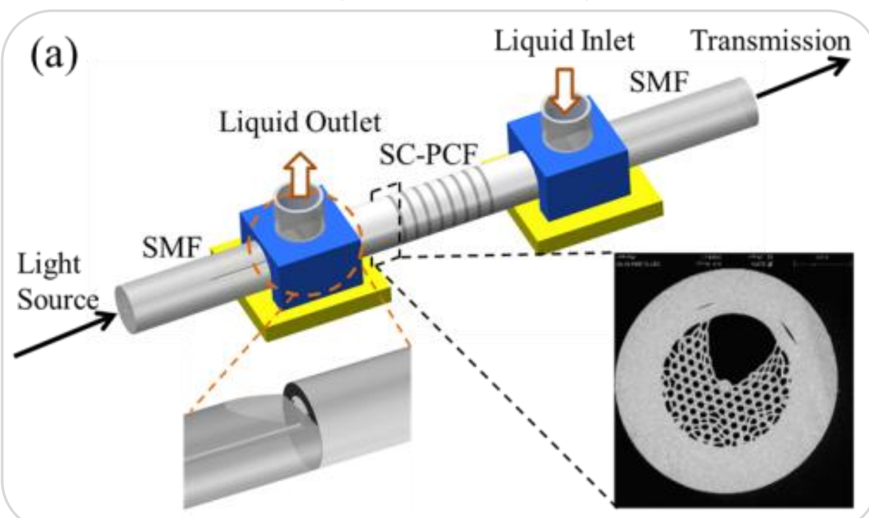
Side-Channel Fiber for Optofluidic Devices

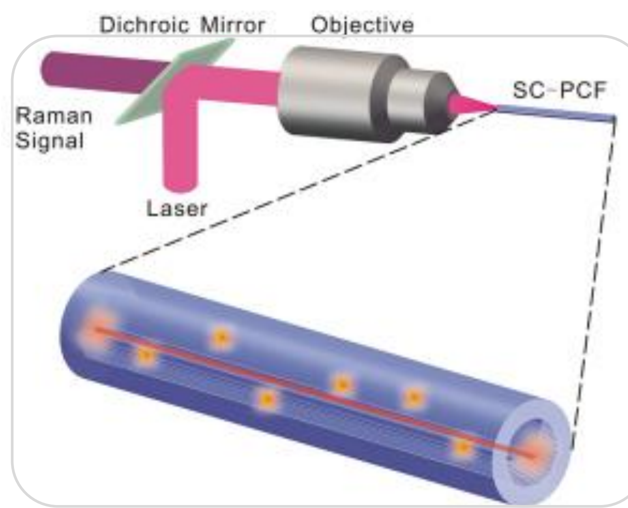
Partners: XLIM Limoges FR and SBIC-A*STAR Singapore





PIs: Wei Lei, Shum Ping, Dinh Xuan Quyen





❑ Achievements

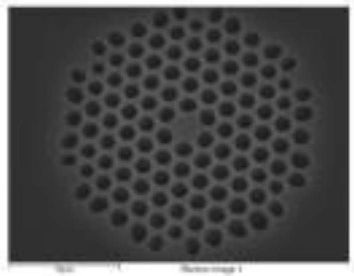
Specialty Fiber for Photon Triplets

Funded by
Singapore MOE Tier 2
2014-2017

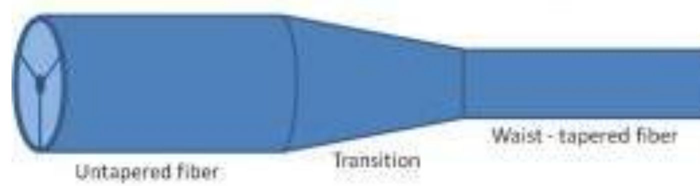
Partner: XLIM Limoges FR

Project title:
Novel Photonic Devices for Third-order Parametric Downconversion

(a)



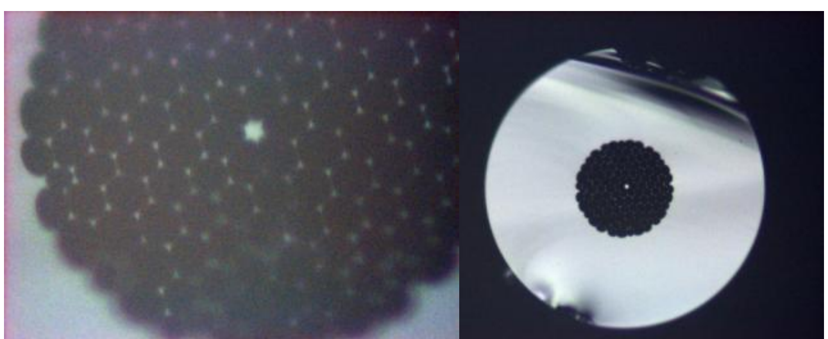
(b)

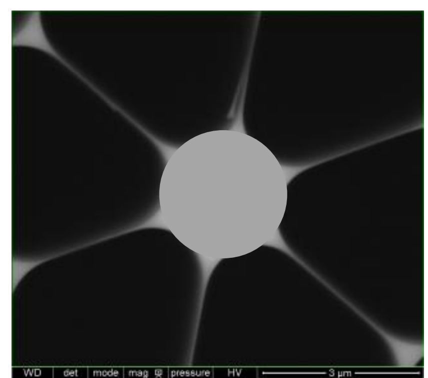


PIs: Shum Ping, Georges Humbert

To demonstrate the feasibility of third-order parametric downconversion (TOPDC) at infrared wavelength for generating photon triplets in phase-matched optical fibers.

ID :	**Photon3 PCF1 band 7**		
Length:	150 m	O.D.:	198 µm
Contact:	Georges Humbert	Date :	19 09 2016

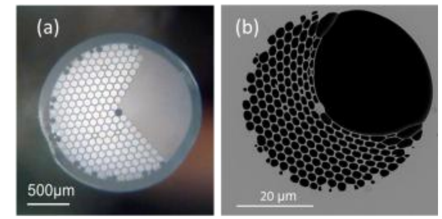




Fiber-based Sensors

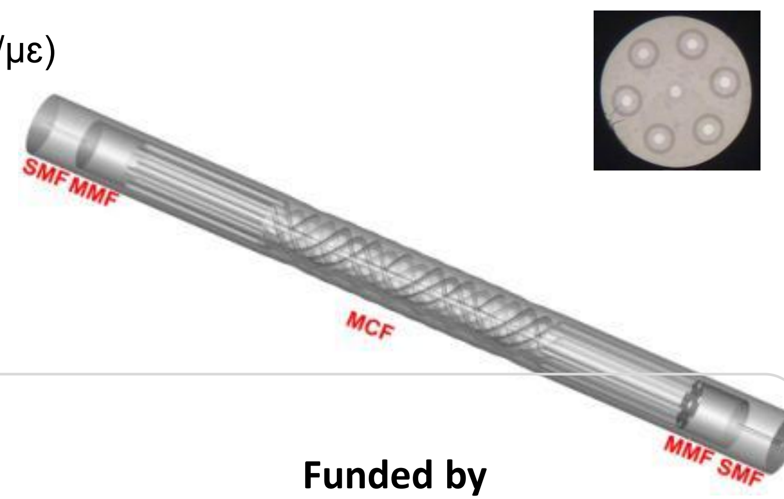
❑ Achievements

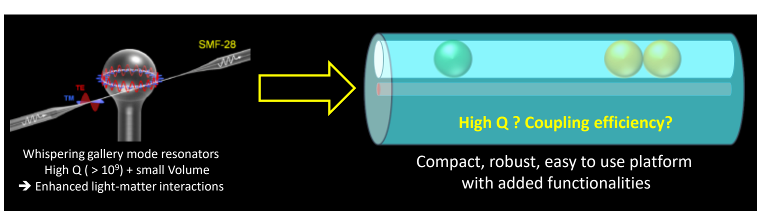
Partner: COFT-EEE

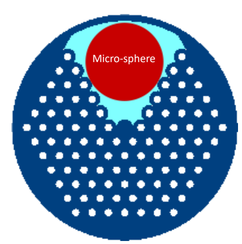


- ➢Side-channel PCF optimized for guiding 632 nm laser: successfully designed & fabricated by CINTRA & XLIM joint work. New design and performance identified ● Patent under discussion
- ➢SC-PCF being used ● at SBIC, giving very strong SERS enhancement ● and at EEE, giving sensitivity of 1042 nm/RIU
- ➢Dual-concentric-core fiber (DCCF)-based curvature sensor immune to temperature and strain. High repetitivity.
- ➢Ultra sensitive temperature (290nm/℃) & strain sensor (701 pm/με) achieved with selective infiltration

Λ=450 μm; length 30 mm







Funded by
Singapore MOE Tier 1
2016-2019

Fiber-based whispering gallery mode microsphere resonator for sensing

PIs: Dinh Xuan Quyen, Shum Ping, Georges Humbert

Z. Wu *et al.* Opt. Lett. 41, 380 (2016); H. Zhang *et al*. CLEO 2016, paper SM2P.3; N. Zhang *et al.* Sens. Actuators B Chem. 223, 195 (2016)

Mid-IR Photodetector

Nanotechnology and Space

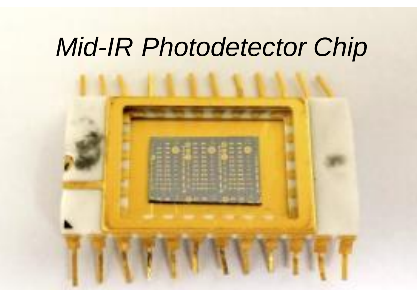
CINTRA UMI 3288 Nanotechnology CNRS-NTU-THALES

❑ Achievements ***Collaboration: NTU-EEE, III-V lab and TAS***

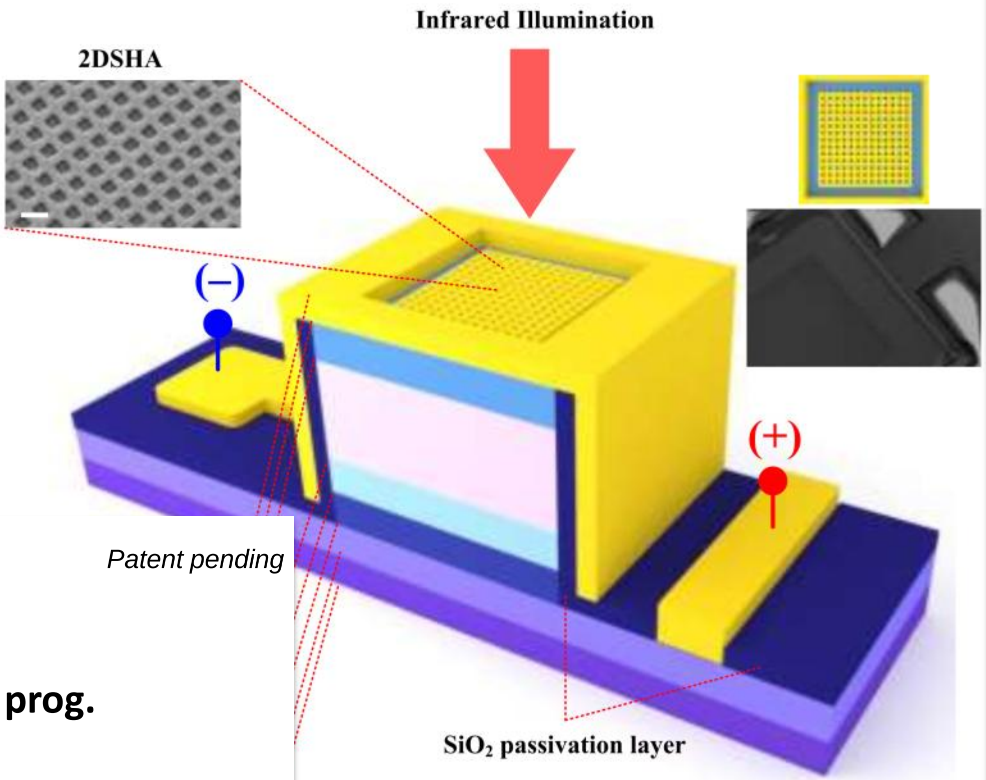
➢Growth and characterization of InAsSb based heterostructure infrared photodetectors with metallic structure for photoresponse enhancement

➢SPP enhancement of p-i-n photodetector observed at room temperature and a new model proposed for detection mechanism

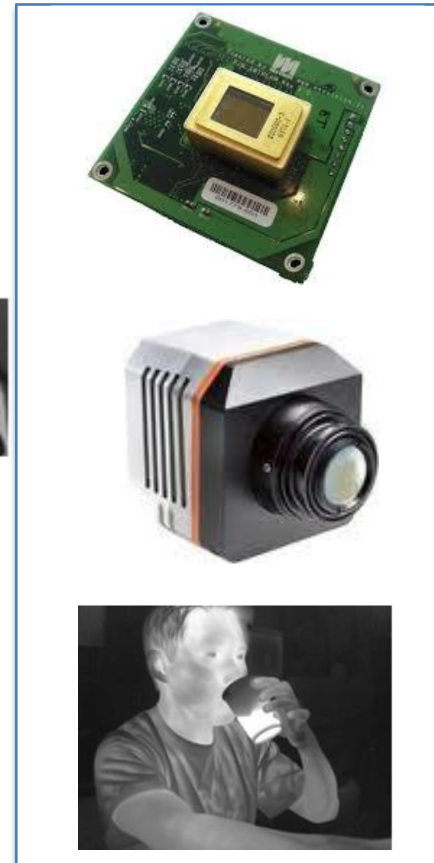
PI: Zhang Dao Hua



EEE ● CINTRA ● III-V lab
collaborative achievement in 2016



Patent pending



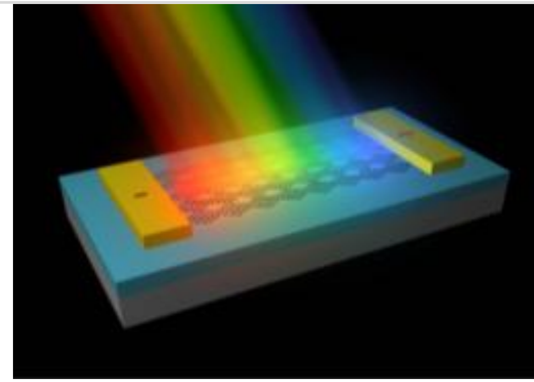
Funded by
Singapore EDB Satellite prog.
2013-2016

Optoelectronic Devices

❑ Achievements

Collaboration: NTU-EEE, III-V lab, TRT FR, Paris 7

❖Infrared photodetector and device
- Graphene p-n junction wideband photodetection
- Integration of IR detector array & CMOS circuit
- Mid-IR camera prototype for Space missions (with TAS)

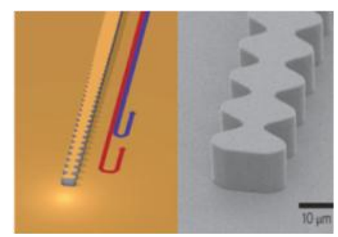


Graphene broadband photodetector

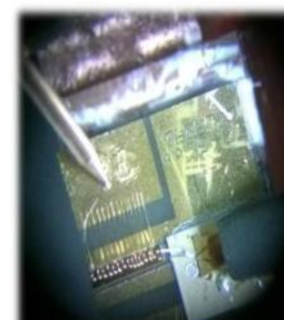
PIs: Wang Qijie, Zhang Dao Hua

❖QCL-based component
- QCL-based mid-IR frequency comb
- Plan to make a portable SPR sensing system

Mode locked QCLs



Double-chirped Mirrors



Partner: III-V lab

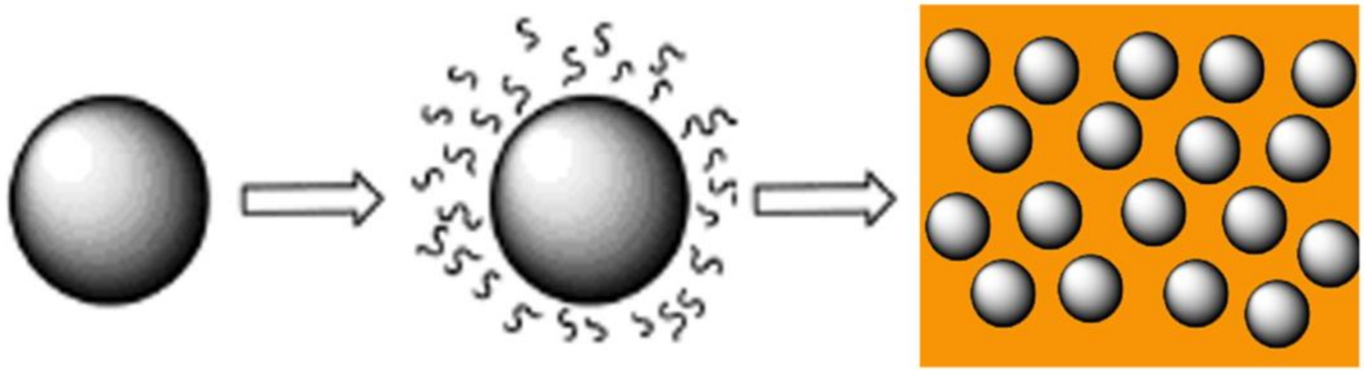
G. Liang, et al, ACS Photonics, 2015; X. Yu, et al, Nano Energy 25, 34-41, 2016

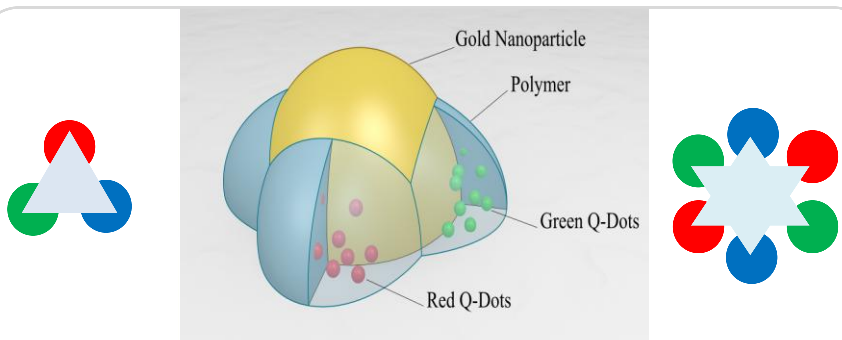
On-chip Hybrid Source for Optical Processor

Nanotechnology CiNTRA UMI 3288 CNRS-NTU-THALES

❑ To be achieved

Collaboration: UTT Troyes FR (ANR-NRF project)





On-chip hybrid source for optical processor

PIs: Renaud Bachelot, Sun Xiaowei, Dinh Xuan Quyen

- **Ultracompact functional integrated optics**
- **New hybrid source directly integrated in the waveguide**
- **For future electrically controlled optical microprocessor**

Funded by
1st ANR-NRF joint grant
2016-2019

Surface Plasmon Resonance Sensors

CiNTRA
UMI 3288
Nanotechnology CNRS-NTU-THALES

❑ Achievements

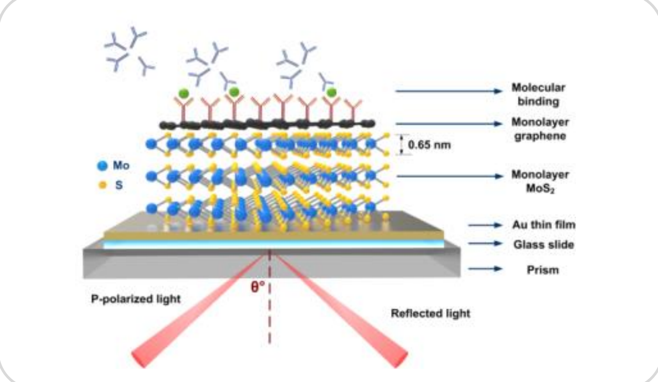
Collaboration: Shenzhen Univ., IEMN

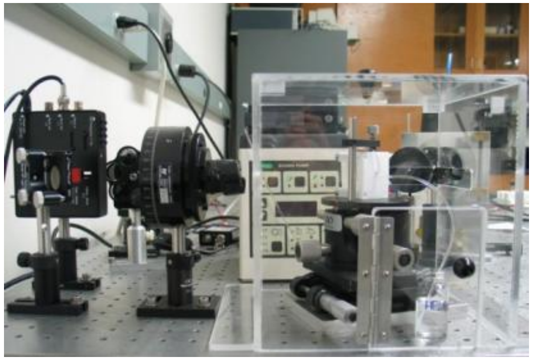
➢Graphene-MoS_2 hybrid structures for ultra-sensitive detection of molecules at very low limit of detection 100 aM (world best)

➢New paper published in *Nature Sci. Reports* 16 June 2016

➢Compared to commercial ones, this home-built sensor collected the phase information from the reflected light where the signal change is 3 orders more sensitive than the angular ones

➢The research has been selected as the top spotlight of 2016 in Nanowerk - leading nanotechnology website, as it is the first study on the phase singularity of graphene SPR





❑ Work Plan

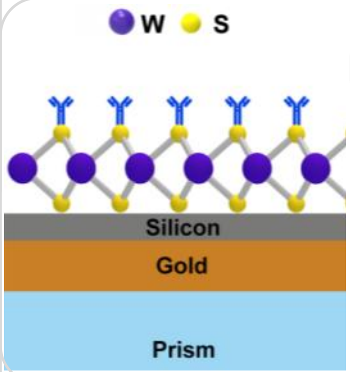
PIs: Yong Ken Tye, Zeng Shuwen

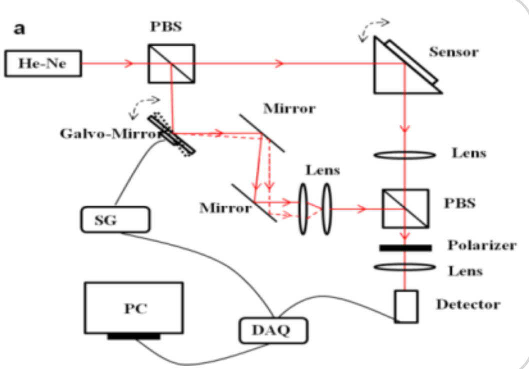
❖SPR Sensors

- Thin film-based high sensitivity SPR sensors
- Graphene enhanced SPR fiber-optic sensor
- Microfluidic-SERS devices for single-molecule detection
- Plan to make a portable SPR sensing system

❖Nano-Plasmonics and NanoOptics

- Flat lens based on plasmonic metasurfaces





S. Zeng *et al.* Adv. Mater. 27, 6163 (2015); S. Zeng *et al.* Sens. Actuators B 207, 801 (2015); Q. Ouyang *et al.* Nature Sci. Rep. 6, 28190 (2016)

Graphene as Nanosensor

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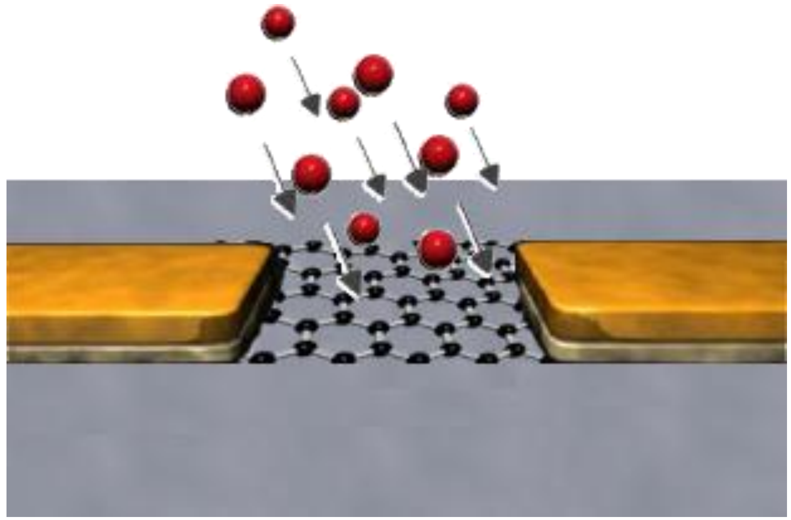


PI: Zhang Qing

For gas detection and environmental monitoring

High sensitivity of graphene to gas molecules:

Unusual carrier density dependent conductivity, minimum quantum conductivity

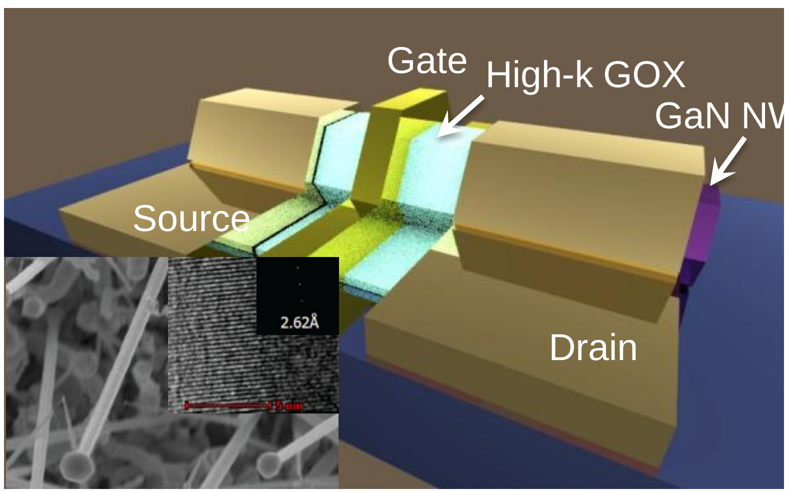
Possible chemical modification of graphene

III-N NW based MOSFETs and sensors (with IEF & LPN)

To explore the potential of high-k dielectric III-N NW MOSFET as a solution to integration with CMOS technology and

The project includes:

1. Synthesis of high quality metal free catalyzed III-N NW
2. Deposition ALD high-k dielectrics on GaN
3. A CMOS compatible fabrication process

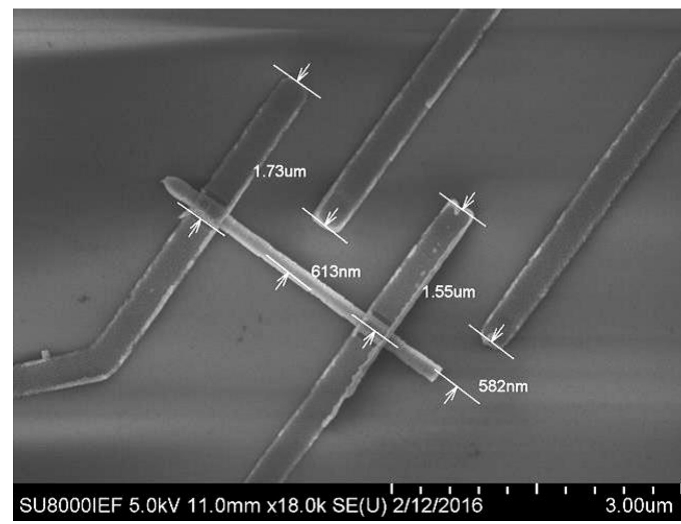


Schematic of GaN NW high-k MOSFET - Single crystal Ge-catalyzed GaN NW grown by LPCVD (Inset)

To realize multi gas sensing detection (CO, CO_2 and NO_x) working in harsh environment based on GaN nanowires

The project includes:

1. A optimized shell oxidation for targeted gases
2. High thermal resistivity devices
3. NW-array multidetection from raw signal



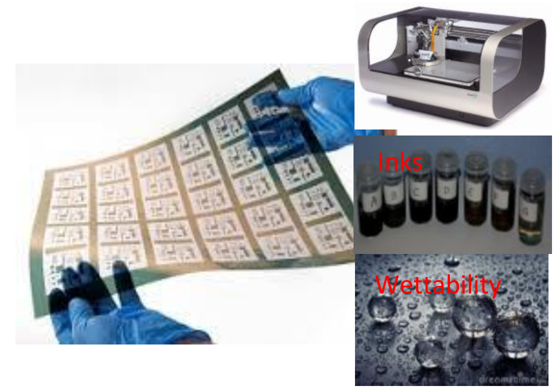
GaN NW based gas sensor with horizontal topology fabricated using electron beam lithography

PI: Wang Hong

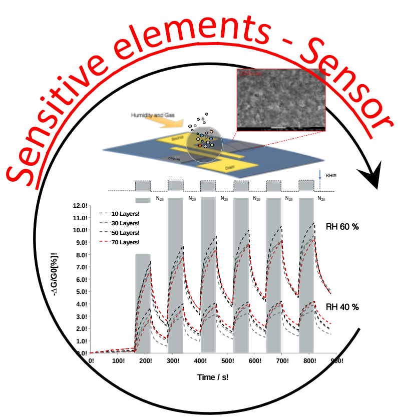
Flexible Electronics

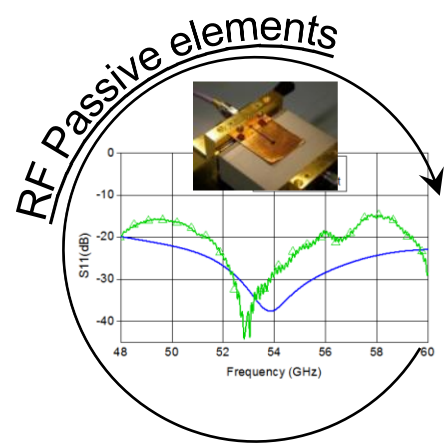
CiNTRA UMI 3288 CNRS-NTU-THALES
Nanotechnology

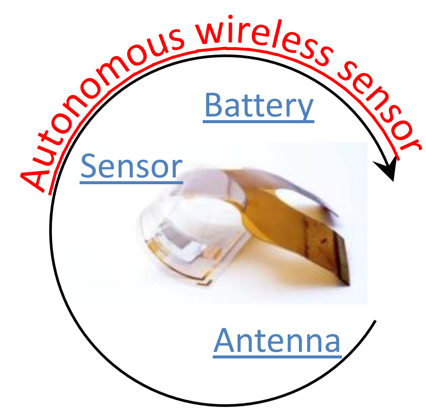
- ADVANTAGES : Low cost, fast prototyping, conformable…
- Ink Printing technology of nanomaterials
  - CNTs, graphene, polymer, composites, metallic …
- Printing on different substrates
  - Paper, PET, Kapton, Silicon, Elastomer …



APPLICATIONS

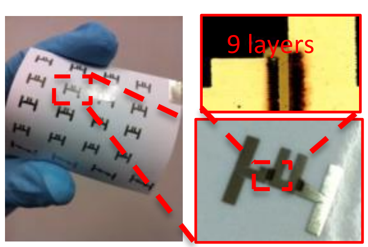




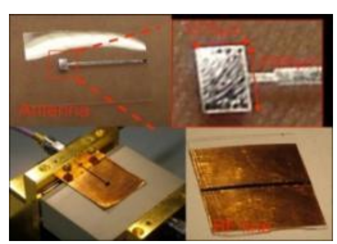


PIs: Philippe Coquet, Zhang Qing

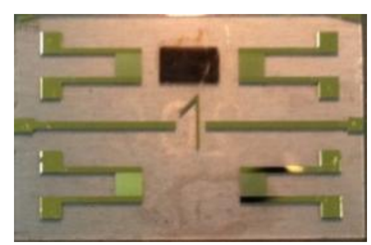
Humidity Sensor on paper



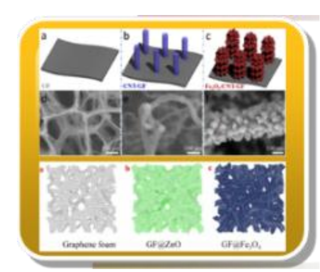
Resonator based CNT on paper



Stretchable millimeter devices



Printed SAW sensor



Fe_2O_3 @ GF/CNT for Energy Storage

Nanotechnology
will very soon be
a part of every area of
our lives

Merci


danke
謝謝
ngiyabonga
teşekkür ederim
спасибо
dank je
thank you
gracias
tapadh leat
hvala
maururu
bedankt
dziękuję
mochchakkeram
go raibh maith agat
sagolun
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kop khun krap
obrigado
arigatō
takk
dakujem
grazie
мерси
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ευχαριστώ
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감사합니다

Cảm ơn