

Graphene: The Wonder 2D-material of the 21st century

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Define tomorrow.



UNISA



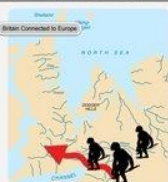
STONE AGE ⇒ BRONZE AGE ⇒ IRON AGE

STONE AGE

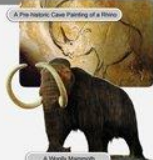
The Stone Age lasted for a very long period of time! It stretches from the very beginnings of humanity three million years ago, to the farmers that lived a few thousand years ago. The reason it's called the Stone Age is because during this time, the people used tools made out of stone!

Palaeolithic (Old Stone Age) Begins

500,000 BC



500,000 BC
The first people arrive in Britain. Early humans migrate into Britain from Europe. They walk over the land, as at this time Britain was connected to European land.



500,000 BC
Prehistoric animals living in Britain. Some now-extinct animals lived in Britain during this period, including the mammoth, and giant beaver. Rhinos also lived here!



500,000 BC
Basic stone tools. During this period, people in Britain used simple tools made out of stone, such as the 'hand axe'. This tool would have been used to cut meat, for digging and chopping wood.



130,000 BC
Neanderthals Britain. This early species of human was known as the Neanderthal. Neanderthals looked very similar to today's humans, but they did have different shaped heads.

130,000 BC

25,000 BC



25,000 BC
The start of the Ice Age. Britain and Northern Europe are plunged into a long Ice Age. The temperature was constantly freezing. Glaciers, snow and ice formed across much of the land, making it a difficult place to survive!

Mesolithic (Middle Stone Age) Begins

10,000 BC



10,000 BC
The Ice Age ends. After the Ice Age ends, the temperature on earth begins to increase. Large amounts of ice started to melt making the sea levels rise. Because of this, Britain becomes disconnected from mainland Europe. Lush green forests grow as a result of a warmer climate.

8,000 BC



8,000 BC
Better tools and shelter. Over time, tools and homes became more advanced. People chose flint stone to make their tools because it was very strong, sharp and easy to hold. The huts that people made provided more warmth and better shelter.

Neolithic

5,000 BC



4,500 BC
Farming is introduced. Before this place to p plants. Ov introduced planting cr sheep, cow

Neolithic (New Stone Age) Begins

5,000 BC



omes became more e flint stone to make us that people made nd better shelter.



4,500 BC - 3,500 BC
Farming is introduced in Britain. Before this period, people would move from place to place hunting and gathering wild plants. Over time, a new way of life was introduced from Europe. People started planting crops and farming animals such as sheep, cows and pigs.

4,000 BC



4,000 BC
Permanent houses, pottery and tools.

Now that stone age people were farming, they started to settle down in communities with other families. Because there were more people, the houses were built using stone and thatched roofs that housed more people, and were a lot warmer! Men and women started crafting pottery items and more complex tools that were used for tasks such as carrying water, cooking and farming.

3,000 BC



3,500 BC
People begin to ride horses.

In a time when people were constantly moving around in search of food and shelter, walking around on foot was slow and painful. Horses were used as faster transport: a way to carry people and belongings.

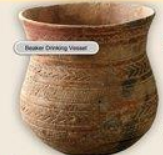


2800 BC
Stonehenge is built. The prehistoric monument Stonehenge is erected, a huge monument that consisted of giant stones arranged into circles. It is believed that the stones were transported from 250 miles away. It is still not known what stonehenge was used for.

BRONZE AGE

2,500 BC

The Bronze Age was a period of time between the Stone Age and the Iron Age, when bronze was used widely to make tools, weapons and other implements. Bronze is made when copper is heated and mixed with tin, creating a stronger metal than copper.



2500 BC
Beaker culture. A group of people migrated from Europe to Britain called the Beaker People, named after their distinctive pottery bell-shaped drinking tools. When they arrived they brought with them the knowledge of making bronze.



2,250 BC



50 BC
The use of bronze tools was a key development in human history. Bronze is made by heating copper and tin until it is molten (liquid). The molten can then be poured into moulds, which allowed people to make a wide range of different shaped tools, many more than was possible when using just flint and stone.



2250 BC
Bronze Age houses. The house of choice in the Bronze Age was the Roundhouse. This was a large round structure that housed many people. A large fire would have been in the centre inside the building that would have been used for cooking and for warmth. The smoke from the fire would escape through small gaps in the thatched roof.

2,000 BC



1800 BC
First Copper mines. People start mining for copper on a large industrial scale, digging deep beneath the earth's surface. They would use strong bronze pickaxes to collect rocks containing copper (copper ore).

1,000 BC

IRON AGE

The Iron Age was the period of time after the Bronze Age. It is the third and last stage of the three-age system. It's named the Iron Age because people started using iron to make tools and weapons: this was a much stronger and reliable metal. We call the people that lived in Iron Age Britain 'Celts'.

800 BC



800 BC
The Celts. The Celts wore brightly coloured clothing, made using dyes made from berries and plants. Celts were very clean people, apparently they invented soap! Some people still speak languages that the Celts spoke - Welsh and Gaelic.

700 BC



800 BC
Iron Age hill forts. A hill fort was a type of settlement that was built on a hill, high up from the rest of the ground. The Celts would construct high walls and dig deep ditches around the hill to stop nasty people from invading their settlements! People would invade hill forts in search of rare, precious metals such as bronze, iron and gold.



700 BC
The use of iron becomes widespread. Celts made tools and weapons out of a metal called iron. Unlike bronze which is poured, iron is worked into a shape by repeatedly heating and hammering against an anvil (a hard piece of stone). This process is called smelting. Iron is much harder than bronze and keeps a cutting edge for longer, which is great for swords!

- ⇒ **Each age is levelled by the Material**
- ⇒ **that bearing the new technology**
- ⇒ **that makes the new society**

**What will be the next age??
What will be next material??**

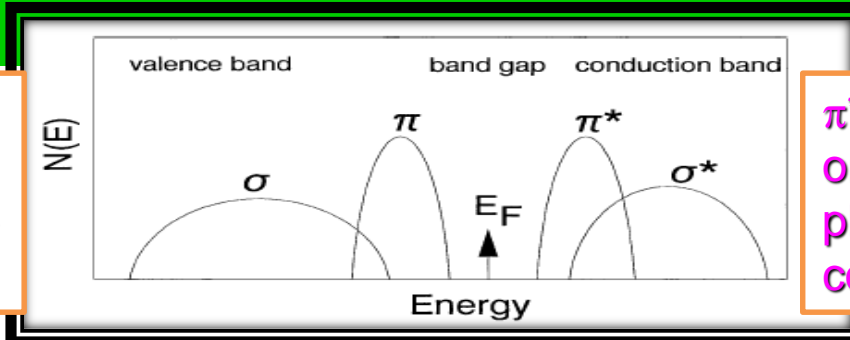
**CARBON AGE
or
GRAPHENE AGE !!**

Electronic distribution of carbon

sp^3 configuration

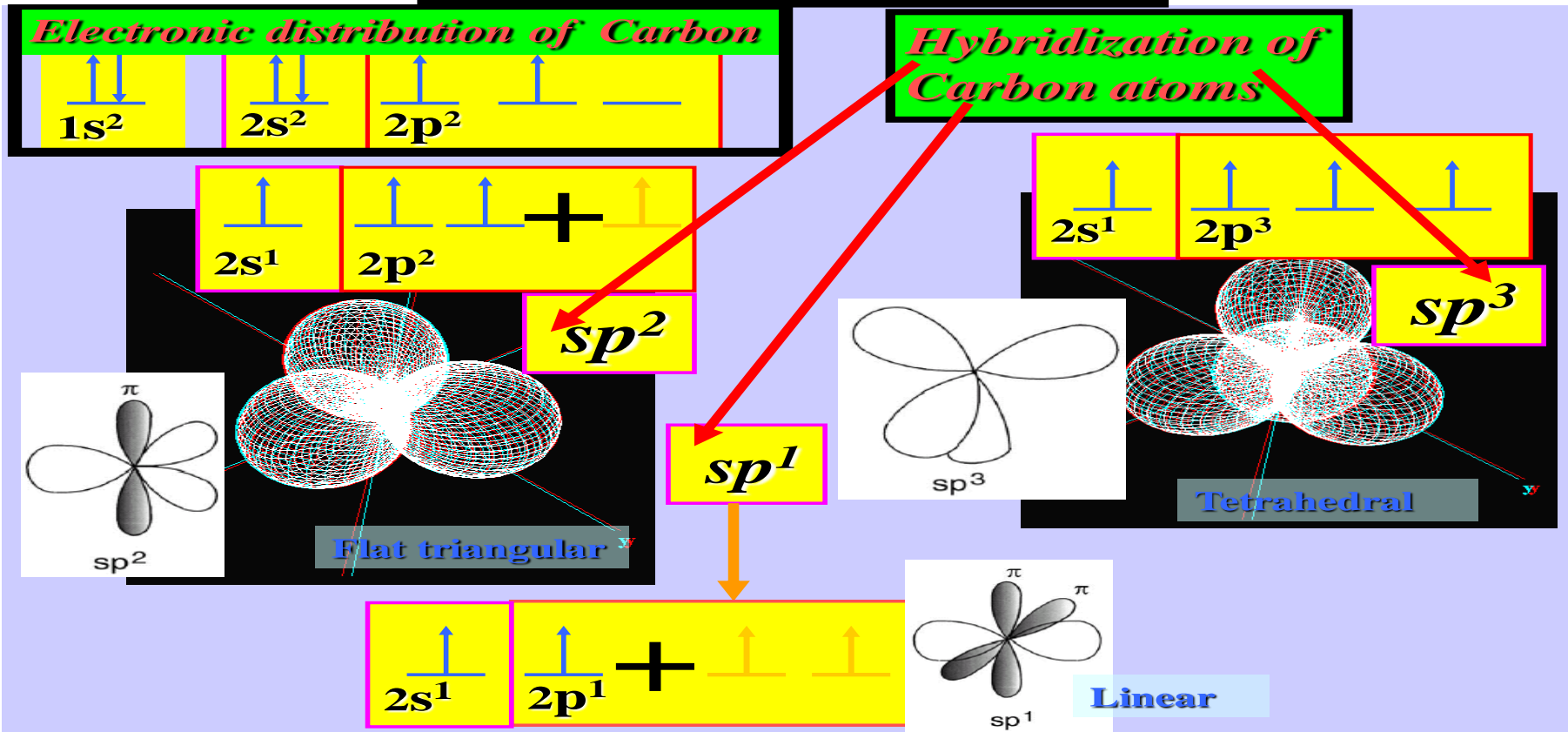
sp^2 configuration

sp^1 configuration

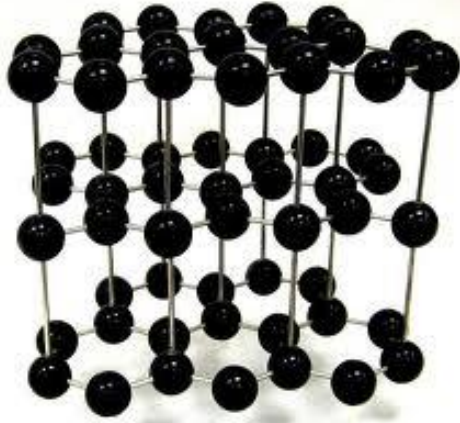


π/σ is bonding state originated from the in-plane, bonds of sp^2 -/ sp^3 - configuration

π^*/σ^* is anti-bonding state originated from the out-of-plane, bonds of sp^2 -/ sp^3 - configuration



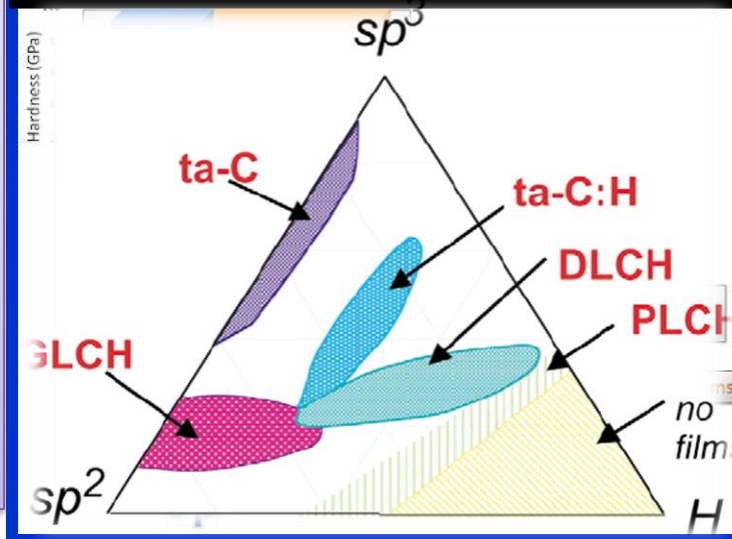
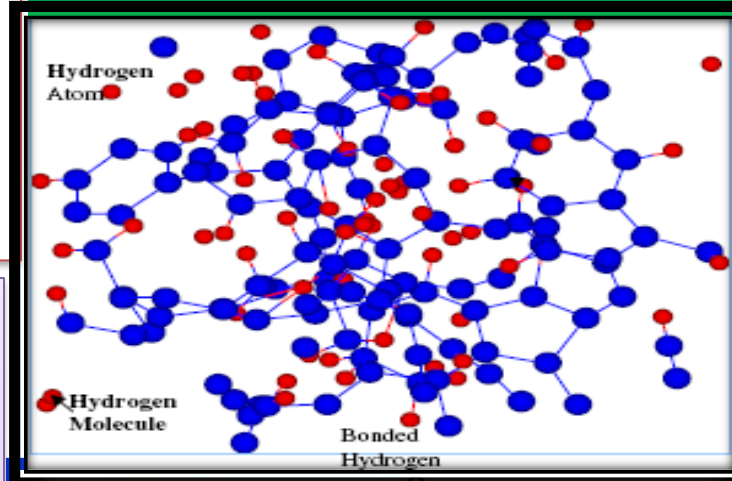
Graphite (100% sp^2)



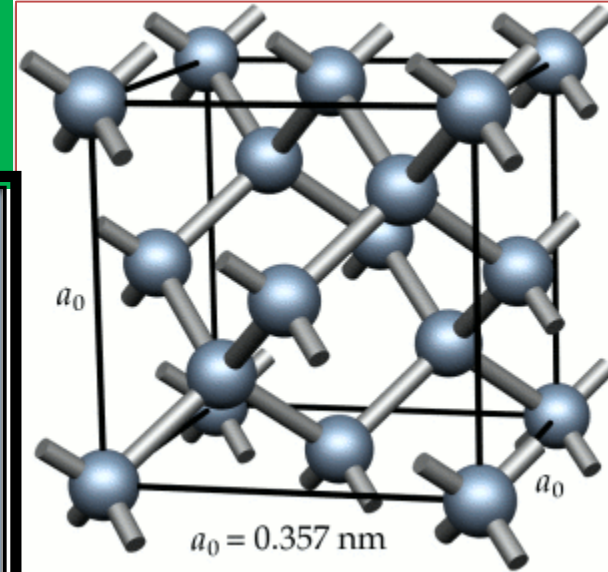
Properties of graphite:

1. Graphite is a soft, slippery, grayish-black substance. It is metallic luster and is opaque
2. Specific gravity is 2.3.
3. Graphite is a good conductor of heat and electricity.
4. Although graphite is a very stable allotrope of carbon but at a very high temperature it can be transformed into artificial diamond.
5. Chemically, graphite is slightly more reactive than diamond.

Amorphous Carbon or Diamond like carbon (Mixture of sp^2 & sp^3)



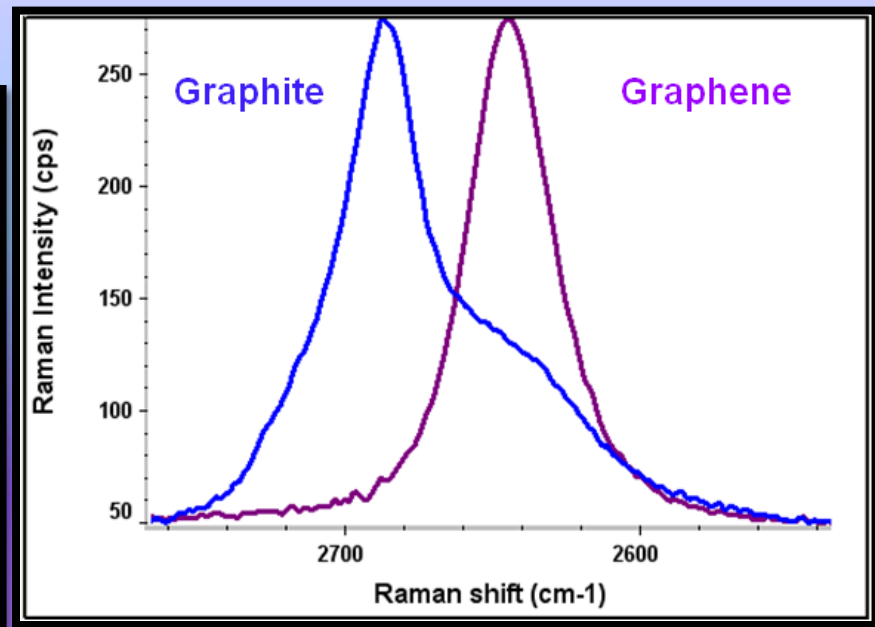
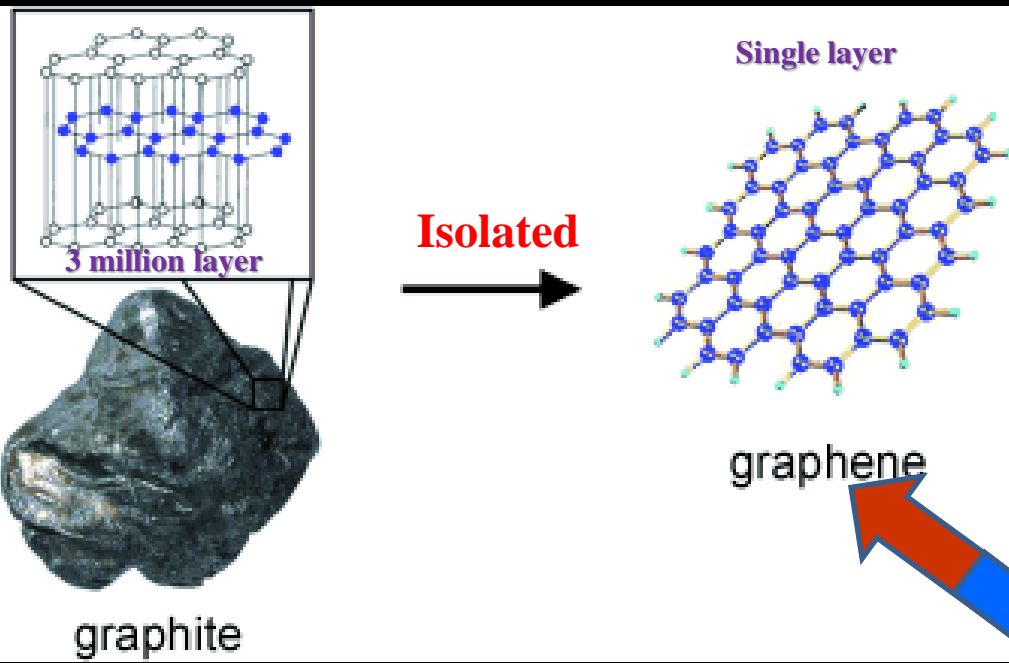
Diamond (100% sp^3)



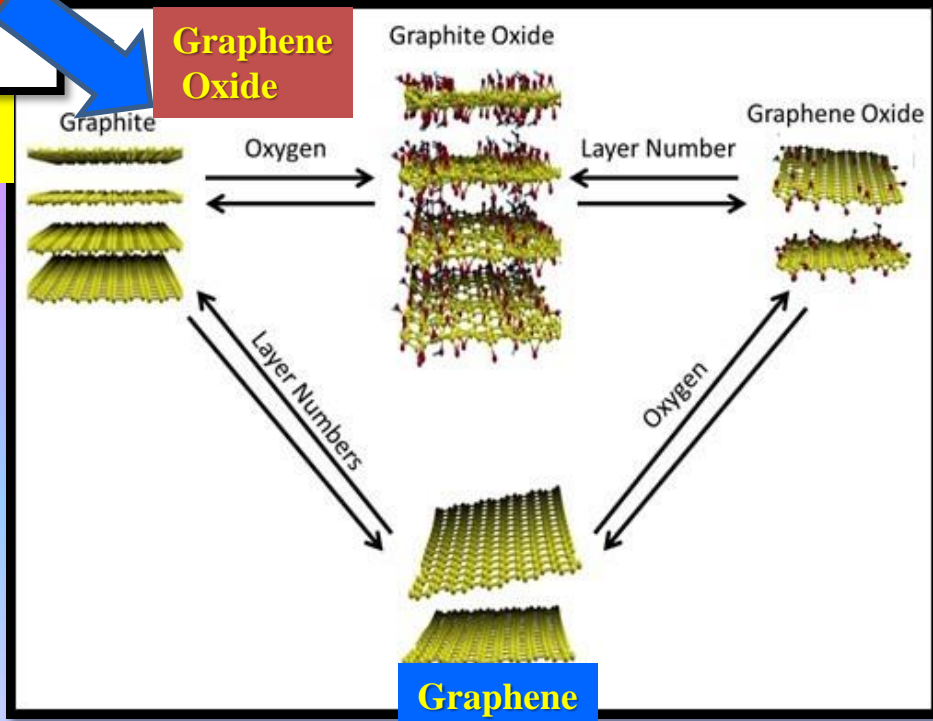
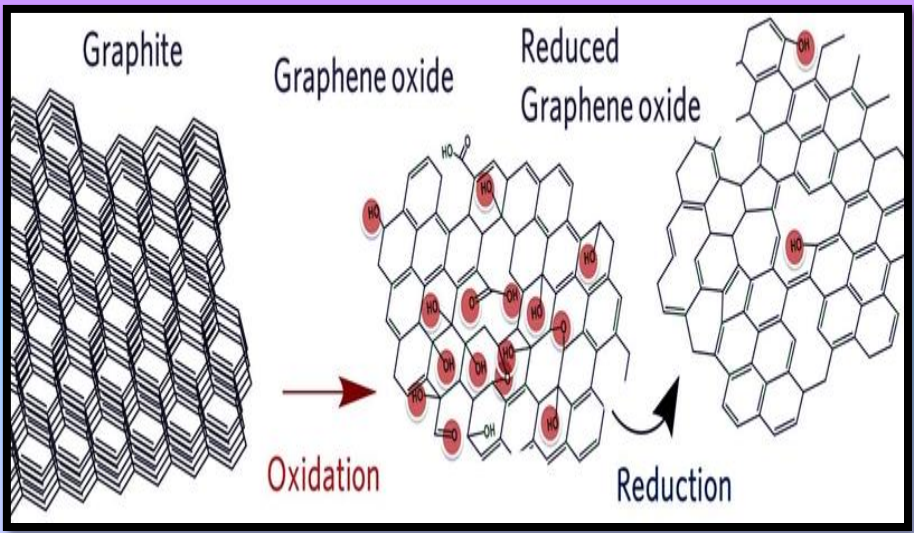
Properties of diamond:

1. It is the hardest substance known.
2. It has a high refractive index and gives an extraordinary brilliance.
3. The specific gravity of diamond is 3.52.
4. Diamond is a bad conductor of heat and electricity because it lacks free electrons.
5. Chemically, diamonds are unreactive under ordinary conditions.

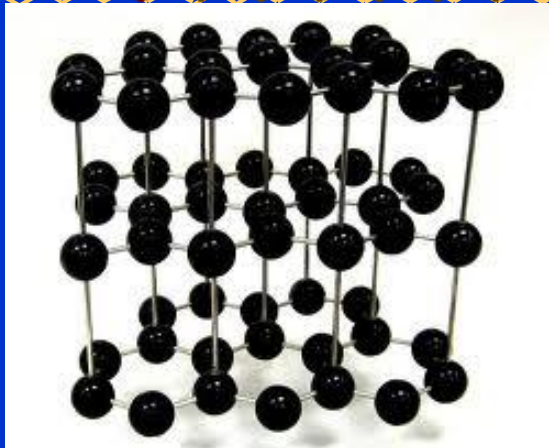
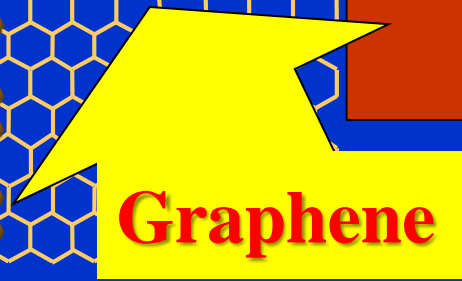
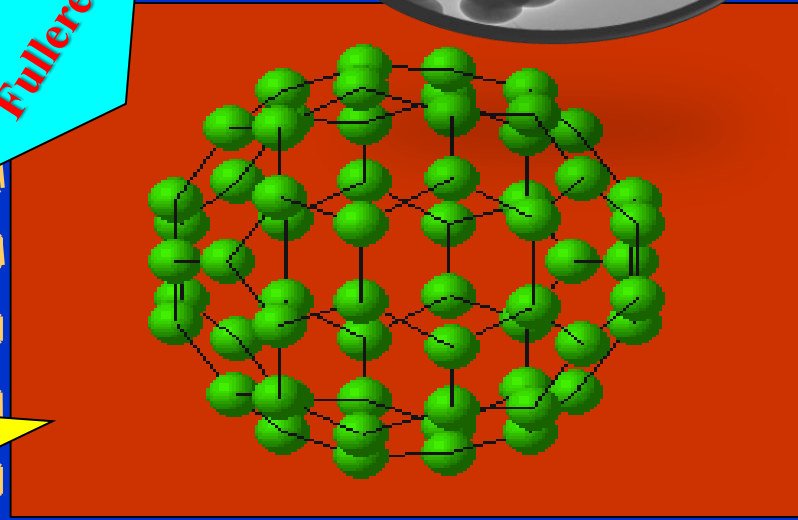
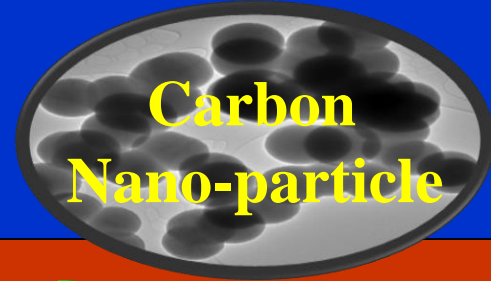
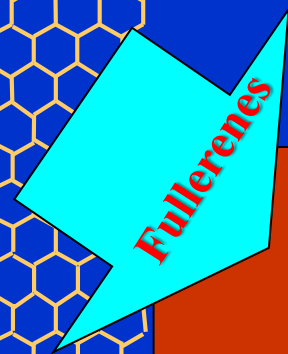
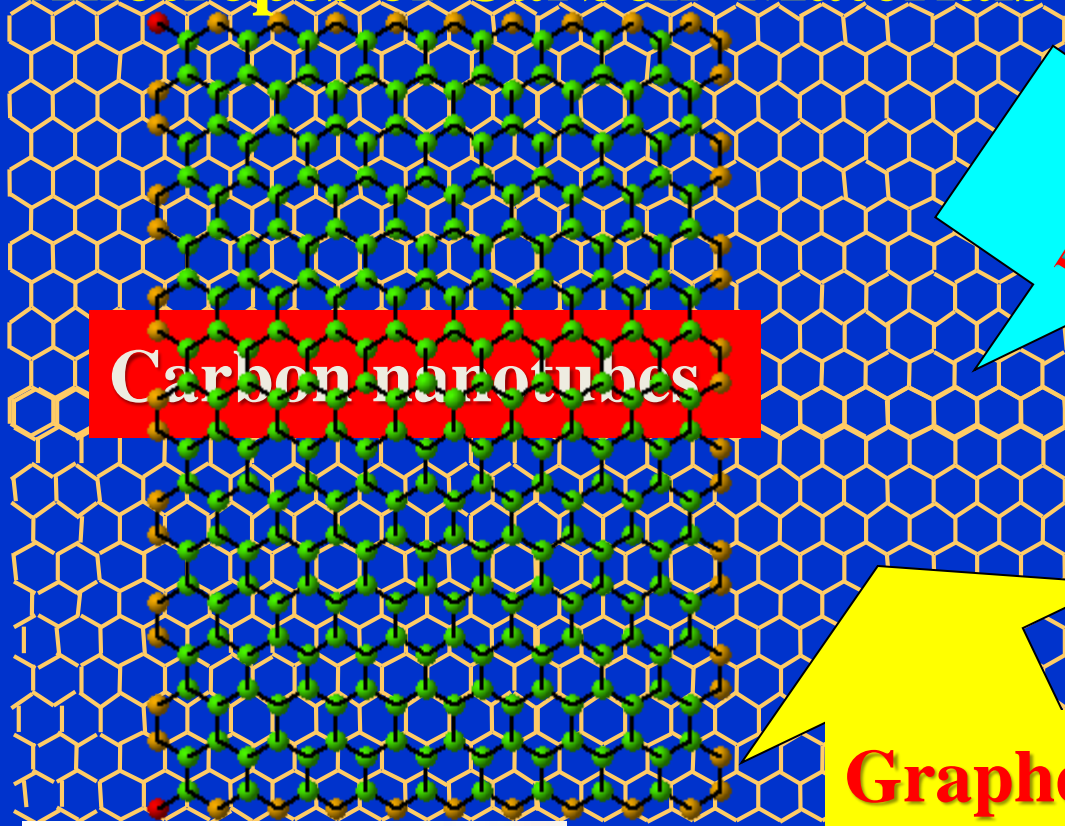
Graphite \Rightarrow Graphene



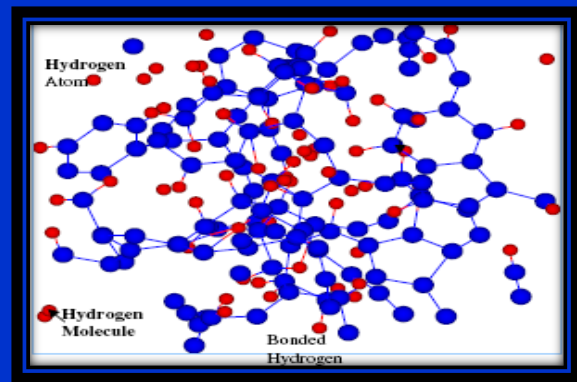
Graphite \Rightarrow Graphene Oxide



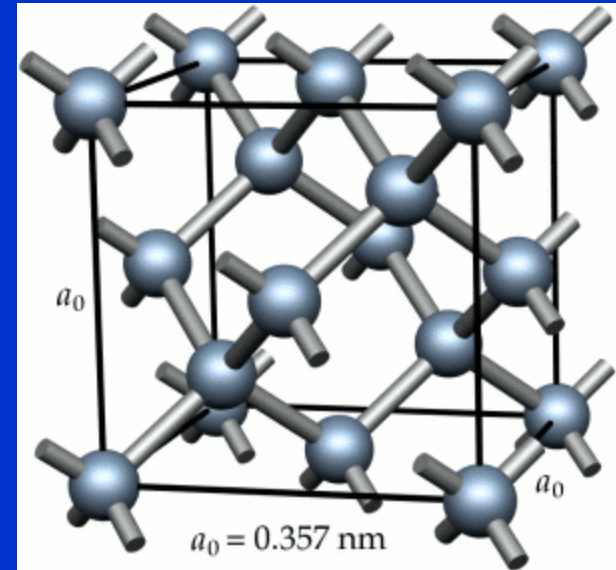
Allotropes of Carbon Materials



Graphite



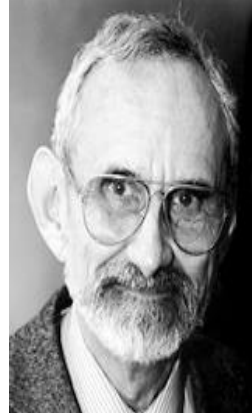
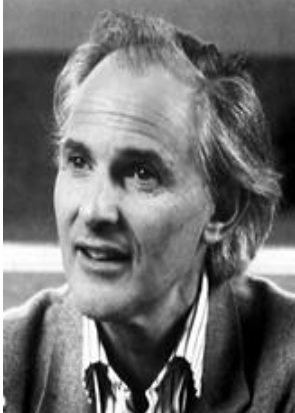
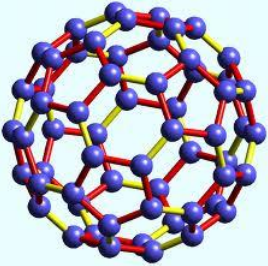
Amorphous carbon



Diamond

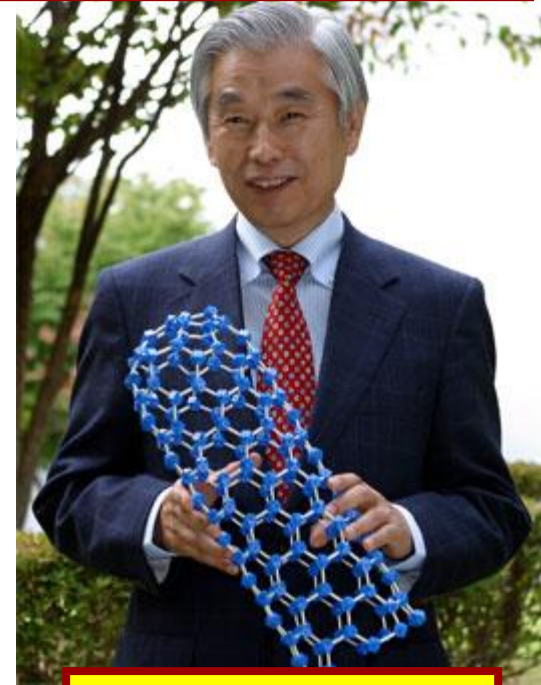
Six Giants of carbon materials

1985 – Fullerene (1996)



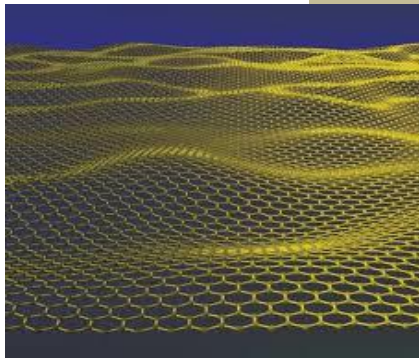
H. W. Kroto, R. E. Smalley and R. F. Curl

1990 – CNTs (1991)



Sumio Iijima

isolated
2004 – Graphene (2010)



Andre Geim

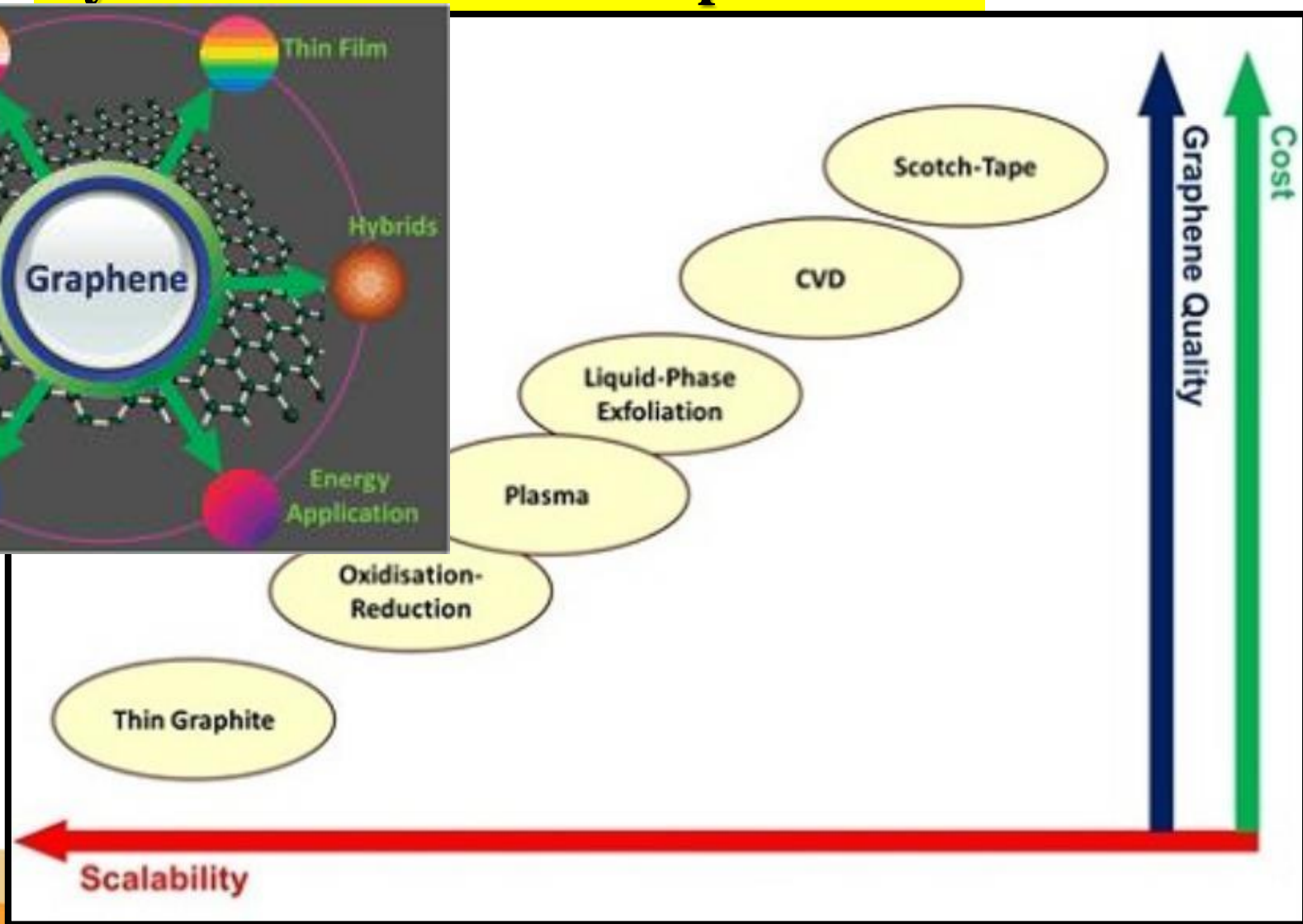
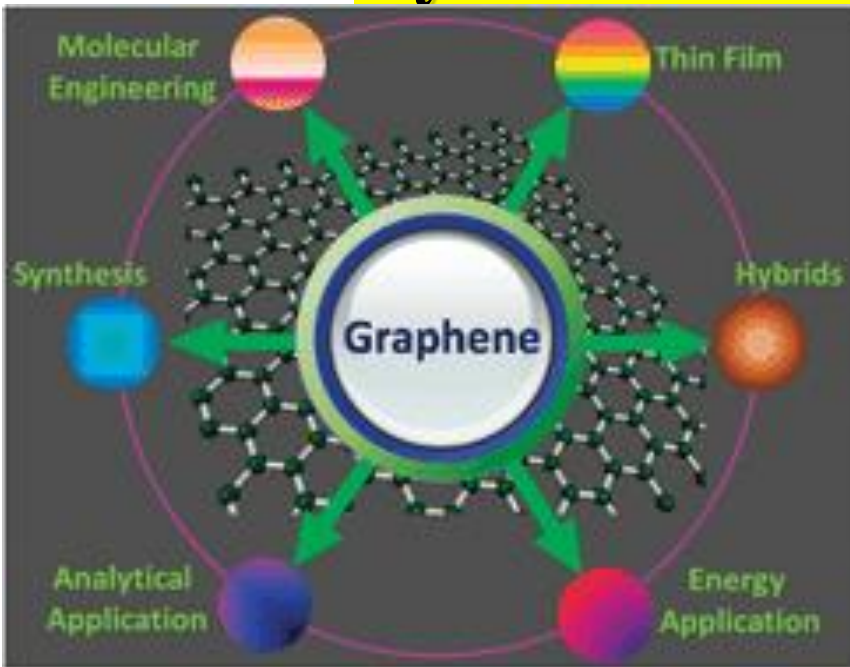
Konstantin Novoselov

Characteristics of Graphene

- **World's first 2D-Materials**
- **World's strongest material**
(100-300 times stronger than steel: 1 TPa)
- **World's lightest/ultra-light material**
(Density 4 times lower than copper)
- **World's thinnest/ultra-thin material**
(0.34 nm \cong One million times thinner than a human hair)
- **Smallest molecule**
- **High surface area of $\sim 2500\text{m}^2/\text{g}$**
- **World's incredibly flexible material**
(highly stretchable, transparent and impermeable)
- **World's superb transparent conducting material** (5-order times that of copper)
- **Able to filter harmful organic materials**
- **Superconductor**



Synthesis Process of Graphene



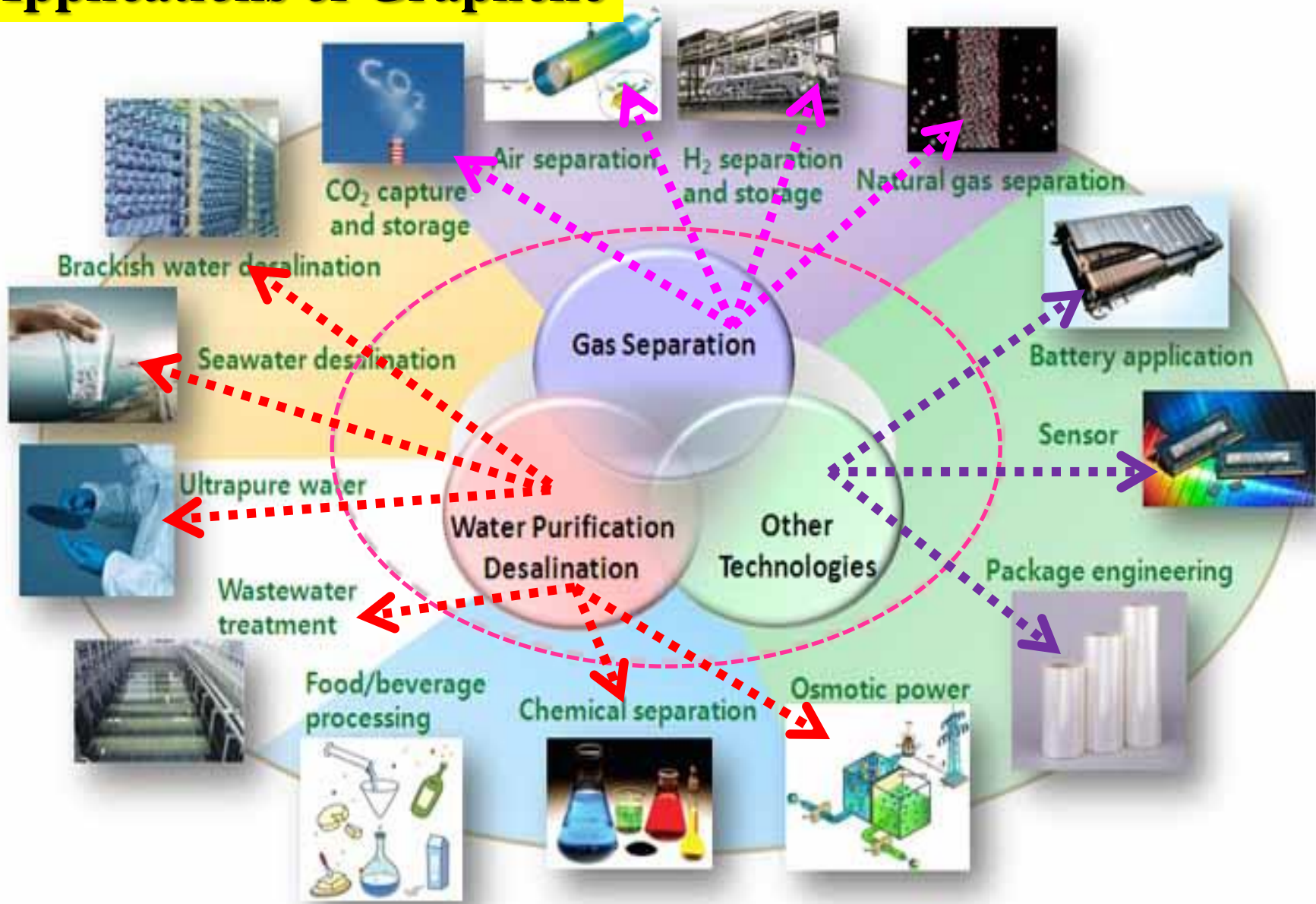
Define tomorrow.



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Applications of Graphene



Application areas of Graphene



Car interior



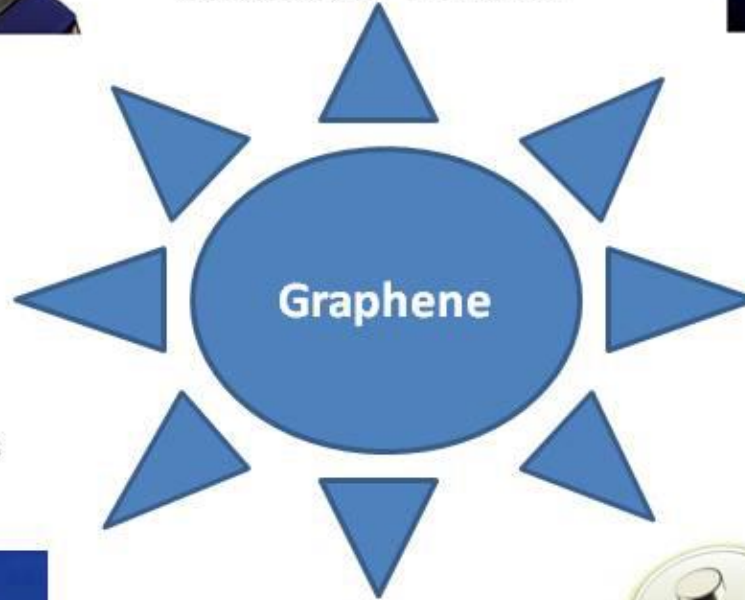
Construction materials



Interior and wings
of aeroplanes



Antimicrobial materials



Lubricants



Wings of wind
turbines



Flame retardants



Battery and supercapacitors

Application areas of Graphene



Sheet Resistance Ranges for Various Applications

500

400

300

200

100

10

1

($\Omega \text{ sq}^{-1}$)



Touch screen



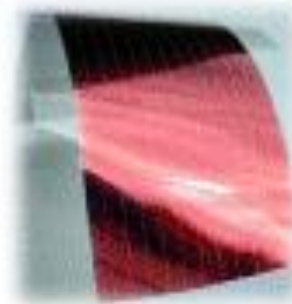
Smart window



Flexible LCD



Flexible OLED



Solar cell

Define tomorrow.



145 years
of lighting the way.

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and technology

Applications of Graphene based on Synthesis Process

Transparent
Electrodes Sensors



Touch Screens,
OLEDs,
Solar cells,
smart windows



Liquid phase
Exfoliation

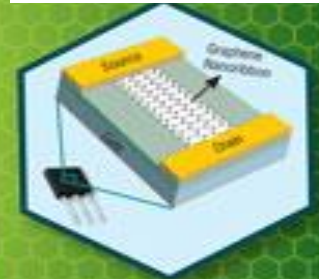
Conductive inks &
paints,
polymer filters,
Battery electrodes,
superconductor
sensors



CVD

Moderate Scalability
High Cost
High Quality
High Process
Temperature
(> 1000°C)

FETs and
interconnects
component



Chemical
Reduction of
GO

High Scalability
Low Cost
Low Purity
High Defect Density

Unzipping
of CNTs

Moderate Scalability
High Yield
High Quality
Potentially Low Cost

Graphene
Synthesis
Methods

Low Yield
High Cost
High Quality
High Process
Temperature (1500°C)
Very Expensive Substrate

Mechanical
Exfoliation



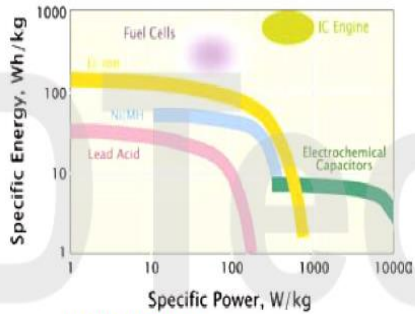
Research
Purpose

Epitaxial
Growth on SiC

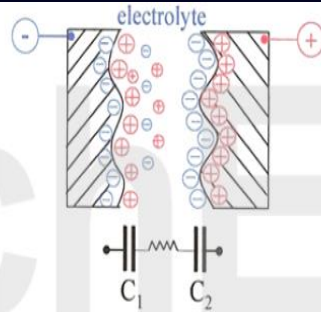


Transistors
circuits,
Interconnects
Memory
Semiconductor

Supercapacitors



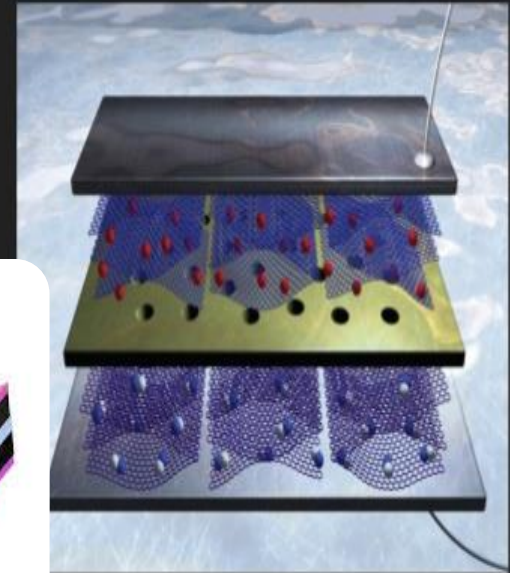
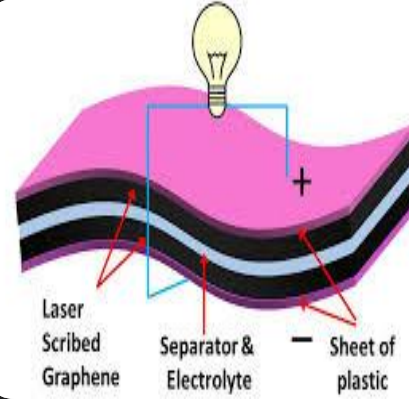
Advantages



Target Markets

Energy Storage Devices

✓ Due to the extremely high



- ✓ Fast power delivery but less energy density
- ✓ Wide temperature compliance range
- ✓ Longer lifetime than Li-ion batteries
- ✓ Simplicity

- ✓ Mobile phones
- ✓ Camera
- ✓ Vehicles (bus, lifters, cars, trucks)
- ✓ Back-up system
- ✓ Renewable energy

Supercapacitor Markets

ULTRA/SUPER CAPACITORS

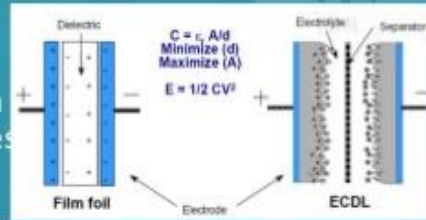
100 years old technology enhanced by modern materials based on polarization electrolytes, high surface area electrodes and extremely small charge separation

Graphene Advantages

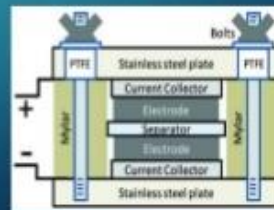
- * High surface area to weight ratio (2600 m² / g)
- * High conductivity
- * Measured specific capacitance 135 F/g

Uses

- * Electric vehicles
- * Backup powering
- * High power capability
- * Cell phones

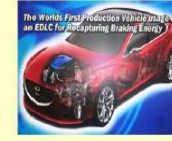


EDCL (Electro Chemical Double Layer) Capa



Super Capacitor Model

Rapid Charge up



Rapid Discharge



T-compliance



PHOTOVOLTAIC CELLS

Currently: silicon wafers, thin films

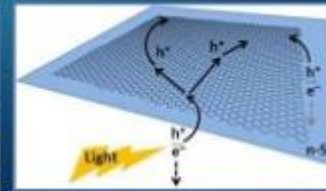
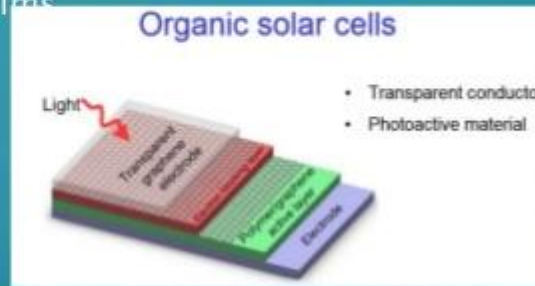
Graphene Advantages

- * Transparent conducting electrode
- * Robust, conductive, abundant
- * Cheaper than ITO
- * Enhanced light trapping
- * Efficient charge transport (1D)

A new design:

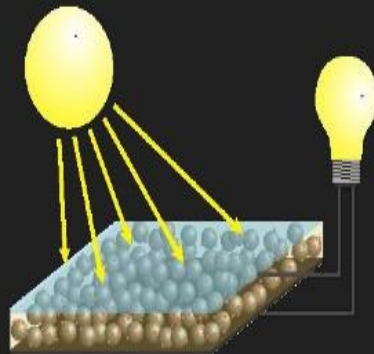
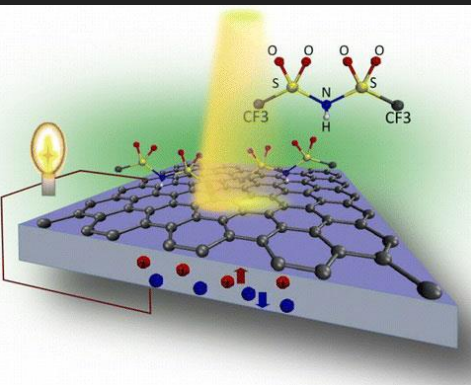
- * Layer of graphene (transparent cathode)
 - * Conductive polymer (maintains integrity)
 - * ZnO nanowire layer (electron transport)
 - * PbS quantum dots (hole transport)
 - * Au layer (anode)
- * 4.2% conversion efficiency (5.1% for ITO)
* Cheaper to produce

Organic solar cells



Solar cell / Flexible solar cell / Solar panel

Solar cells



MAJESTIC FUTURE

➤ Advancements in touch screens

It is practically transparent and a good conductor

**Transparent-Flexible
Touch Screen**

Electronics Engineering

- Will definitely replace silicon and germanium as device material.
- Conducting material on PCBs.
- Single molecule sensors
- Touchscreens
- Graphene transistor.
- Graphene integrated circuits.
- Graphene chips.

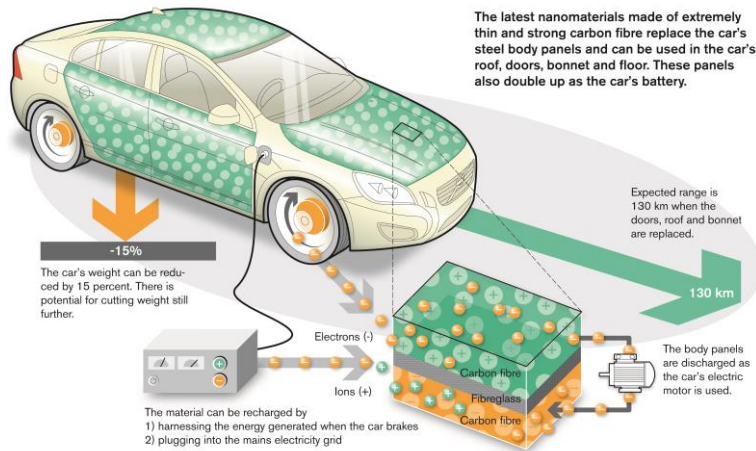


Mechanical engineering

- In Manufacturing process as Manufacturing material.
- As a composite material for machines ,cars.
- Defense.
- Airplanes, space shuttles , satellite.

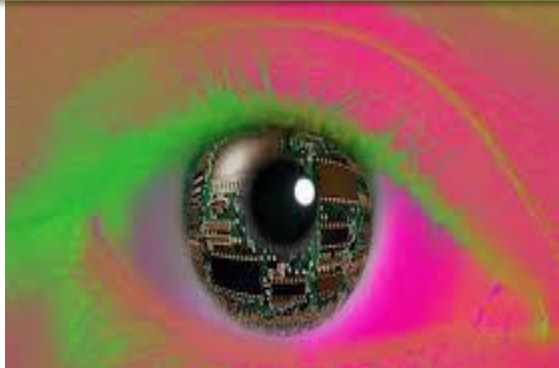


The car's body panels serve as a battery

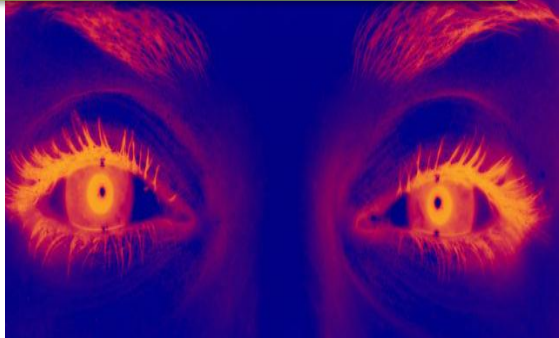


BIOLOGICAL ENGINEERING

Superhero Vision Coming in Graphene Contact Lenses



New sensor could make night vision

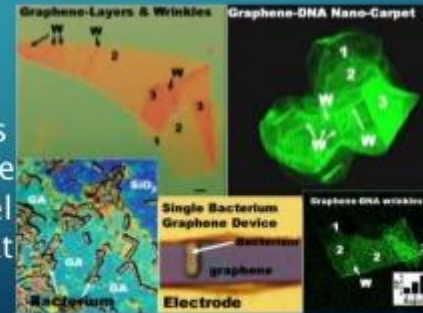


Graphene Advantages

- * Large Surface Area
- * High Electrical Conductivity
- * Thinness and Strength

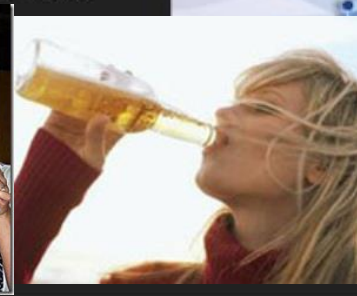
Uses

- * Efficient Bioelectric Sensory Devices
- * Able to monitor Glucose level, chole DNA sequencing, Haemoglobin level
- * Toxic Graphene as anti-cancer treat
- * Process of Tissue Regeneration

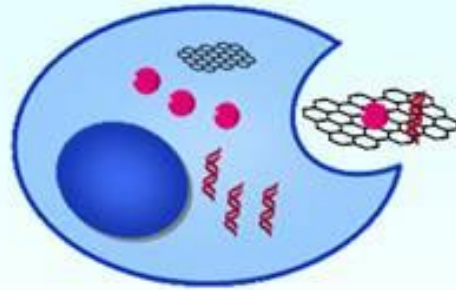


Anti-Bacterial

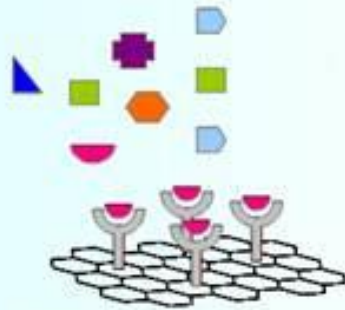
- In 2010, the Chinese Academy of Sciences has found that sheets of graphene oxide are highly effective at killing bacteria such



Graphene in Bio-applications



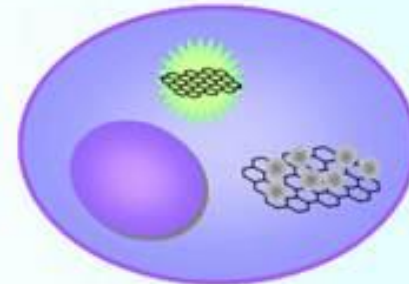
Drug/Gene Delivery



Biosensing



Graphene



Bioimaging

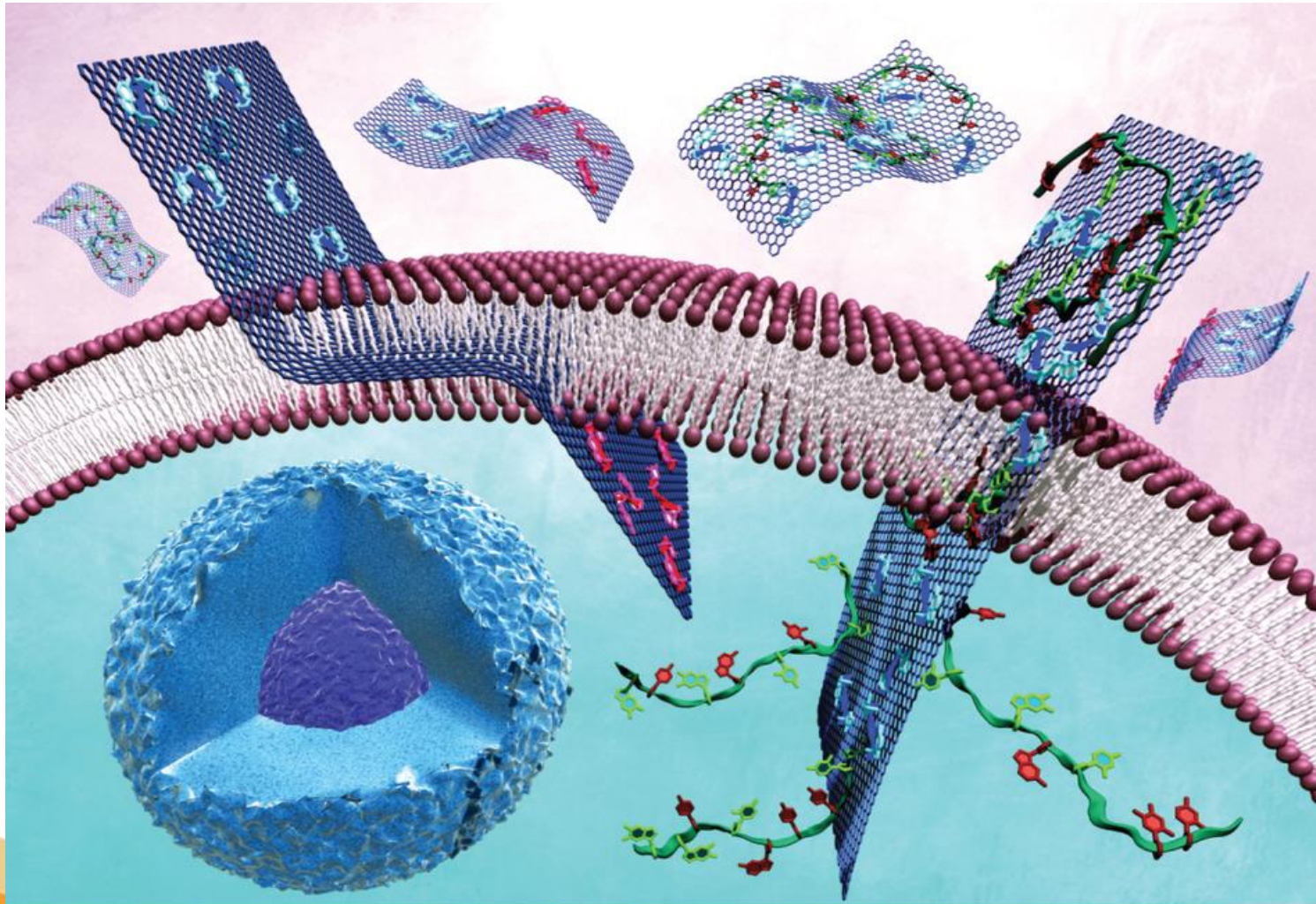


Cancer therapy



Scaffold

Graphene in drug delivery into the interior of a cell



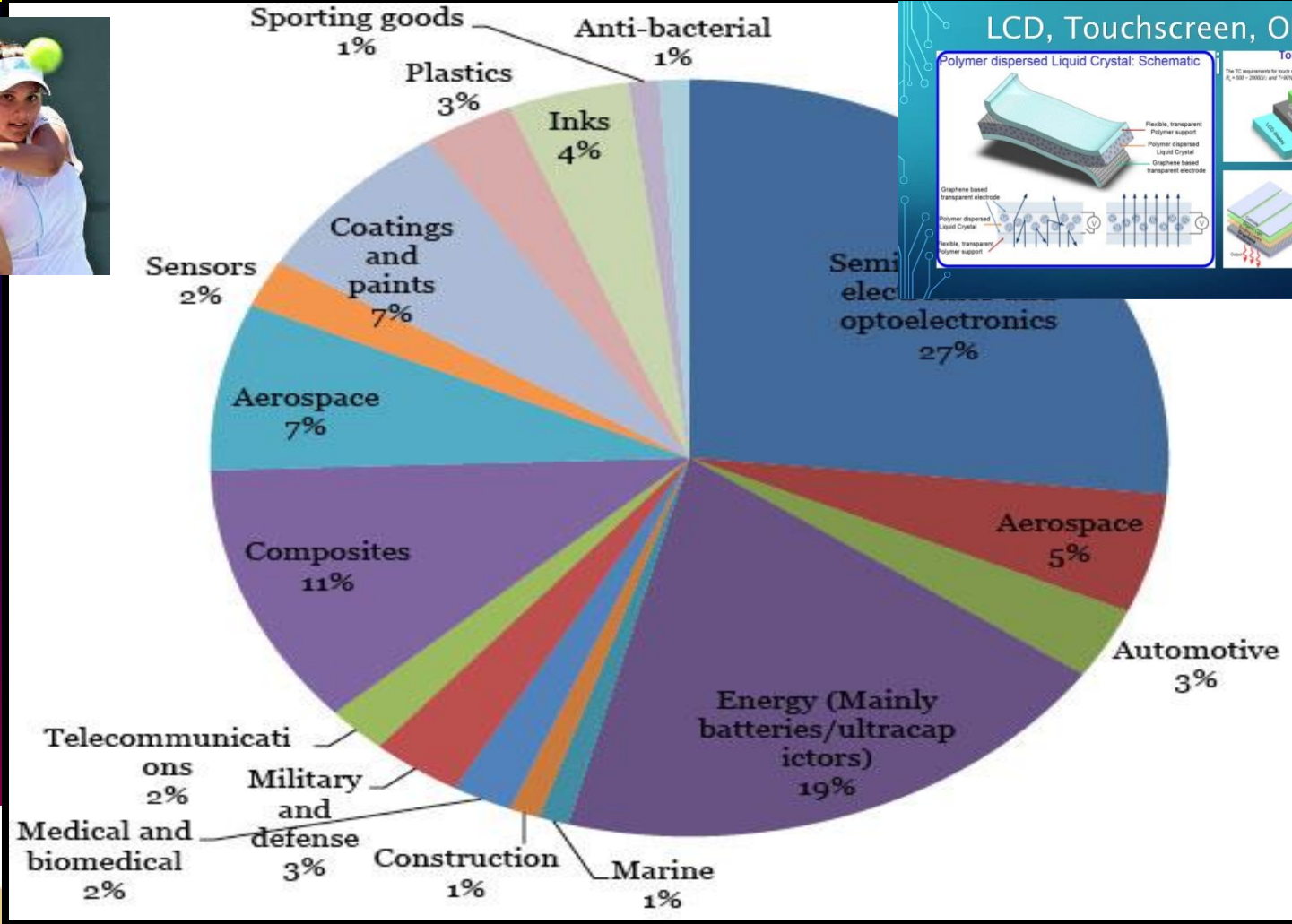
Define tomorrow.



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Applications chart for Graphene companies



LCD, Touchscreen, OLEDs

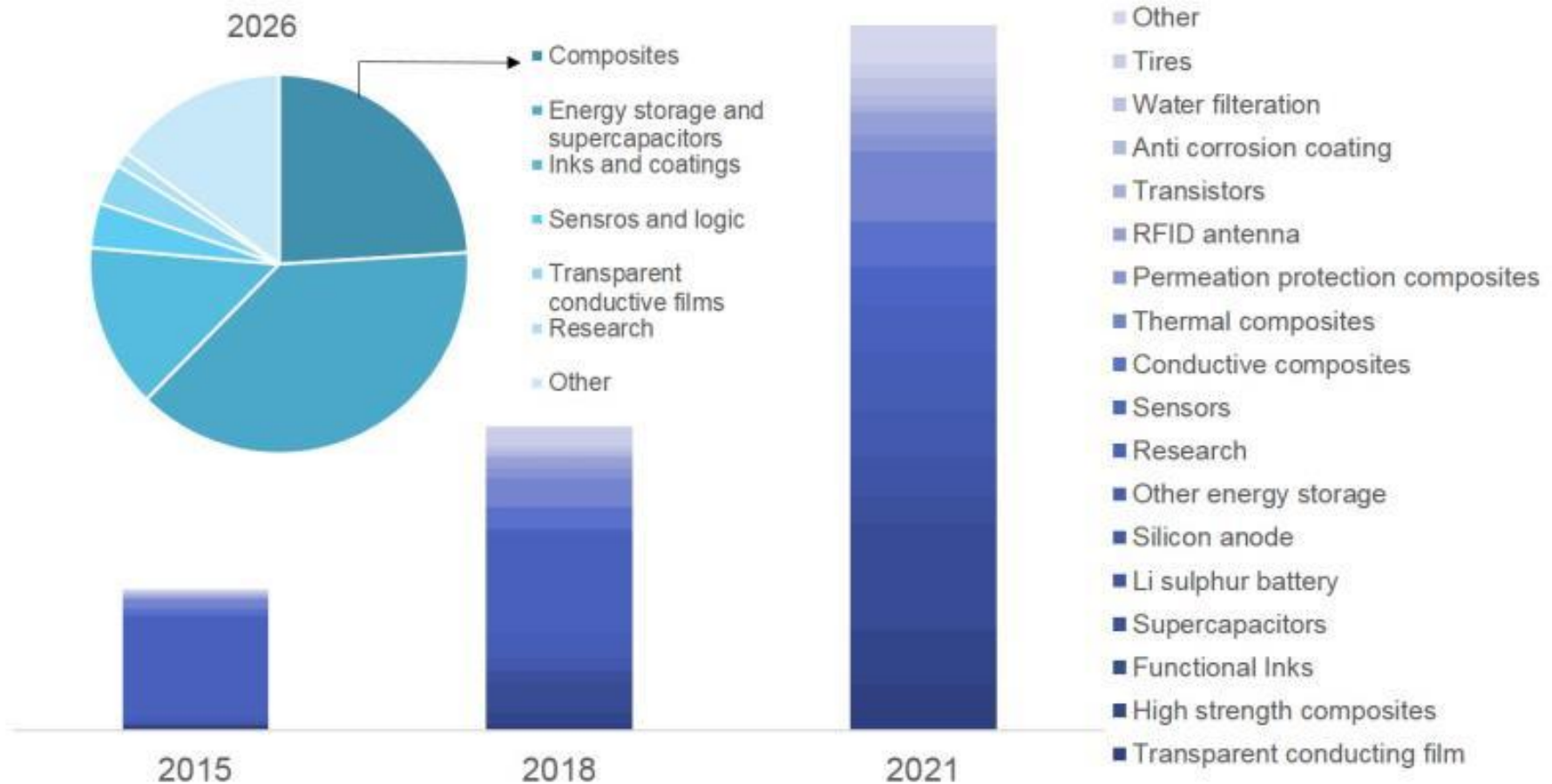
Polymer dispersed Liquid Crystal: Schematic

Labels: Flexible, transparent Polymer support; Polymer dispersed Liquid Crystal; Graphene based transparent electrode.

Touch screens

Labels: Graphene based transparent electrode; Polymer dispersed Liquid Crystal; Flexible, transparent Polymer support.

A roadmap for graphene



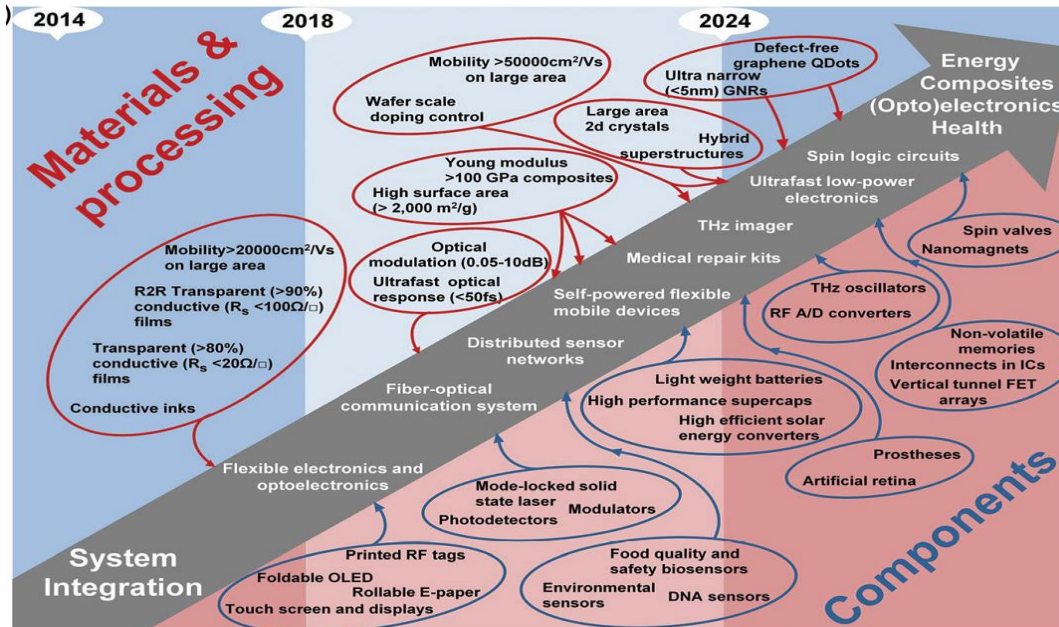
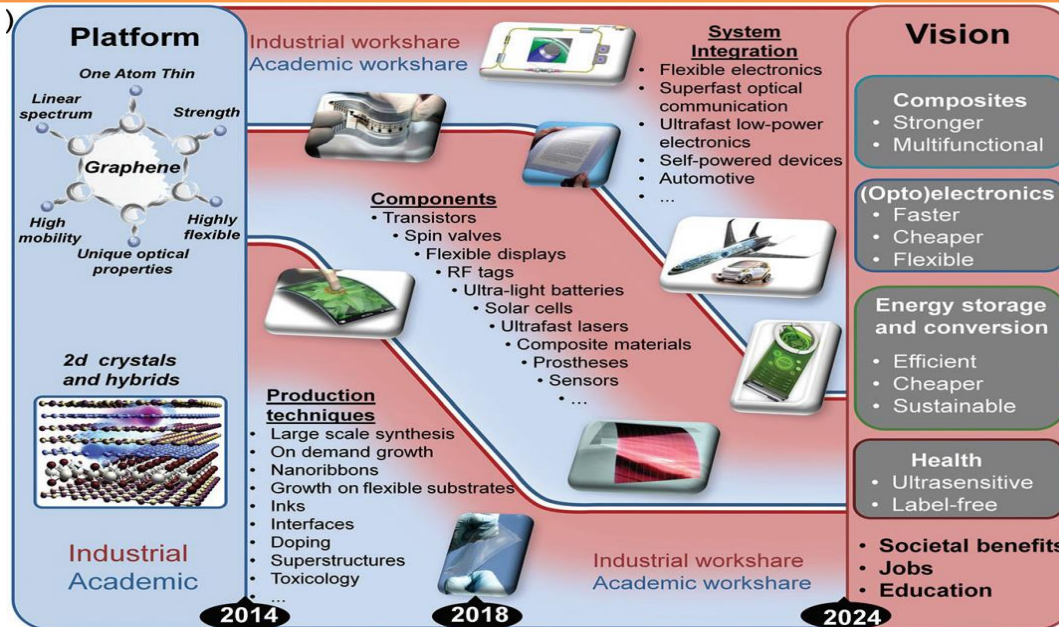
Define tomorrow.



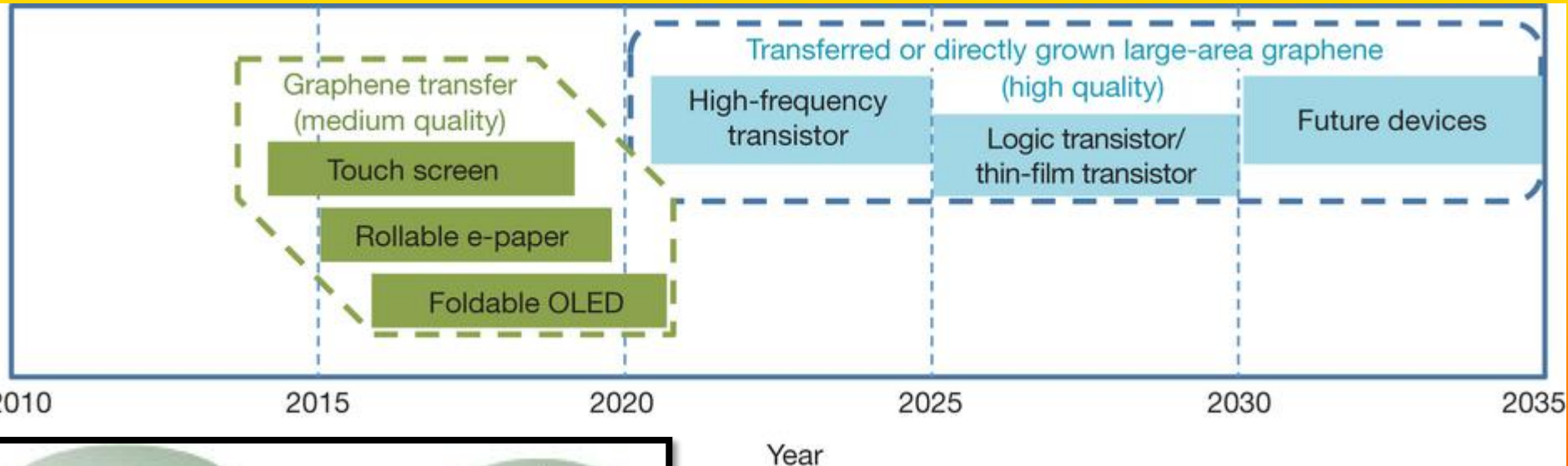
UNISA



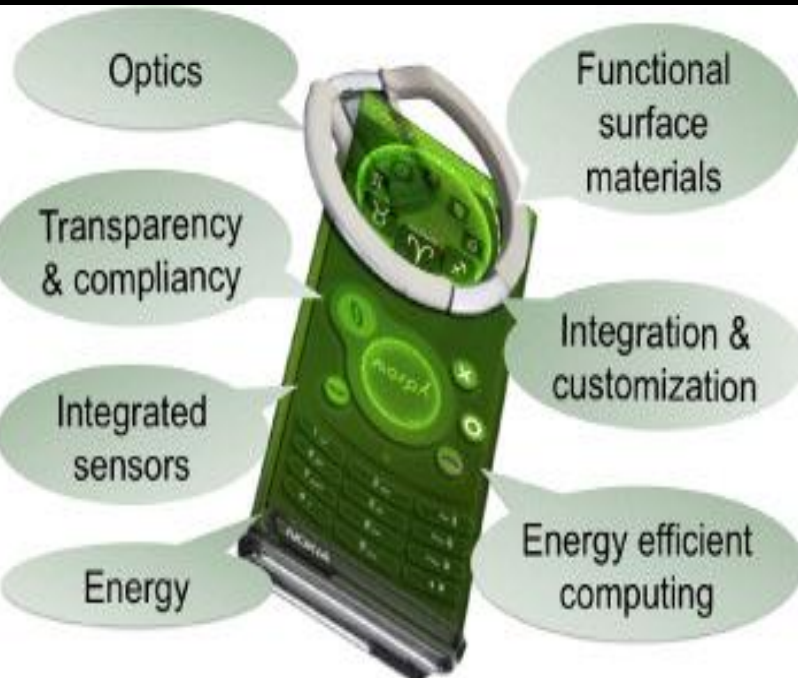
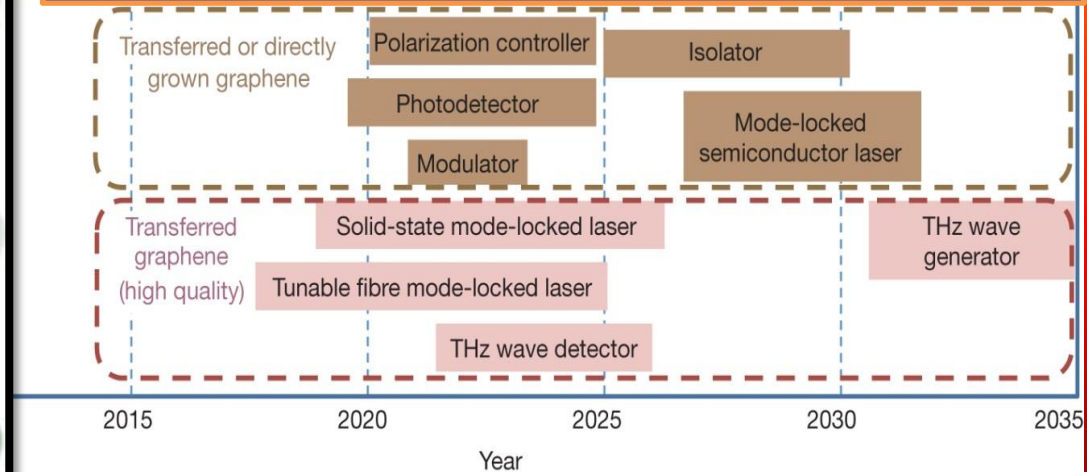
Vision – Future Applications of Graphene



Vision-Graphene-based display and electronic devices



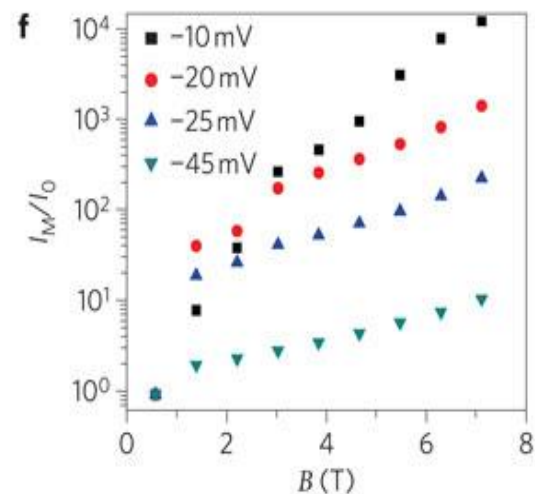
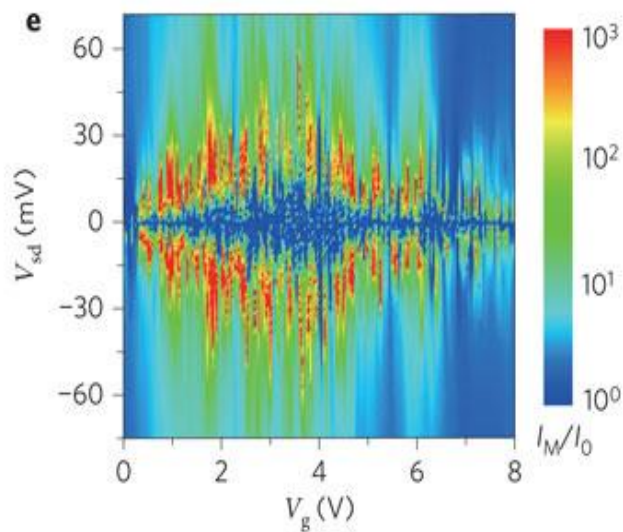
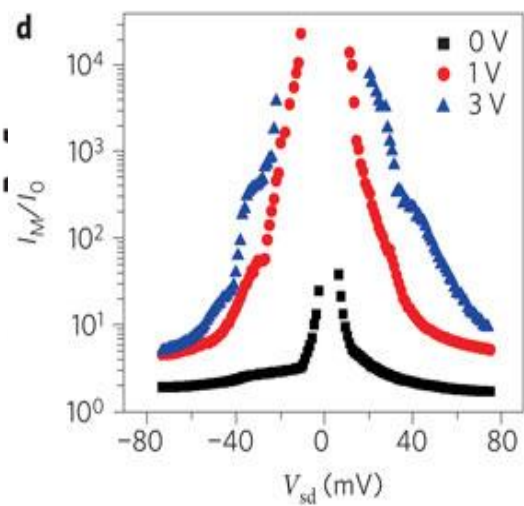
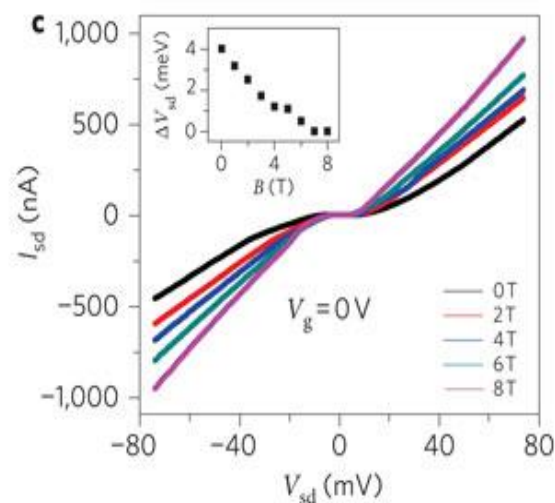
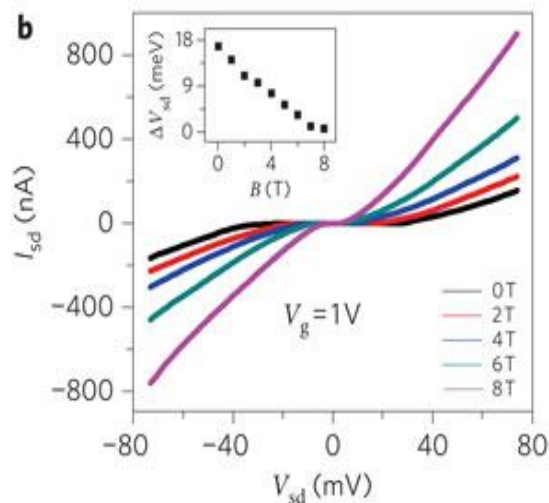
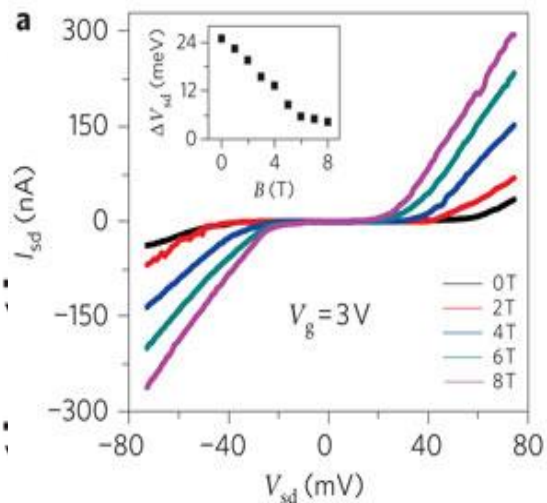
Vision-Graphene-based photonics devices



(Prototype Graphene Phone:within 3 years)



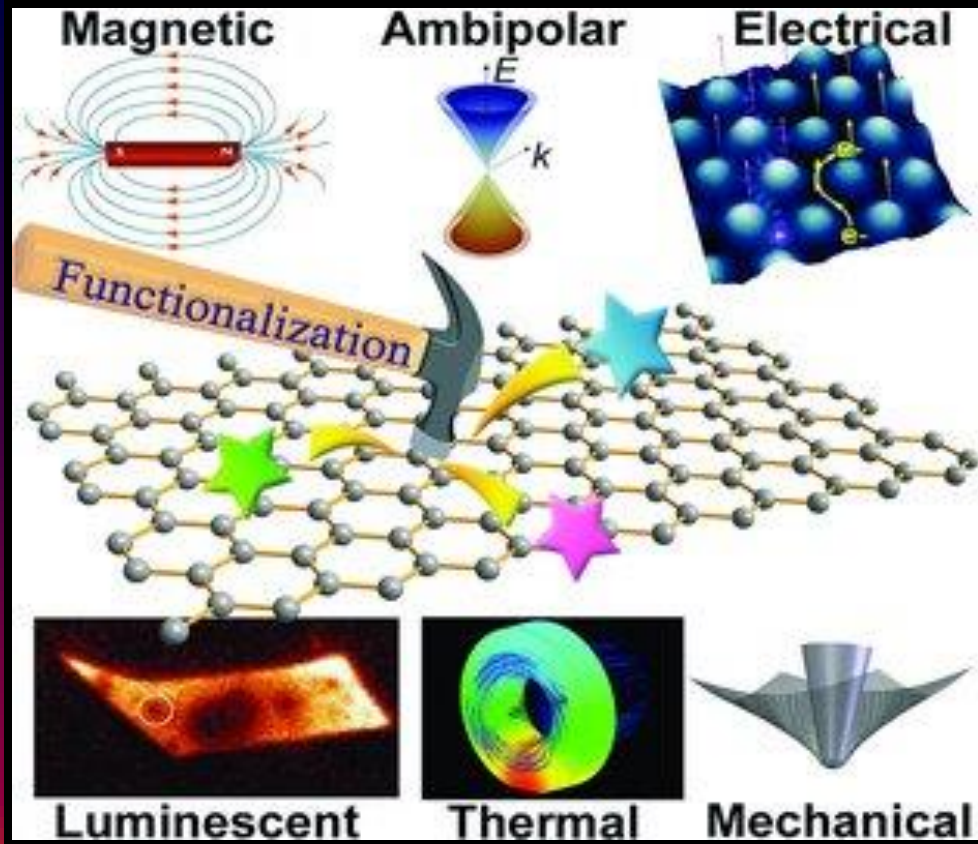
Magnetic properties



Magnetic devices using Graphene

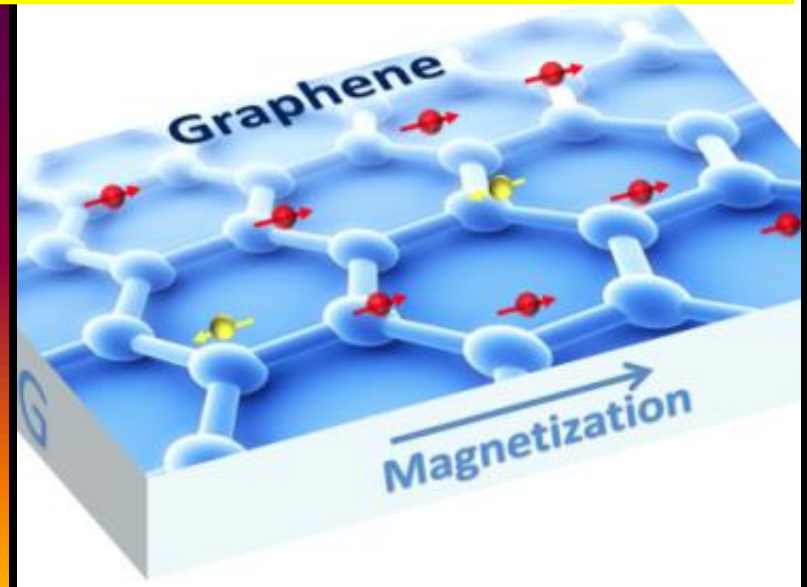


Functionalization of Graphene by Hydrogen, Silicon and Nitrogen, Iron, Gold, Cobalt-----



Why Carbon / Graphene??

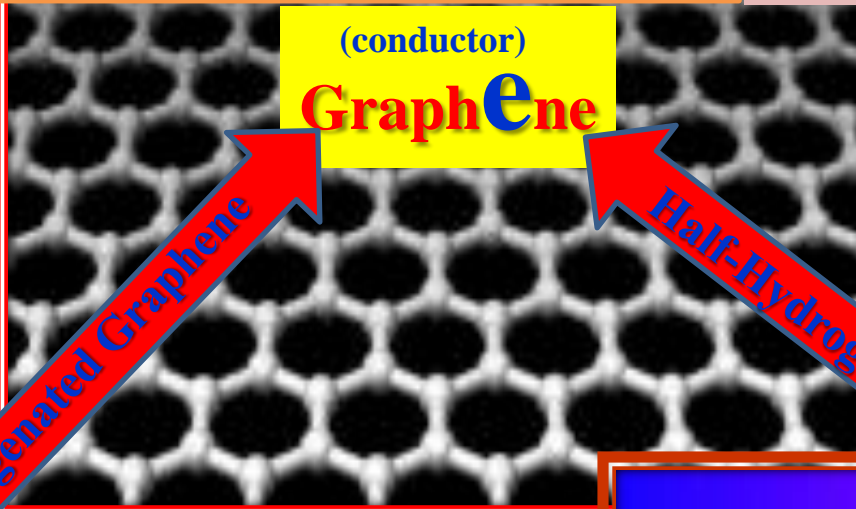
Carbon-based materials are very promising for spintronic applications due to their weak spin-orbit coupling and potentially providing a long spin life time



Graphene-Graphone-Graphane

Ferromagnetism of Graphone by Zhou et al. Nano Letters 2009, 9/11, 3867

Graphene: 2D crystal made of carbon atoms arranged in a honeycomb lattice



Graphone: The semi-hydrogenation of graphene (hydrogen atoms are the white dots) makes the material ferromagnetic

Fully Hydrogenated Graphene

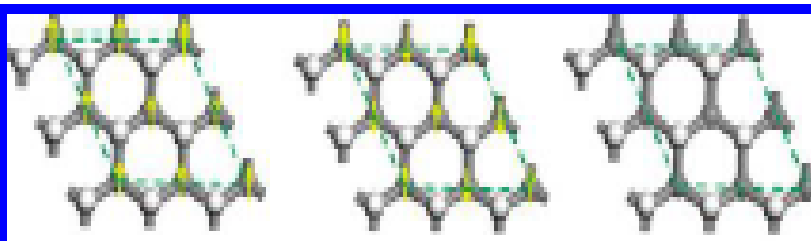
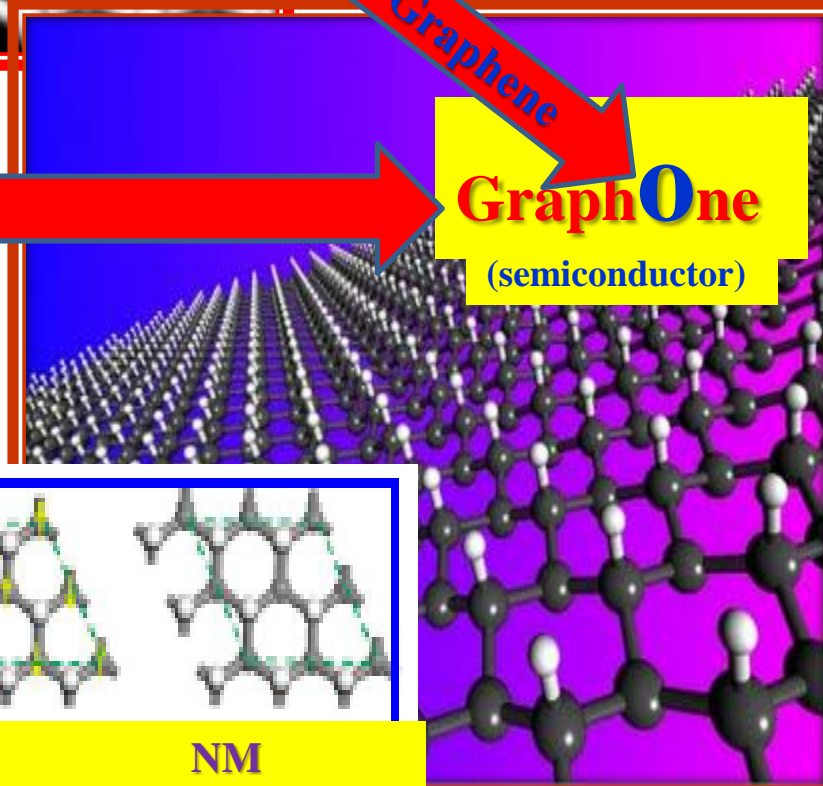
Half-Hydrogenated Graphene

Conversion $sp^2 \rightarrow sp^3$

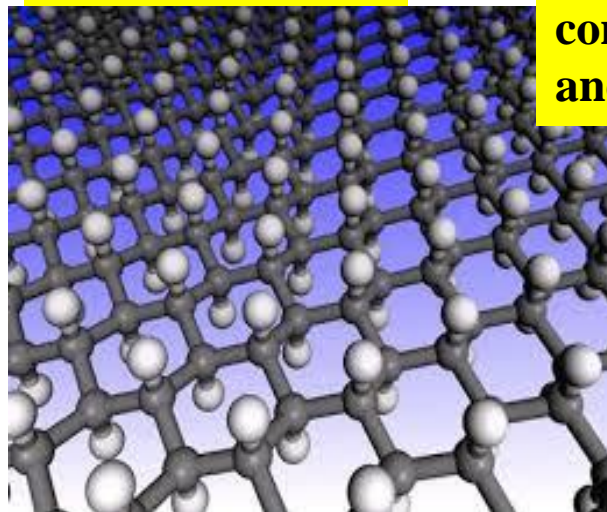
(Insulator)
Graphane

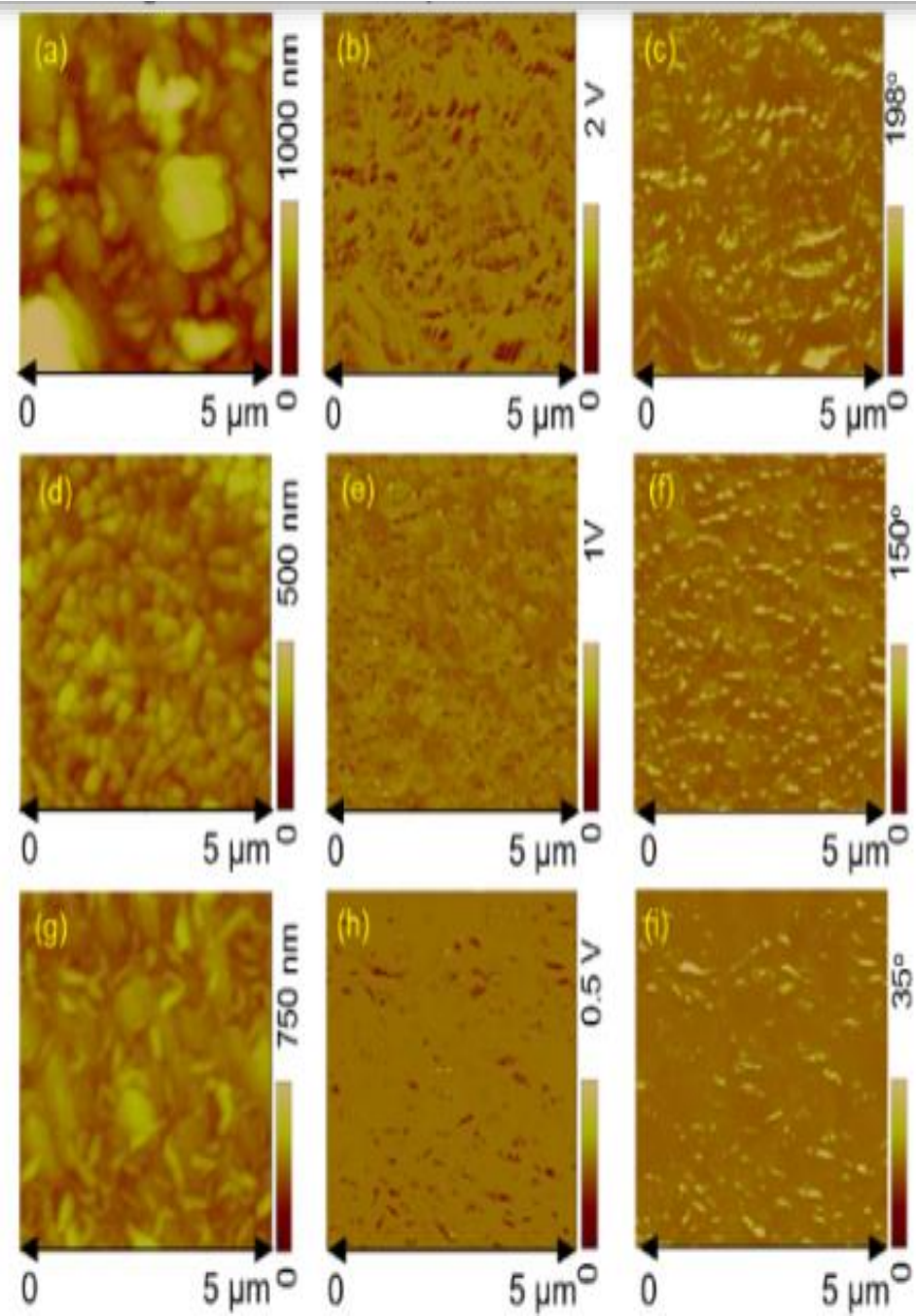
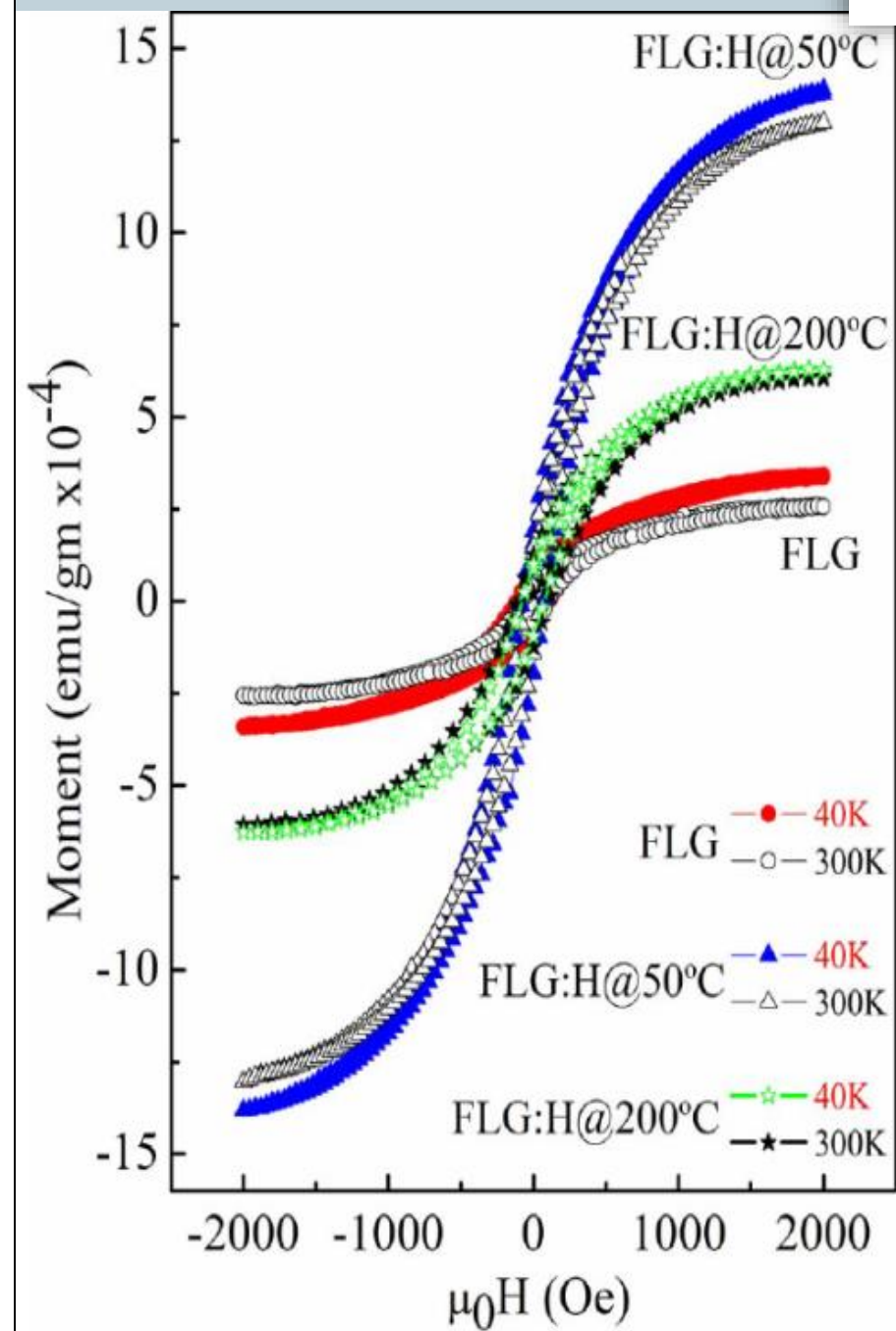
GraphOne
(semiconductor)

by removing conduction π -bands and opening band gaps

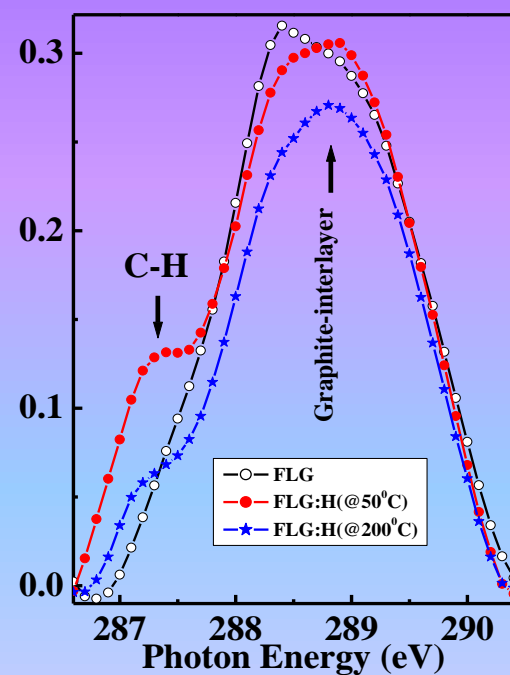
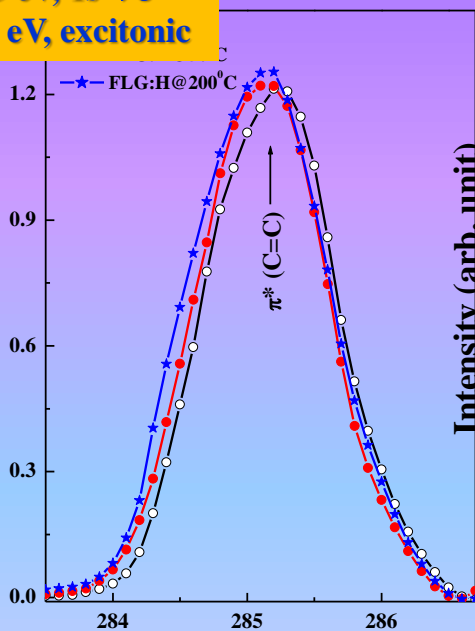
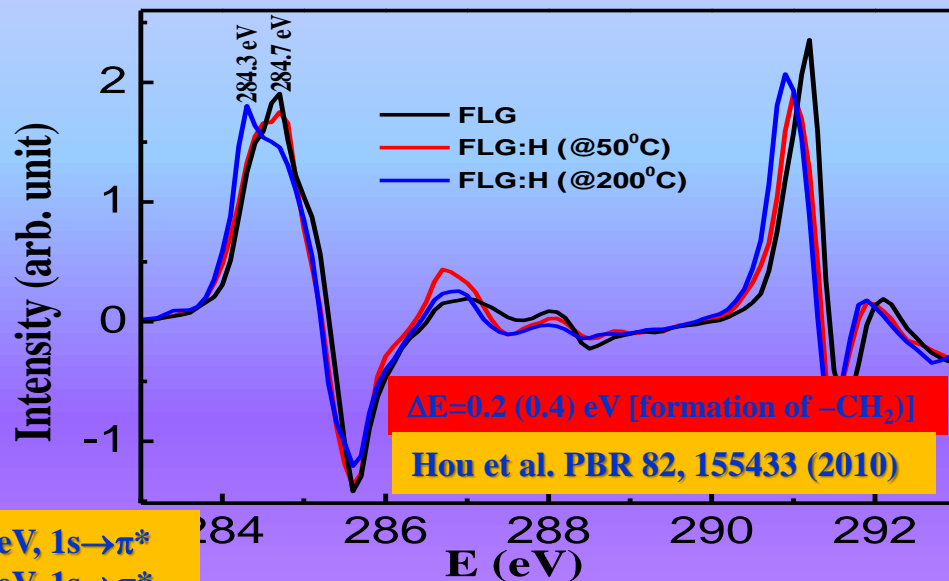
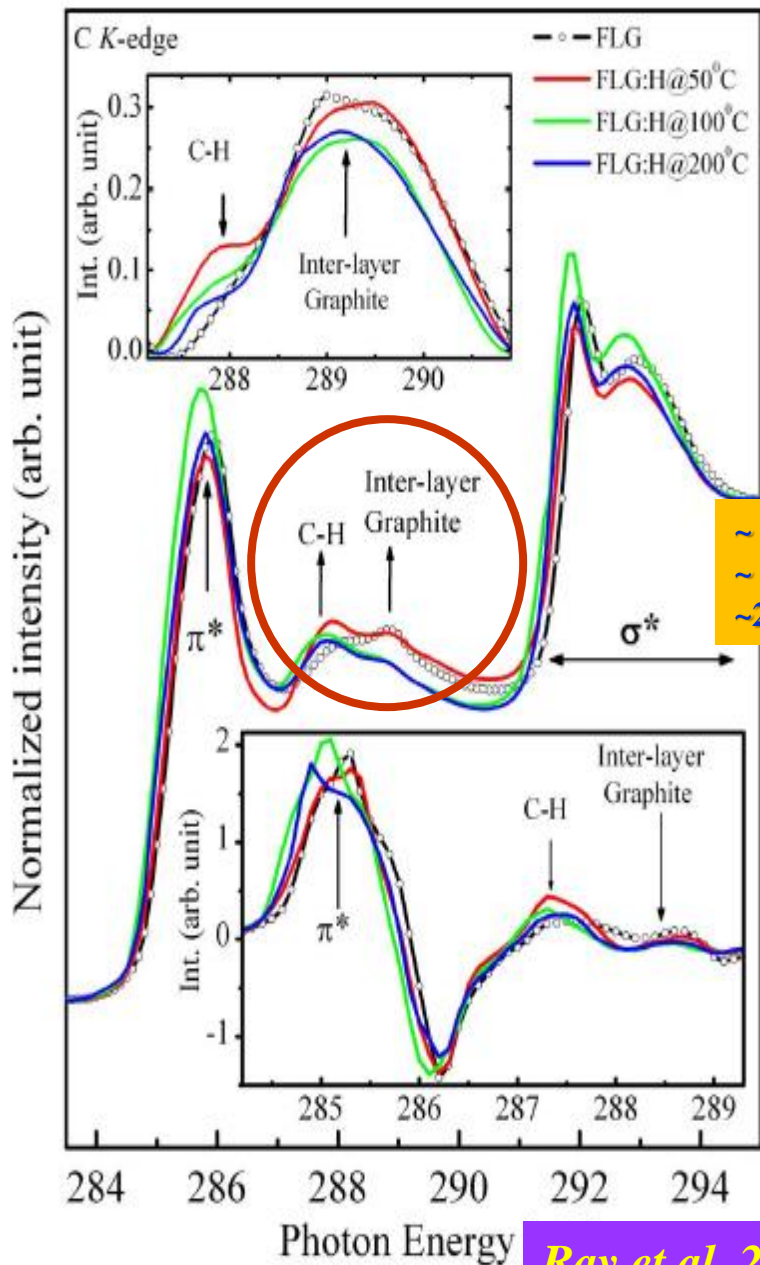


FM $m=4\mu_B, E=0;$ AF $m=0\mu_B, E=0.15;$ NM $m=0\mu_B, E=0.49$





C K-edge XANES of Semi-hydrogenated Graphene Sheet

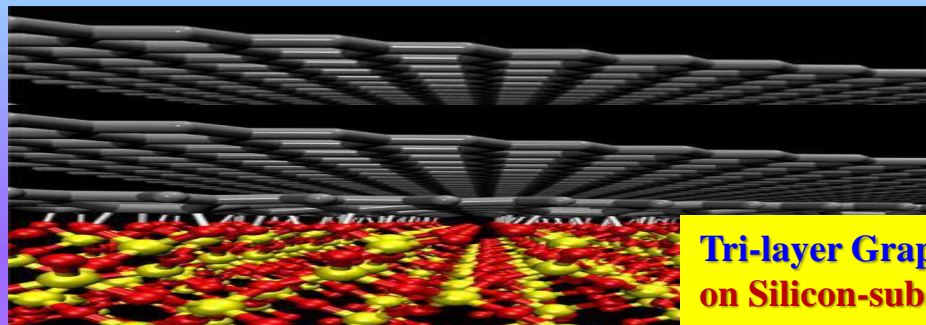
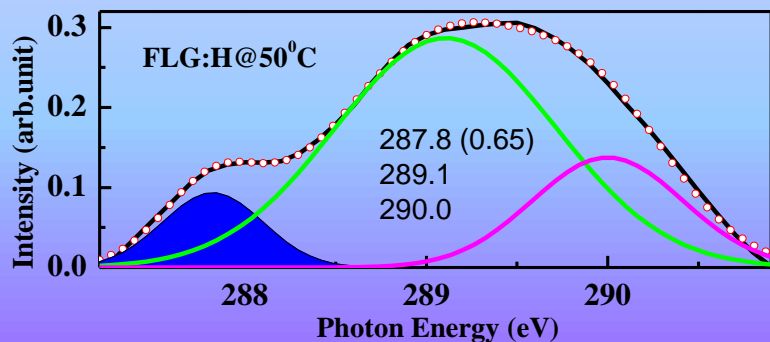


Ray et al. 2014 (Sci Reports 4, 3862)

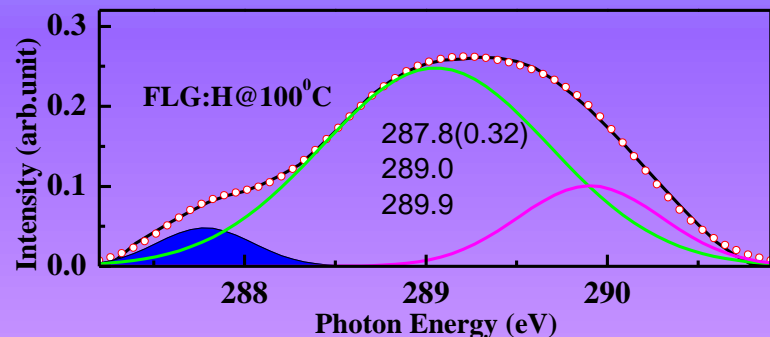
Determination of C-H content from C K-edge XANES spectra

CH ratio

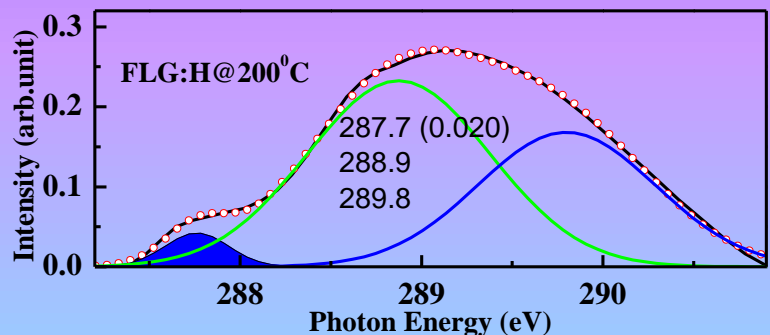
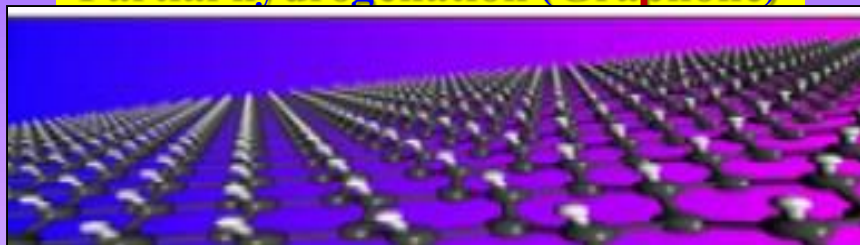
$0.65 : 0.32 : 0.19 \approx 6 : 3 : 2$



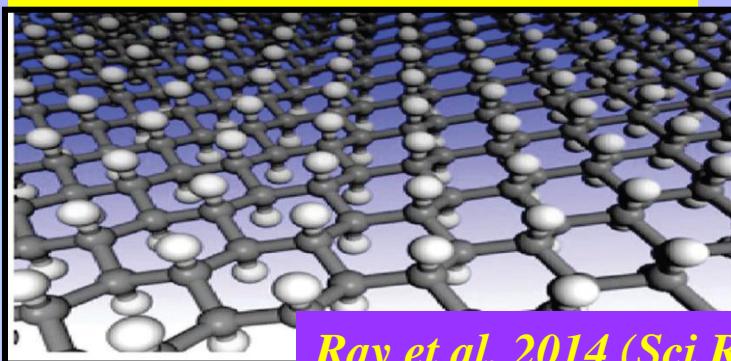
Tri-layer Graphene on Silicon-substrate



Partial hydrogenation (Graphone)

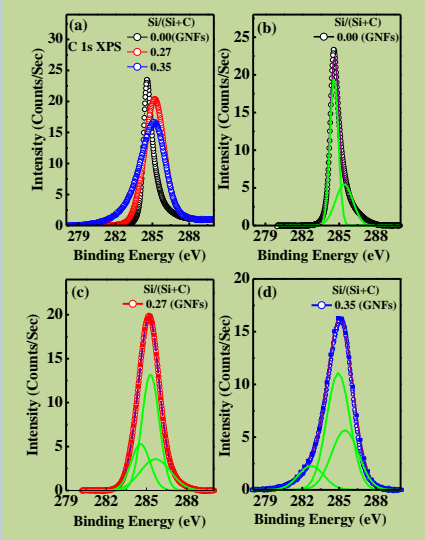
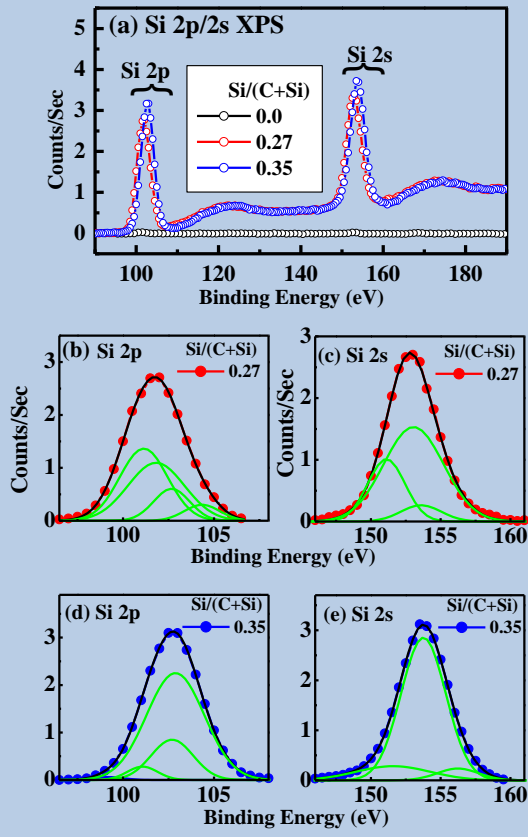
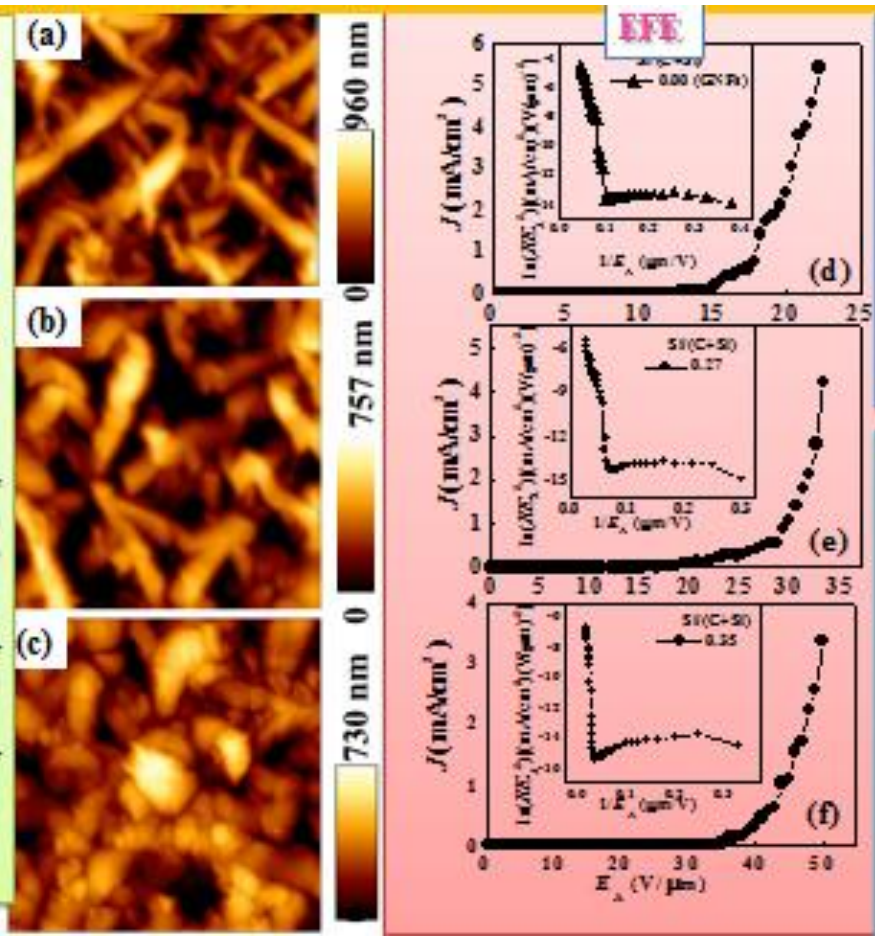


Full hydrogenation (Graphane)



	C-H
FLG:H@50°C	0.65 (287.8)
FLG:H@100°C	0.32 (287.8)
FLG:H@200°C	0.19 (287.7)

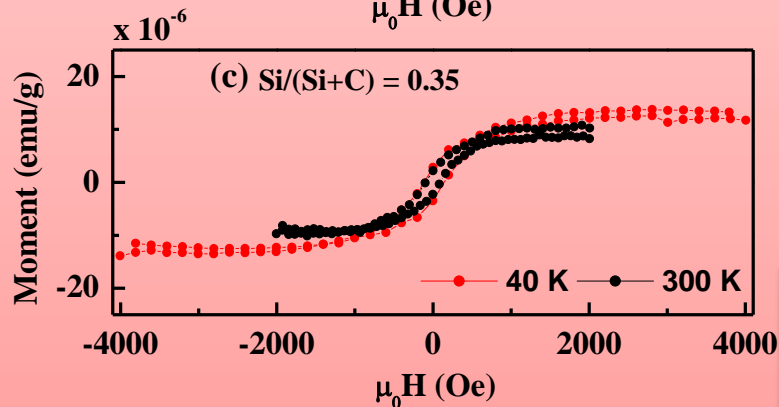
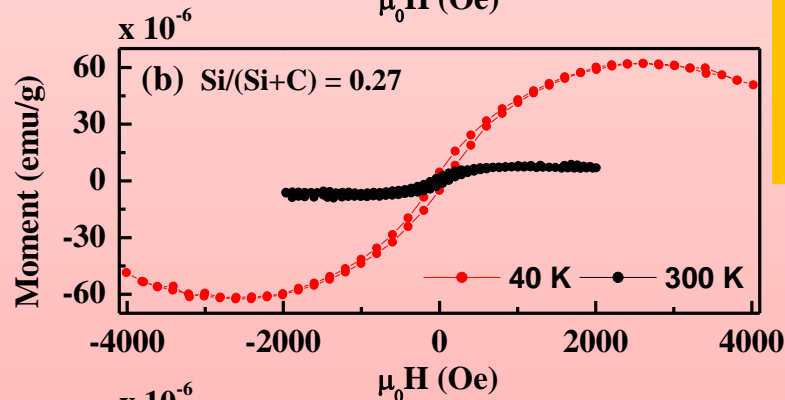
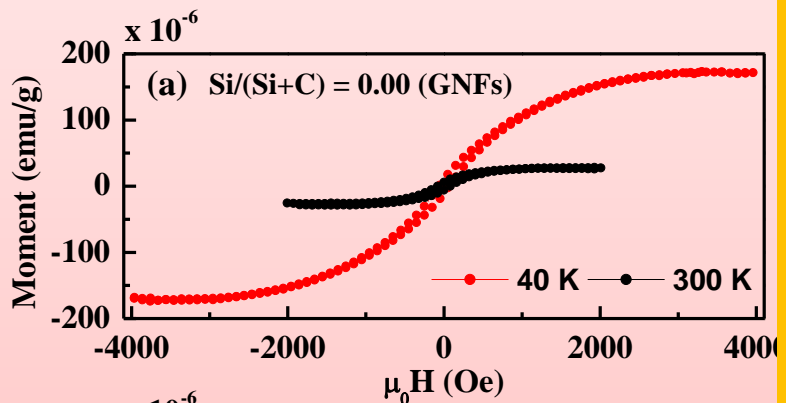
Silicon-Functionalized Graphene Nanoflakes: Electronic Structure



GNFs
 ~284.6 eV Carbon sp^2 -hybridization
 ⇒ ~286.1 eV assigned as C-O bonds

GNFs:Si
 ⇒ ~285.4 eV carbon sp^2 -hybridization is shifted to the higher energy and became broader for GNFs:Si having Si/(Si+C) is 0.35 indicating the formation of Carbon sp^3 -hybridization
 ⇒ ~285.0 eV is “defect peaks”
 ⇒ ~285.6 eV defined as Si-C-O bonding peak
 ⇒ ~286.8 eV is the C-O bonds

Silicon-Functionalized Graphene: Ferro-Magnetic Behaviour



⇒ M_S values are reduced with increasing coercivity (H_c) as the Si-content is increased, implying the loss of magnetization with silicon content.

⇒ With increase of Si-content, non-defect Si-C tetrahedral bonding along with SiO are formed that make sp^3 -rich structured GNFs materials that are responsible for reducing the magnetisation of GNFs.

⇒ Formation of Si-O-C due to air exposure known as a defect structure that is responsible for the reducing of ferromagnetic behaviours

Saturation magnetization (M_S), Coercivity (H_c) and Remanence (M_R) of GNFs and GNFs:Si.

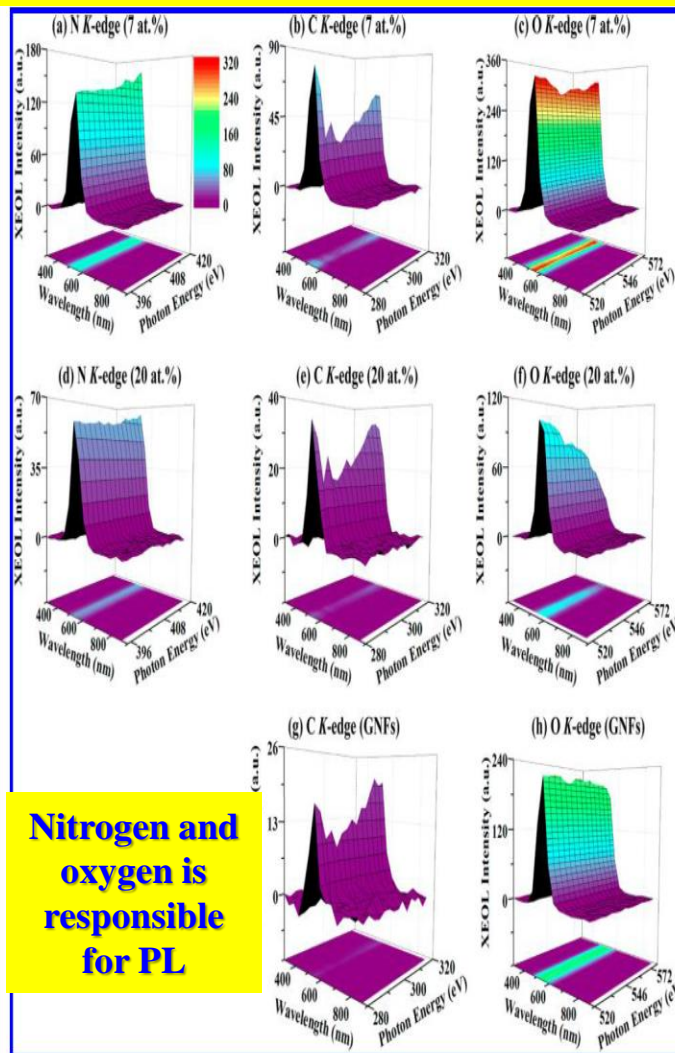
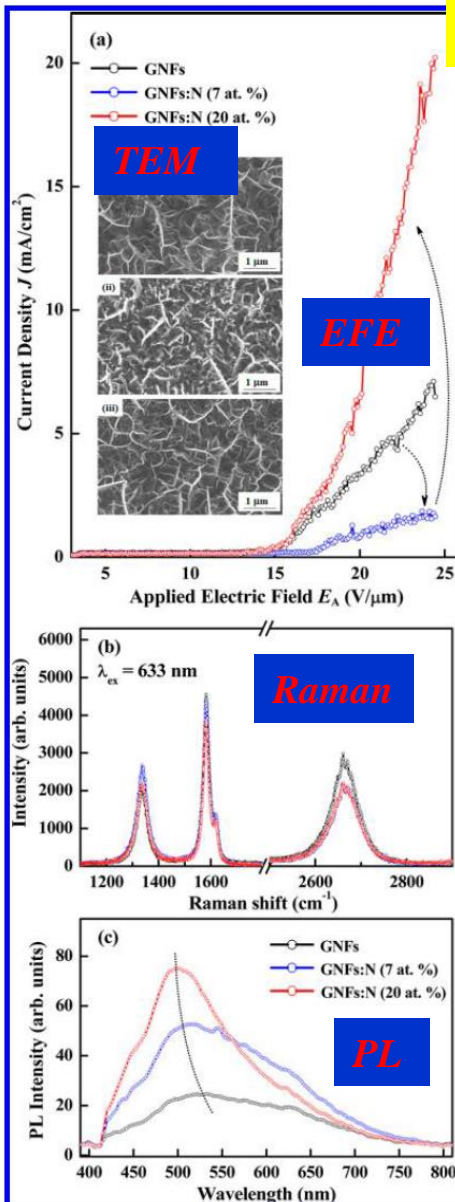
Sample	$\frac{\text{Si}}{(\text{Si} + \text{C})}$ Ratio	M_S ($\times 10^{-6}$ emu/g)		H_c (Oe)		M_R ($\times 10^{-6}$ emu/g)	
		40K	300K	40K	300K	40K	300K
GNFs	0.00	172.53	27.19	66.00	81.27	9.38	5.83
GNFs:Si	0.27	62.05	6.92	90.00	108.00	4.62	2.25
GNFs:Si	0.35	13.00	12.00	149.00	101.00	2.85	2.20

Ferromagnetic materials with high coercivity are called magnetically hard materials, and are used to make permanent magnets. Materials with low coercivity are said to be magnetically soft and are used in transformer and inductor cores, ring heads, microwave devices, and magnetic shielding.

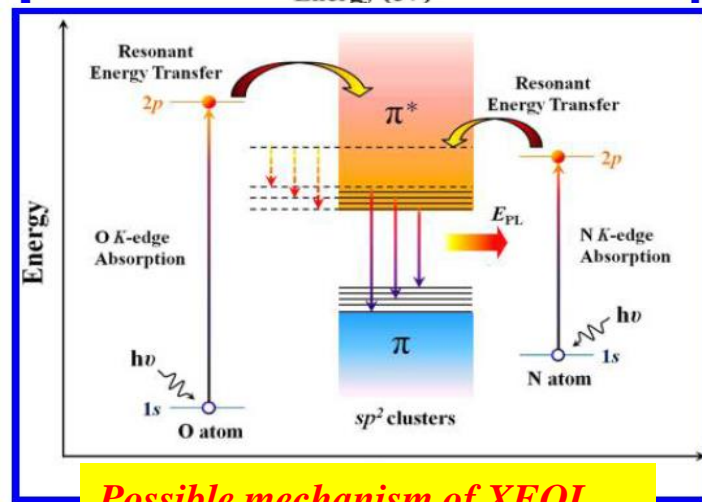
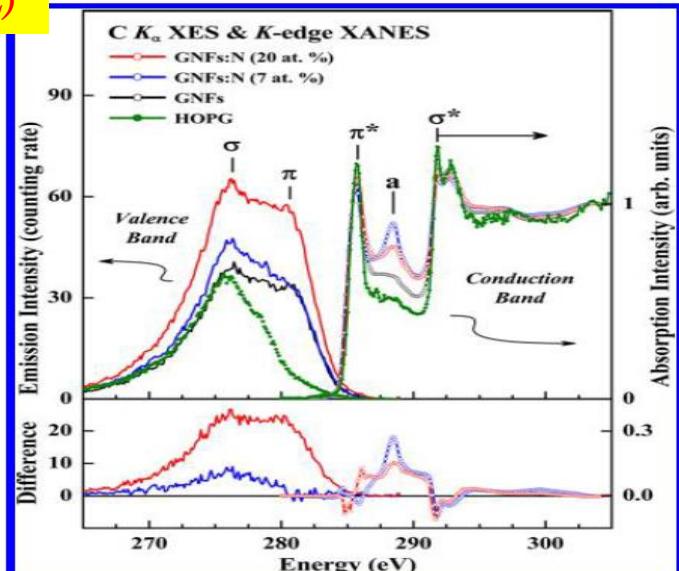
Nitrogen-Functionalized Graphene : Tunable PL and Electronic Structure, Magnetic Behaviors

$C K_{\alpha}$ XES & K -edge XANES

X-ray-excited optical Luminescence (XEOL)



Nitrogen and oxygen is responsible for PL



Possible mechanism of XEOL

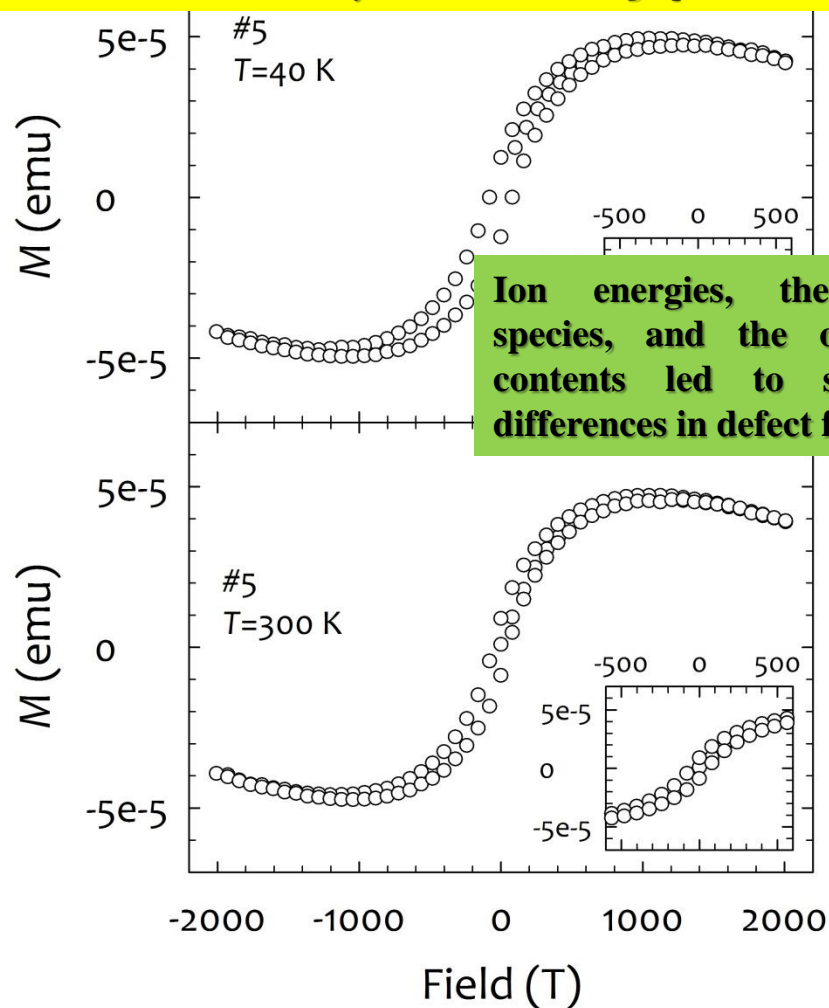
Chiou and Ray et al. 2012, 116. 16251-16258

THE JOURNAL OF PHYSICAL CHEMISTRY C

Nitrogen Functionalized Graphene: Ferro-Magnetic Behaviour

ECR-Plasma

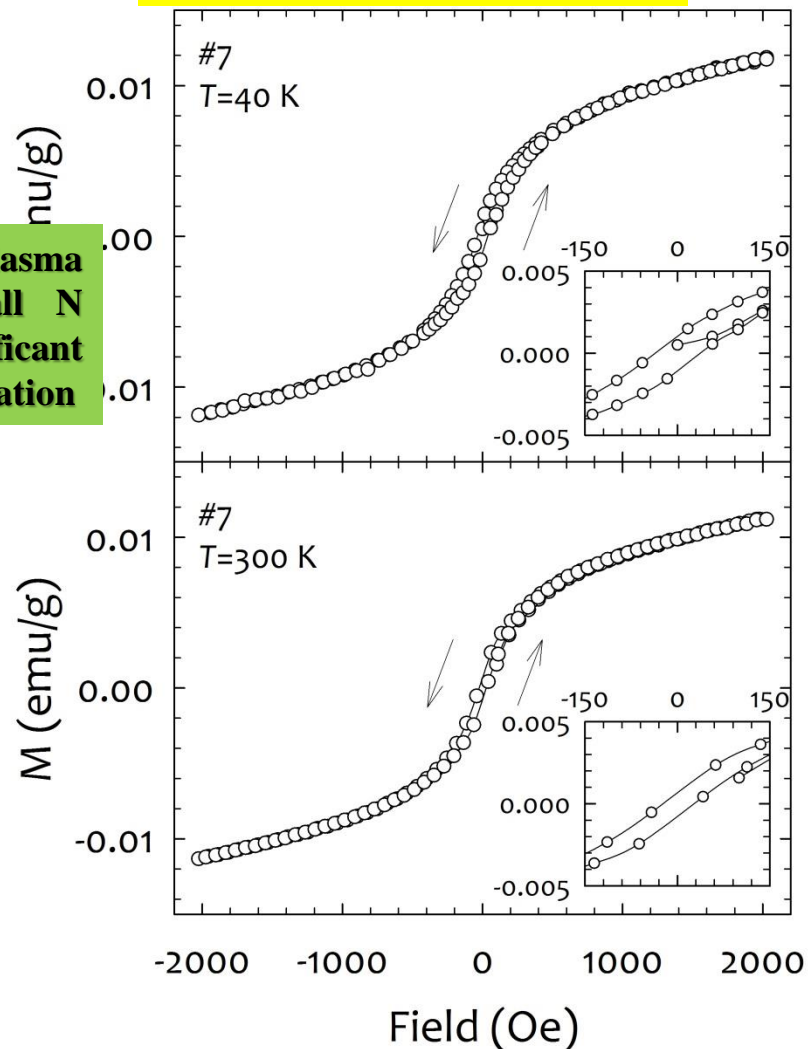
Substitutional and vacancy-like defects in the graphene lattice



Ion energies, the plasma species, and the overall N contents led to significant differences in defect formation

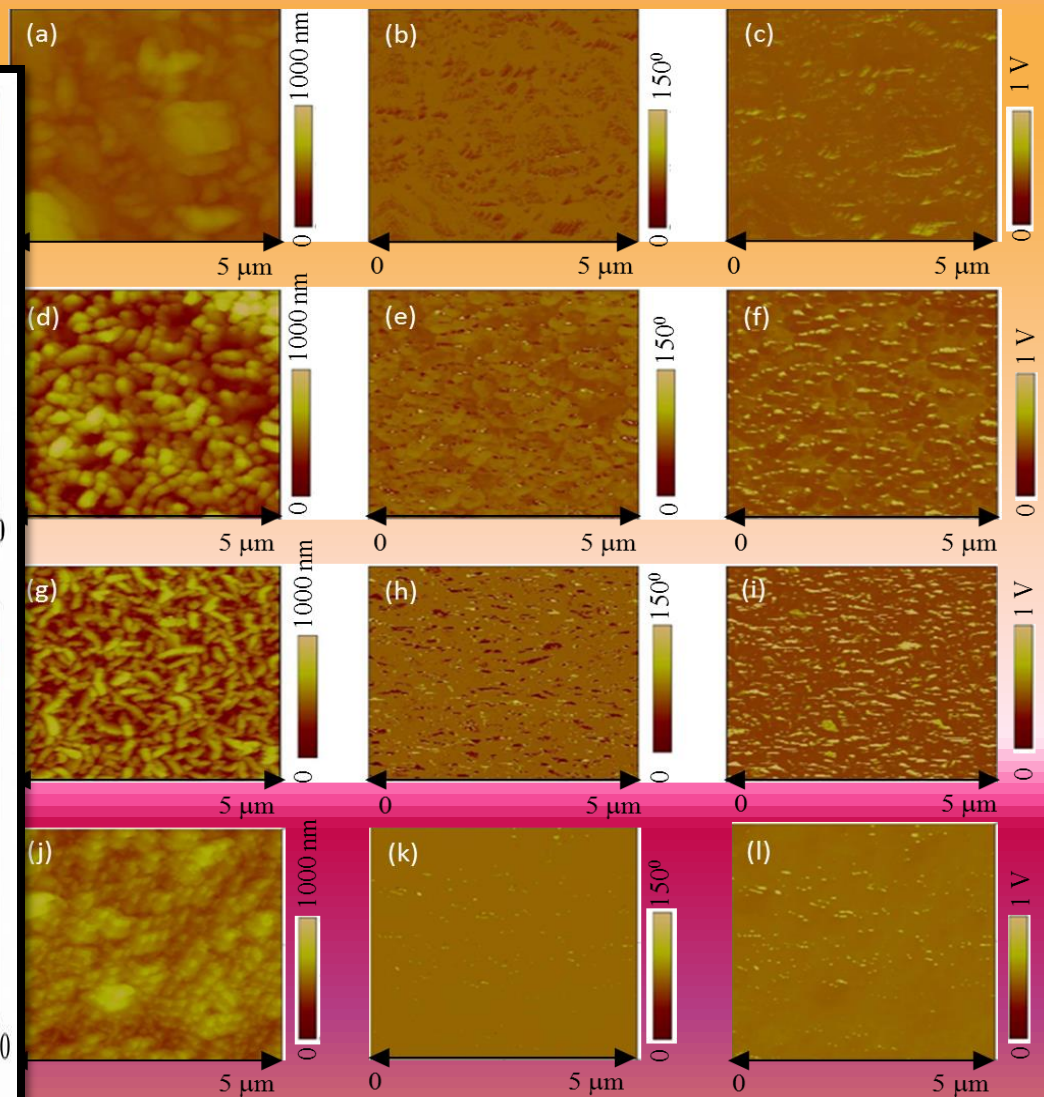
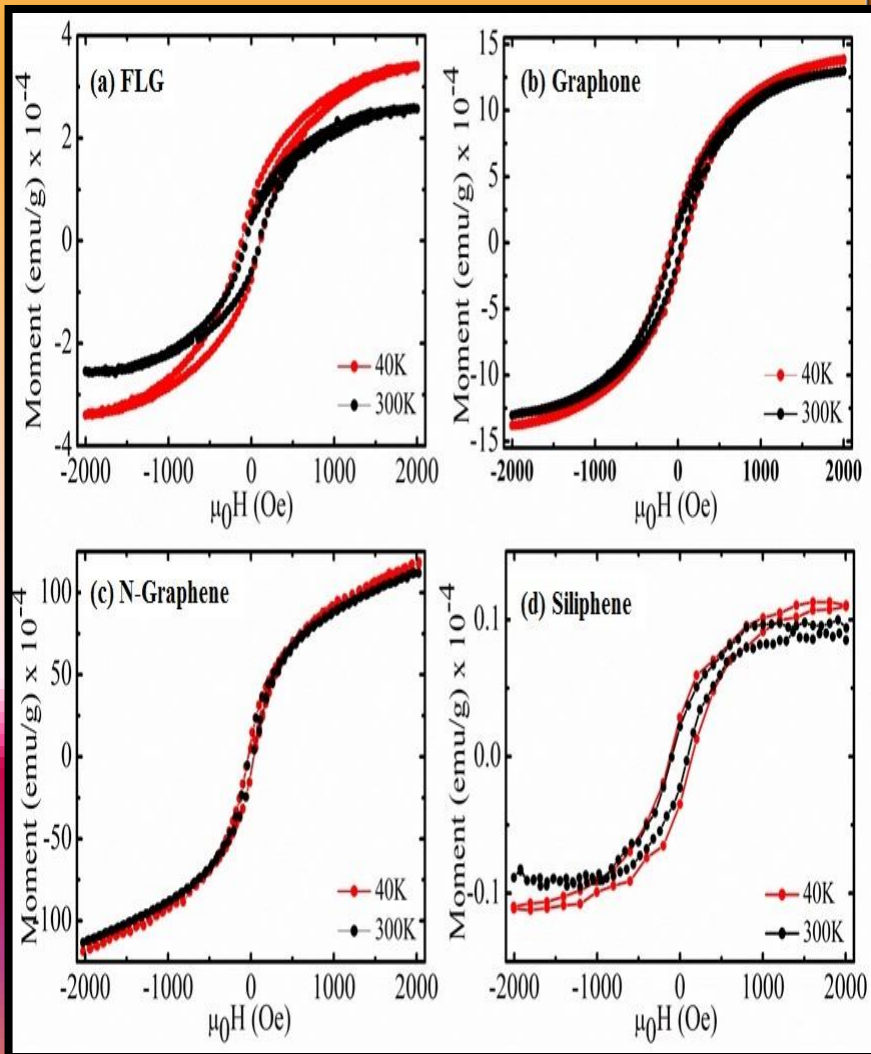
rf-PECVD

More sp^3 -type defect structures



Magnetic hysteresis loops of pristine Graphene, Graphone, N-graphene and Siliphene at 300 K and 40 K.

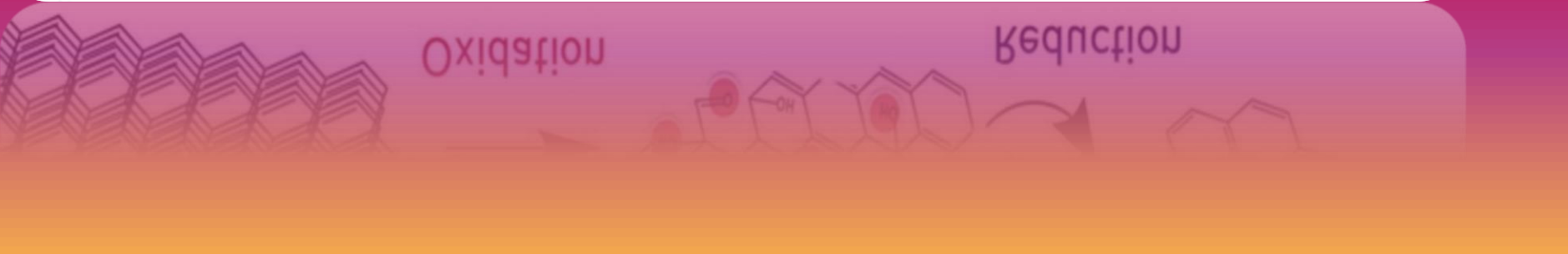
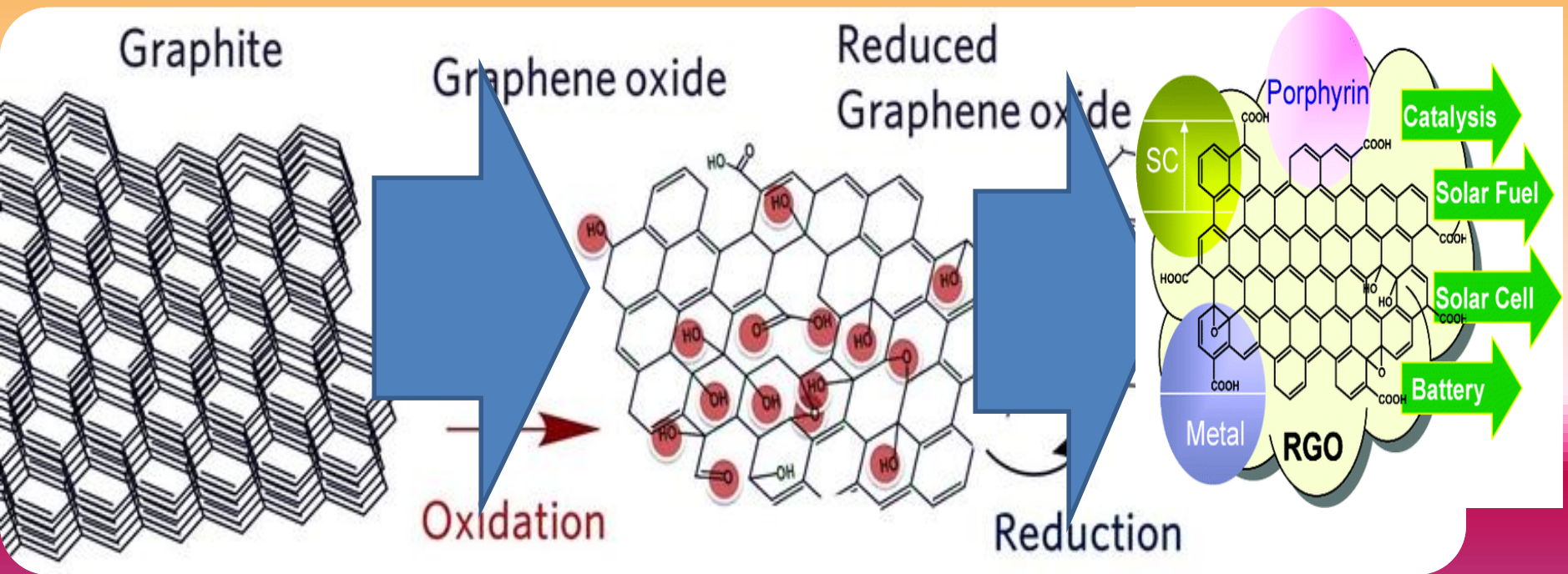
Magnetic Force Microscopy images of pristine Graphene, Graphone, N-graphene and Siliphene



Magnetic properties of the pristine and plasma treated graphenes at 40 K and 300 K

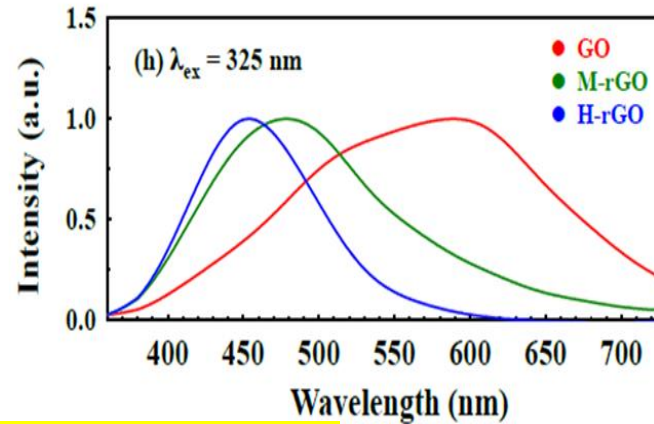
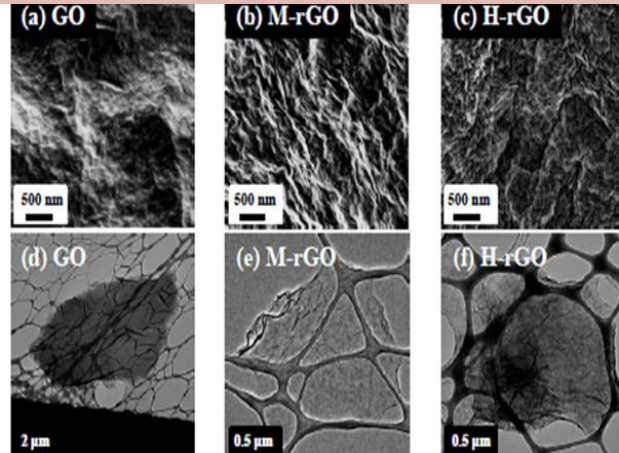
Sample/ Temperature	H _c (Coercivity) (Oe)	M _s (Saturation magnetisation) (emu/gm)	M _r (Remnant magnetisation) (emu/gm)
FLG			
40K	112.37	3.47 x 10 ⁻⁴	0.52 x 10 ⁻⁴
300K	62.98	2.60 x 10 ⁻⁴	0.42 x 10 ⁻⁴
Graphone			
40K	76.19	13.94 x 10 ⁻⁴	1.91 x 10 ⁻⁴
300K	52.88	12.91 x 10 ⁻⁴	1.28 x 10 ⁻⁴
N-Graphene			
40K	40.00	118.62 x 10 ⁻⁴	9.74 x 10 ⁻⁴
300K	25.42	111.91 x 10 ⁻⁴	6.04 x 10 ⁻⁴
Siliphene			
40K	120.03	0.11 x 10 ⁻⁴	0.03 x 10 ⁻⁴
300K	94.75	0.09 x 10 ⁻⁴	0.02 x 10 ⁻⁴

Role of Oxygen Functional groups (C-O, O-C-OH, C-OH) of Graphene / Graphene Oxides: Magnetic behavior



SEM, TEM, Raman and PL of Graphene Oxides

FE-SEM images: Change of surface morphology



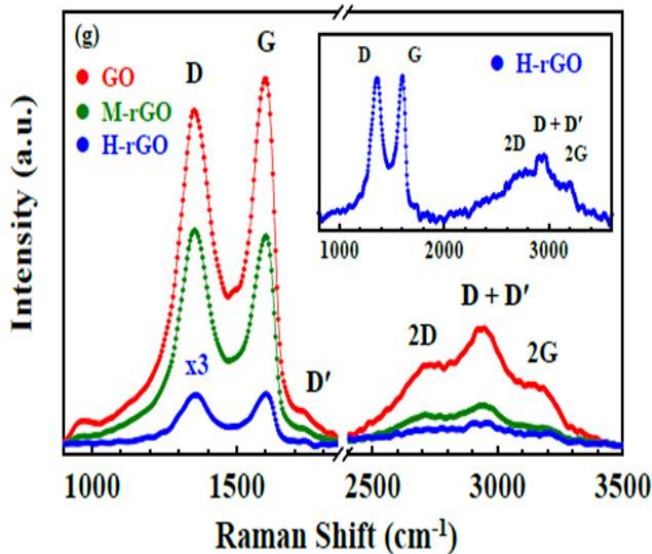
GO: A significant number of disorder-induced defect states within the π - π^* gap and exhibits a predominant **broad PL spectrum** centered at longer wavelengths.

rGO: The number of disorder-induced states within the π - π^* gap decreases, and an increased number of small sp^2 clusters in the rGO result in **blue luminescence**.

Photoluminescence:

P-T reduction process does not always remove all of the oxygen and oxygen containing functional groups from the GO but that the process can increase the number of $\pi^*(C-OH)$ and $\pi^*(C-O-C)$ bonds upon the rearrangement of oxygen and oxygen-containing functional groups with carbon; this consequence may also play a role in enhancing the transfer of resonance energy from O sites to the sp^2 clusters in the graphene lattice, which results in broad PL emission.

TEM images: Change of surface morphology

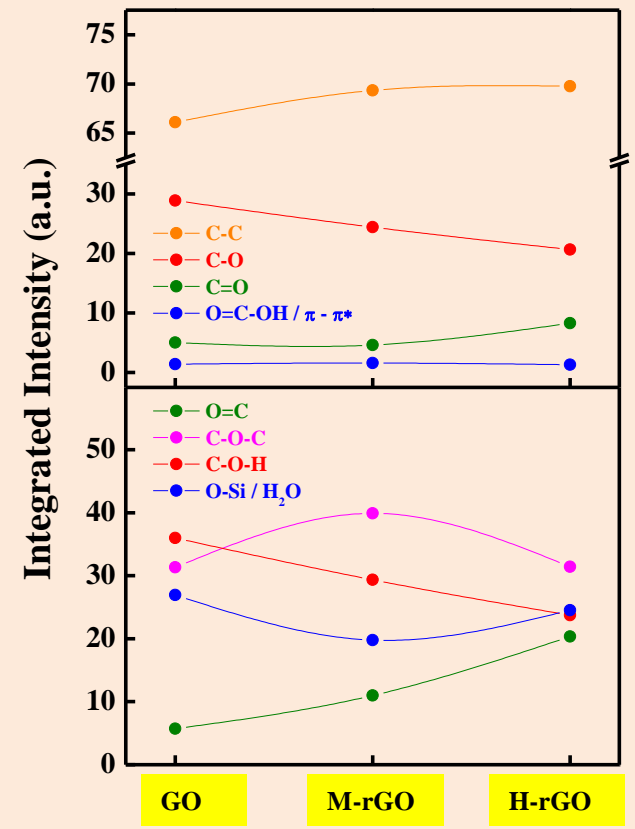
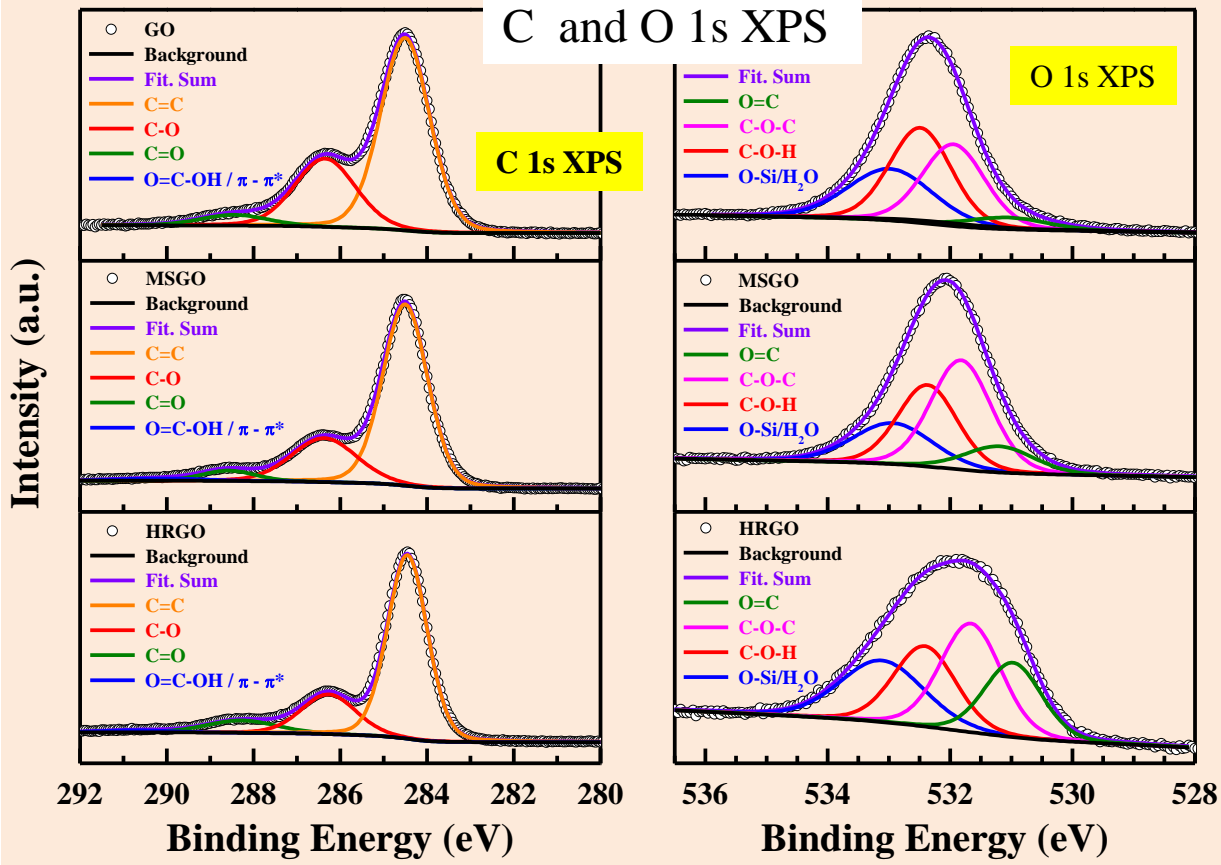


G-Band: 1587 cm^{-1} is attributed to the E_{2g} phonon of sp^2 states

D-band: 1327 cm^{-1} is A_{1g} symmetry disorder - defects/ vacancies in grain boundaries

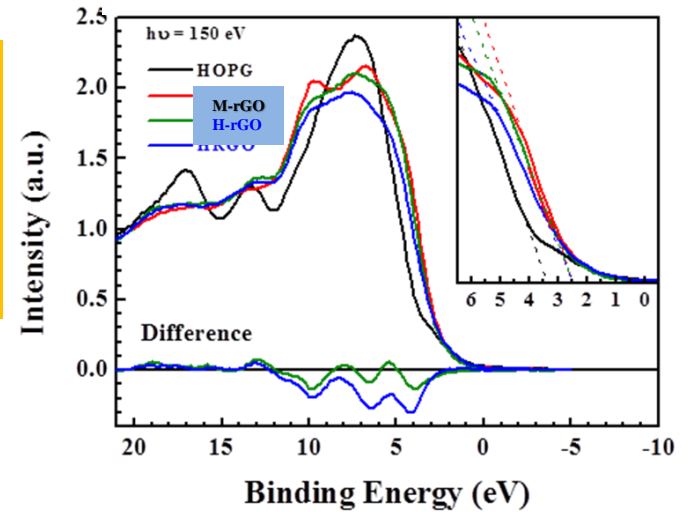
Removal of oxygen and/or oxygen-containing functional groups and is based on the restoration of the $C=C\ sp^2$ bonds in the Graphene hexagonal lattice

C and O 1s XPS

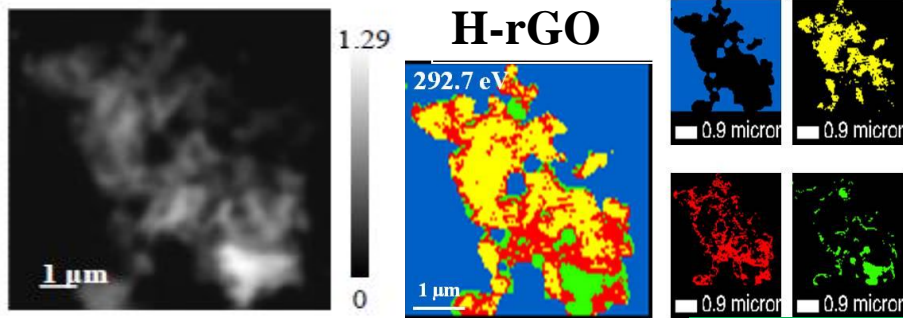
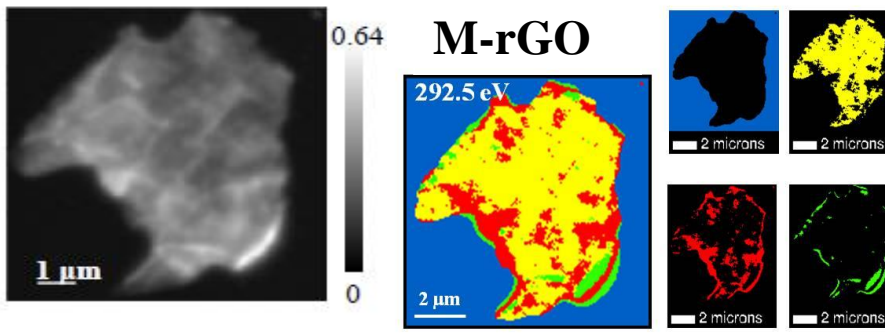
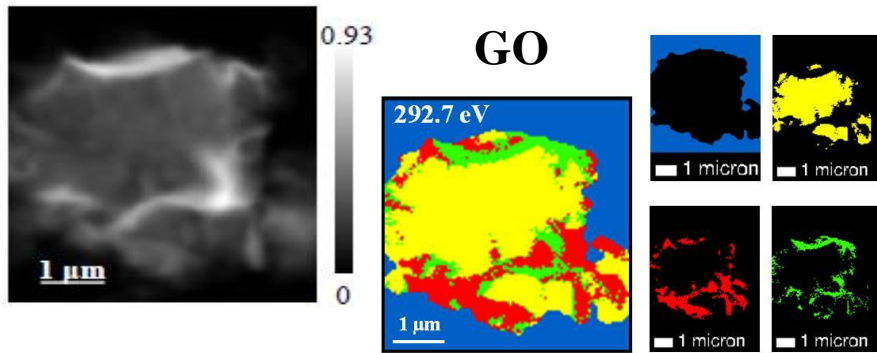


The hydroxyl (C-OH) groups are gradual consumes and in the same time carbonyl (C=O) group are formed in rGO on PT-reduction process.

Valence Band PES



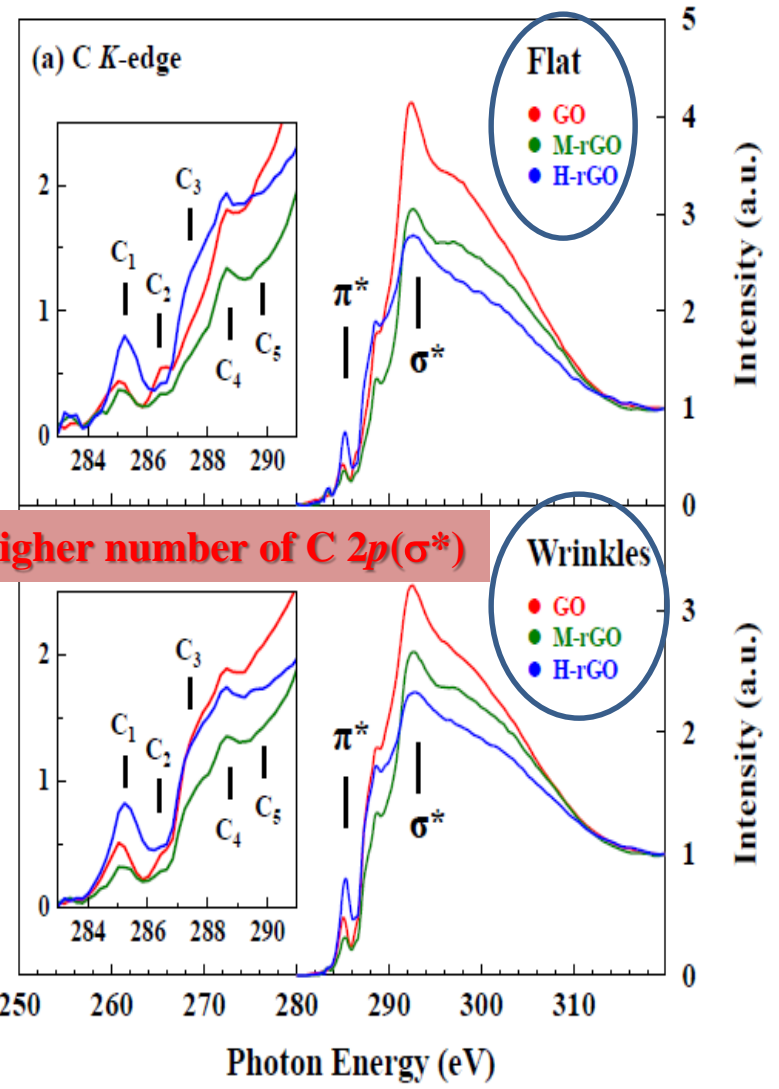
C and O K-edge Scanning Tunneling X-ray microscopy (STXM) -XANES spectra



Optical Density images

C K-edge STXM stack mappings

Decomposed STXM mappings



C K-edge STXM-XANES provide clear evidence that the number of C 2p(σ^*)-derived states, rather than of C 2p(π^*) states that bound with oxygen-containing and hydroxyl groups on the GO surface, is related to the change of magnetic behavior from that of ferromagnetic GO to that of paramagnetic M-rGO / H-rGO

Magnetic behavior of Graphene Oxides

Origin of magnetic behavior in Graphene Oxides !!

In general,

- ⇒ Symmetry breaking at the edges
- ⇒ Vacancy
- ⇒ Substitution and absorption of atoms
- ⇒ Origin of magnetism due to presence of Oxygen functional groups

DFT calculations:

- (i) The local spin moment of the carboxyl (COOH) and hydroxyl (OH) functional groups adsorbed on the **GRAPHENE** are **1.00 μ_B** and **0.56 μ_B** respectively.
- (ii) Two hydroxyl groups at non neighboring carbon atoms (having one carbon in between) favors the magnetism in GO
- (iii) Hydroxyl groups present at neighboring carbon atoms shows no magnetism !!
- (iv) The most stable magnetic configuration corresponds to seven OH-groups

Ref: (i) Santos, E. J. G. et al. *New J. Phys.* 2012, 14, 043022.

(ii) Wang, M. et al. *Nanotechnology* 2011, 22, 105702.

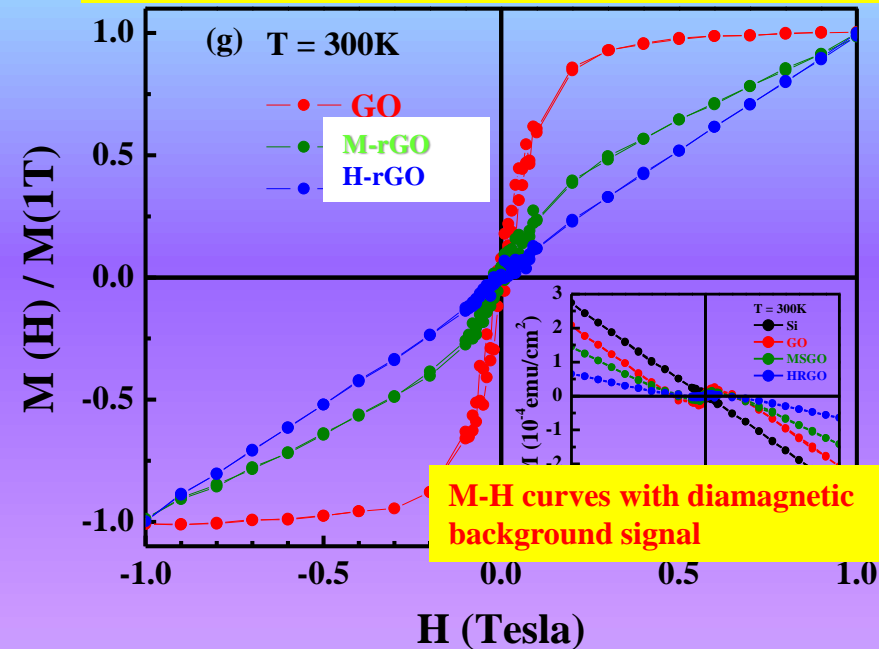
(iii) Boukhvalov, D. W. et al. *ACS Nano* 2011, 5, 2440

Wang & Ray et al. 2015, *Sci. Reports*

GO is usually considered as an diamagnetic insulator / semiconductor material

Carbon-based materials are very promising for spintronic applications due to their **weak spin-orbit coupling** and potentially providing a **long spin life time**

After subtracting the diamagnetic (Si-substrate) contribution



Absence of *d* and *f* electrons but strongly supports the intrinsic d^0 magnetism of GO

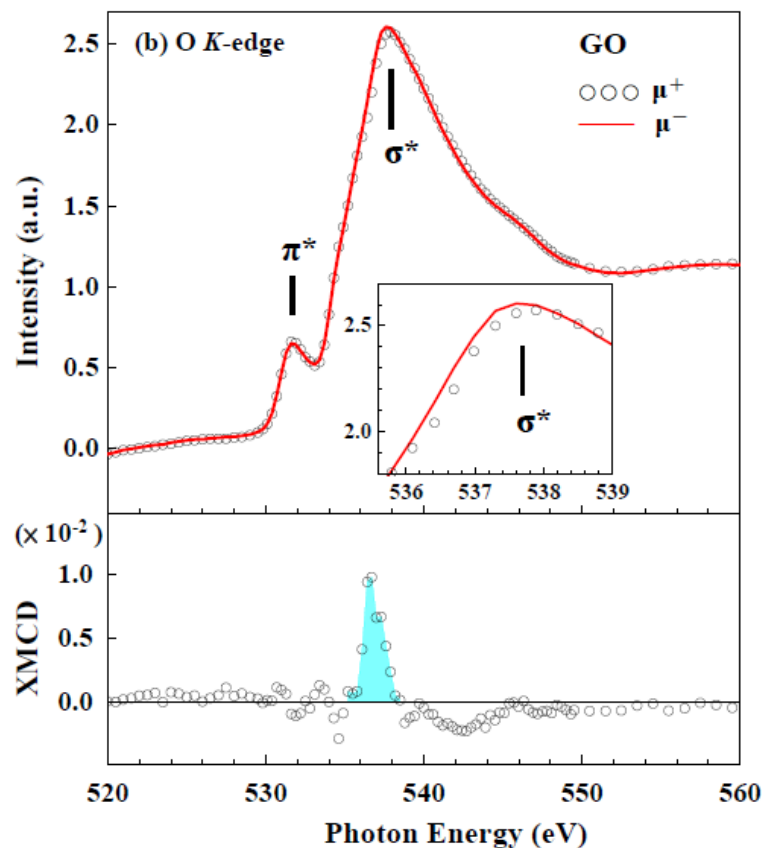
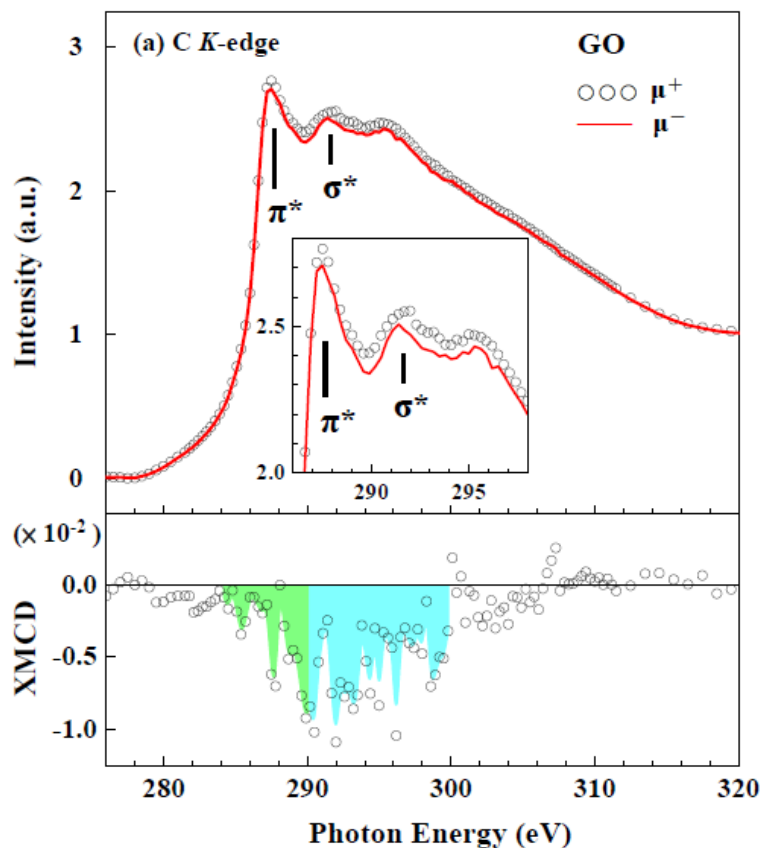
Room temperature FM in GO

Coercivity ~150 Oe

Saturated Magnetic field about ~3000 Oe

Ferromagnetic behavior gradually decreases (paramagnetic behavior) for MrGO / HrGO on PT-reduction process.

X-ray Magnetic Circular Dichroism (XMCD) of Graphene Oxides



C and O *K*-edge: X-ray magnetic circular dichroism (XMCD) spectra with the photo-helicity of incident x-rays parallel (μ^+) and anti-parallel (μ^-) to the direction of magnetization of GO

Electronic and magnetic properties of nitrogen functionalized graphene-oxide

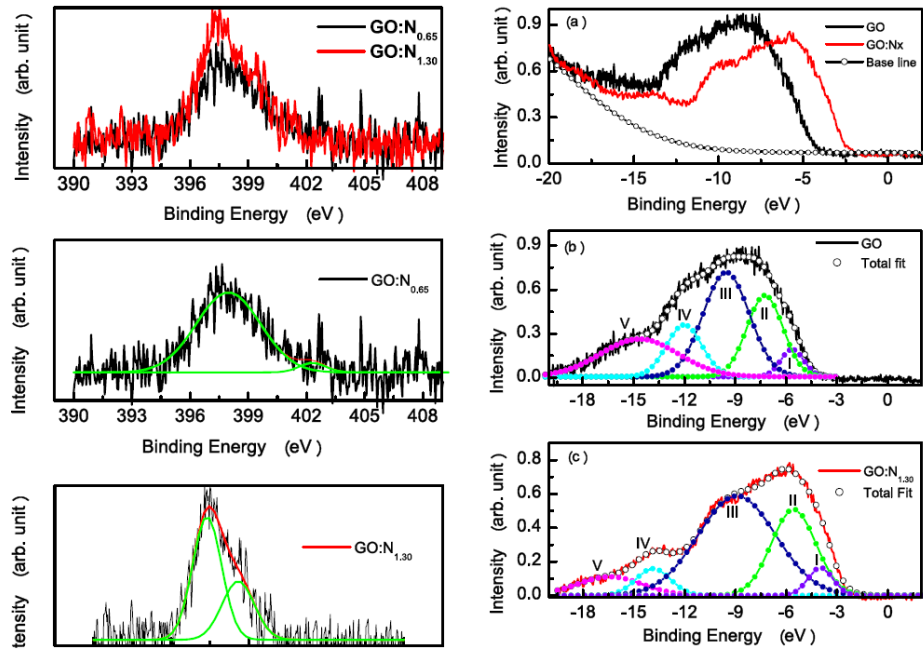
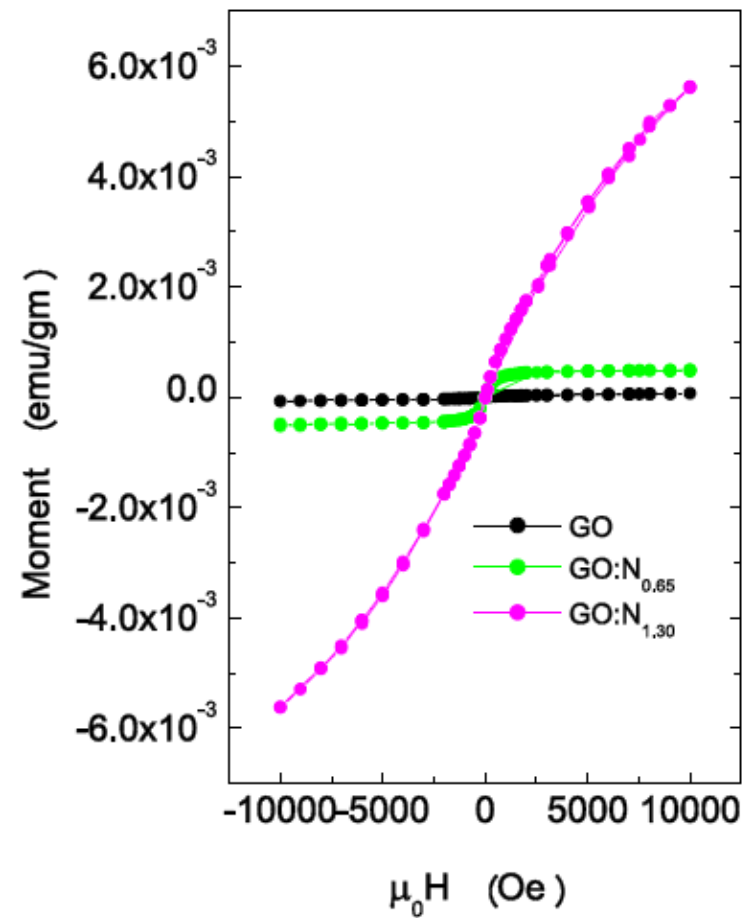
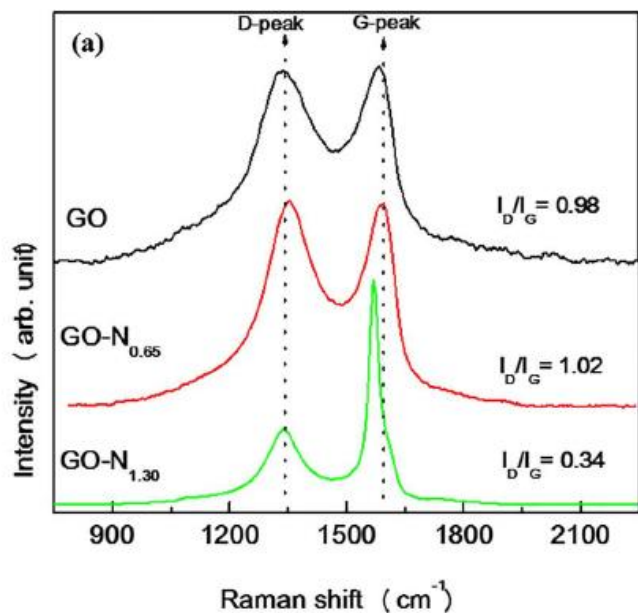


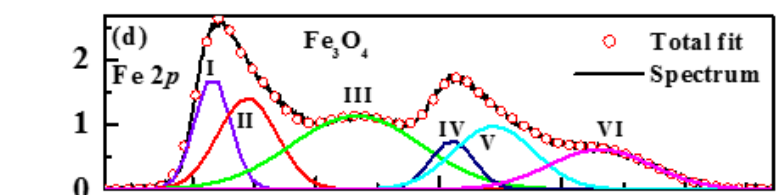
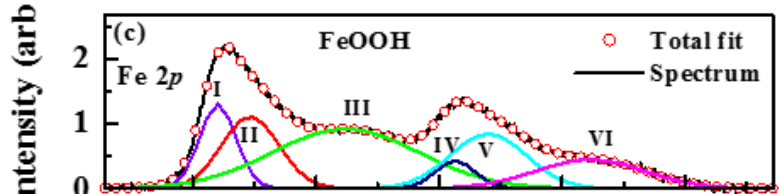
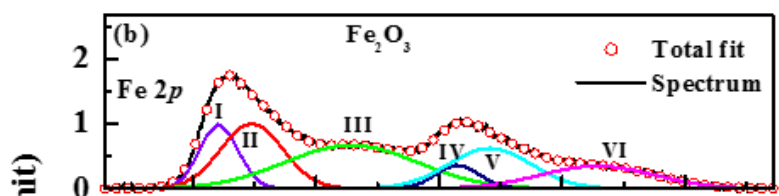
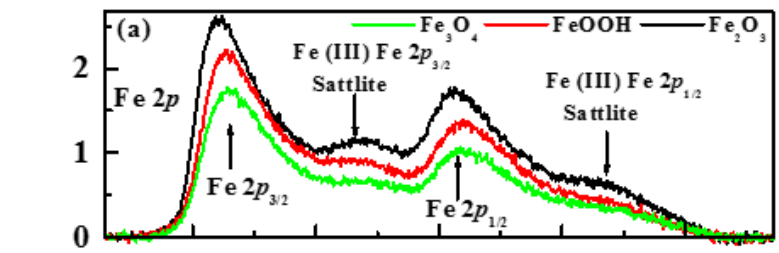
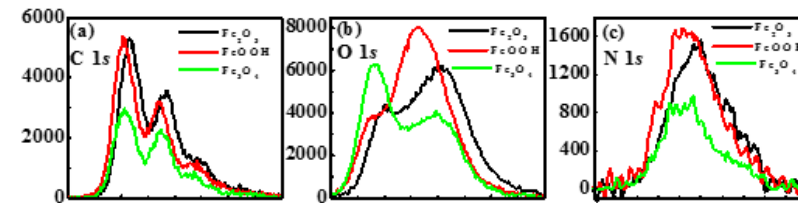
Fig. 5. (a) UPS He-II spectra for the measurement of density of states below the Fermi level, (b) the change of the chemical composition and oxygen binding modification as observed in the UPS He-II spectra for (b) GO, (d)

Fig. 4. (a) Raman spectrum of



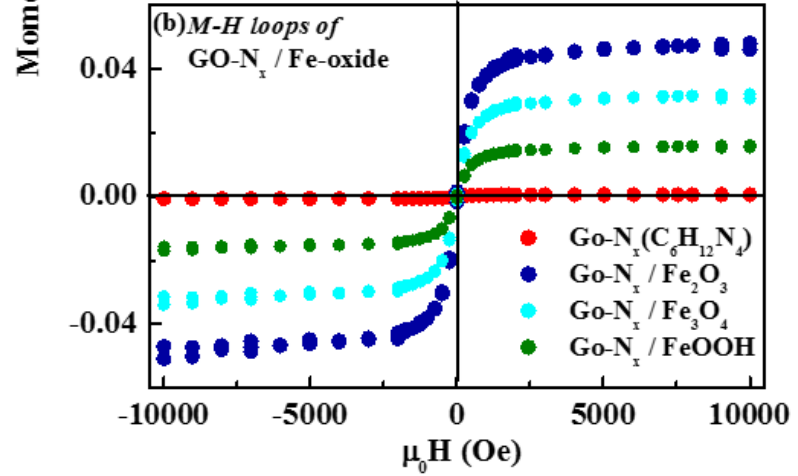
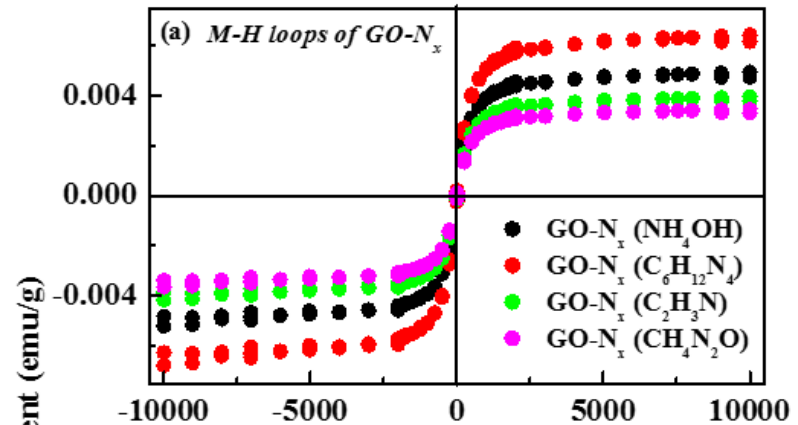
Sarma & Ray 2017, Diamond & Rel. Mater.

Electronic and magnetic properties of GO:N_x functionalized with Iron oxide



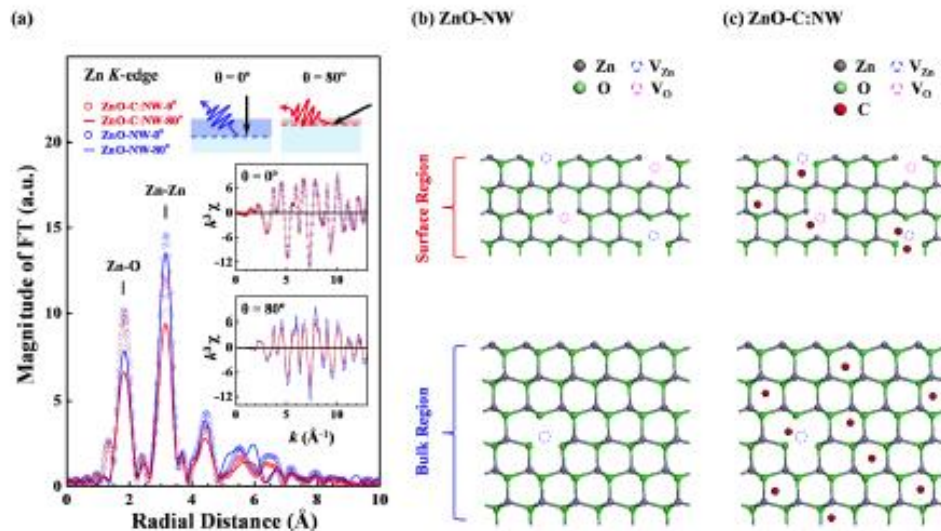
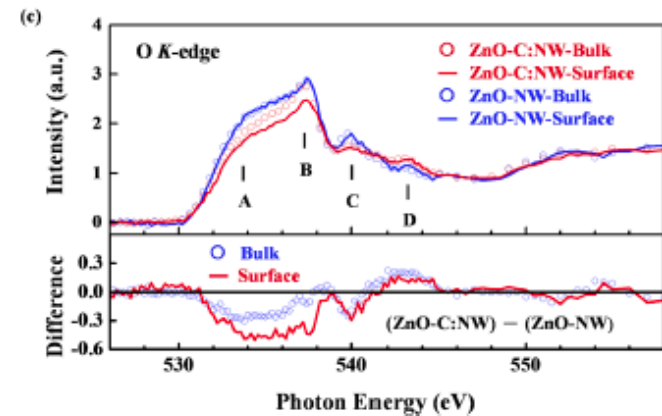
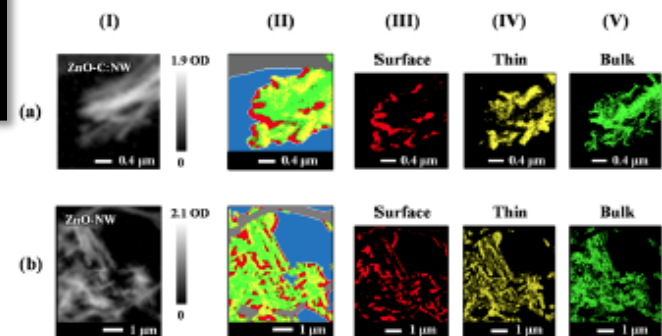
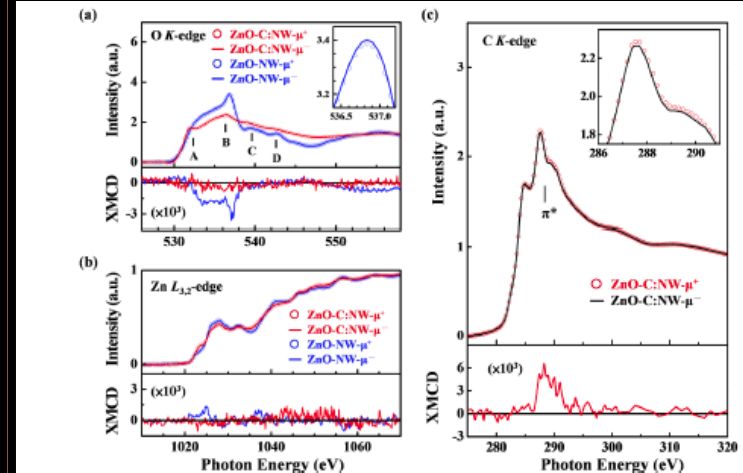
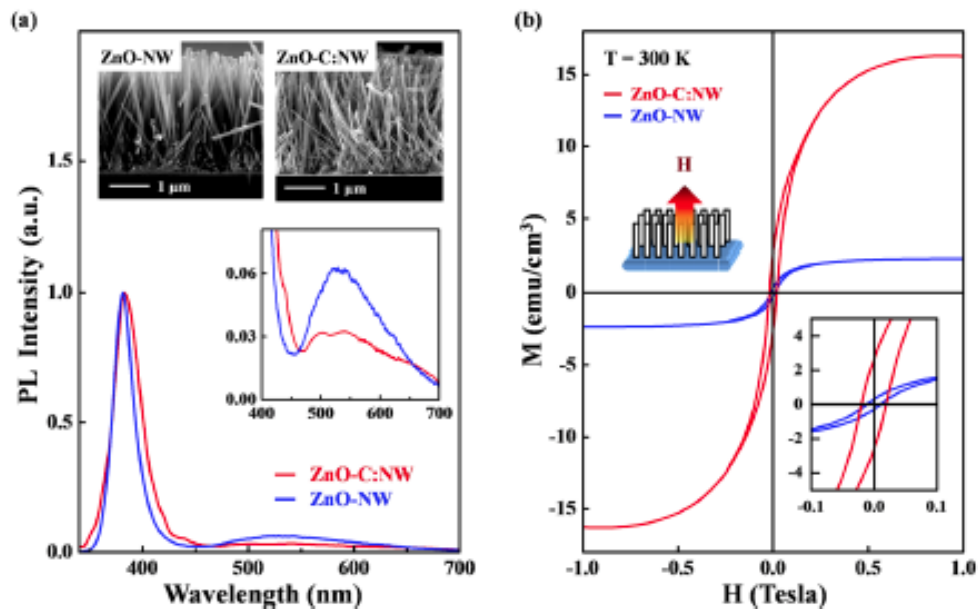
Intensity (arb unit)

Binding Energy (eV)



Ghosh & Ray 2018, Diamond & Rel. Mater. (Communicated)

Origin of magnetic properties in carbon implanted ZnO nanowires

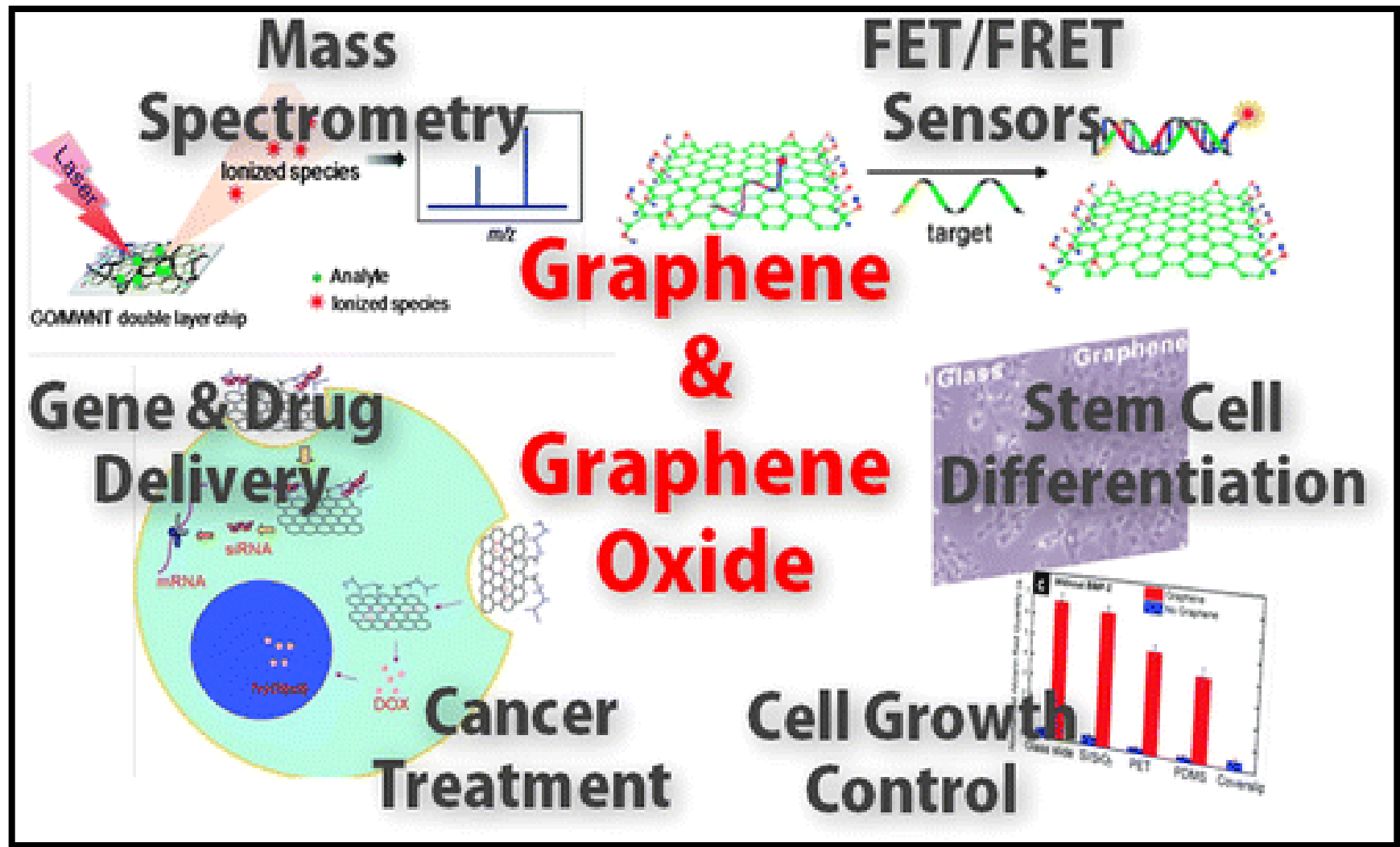


CONCLUSION

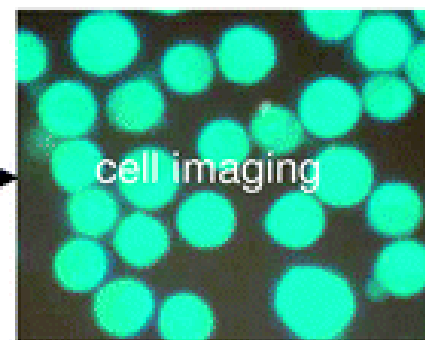
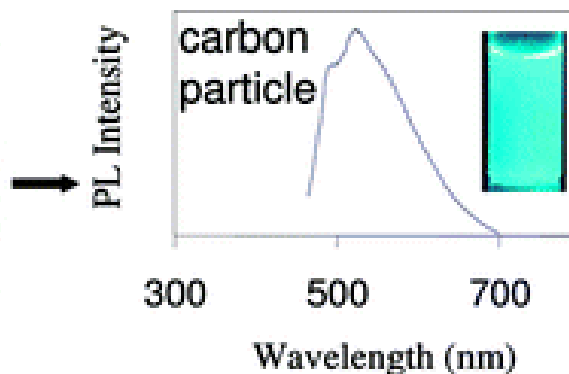
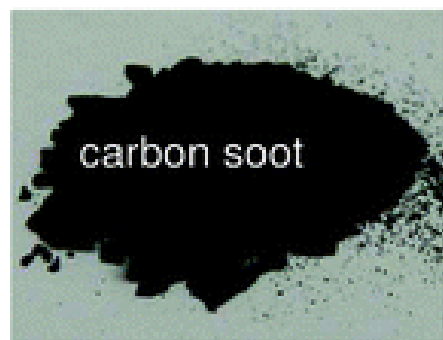
- Graphene is a new hope for electronic devices and could possibly replace or rejuvenate Silicon based devices. It seems to be a better material than Silicon and CNT.
- Lack of Natural Band Gap prevents Graphene to replace Silicon based devices very now.
- Successful prototypes include Superconductor, Flexible Displays and Ultra-Capacitor.
- It shall introduce new era of devices for electronics, space, bio-medical and energy harvesting.
- Graphene devices might surround us very soon.

Graphene is a promising and useful material for new types of systems, circuits and devices where several functionalities can be combined into a single materials

Graphene/Graphene based Carbon for Bio-imaging application



Graphene based Carbon Nanoparticles for Bio-imaging application

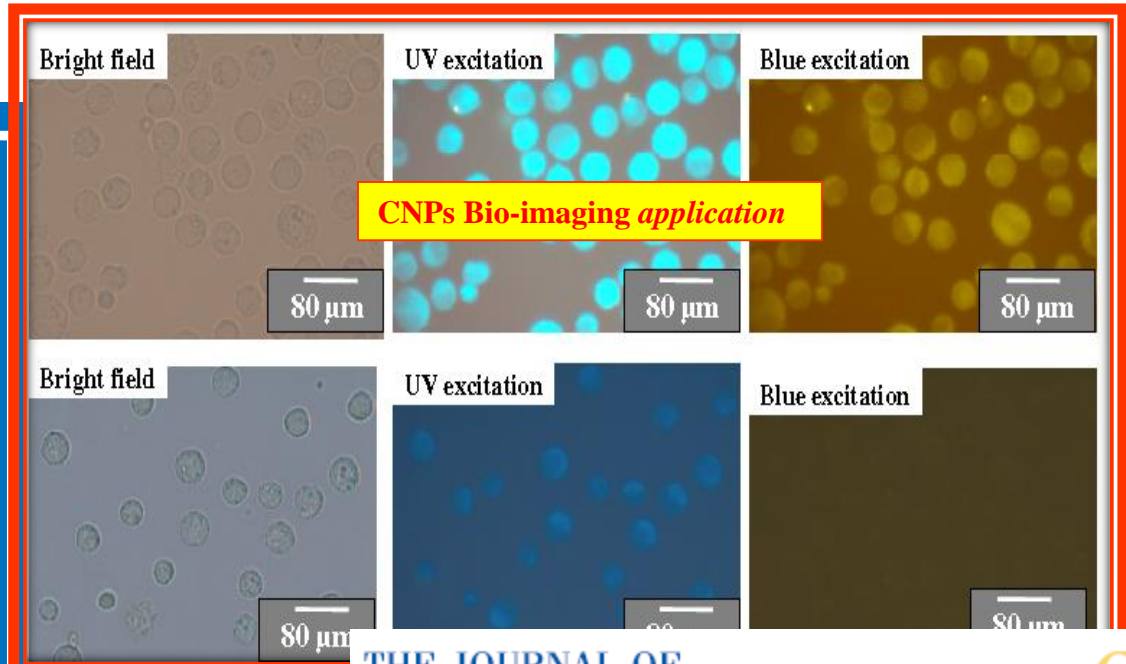
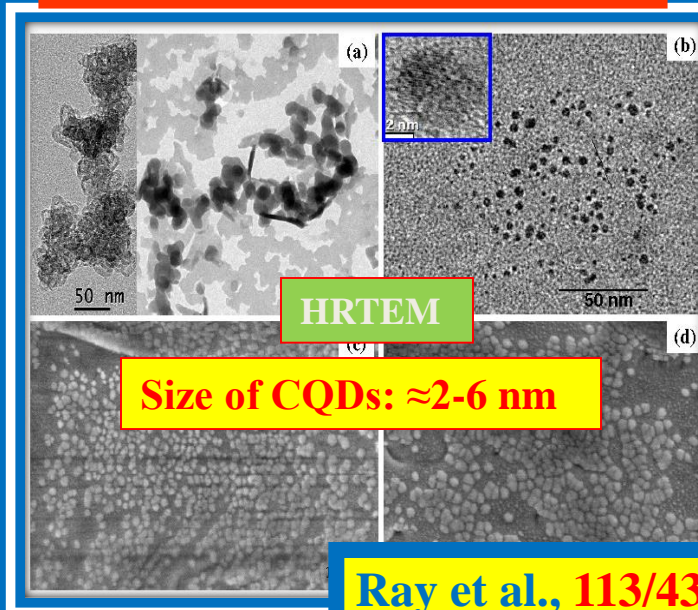
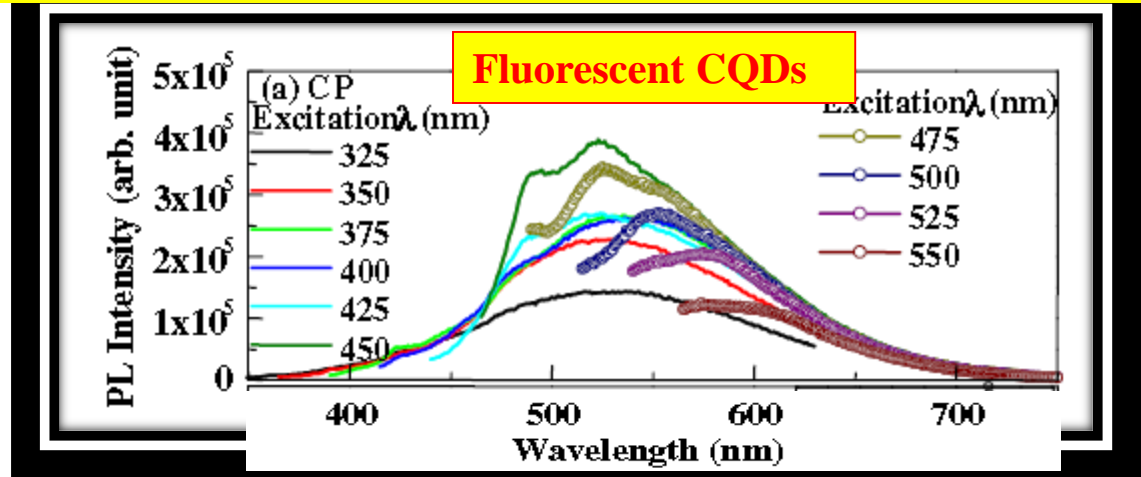
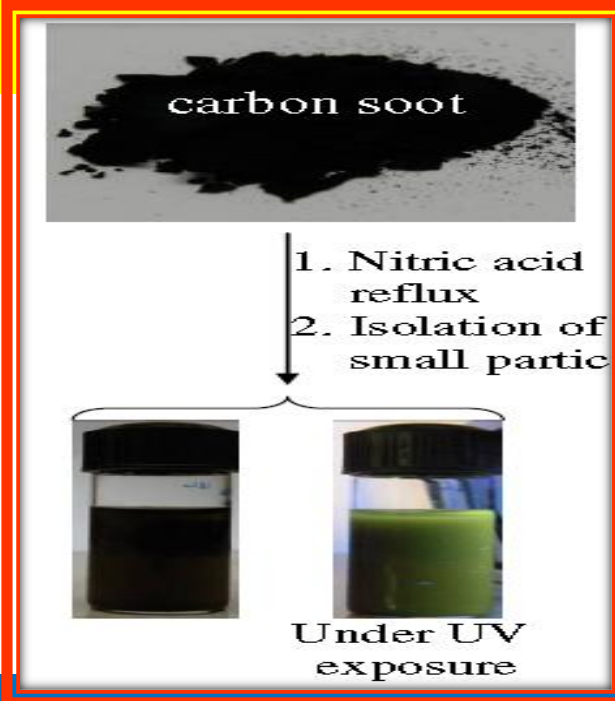


Ray et al.

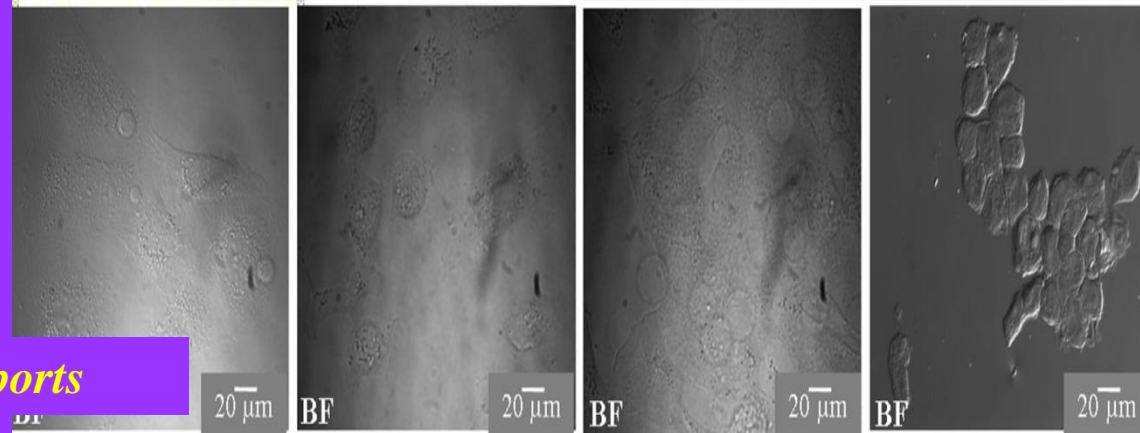
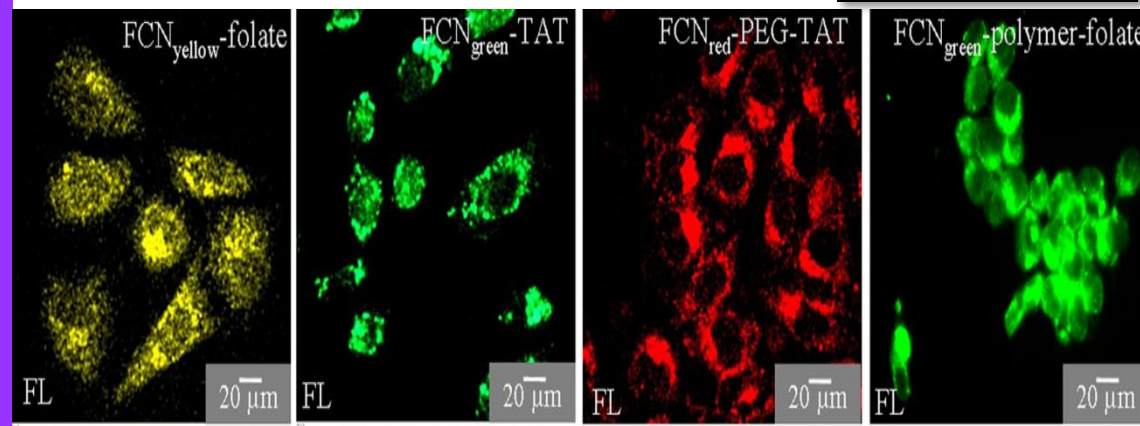
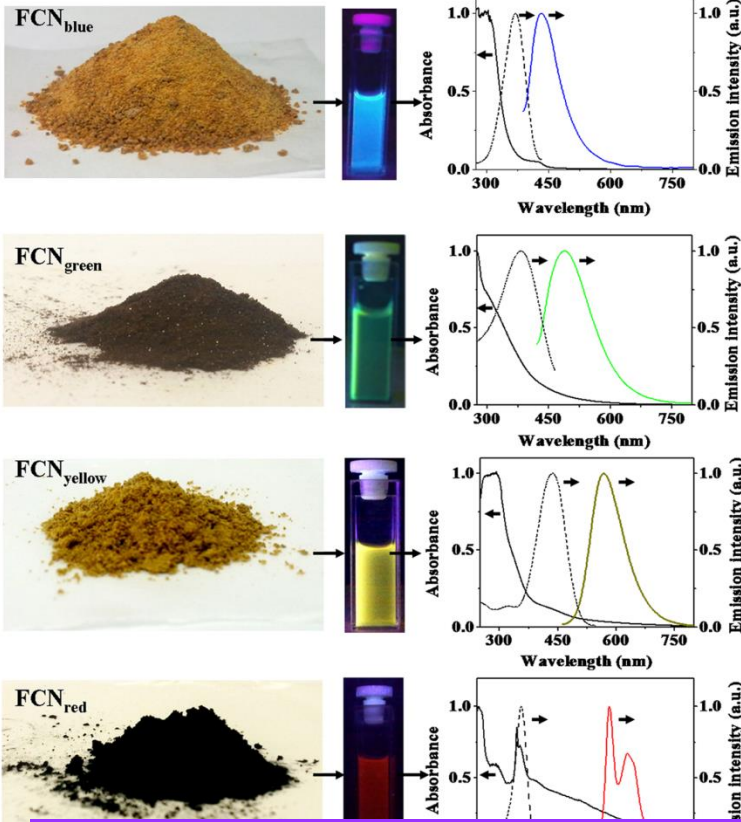
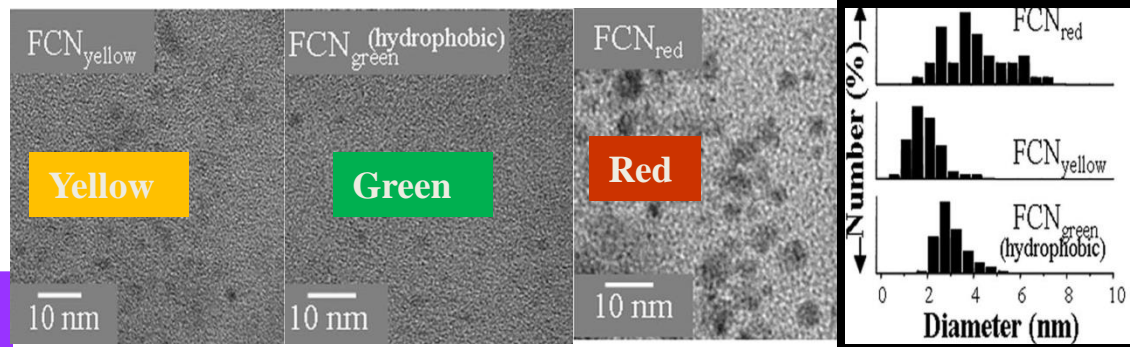
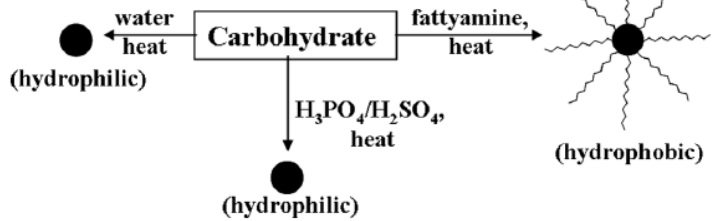
J. Phys. Chem. C 2009, 113, 18546–18551

Fluorescent Carbon Nanoparticles for Bio-imaging probes

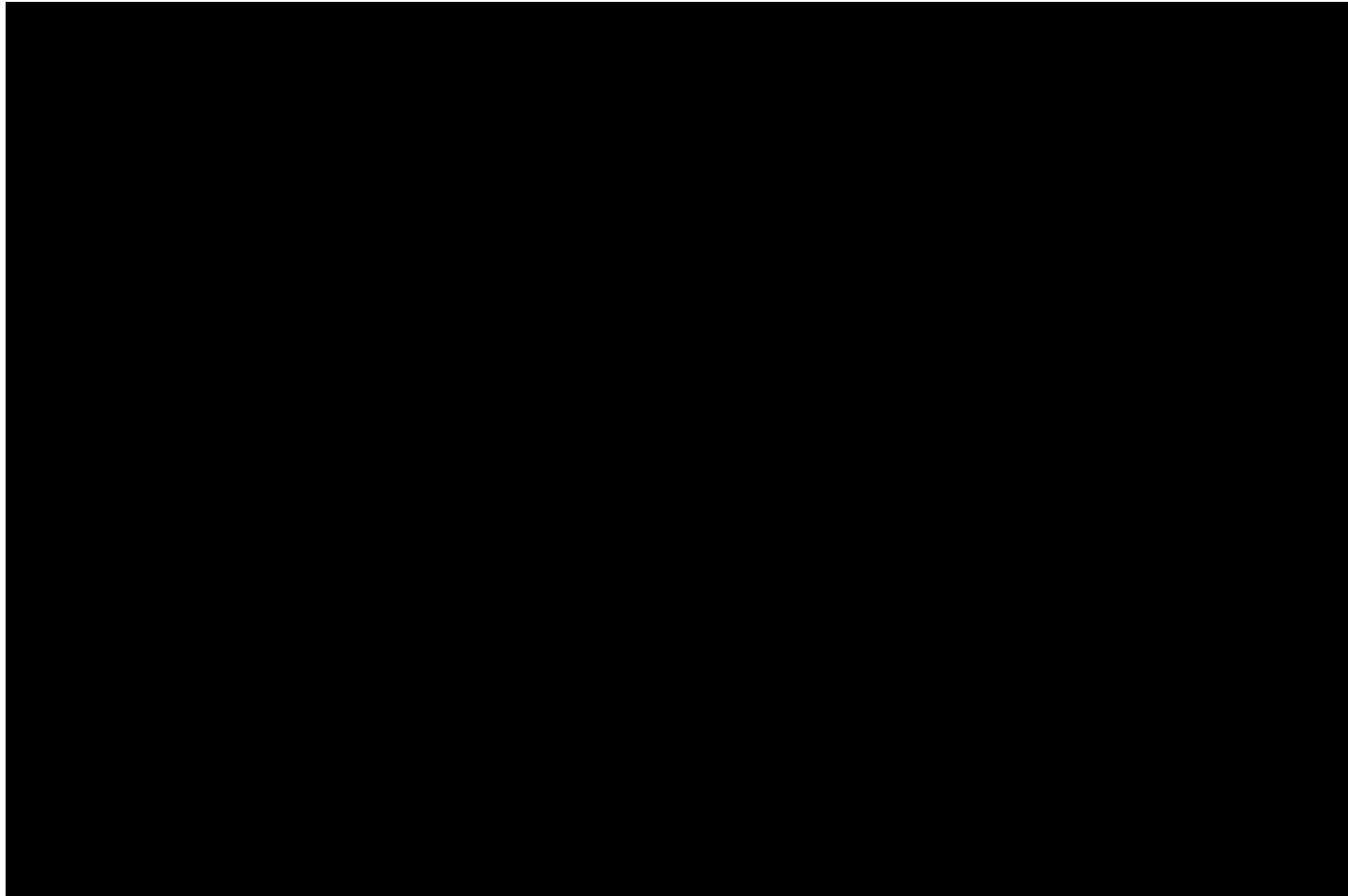
(Carbon Quantum DOTs: $\approx 2 - 6$ nm)



Functionalized with Nano pores



Vision – Applications of Graphene (within 50 years)



Vision – Applications of Graphene (within 50 years)!

THANK YOU FOR YOUR ATTENTION



GRAPHENE The 'miracle material' that could revolutionize our world

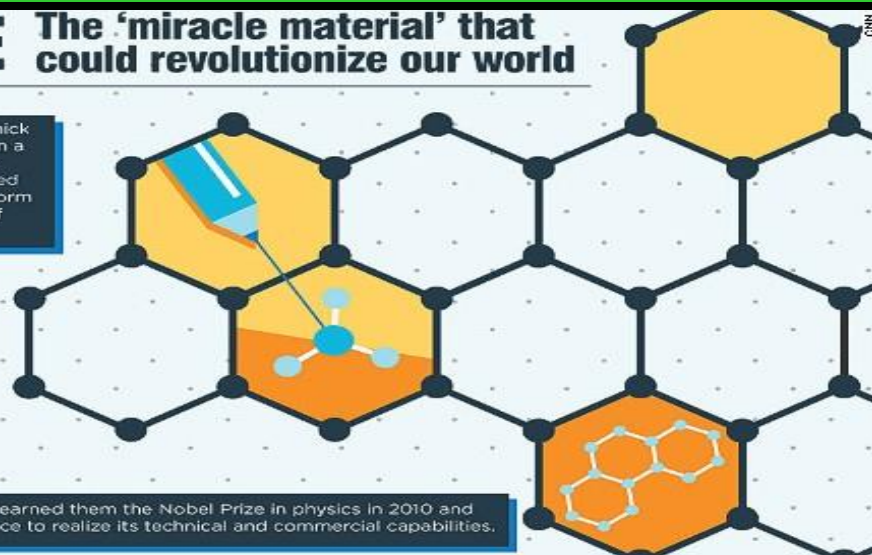
What is it?

Graphene is a one-atom thick layer of carbon arranged in a honeycomb lattice. When millions of these are stacked one on top of another they form graphite – a mineral consisting of carbon which is found in pencils.

Graphene was discovered in 2004 at the UK's University of Manchester by physicists Andre Geim and Konstantin Novoselov when they isolated a single-layer of graphene using Scotch Tape before going on to demonstrate its remarkable conductive and resilient properties.



Geim and Novoselov's work earned them the Nobel Prize in physics in 2010 and today researchers are in a race to realize its technical and commercial capabilities.



Define tomorrow.



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