Dr. S. N. Chakravarty (born 1940) (M.Sc. & D.Phil., FPRI.(UK), FIRI, FICS, FIIChE , FIC-India) of KPS Consultants & Impex Pvt. Ltd. , Delhi is a leading Consultant in rubber & allied field and functioning as retainer Consultant to many well-known rubber industry in India & abroad.

Dr. Chakravarty has **50 years experience in rubber industry** - both India & abroad. After working with **German** rubber industry & **Bayer AG, Germany** for many years he returned to India as Technical Manager of **Bayer (India) Ltd.** and then of **Modi Rubber Ltd.** (leading-most Tyre manufacturing company with German collaboration). Subsequently he started his own **Consultancy Organisation** in Rubber and related field.

He is the past **Chairman** of **IRI** and **Rubber Committee** (PCD 14) of **BIS**, **Fellow** of **PRI (UK)** , **IRI , ICS** , **IIChE , Inst. of Chemist** and Member of **Rubber Division , ACS** (USA).

Dr. Chakravarty has been **Hon. Professor** of **IIT, Delhi and Kharagpur,** visiting Faculty to different Universities & Institutes. He represented India in **Rubber Committee (TC 45)** of **ISO** for about 10 years & was a member of **IRCO, UK** Committee. He was the **Convenor** of **first IRCO Conference**, **Rubber Con '93** held at Delhi in 1993 and member of **ITTAC** for many years.

Dr. Chakravarty has been selected to receive one of its most internationally prominent honors, the **GOLD MEDAL FOR INDIA** by **American Biographical Institute**, a highly esteemed, world leader in the research of outstanding individuals around the globe in 2012. Dr. Chakravarty was conferred "**Life Time Achievement Award**" by the **IIChE**, in October 2011 and by **"Tyre Times" TRiLA Awards 2015** at Chennai SingEx Expo. (organized by Singapore) on 8th July 2015. He delivered **C. K. Murthy Memorial Lecture** at Chemcon 2014 (IIChE) **at Chandigarh** on 27th, Dec. 2014.

Dr. Chakravarty has 118 Publications in National & International journals of repute and published books on **"Introduction to Tyre Technology"** and **"Rubber Technology and Manufacture of Rubber Products" "Rubber Research in India – Two Decades"**, **"Compilation of Recent Lectures"** among others. He has travelled widely over the world and has command over different languages.

Graphene

Dr. S. N. Chakravarty

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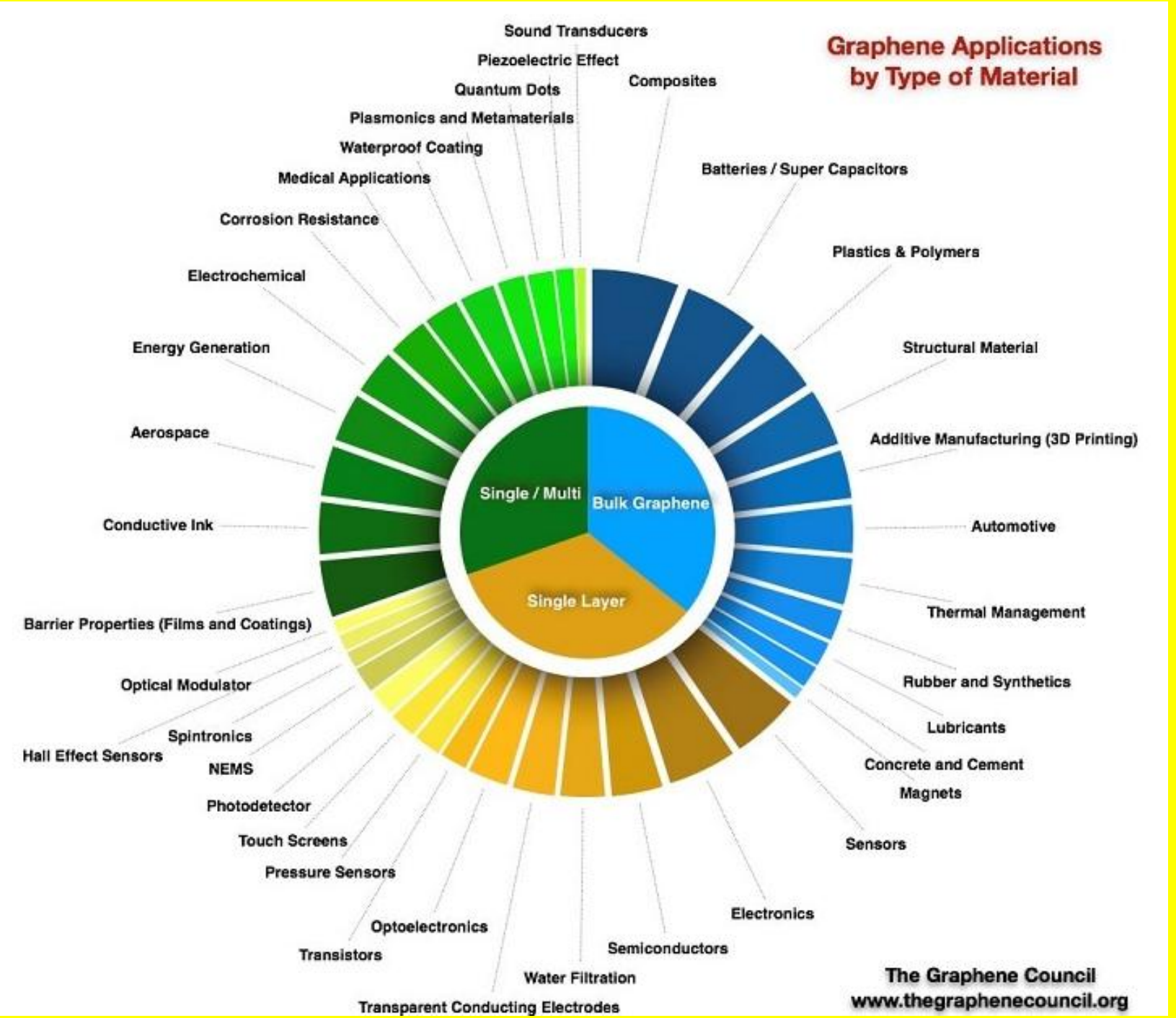
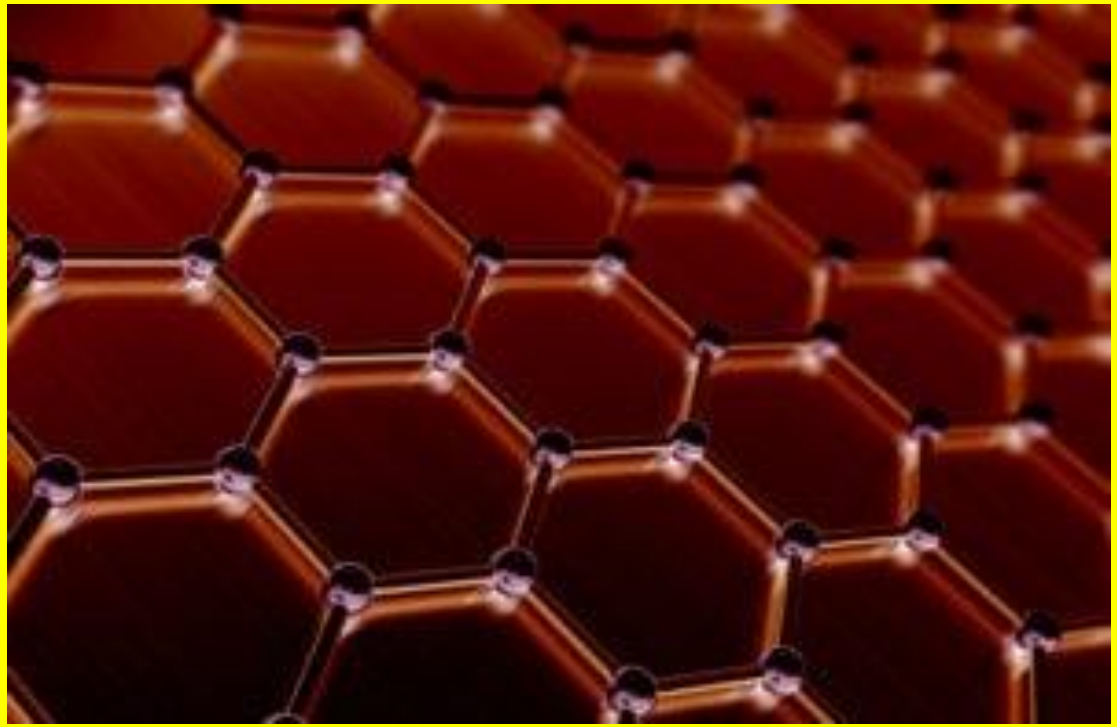
IIChE Seminar 06 April 2019


Graphene Applications
by Type of Material
Sound Transducers
Piezoelectric Effect
Quantum Dots
Plasmonics and Metamaterials
Waterproof Coating
Medical Applications
Corrosion Resistance
Electrochemical
Energy Generation
Aerospace
Conductive Ink
Barrier Properties (Films and Coatings)
Optical Modulator
Spintronics
Hall Effect Sensors
NEMS
Photodetector
Touch Screens
Pressure Sensors
Optoelectronics
Transistors
Transparent Conducting Electrodes
Water Filtration
Semiconductors
Electronics
Sensors
Magnets
Concrete and Cement
Lubricants
Rubber and Synthetics
Thermal Management
Automotive
Additive Manufacturing (3D Printing)
Structural Material
Plastics & Polymers
Batteries / Super Capacitors
Composites
Single / Multi
Bulk Graphene
Single Layer
The Graphene Council
www.thegraphenecouncil.org

A Guide to Graphene

These Slides are related to the properties, synthesis, and applications of graphene, is meant to provide a broad understanding of these topics for both researchers and non-researchers alike.



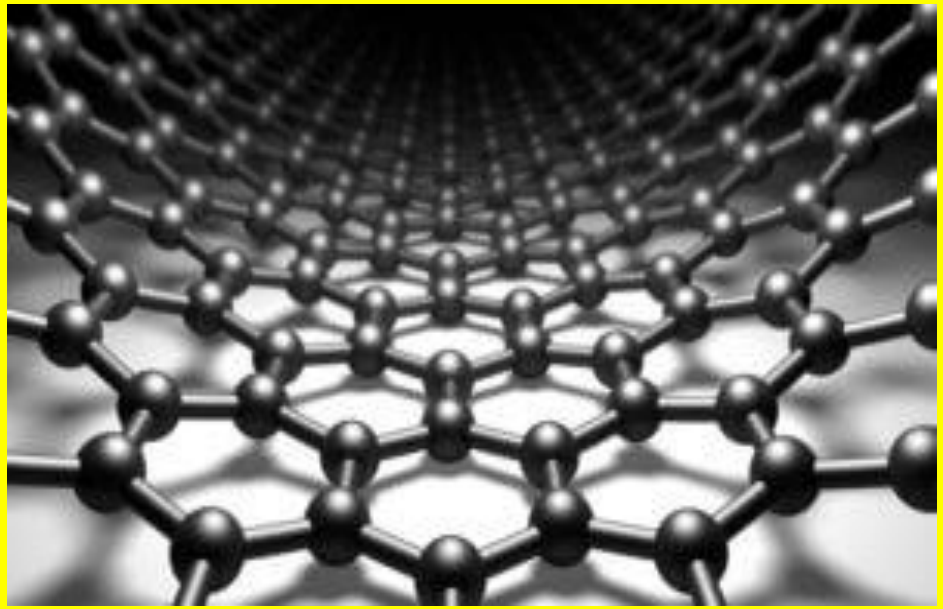
Graphene's Atomic Structure

What is Graphene?

An allotrope of carbon, **graphene** exists as a two-dimensional (2D) planar sheet and can be regarded as a single atomic graphite layer. Technically, graphene is a non-metal but it is usually known as a quasi-metal because its properties are similar to that of a semi-conducting metal. Therefore, graphene possesses a number of unique properties that cannot be found in other non-metallic materials. Each carbon atom is bonded covalently (sp^2 hybridized) to three other carbon atoms in a hexagonal arrangement, leaving one free electron for each carbon atom.

Types of Graphene

Real graphene has a thickness of a single atomic layer (often known as a monolayer). While this material usually exists as a film, it can be floated off the substrate and can be deposited again onto another substrate or employed in its isolated form. However, there are different types of graphene that contain powder-form materials, such as graphene nanoribbons, graphene nanoplatelets, graphene oxide, graphene quantum dots, and even graphene-enabled products like graphene masterbatches or graphene ink.



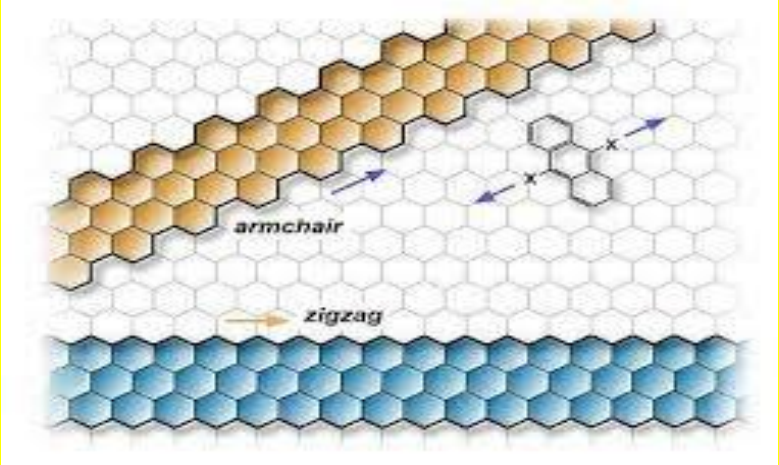
A Graphene Sheet

Graphene can be synthesized by three different ways.

They are as follows:

- Chemical vapor deposition
- Mechanical cleavage from natural graphite
- Chemical or plasma exfoliation from natural graphite

Graphene Nanoribbons



In contrast to many other forms of graphene, which are 2D, graphene nanoribbons (GNRs) are quasi-one-dimensional materials possessing an ultra-thin width. The electrical properties that GNRs display are very tenable and can be tuned by edge morphology, dimension confinement, and functionalization of the GNR. GNRs also display large aspect ratios, a conductive matrix, a high surface area, and good mechanical flexibility. The combination of these properties has bestowed GNRs a robust footing in composite materials for electronic applications.

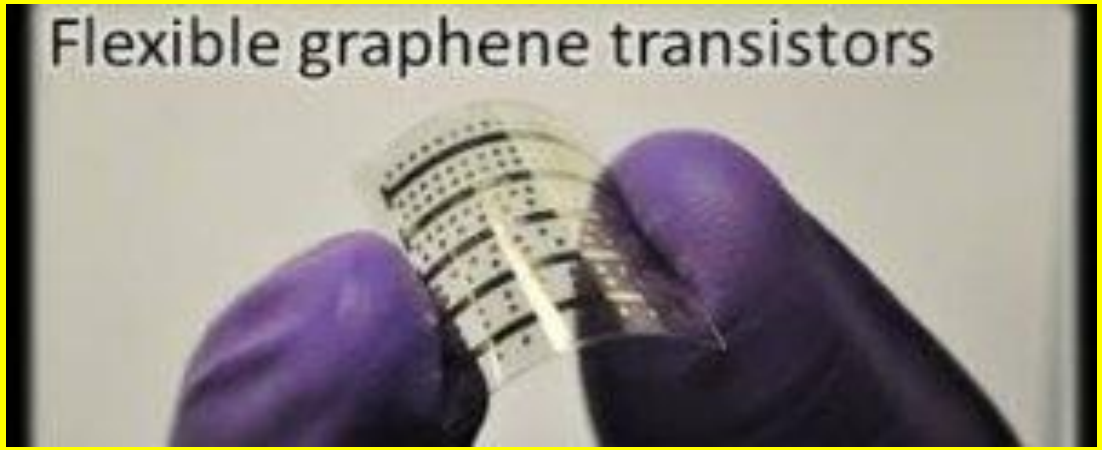
Graphene Masterbatches

Graphene masterbatches are composite materials that have a graphene-based compound (most frequently GO) and a polymer. The graphene is used to improve the properties of a range of common polymeric materials. Many polymers display desirable properties such as low toxicity, bio-compatibility, low cost, and chemical resistance, but they lack the necessary mechanical properties. By adding graphene into polymer matrices, the polymers keep their original properties but benefit from improved stiffness and rigidity, while still being lightweight.

Properties of Graphene

Graphene has many unique and necessary properties because of its all carbon structure and nanoscale geometry.

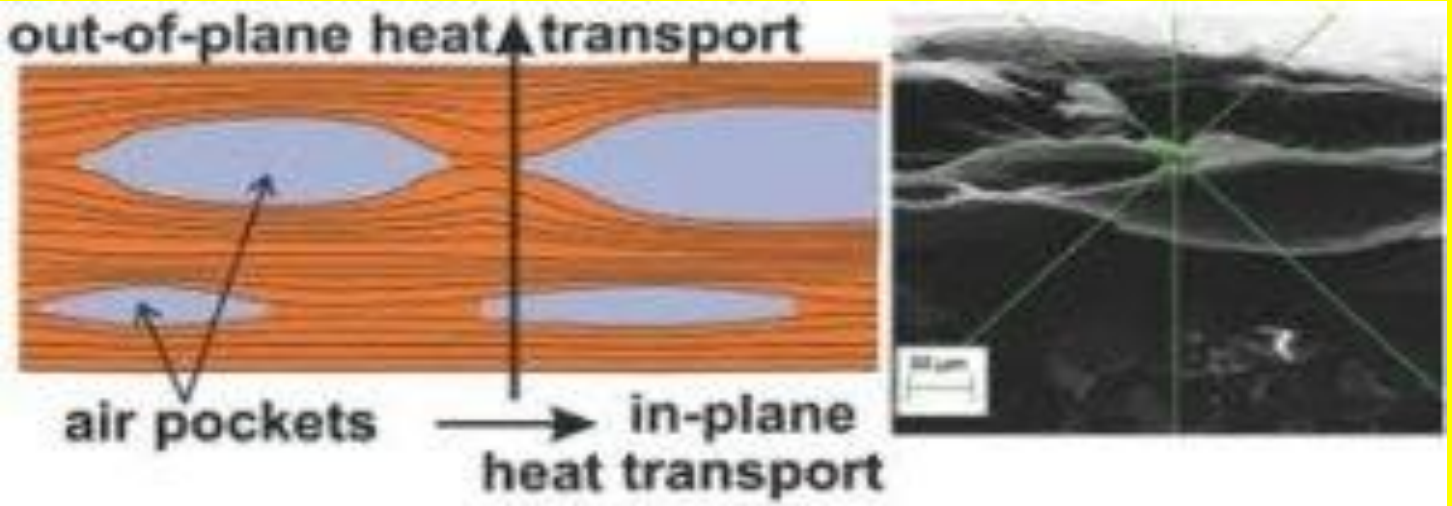
Electronic Properties



Flexible Graphene Transistors

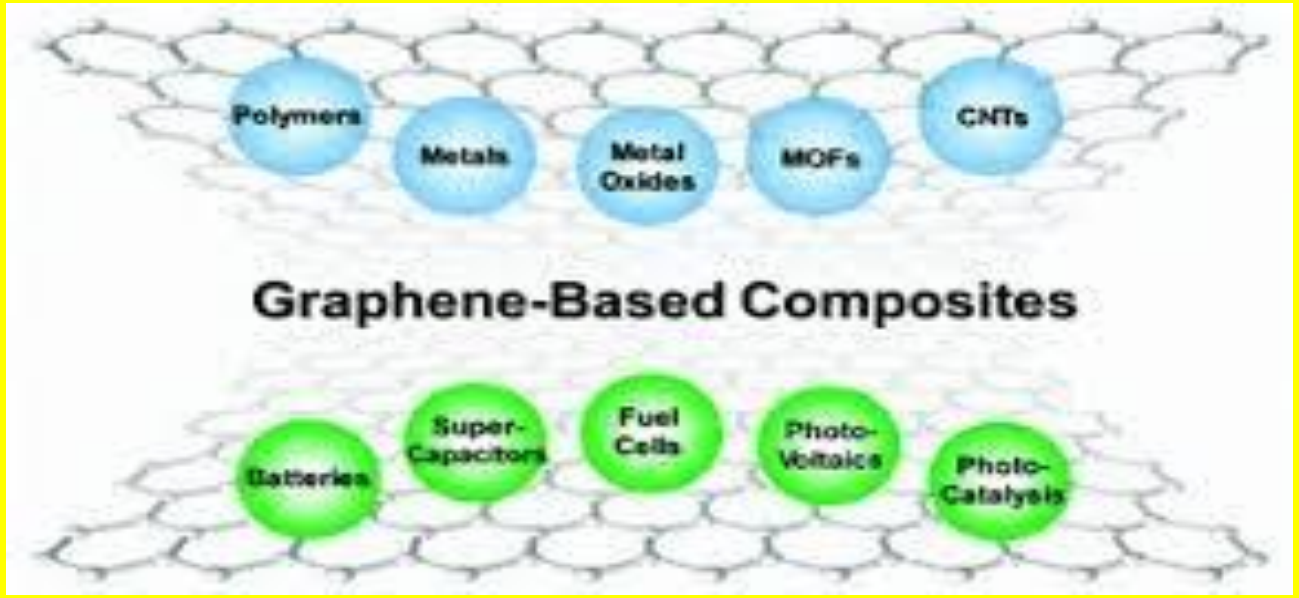
As graphene has a delocalized pi-electron system across the totality of its surface, the movement of electrons is extremely fluid. The graphene system also displays no band gap, because of overlapped pi-electrons, allowing for a smooth movement of electrons without the need to input energy into the system. **$cm^2\ V^{-1}\ s^{-1}$.**

Thermal Properties



The repeating structure of graphene makes it a suitable material to conduct heat in plane. Interplane conductivity is challenging and normally other nanomaterials such as CNTs are added to increase interplane conductivity.

Mechanical Strength



Graphene's Strength Enables High Performance Composites

Graphene is one of the sturdiest materials ever discovered possessing a tensile strength of 1.3 x 10^{11} Pa. Besides having an unsurpassed strength, it is also extremely lightweight (0.77 mg m^{-2}). The graphene's mechanical strength is unrivalled and as such can considerably improve strength in a number of composite materials.

Flexibility / Elasticity

The repeating sp^2 hybridized backbone of graphene molecules permit flexibility, as there is rotation around few of the bonds, whilst still providing sufficient rigidity and stability that the molecule can endure variations in conformation and support other ions. This is a highly desirable property as there are not many molecules that can be flexible and supportive at the same time. With regards to its elasticity, graphene has found to possess a spring constant between 1 and 5 N m^{-1}, with a Young's modulus of 0.5 TPa.

Applications of Graphene

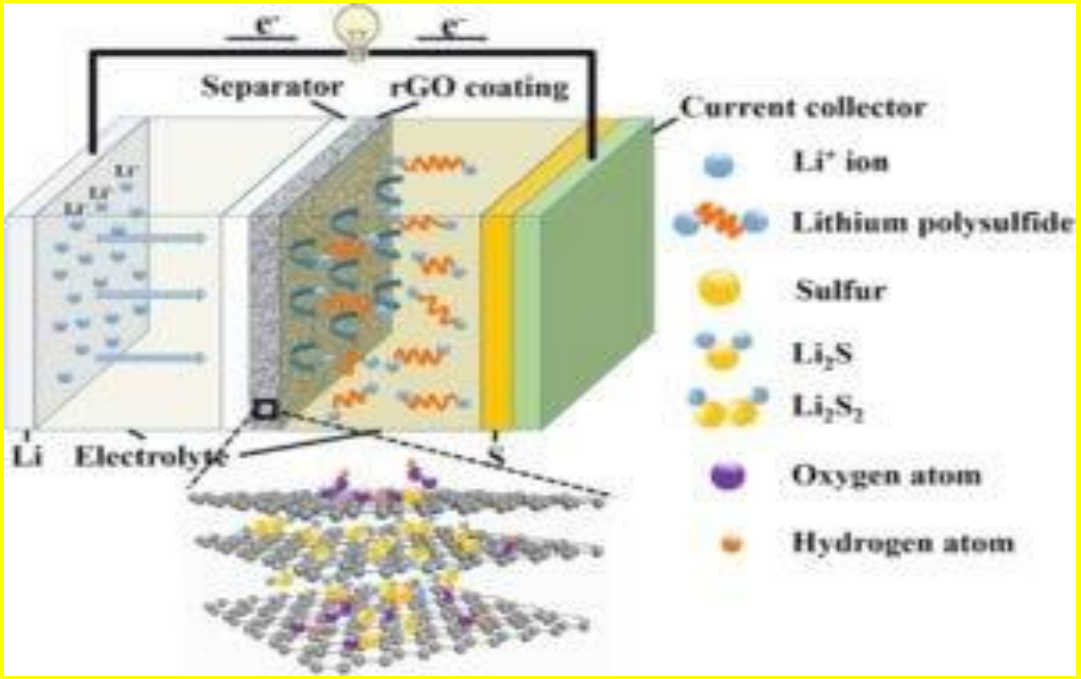
Graphene is a ground-breaking material. It has numerous applications substituting conventional materials as well as the ability to support applications formerly not possible before the arrival of 2D materials. The applications of graphene are truly infinite, and many are yet to be discovered.

Sensors

The perfect sensor can detect miniscule changes in its surrounding environment. Due to the planar and consistent arrangement of atoms in a graphene sheet, all the atoms within the sheet are exposed to the surrounding environment.

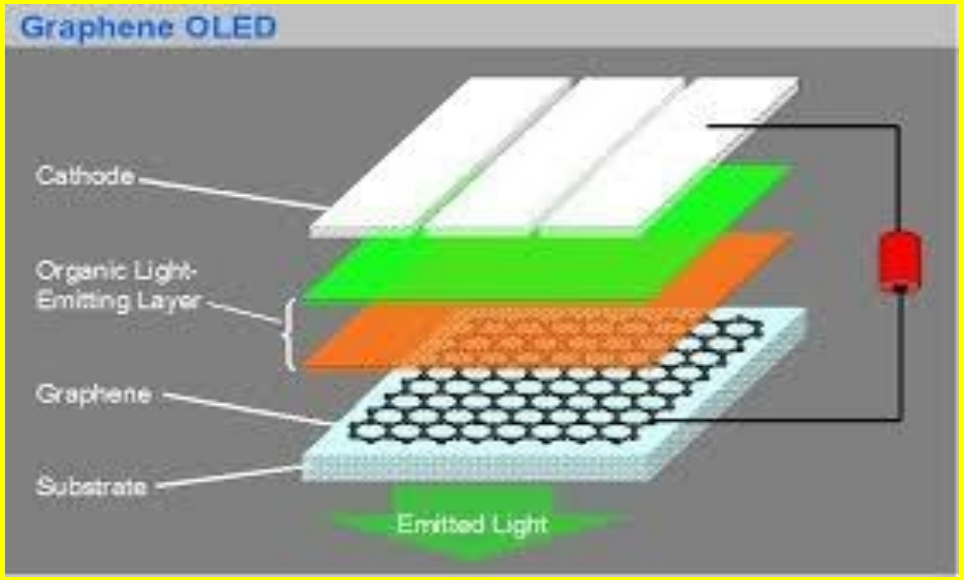
Newly Developed Graphene Biosensor Could Provide Early Lung Cancer Diagnosis.

Graphene-Lithium-Sulfur Battery



Graphene can be added into both the anode as well as the cathode in a range of battery systems to boost the efficiency of the battery and enhance the charge/discharge cycle rate. The exceptional electrical conductivity, surface area, and dispersibility of graphene improve the useful properties found in many traditional inorganic-based electrodes, whilst simultaneously relieving the electrodes of their limitations.

Electron Emission Displays



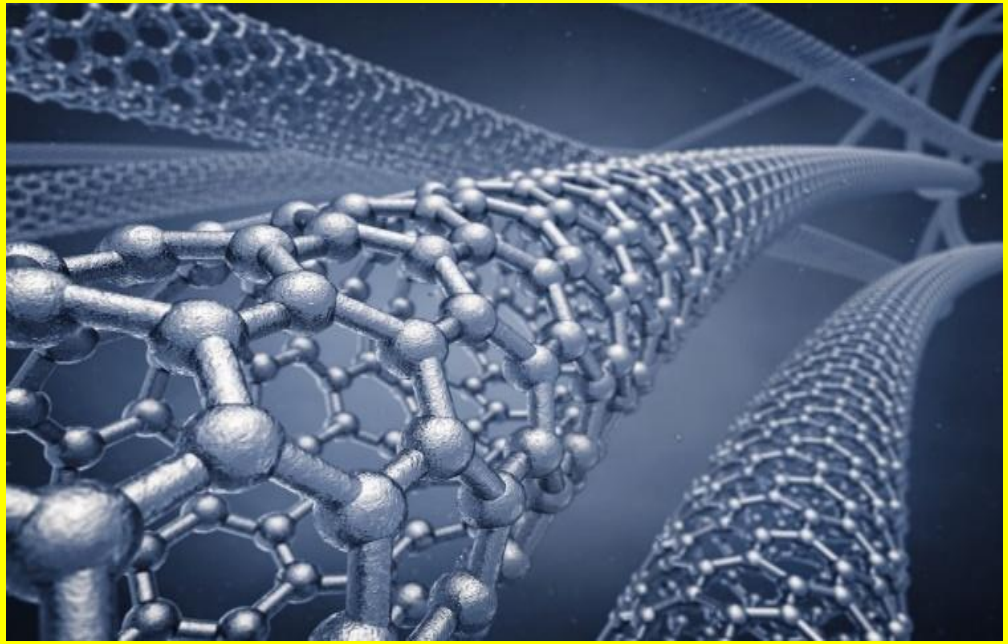
Graphene Displays

Graphene is an ideal material for use in electron emission displays as it displays a high aspect ratio and the dangling bonds at either end of the sheet permit for efficient electron tunnelling.

Structural Composites

Graphene is added into a range of composites for applications where weight and strength are limiting factors, for instance in the aerospace sector. Graphene is being added to numerous materials to make the current material more lightweight and stronger. For the aviation sector, a composite material which is much lighter than steel but will still provide the required strength will save plenty of money on fuel consumption.

Graphene Nanotubes and Nanoribbons



Graphene is a one-atom thick, two-dimensional layer of carbon atoms in a honeycomb structure. Its intriguing electrical, optical, and mechanical qualities have sparked monumental interest from various scientific fields.

Carbon Nanotubes

Carbon nanotubes are essentially rolled up sheets of graphene that can be as long as millimetres, but still retain nanometre dimensions. Nanotubes can be single-walled or have multiple walls, being essentially cylinders within cylinders.

Graphene has received an astonishing amount of interest these past few years, so much so that now it is commonly referred to as the miracle material that’s predicted to revolutionize the 21st century. However, all of this interest, and by extension, potential for commercialization, stems from graphene’s unique properties; it’s one-atom thick, incredibly strong, flexible, and a great electrical and thermal conductor, to name but a few.

How Graphene is Making Building with Concrete Greener

New research suggests that graphene could make concrete stronger, more water-resistant and greener than current forms of the building material.

The so-called super material, graphene, has been added to concrete in order to form a brand-new composite material. During testing, the material has shown to be twice as strong as regular concrete and four times more water-resistant.

Making Brain Probes More Sensitive with Graphene

Human brain disorders, such as epilepsy, depression, migraine, schizophrenia, autism, and dementia, emerge when large-scale interactions within the brain are disrupted. Severe damage to the central nervous system of the body occurs as a result of extensive traumatic and degenerative lesions.

Graphene helps to make Brain Probes more sensitive and detection of the problem.

Graphene as a Renewable Energy

There is a huge demand to find renewable alternatives to our traditional, finite energy sources. The elements are already playing an important role – only this year wind and solar energy generated more energy over a three-month period than coal – but other substitutes are still required.

Renewable Fuels

Researchers at the University of Manchester have recently discovered that graphene membranes, when illuminated with sunlight, can conduct protons at an increased rate. This photo-proton effect could be employed to artificially mimic photosynthesis and directly harvest solar energy to produce hydrogen gas. This gas, could then be used in fuel cells in electric vehicles.

Photovoltaic Cells

Eight thousand times more solar energy is produced each year than is consumed worldwide; while some of the power reaching the Earth is harvested and utilized, a massive percentage is not. As energy need increase, solar power is becoming an attractive alternative, but its efficiency is still lagging. Furthermore, commercially available silicon-based photovoltaic cells are expensive to produce and install.

Graphene could have an important role to play here too, in anti-reflection coatings for solar cells. Researchers in India found that such cells lower reflectance near the ultraviolet part of the spectrum from 35% to 15%.

The Optical Properties of Graphene

Graphene exhibits some excellent optical properties, but again, these properties vary between the different types of graphene. Graphene, i.e. a pure CVD-grown monolayer of graphene, is a very transparent material, hence its used in optical devices. A single sheet of graphene will only absorb a maximum of 2.3% of incoming light (i.e. a 97.7% optical transmittance) with less than 0.1% reflectance.

A research team based at The University of Manchester has discovered a novel, low-cost technique for creating graphene printed electronics which considerably expedites and lowers the cost of conductive graphene inks.

Printed electronics bring innovation to the penetration of information technology into daily life. The spread of the internet of things, or IoT, applications will be further promoted by the prospects of printing electronic circuits.

Industrial and Commercial Uses of Graphene in 2018

Graphene a marked 2018 by launching a host of original products geared towards the commercial and industrial use of graphene, recruiting more experienced staff and continuing to provide high-quality graphene for advanced research and industrial use.

Graphene Wafers

In January, a company already began selling 6” graphene wafers on all their standard substrates along with user-provided ones.

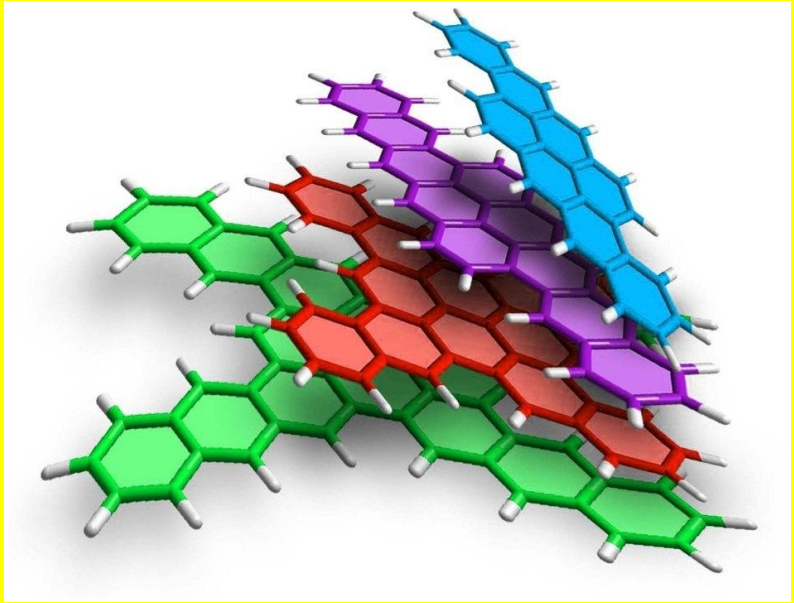
Applications of Graphene Field Effect Transistor

Being the most frequently used graphene device, The GFET's applications include magnetic sensors, detection of dangerous chemicals, high-speed photodetectors for optical communications and biomedical applications.

GFET – graphene field effect transistors

Graphene Foundry Service

Following up on GFET and 6" wafers, Graphene was introduced in foundry service for bespoke graphene circuits printed on the 6" wafers.

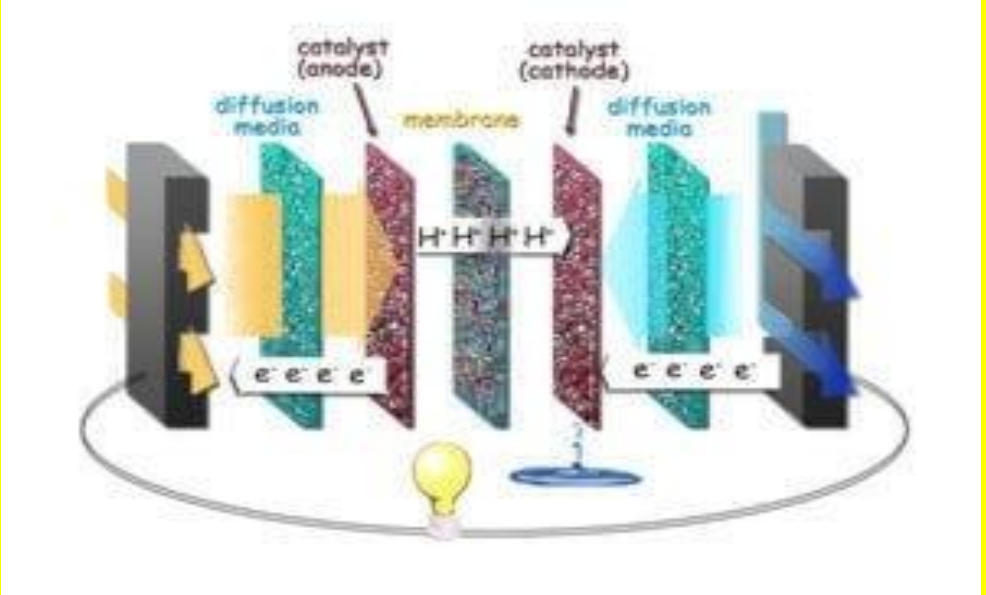


A New Approach to Create Waterproof Graphene-Based Sensors

The electrical resistance of graphene—a two-dimensional (2D) material—is generally distorted by water molecules, but now a group of European researchers has reported that contact resistance is not affected by humidity when graphene is incorporated with the metal of a circuit.

Graphene Fuel Cells

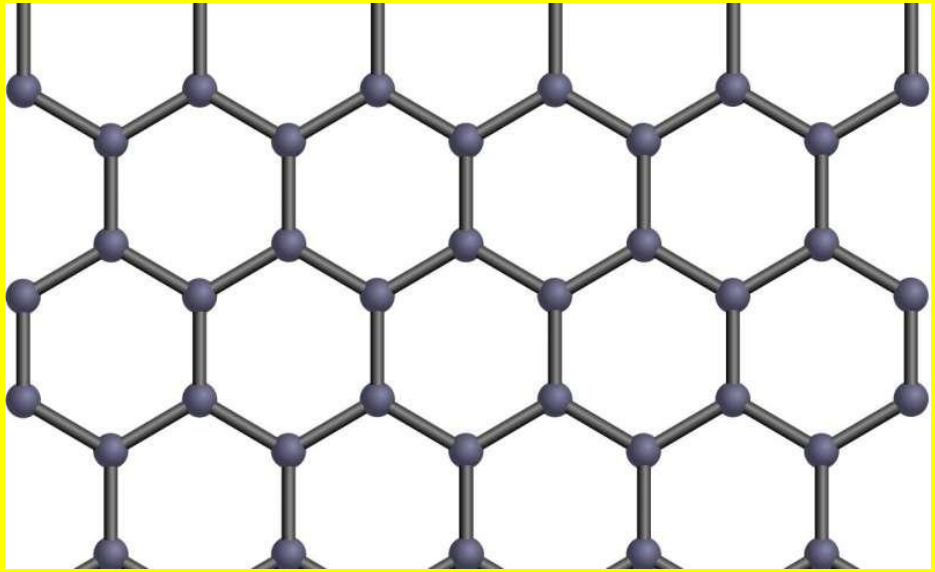
Unlike batteries and capacitors, fuel cells generate electricity rather than store it. Many fuel cells consist of a platinum-based catalyst, which is very expensive to produce. The cost of fuel cells can be lowered using carbon allotropes as a support for the platinum catalysts. One such catalyst support is graphene.



A fuel cell inside view

1 + 1 does not equal 2 for graphene-like 2-D materials

Physicists from the University of Sheffield have discovered that when two atomically thin graphene-like materials are placed on top of each other their properties change, and a material with novel hybrid properties emerges, paving the way for design of new materials and nano-devices.



What's so special about Graphene?

In 2004, researchers from the University of Manchester successfully extracted **one atom thick, 2D crystal graphene from graphite.**[2]

THIS MAKES GRAPHENE: [3,4]

World's first **2D material** ever known.

Thinnest and lightest object ever obtained — million times thinner than human hair.

World's strongest material, harder than diamond and 300 times stronger than steel.

Bendable, can take any form you want.

A **good conductor of electricity**, much better than copper.

A **transparent** material.

THESE UNIQUE QUALITIES GIVE GRAPHENE THE CAPABILITY TO DO SO MUCH, BUT WHAT EXACTLY COULD IT BE USED FOR?

NEXT GENERATION ELECTRONICS

1

Flexible and foldable screens

The flexibility of graphene could bring phones you wrap round your wrist and TV screens you could roll up like a newspaper.

2

Enhanced batteries

Batteries would charge in seconds and last longer. Their lightness and flexibility could bring batteries stitched into clothing that measure heart rate and predict health problems.[5 6 7]

3

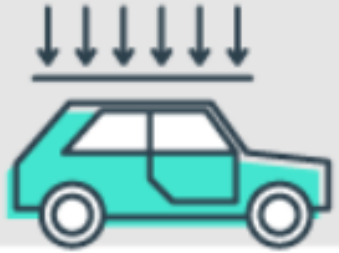
Lightning speed computers

Graphene transistors could replace silicon, operating at 100 GHz. Current processors work at 2.9 GHz.[8 9]

INNOVATIVE TRANSPORT

4 **Rust-free future**

Coating of graphene in paint could end deterioration of ships and cars.[10]



5 **Fuel-efficient cars**

Converting heat to energy could power: air conditioning, power steering or stored in car battery.[11]

6 **Faster and lighter aircraft**

Structural components made from graphene would be extremely lightweight and fuel efficient.[12]

GAME-CHANGING SPORT

7

Tennis racquets

HEAD have produced racquets made with graphene, distributing weight where it's needed for ultimate performance.[13]

8

Cycling helmets

Catlike has used graphene to protect cyclists' skulls with maximum durability and minimum weight.[14]

9

Skis

Graphene allows skis to be stiff but flexible, as well as lighter, easier to control, and more balanced.[14]

TRANSFORMATIONAL MEDICAL TECH

10 **Replacement nerves**

Using 3D bioprinting, replacement nerves would utilise graphene's mechanical strength and electrical conductivity.[15]

11 **Cancer killer**

Graphene oxide may act as an anti-cancer agent that selectively targets cancer stem cells, shrinking tumors.[15]

12 **Night vision contact lenses**

The ultra-thin and flexible material could replace the bulky night vision headset used by soldiers and spies.[16]

PLANET SAVING SOLUTIONS

13

Protect crops from harmful gases

Graphene sensors could detect minute dangerous particles allowing farmers to take relevant action.[17]

14

Storing wind and solar power

The University of Manchester are investigating graphene's potential to store wind or solar power, providing clean energy.[5]

15

Clean drinking water

Graphene oxide forms a barrier separating water from pollutants, and could provide clean water for millions in developing countries.[18]

THANK YOU

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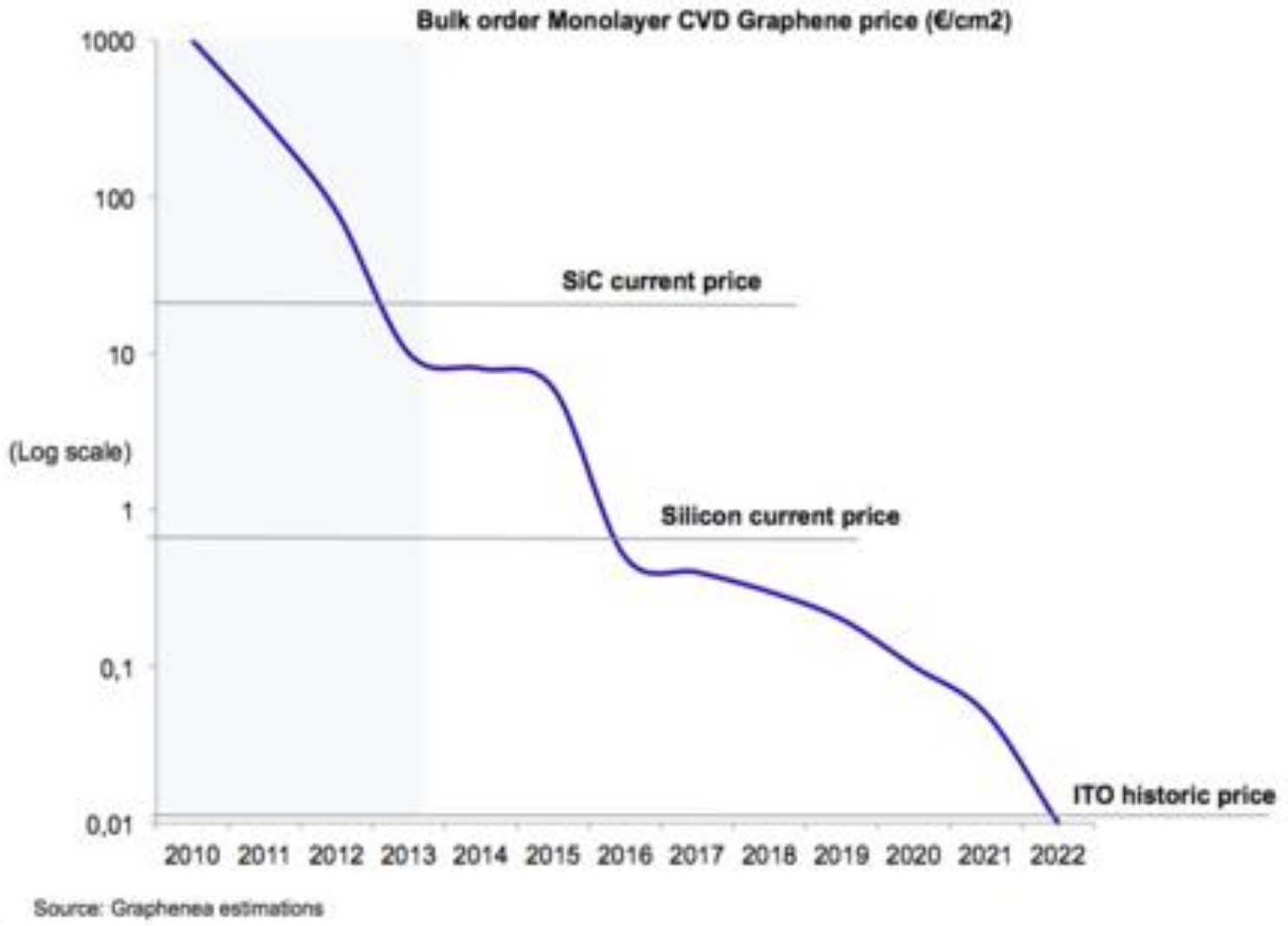
Graphene is intrinsically cheap due to low marginal cost!



Source: Grapheneа estimations

GRAPHENEA

Private and confidential

14