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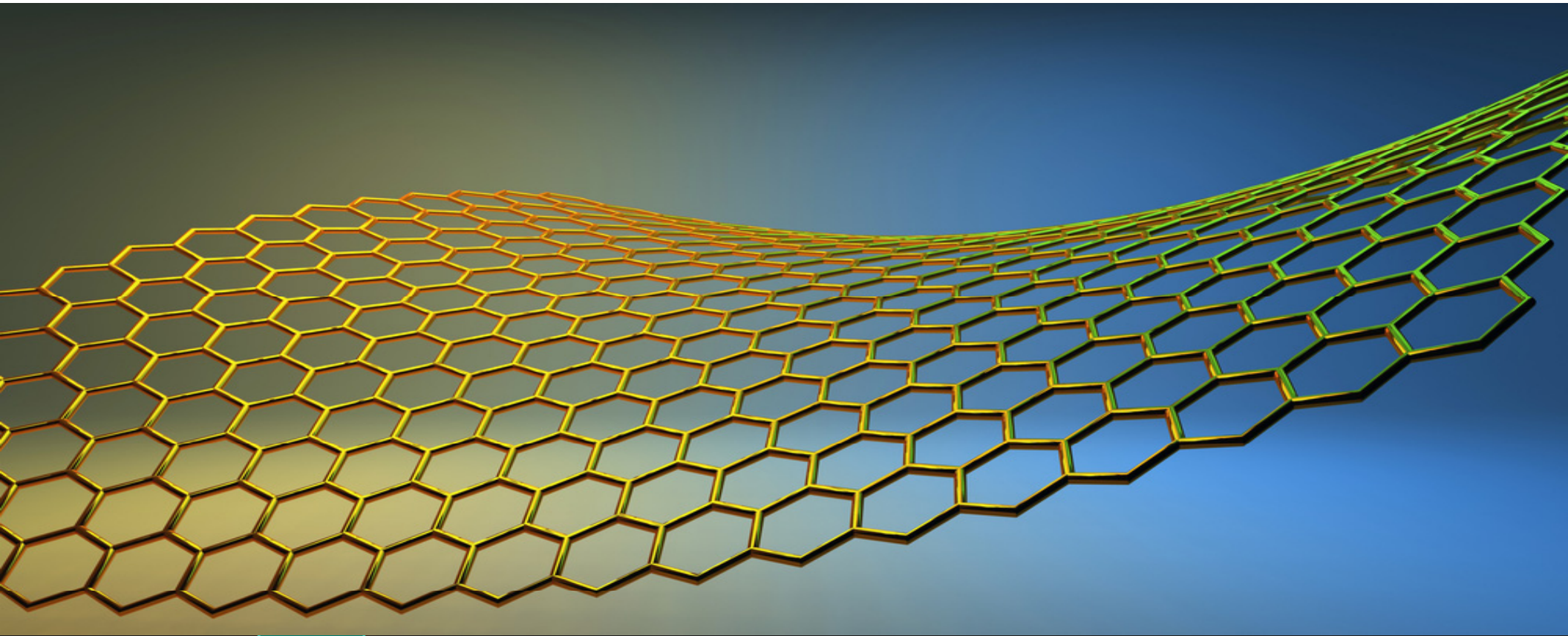
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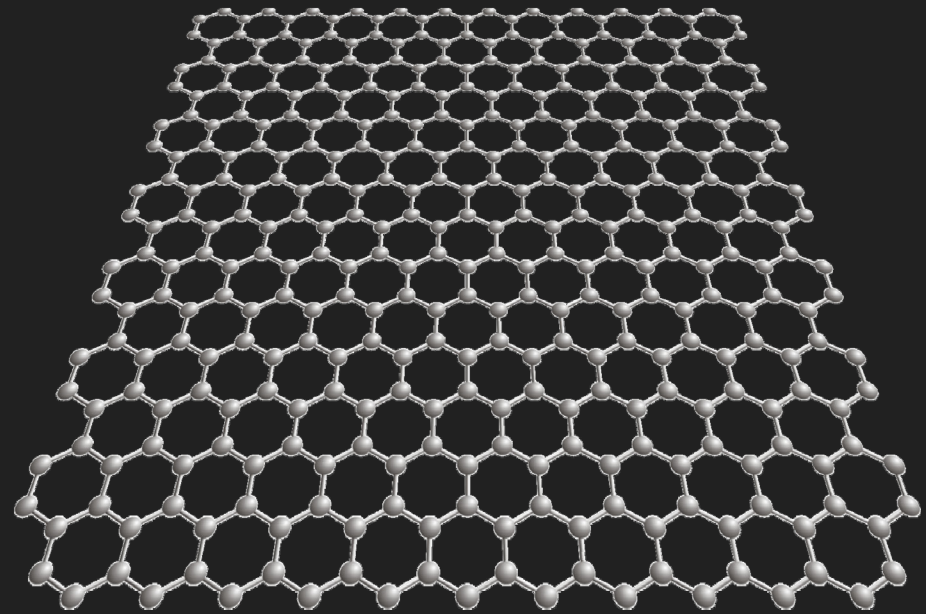




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# Introduction

- Graphene can be described as a one-atom thick layer of graphite.
- It is the basic structural element of other allotropes, including graphite, charcoal, carbon nanotubes and fullerenes.
- Graphene is the strongest, thinnest material known to exist.

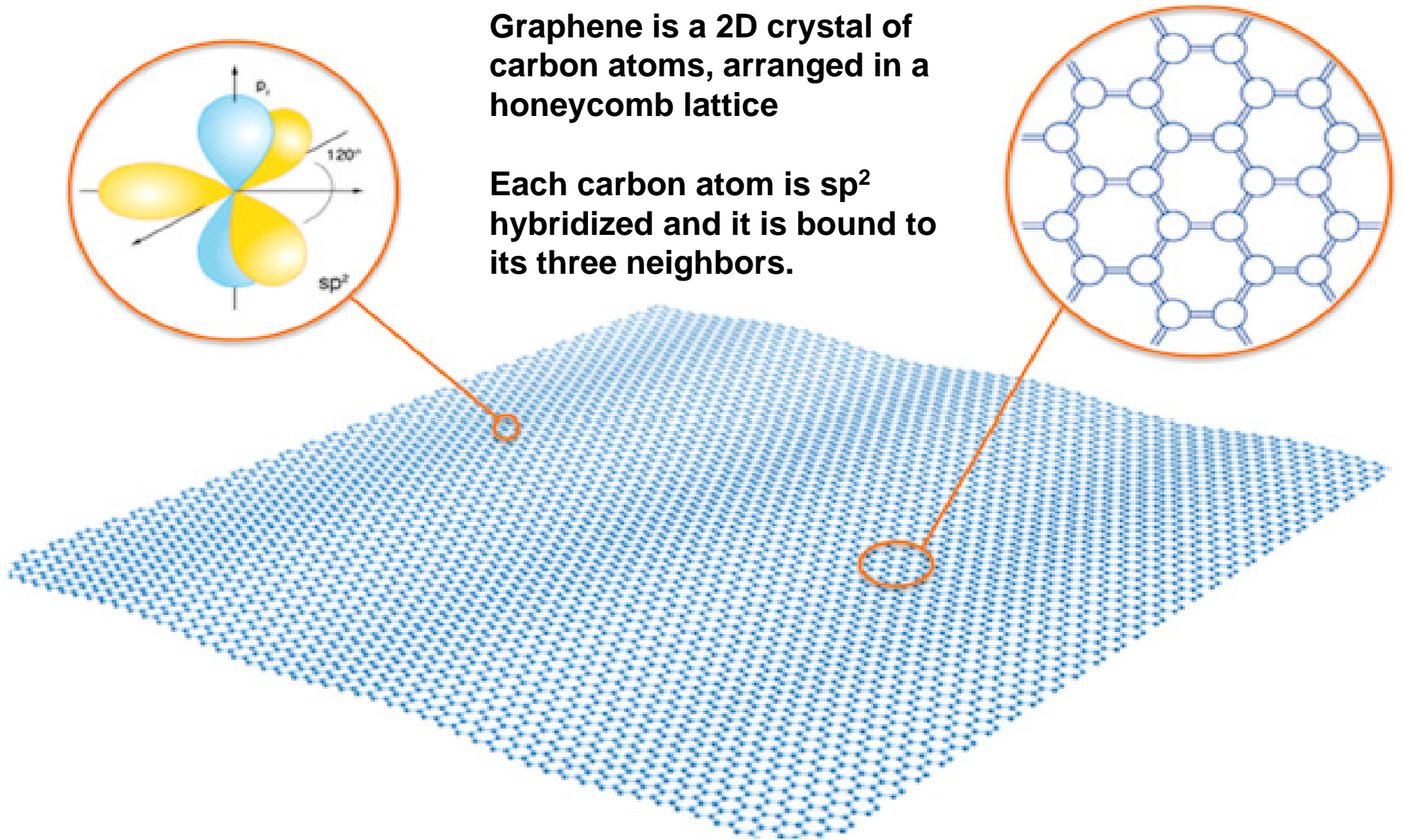


Graphene is an atomic-scale honeycomb lattice made of carbon atoms.



**Graphene is a 2D crystal of carbon atoms, arranged in a honeycomb lattice**

**Each carbon atom is  $sp^2$  hybridized and it is bound to its three neighbors.**



# History

- One of the very first patents pertaining to the production of graphene was filed in October, 2002 entitled, "Nano-scaled Graphene Plates".
- Two years later, in 2004 **Andre Geim** and **Kostya Novoselov** at University of Manchester extracted single-atom-thick crystallites from bulk graphite
- Geim and Novoselov received several awards for their pioneering research on graphene, notably the 2010 Nobel Prize in Physics.

# Structure

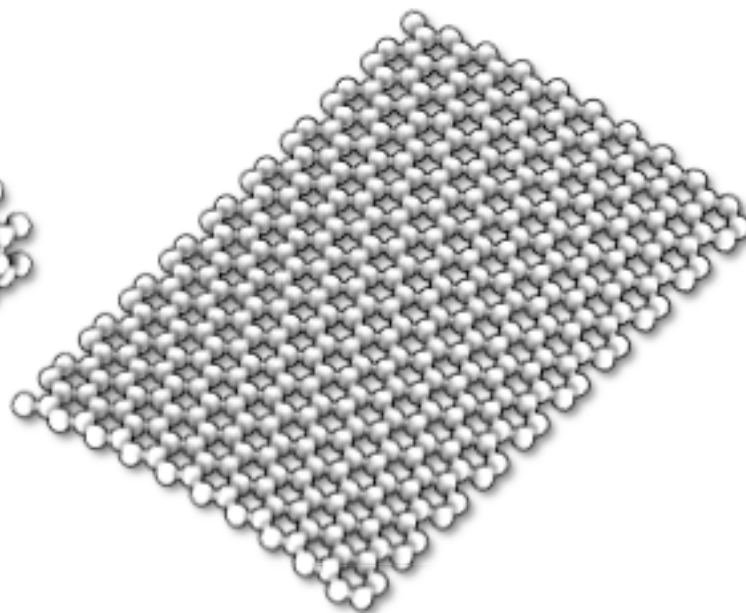
- Graphene is a 2-dimensional network of carbon atoms.
- These carbon atoms are bound within the plane by strong bonds into a honeycomb array comprised of six-membered rings.
- By stacking of these layers on top of each other, the well known 3-dimensional graphite crystal is formed.
- It is a basic building block for graphitic materials of all other dimensionalities.
- It can be wrapped up into 0D fullerenes, rolled into 1D nanotubes or stacked into 3D graphite.
- Thus, graphen is nothing else than a single graphite layer.



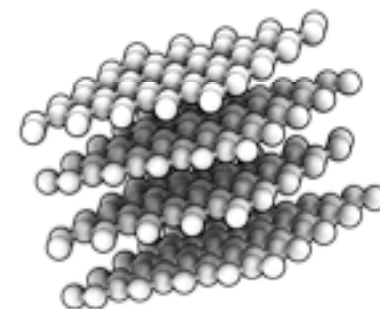
0D - Fullerenes



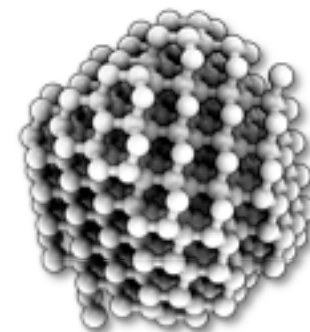
1D - CNTs



2D - Graphene



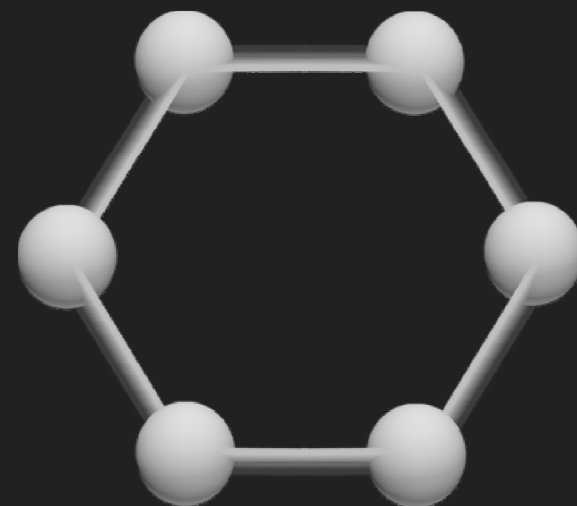
3D - Graphite



3D - Diamond

# Chemical Properties

- Graphene is chemically the most reactive form of carbon.
- Only form of carbon (and generally all solid materials) in which each single atom is in exposure for chemical reaction from two sides (due to the 2D structure).
- Carbon atoms at the edge of graphene sheets have special chemical reactivity.
- graphene burns at very low temperature (e.g., 350 °C).
- Graphene has the highest ratio of edgy carbons (in comparison with similar materials such as carbon nanotubes).
- Graphene is commonly modified with oxygen- and nitrogen-containing functional groups

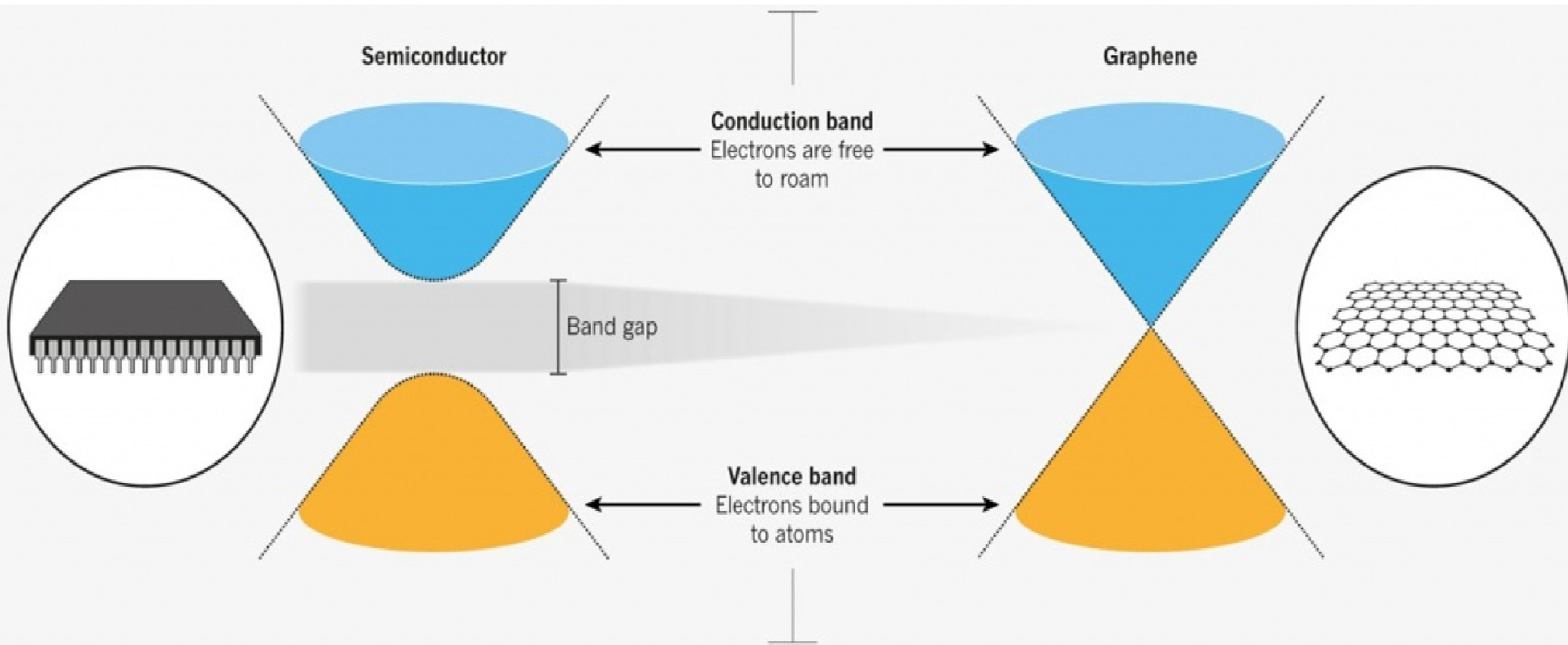


# Electronic Properties

- It is a zero-overlap semimetal (with both holes and electrons as charge carriers) with very high electrical conductivity.
- Electrons are able to flow through graphene more easily than through even copper.
- The electrons travel through the graphene sheet as if they carry no mass, as fast as just one hundredth that of the speed of light.
- High charge carrier mobility, for which values of  $10,000 \text{ cm}^2/\text{Vs}$ , in some cases even  $200,000 \text{ cm}^2/\text{Vs}$  were reported.

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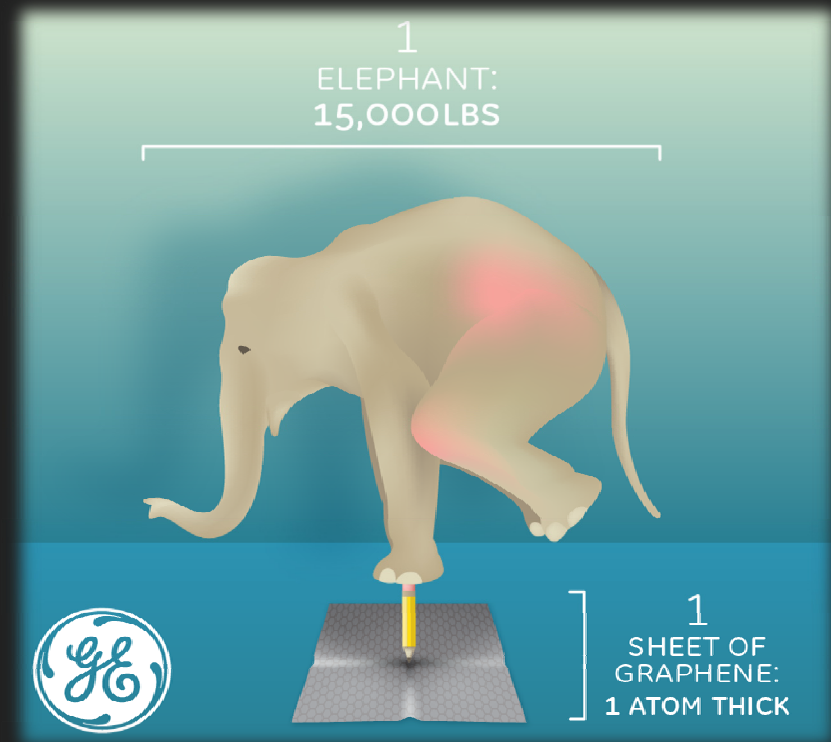




In an insulator or semiconductor, an electron bound to an atom can break free only if it gets enough energy from heat or passing photon to jump the 'band gap'. But in graphene the gap is infinitesimal. This is the main reason why graphene's electron can move easily and very fast

# Mechanical Properties

- To calculate the strength of graphene, scientists used a technique called Atomic Force Microscopy.
- It was found that graphene is harder than diamond and about 300 times harder than steel.
- The tensile strength of graphene exceeds 1 TPa.
- It is stretchable up to 20% of its initial length



It is expected that graphene's mechanical properties will find applications into making a new generation of super strong composite materials and along combined with its optical properties, making flexible displays.

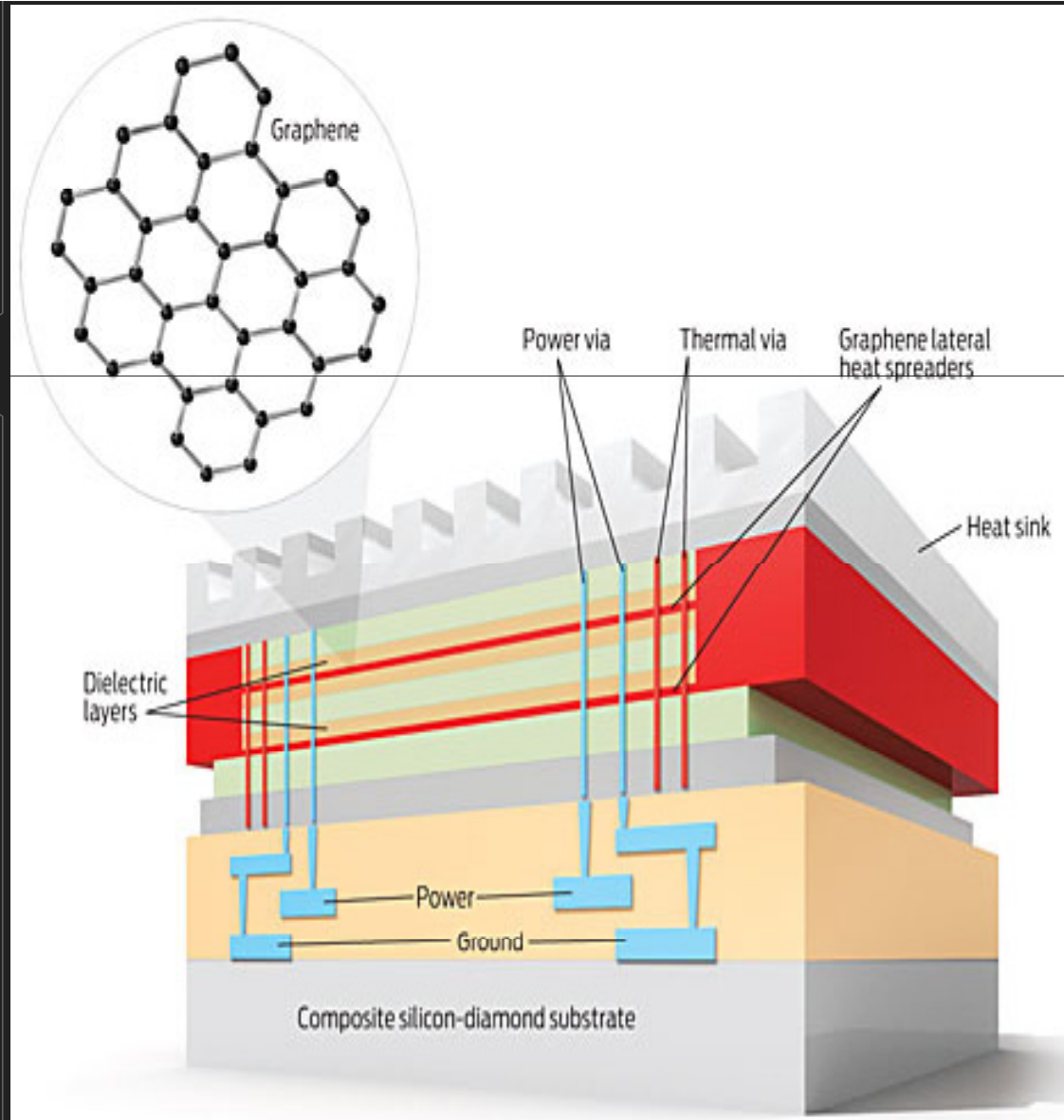


# Thermal Properties

- Graphene is a perfect thermal conductor
- Its thermal conductivity is much higher than all the other carbon structures as carbon nanotubes, graphite and diamond ( $> 5000 \text{ W/m/K}$ ) at room temperature
- Graphite, the 3 D version of graphene, shows a thermal conductivity about 5 times smaller ( $1000 \text{ W/m/K}$ )
- The ballistic thermal conductance of graphene is isotropic, i.e. same in all directions

The material's high electron mobility and high thermal conductivity could lead to chips that are not only faster but also better at dissipating heat.

This schematic shows a three-dimensional stacked chip with layers of graphene acting as heat spreaders.



# Optical Properties

- Graphene, despite it is only 1 atom thick, is still visible to the naked eye.
- Due to its unique electronic properties, it absorbs a high 2.3% of light that passes through it.

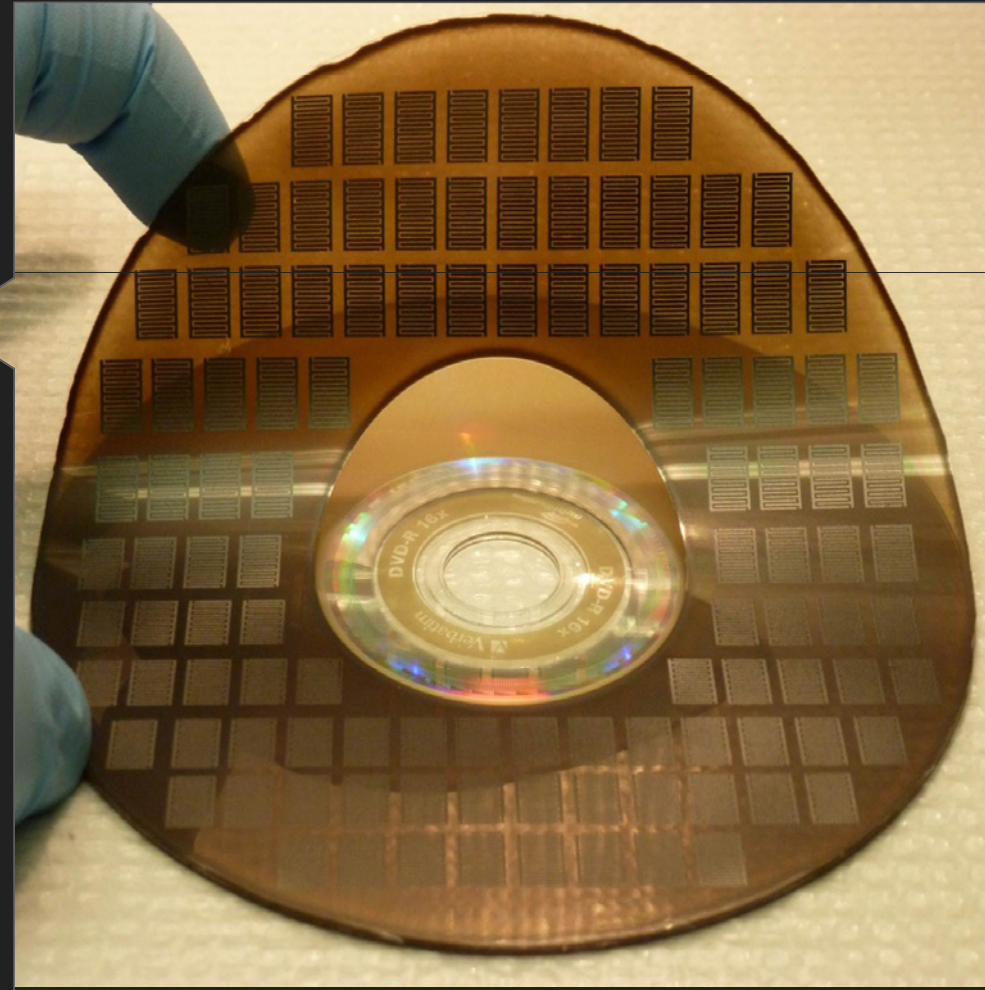


Photograph of graphene in transmitted light. This one-atom-thick crystal can be seen with the naked eye.



# Applications

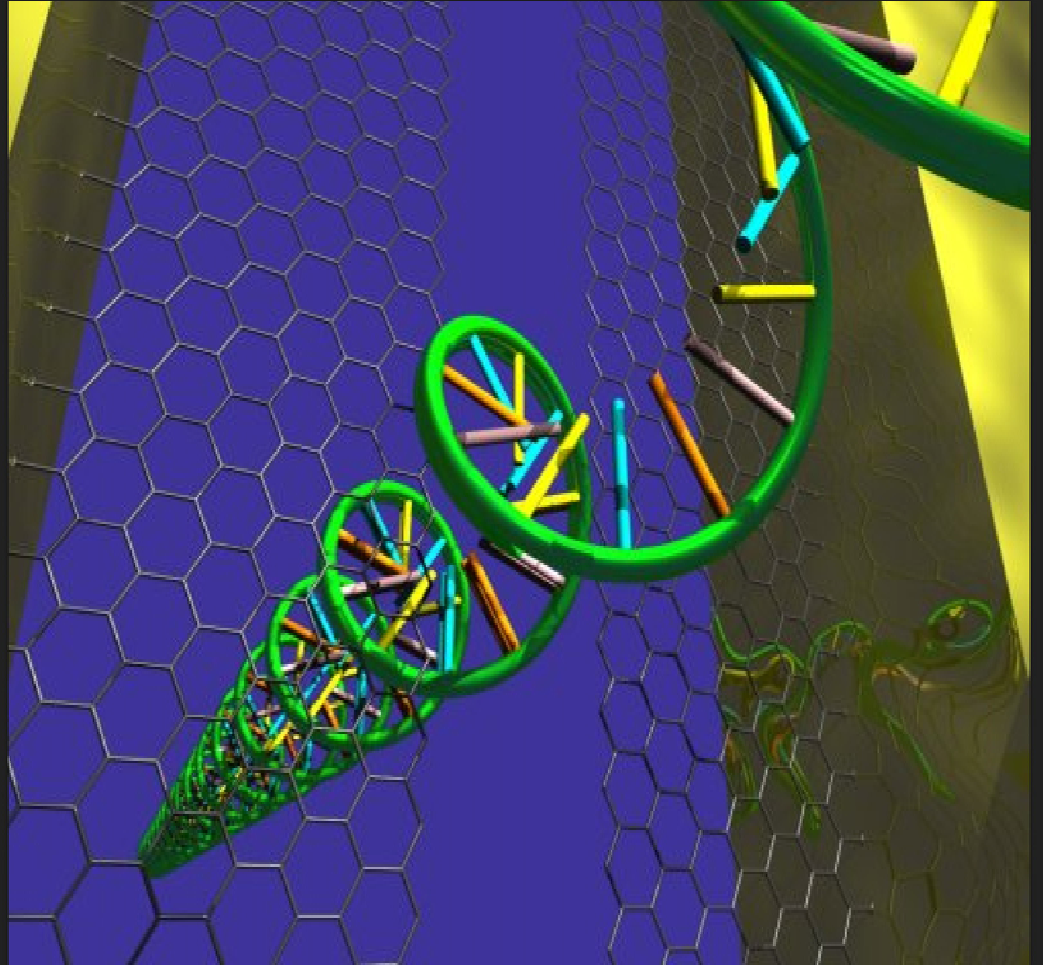
While as of 2014, graphene is not used in commercial applications, many have been proposed and/or are under active development, in areas including electronics, biological engineering, filtration, lightweight/strong composite materials, photovoltaics and energy storage.



# Biomedical

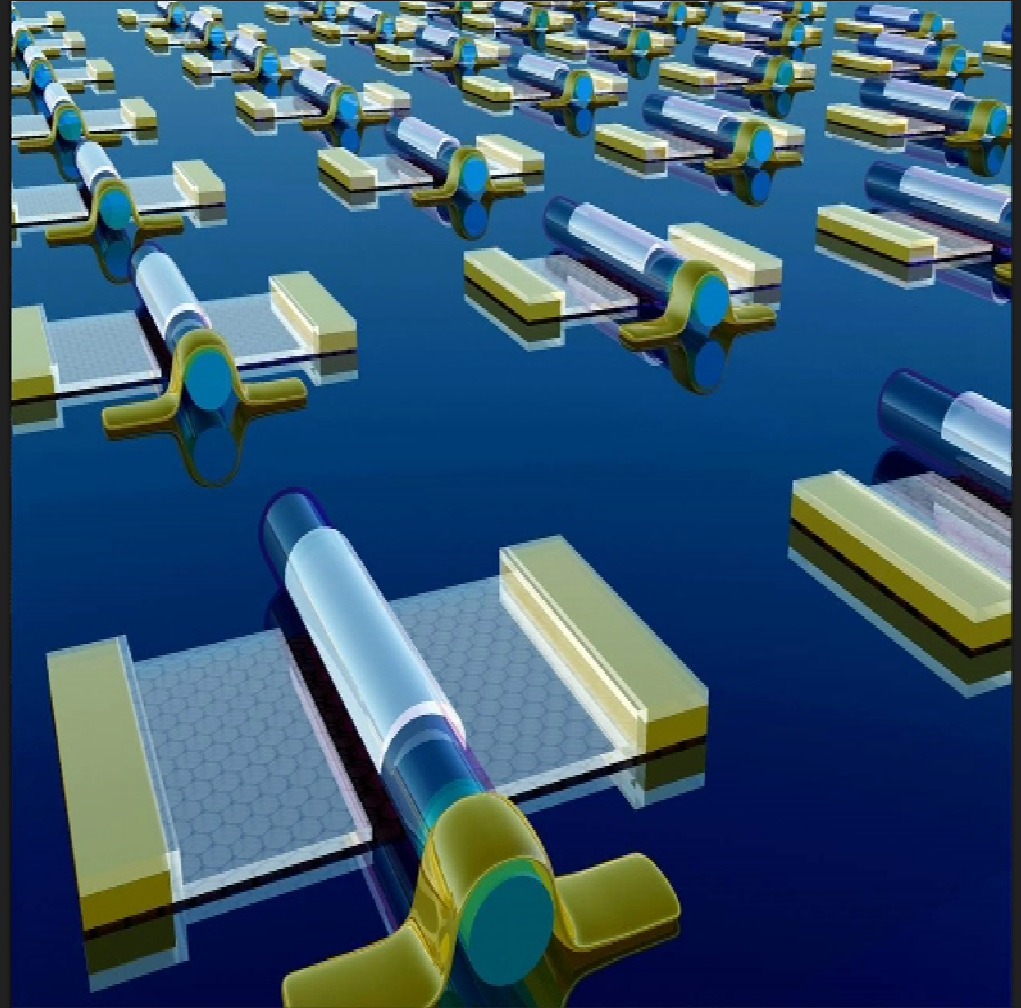
Graphene could soon be used to analyze DNA at a record-breaking pace.

That's the claim of a physicist in the US who has proposed a new way of reading the sequence of chemical bases in a DNA strand by sending the molecule through a tiny slit in a graphene sheet.



# Integrated circuits

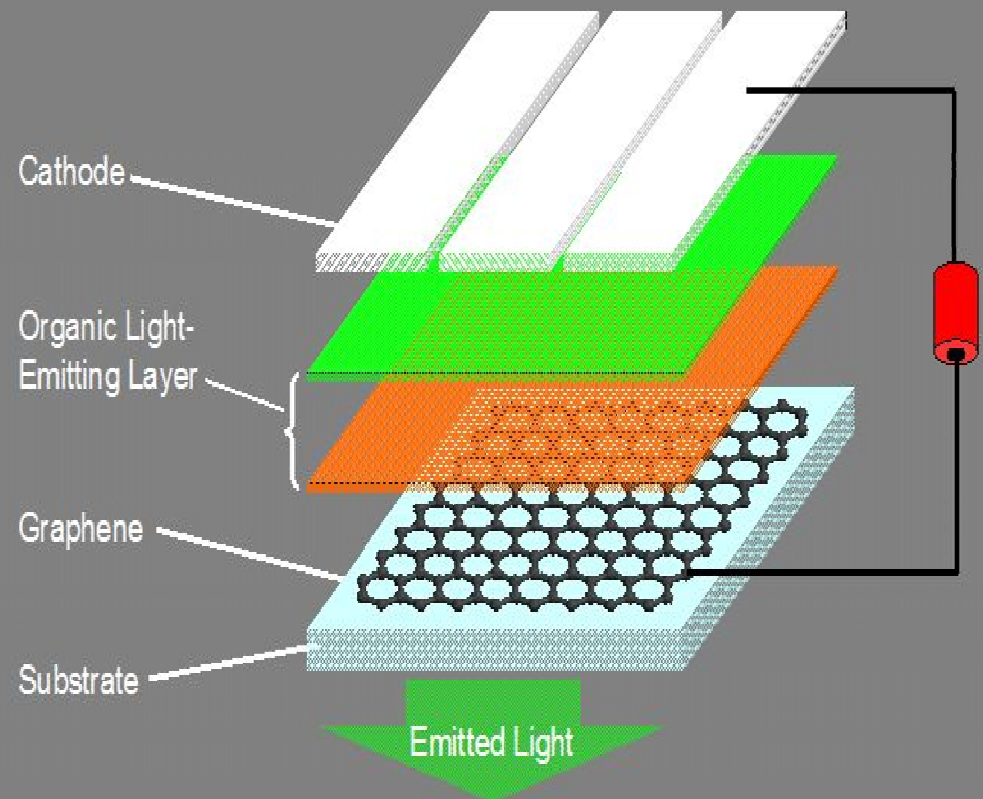
- Graphene has a high carrier mobility, as well as low noise, allowing it to be used as the channel in a field-effect transistor.
- Processors using 100 GHz transistors on 2-inch (51 mm) graphene sheets.
- Graphene-based integrated circuit handled frequencies up to 10 GHz.
- Transistors printed on flexible plastic that operate at 25 gigahertz
- Terahertz-speed transistor



# Optical Electronics

- Graphene's high electrical conductivity and high optical transparency make it a candidate for transparent conducting electrodes.
- Graphene's mechanical strength and flexibility are advantageous compared to indium tin oxide, which is brittle.
- So it would work very well in optoelectronic applications: touchscreens, liquid crystal displays, organic photovoltaic cells, and organic light-emitting diodes.

Graphene OLED



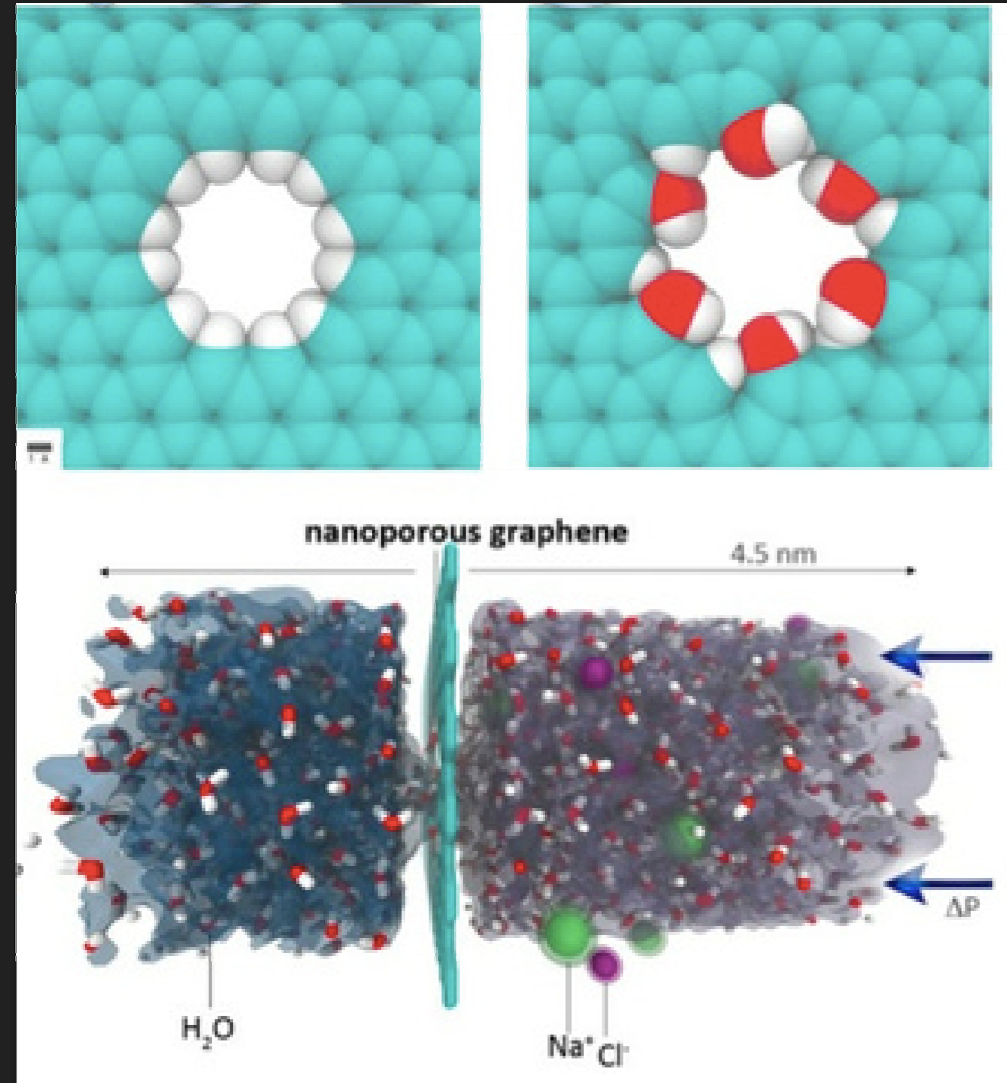


# Filters

**Desalination**: By very precise control over the size of the holes in the graphene sheet, graphene oxide filters could outperform other techniques of desalination by a significant margin.

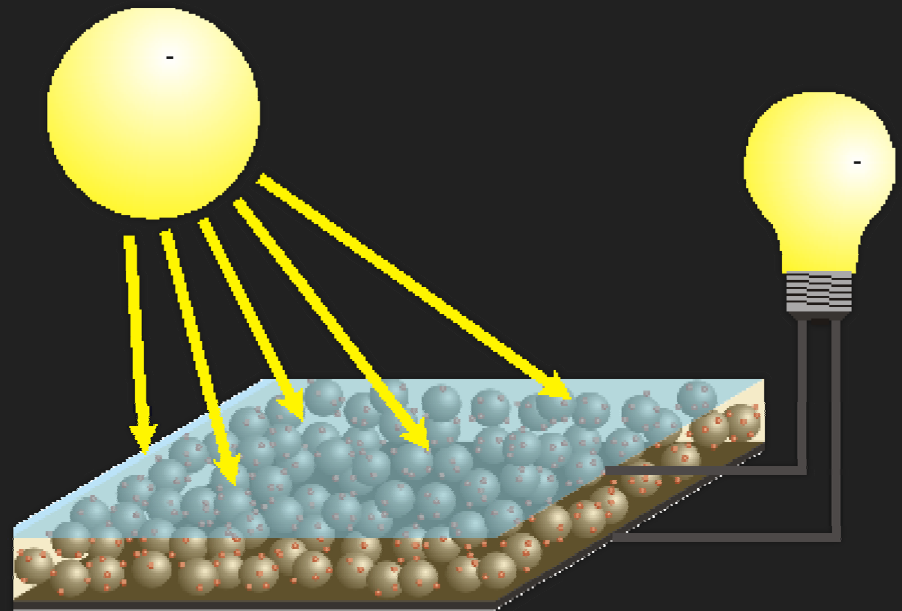
**Ethanol distillation**: Graphene oxide membranes allow water vapor to pass through, but are impermeable to other liquids and gases.

Such membranes could revolutionize the economics of biofuel production and the alcoholic beverage industry



# Solar cells

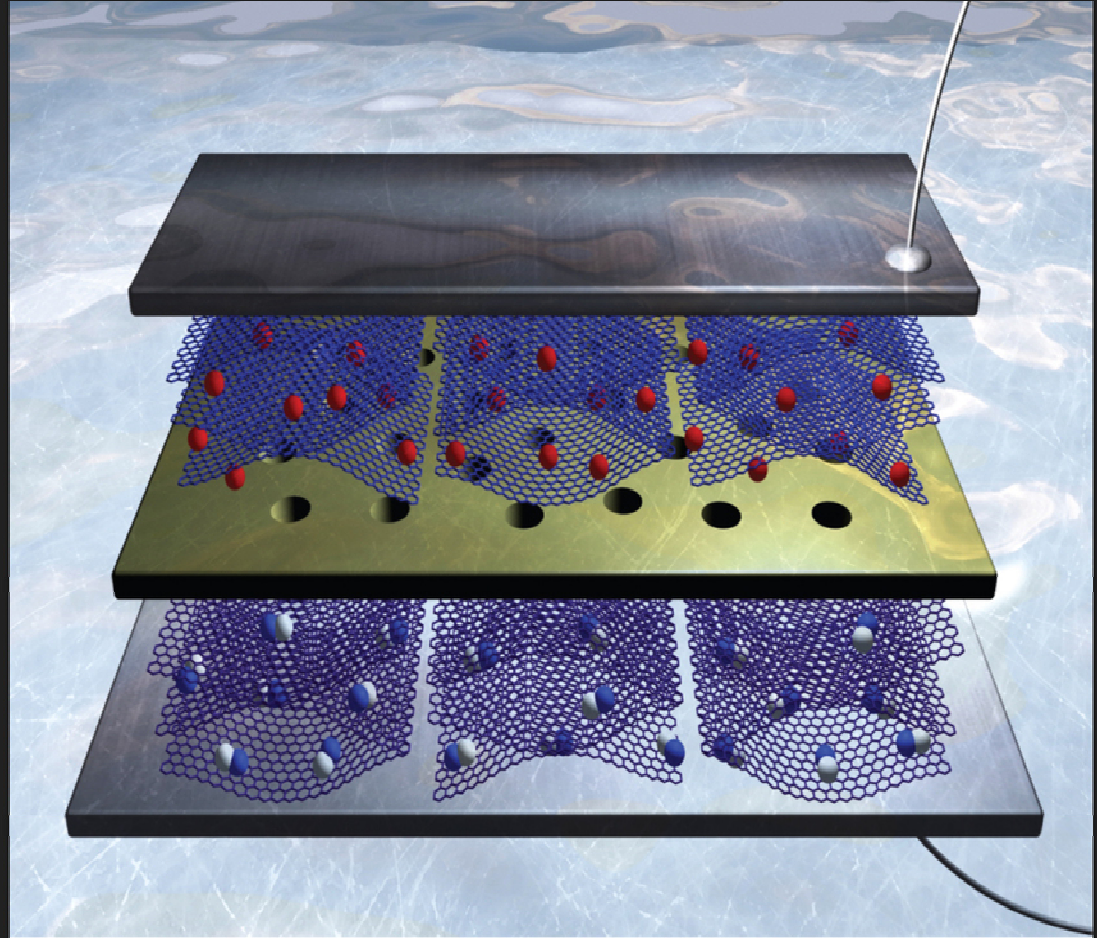
- Graphene turned to be a promising material for photoelectrochemical energy conversion in dye sensitized solar cells.
- The transparent, conductive, and ultrathin graphene films are fabricated from exfoliated graphite oxide, followed by thermal reduction.
- The obtained films exhibit a high conductivity of 550 S/cm and a transparency of more than 70% over 1000-3000 nm.





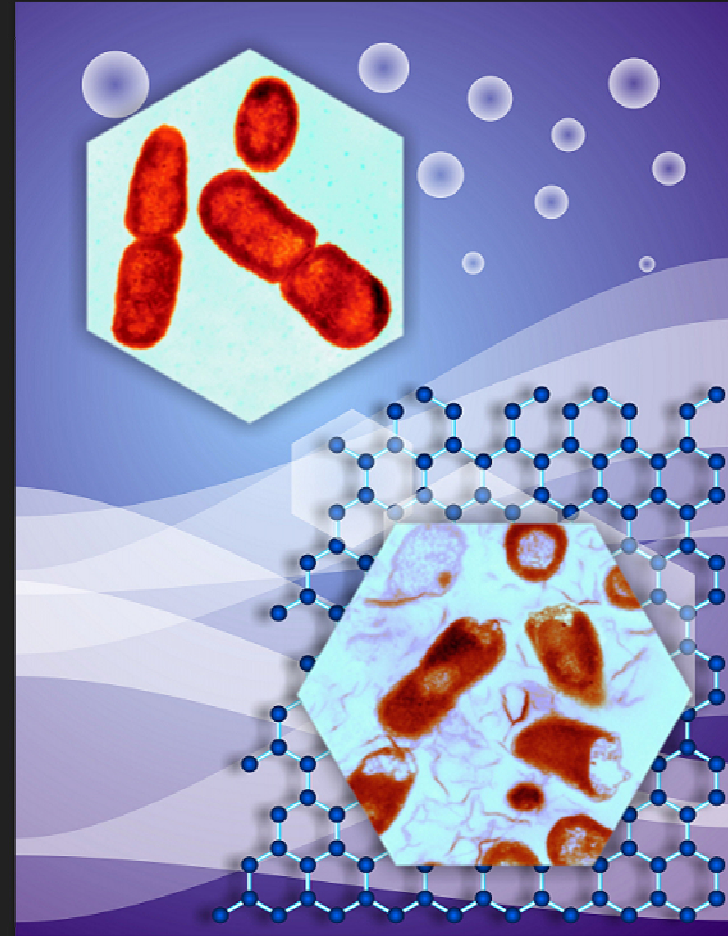
# Energy Storage Devices

- Due to the extremely high surface area to mass ratio of graphene, one potential application is in the conductive plates of Supercapacitors.
- It is believed that graphene could be used to produce Supercapacitors with a greater energy storage density than is currently available.



# Anti-Bacterial

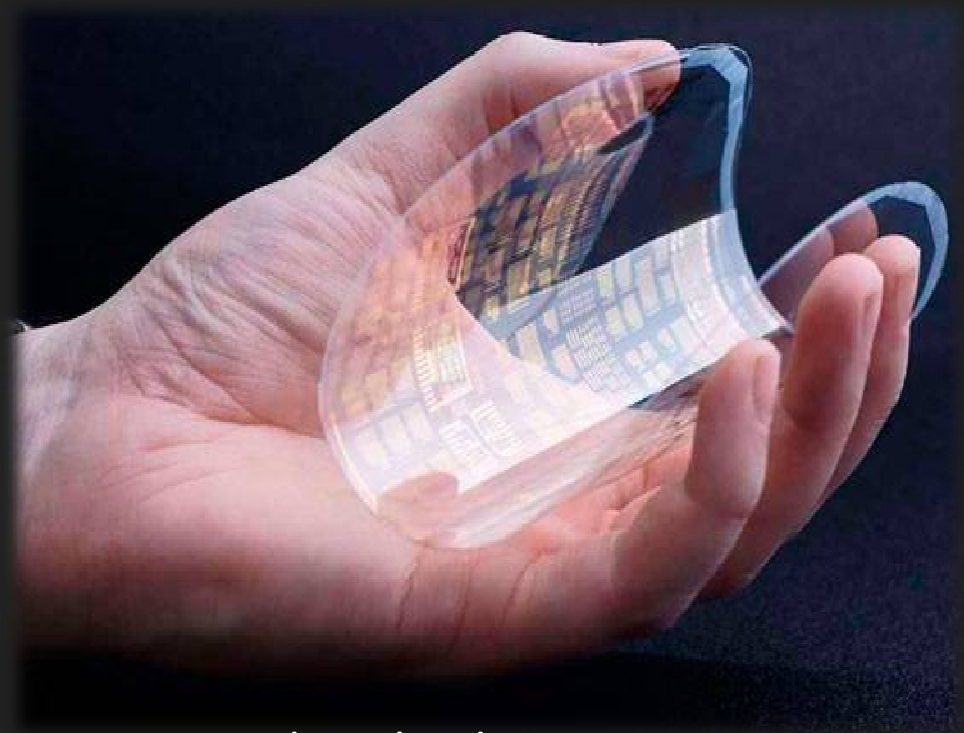
- In 2010, the Chinese Academy of Sciences has found that sheets of graphene oxide are highly effective at killing bacteria such as *Escherichia coli*.
- This means graphene could be useful in applications such as hygiene products or packaging that will help keep food fresh for longer periods of time.



# Other Applications

- Graphene nanoribbons
- IR detectors
- Single-molecule gas detection
- Piezoelectric materials
- Energy Harvesting
- Composite Materials
- Liquid Cells for Electron Microscopy
- Thermal management materials
- Optical Modulators
- Chemical sensors

# Its a Wonder material that could revolutionize the world



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