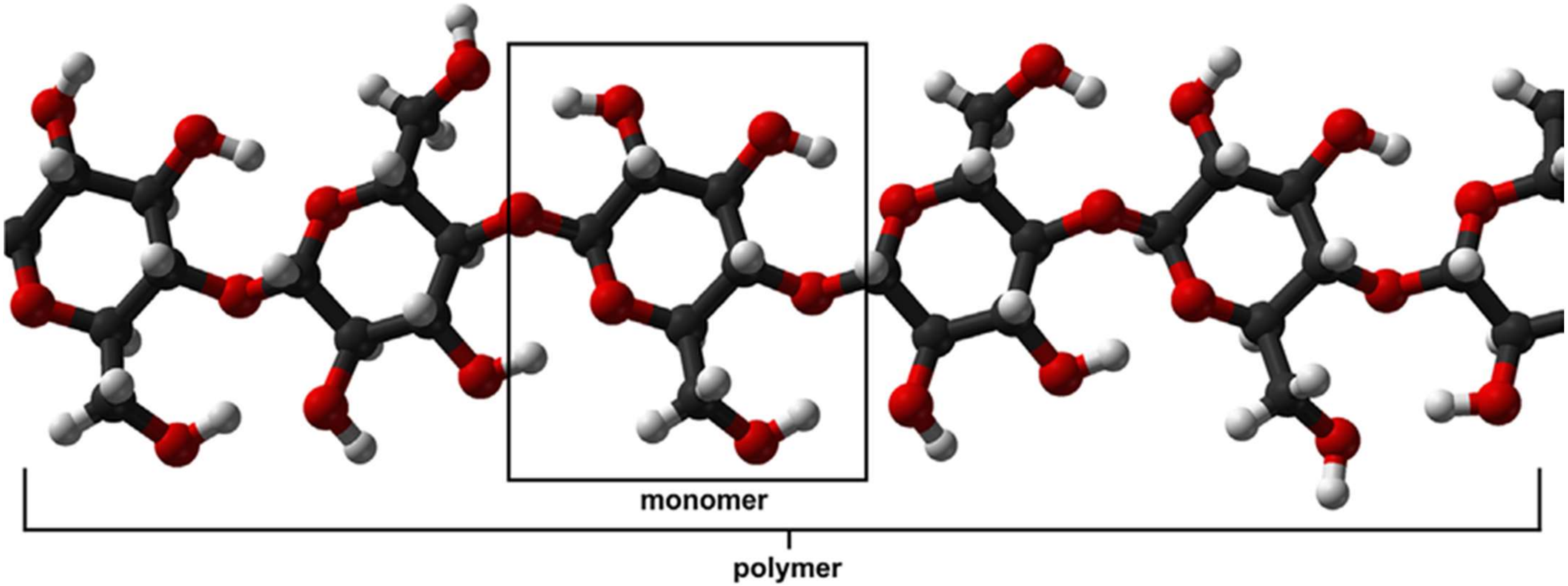
Review: Development of Polymer



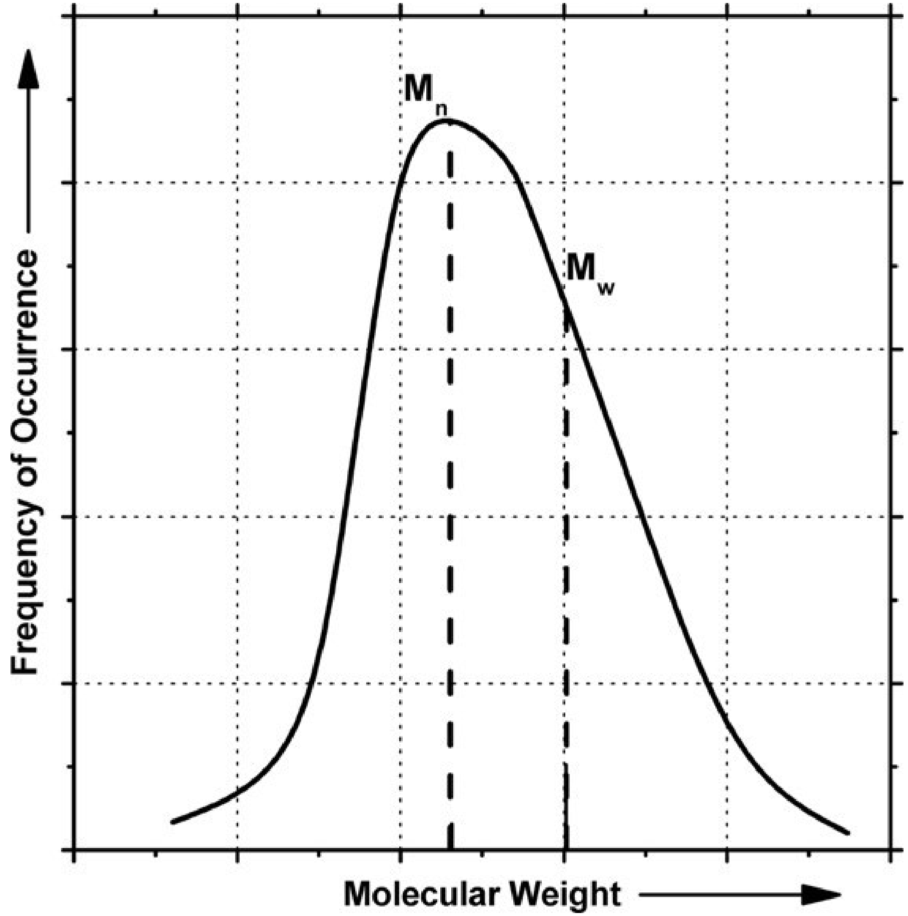
Arumugam， et al., 2016

Review: Polymer Molecular Weight

- All polymer molecules of a particular grade do not all have the exact same molecular weight.

- Same polymer from different sources may have different weight.

- How to measure molecular weight?
  - ✓ Light scattering
  - ✓ Ultracentrifugation

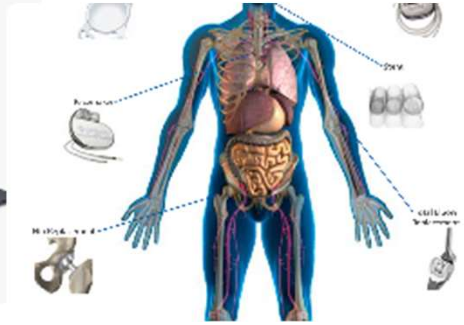
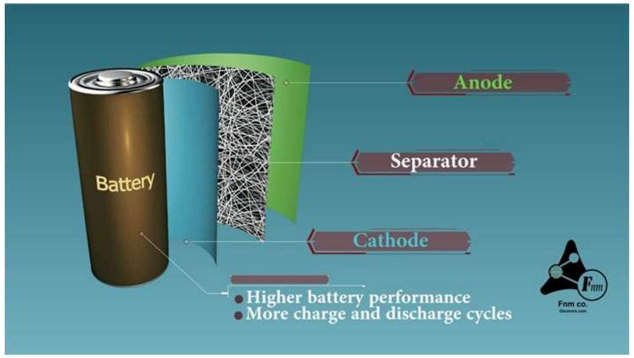


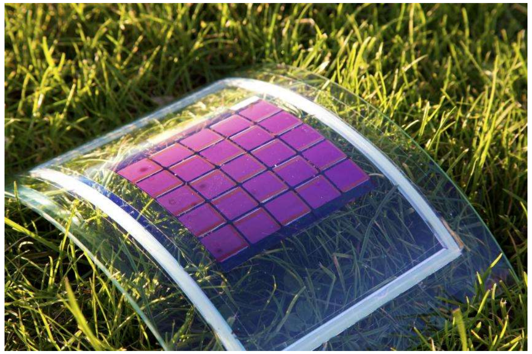
http://dx.doi.org/10.1016/B978-1-4557-2598-4.00002-2

Review: Use of Plastics

- 3D printing
- Electronics
- Medical implants
- Battery
- Renewable energy
- …..



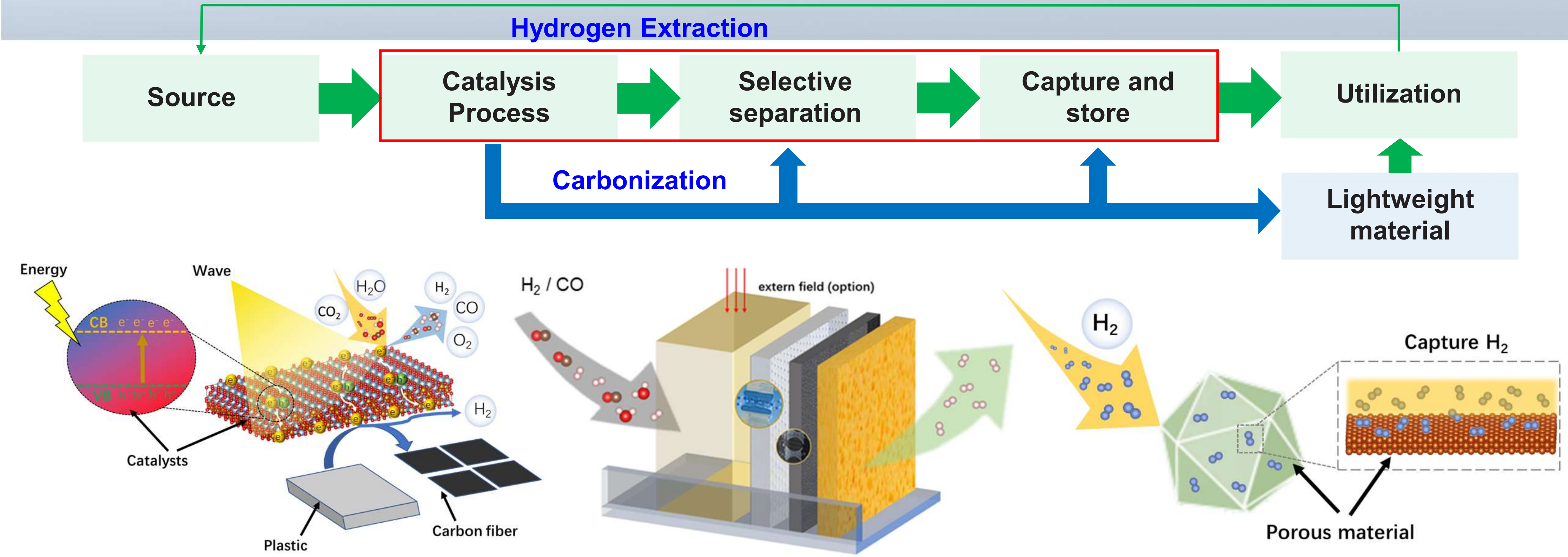


Credit to Prof. Gao

Review: Plastic Pollution

- Pollute landscapes
- Kill wildlife
- Deteriorate habitats of plants and animals
- Microplastics are everywhere, including drinking water and our blood

Review: Polymer hydrogen extraction and carbonization - GeM (Green e Materials Lab, HKUST (GZ))



How to effectively extract carbon and hydrogen?

1. Efficient, stable, tunable, reusable and non-toxic catalysts
2. Energy efficient porous material for selective separation
3. Environment-friendly material for H_2 capture and storage

Space Elevator

www.youtube.com

Introduction to Function Hub For Sustainable Future
FUNH 5000

Lecture 3： Graphene

Qichun Yang

2024-9-23

香港科技大学(广州)
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY (GUANGZHOU)

Vocabulary of this lecture

- Hexagon: 六边形
- Graphite: 石墨
- Van der Walls bond: 范德华力
- Refractory：耐火材料
- Electron: 电子
- Neutron: 中子
- Orbital: 轨域
- Electron microscope: 电子显微镜
- Exfoliation:剥离
- Lattice: 结构
- Substrate: 基质/衬底
- Silicon：硅
- Precursor: 前体
- Flake: 薄片
- Sonication: 声波降解
- Surfactant: 表面活性剂
- Oxidation: 氧化
- Oxide:氧化物
- Epitaxial: 磊晶
- Cathode: 阴极
- Anode: 阳极

Content

- Discovery of Graphene
- Structure and Properties of Graphene
- Production of Graphene
- Application of Graphene
- From graphene to other 2D materials

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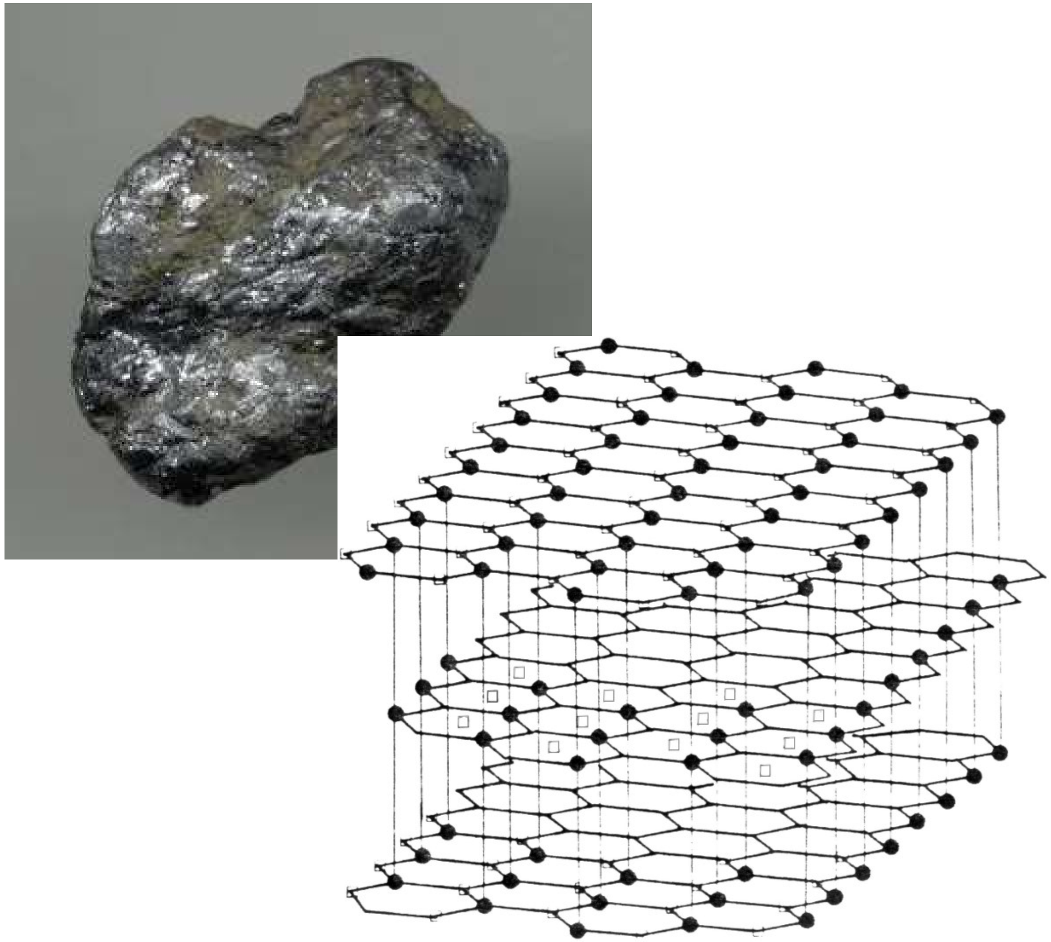
Graphite

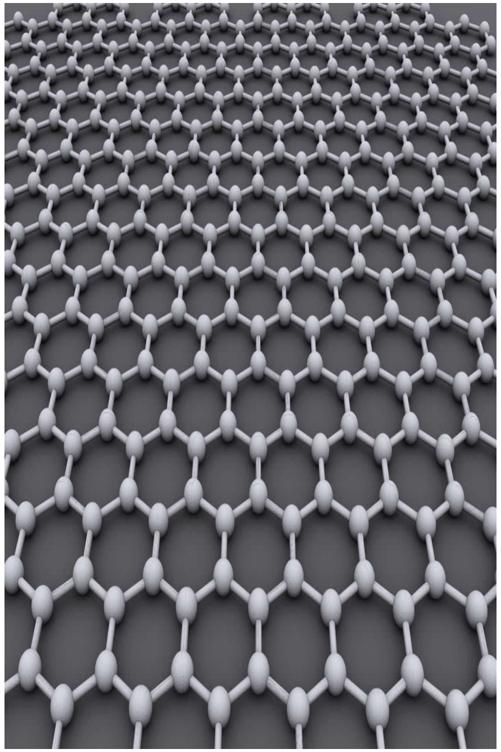
- Crystalline carbon
- Layered structure
- Natural existing, and can be synthesized
- Chemically inert
- Long history of graphite use
  - ✓ Painting/writing
  - ✓ Refractory
  - ✓ Electrodes
  - ✓ Lubricants



https://www.mining-journal.com/; Marti 1986

Discovery of Graphene

- Layered structure of graphite was identified in 1916
- Few-layer graphene was observed in the 1940s using transmission electron microscope, in bulk graphite
- Since the 1970s, single layers of graphene were grown on other materials (interactions with substrate materials)
- Mechanical exfoliation started in 1990, producing thin graphite of 50-100 layers.
- ‘Graphene gold rush’ started in 2004.



https://dawson-shanahan.co.uk/

Nobel Prize and Sticky Tape

- Andre Geim and Konstantin Novoselov
- Successfully extracted single-layer graphene
- Winners of Nobel Prize in Physics 2010.

Holger Motzkau, 2010

Nobel Prize and Sticky Tape

- Mechanical exfoliation using sticky tape!
- Visual recognition of graphene
- Proved the existence of single-atom-thick of hexagonal lattice of carbon atoms- GRAPHENE!

By Gabriel Hildebrand - Nobelmuseet, Public Domain

Nobel Prize and Sticky Tape

www.youtube.com

Content

- Discovery of Graphene
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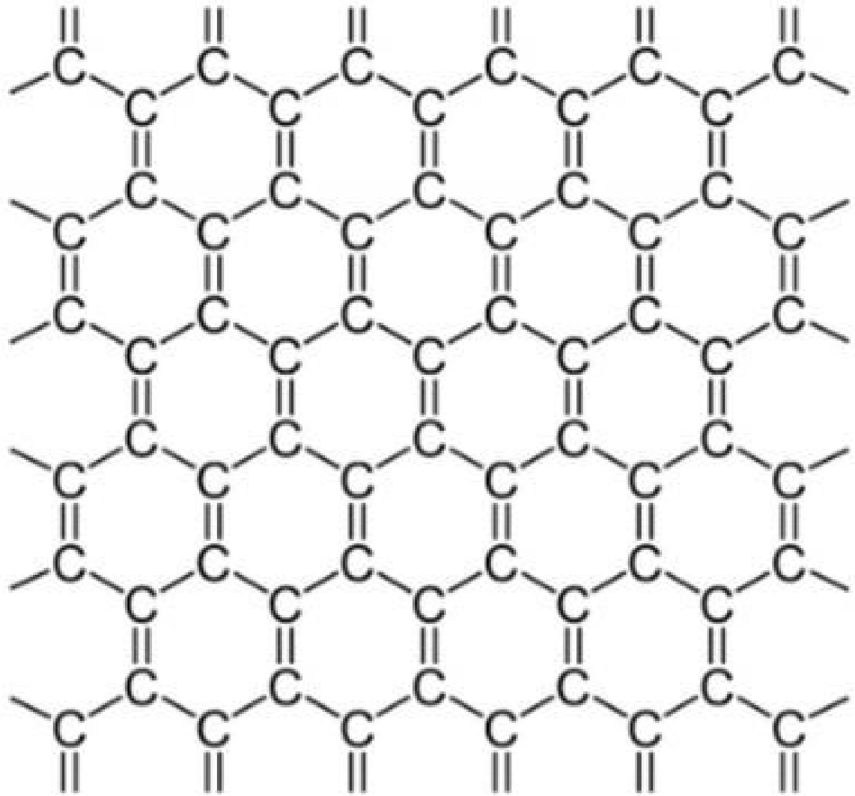
Structure of Graphene

- 2-D structure, with one layer of carbon atoms, extremely thin (0.335nm)

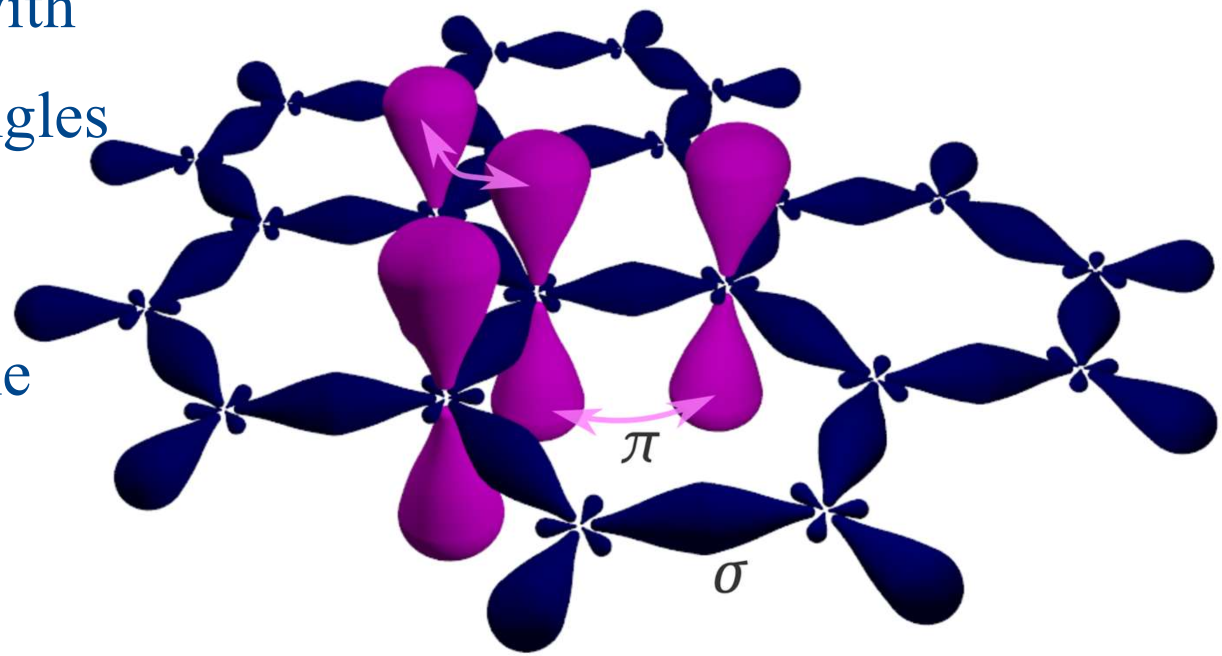
- Six C adjacent atoms form a hexagonal lattice, with bond lengths of 0.142nm; honeycomb structure



https://www.graphene-info.com/graphene-structure-and-shape

Structure of Graphene

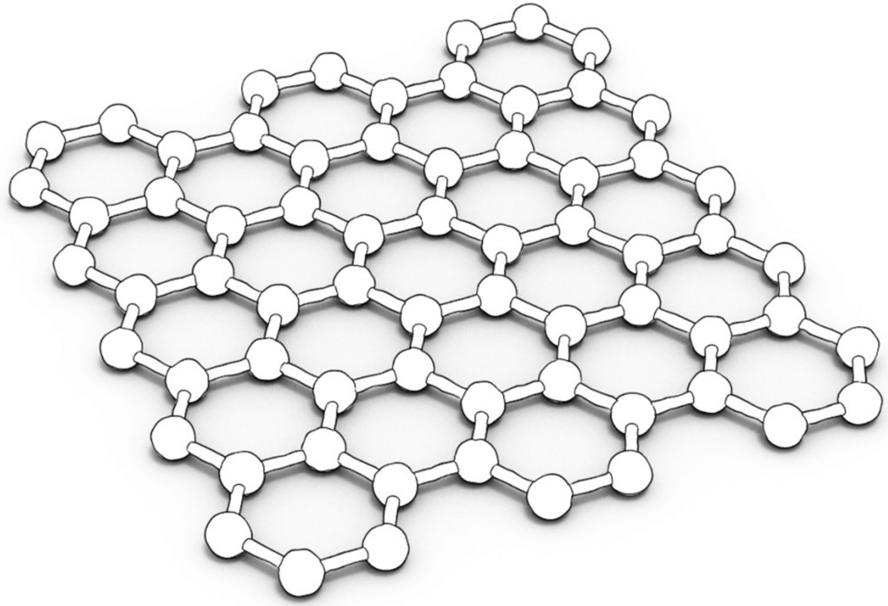
- Adjacent C atoms are linked with sigma (**σ**) bonds, with bond angles of 120°
- **σ** bonds the same surface of the graphene sheet.
- Each C has a ***π*** bond, perpendicular to the**σ** bonds



Ponor 2020

Properties of Graphene

- Graphene is highly stable
  - ➢ Resistant to high temperature, melting point 4510 K
  - ➢ Resistant to corrosion



Properties of Graphene

- Due to the single-layer structure, graphene is:
  - ➢ High surface area: 2600 m^2/g
  - ➢ Almost transparent

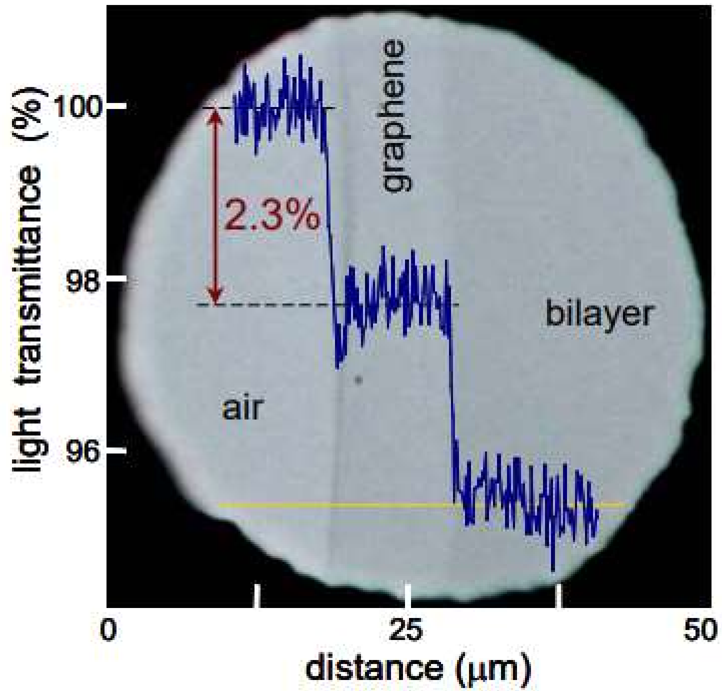
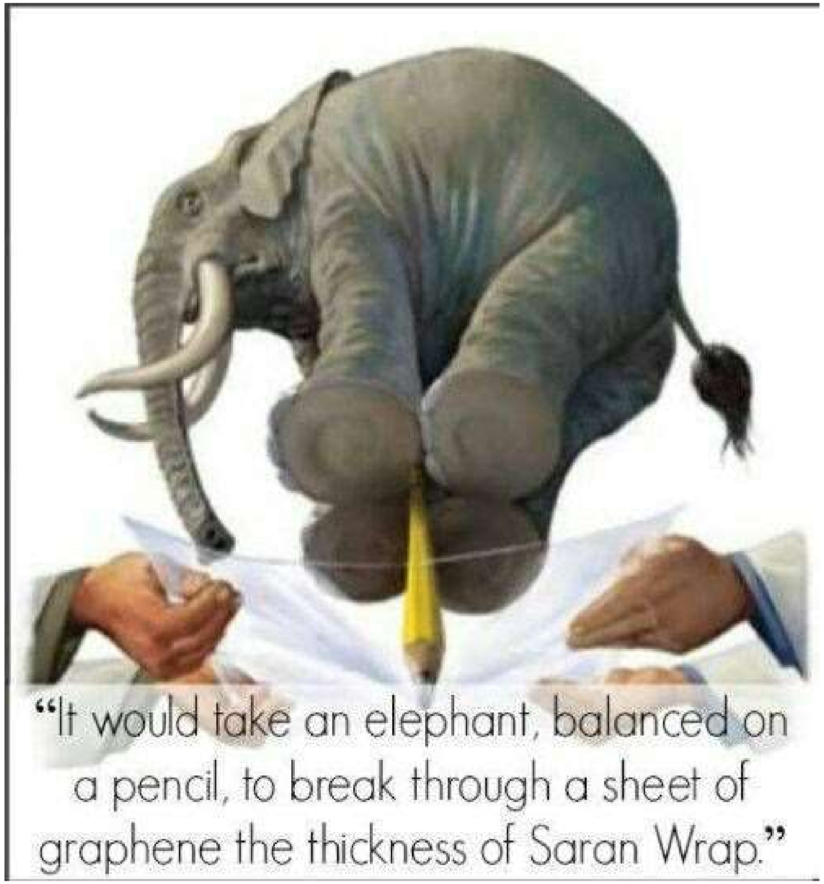


Figure 3. Looking through one-atom-thick crystals. Optical photograph of a 50 μm aperture partially covered by graphene and its bilayer. The line scan profile shows the intensity of transmitted white light along the yellow line.

Blake et al., 2008

Properties of Graphene

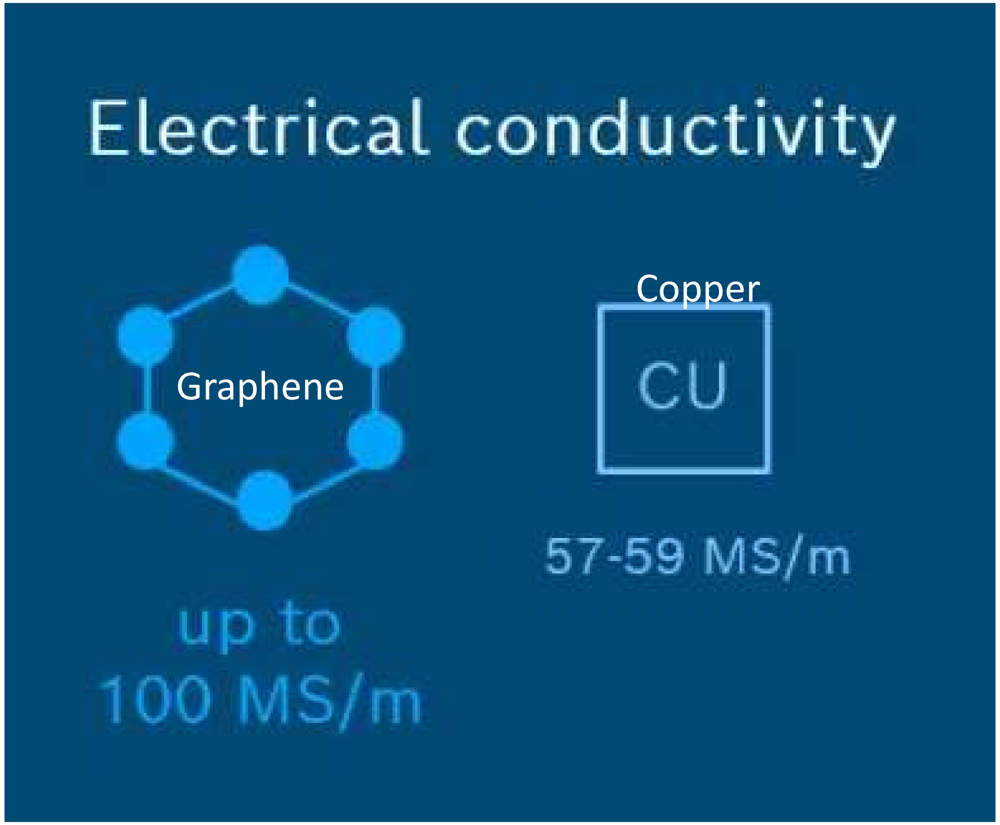
- Due to the strong **σ** bonds, graphene is:
  - ➢ Very strong, with tensile strength of 130 GPa (1GPa=9869 standard atmosphere)
  - ➢ 200 times stronger than steel



https://www.pinterest.com/

Properties of Graphene

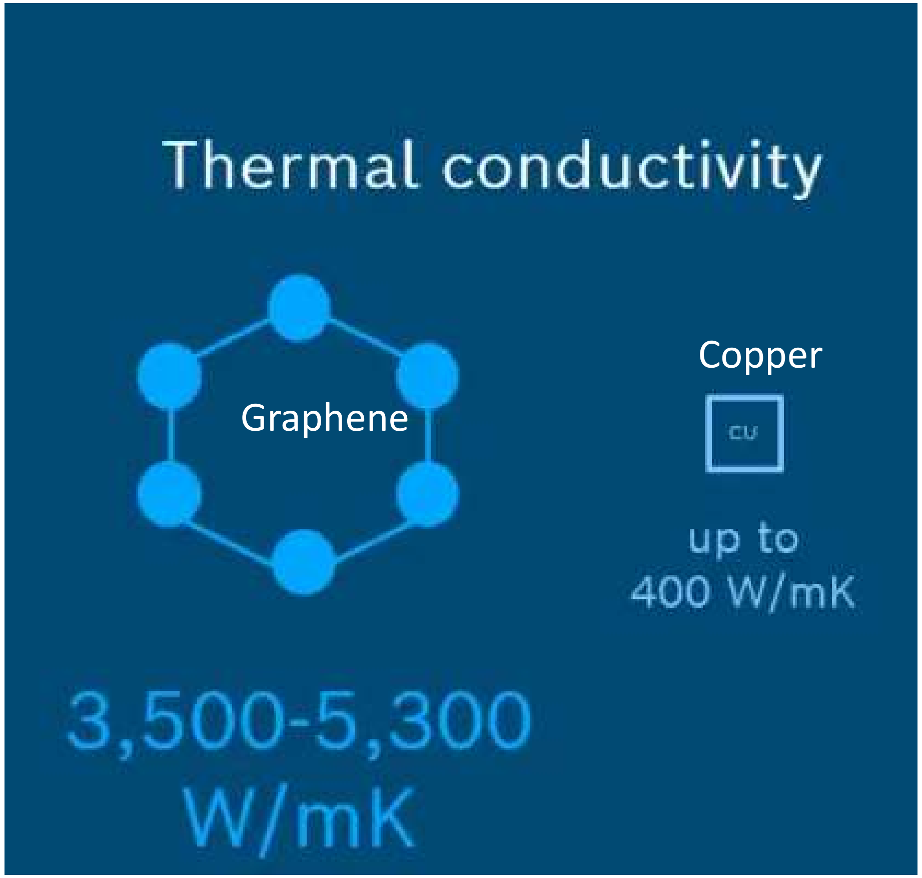
- Due to the delocalized electrons in ***π*** bonds, graphene is:
  - ➢ Highly conductive to electricity
  - ➢ Outperform Copper by 70% in electrical conductivity
  - ➢ 70 times faster than Silicon



https://www.bosch.com/

Properties of Graphene

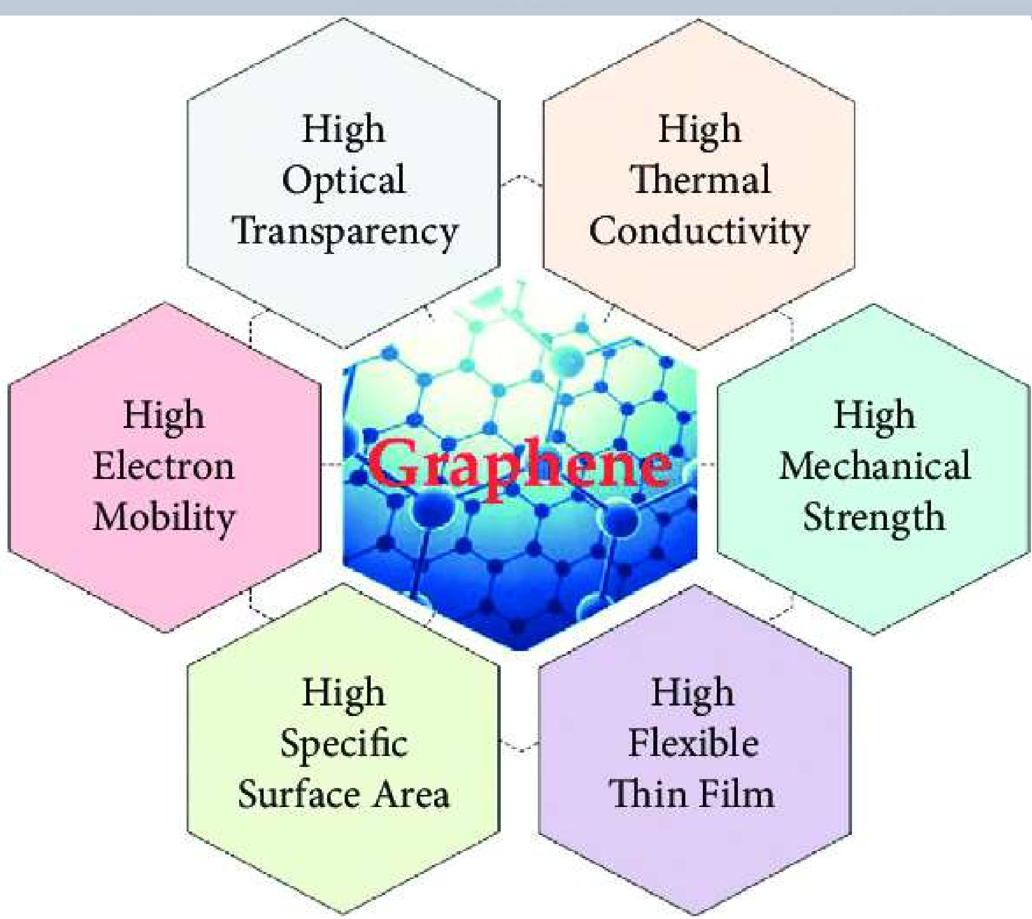
- Due to the delocalized electrons in $\boldsymbol{\pi}$ bond, graphene is:
  - ➢ Highly thermal conductive
  - ➢ ~10 times faster than Copper



https://www.bosch.com/

Properties of Graphene

- 'Miracle Material'
- 'Wonder Material'
- 'King of New Materials'
- 'Black Gold'
- 'Graphene Gold Rush'



Murthy et al., 2021

Content

- Discovery of Graphene
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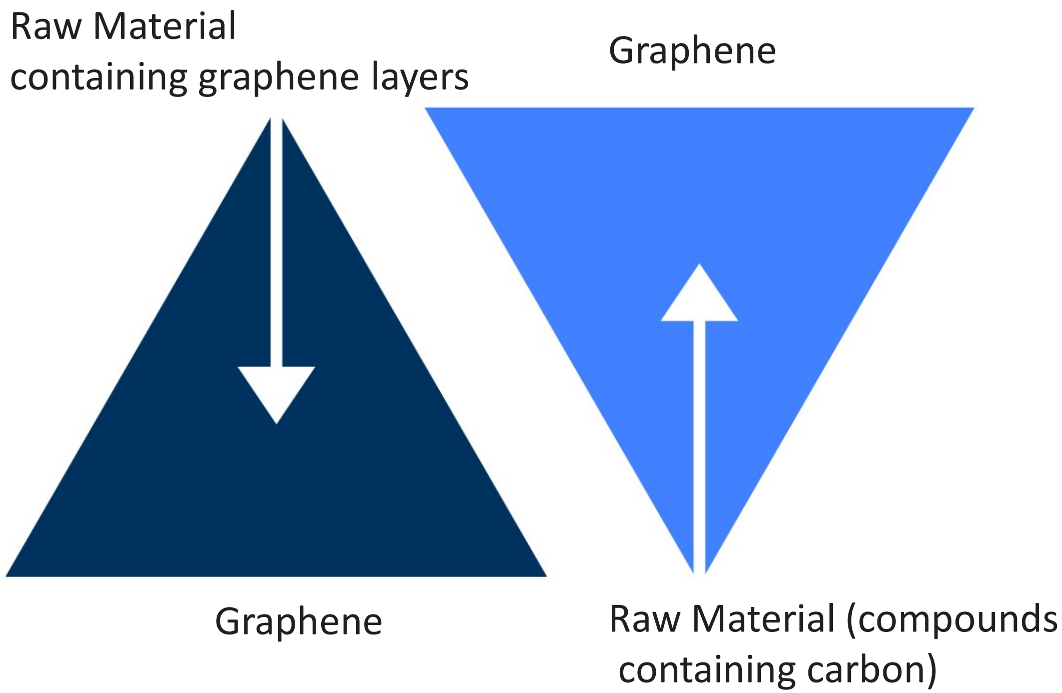
- From graphene to other 2D materials

Graphene Production

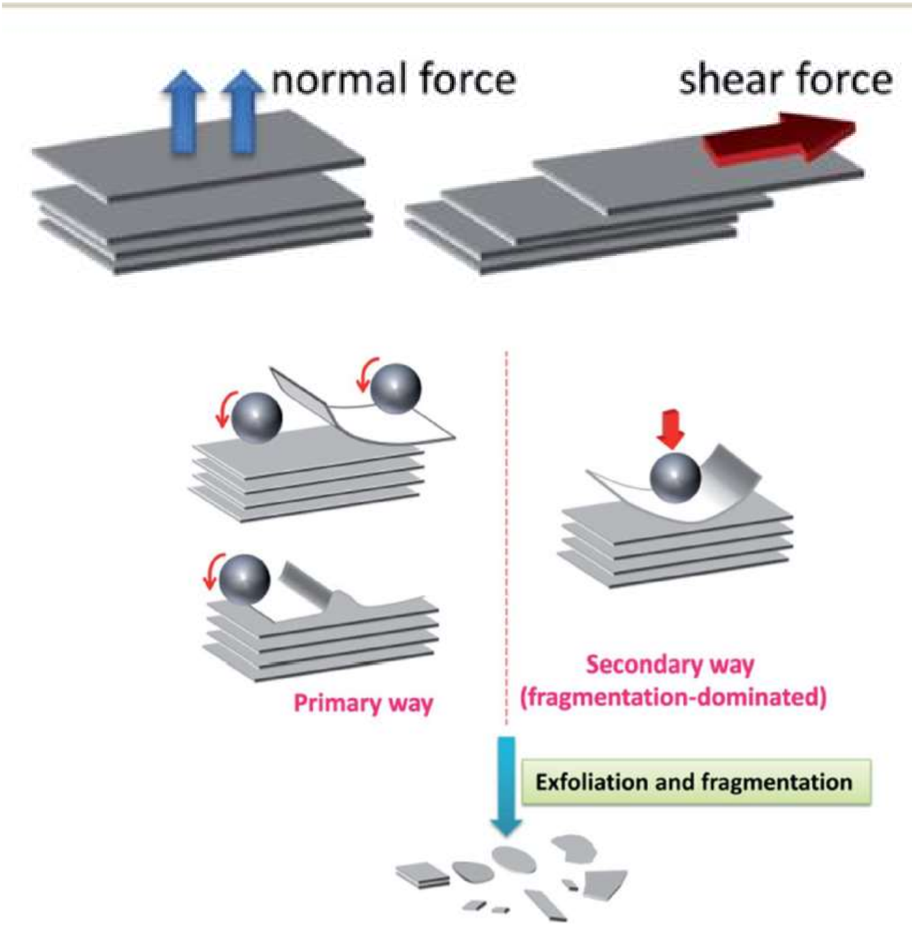
- Top-down
  - ➢ breaks down precursors like graphite into layers that are atom thick.
- Bottom-up
  - ➢ Graphene is assembled atom by atom



https://bootcamp.uxdesign.cc/

Top-down Production

- Mechanical exfoliation
  - Normal force vs. lateral force
  - examples for mass production: Ball milling, Fluid dynamics, Supercritical fluid method, etc.



Yi and Shen, 2015

Fluid dynamics exfoliation

- Solvent or water mixed with graphite
- Rapid rolling tube provides centrifugal force

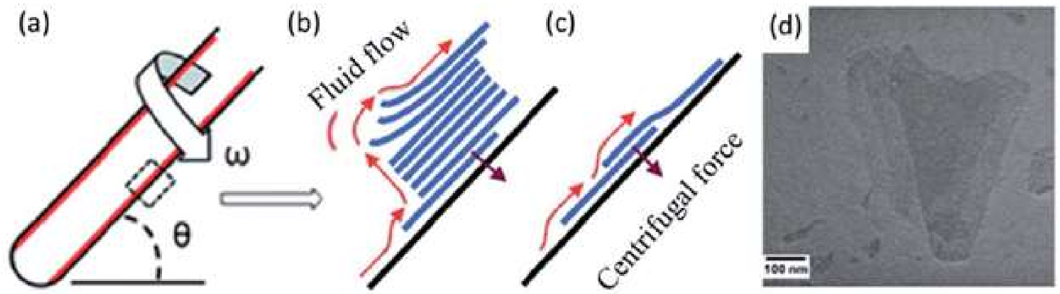


Fig. 16 (a) Schematic of the vortex fluidic device. (b) The exfoliation process with slippage and partial lift. (c) Slippage on the inner surface of the tube. (d) Partially stacked graphene for the evidence of slippage. Reproduced with permission from ref. 99. Copyright 2012 The Royal Society of Chemistry.

Yi and Shen, 2015

Top-down Production

- Liquid-phase exfoliation
  - Using organic solvent, ionic liquid, polymer or surfactant solution
  - Producing forces through Sonication, high-shear mixing, or Microfluidization.

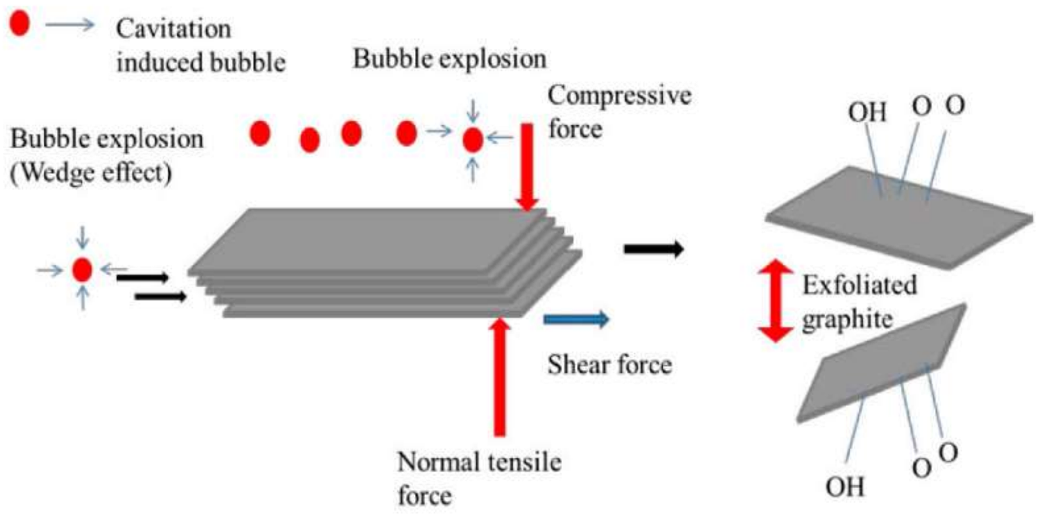
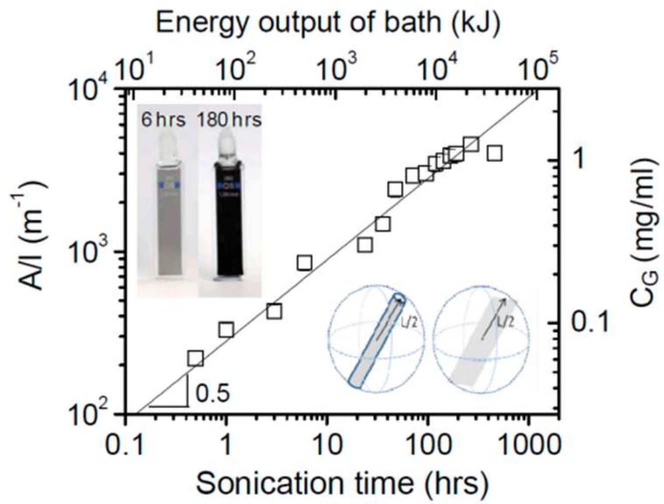


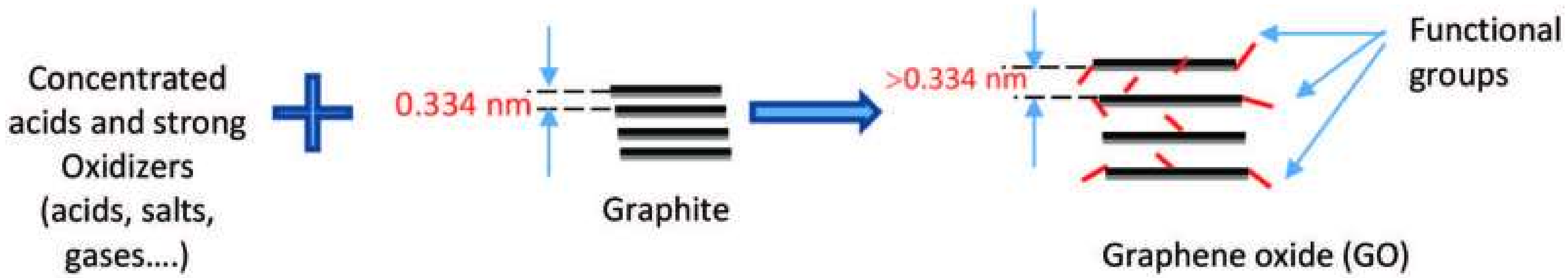
Figure 5. Illustration of the possible mechanism of graphite exfoliation. Reproduced from [37]. Copyright Multidisciplinary Digital Publishing Institute, 2016.



Xu et al., 2018

Top-down Production

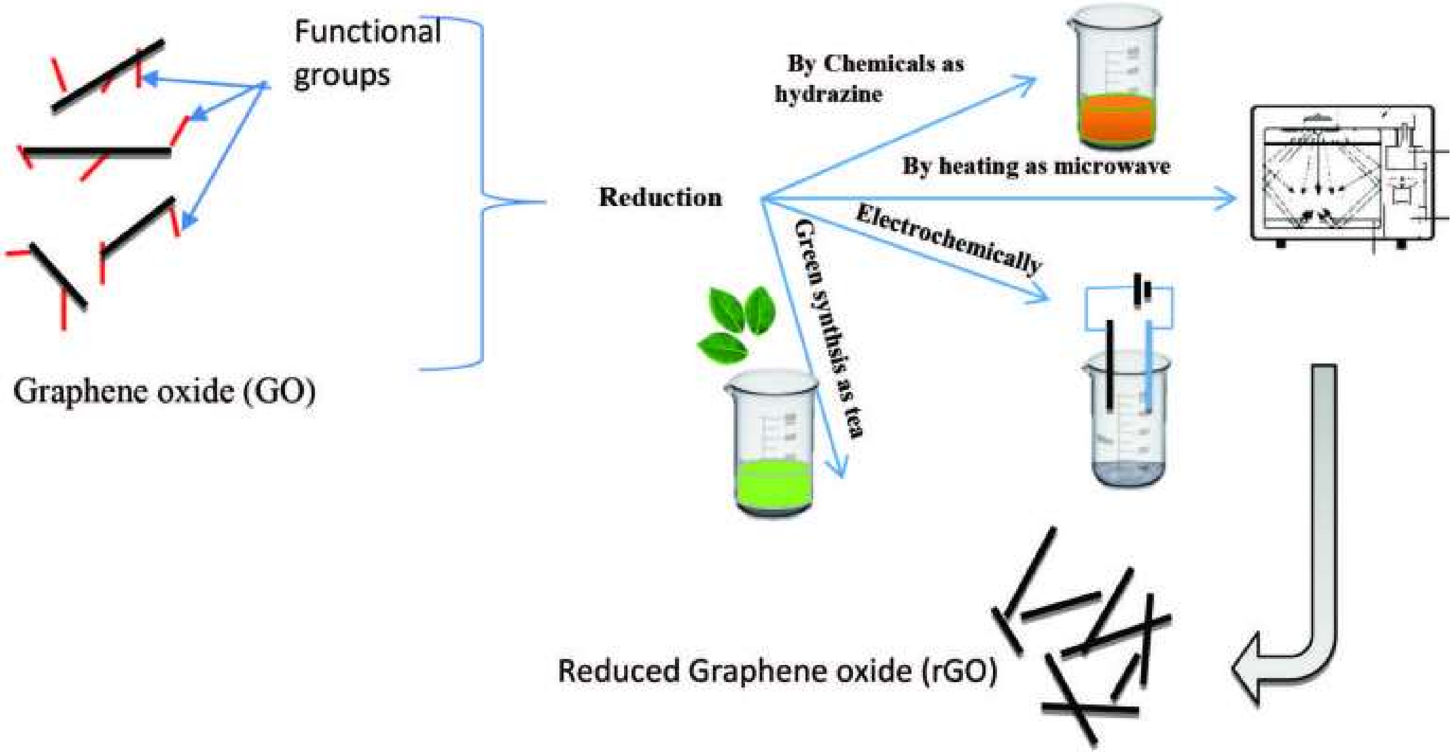
- Oxidation exfoliation
  - ➢ Graphite Oxidation to produce Graphene Oxides (GO)



https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8326494/

Top-down Production

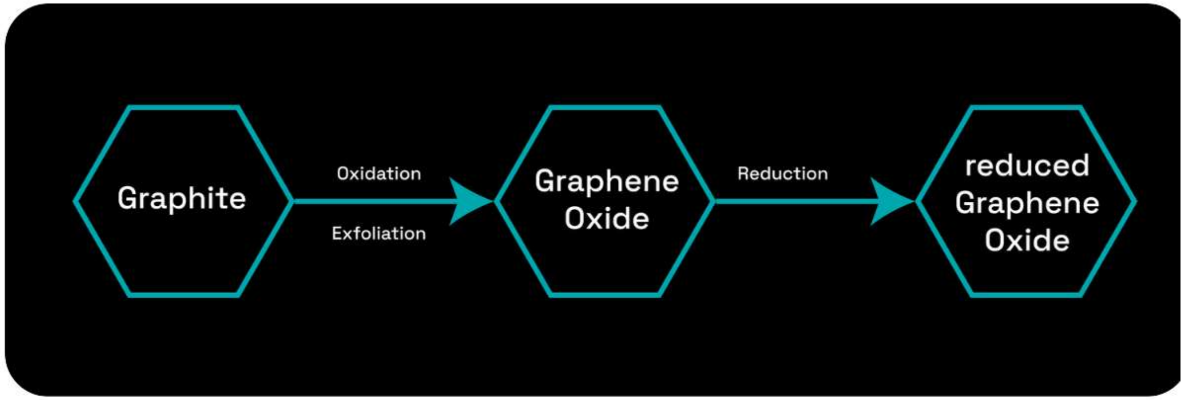
- Oxidation exfoliation
  - GO has a single layer, and is soluble to water and other solvents.
  - Reduction removes O and produce reduced GO (rGO)

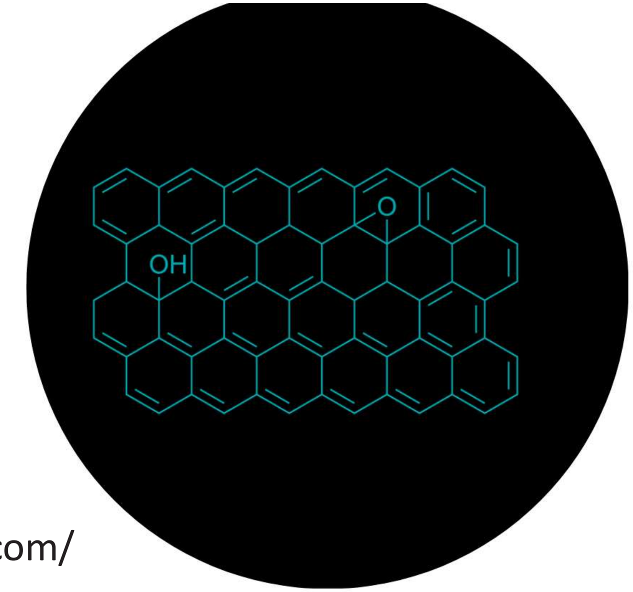


https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8326494/

Top-down Production

- Oxidation exfoliation
  - rGO has excellent electrical conductivity
  - But not perfectly comparable with pure Graphene
  - However, suitable for mass production

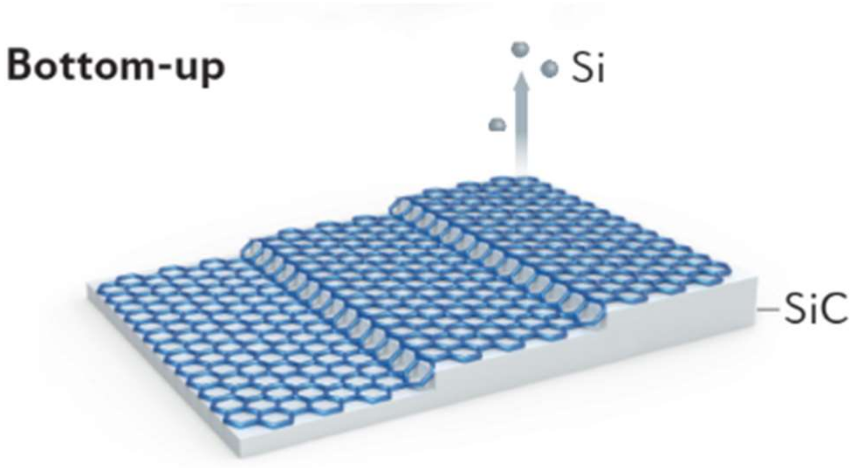


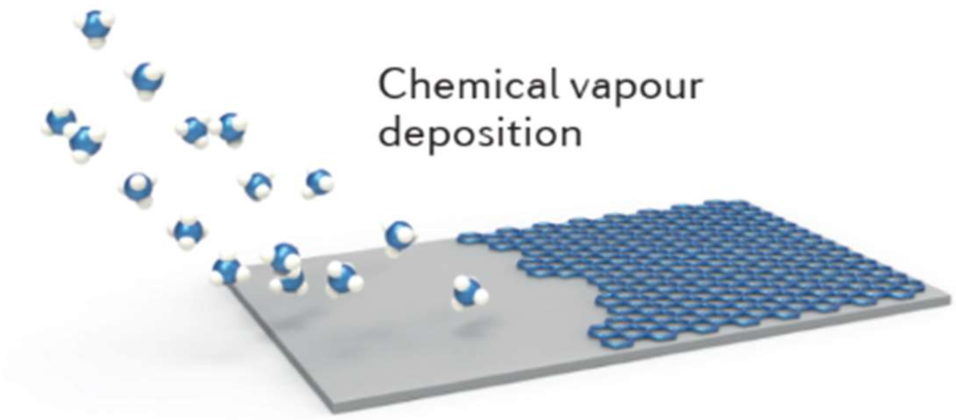


https://www.layeronematerials.com/

Bottom-up Production

- Epitaxial Growth (SiC heating)
- Chemical Vapor Deposition (CVD)

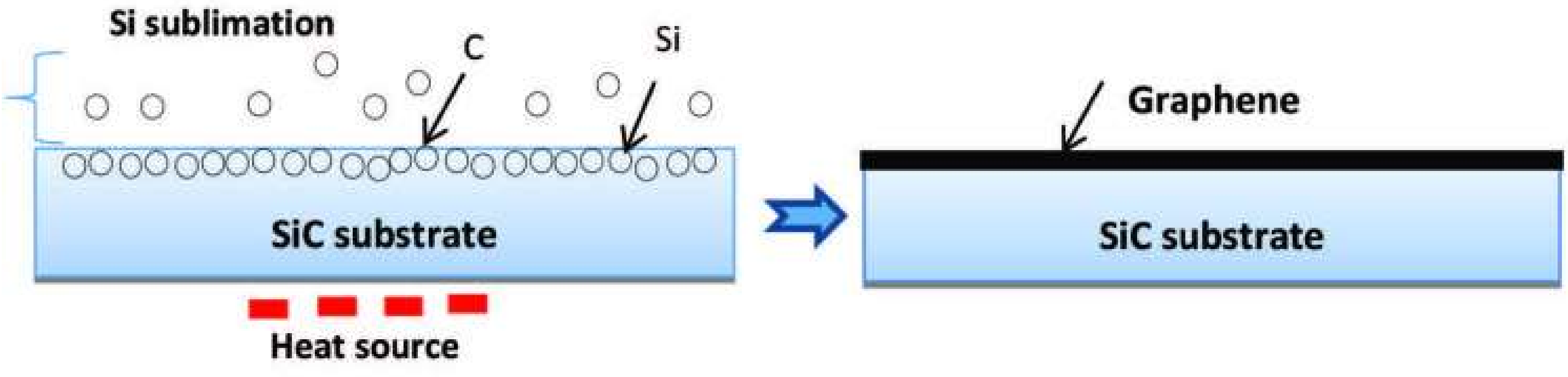




https://www.layeronematerials.com/

Bottom-up Production

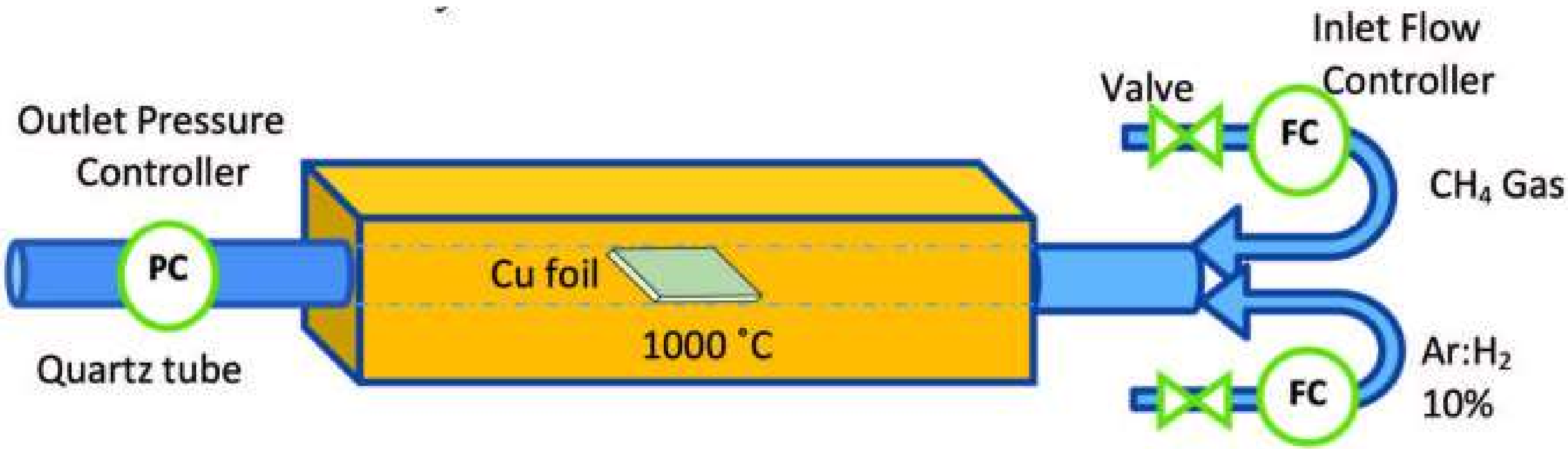
- Epitaxial Growth (SiC heating)
  - ➢ Silicon carbide is used as the substrate
  - ➢ Heated to >1250°, resulting in thermal decomposition on the surface of the substrate
  - ➢ Films with 3 layers of graphene are typically formed



https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8326494/

Bottom-up Production

- Chemical Vapor Deposition (CVD)
  - Transition metals (e.g., Fe, Co, Ni, Cu, Pd) as substrate
  - Hydrocarbon gas (e.g., CH_4) as the precursor
  - Require temperature of > 1000°



https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8326494/

Bottom-up Production

- Chemical Vapor Deposition (CVD)
  - Suitable for producing high-quality single-layered graphene over large areas
  - Transfer-printing to a flexible substrate allows for more broader application

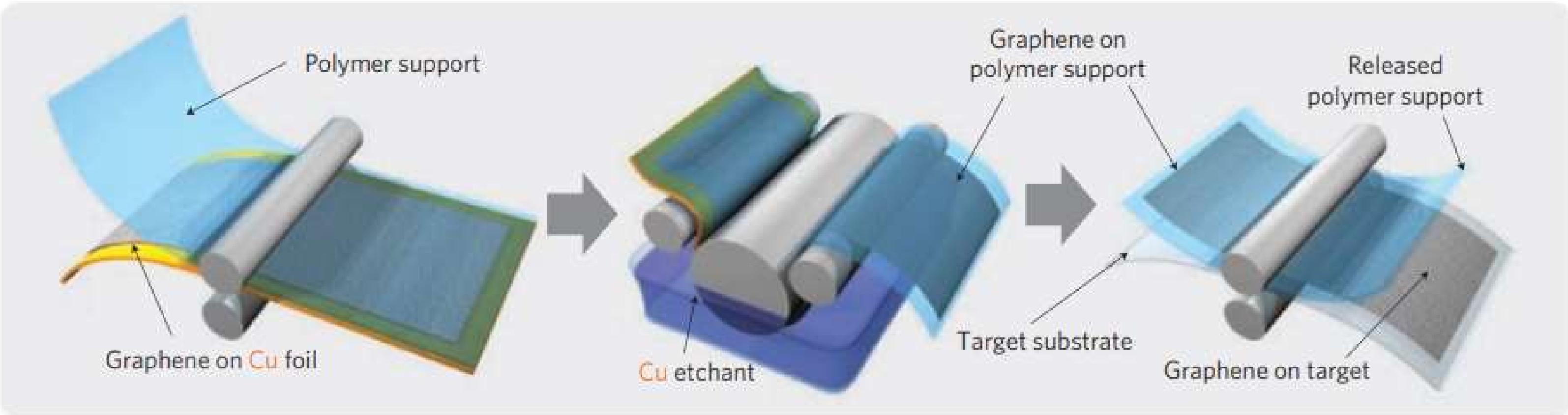
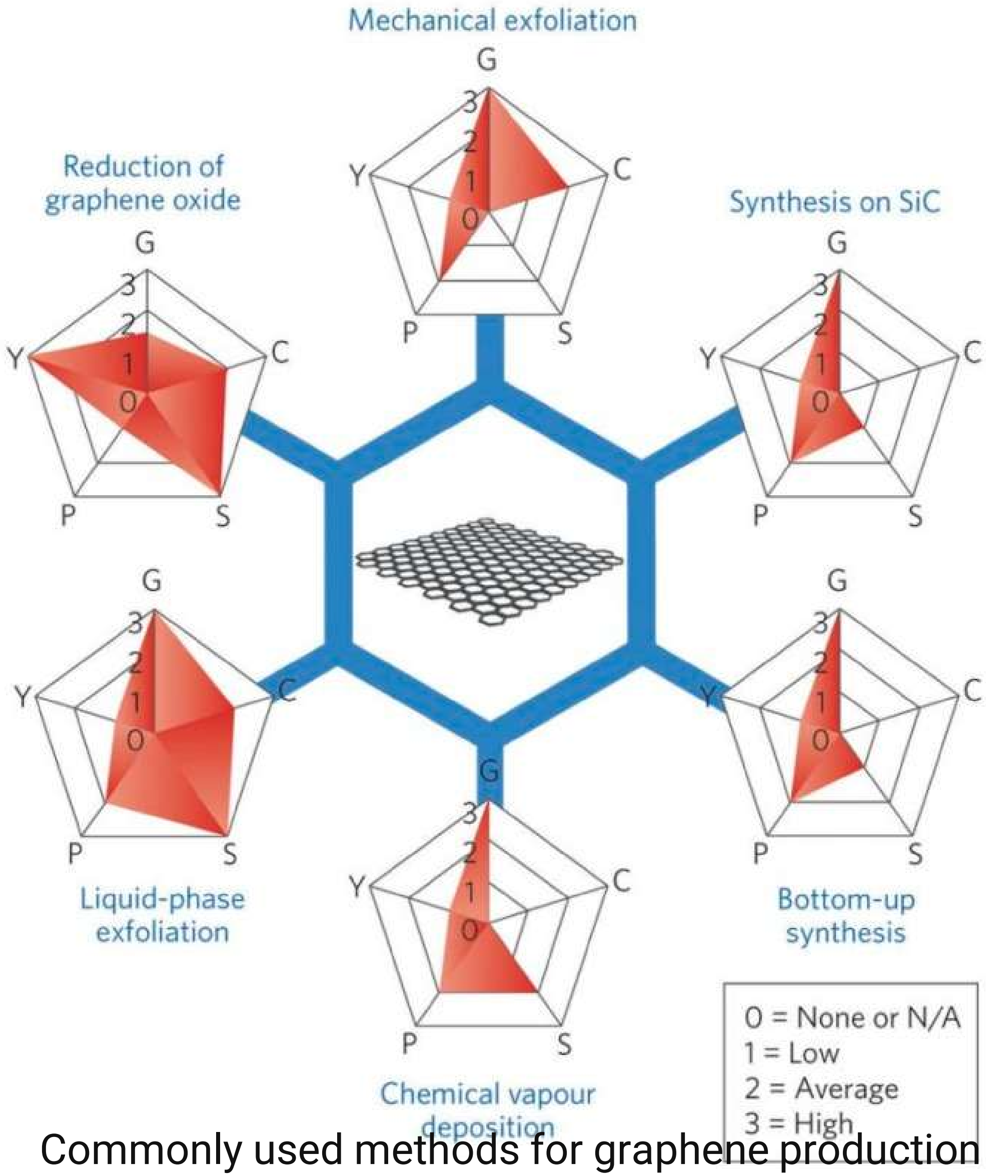
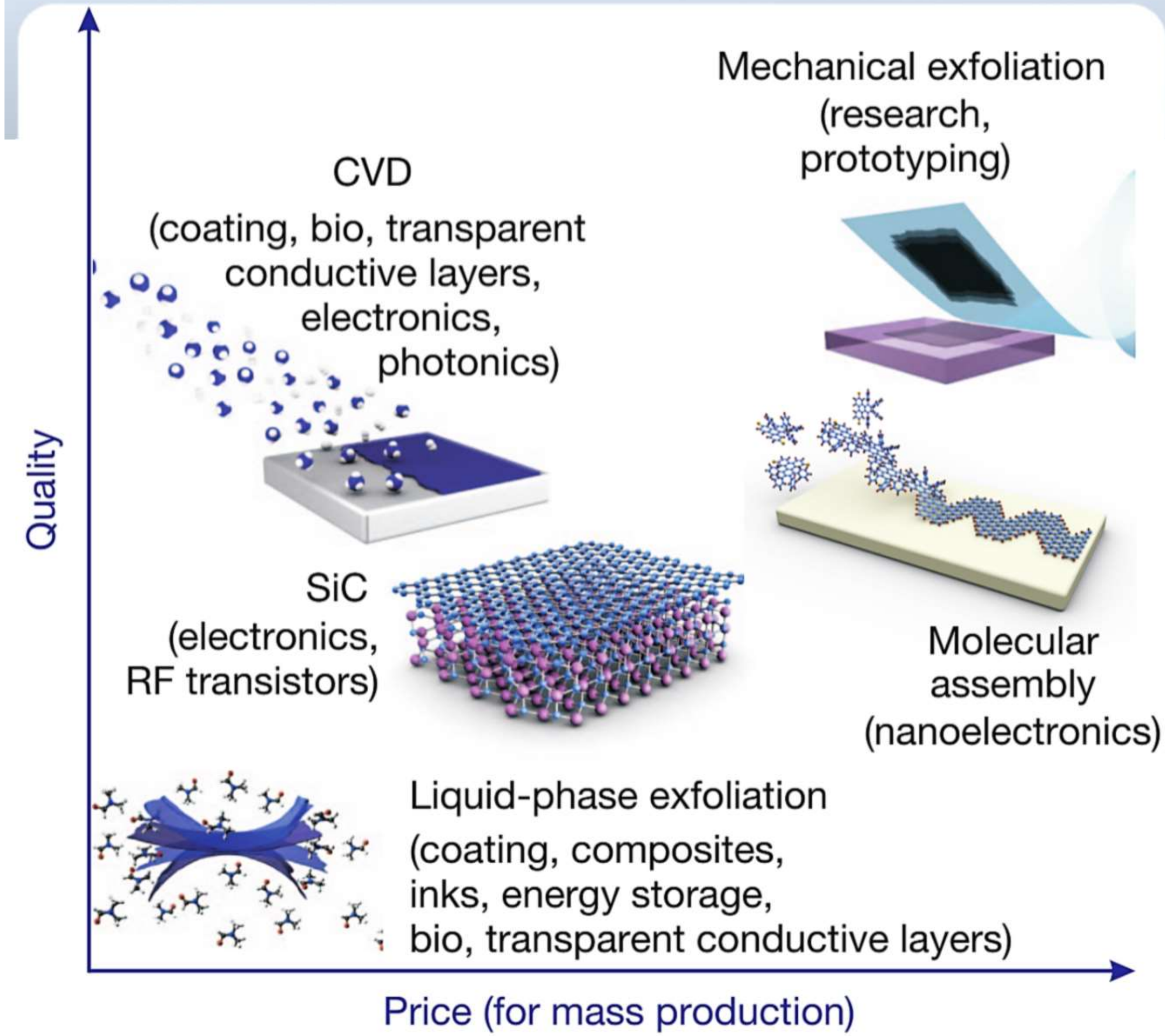


Figure 1 | Schematic of the roll-based production of graphene films grown on a copper foil. The process includes adhesion of polymer supports, copper etching (rinsing) and dry transfer-printing on a target substrate. A wet-chemical doping can be carried out using a set-up similar to that used for etching.

Bae et al., 2010





Commonly used methods for graphene production in terms of quality (G), cost (C), scalability (S), purity (P), and yield (Y). Reproduced from Raccichini et al. (2015)

Content

- Discovery of Graphene
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- **Application of Graphene**
- From graphene to other 2D materials

Graphene Applications

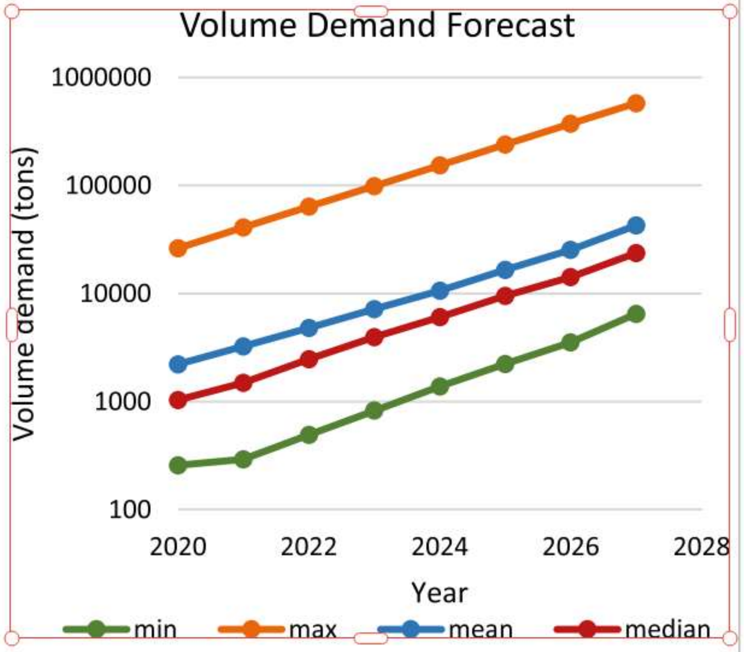


Figure 7. Graphene volume demand scenarios, based on the graphene price development (median scenario, figure 6) and revenue forecast scenarios (figure 2).

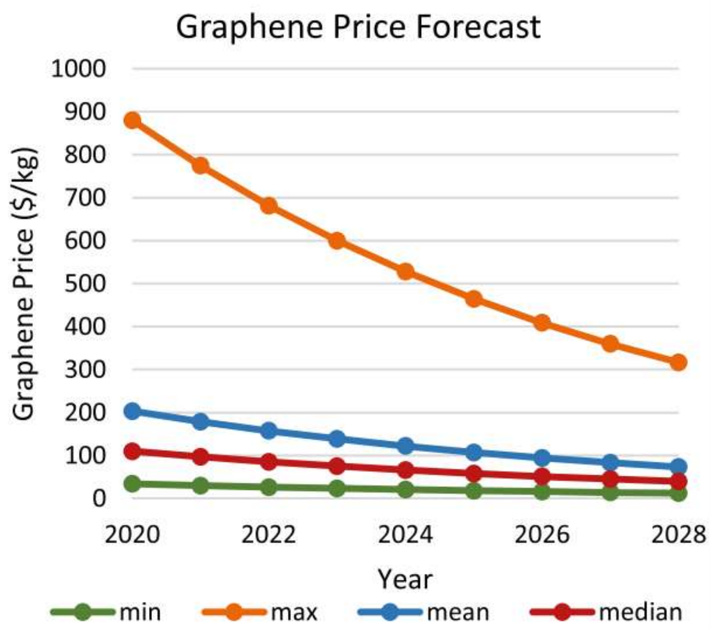


Figure 6. Graphene price development scenarios based on recent price estimates and the assumption of an annual price reduction rate of 12%.

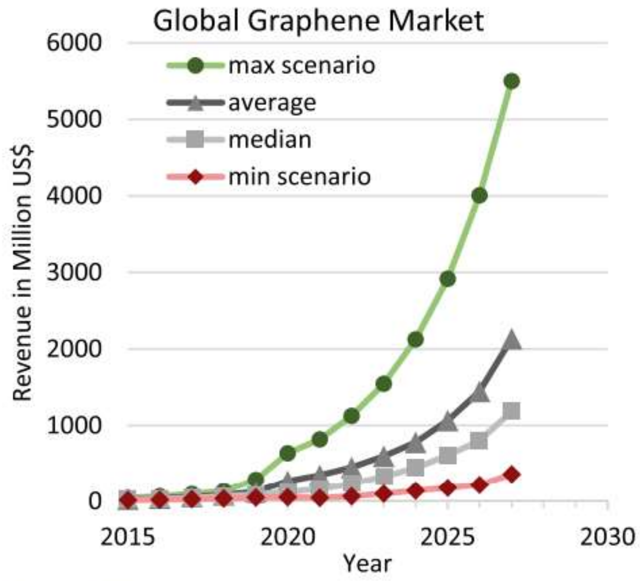
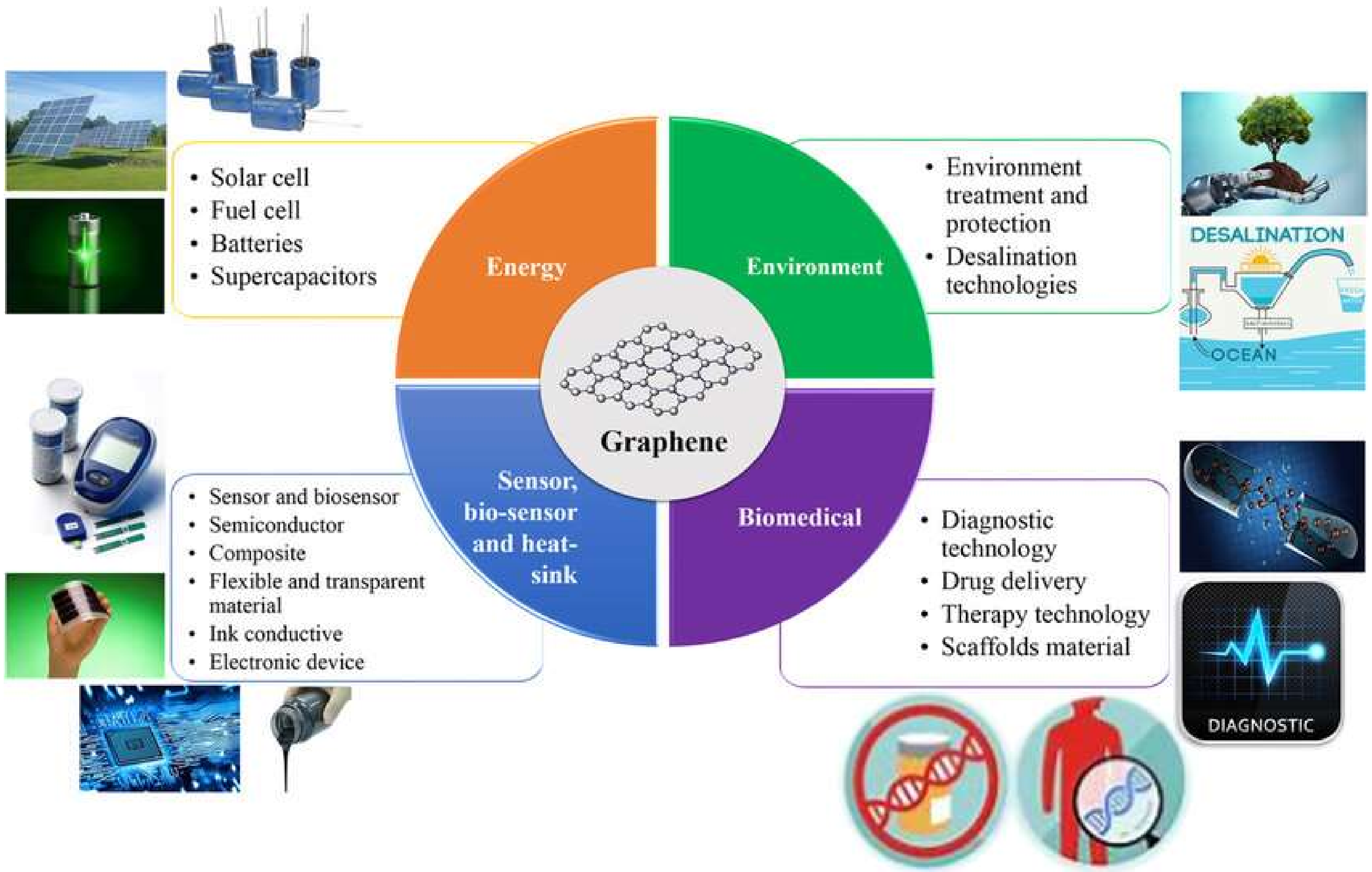


Figure 2. Predicted global graphene market revenue between 2015 and 2027, resulting from our meta-analysis. The true market development is likely to be between the extreme (min/max) predictions, possibly close to the mean or median curve.

Schmaltz et al., 2024

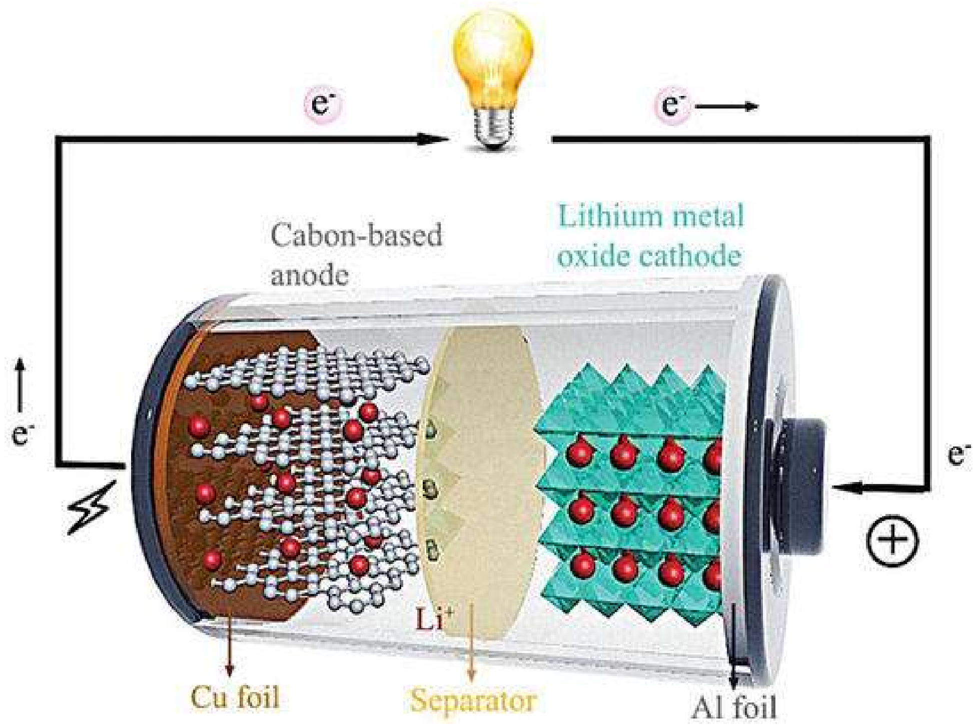
Areas of graphene applications



Madurani et al., 2020

Application of graphene in batteries

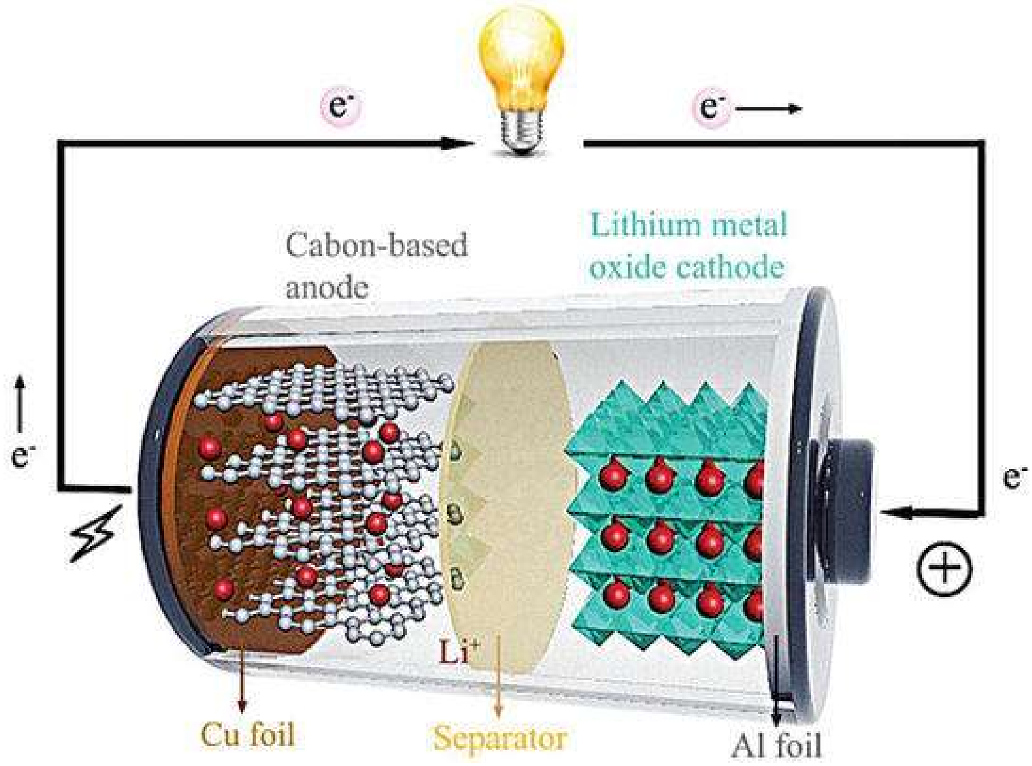
- Graphene as conductive agent: increase electron transport efficiency and reduce the polarization of the electrode.
- Graphene as LIBs cathode materials
  - ➢ Graphene coating improved the conductivity of Li^+



Qi et al., 2023

Application of graphene in batteries

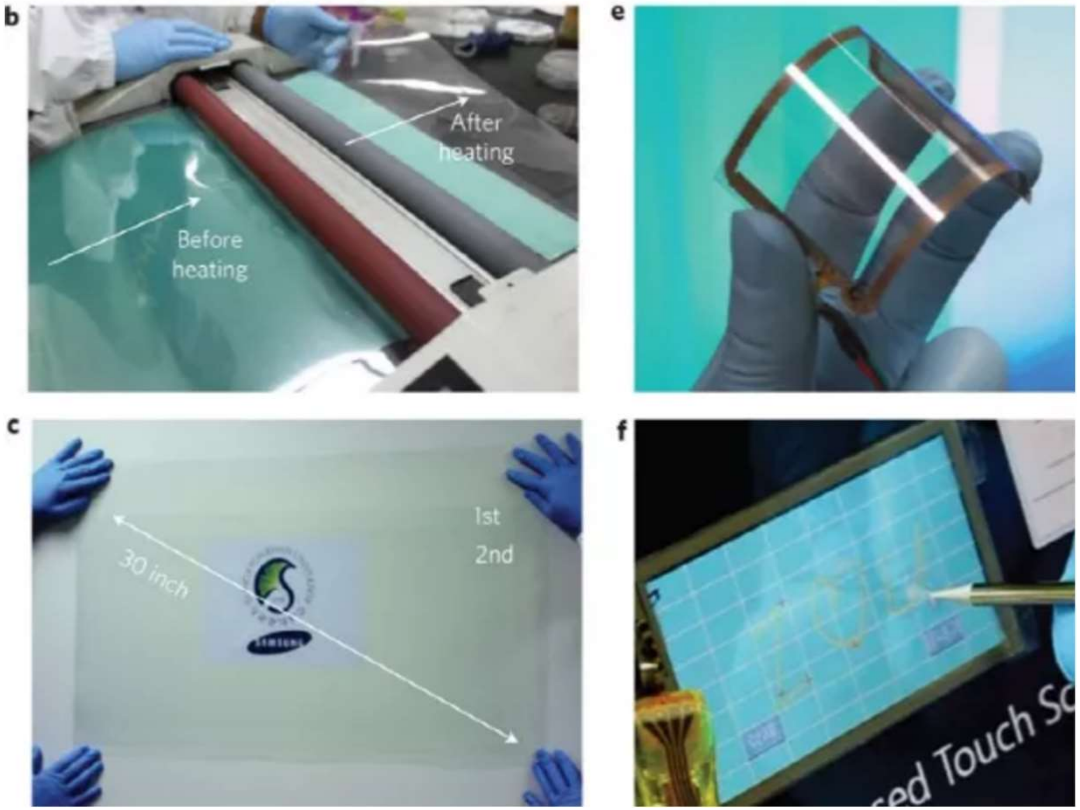
- Graphene as LIBs anode materials
  - ➢ Graphene can effectively inhibit the metal electrode volume expansion during the charging and discharging process
- Improve LIB safety, capacity and charging speed.



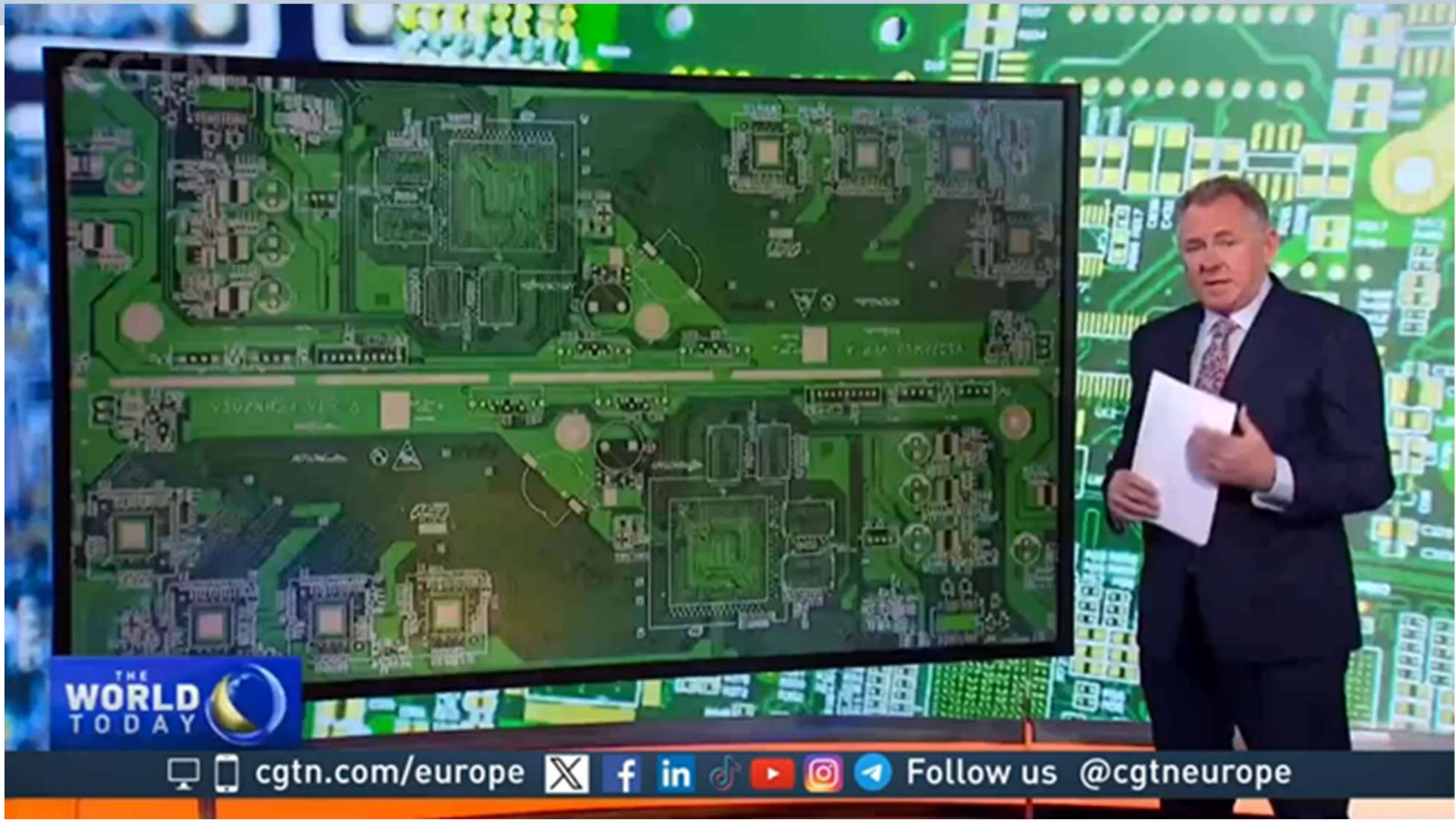
Qi et al., 2023

Application of graphene in touch-screen and other electronics

- Transparent
- Conductive
- May replace silicon in semiconductors



1st functional graphene chip, Made in Tianjin



Application of graphene in thermal management

- Light
- Thermal conductive

Thermal management using graphene in iphone16

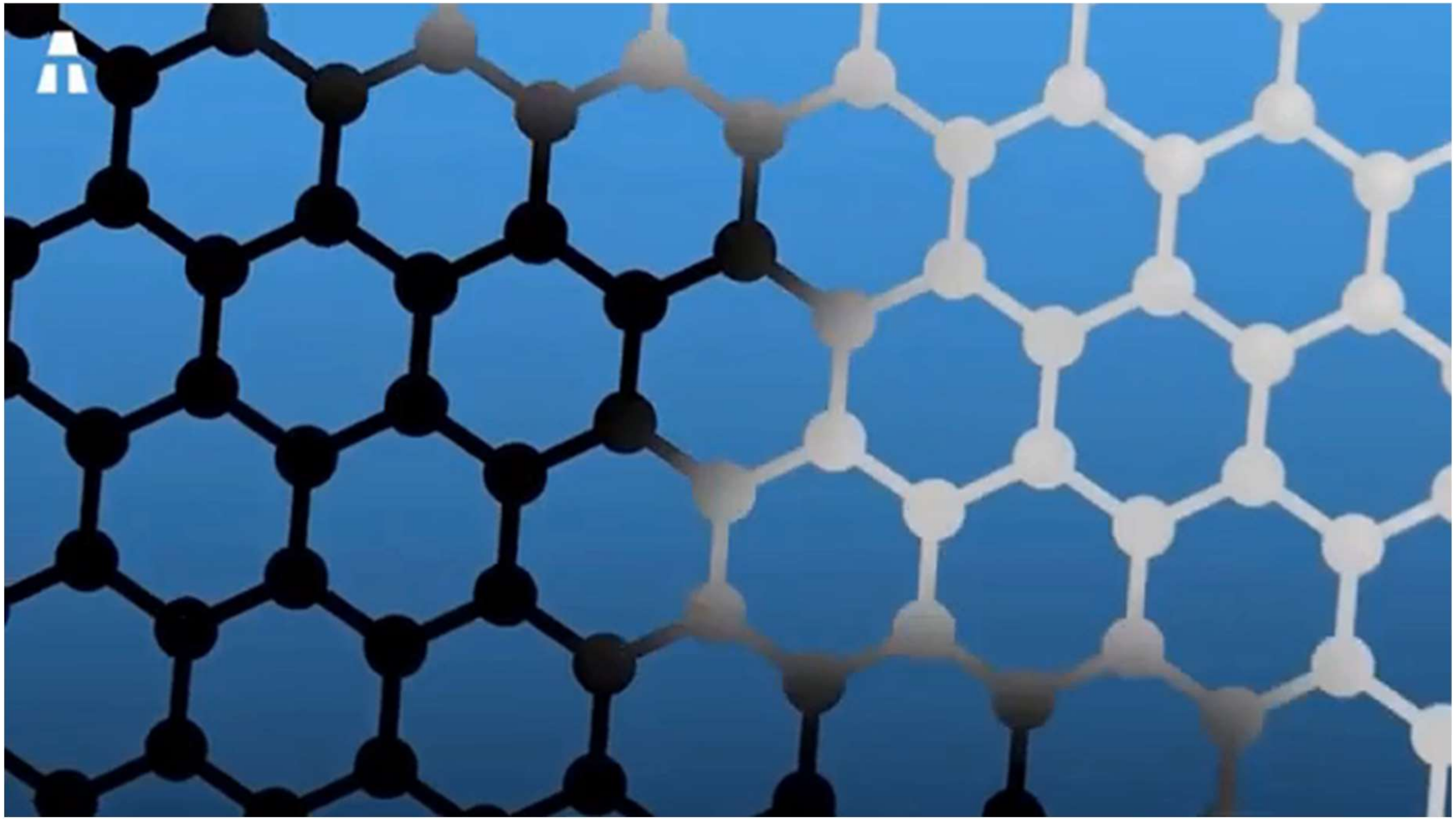
www.youtube.com

Application of graphene in construction

- Graphene additive makes concrete stronger and increase its longevity
- Could reduce the use of concrete by up to 50%
- Could reduce carbon emission of concrete production, which contributes 8% of global carbon emission

AAAAA

Challenges in using Graphene



www.youtube.com

Challenges in applying Graphene

- **Production**
  - Quantity, Quality, Cost

- **Transfer from research to application takes time**

- **Toxicity**

Graphene research in AMAT

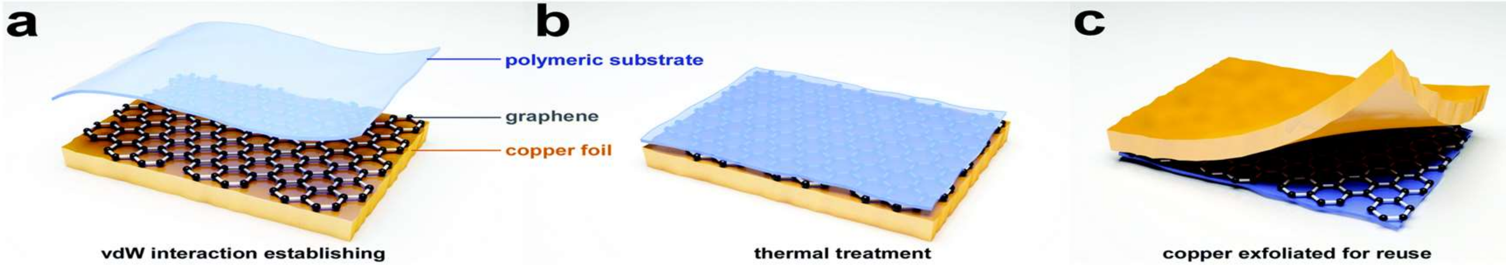
Ping GAO
高平
PhD in Chemical Engineering
University of Cambridge, 1990

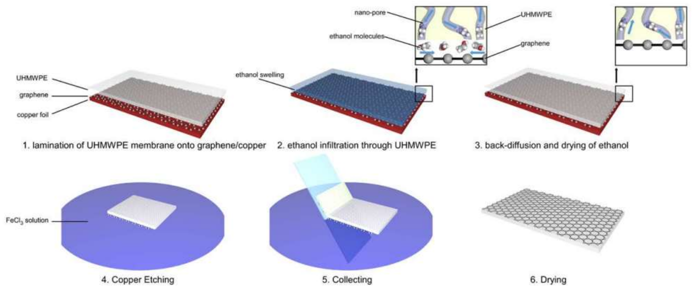
Thrust Head
Thrust of Advanced Materials

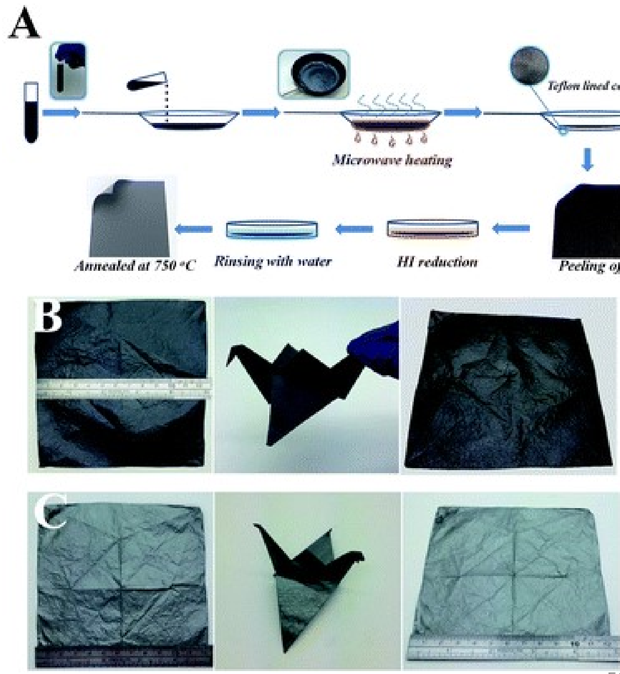
Professor
Thrust of Advanced Materials

Yang HUANG
黄扬
PhD in Physics and Materials Science
City University of Hong Kong, 2016

Assistant Professor
Thrust of Advanced Materials







- Etching-and intermediate-free graphene dry transfer onto polymeric thin films with high piezoresistive gauge factors, Li et al., 2019
- Use of Hydrophobic-Hydrophobic Interactions for Direct Graphene Transfer, , Li et al., 2016
- Robust reduced graphene oxide paper fabricated with a household non-stick frying pan: a large-area freestanding flexible substrate for supercapacitors, Huang et al., 2015
- Graphene stirrer with designed movements: Targeting on environmental remediation and supercapacitor applications, Huang et al., 2017

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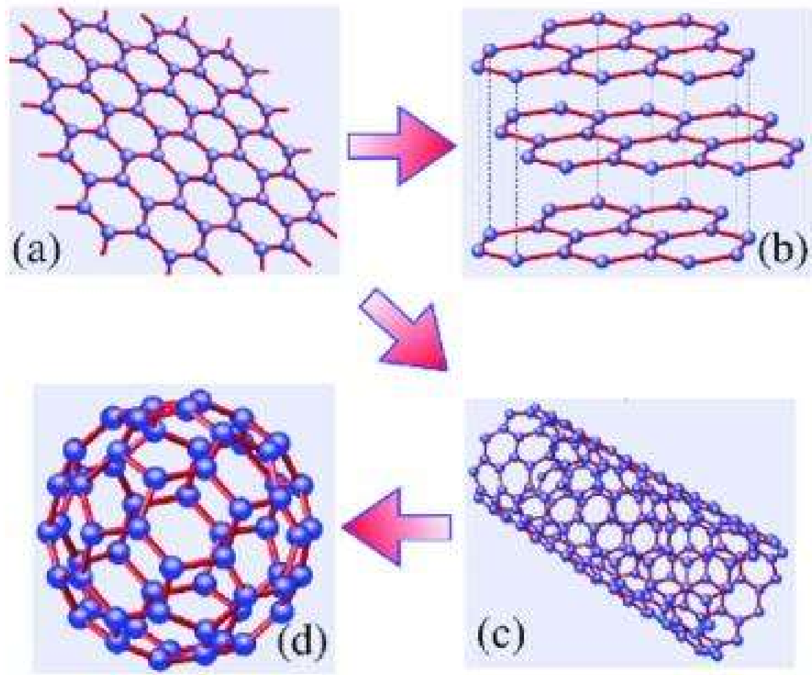
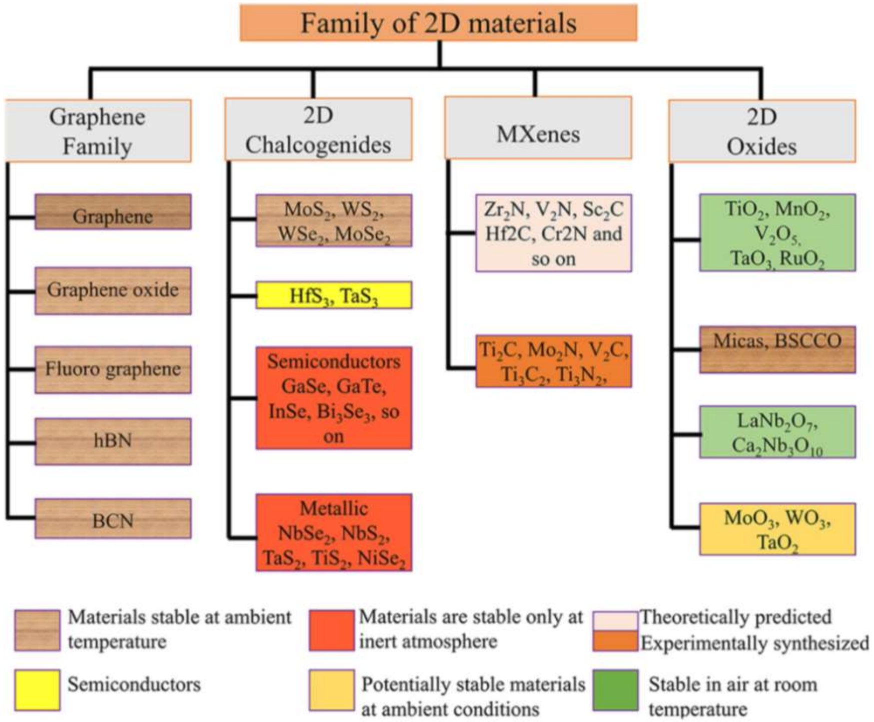
Beyond Graphene

- **Fullerene： cosmetics**
- **Carbon nanotube： electronics, battery, composite materials**

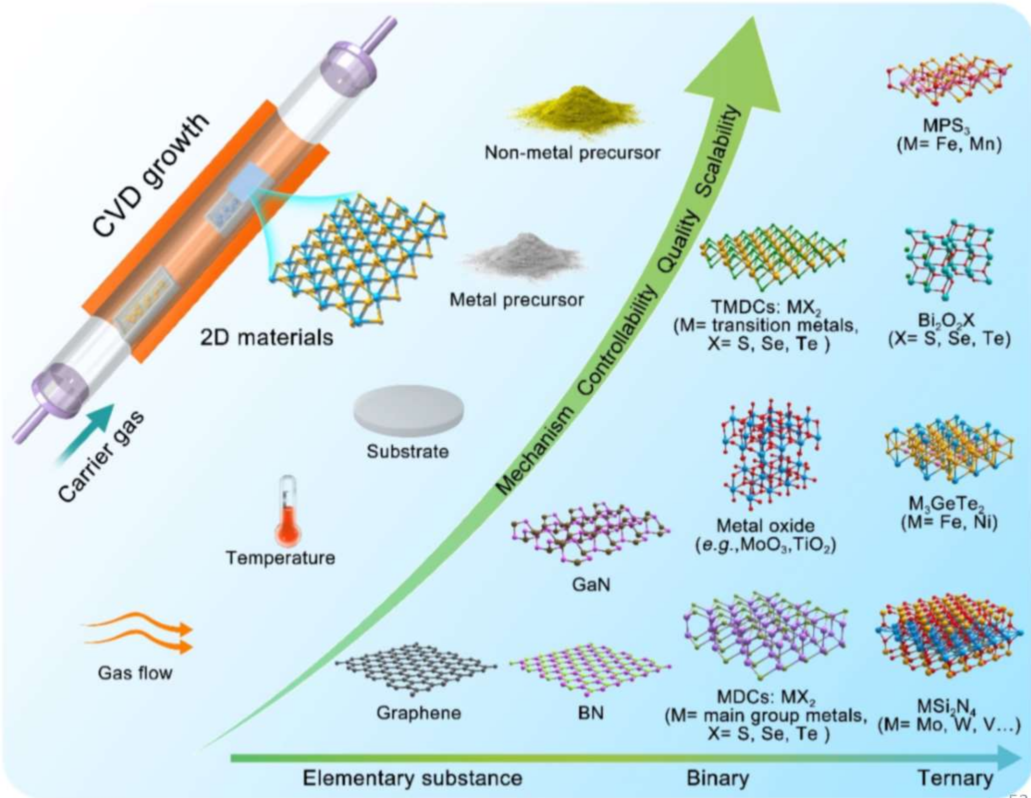


Beyond Graphene: 2D materials

- Many 2D materials could be synthesized by the similar strategies



Adv. Mater. **2022, 34, 2108473**



Essay 1

- **Deadline is 29th of September**
- **Late submissions will get a reduction of 10 points**

Lab tour this coming Thursday

- **When: Thursday afternoon 1:50pm**
- **Where: W3, level 4, Function Hub office**
- **Who: anyone interested in AMAT research**
- **Which labs: Quantum science and Green e Materials**

Research facility of the AMAT Thrust

- Green e Materials (GeM) Lab
- Quantum Science and Technology (QST) Lab
- Multifunctional Materials Lab
- Material Characterization and Processing Facility (MCPF)
- Center for Multifunctional Membrane
- Smart Wave Functional Materials Lab

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