Synthesis of Graphene

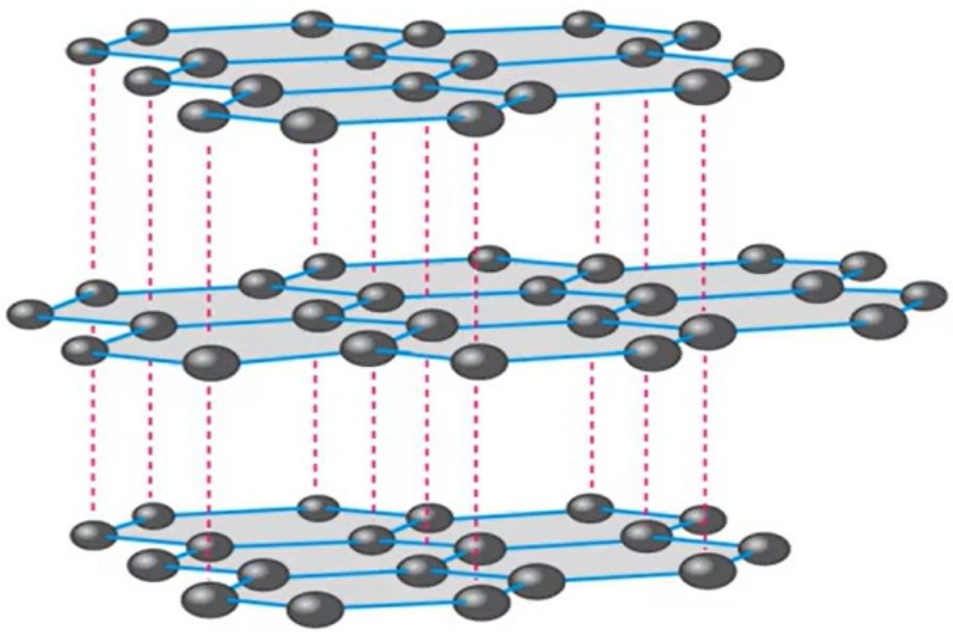
i. **Top-down methods** where layers of graphene derivatives are extracted from a carbon source, typically graphite

(mechanical cleavage, exfoliation)

ii. **Bottom-up methods** where simple carbon molecules are used to construct pristine graphene

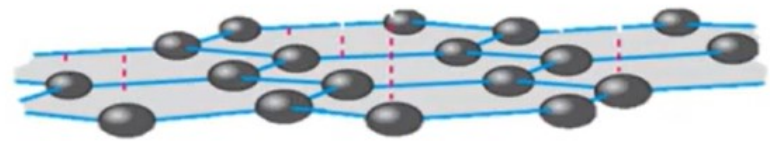
(chemical vapor deposition, epitaxial growth on substrate)

1. Top-down method



Graphite

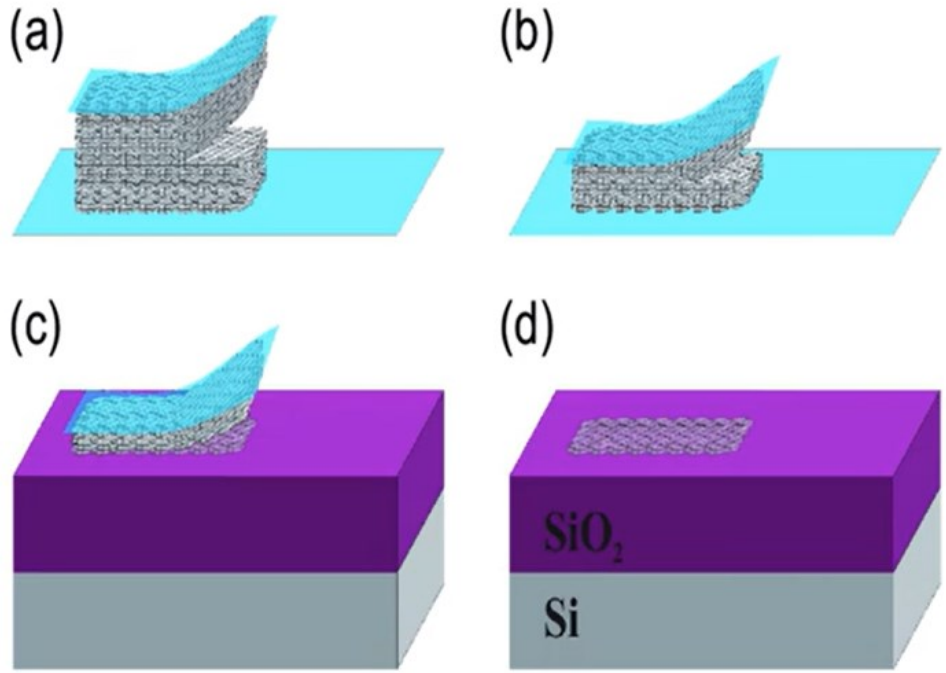
Exfoliation
(Mechanical cleavage,
liquid-phase, oxidation)

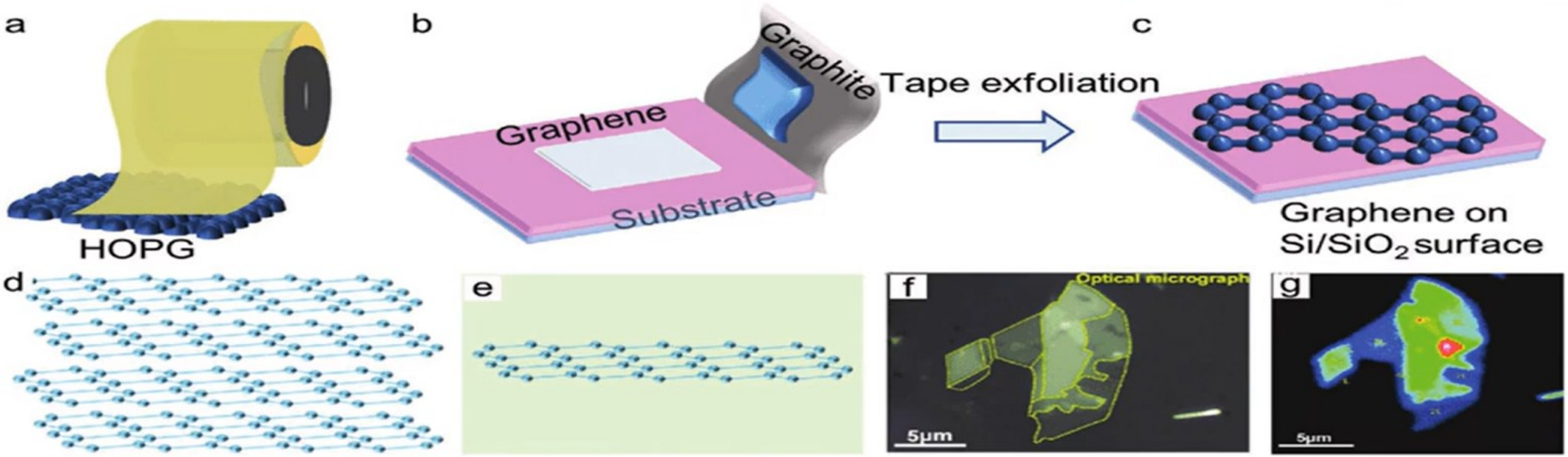


Graphene

1. Exfoliation through Mechanical cleavage

Mechanical cleavage is the method **to isolate graphene by peeling it off from graphite flakes using a Adhesive tap.** Since the **interlayer vander waals force in graphite is very weak,** graphite can be easily exfoliated using adhesive tap. Multilayers of graphne are attached on tap, so by repeated peeling, the multilayer graphene is cleaved in to few/mono-layer graphene. Afterwards, the **tap is attached to clean substrate (Si/SiO_2)** by gentle pressing and the **glue dissolved using acetone.**

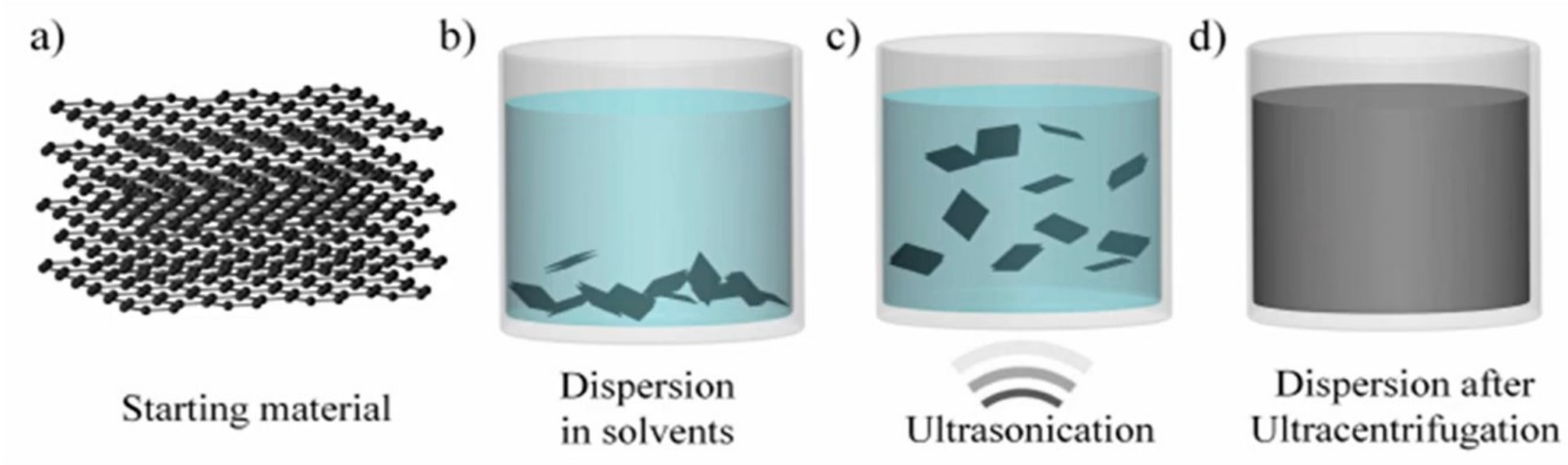




2. Liquid phase Exfoliation

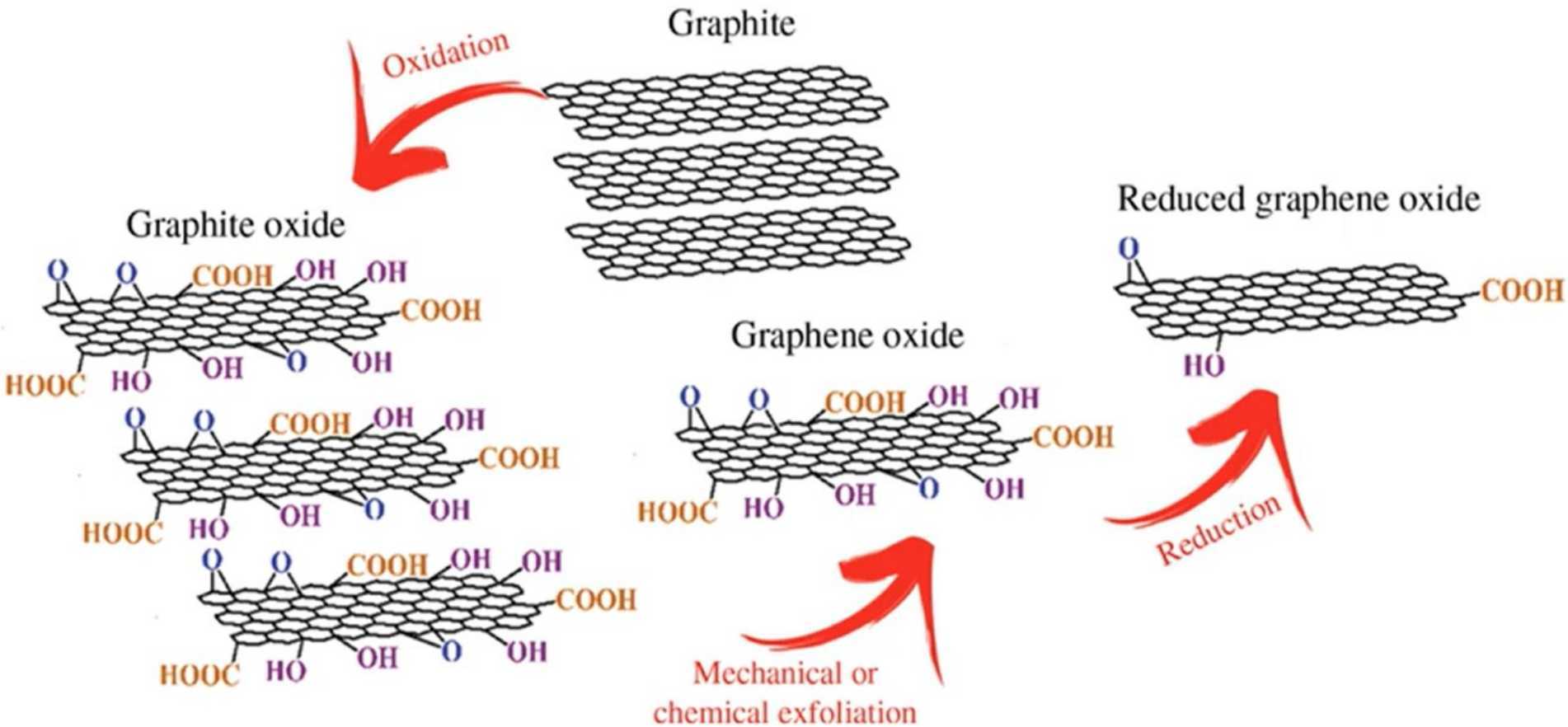
Graphene can be prepared in liquid phase. In this method, the **graphite is dispersed in organic solvent** with nearly same surface energy as graphite, which has to overcome to detach a graphene from graphite.

The solution is **sonicated** in ultrasonication bath and after **dispersion** and centrifugation, the graphene thicker flakes are obtained.



3. Oxidation Exfoliation

Due to several functional groups like epoxide or hydroxyl, graphene oxide is hydrophilic and can be solved in water by sonication or stirring. Thereby the layers become negatively charges and the recombination is inhibited by electrical repulsion. After centrifugation, the graphene oxide has to be reduced to regular graphene by thermal or chemical methods.

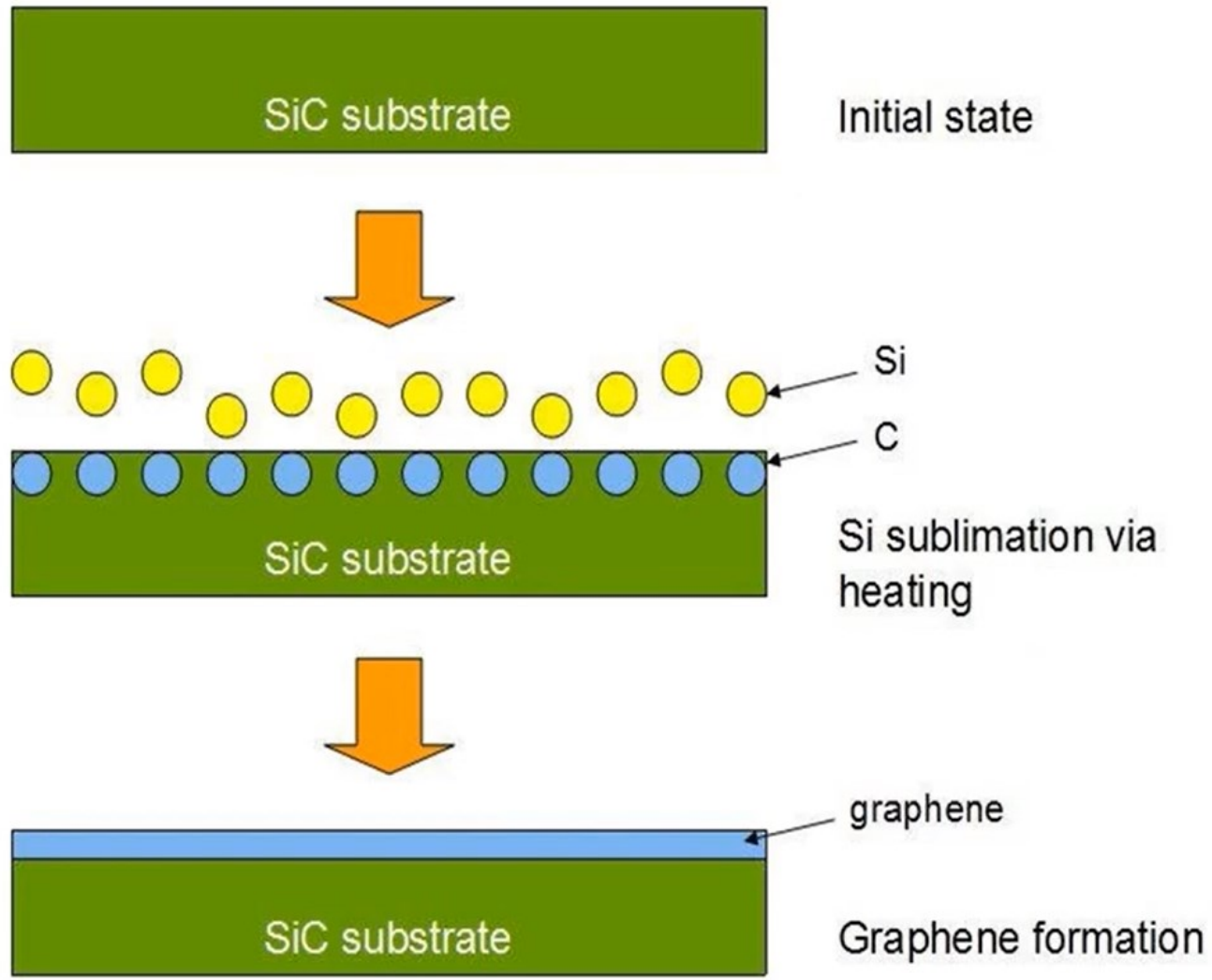


2. Bottom-up methods

1. Epitaxial growth

Epitaxial graphene growth is a **substrate-based method**, where isolated monolayer of graphene is grown on **single crystal SiC** under vacuum.

Due to the fact that the vapor pressure of carbon is negligible compared to that of silicon, so the thermal treatment of SiC at ~ 1300 ^{0}C under vacuum, the **Si atoms desorb (sublimation) at high temperatures** and leave behind the carbon atoms which undergo reorganization and form graphitic layers.

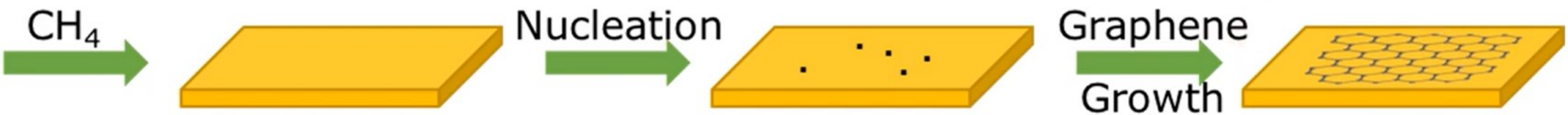


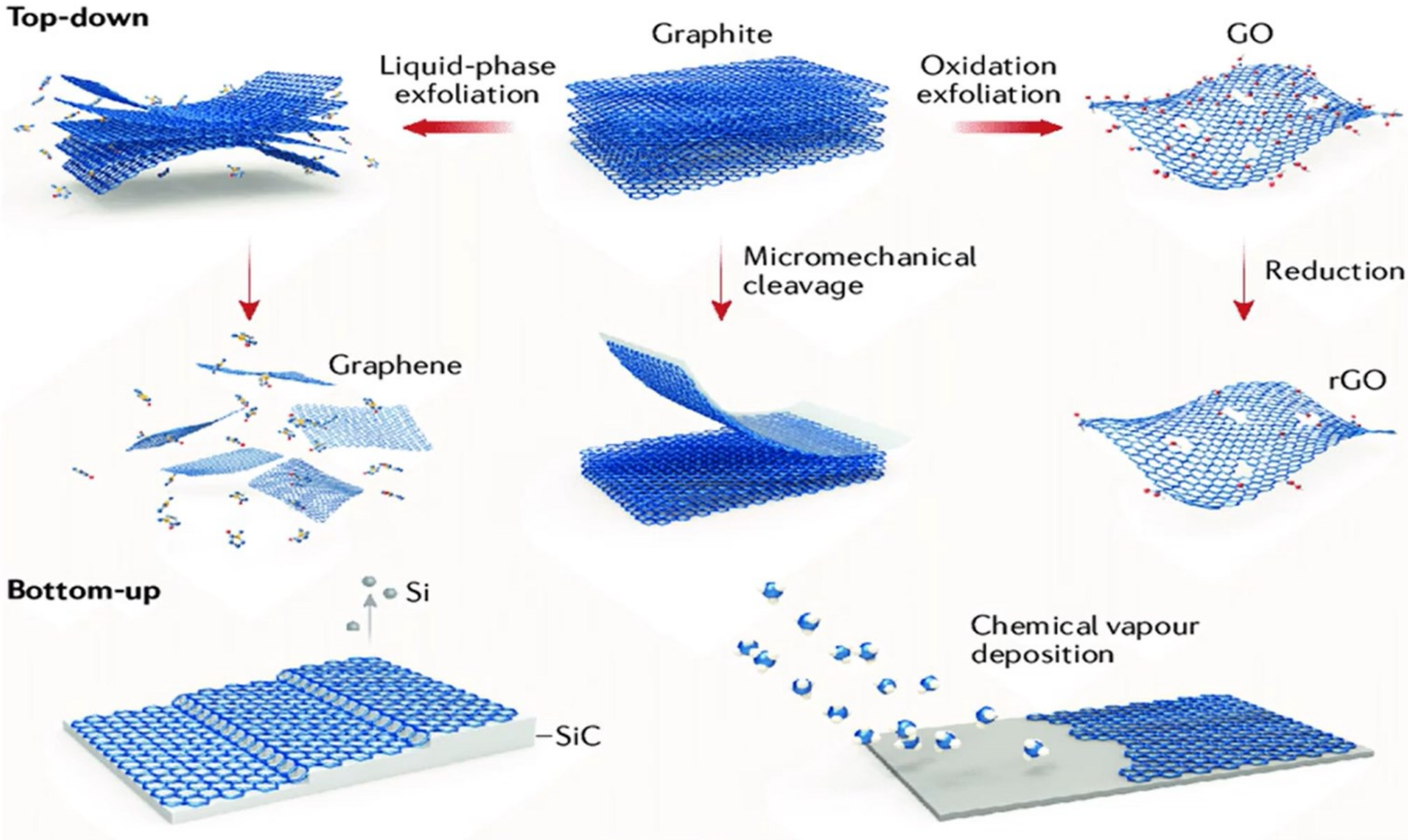
2. Chemical Vapor deposition (CVD)

Chemical vapor deposition is a well-known process in which a **substrate is exposed to gaseous compounds. These compounds decomposed on the surface in order to grow a thin film.**

In CVD methods, graphene is grown directly on transition metal substrate via saturation of Carbon upon exposure to Hydrocarbon gas at high temperature. **Ni and Cu films are typically used as substrate with methane as a precursor gas.** When the substrate is cooled, the solubility of Carbon on substrate decreases and the carbon precipitates to form layers of graphene sheet on substrate.

$$CH_4 \longrightarrow C\ (Graphene) + 2H_2$$




Top-down
Graphite
GO
Liquid-phase exfoliation
Oxidation exfoliation
Micromechanical cleavage
Reduction
Graphene
rGO
Bottom-up
Si
SiC
Chemical vapour deposition