Honeycomb carbon: A Review of Graphene[1]

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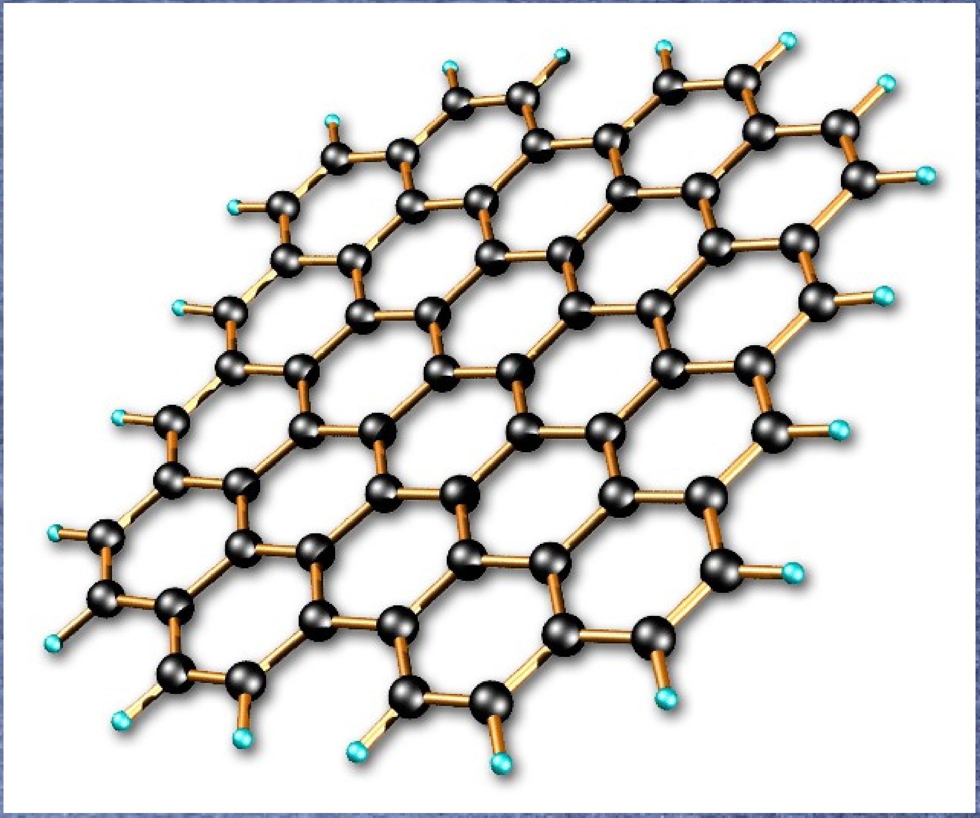
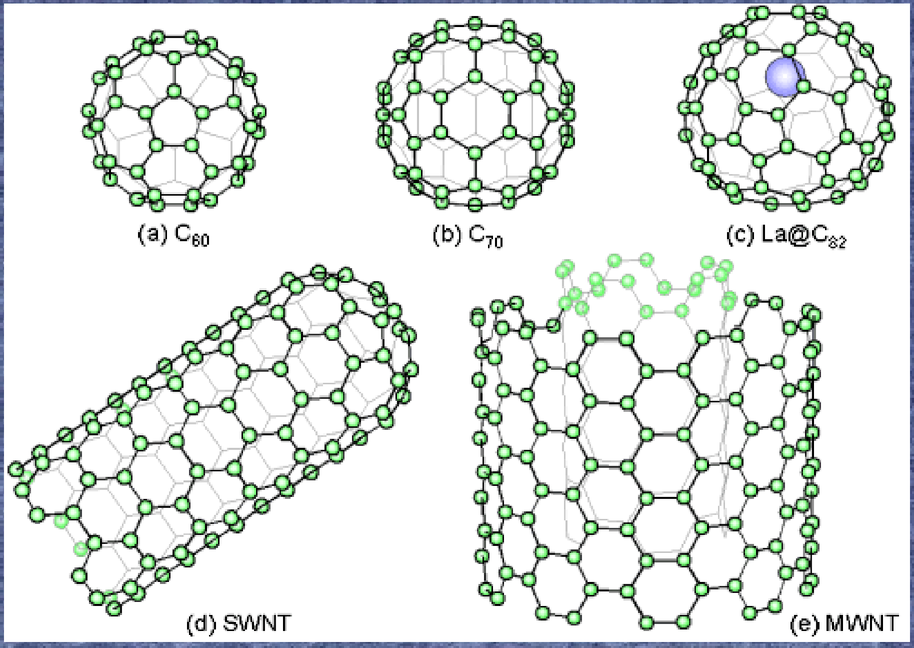
What is graphene?

- 2D structure
- sp^2-hybridized



Building block for:

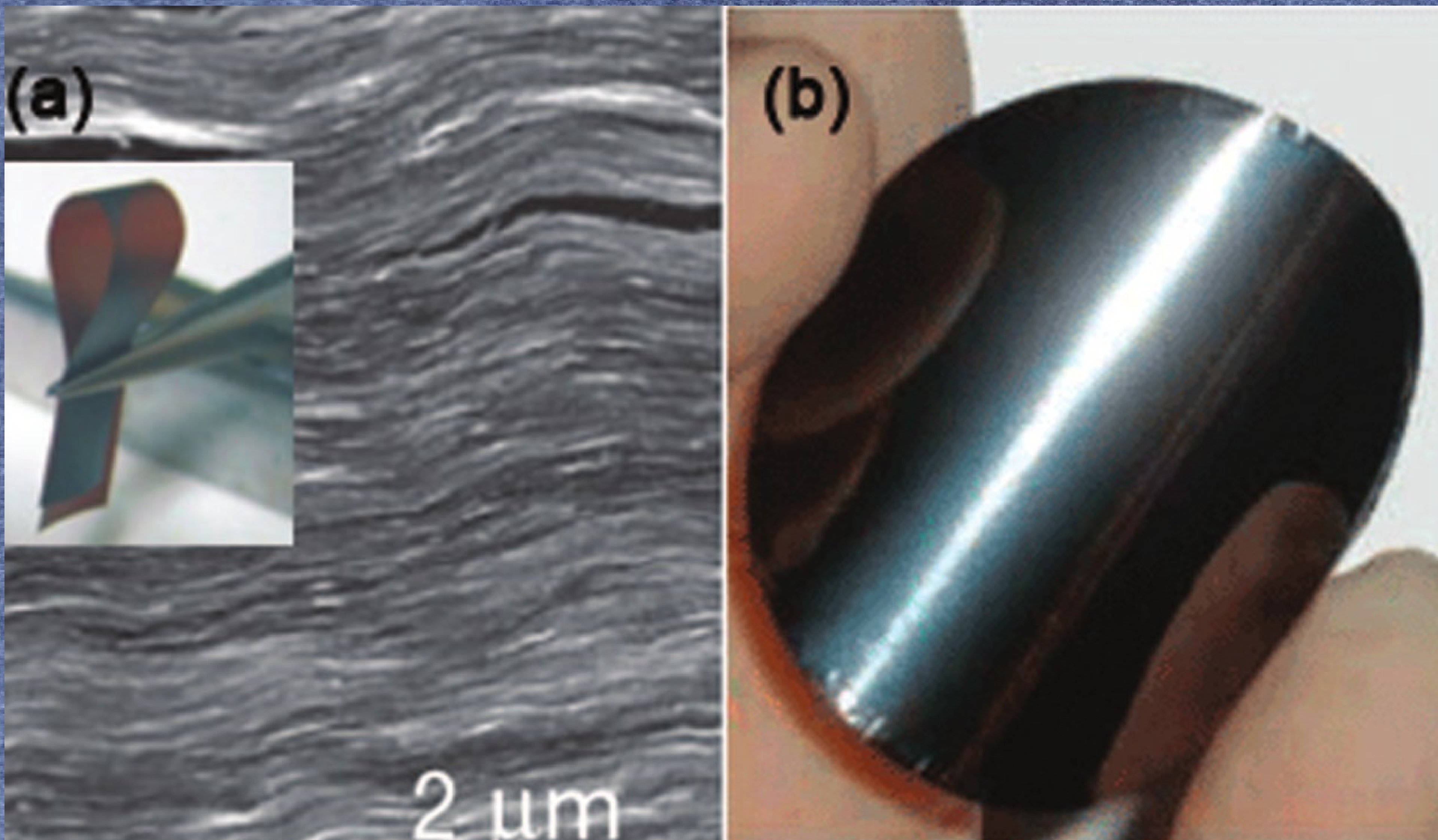
- 3D graphite
- 1D nanotubes
- 0D fullerenes



Properties of graphene

- Stable sheets without growing substrate
- Quantum Hall effect at room temperature
- In-layer / out-layer conductivity ~ 1000 times
- Ambipolar field effect

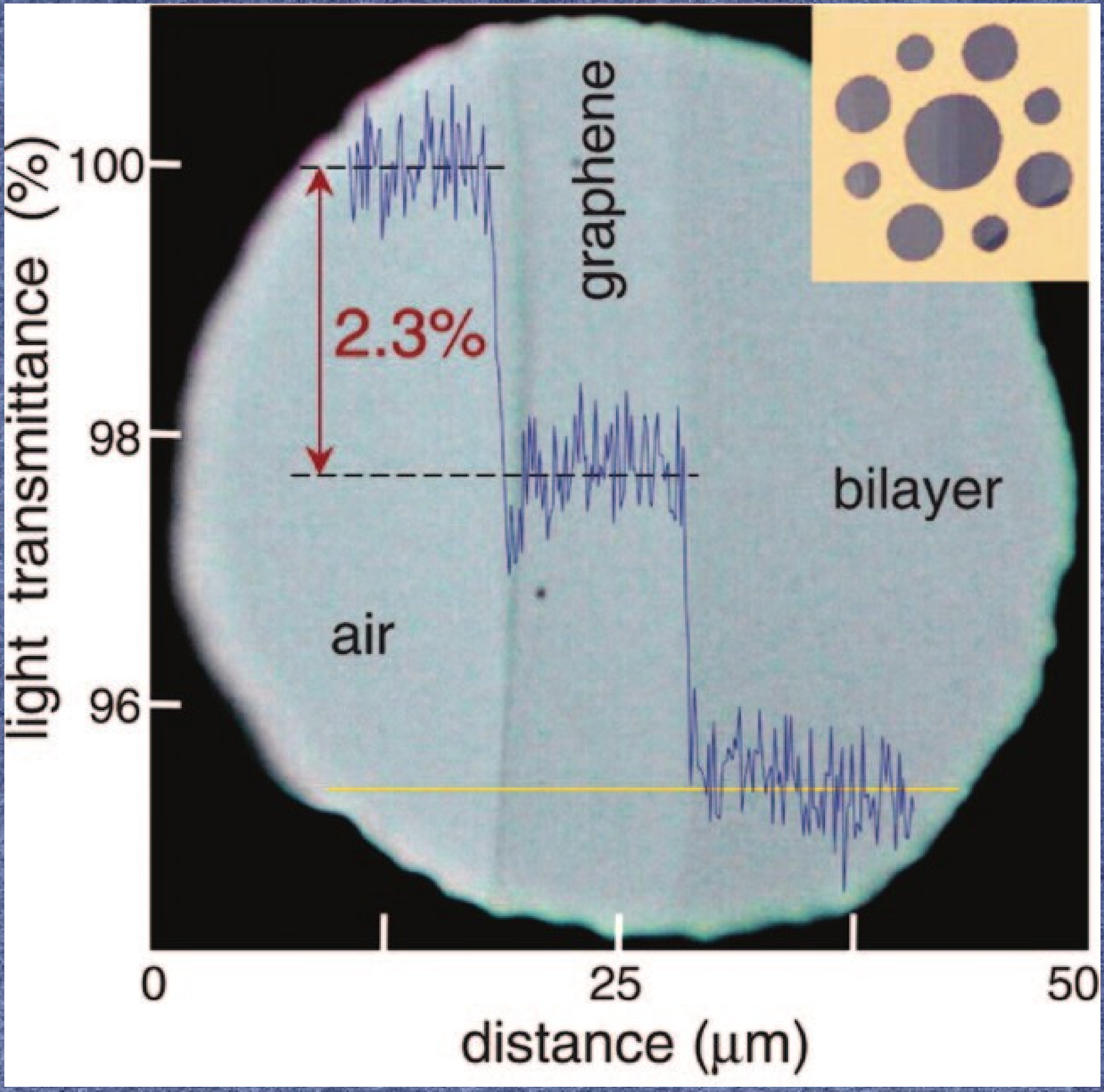
Strength of graphene



Cross section of graphite oxide film. SEM image.

Optical absorbance of graphene

Single and bilayer graphene on porous membrane



Ambipolar field effect

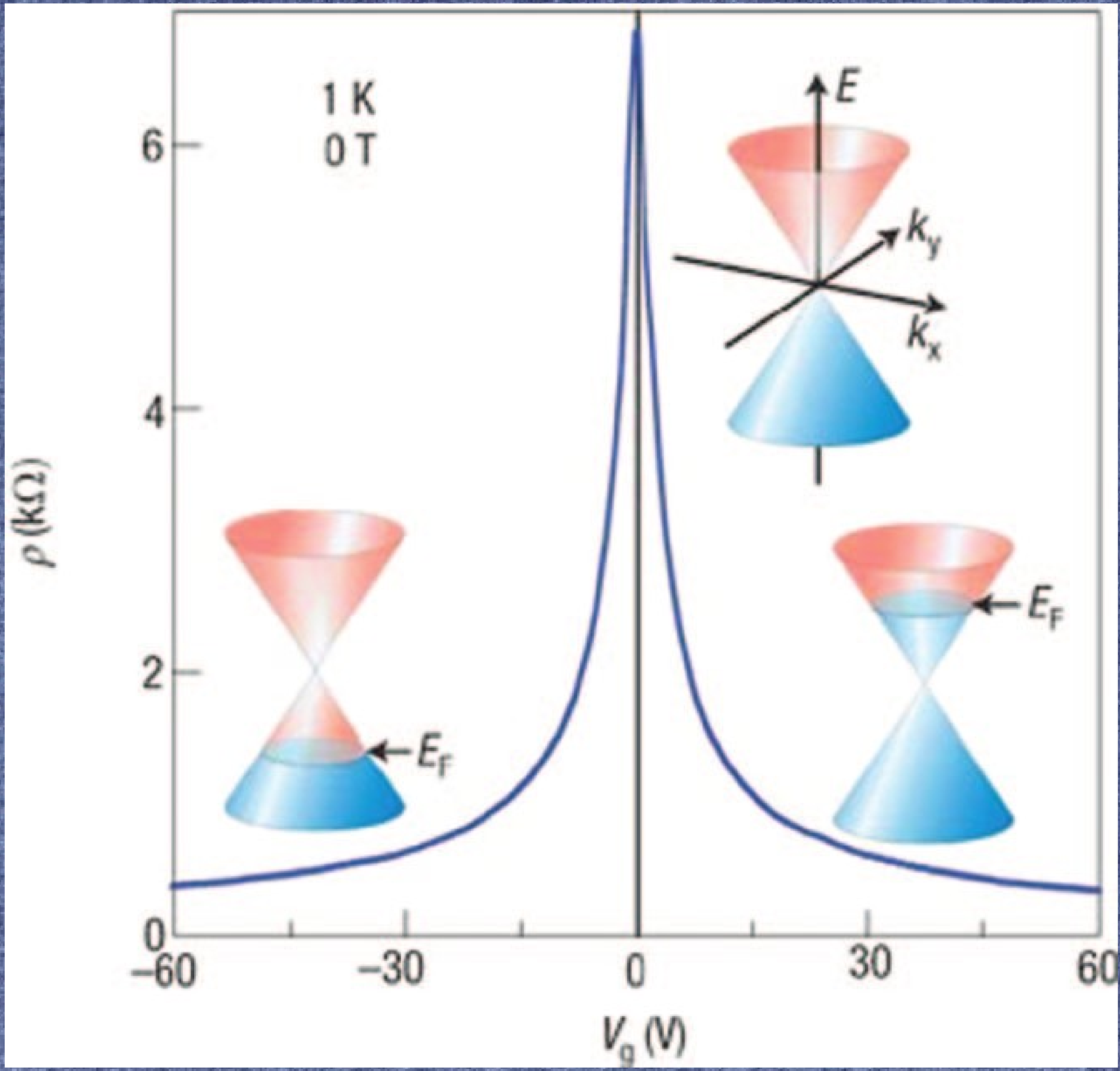
Band structure in graphene.

Conduction band

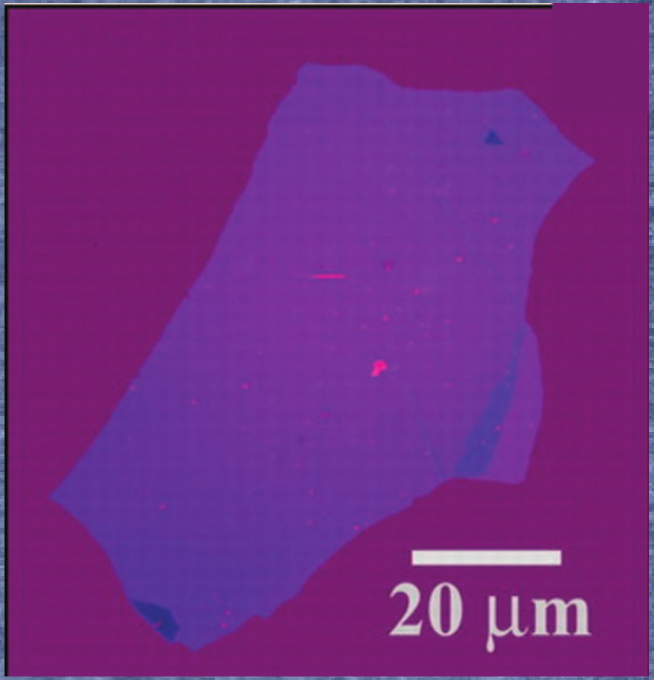
Dirac point

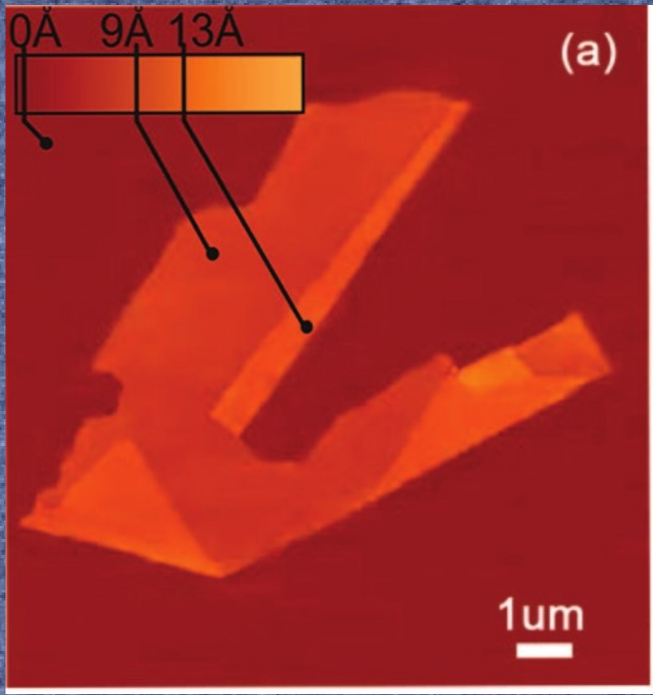
Valence band

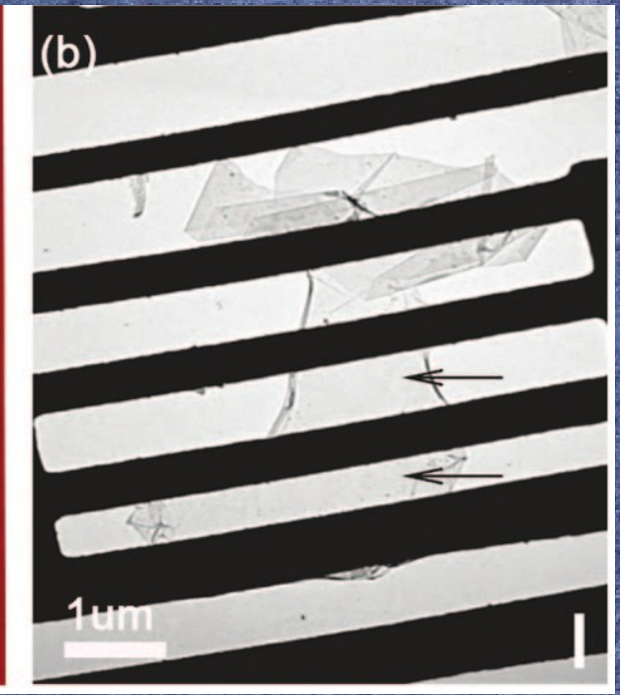
Fermi level.



Graphene flake examples





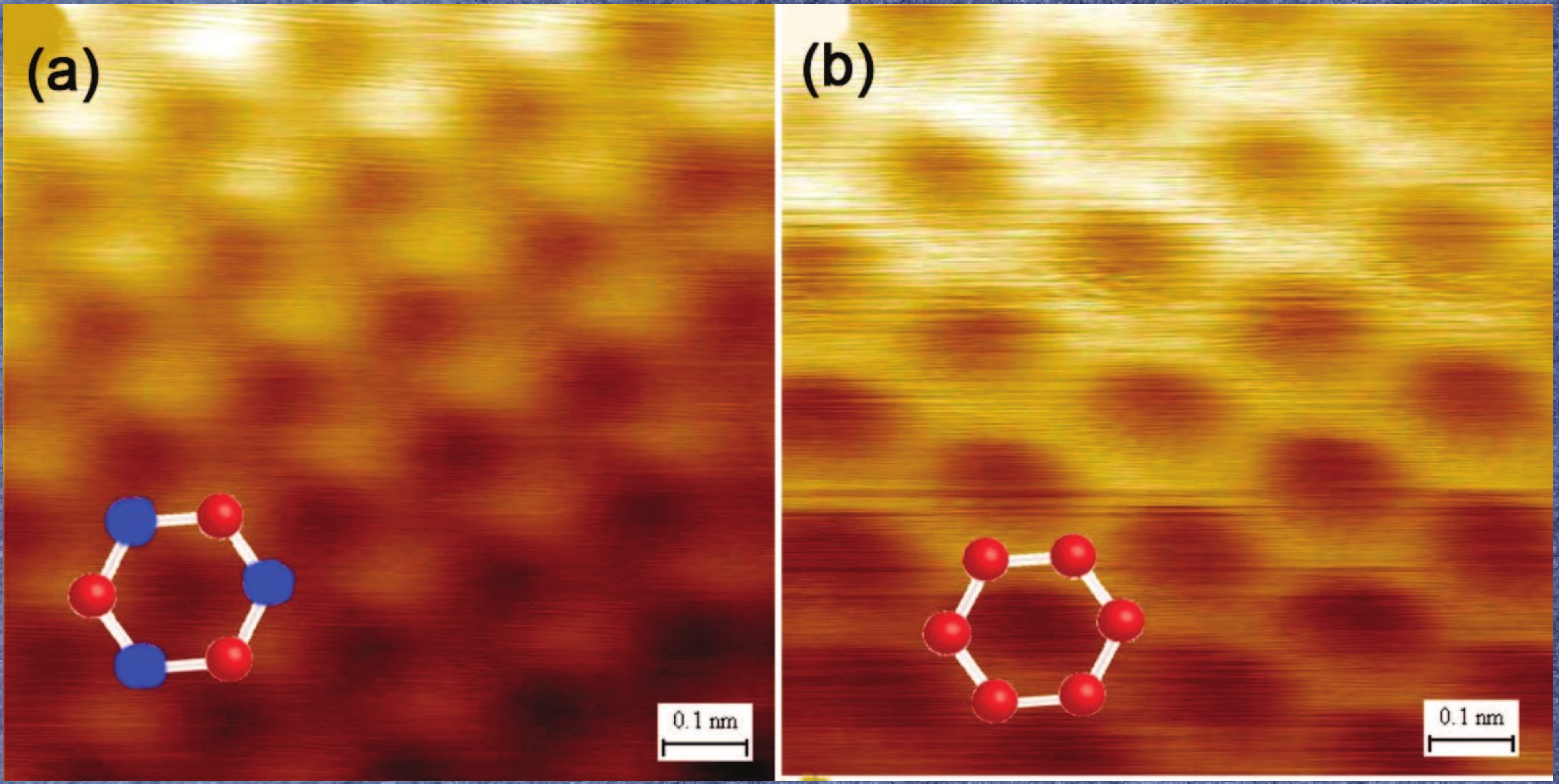


A few layer flake,optical interference microscopy.

Single layer graphene flake. AFM image.

Free-standing graphene film. TEM image.

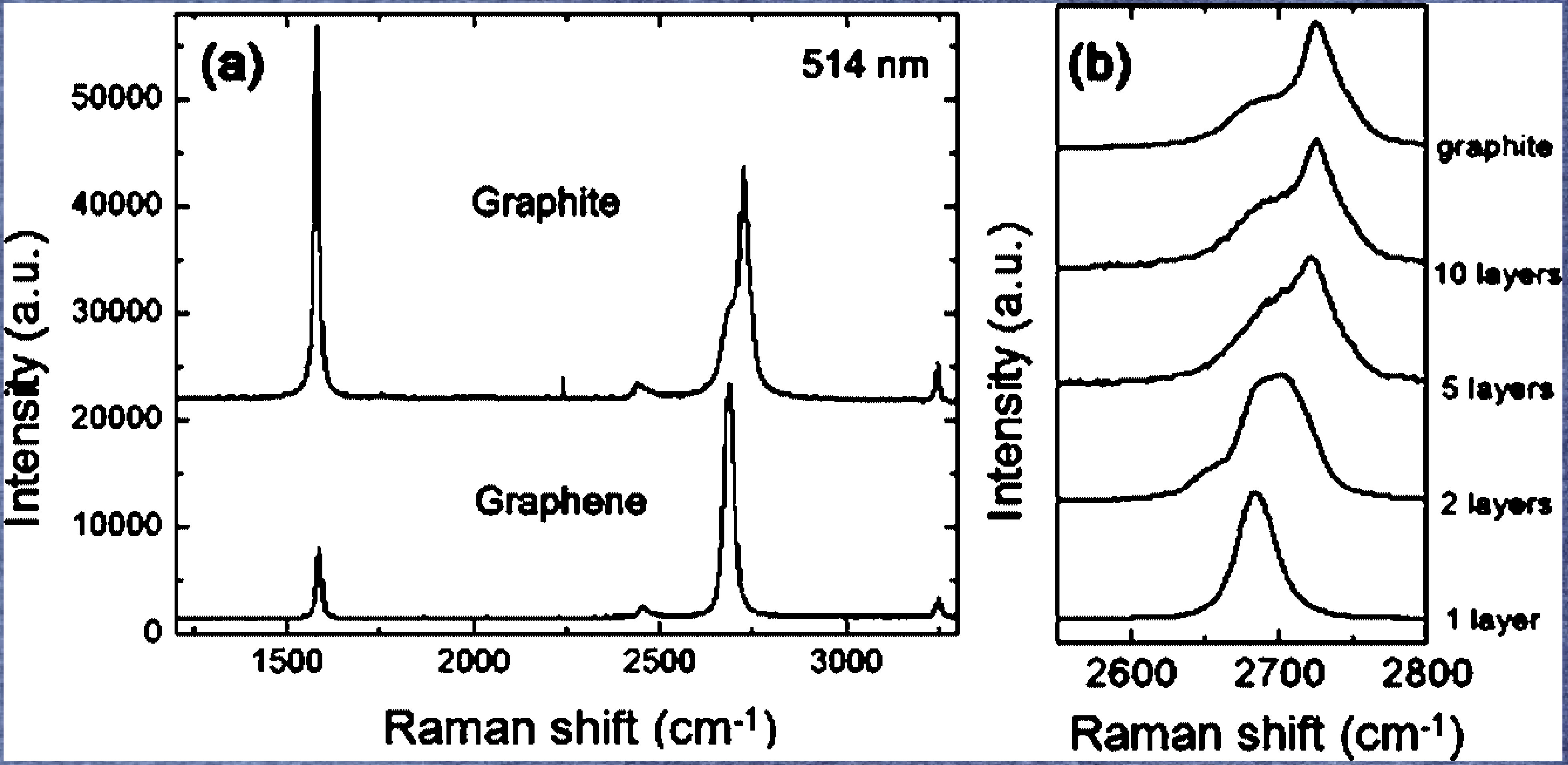
Surface electron structure



Graphite.
STM image.

Mechanically exfoliated
single-layer graphene.

Thickness measurement using Raman spectroscopy



Raman spectra of graphene flakes with varied thickness produced by mechanical exfoliation.

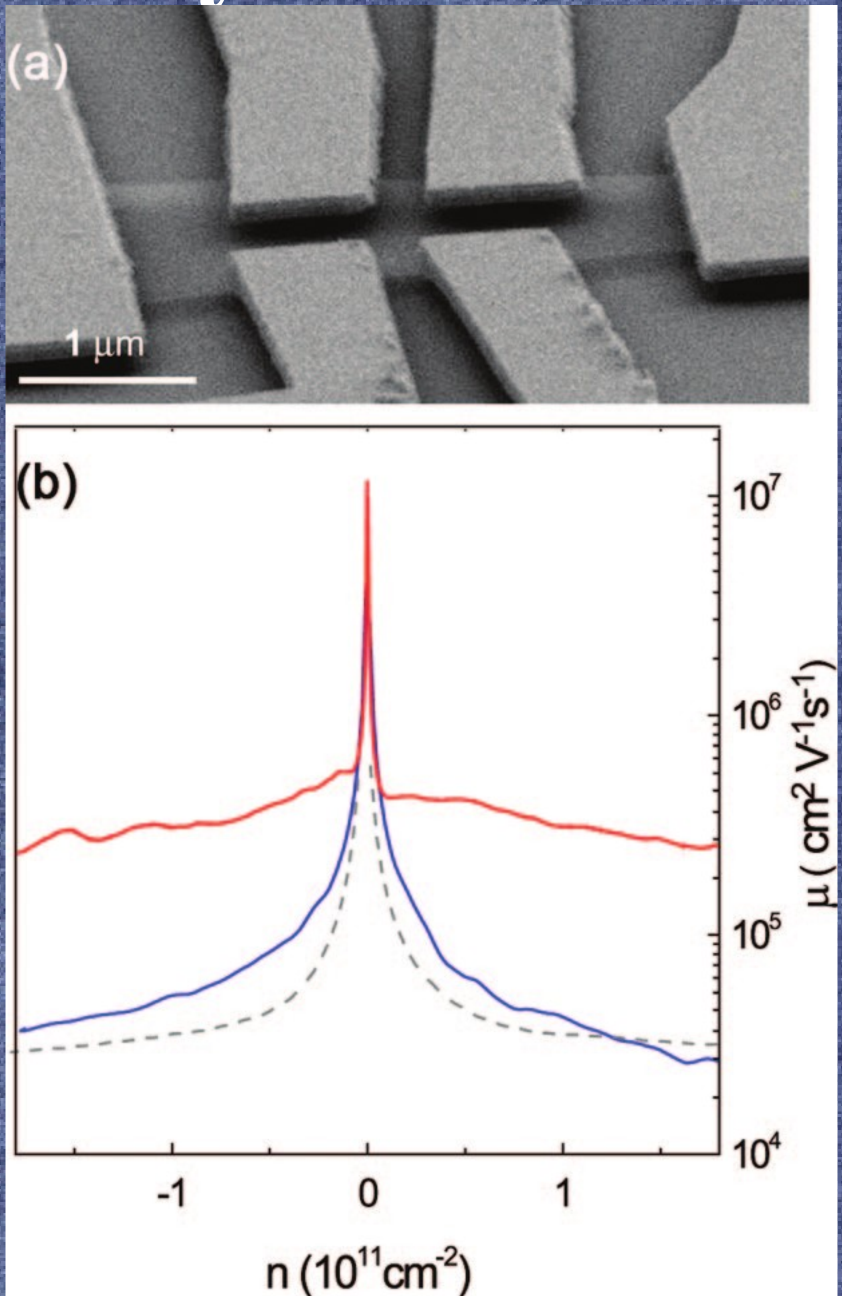
Uses of graphene

- High speed logic devices
- Thermally and electrically conductive composites
- Sensors
- Transparent electrodes

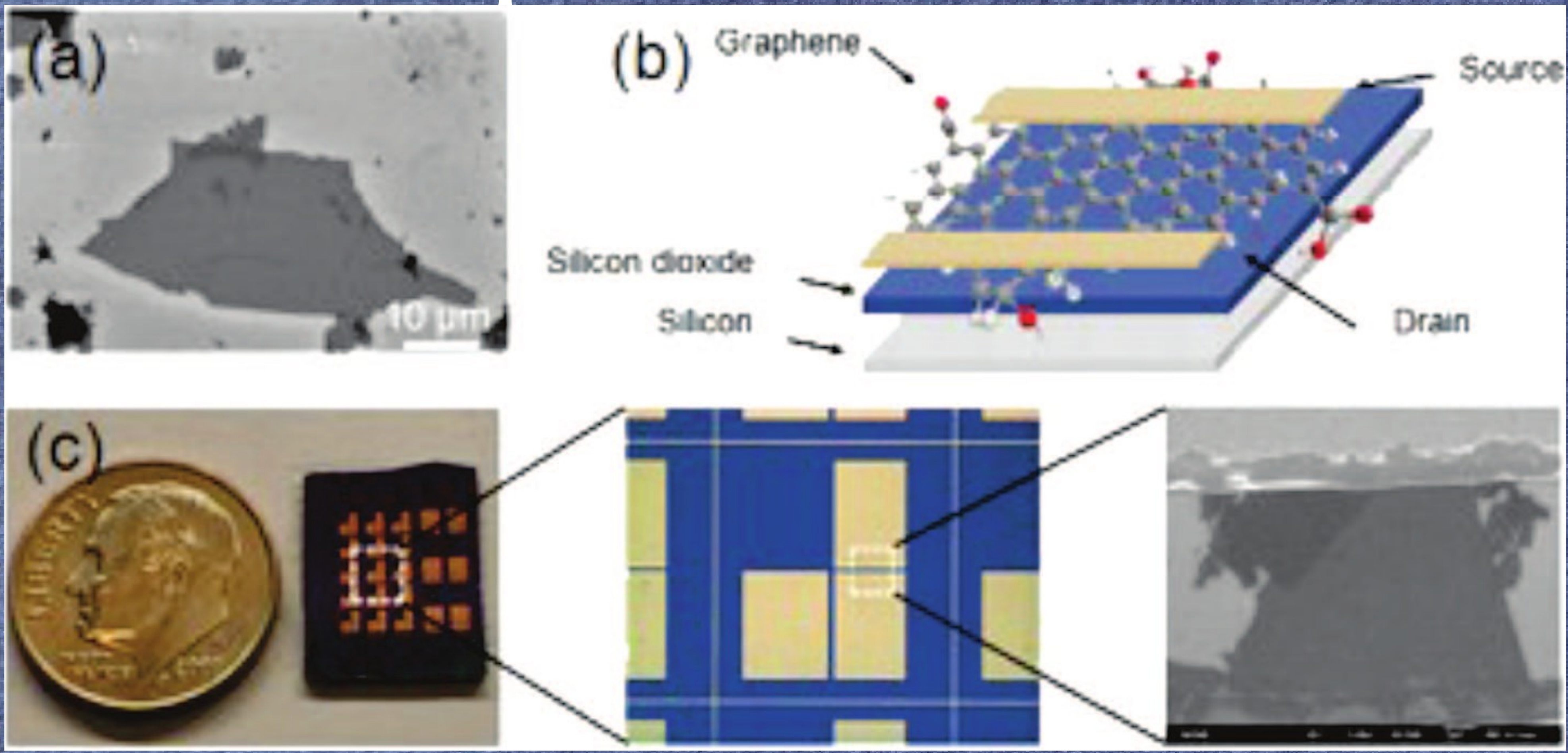
Electron mobility

SEM image of a suspended sheet.

Field-effect measurements indicate mobility greater than 200,000 cm2/(V s).

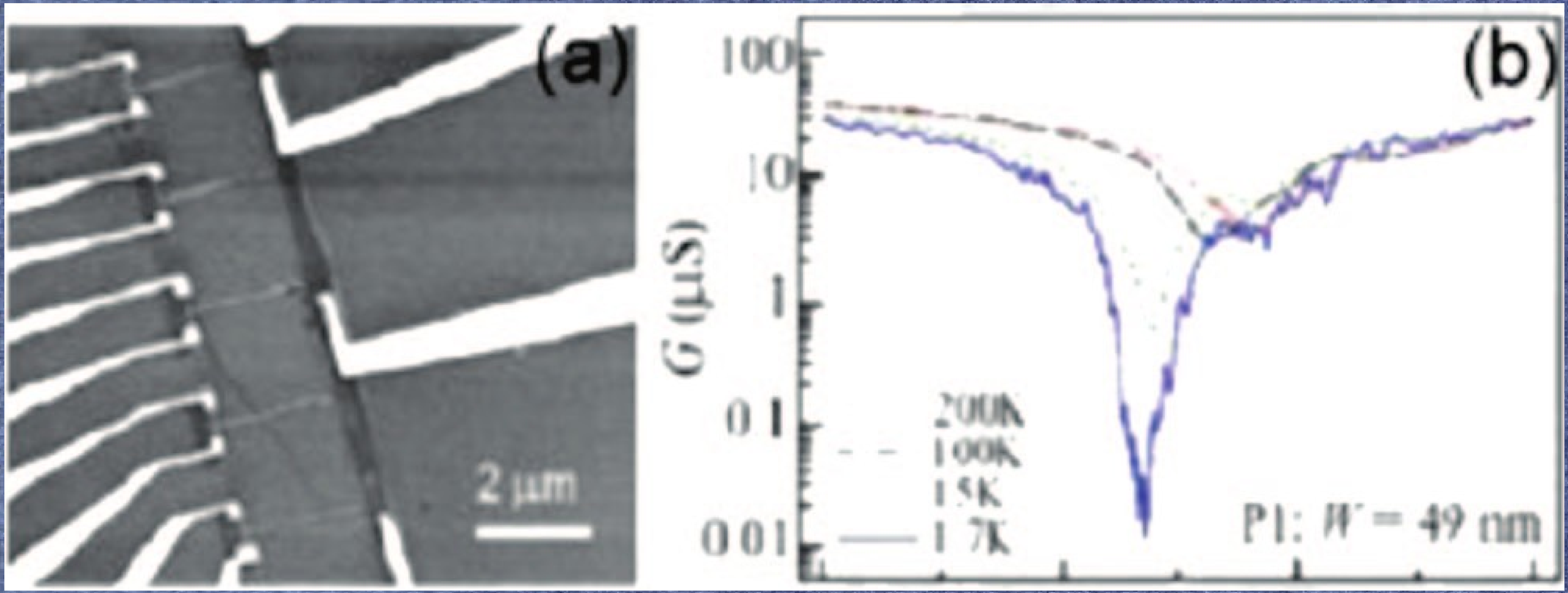


Graphene transistors



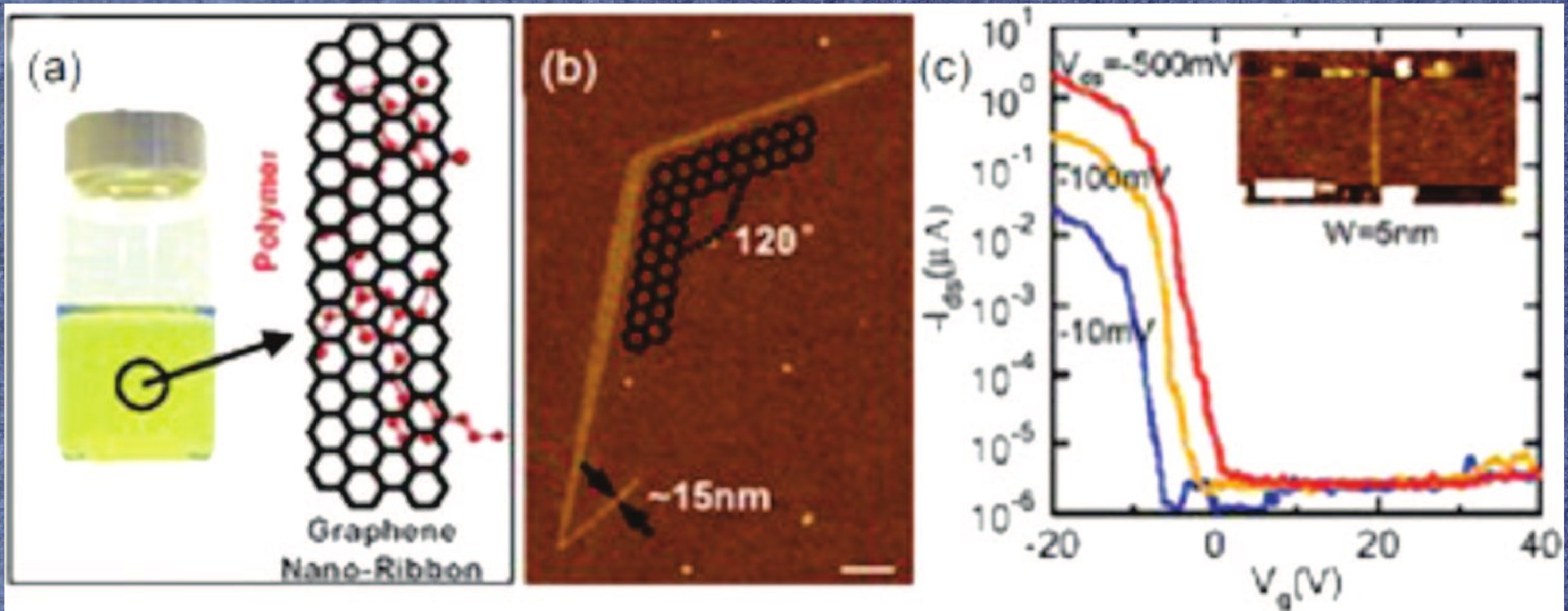
(a) Single graphene sheet on SiO2. SEM image.
(b) Construction of a top-contact, back-gated device.
(c) working device with a channel length of 7 μm.
Photograph, optical, and SEM image.

Etched ribbons



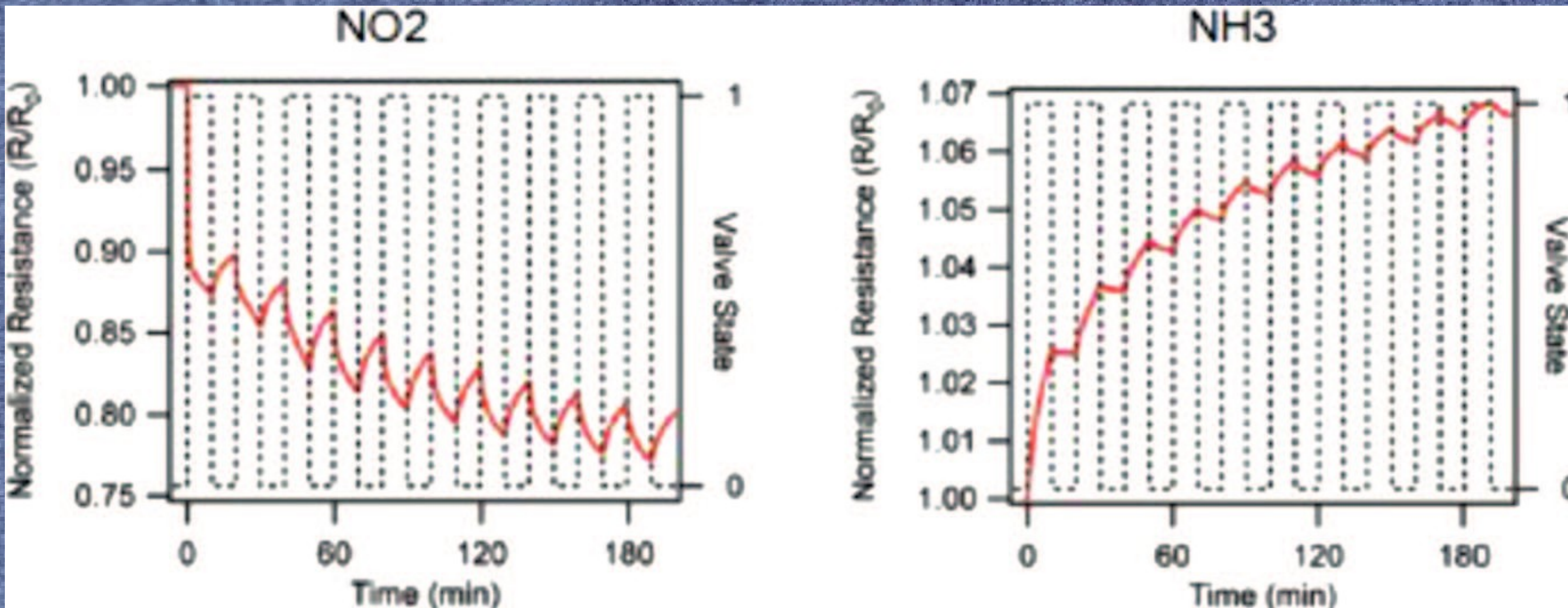
Lithographically created nanoribbons.
I_{on}/I_{off} ratio up to 10^4

Chemically derived nanoribbons



(a) ribbon stabilized in solution by π-stacking polymer agents.
(b) Spin-coated surface with ribbon widths 10 nm and up. AFM image.
(c) I_{on}/I_{off} ratios up to 10^6

Graphene gas sensors

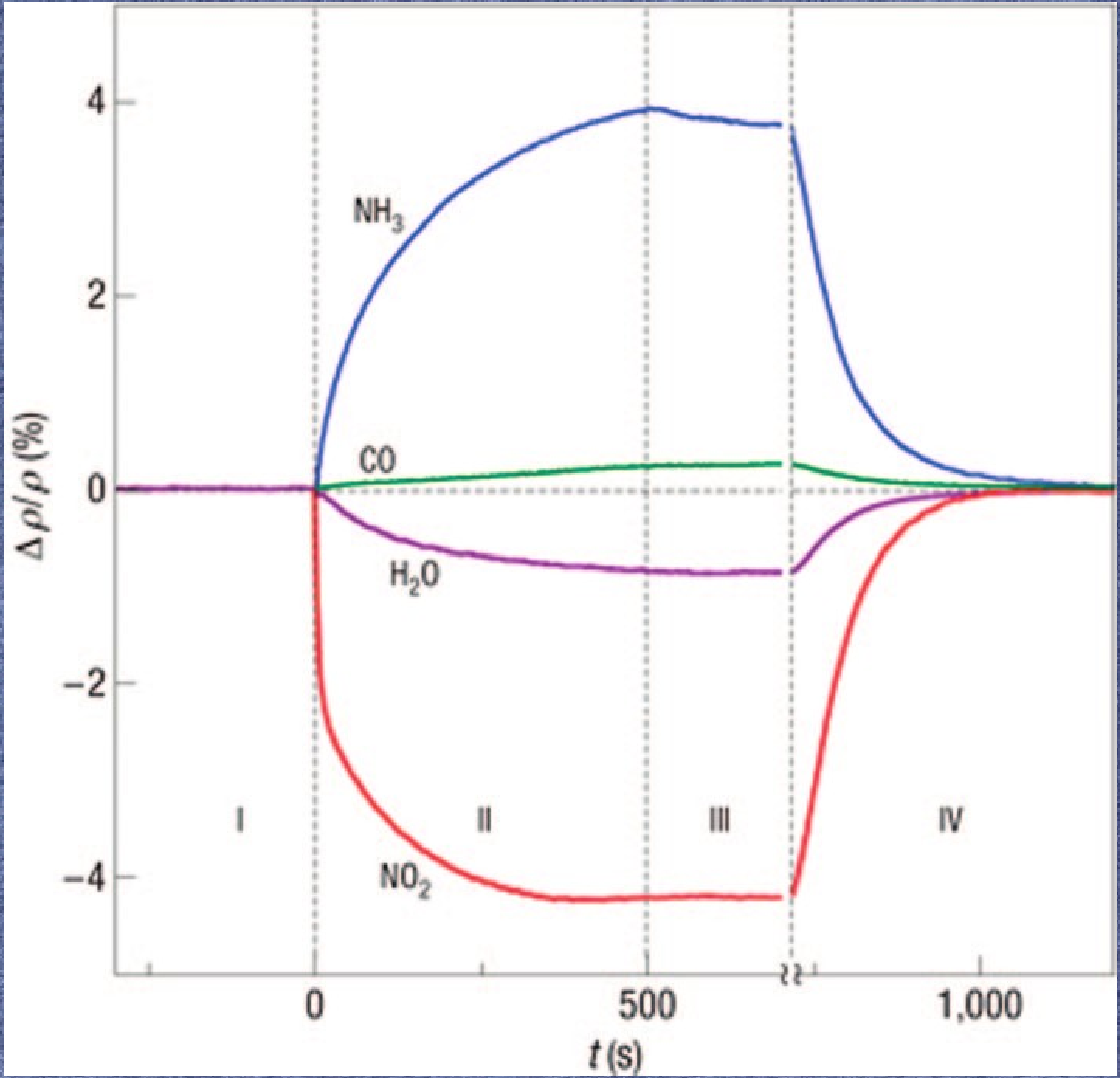


Resistance response of chemically derived p-type graphene to electron withdrawers (NO2) and electron donors (NH3).

Single molecule adsorption sensor

electrons

holes



Production of graphene

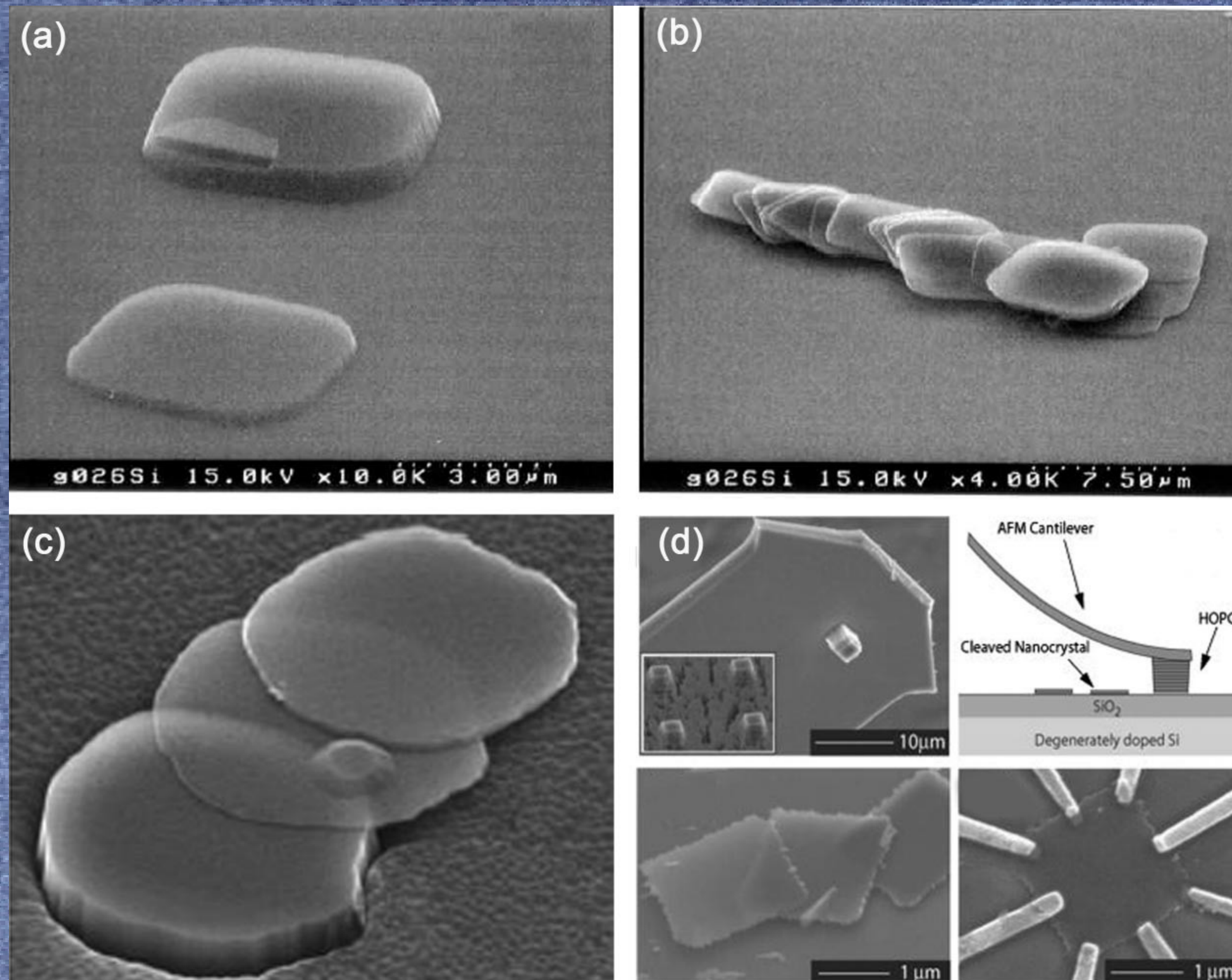
- Mechanical exfoliation
    - slow, low yield
- Chemical exfoliation in solution
    - modifies 2D crystal structure
- Bottom-up synthesis from organic precursors
    - small fragments only
- Growth on a substrate
    - polycrystallinity, uneven thickness

Mechanical exfoliation process of graphite pillars

Using AFM probe:

Using tipless cantilever:

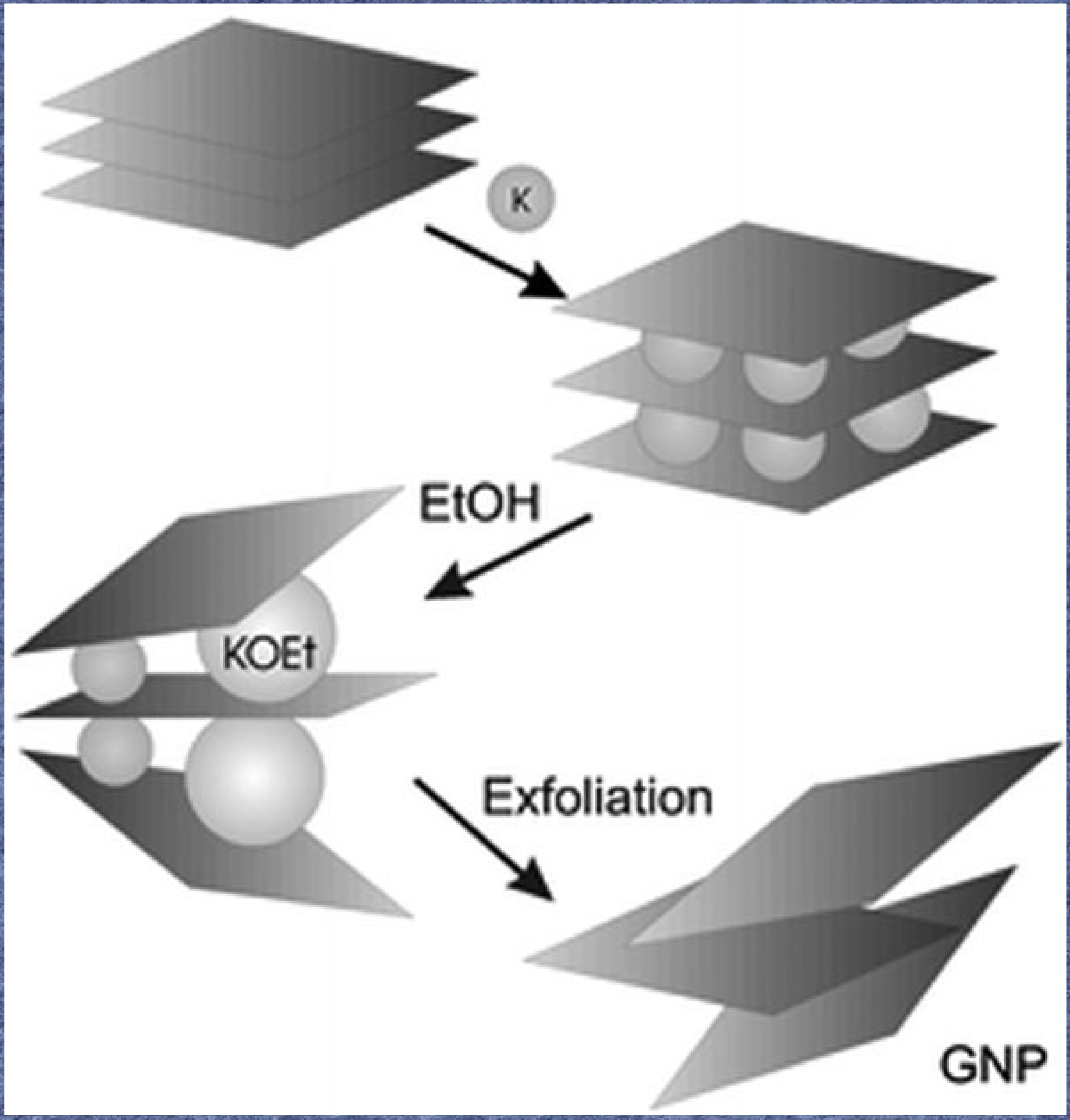
SEM images.



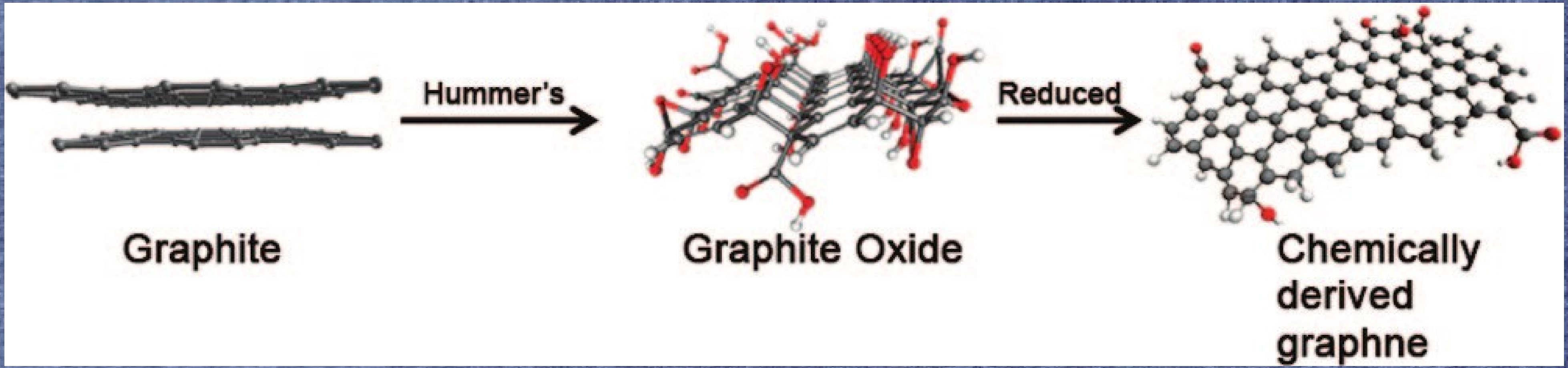
Graphite intercalation

Intercalation and exfoliation of graphite using K^+ and alcohols.

Resulting thickness: 30 layers.

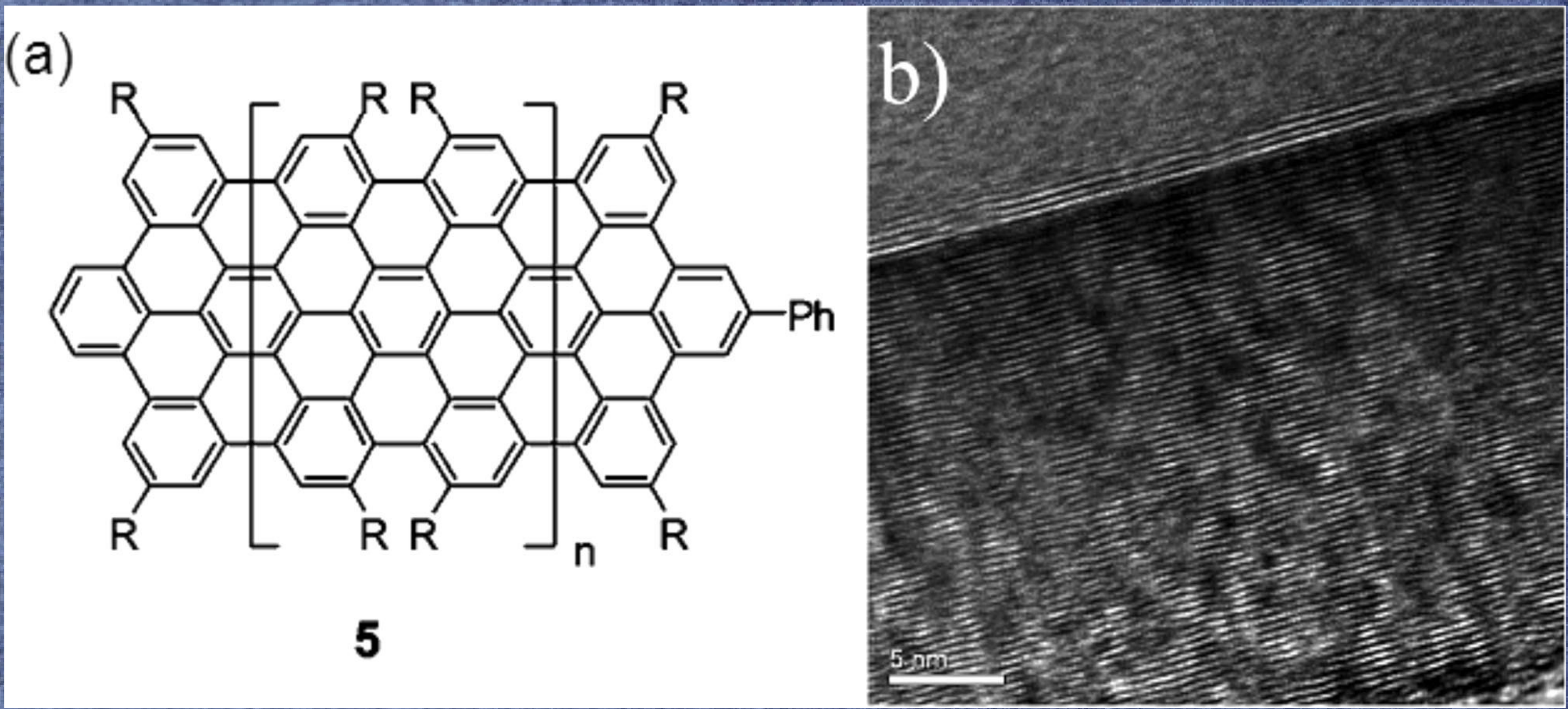


Chemically derived graphene



Conversion of graphite to graphene.

Ground-up synthesis



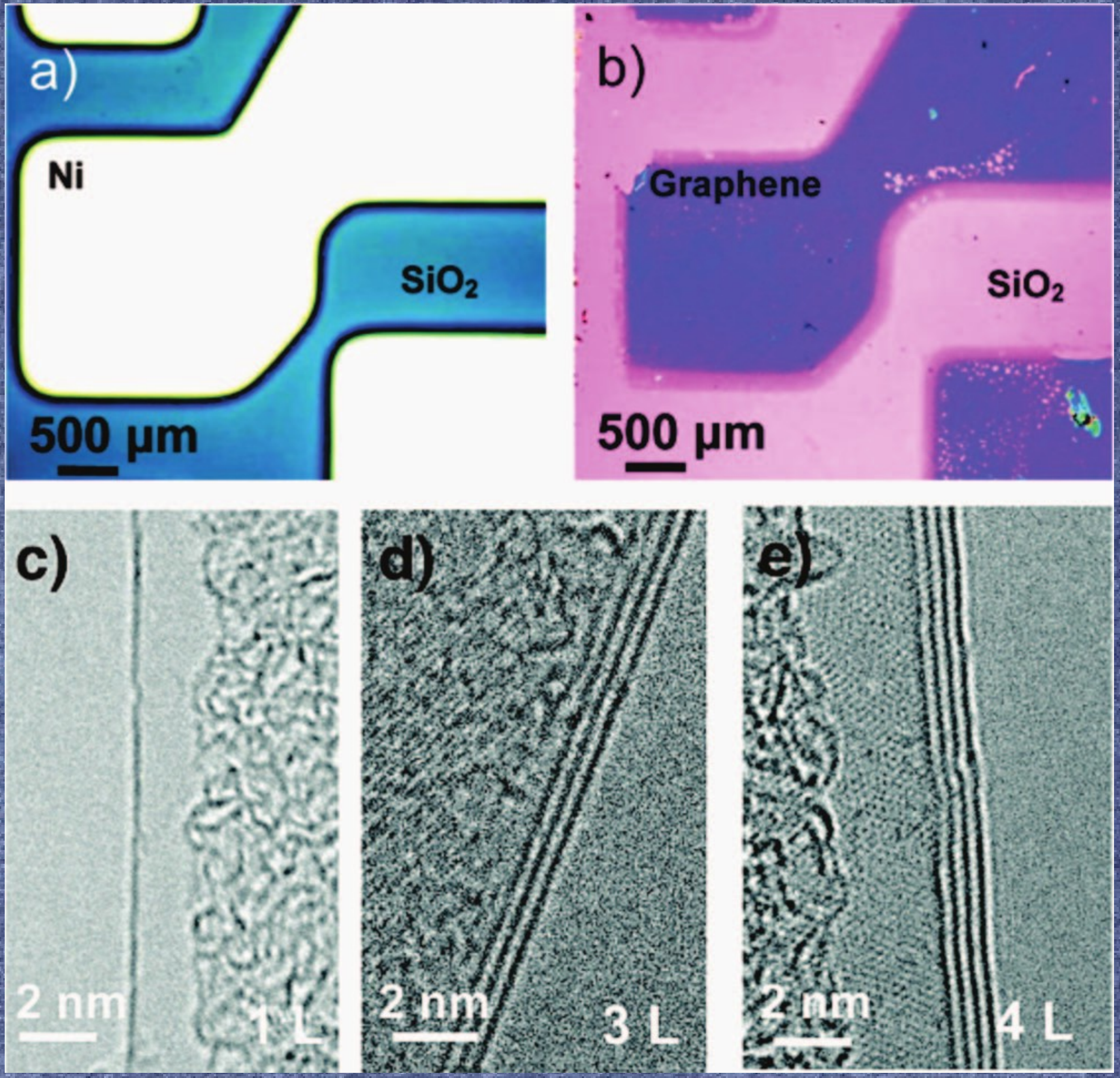
Chemical structure of a polyacyclic aromatic hydrocarbon

Synthesized nanoribbon. Length 12 nm. TEM image.

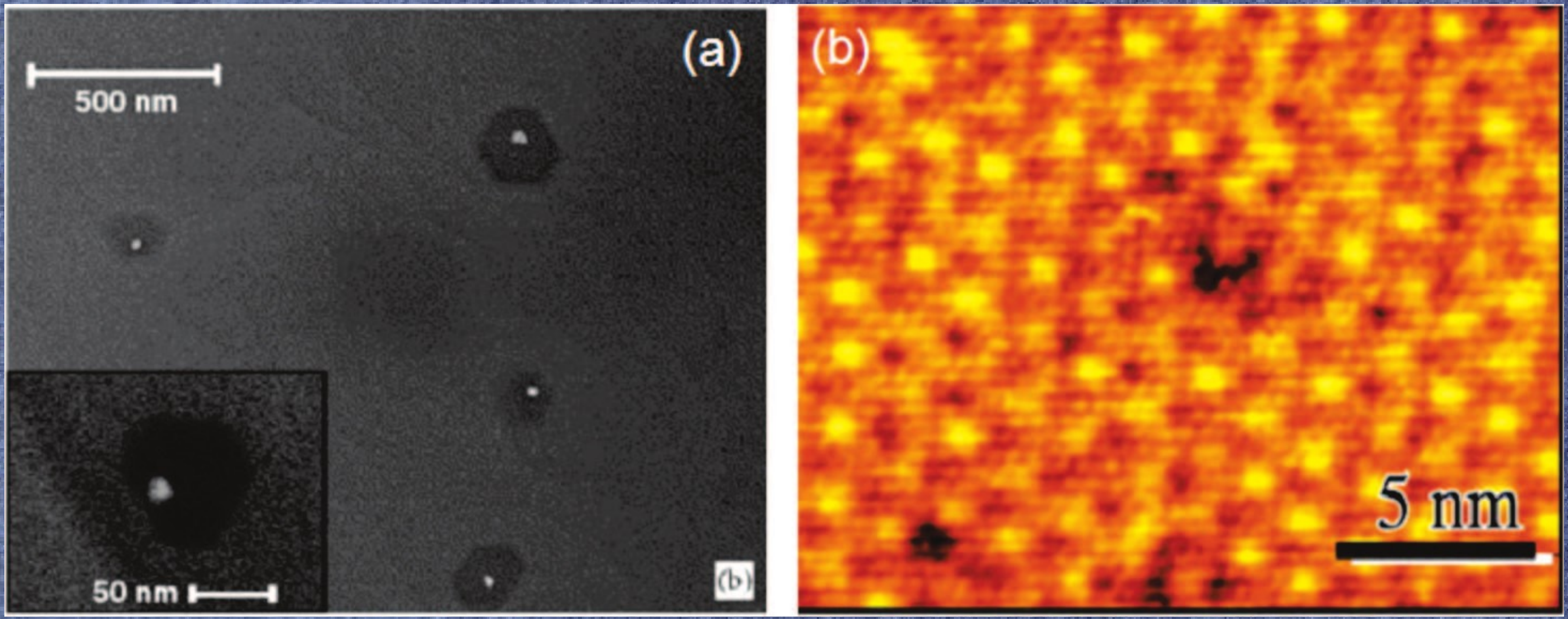
Chemical Vapour Deposition

(a) the nickel catalyst
(b) graphene film.
Optical microscopy.

Nucleation of
(c) one,
(d) three, or
(e) four layers.
TEM images.



Epitaxial silicon carbide derived graphene



(a) Small hexagonal crystallites. SEM image.
(b) Long-range order and a low density of defects. STM image.

Reference

M. J. Allen, V. C. Tung, R. B. Kaner, *Chem. Rev.* **110**, 132-145 (2010)
http://dx.doi.org/10.1021/cr900070d