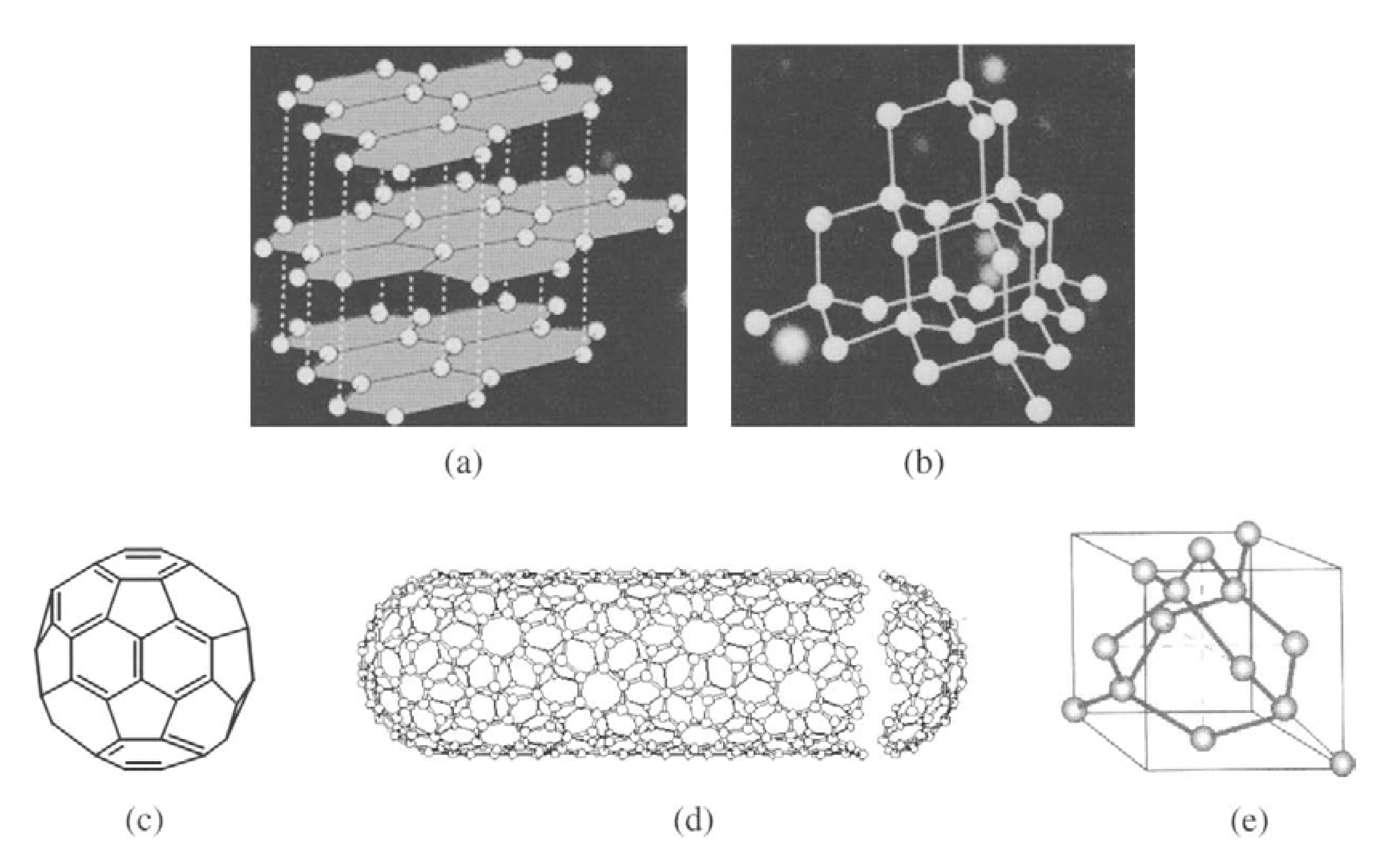
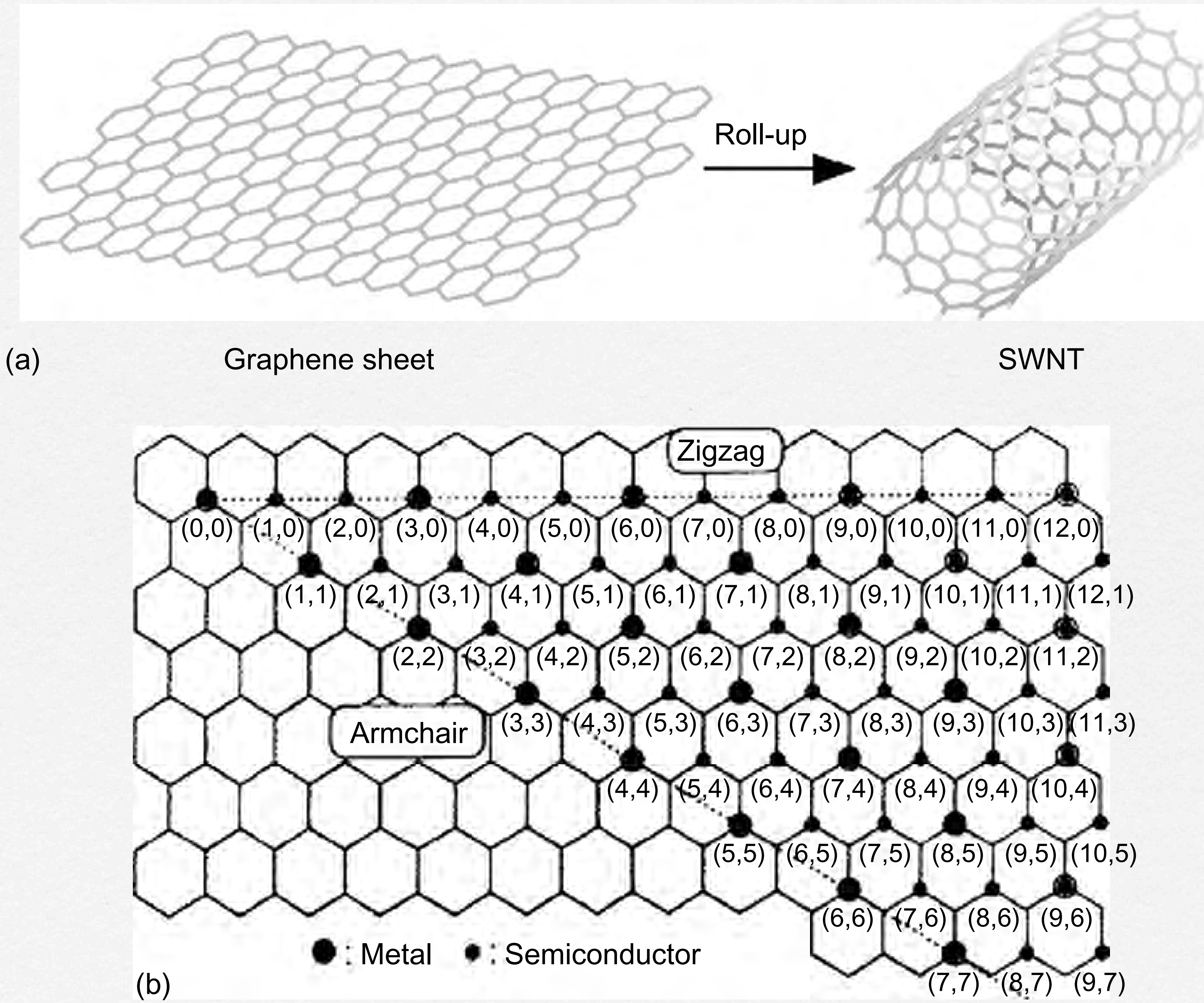
nanoparticles

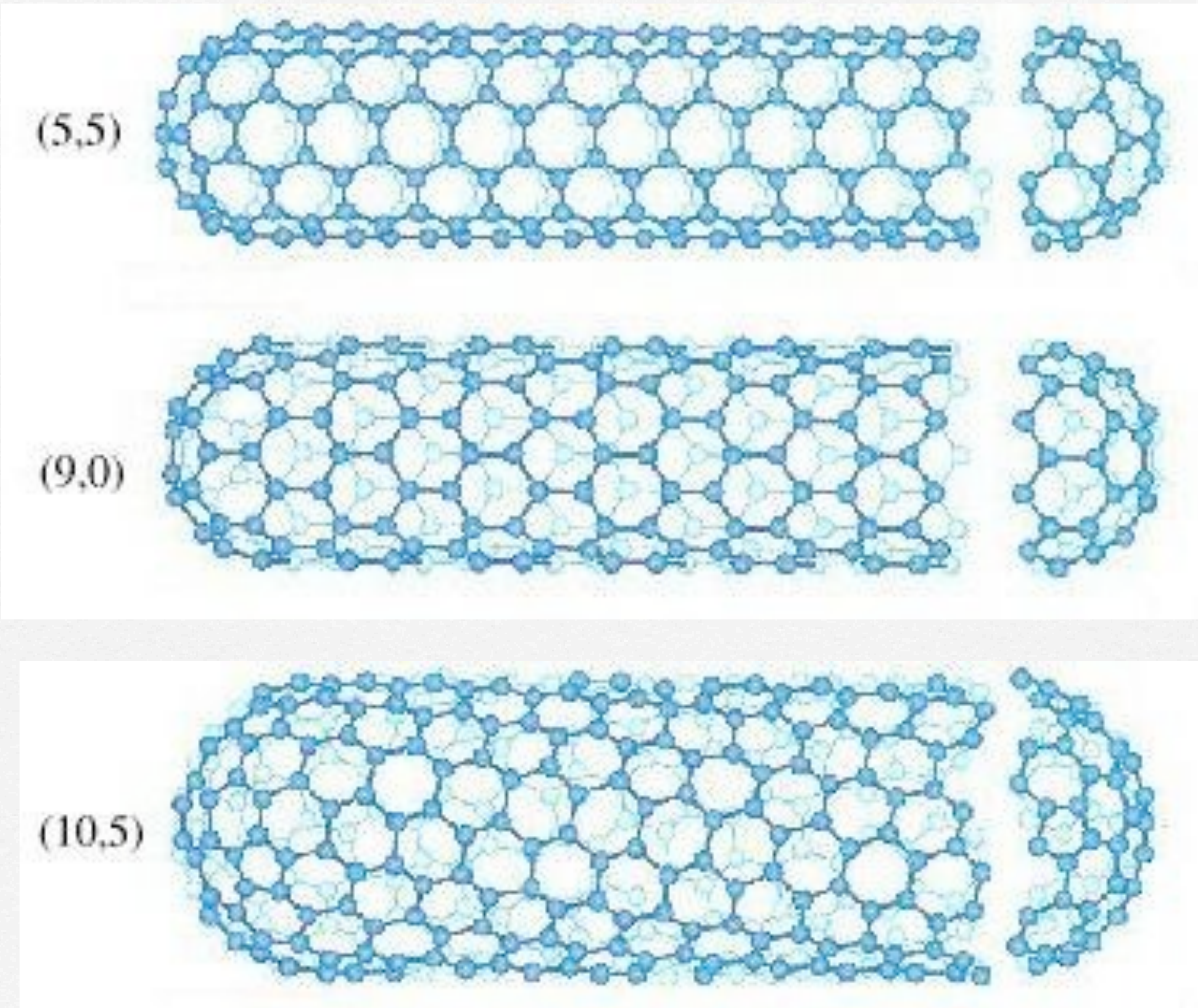
carbon materials



carbon nanotubes



carbon nanotubes

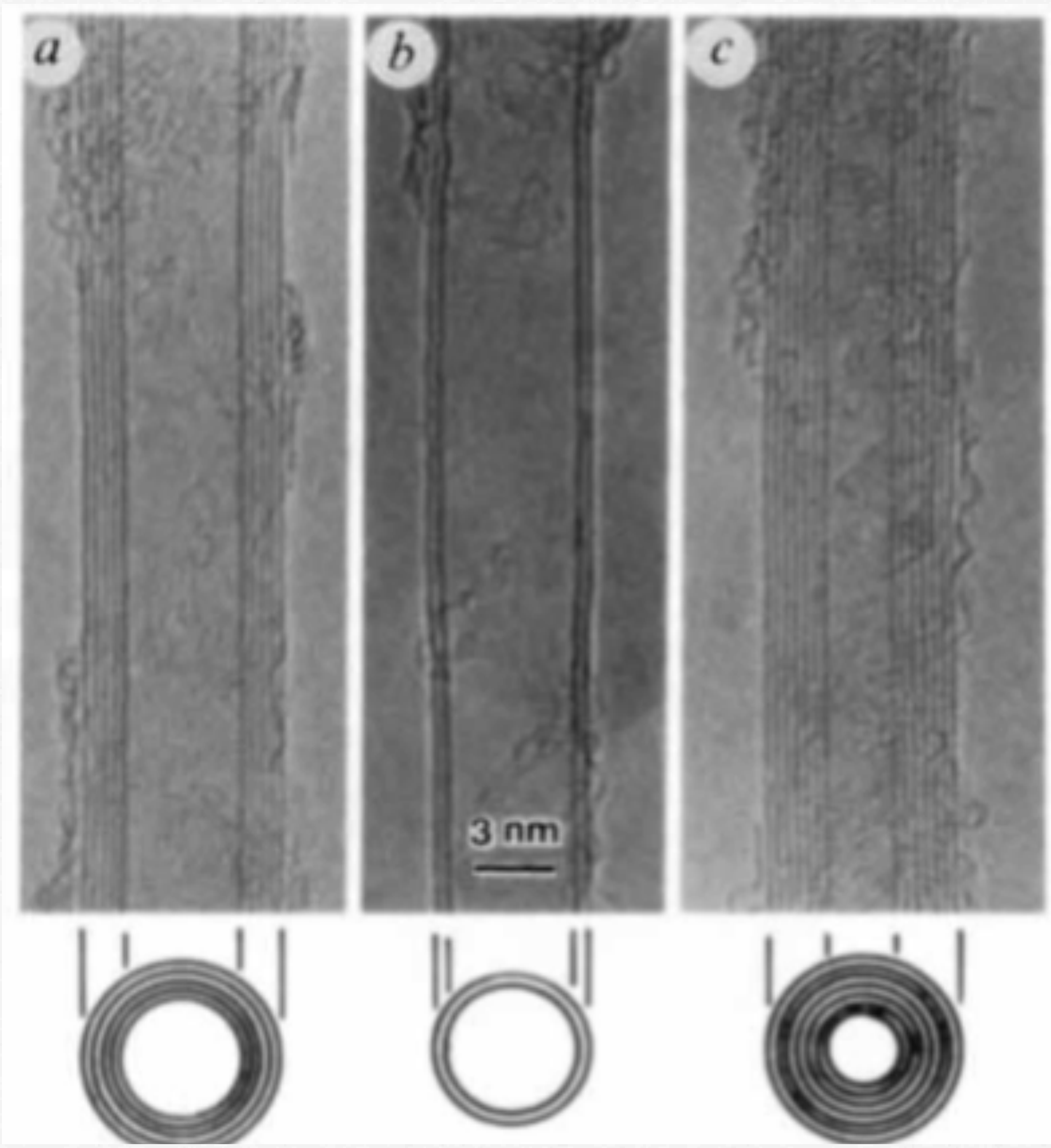


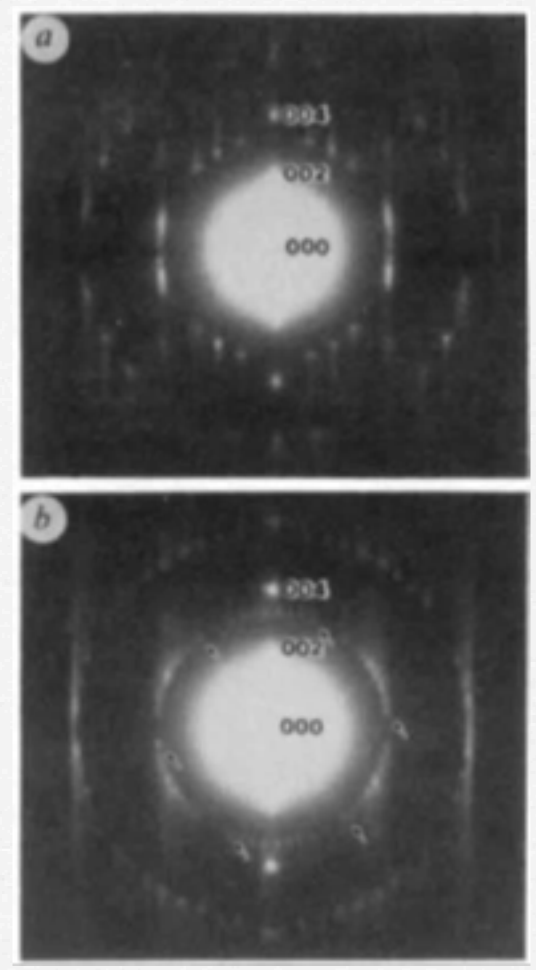
armchair

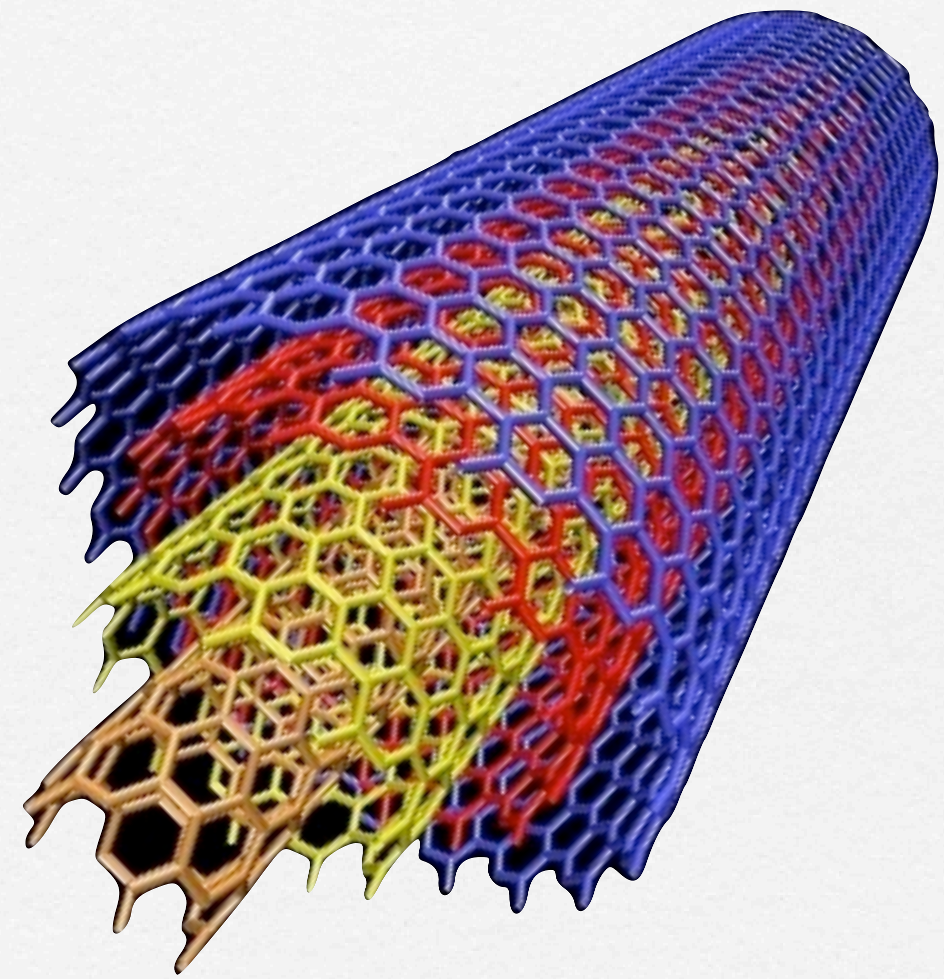
zig-zag

chiral

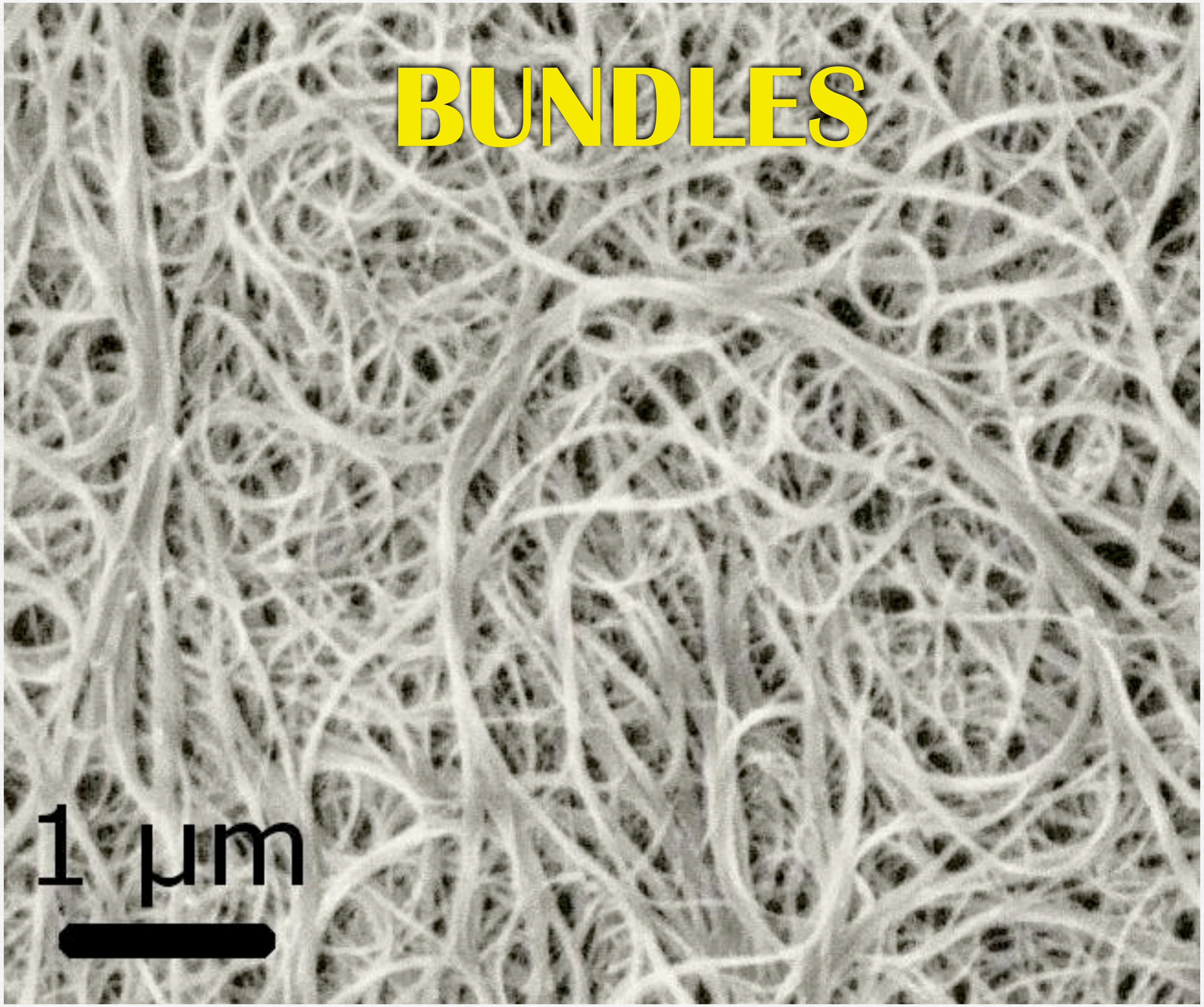
carbon nanotubes





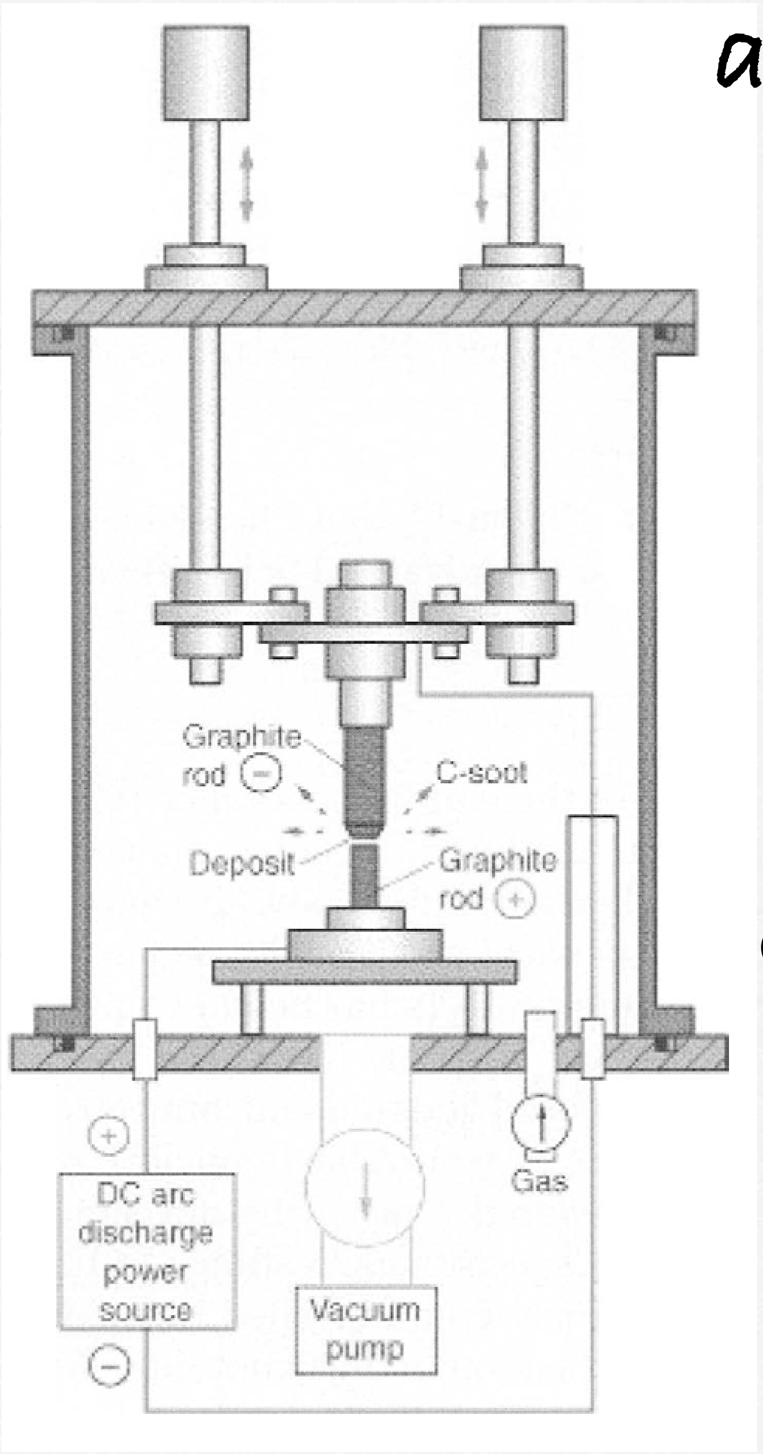


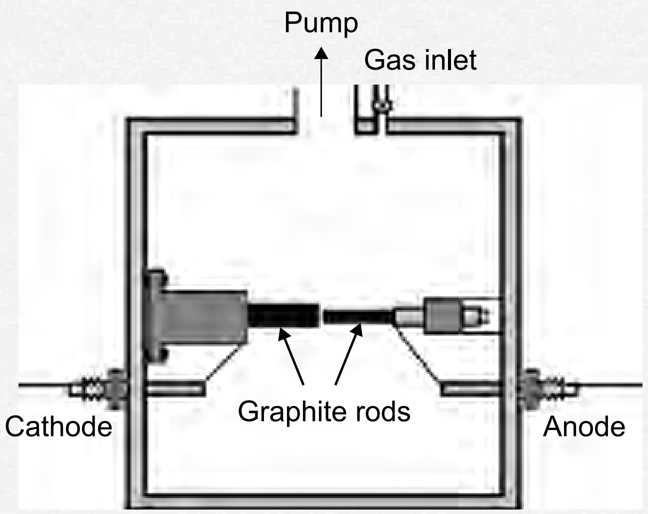
carbon nanotubes



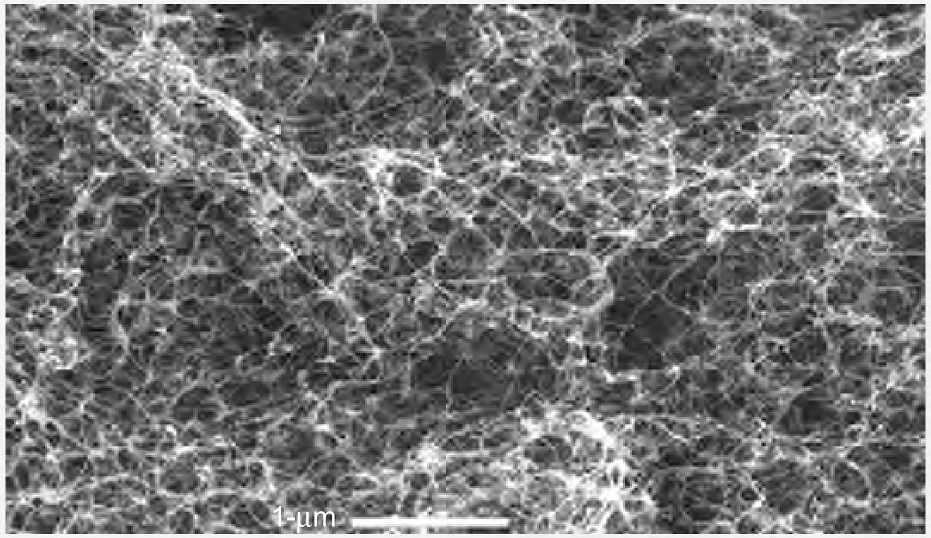
carbon nanotubes

arc discharge method



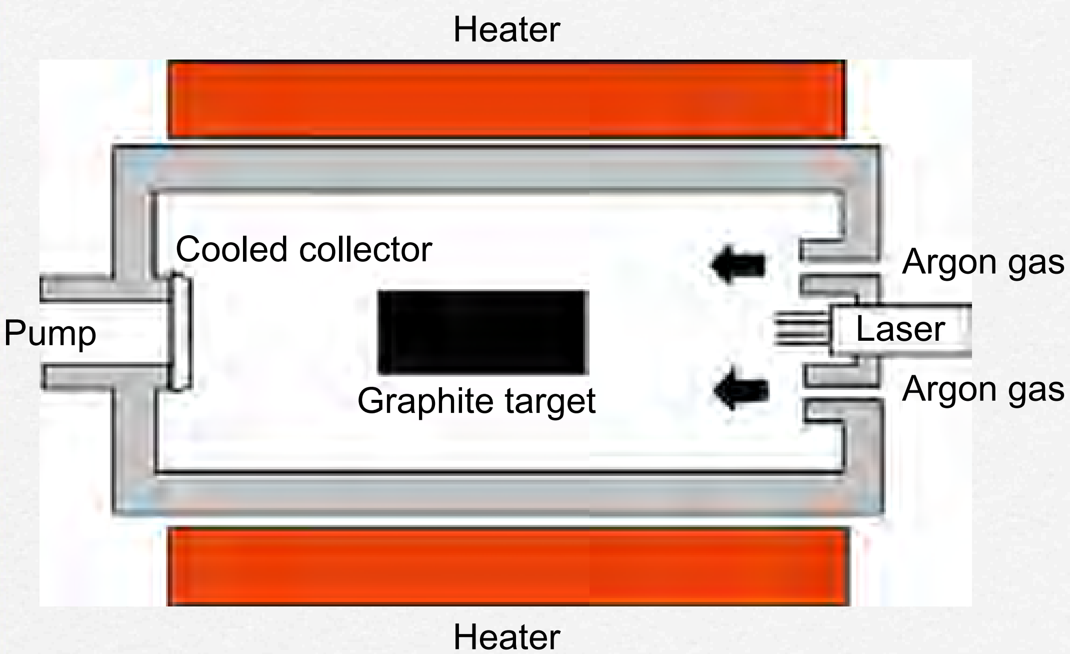


(a)



(b)

carbon nanotubes



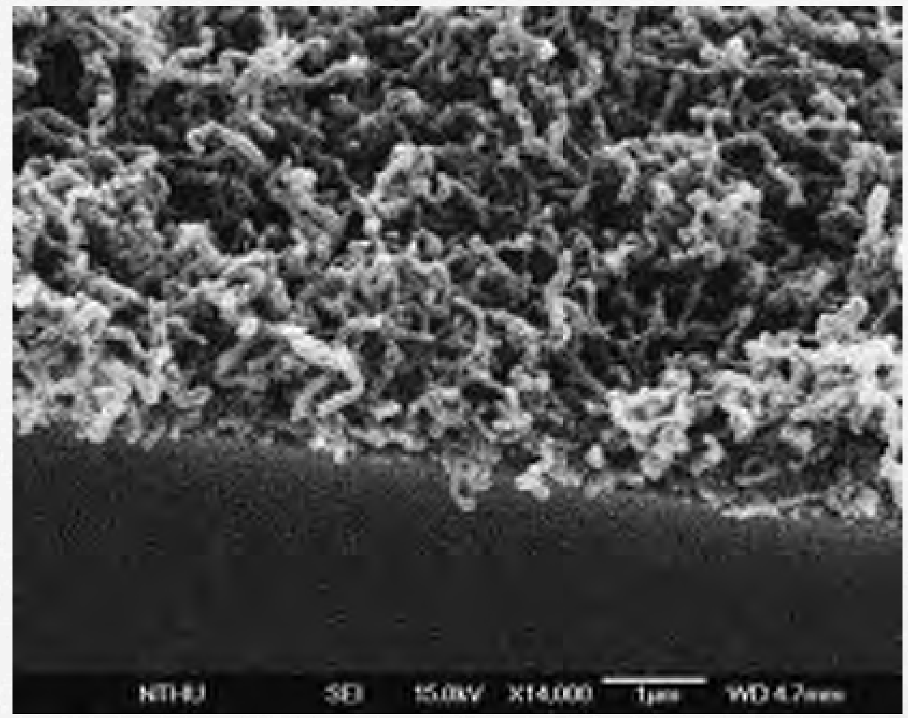
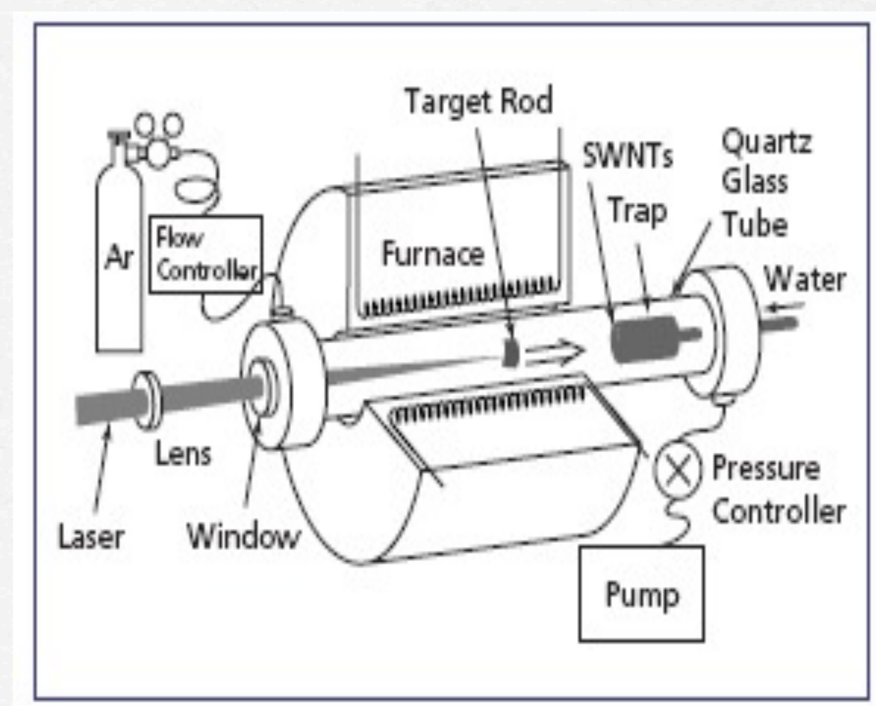


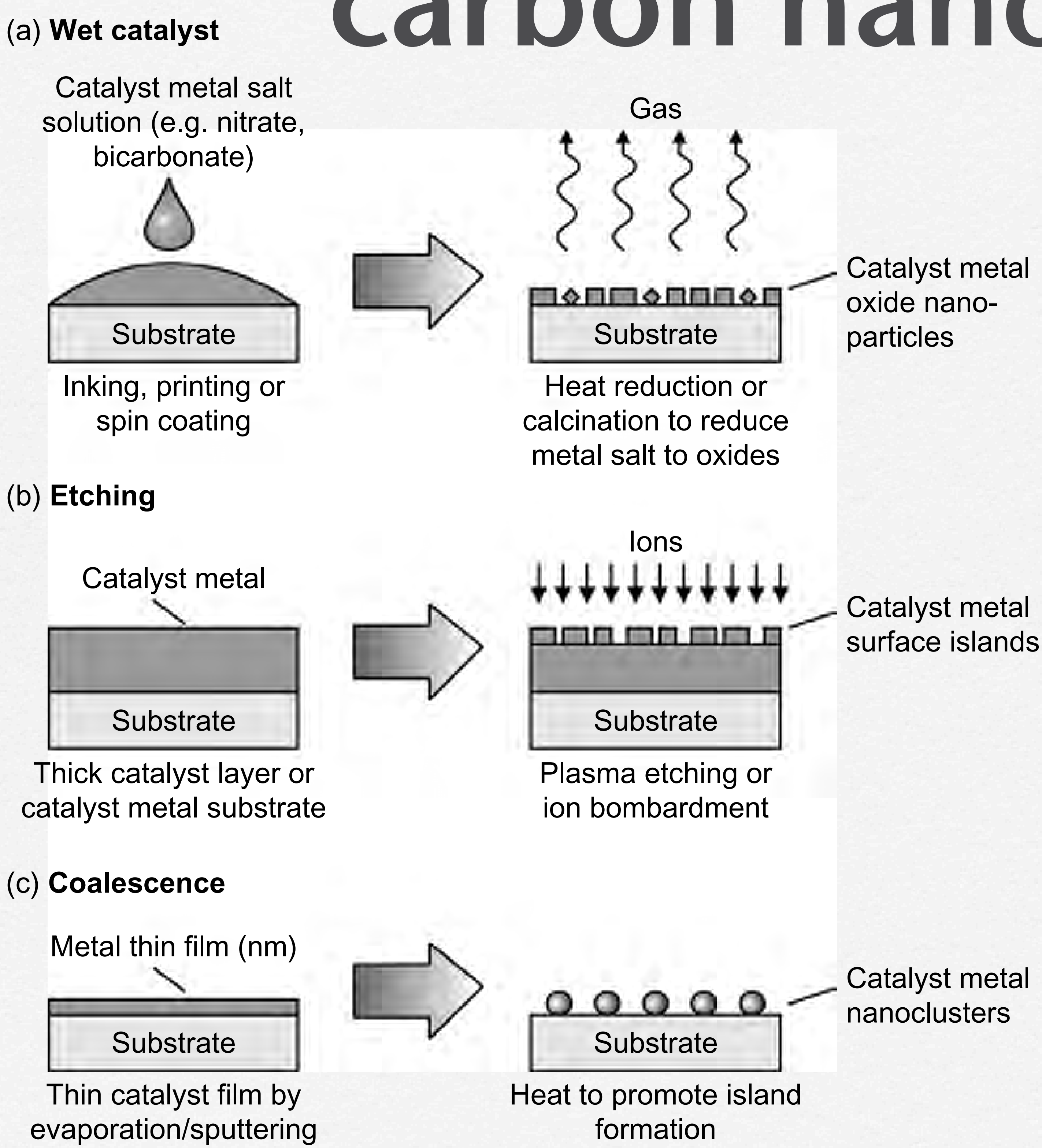
FIGURE 5.3

(a) Schematic diagram of typical apparatus used to grow CNTs by laser ablation. (b) A typical result of CNTs grown by laser ablation. Note the lack of orientation in the grown CNTs. The scale bar is 1 μ.

- Laser-Furnace method
  - High quality SWNTs
  - Diameter control
  - New materials- "peapods"
  - Allows for study of formation dynamics



carbon nanotubes



carbon nanotubes

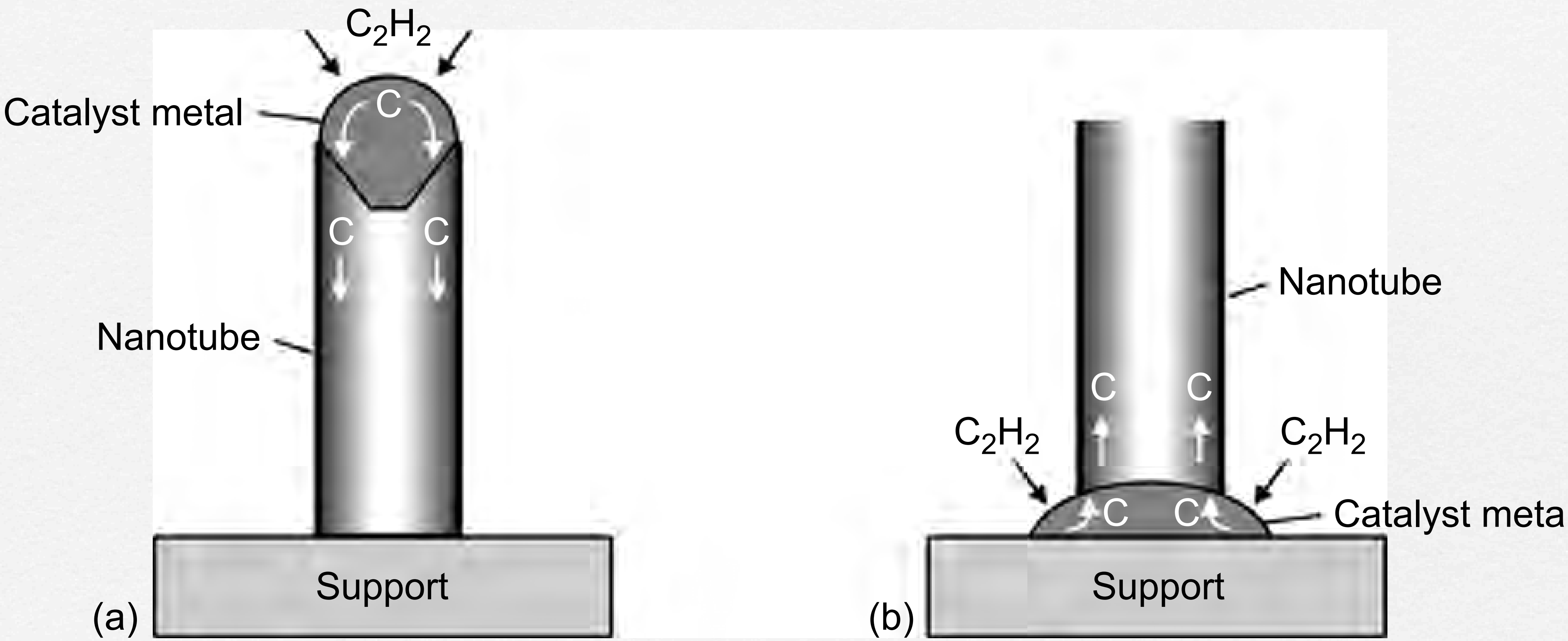
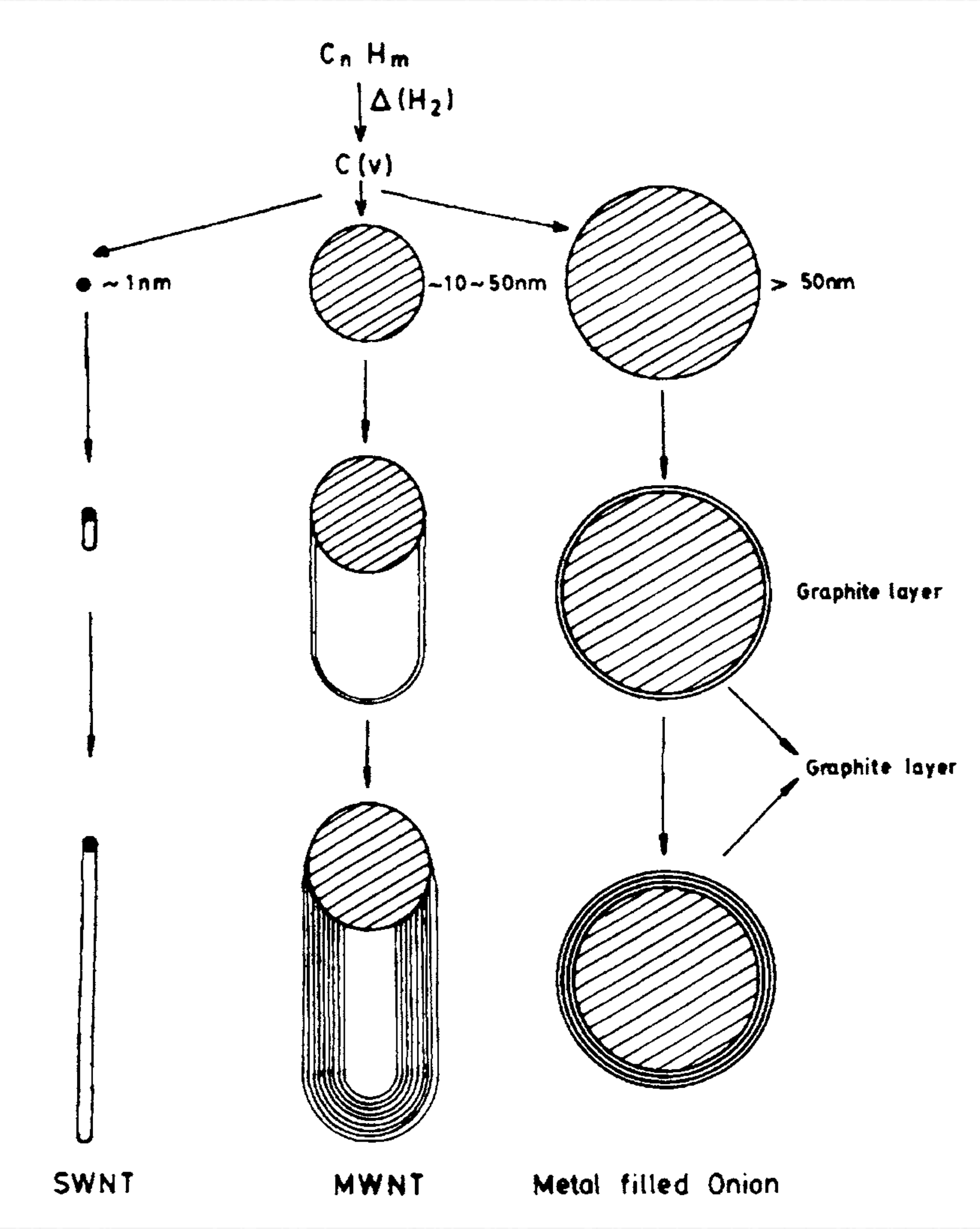


FIGURE 5.5 *There are two types of growth, tip or base growth, which results from differences in the catalyst–support interaction. (a) Weak catalyst–support interaction, (b) strong catalyst–support interaction. Source: Ref. [39].*

CNTs



$C_n H_m$
$\Delta (H_2)$
C (v)
~ 1nm
~10 ~ 50nm
> 50nm
Graphite layer
Graphite layer
SWNT
MWNT
Metal filled Onion

carbon nanotubes

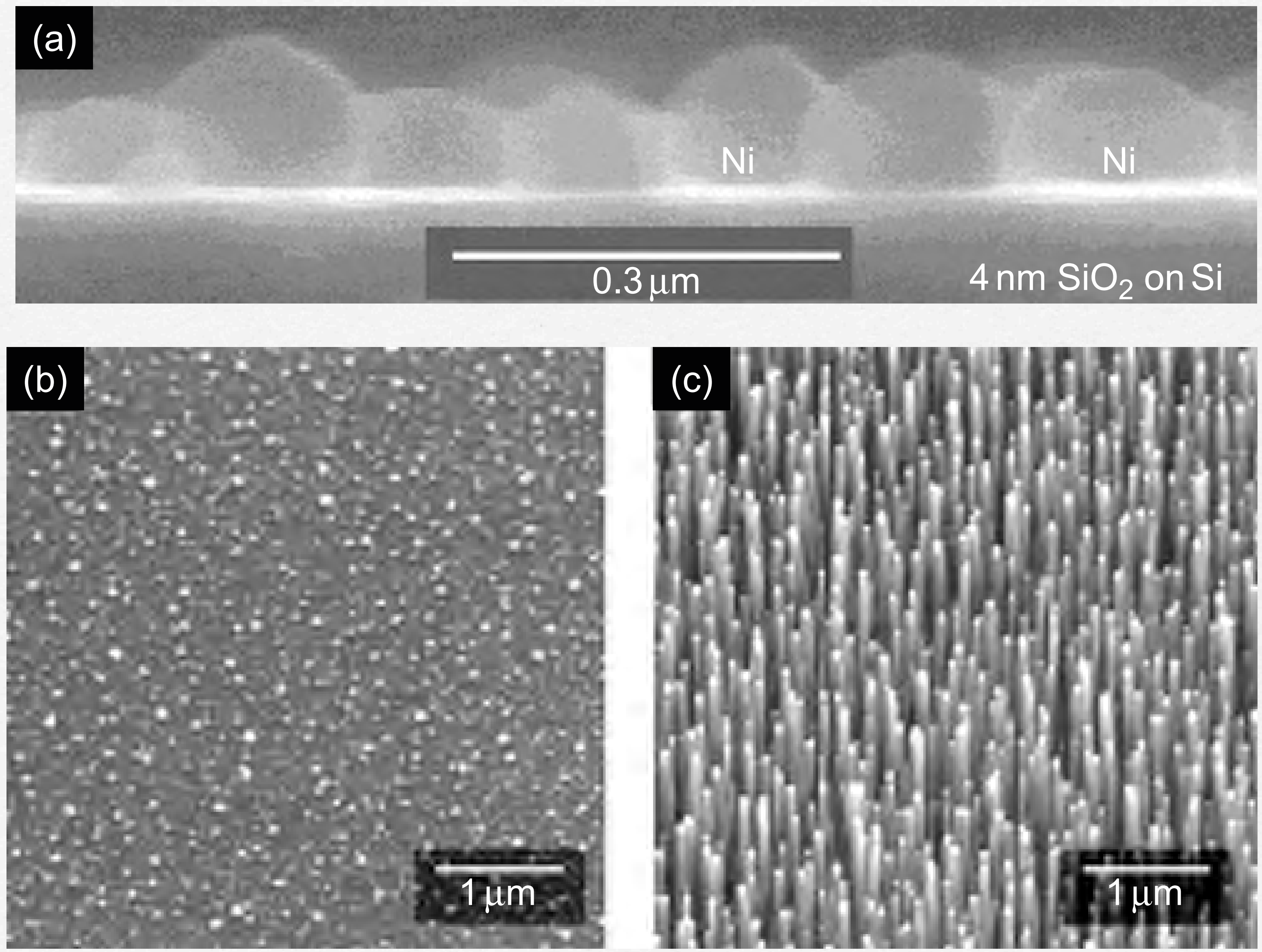
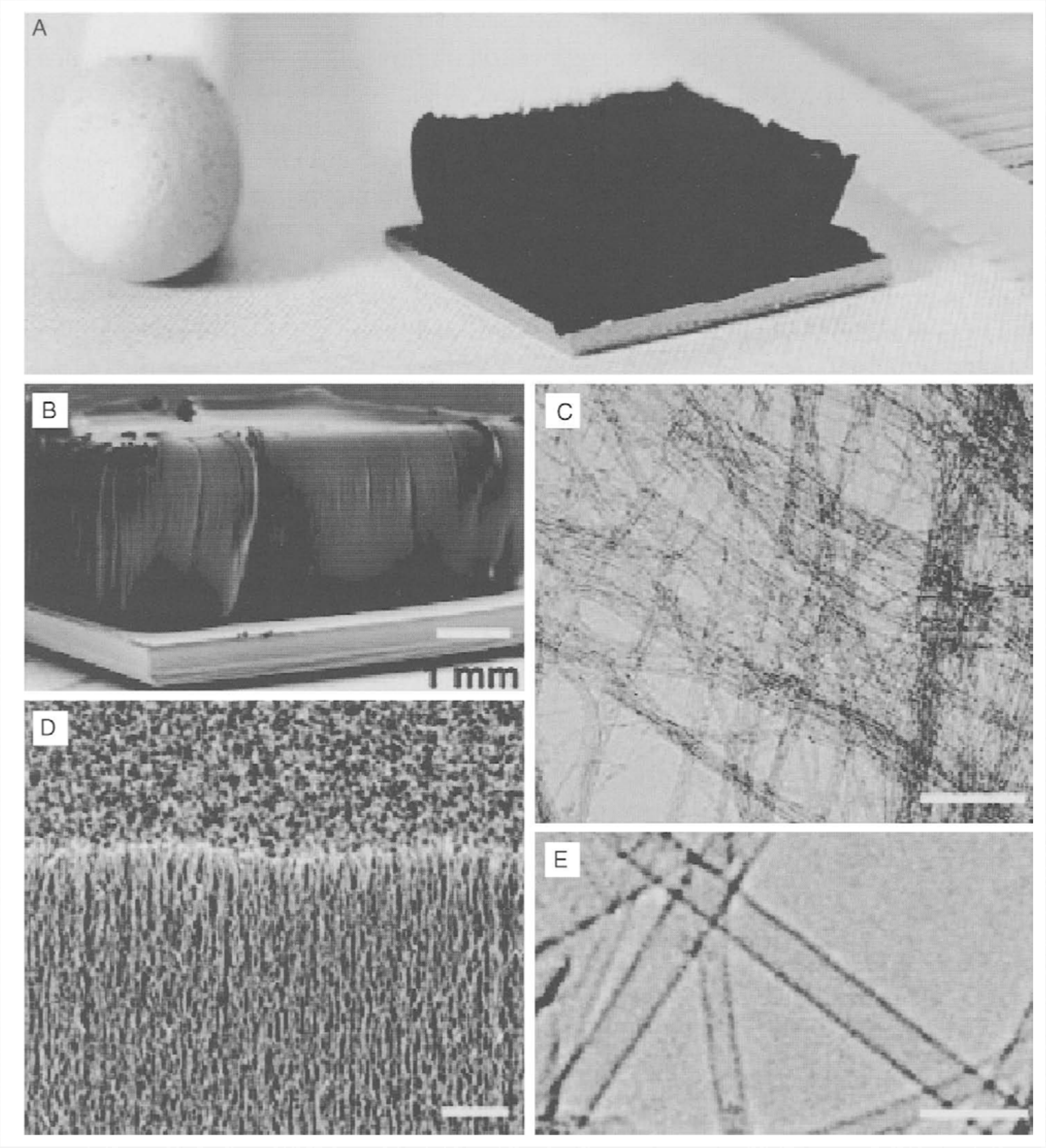


FIGURE 5.6 *When Ni nanoclusters ((a) and (b)) are on a 4-nm layer of SiO_2 deposited onto a Si substrate, they exhibit weak interactions (c.f. 'hydrophobic') with their supports hence favouring tip growth (the Ni is the high contrast dot seen at the tip of the nanotube as in (c)).*

carbon nanotubes



By adding a trace amount of water vapor into mixtures of ethylene, helium and hydrogen, SWNTs grow vertically and form dense forests on surface (Fig. 11). The yield is up to 50 000% [61]. The effect of water is due to the ability of water vapor to remove amorphous carbon and maintain catalyst activity during the growth.

carbon nanotubes

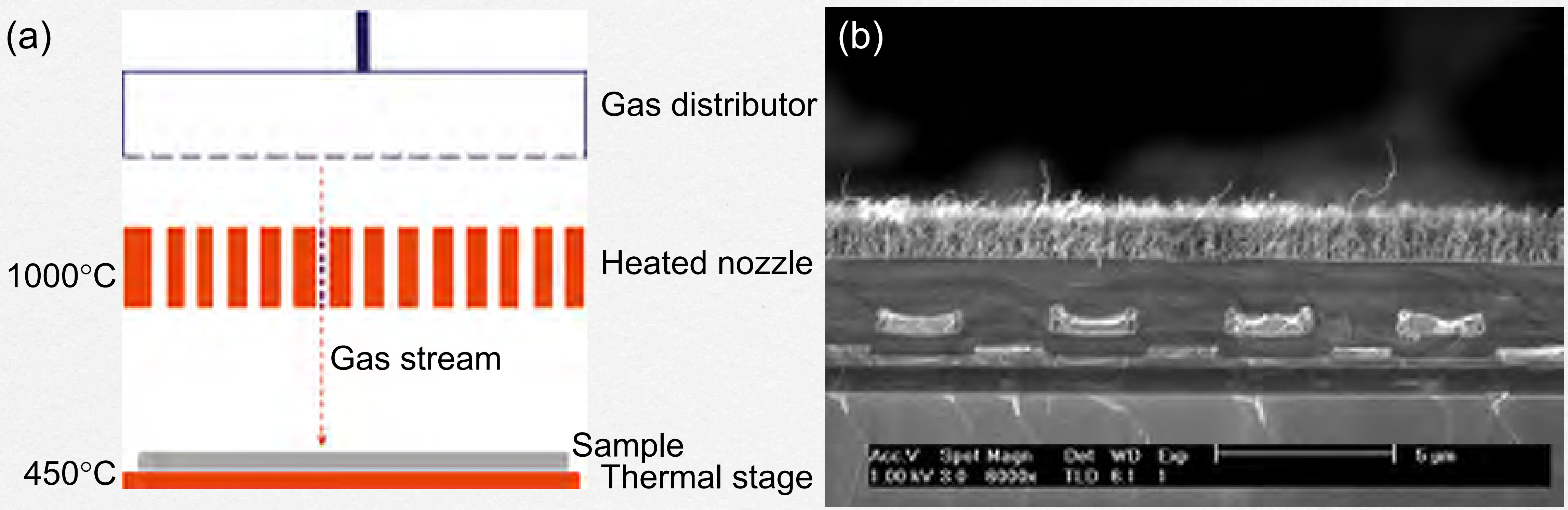
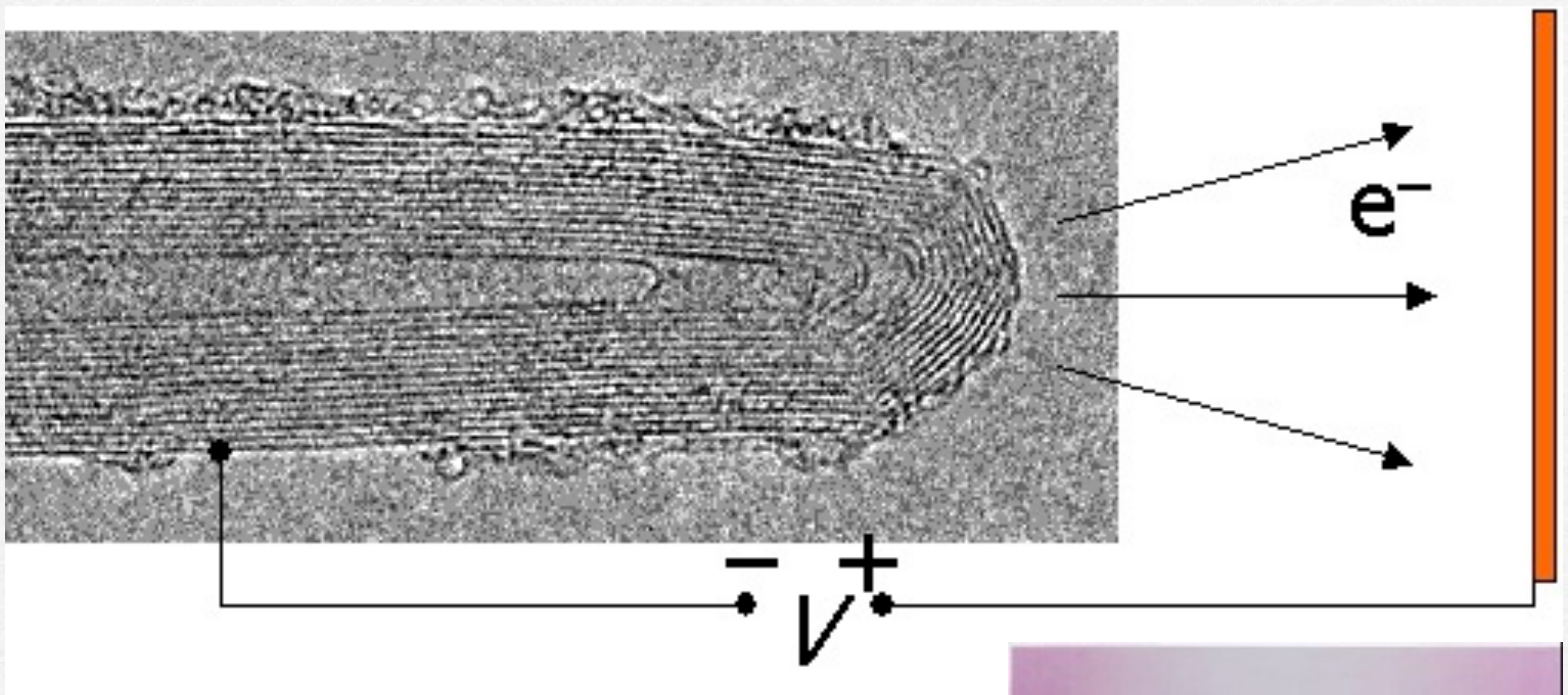
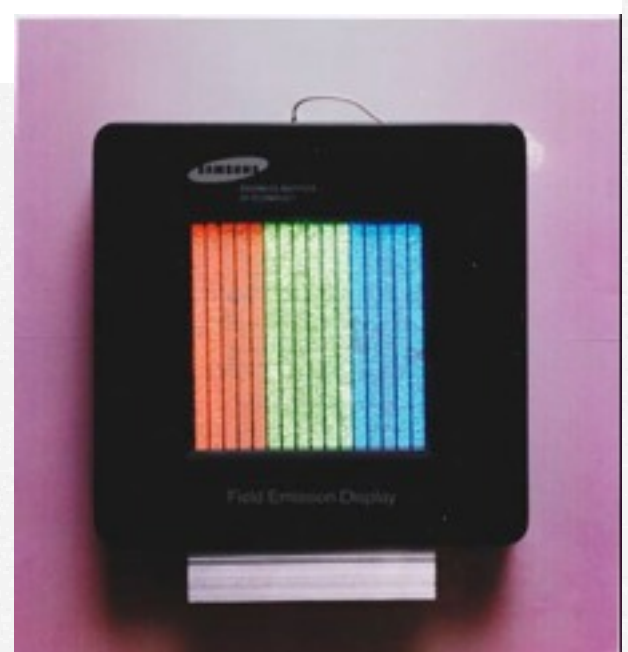


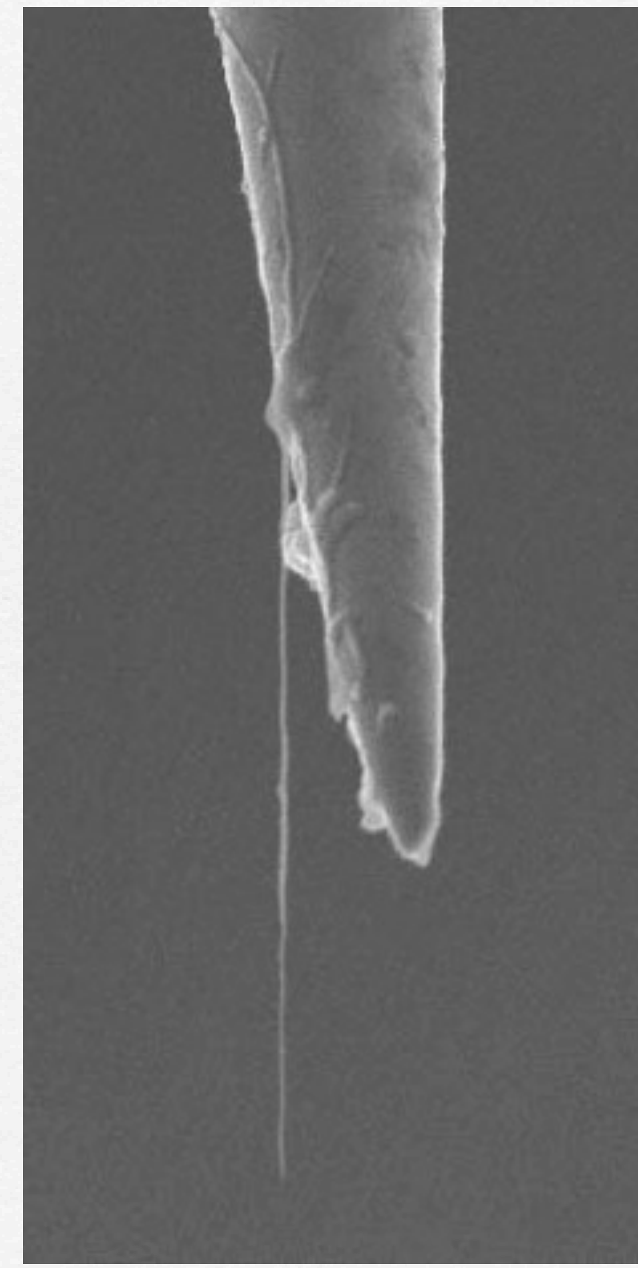
FIGURE 5.8 *(a) A schematic diagram of a setup used to grow CNTs at low temperatures. Gas is broken down by the heated nozzle at 1000°C instead of at the substrate surface enabling the substrate itself to be kept at a much lower temperature. (b) A cross section of the resultant growth of CNTs on CMOS. Four Al contacts can clearly be seen to be still intact.*

carbon nanotubes

Field Emitters







CNTs as field emission displays

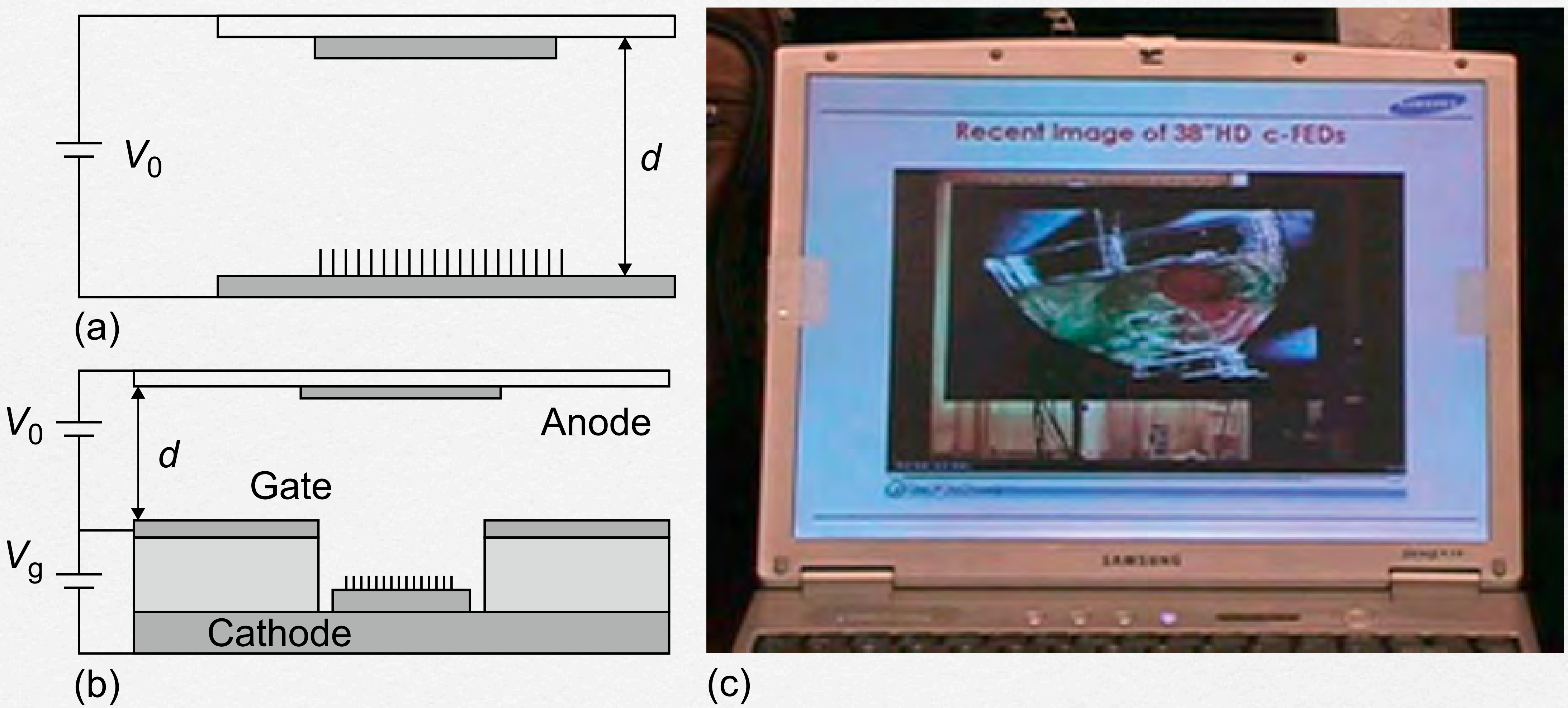


FIGURE 5.14 *Schematic of the working principle of a field emission display pixel. (a) Diode structure, (b) triode structure with ballast resistor in series with the emitters, (c) image of a prototype of a CNT field emission display with a gate structure, an active area of 38in. in diagonal, full colour and 100Hz.*

CNTs as micro lenses

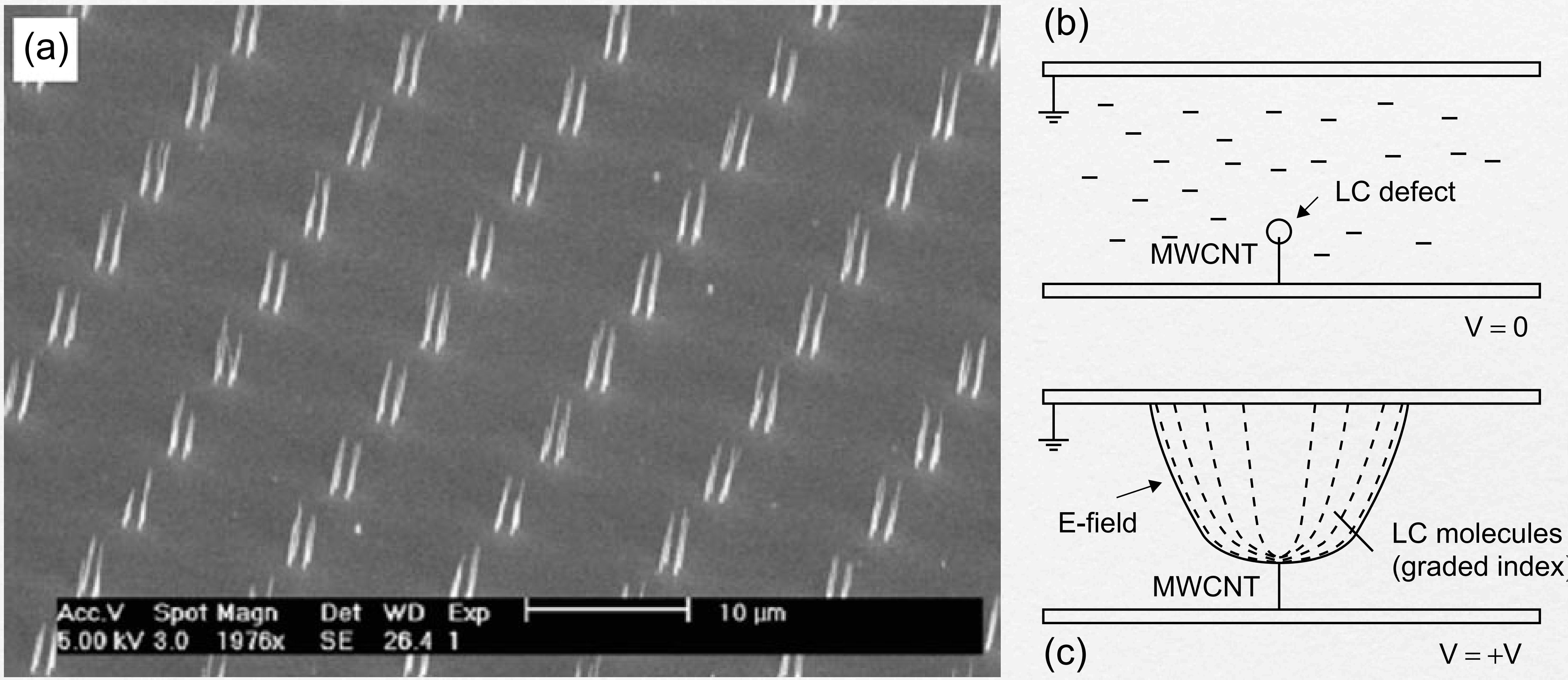
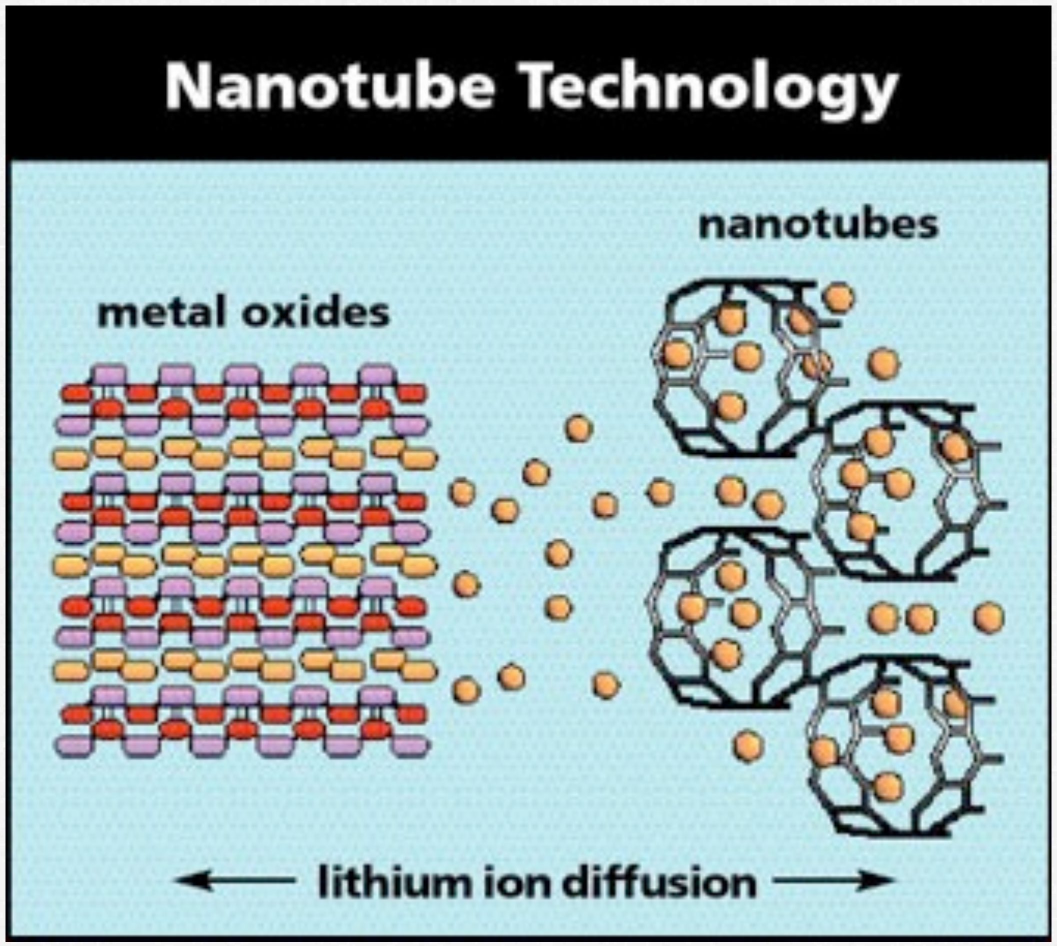


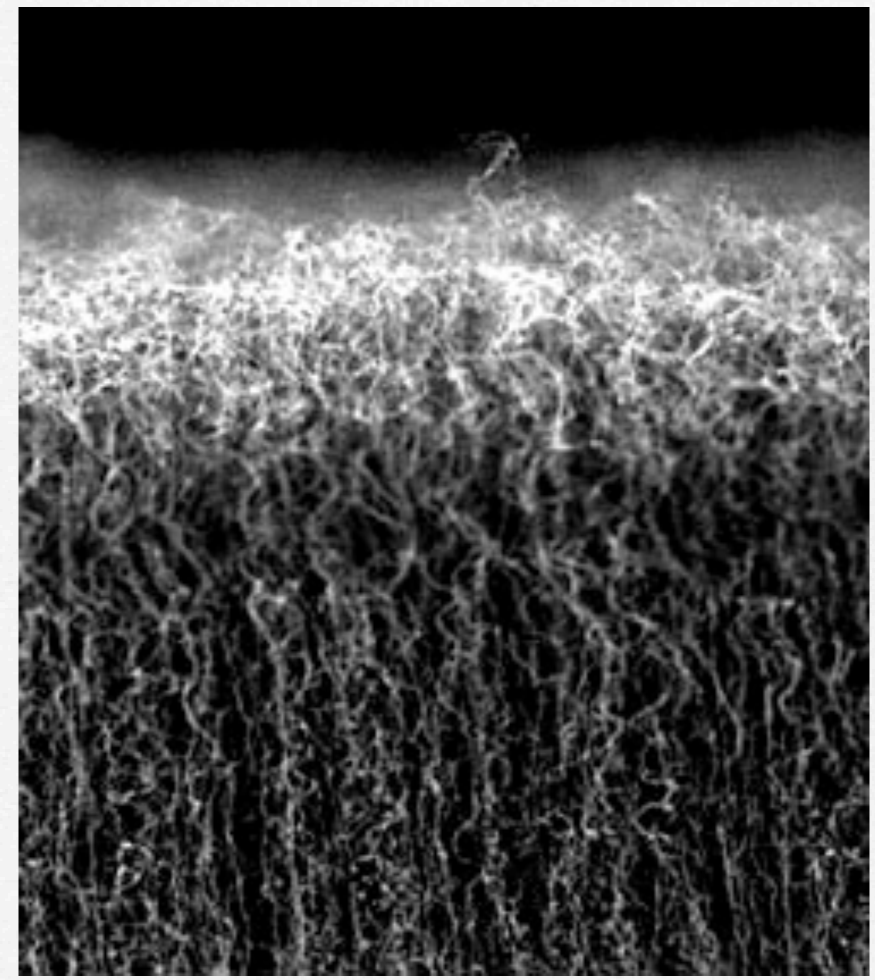
FIGURE 5.15 *(a) A pair of CNTs grown from single spots of catalyst separated by 10μm. (b) Schematic diagram representing the multi-walled CNT (MWCNT) immersed in a liquid crystal (LC). (c) A voltage applied to the top gate causes the LC to align with the induced electric field which is distorted by the MWCNT.*

CNTs for charge storage



J. Fischer, Matt Ray/EHP

Lithium Ion Batteries



MIT/Riccardo Signorelli

Ultra Capacitors