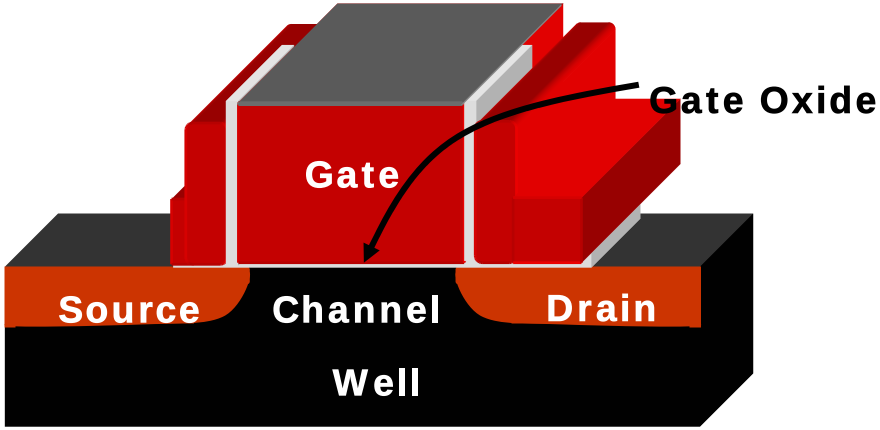
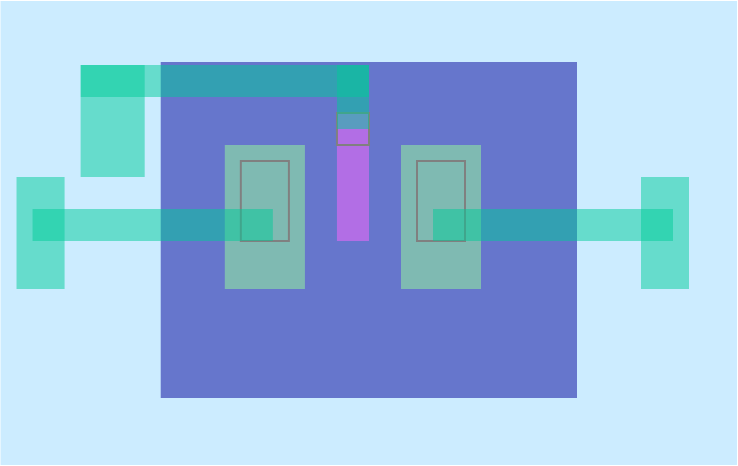
Building a 3D Structure, layer by layer





Well

Source and drain

<u>Gate</u>

Windows

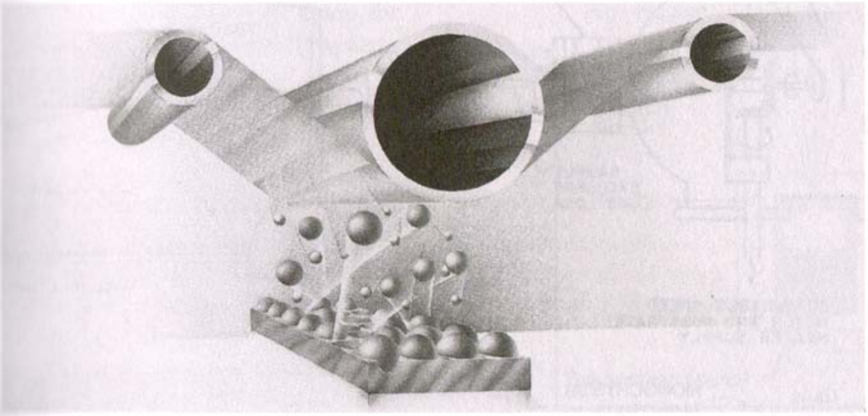
<u>Metal interconnects</u>

Placing thin films onto the device

Placing Thin Films onto a Substrate Surface

Continuous deposition

Courtesy of I.S.T. Belgium.



Madou, Fundamentals of Microfabrication, p. 141

Questions, questions, questions …..

- is the thin film a compound or single element?
- is its structure critical?
- does it have to be ‘epitaxial’: have a unique relationship to the substrate?
- what is the *source* of the material (liquid, solid, gas)
- what is the *best way* of transporting the material from *source* to *substrate?*

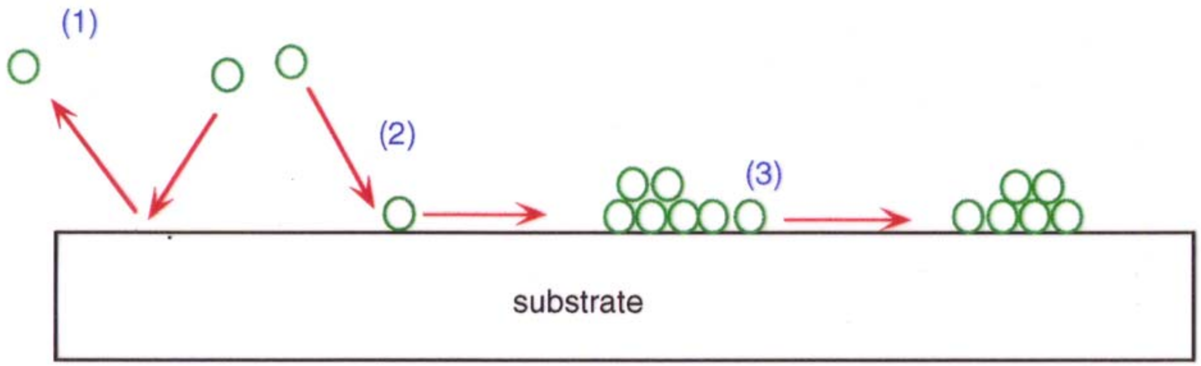
Our Focus….

Questions, questions, questions …..

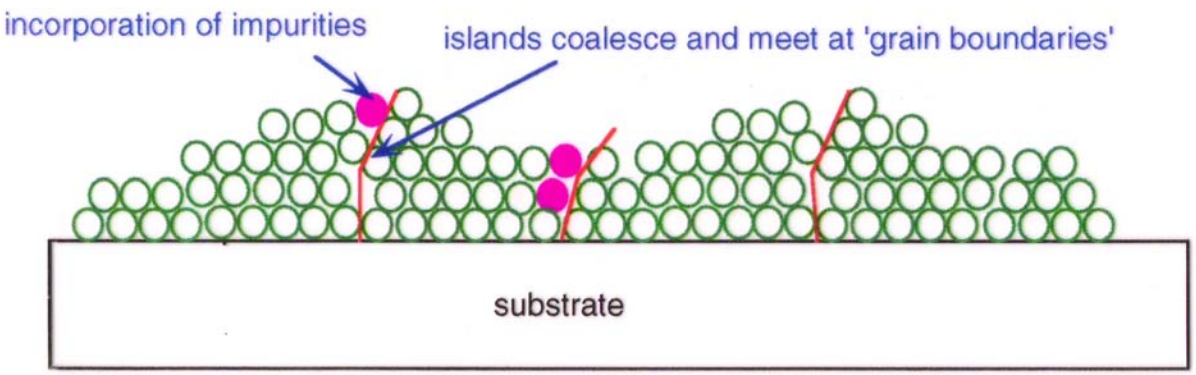
- is the thin film a compound or single element?
- is its structure critical?
- does it have to be 'epitaxial': have a unique relationship to the substrate?
  - ✓ not epitaxial….but we will look at Molecular Beam Epitaxy
- what is the *source* of the material (liquid, solid, gas)
  - ✓ we will start with solid sources
- what is the *best way* of transporting the material from *source* to *substrate?*
  - ✓ we will transport the material through *gas phase*

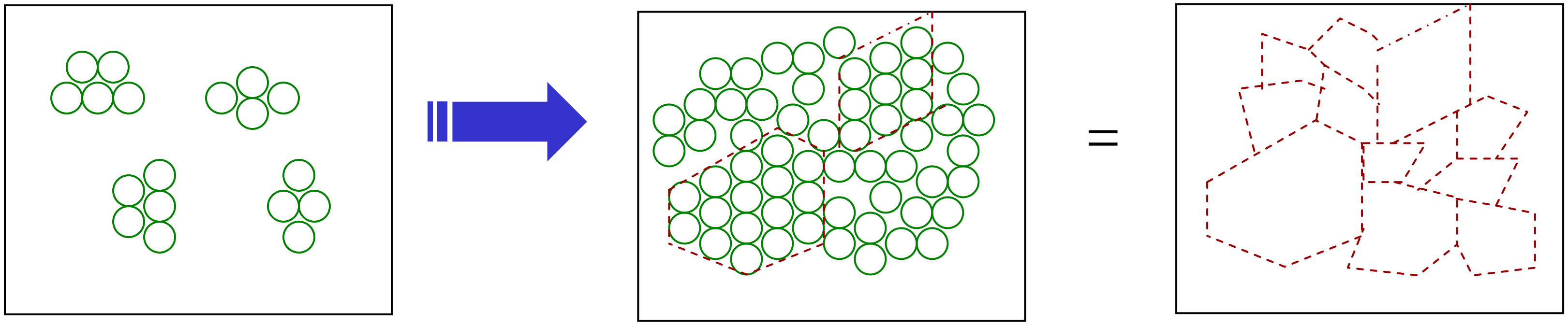
Physical Vapor Deposition
(as opposed to Chemical Vapor Deposition)

1. gas-phase transport: what is important here?
2. How do we take a solid source and transform it into vapor phase?
   a. (does how we do this make any difference to the final film?)
3. How does the thin film interact with the substrate?
   a. How do macroscopic controls influence the microstructure of the thin film?



1. Atoms from vapor impinge on substrate and 'bounce off'
2. Atoms from vapor 'physisorb' onto substrate, with some surface mobility
3. Nucleation: clusters of atoms form, but island size may be unstable





1. Clusters of atoms nucleate to form islands
2. Some islands are 'unstable'. Stable islands increase in size.
3. Growing islands meet at *grain boundaries.*
4. Is this film structure stable? What happens if you put additional energy into the film?

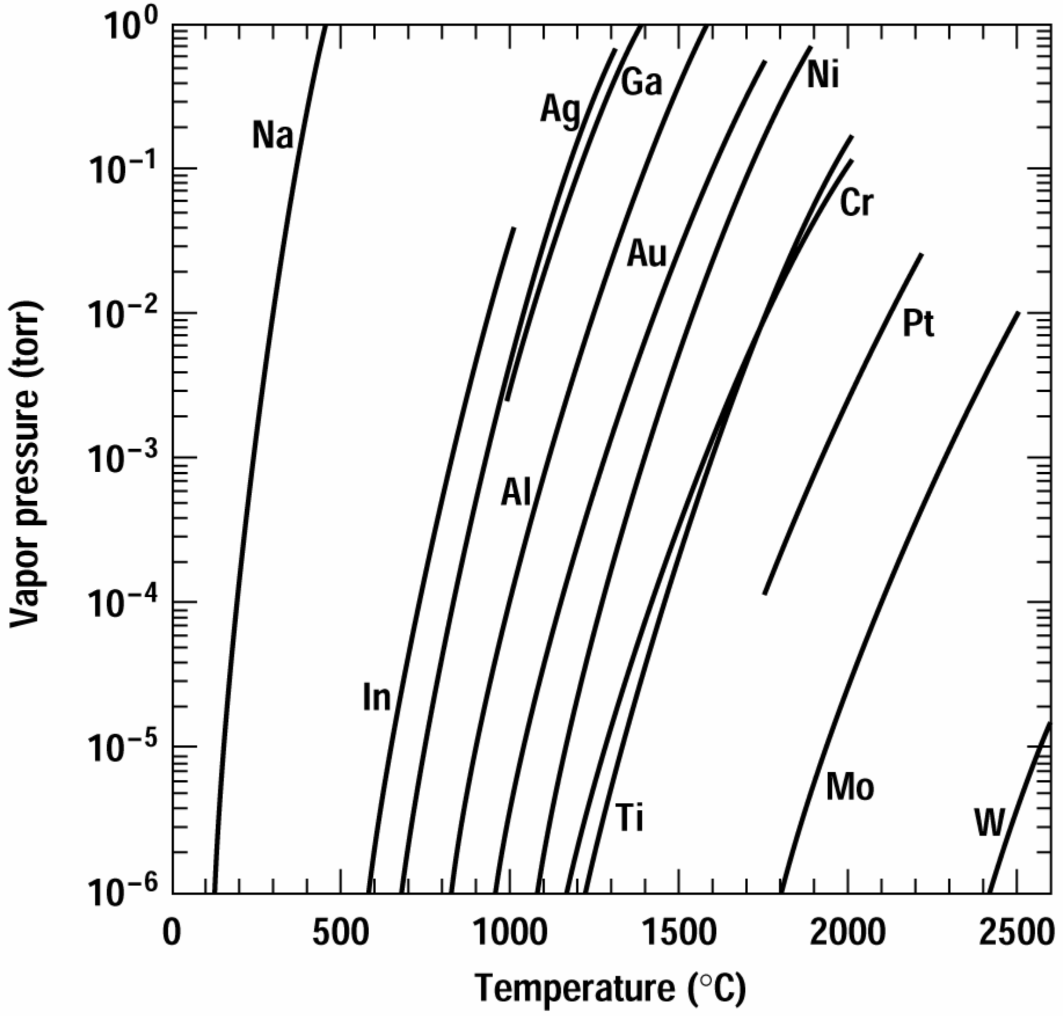


Figure 12.2 Vapor pressure curves for some commonly evaporated materials *(data adapted from Alcock et al.)*.

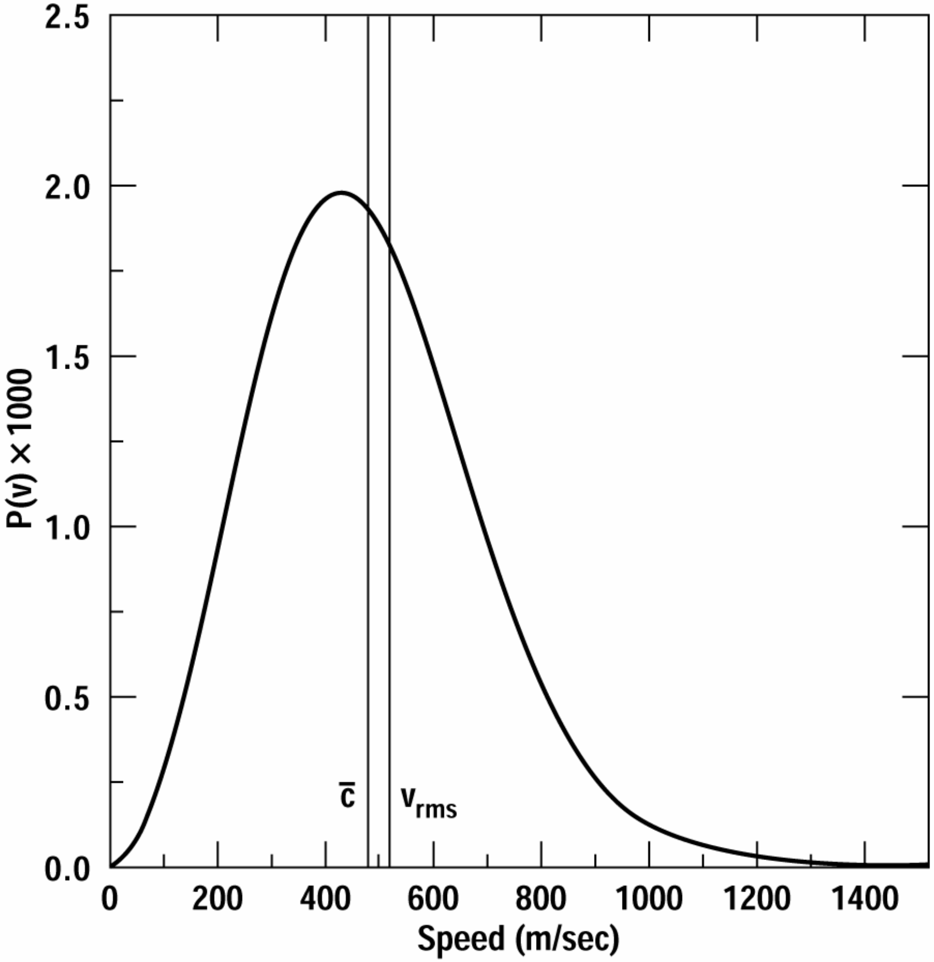


Figure 10.1 A Maxwellian speed distribution of particles. *P*(y) is the probability that a particular particle will have the magnitude of velocity.

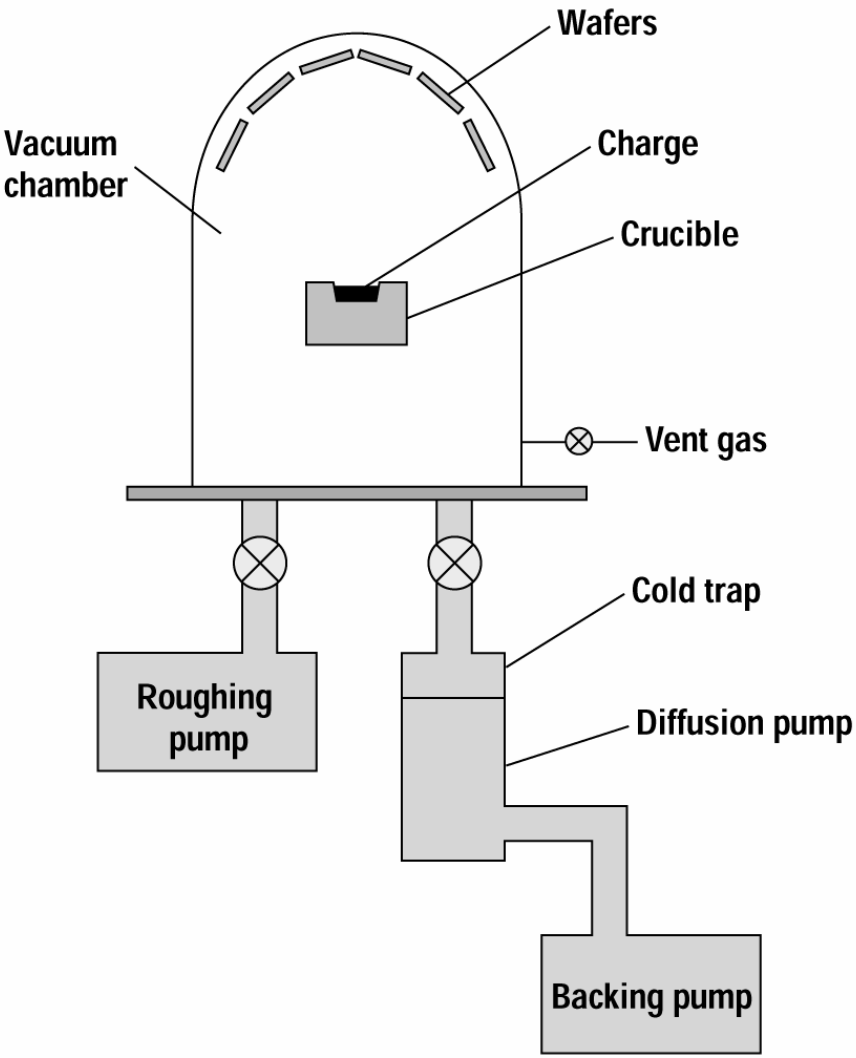
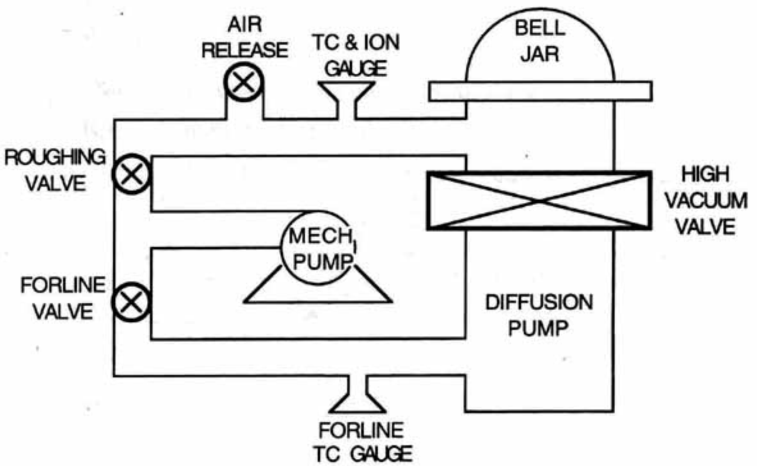


Figure 12.1 A simple diffusion-pumped evaporator showing vacuum plumbing and the location of the charge-containing crucible and the wafers.

Thermal Evaporation System



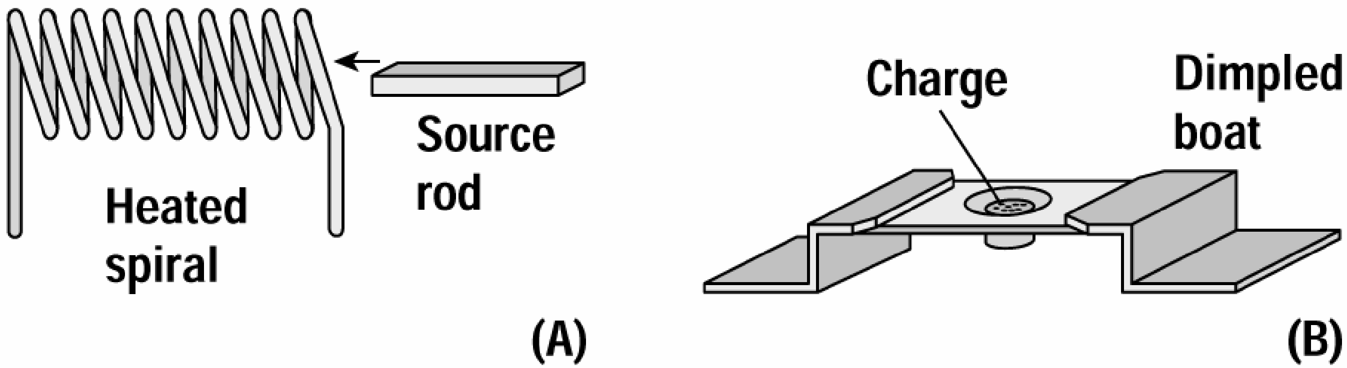
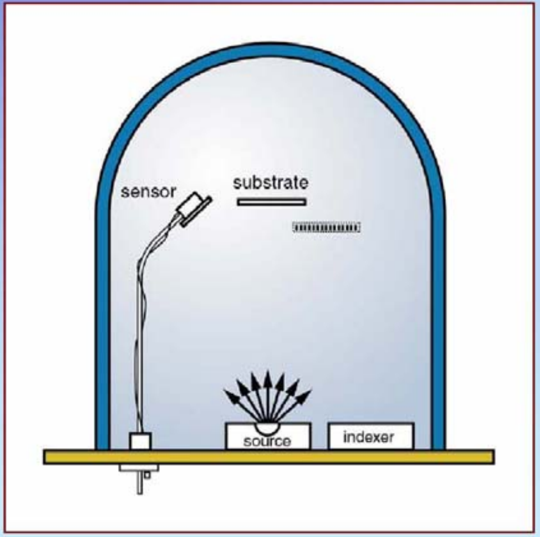


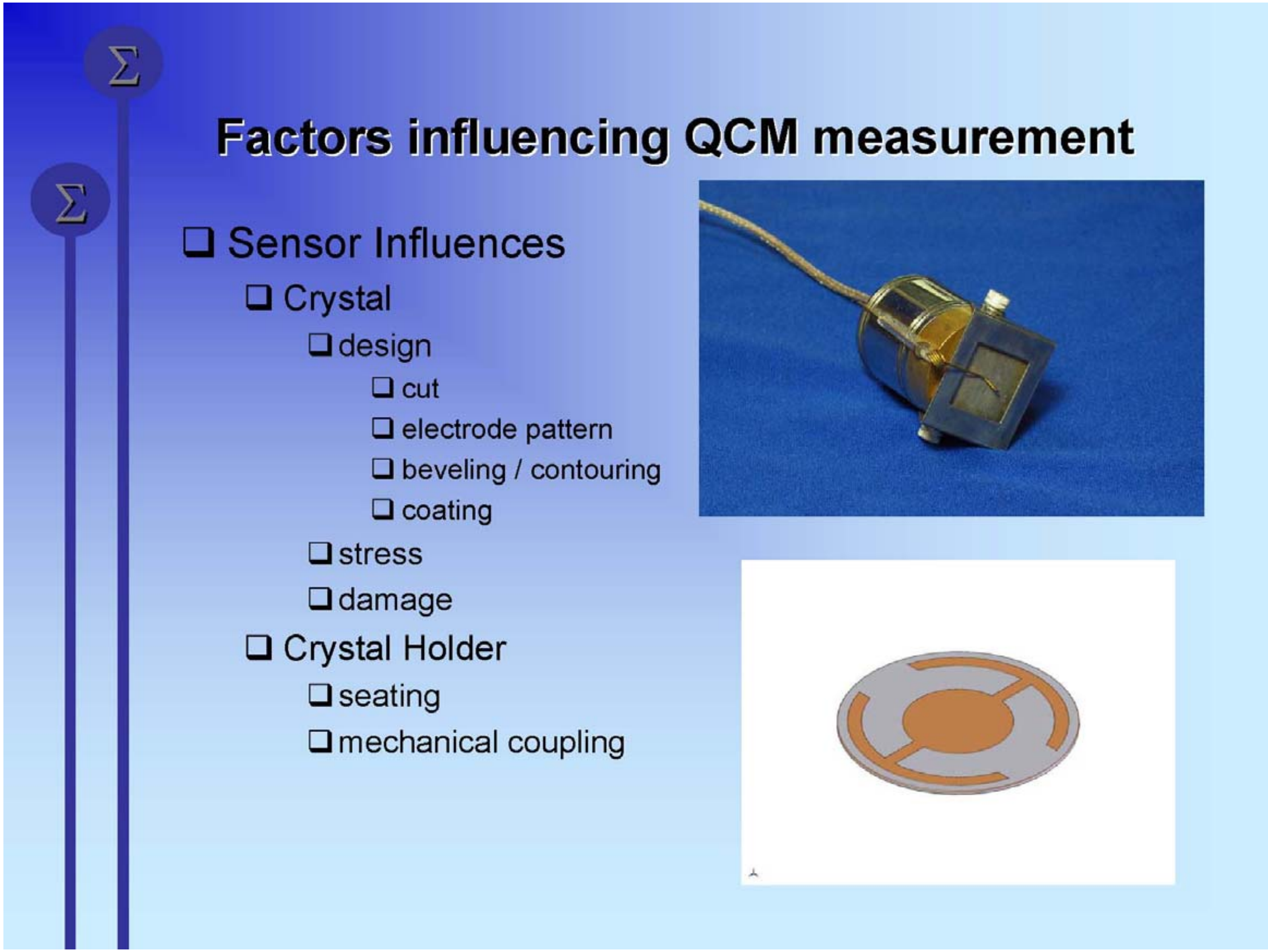
Figure 12.6 Resistive evaporator sources. (A) Simple sources including heating the charge itself and using a coil of refractory metal heater coil and a charge rod. (B) More standard thermal sources including a dimpled boat in a resistive media.

Quartz Crystal Microbalance

Basic Concepts

- ☐ Quartz crystal oscillates at 5 to 6 MHz.
- ☐ Material coats the substrate and quartz crystal, which causes the crystal to oscillate more slowly.
- ☐ Frequency change versus time yields rate and thickness.





Factors influencing QCM measurement

- ☐ Sensor Influences
  - ☐ Crystal
    - ☐ design
      - ☐ cut
      - ☐ electrode pattern
      - ☐ beveling / contouring
      - ☐ coating
    - ☐ stress
    - ☐ damage
  - ☐ Crystal Holder
    - ☐ seating
    - ☐ mechanical coupling

- Deduce thickness from change of mass (= $\rho \times d$)
- Deduce change of mass from change of frequency

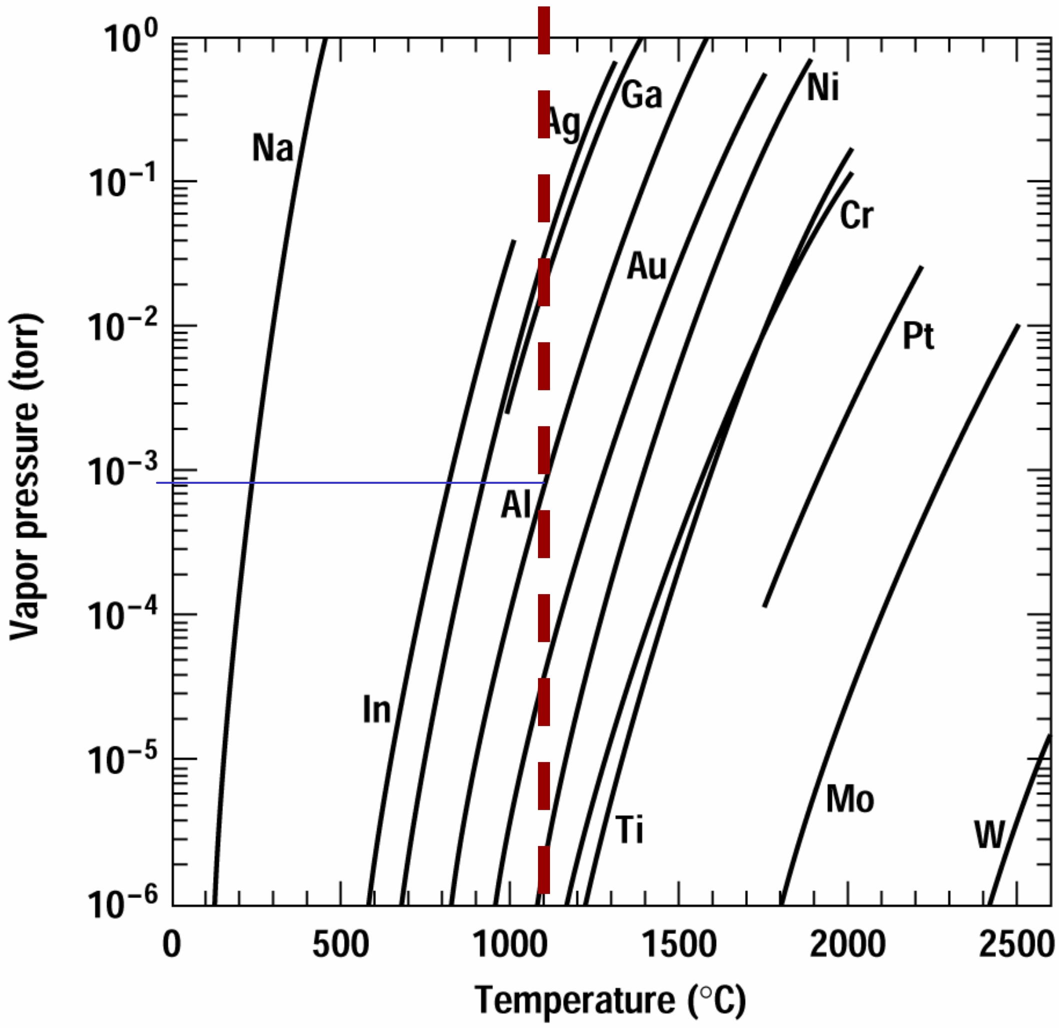


Figure 12.2 Vapor pressure curves for some commonly evaporated materials (*data adapted from Alcock et al.*).

Finding a more *efficient* deposition process that will preserve stoichiometry in multi-component films

Electron-beam deposition: localized melting

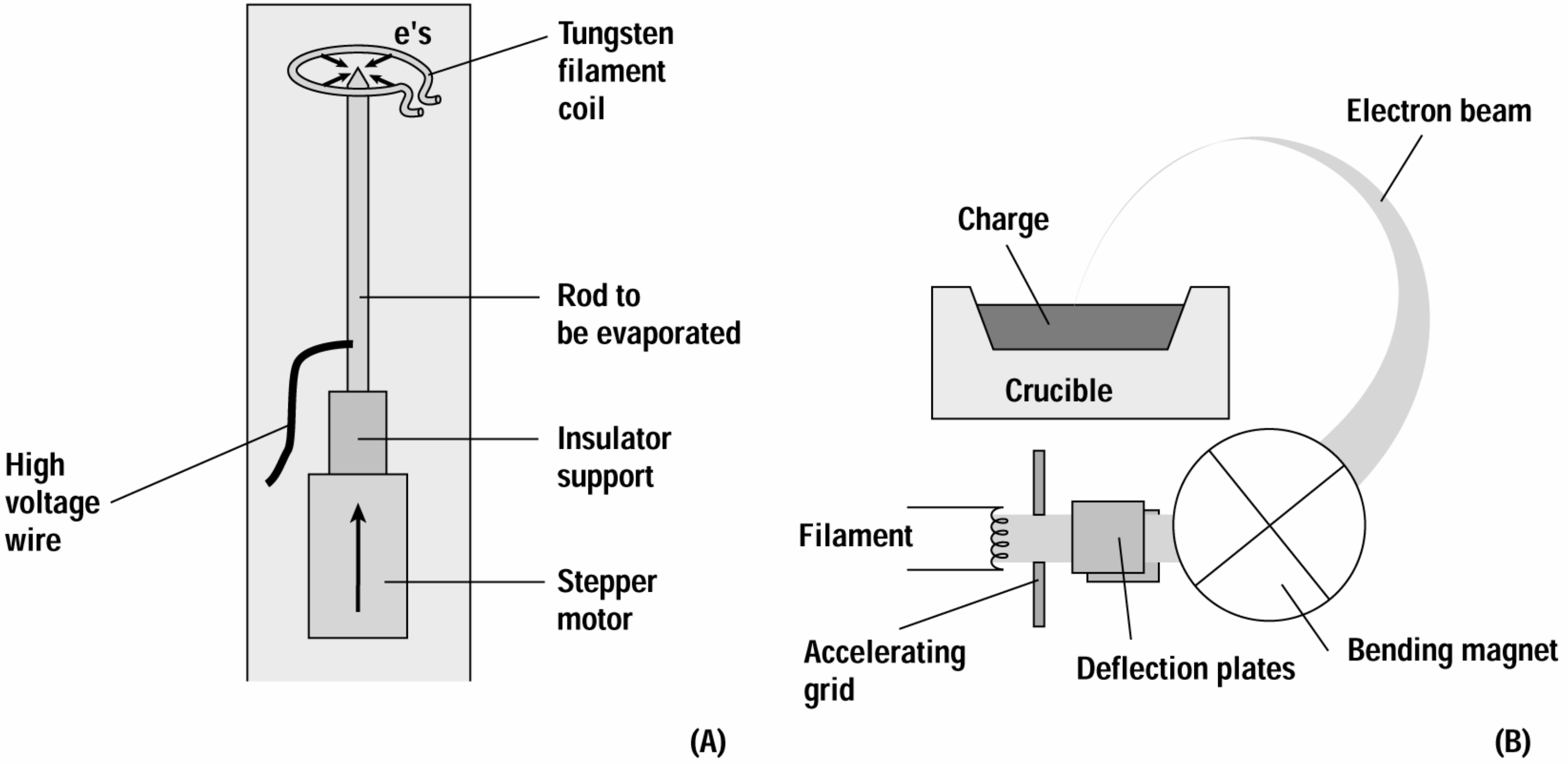


Figure 12.8 Electron beam evaporative sources. (A) A simple low-flux source using a hot wire electron source and a thin movable rod. (B) A popular source using a 2707 source arc in which the beam can be rastered across the surface of the charge. The magnet must be much larger than shown to achieve the full 2707 of arc.

By-product: production of X-rays

X-ray sources can be formed from electron beam irradiation of metals

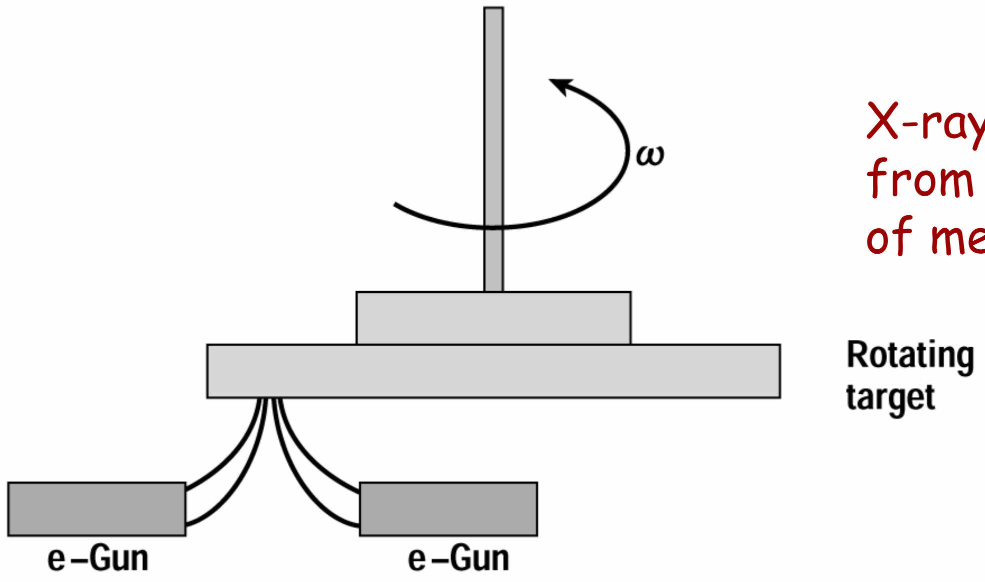
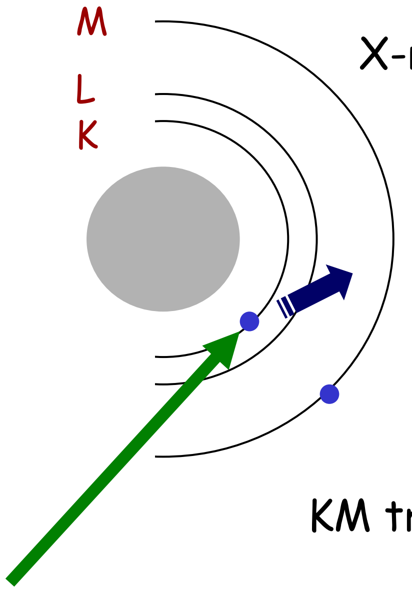


Figure 9.14 A simple rotating electron impact x-ray source uses electron beams focused on a rotating tungst anode.

Typical X-rays:
Cu, 1.5 angstrom wavelength, 8 KeV
Al, 8.3 angstrom, 1.5 keV
Range of x-rays in material is several microns



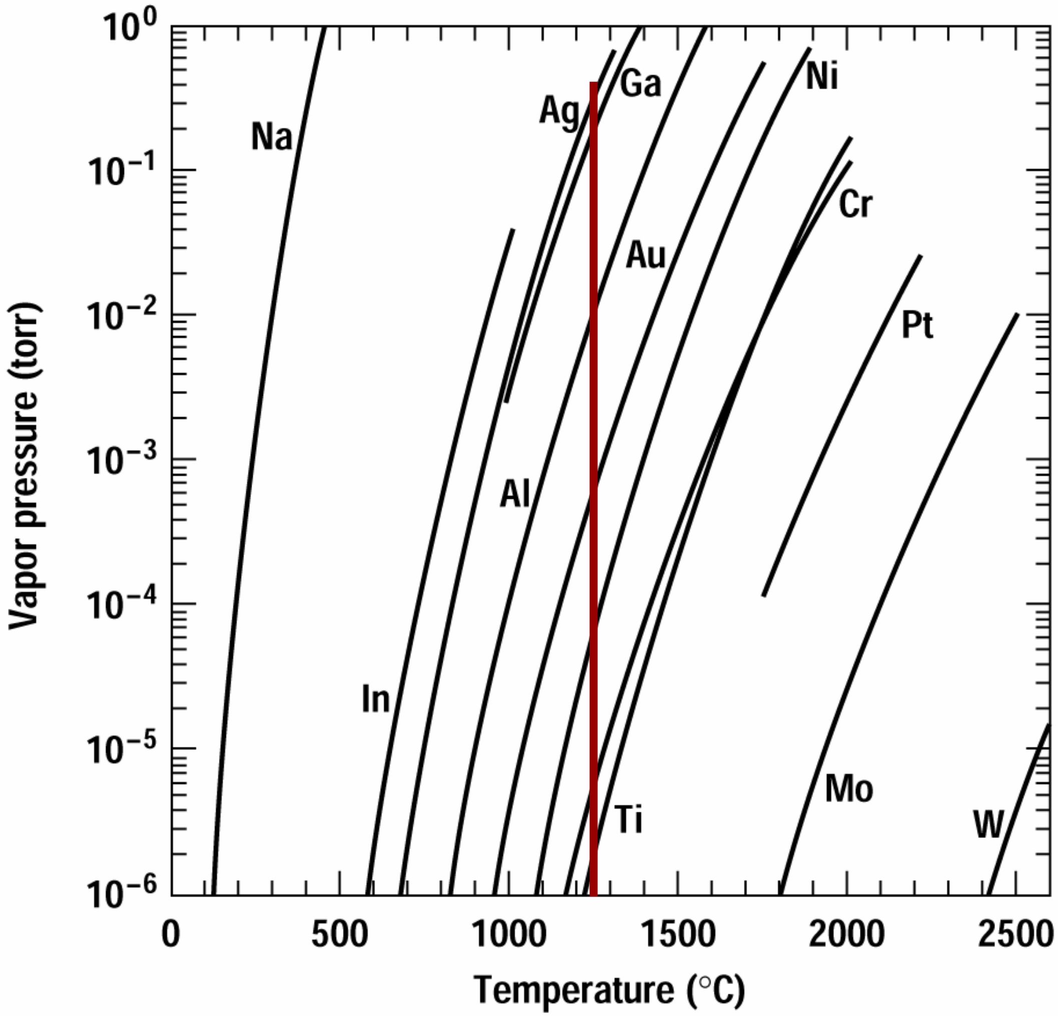


Figure 12.2 Vapor pressure curves for some commonly evaporated materials *(data adapted from Alcock et al.)*.

Problems of stoichiometry: dramatically different vapor pressures at a given temperature

Depositing Compound, Alloy Materials

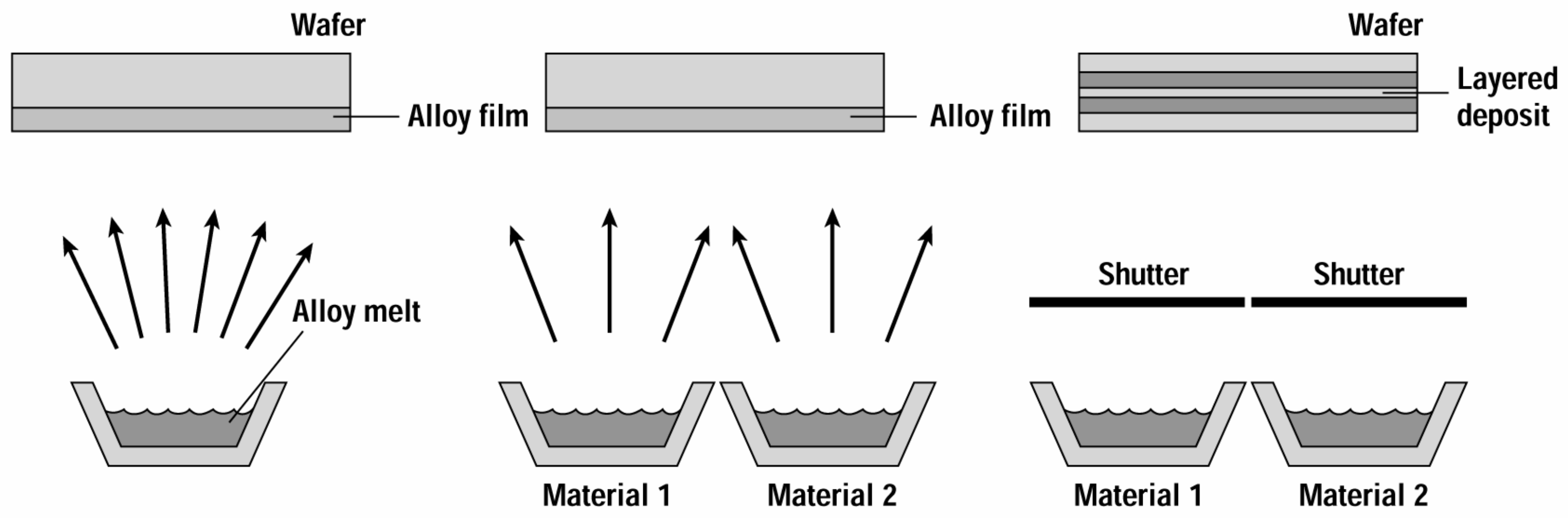


Figure 12.10 Methods for evaporating multicomponent films include (a) single source evaporation, (b) multisource simultaneous evaporation, and (c) multisource sequential evaporation.

A lower-temperature deposition process that
can preserve stoichiometry (of the target material):
SPUTTER DEPOSITION ---→

What Can an Ion Do to a Substrate?

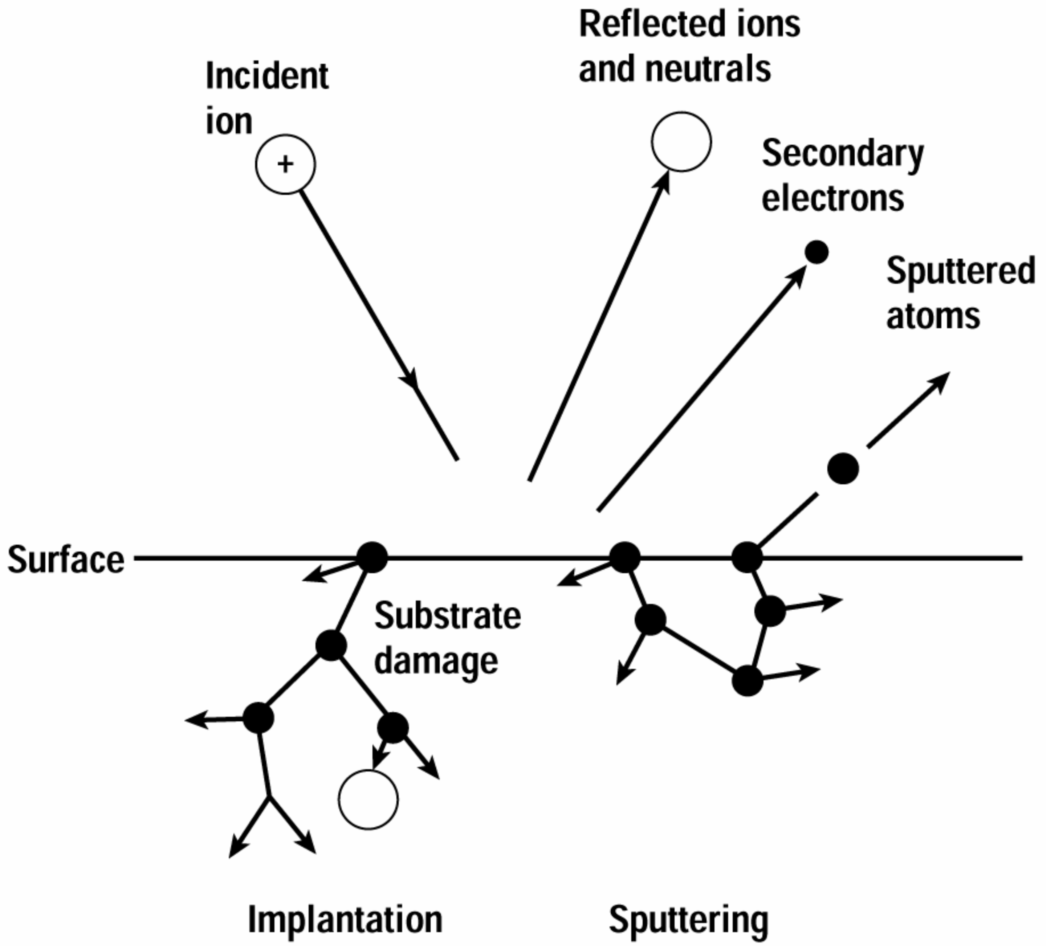


Figure 12.12 Possible outcomes for an ion incident on the surface of a wafer.

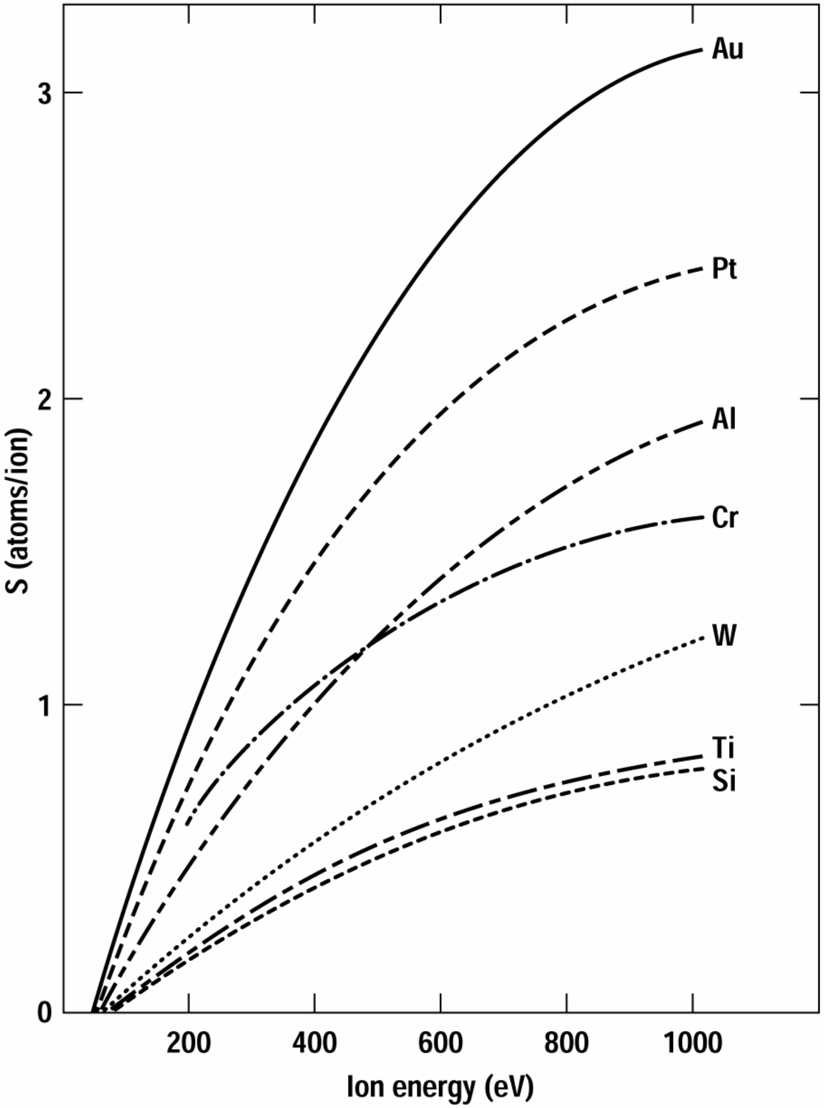


Figure 12.13 Sputter yield as a function of ion energy for normal incidence argon ions for a variety of materials *(after Anderson and Bay, reprinted by permission)*.

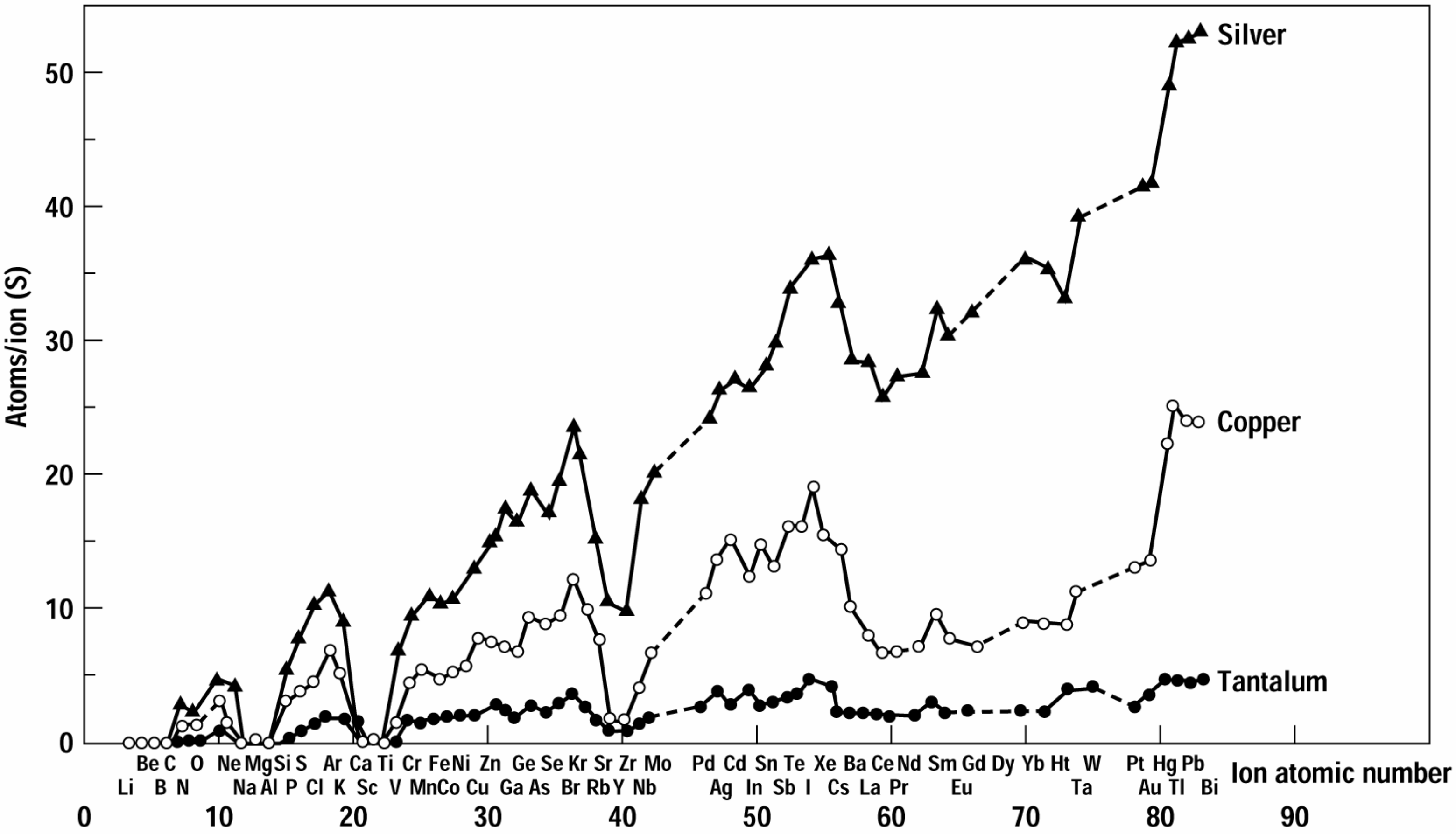


Figure 12.14 Sputter yield as a function of the bombarding ion atomic number for 45-keV ions incident on silver, copper, and tantalum targets *(after Wehner, reprinted by permission, AIP).*

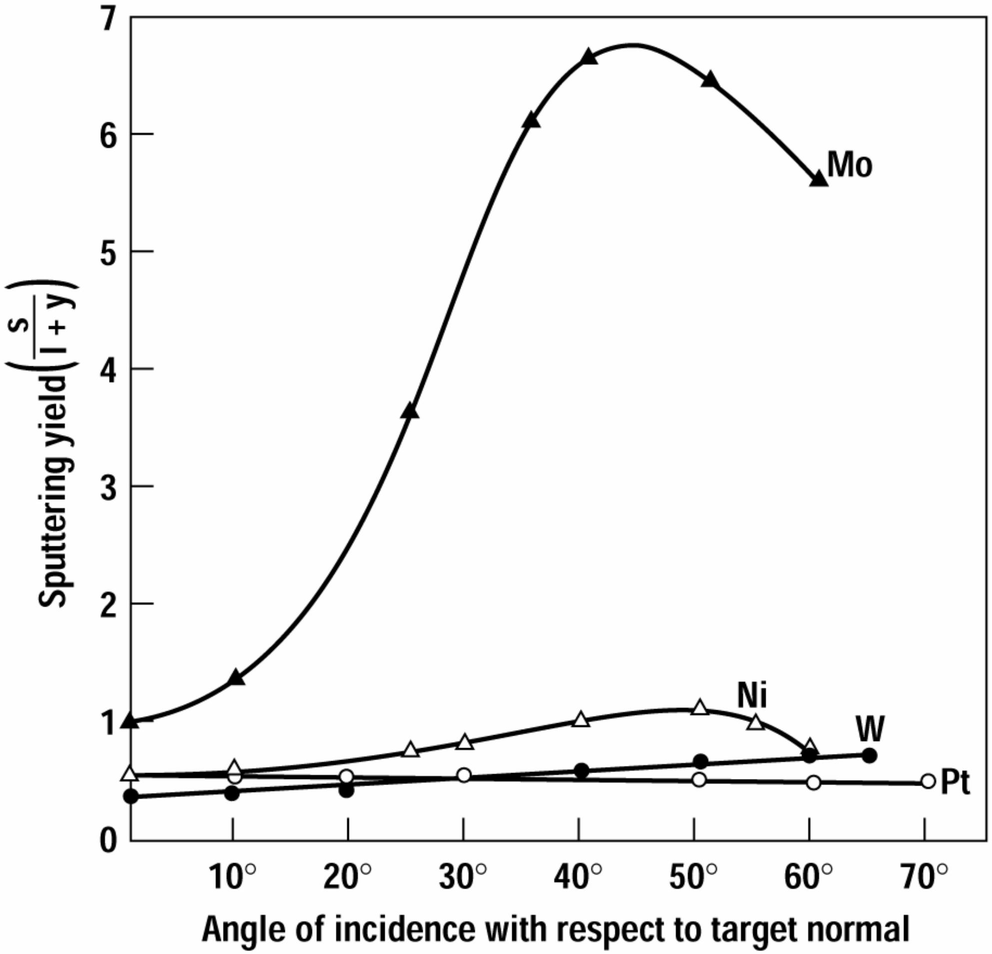


Figure 12.15 Typical angular dependence of the sputter yield for several different materials. The sputter profiles follow a cosine distribution *(after Wehner, reprinted by permission, AIP).*

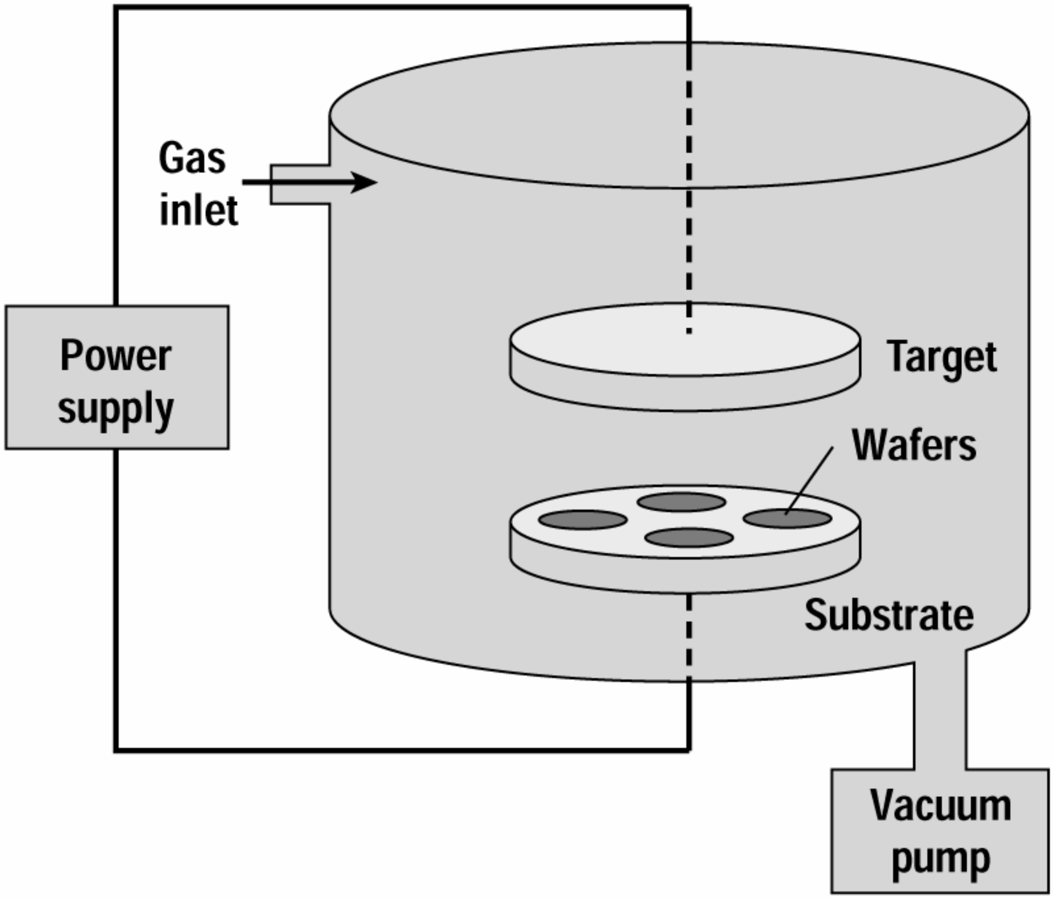
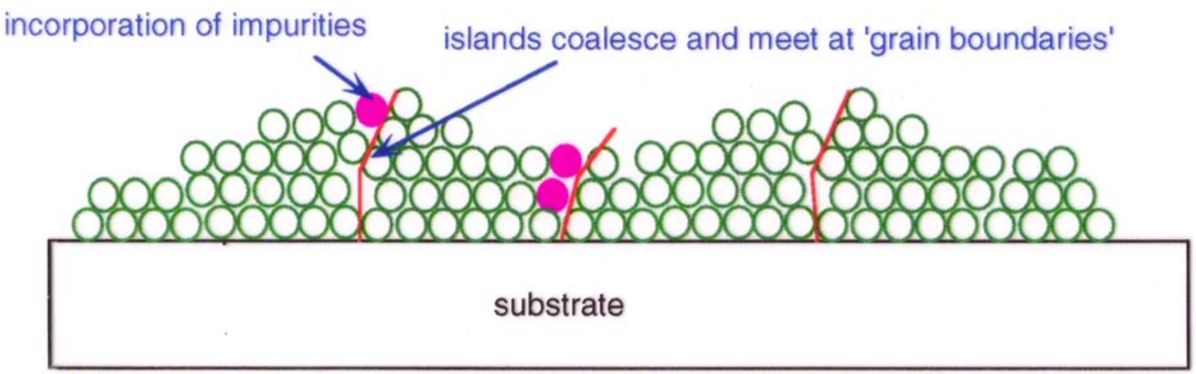
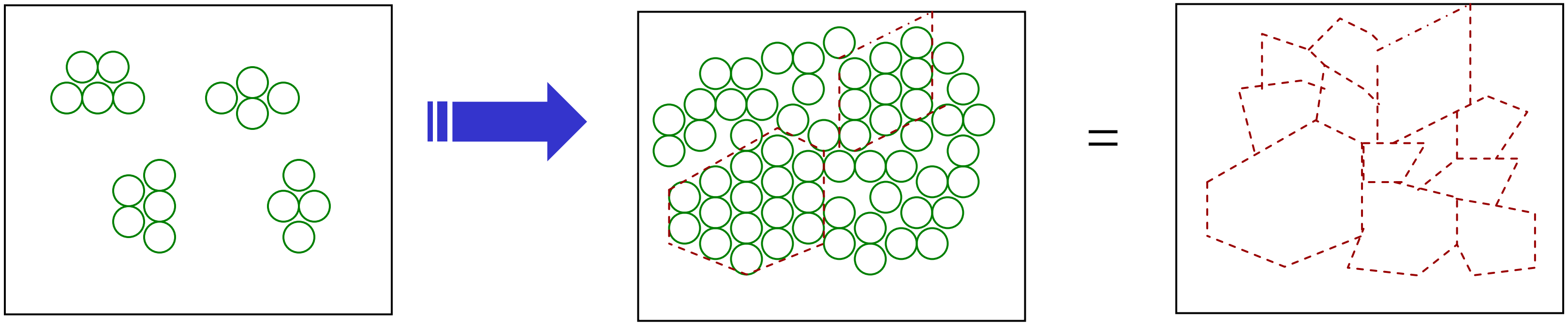


Figure 12.11 Chamber for a simple parallel-plate sputtering system.





1. Clusters of atoms nucleate to form islands
2. Some islands are ‘unstable’. Stable islands increase in size.
3. Growing islands meet at *grain boundaries.*
4. Is this film structure stable? What happens if you put additional energy into the film?

Zone 1: amorphous, porous

Zone 2: larger grain size, columnar

T: smaller grains

Zone 3: large 3D grains

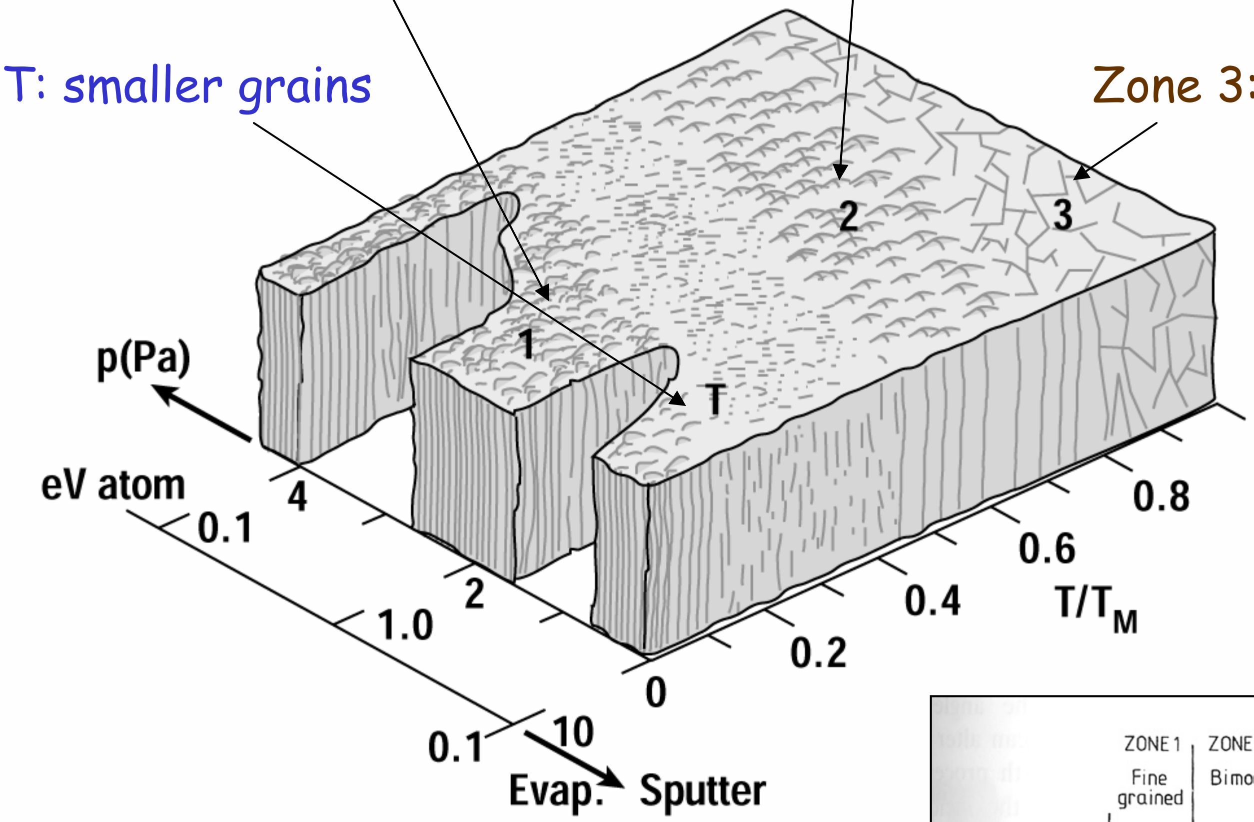


Figure 12.20 The three zone model of film
proposed by Movchan and Demchishin (*after*
reprinted by permission, AIP).

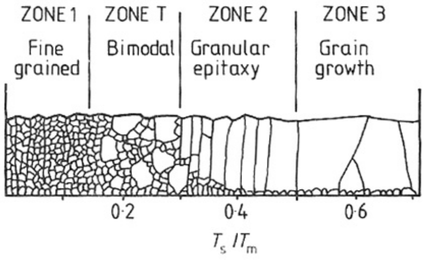


Figure 4.5 A schematic illustration of the variation in the grain size and morphology in thin metallic films with T_s/T_m, the ratio of the substrate temperature to the melting temperature of the metal.

Effect of deposition conditions on film structure

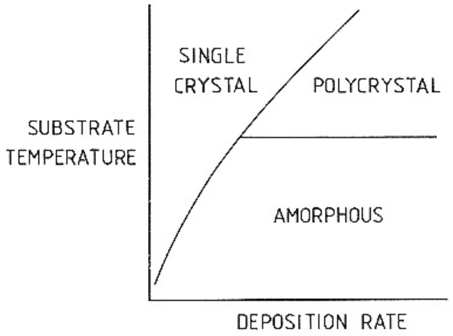


Figure 4.3 A schematic illustration of the relationship between deposition rate, substrate temperature and the structure of a film grown from the vapour phase. Figure 3.25 shows a plot of this kind for silicon films deposited by the CVD technique.

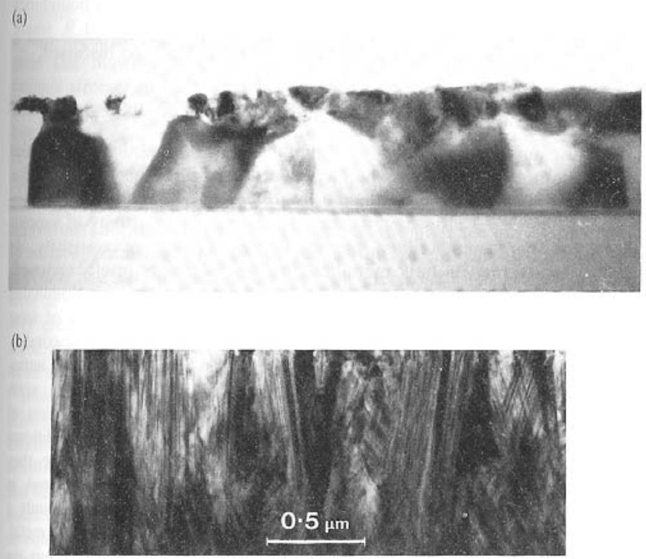


Figure 4.6 Cross-sectional transmission electron micrographs showing a comparison of the grain structure in as-evaporated (a) aluminium and (b) silicon films. (Courtesy of Mr D Gold.)

From *Microelectronic Materials,*
CRM Grovenor

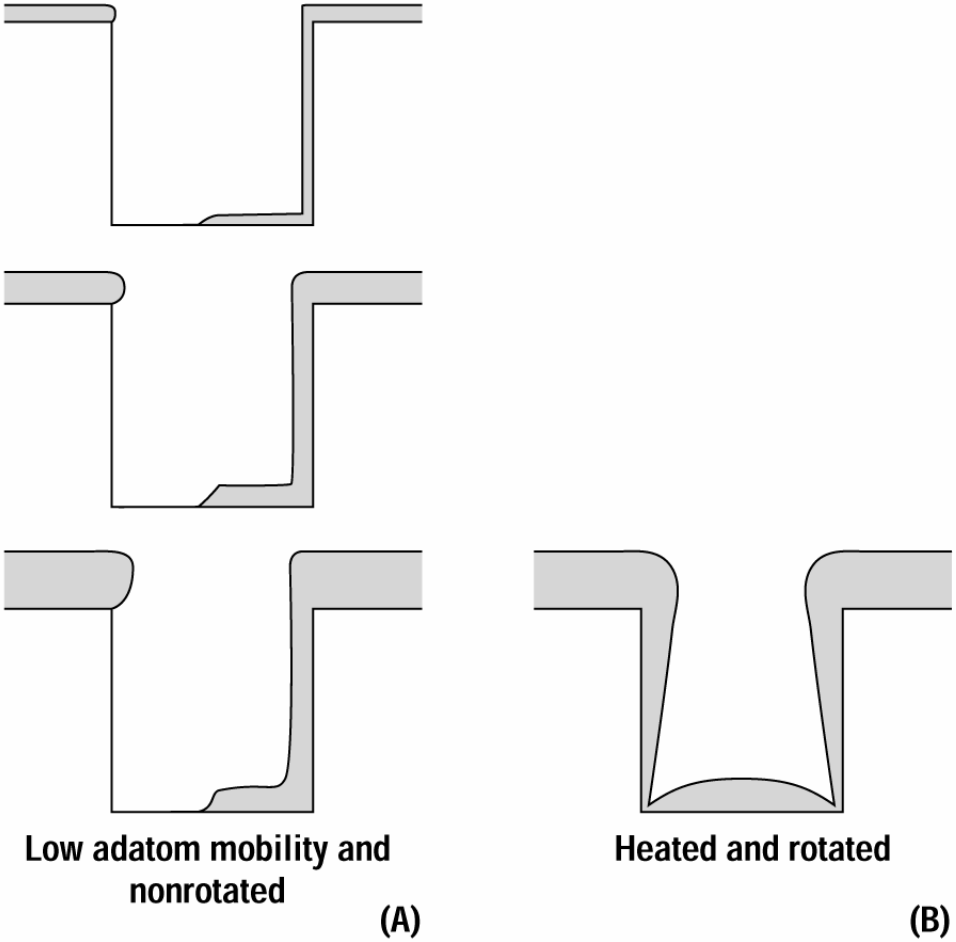
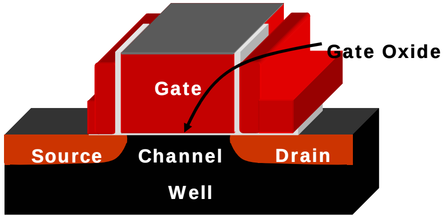
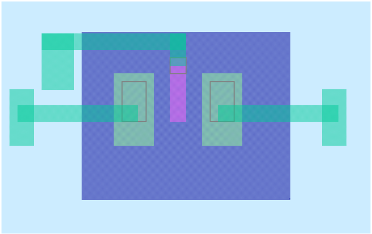


Figure 12.5 (A) Time evolution of the evaporative coating of a feature with aspect ratio of 1.0, with little surface atom mobility (i.e., low substrate temperature) and no rotation. (B) Final profile of deposition on rotated and heated substrates.

Four-point Probe

Building a 3D Structure, layer by layer





Well
Source and drain
Gate
Windows
Metal interconnects

Placing thin films onto the device

Figure 2: Schematic of Four-Point Probe