Thin film deposition techniques

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Thin film deposition techniques

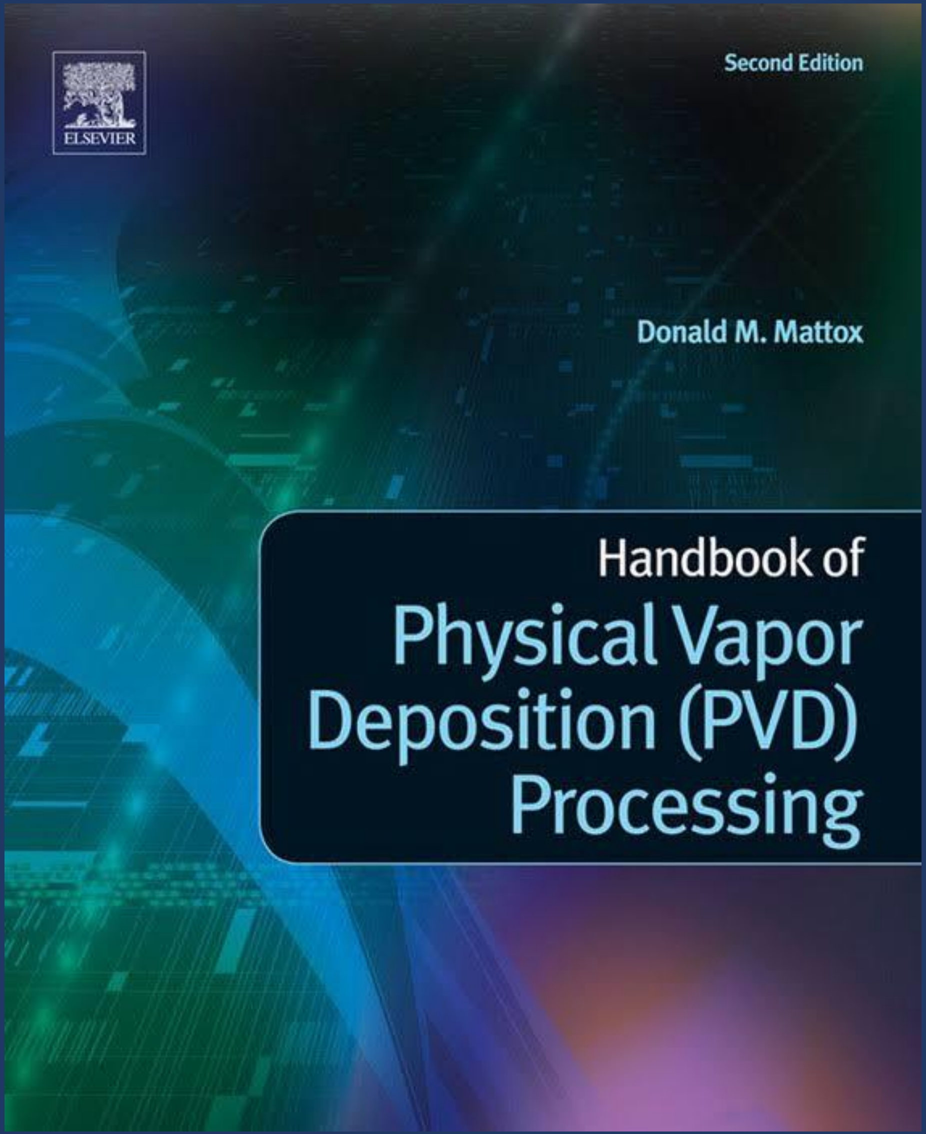
Evaporative deposition

Sputter deposition

Chemical vapour deposition

Atomic layer depositon

- How
- Properties of deposition processes
- Advantages
- Disadvantages
- Comparisons



ELSEVIER

Second Edition

Donald M. Mattox

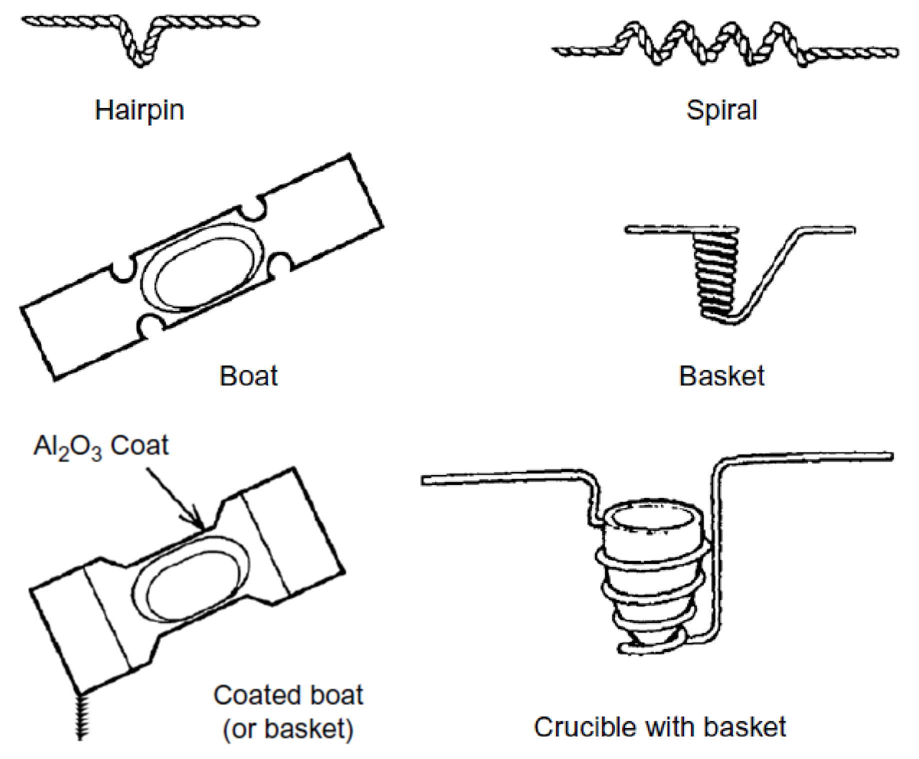
Handbook of
Physical Vapor
Deposition (PVD)
Processing

Evaporative deposition: How

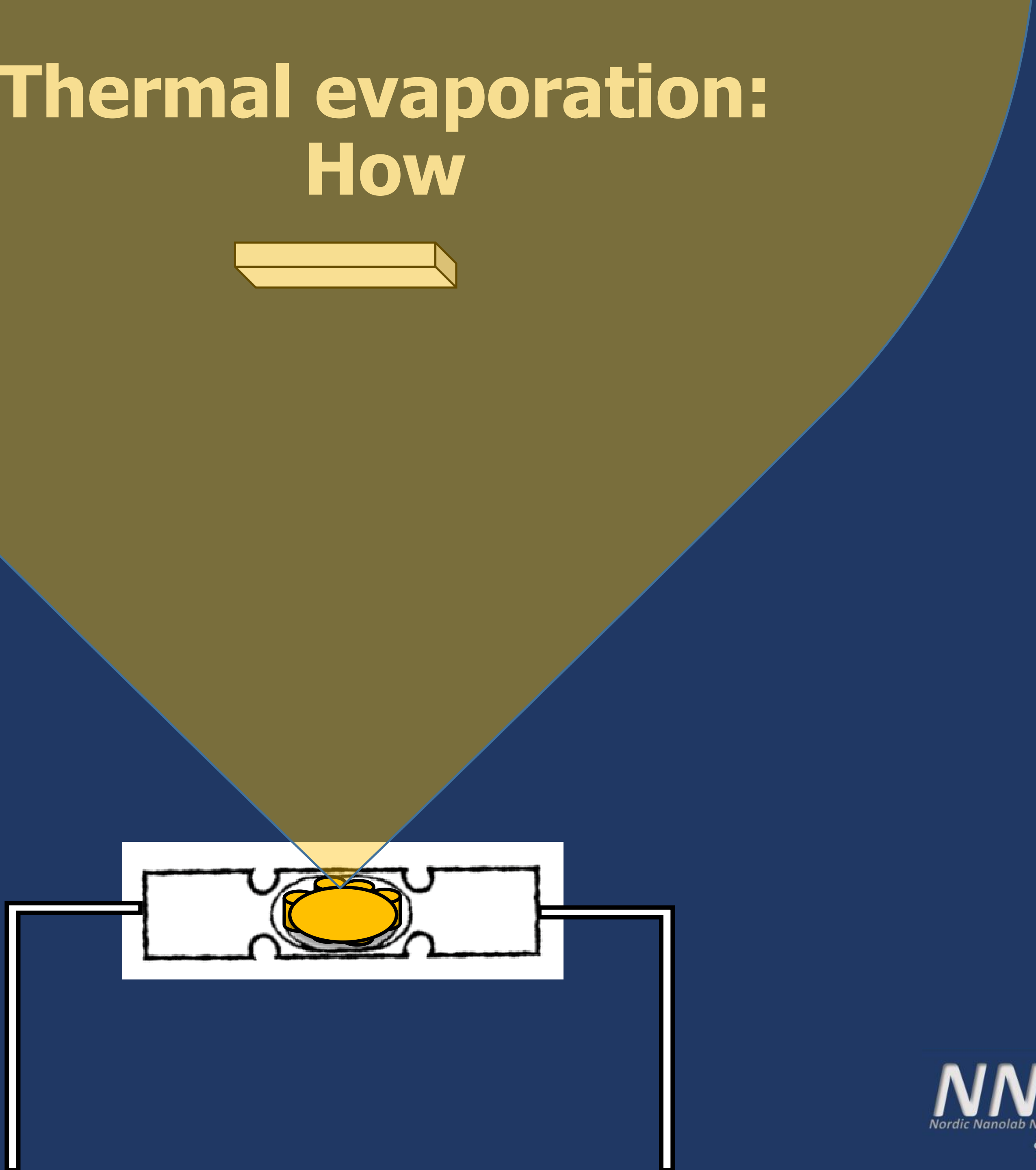
- Heat what you want to deposit until it has a high vapour pressure in vacuum
- Put substrate in «vapour cloud»

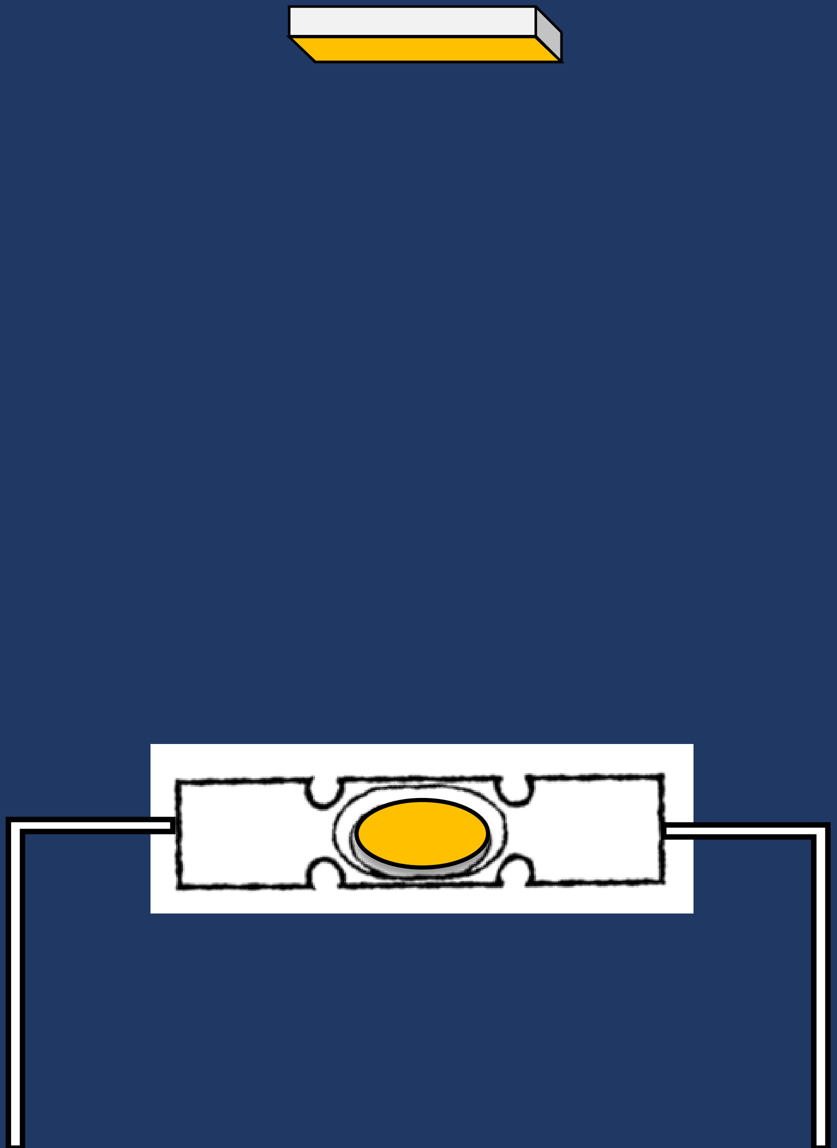
Thermal evaporation: How

- Heat target material (charge) with resistive heating



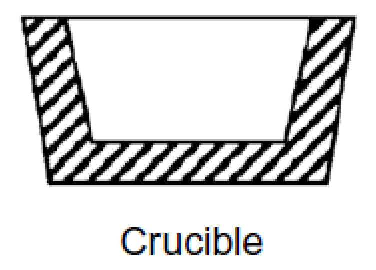
Thermal evaporation: How



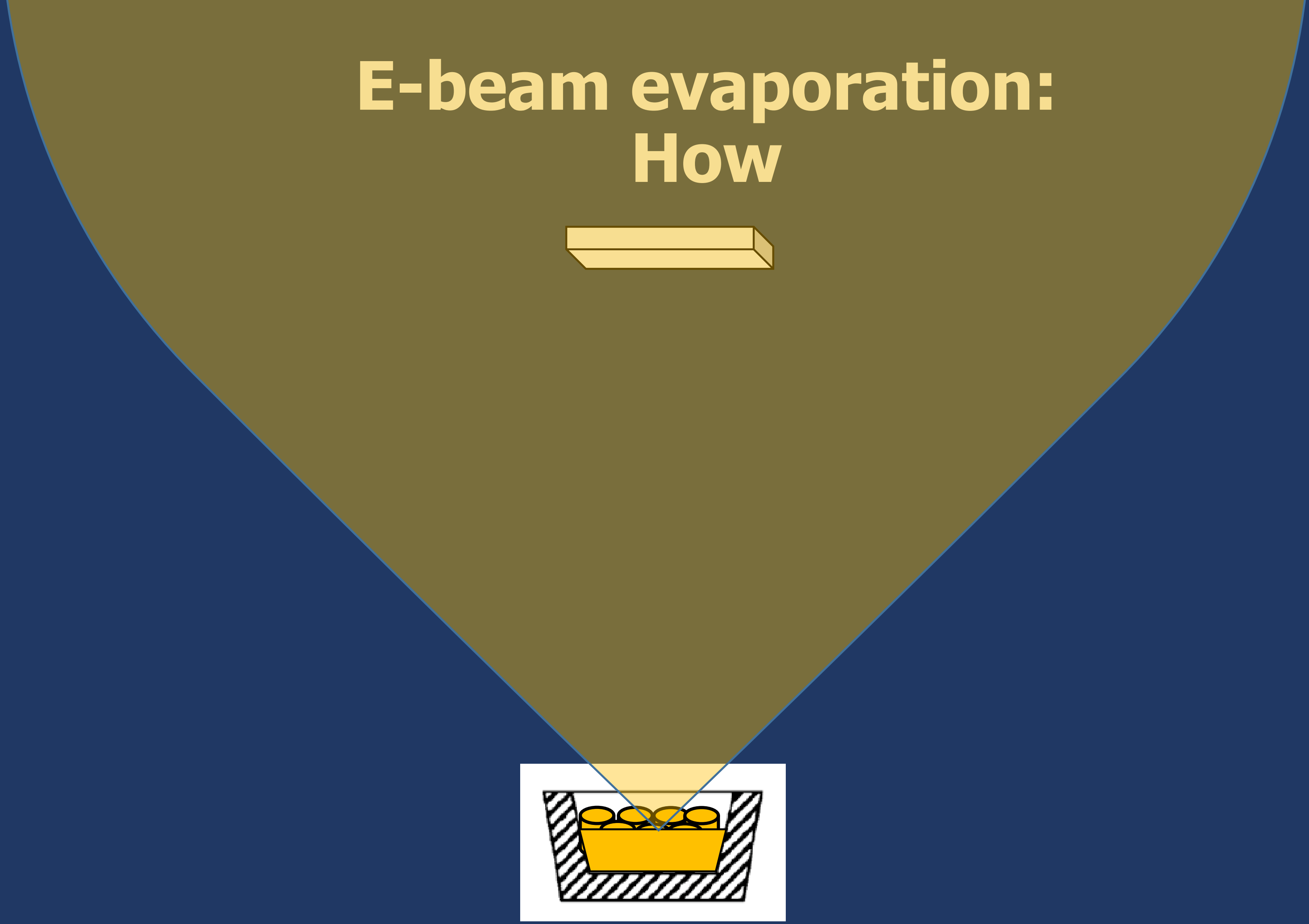


E-beam evaporation:

- Use electron beam instead of current



E-beam evaporation: How



Thermal or e-beam?

- Reaction with crucible/boat/wire
  - Can become brittle and break

- Melting temperature of target material
  - 1600 °C

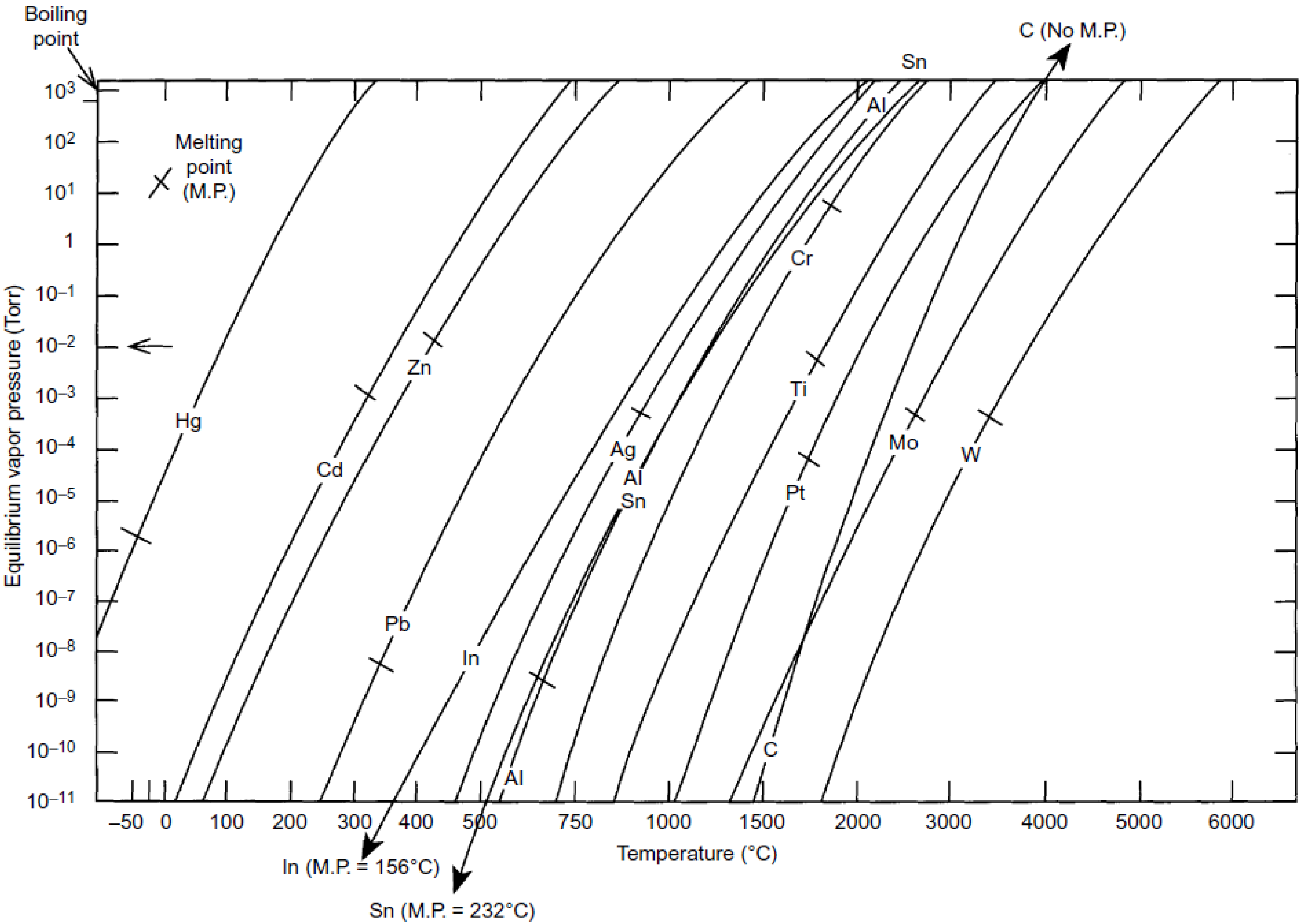


Figure 6.1: Equilibrium Vapor Pressures of Selected Materials. The Slashes Indicate the Melting Points (MPs)

Selective deposition of alloys

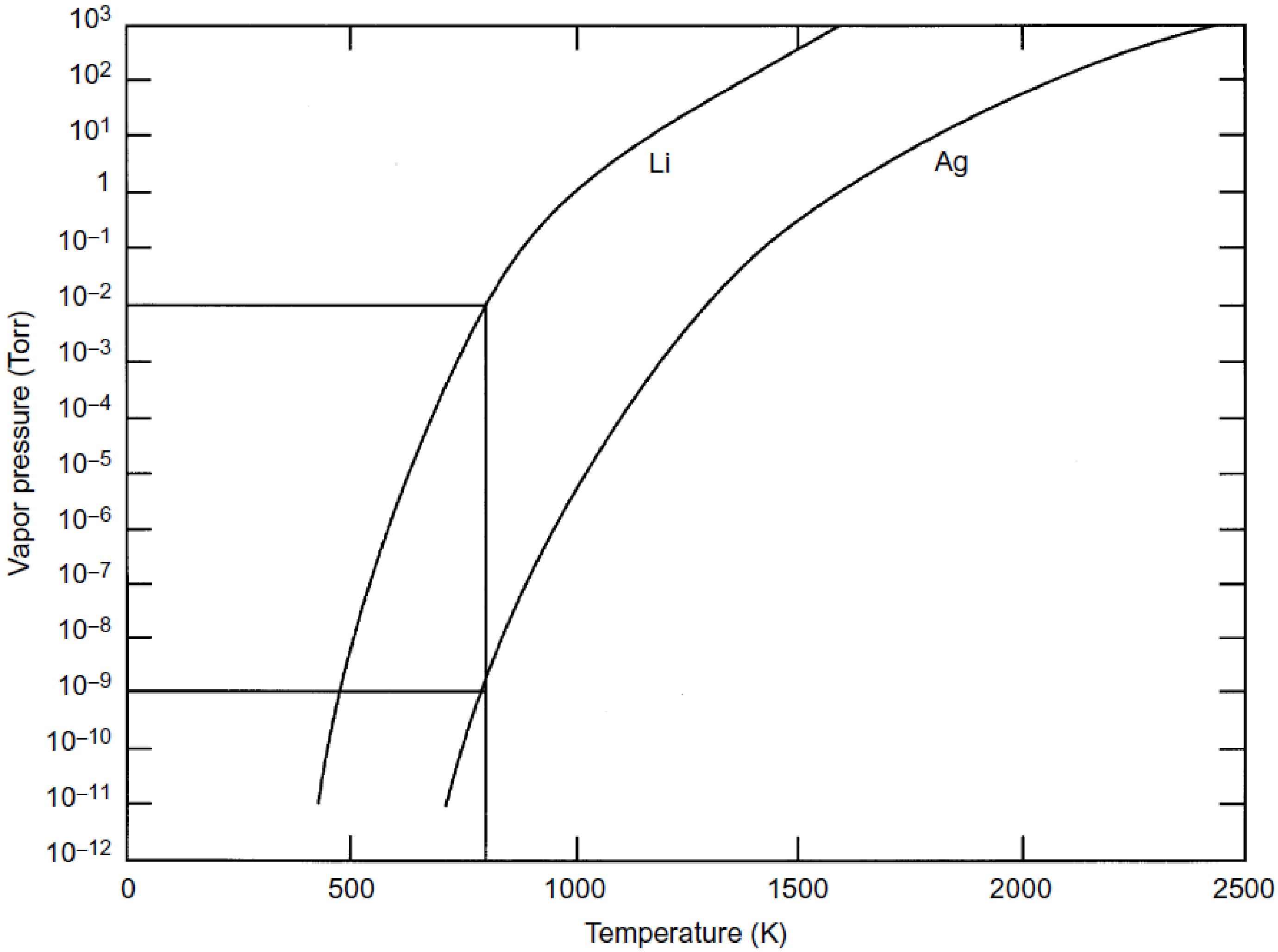


Figure 6.2: Equilibrium Vapor Pressures of Lithium (Li) and Silver (Ag)

Properties of evaporative deposition

- Difficult to deposit alloys/mixtures
  - Selective deposition

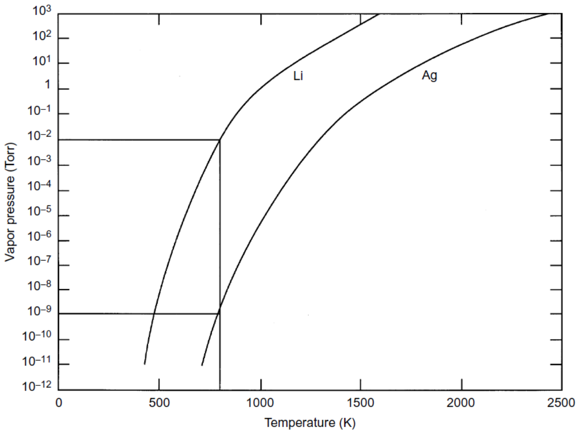


Figure 6.2: Equilibrium Vapor Pressures of Lithium (Li) and Silver (Ag)

- Radiative heating
  - Temperature sensitive samples
  - Increase distance
- Energy of atom corresponding to temperature, ~0.2 eV
  - Films often not completely dense
  - Tensile stress
- Line of sight deposition
  - Allow shadow-masks with no backside deposition
  - Easy to use shields to protect equipment
  - Little impurities from walls
  - Non-conformal on uneven substrates

Properties of evaporative deposition

- Low vacuum (<10^{-5} Torr)
- Can allow high deposition rates
- Oxidation of target
- Large spread in thickness with angle
  - Design of chamber
- Easy to measure thickness in-situ
  - Quartz Crystal Microbalance

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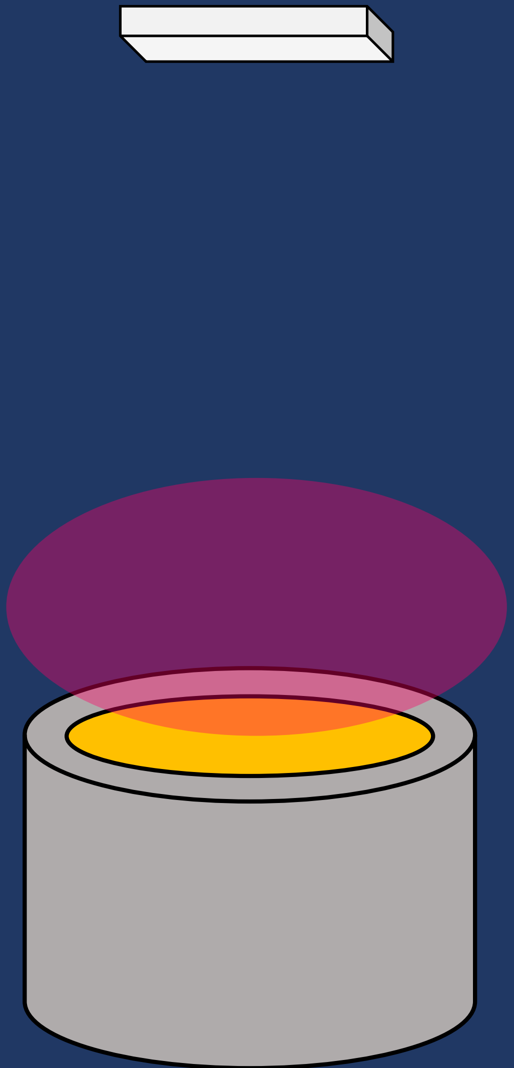
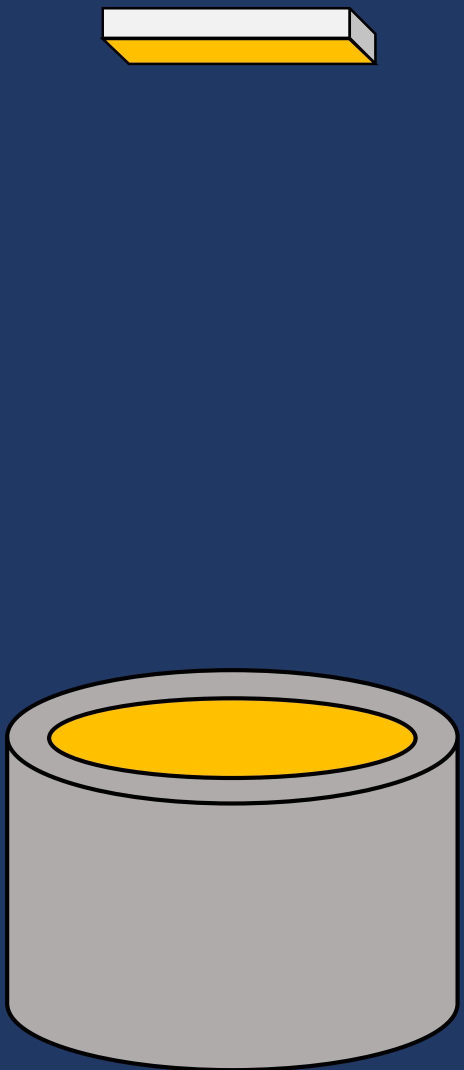
Sputter deposition



Sputter deposition



Sputter deposition: Higher energy and reactivity

- Why does it matter?

- With higher energies, the effective temperature of the film increases

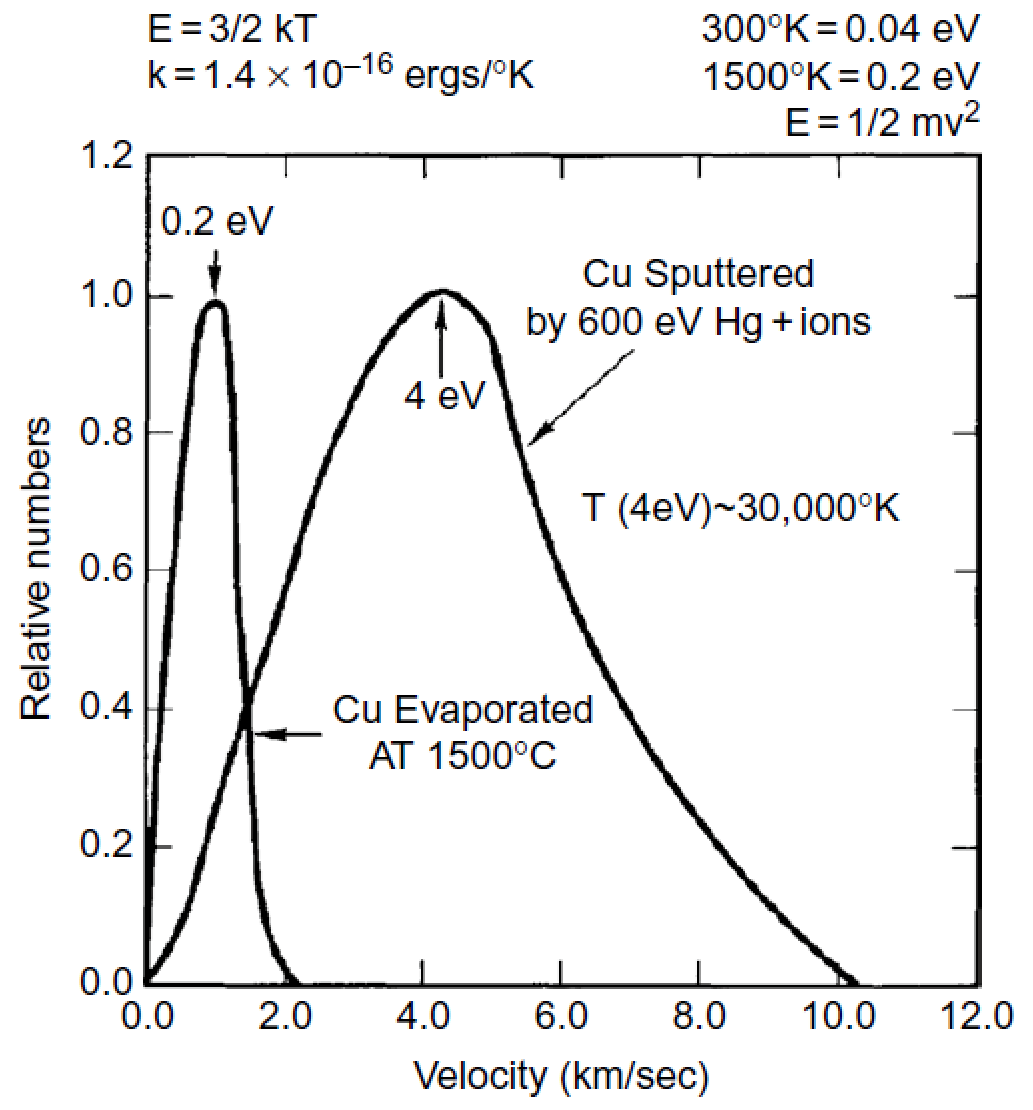
  - Increase mobility of adatoms on the surface

  - Increase density

  - Can tune stress compressive/tensile

  - Influence reaction rates and pathways

  - Influence grain growth


E = 3/2 kT
k = 1.4 × 10−16 ergs/°K
300°K = 0.04 eV
1500°K = 0.2 eV
E = 1/2 mv2
0.2 eV
Cu Sputtered
by 600 eV Hg + ions
4 eV
T (4eV)~30,000°K
Cu Evaporated
AT 1500°C
Relative numbers
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0.0
2.0
4.0
6.0
8.0
10.0
12.0
Velocity (km/sec)

Compound deposition

- The target is sputtered layer by layer

- The composition of the sputtered material always the same as the bulk target

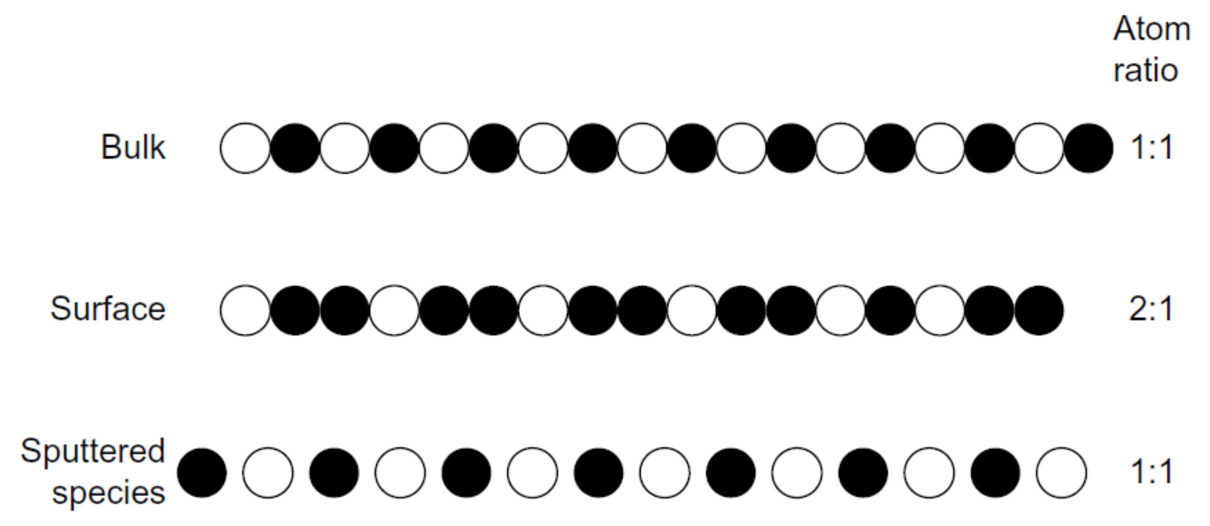


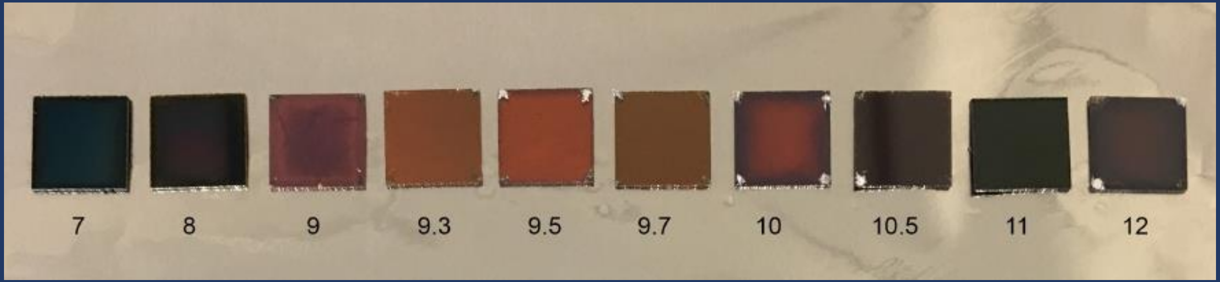
Figure 7.4: Sputtering, Layer by Layer

- Lighter atoms (oxygen, nitrogen, carbon) often lost in transport
  - Add gases to deposition chamber

Oxides, nitrides and carbides: Reactive deposition

- Oxides, nitrides and carbides can be deposited *reactively*
  - Oxygen, nitrogen or methane/acetylene introduced with argon

- Can shift the composition with changing amounts of reactive gas
  - No O_2: Cu
  - Cu + Cu_2O
  - Cu_2O
  - Cu_2O + CuO
  - CuO

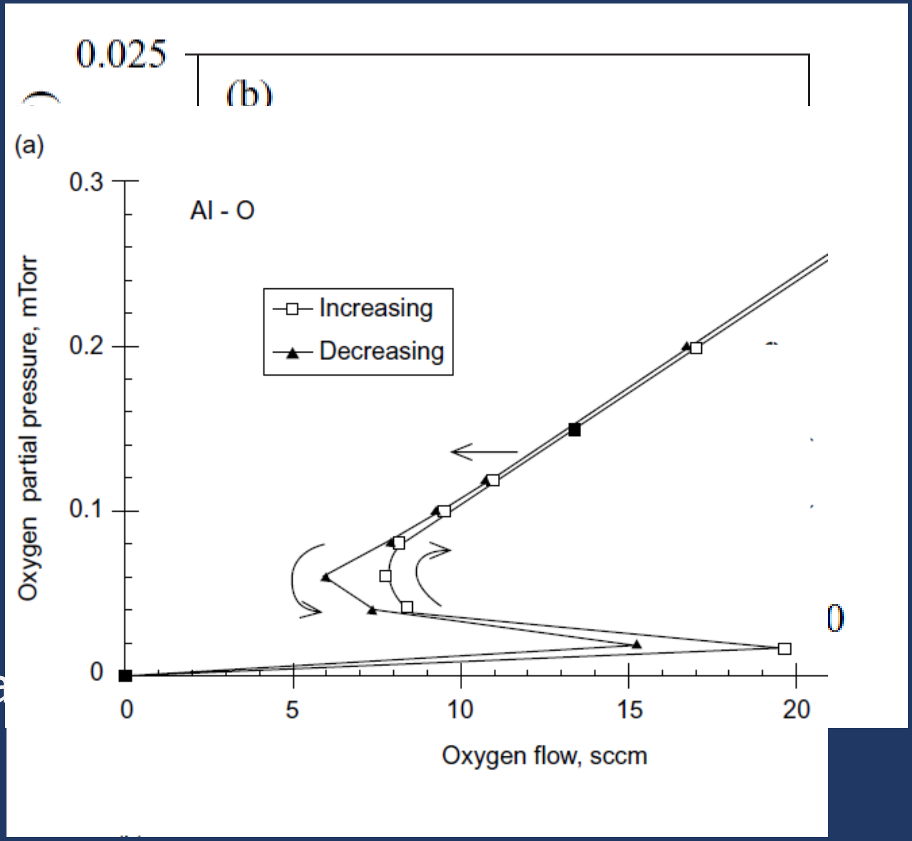


- Can control the stoichiometry using optical emission spectrometry

- Poisoning of target

Reproducibility

- Many parameters in sputter deposition affect the film
  - Deposition pressure
  - Power of sputtering ions
  - Partial pressure of reactive gas
  - Density of plasma
  - «Racetrack» formation
  - Prefential sputtering of crystallogra



Some comparisons: sputter and evaporative deposition

- More deposition parameters are available for sputtering
  - Allow non-equilibrium deposition
  - More complicated parameter-space
  - Denser films

- Sputtered films can have a higher energy impinging on the substrate
  - Energy can depend on voltage applied and pressure
  - Can change density and character of films by improving adatom mobility

- Sputtered atoms contain more reactive species
  - Radicals, ions

- Sputtering more complicated and expensive

Comparison : Sputter and evaporative deposition

- Evaporative deposition easier and more reproducible

- Sputter deposition not only line – of – sight.
  - Deposits on all surfaces in chamber
  - More difficult to keep clean
  - Can have impurities from chamber walls

- Sputter deposition better for temperature sensitive materials

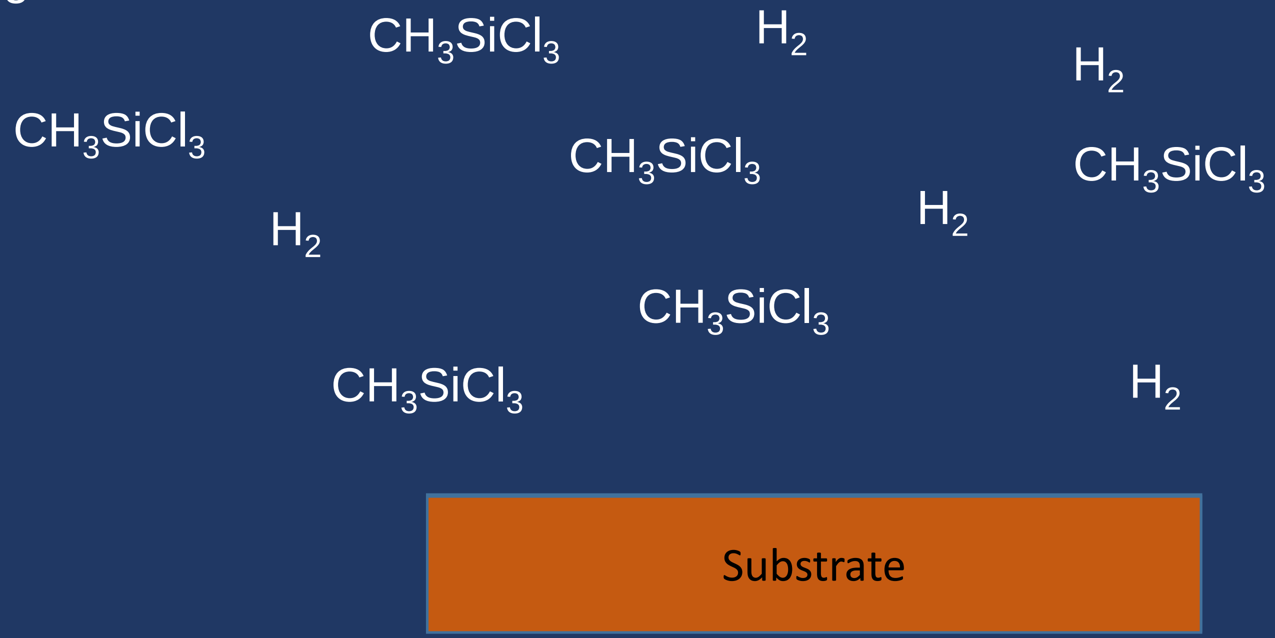
Chemical vapour deposition (CVD)

- Relies on chemical bonding/chemical reactions rather than bombardment of atoms
- Less damage at interfaces
- CVD
  - Plasma or thermally assisted
- Atomic Layer Deposition (ALD)
  - Plasma or thermally assisted
  - ALD is a subset of CVD
- Impurities depend on the chemical reaction completeness

Chemical vapour deposition (CVD)

Reactants and
carrier gas in →

Unused reactants, bi-products
and carrier gas out→



CH_3SiCl_3 H_2

H_2

CH_3SiCl_3

CH_3SiCl_3

CH_3SiCl_3

H_2

H_2

CH_3SiCl_3

CH_3SiCl_3

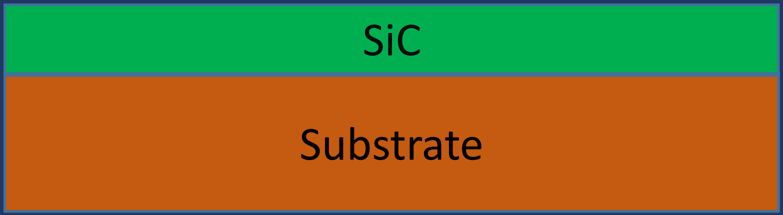
H_2

Substrate

Chemical vapour deposition (CVD)

Reactants and
carrier gas in →

Unused reactants, bi-products
and carrier gas out→



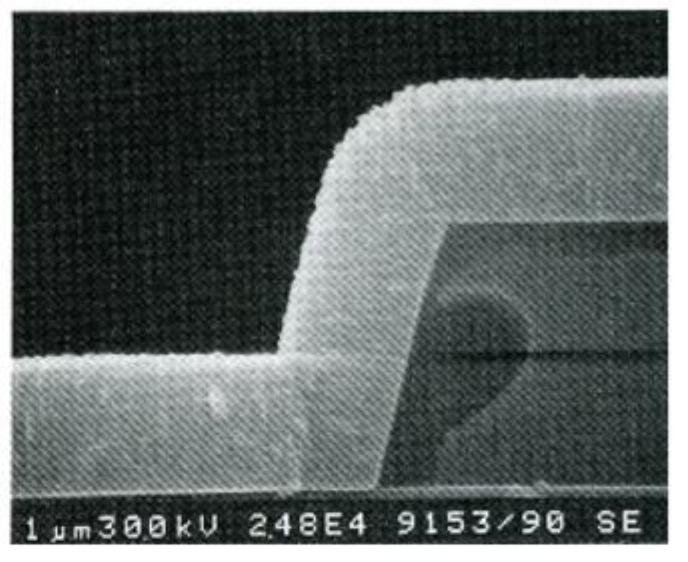
SiC

Substrate

Chemical vapour deposition (CVD)

- Non-line of sight process
  - Conformality also on uneven substrates
  - Up to ~1:50 ratio
  - Can coat trenches

- Great flexibility in films deposited
  - Carbides, nitrides, polymers



Chemical vapour deposition, Y.Xu / X.-T. Tan

- Deposition temperature can be reduced using plasma

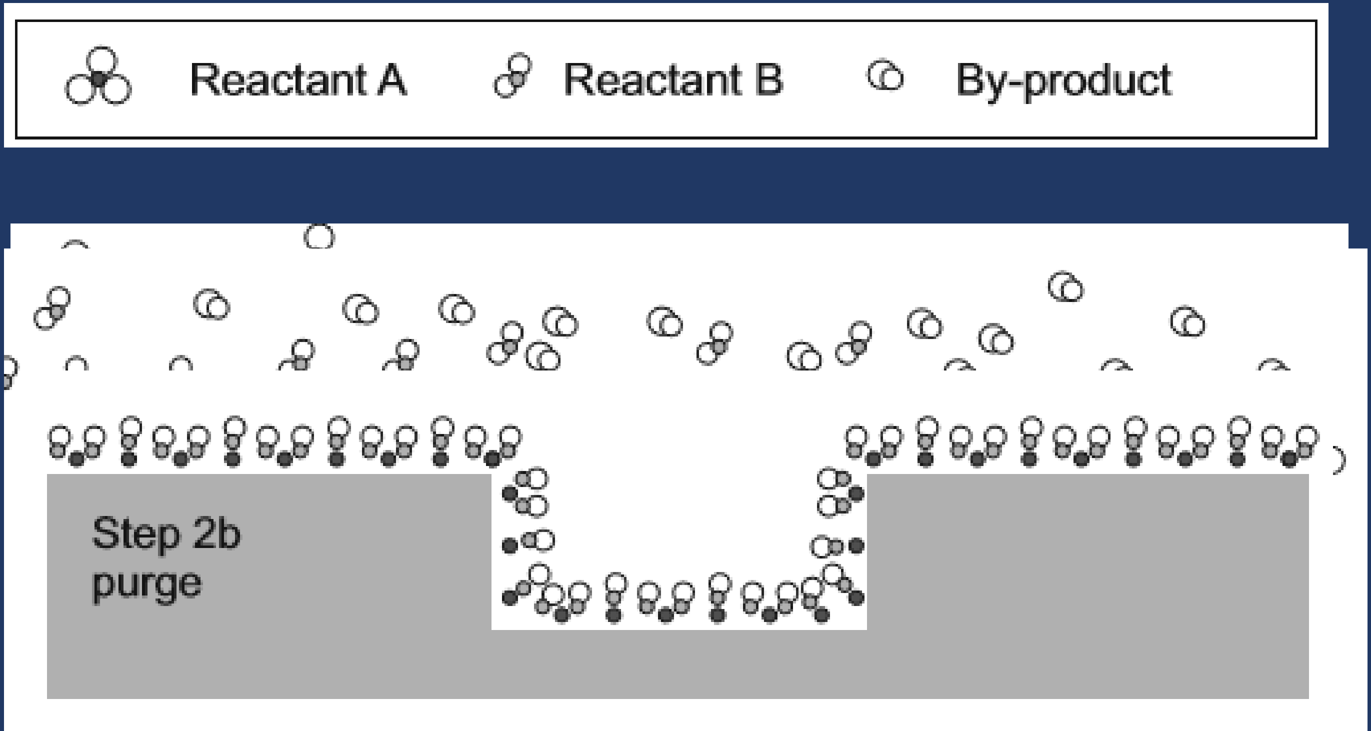
- From ultra-high vacuum to atmospheric pressure

- Can tune deposition rate, microstructure, stoichiometry, morphology, orientation

Atomic layer deposition (ALD)

- The chemical reaction divided into two «half-reactions»
- Reactants separated in time
- Surface saturation

Atomic layer deposition (ALD)



V. Miikkulainen et al., «Crystallinity of inorganic films grown by atomic layer deposition: overview and general trends»

Atomic layer deposition (ALD)

- Can deposit on very high aspect-ratio substrates
  - Conformal and dense films

- Deposition temperature can be reduced using plasma
  - Some chemistries require plasma to occur
  - Can reduce conformality

- No pinholes

- Excellent thickness control (nm control)

- Often expensive and time-consuming
  - Batch process (not spatial ALD)
  - Precursors can be expensive
  - Low deposition rates

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Systems in our labs

	Evaporative deposition	Sputter deposition	Atomic layer deposition
Lund		1	3
Chalmers	9	8	1
Uppsala	3	2	2
DTU	4	2	2
UiO	3	4	1
USN	1	1	
KTH	3	2	
Aalto			3

Properties	ALD	PEALD	CVD	PECVD	Sputtering	Evaporation
Temperature	Lower < 400 °C common	Lower than similar ALD processes	Higher > 1000 °C possible	Lower than similar CVD processes	RT possible	RT possible
Pressure	mbar range common, can go to AP	mbar range common	mbar range for LPCVD and higher for APCVD	mbar range common	0.1-5 Pa (0.001-0.05 mbar)	Vacuum
Growth rate	Very low 1 Å/s is a fast process, sALD can go higher	Higher than comparable thermal ALD processes	Moderate to high µm/min range possible	Higher than corresponding TACVD processes	Moderate µm/hour typical	High µm/min range possible
Uniformity	Excellent	Very good	Good, but can be worse on larger surfaces	Good, but can be worse on larger surfaces	Very good	Poor
Step coverage	Excellent	Worse than ALD due to reactive plasma species	Good for a surface controlled process	Worse than CVD due to reactive plasma species	Poor on small features, big features possible	Very poor, true line-of-sight method.
Impurity levels	Moderate Precursor contamination due to low temperature	Higher or lower than ALD due to plasma effects and temp.	Moderate Low cont. can be obtained at high temp.	Higher or lower than CVD due to plasma effects and temp.	Low, determined by the quality of vacuum	Very low Limited only by the vacuum and source material
Adhesion	Very good	Very good	Very good	Very good	Good	Poor
Film density	Excellent	Excellent	Excellent	Good	Good	Poor

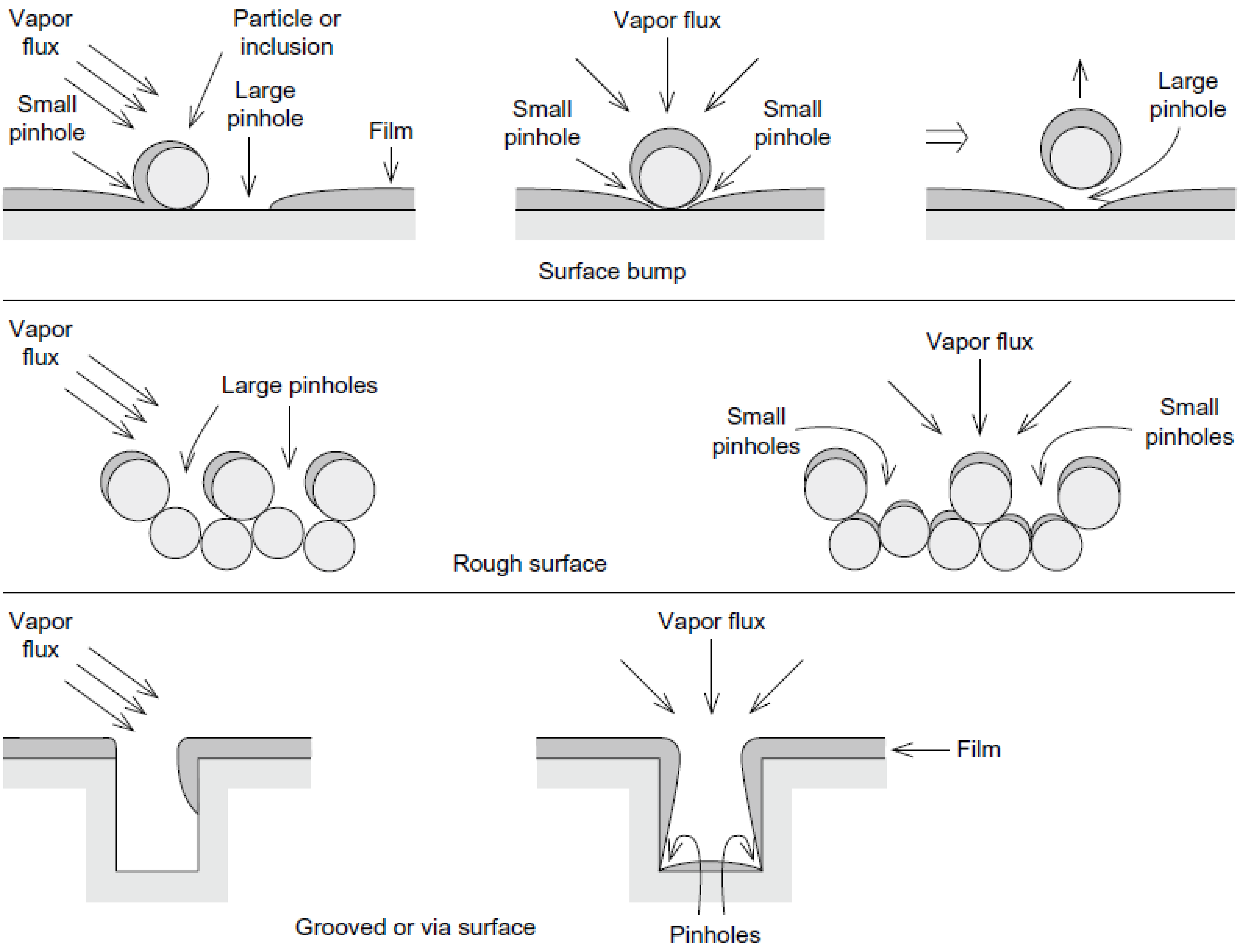
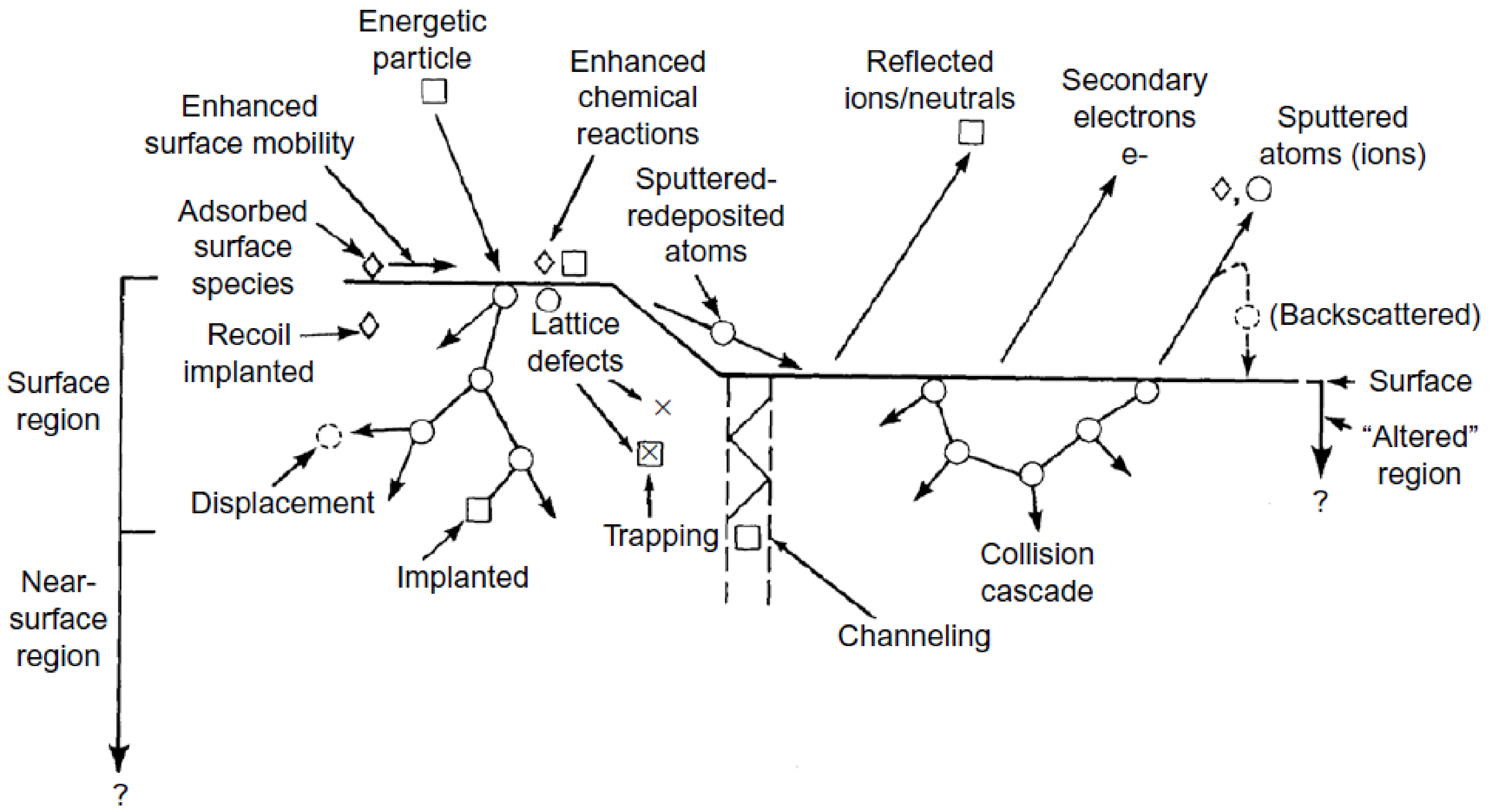


Figure 6.10: Geometrical Shadowing of the Deposition Flux by a Particle on the Surface and by Surface Features


Energetic particle
Enhanced surface mobility
Enhanced chemical reactions
Reflected ions/neutrals
Secondary electrons e-
Sputtered atoms (ions)
Adsorbed surface species
Sputtered-redeposited atoms
Recoil implanted
Lattice defects
(Backscattered)
Surface region
Surface
"Altered" region
?
Displacement
Trapping
Implanted
Collision cascade
Channeling
Near-surface region
?

Thank you!

Evaporative deposition	**Sputter deposition**
Easy	Complex
Little energy during film formation (temperature and condensation)	More energy deposited during film formation (higher speed, plasma presence)
Films tensile stress and less dense	Can deposit wide range of properties in films

Other

- There is a threshold energy below which nothing will sputter (25 eV)
  - No sputtering by electrons
- Sputtering yields decrease at high energies due to energy lost far beneath surface