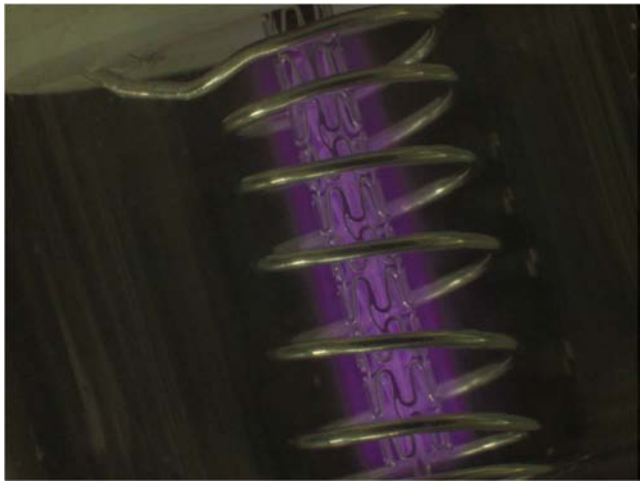
Treatment of Surfaces with Ions in a Glow Discharge



MB-JASS 2011

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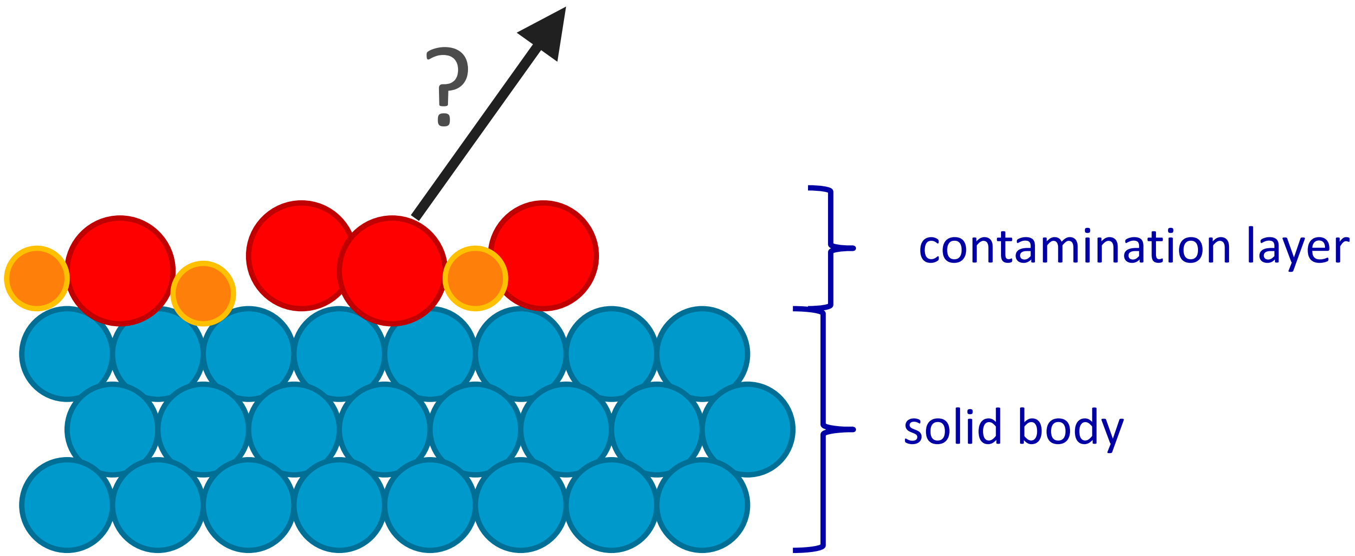
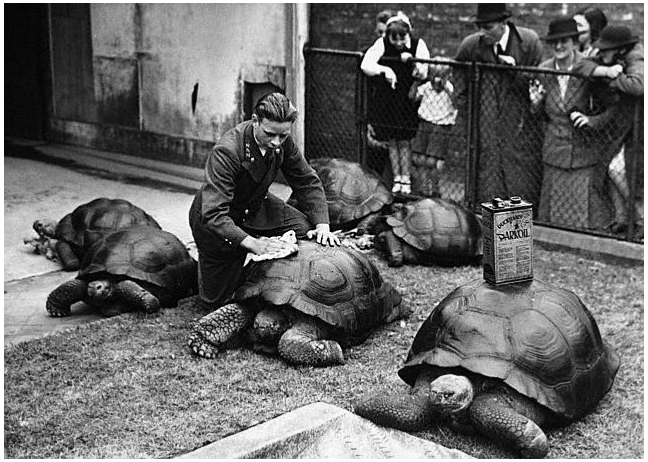
How to Remove a Contamination Layer from a Surface?



Available Surface Cleaning Methods

- chemical methods:
  - chemical etching
  - electro polishing
- physical methods:
  - grinding
  - polishing
  - **sputtering**



Sputtering

definition:

to cause the atoms of a solid to be removed from the surface by bombardment with atoms in a discharge tube

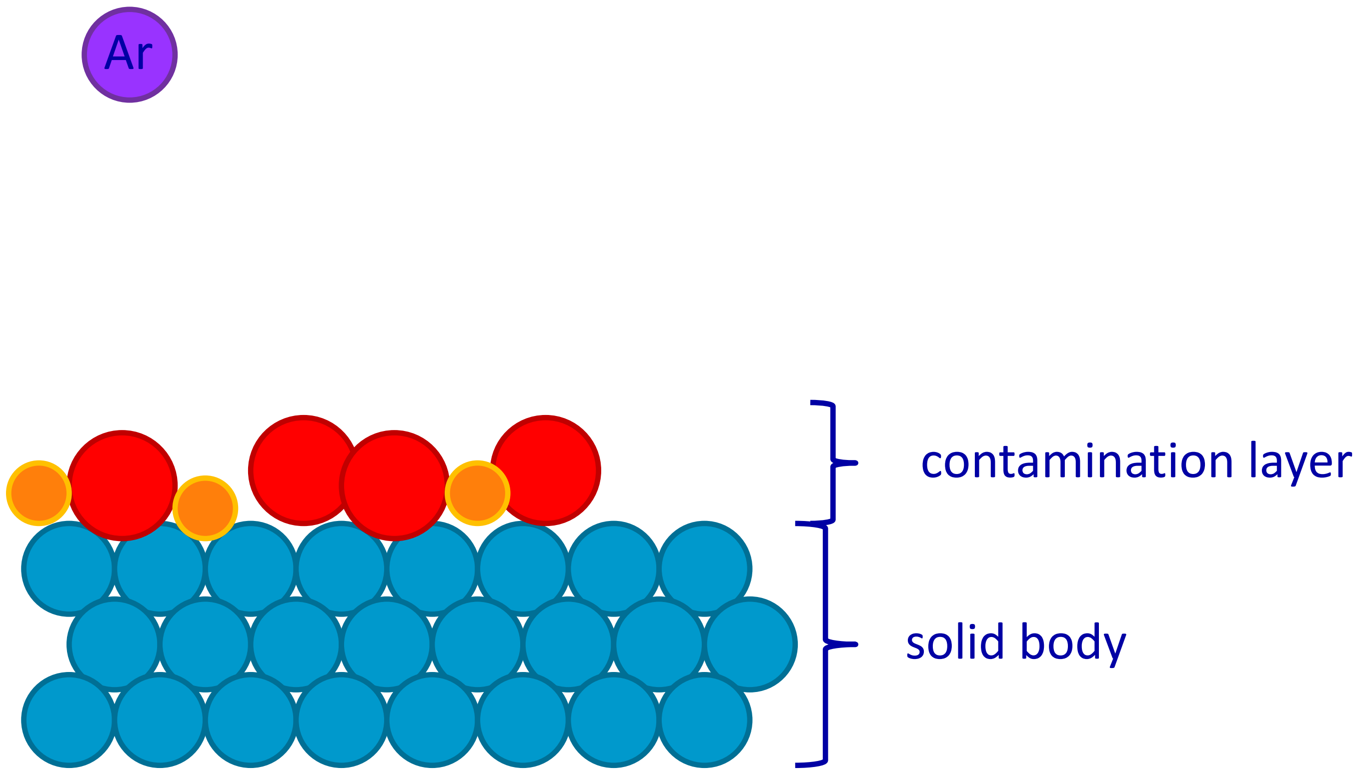
advantages:

- no residues
- applicable even for complex geometries
- no toxic materials needed
- no waste

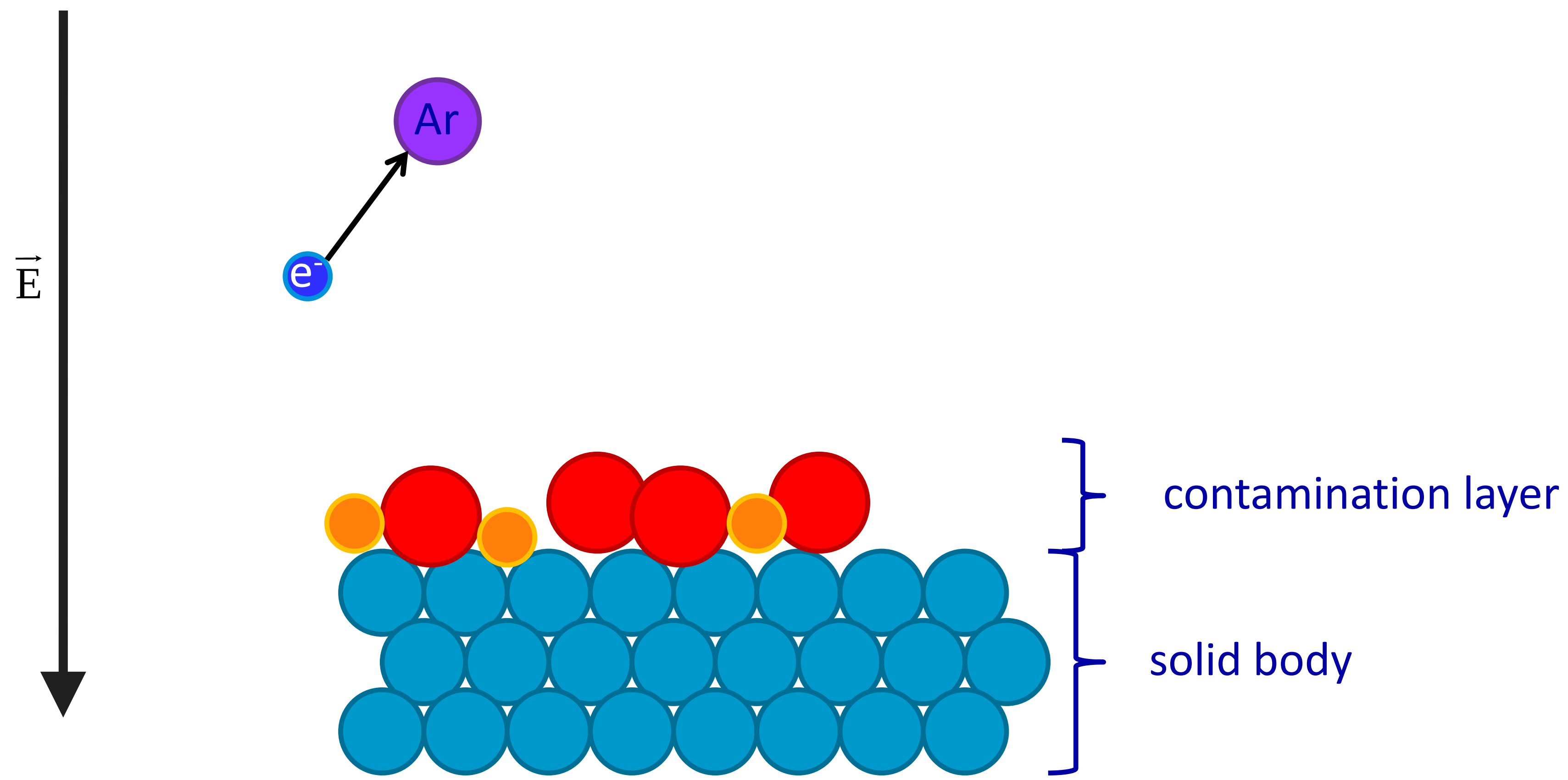
disadvantage:

- vacuum needed

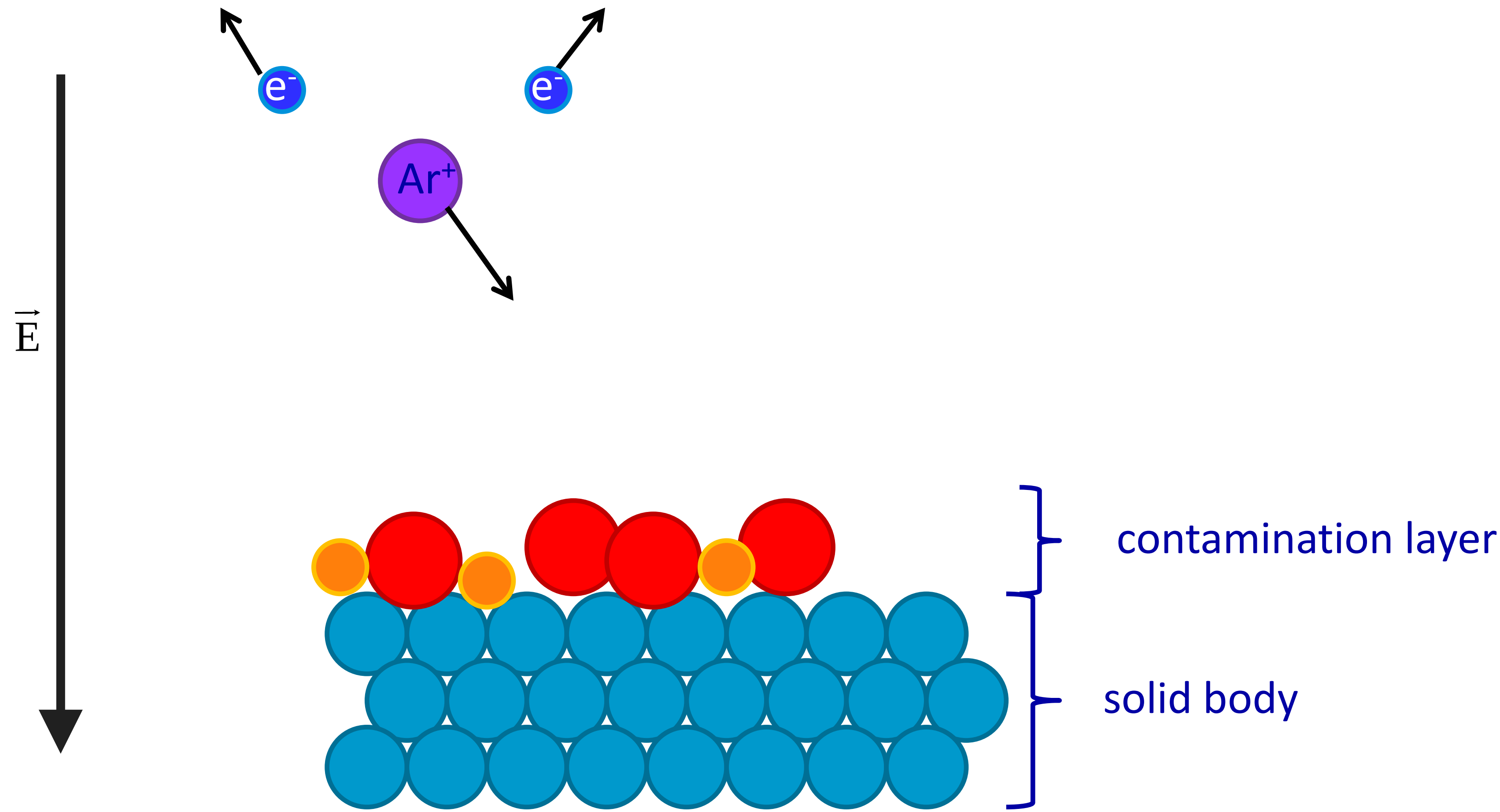
Sputtering



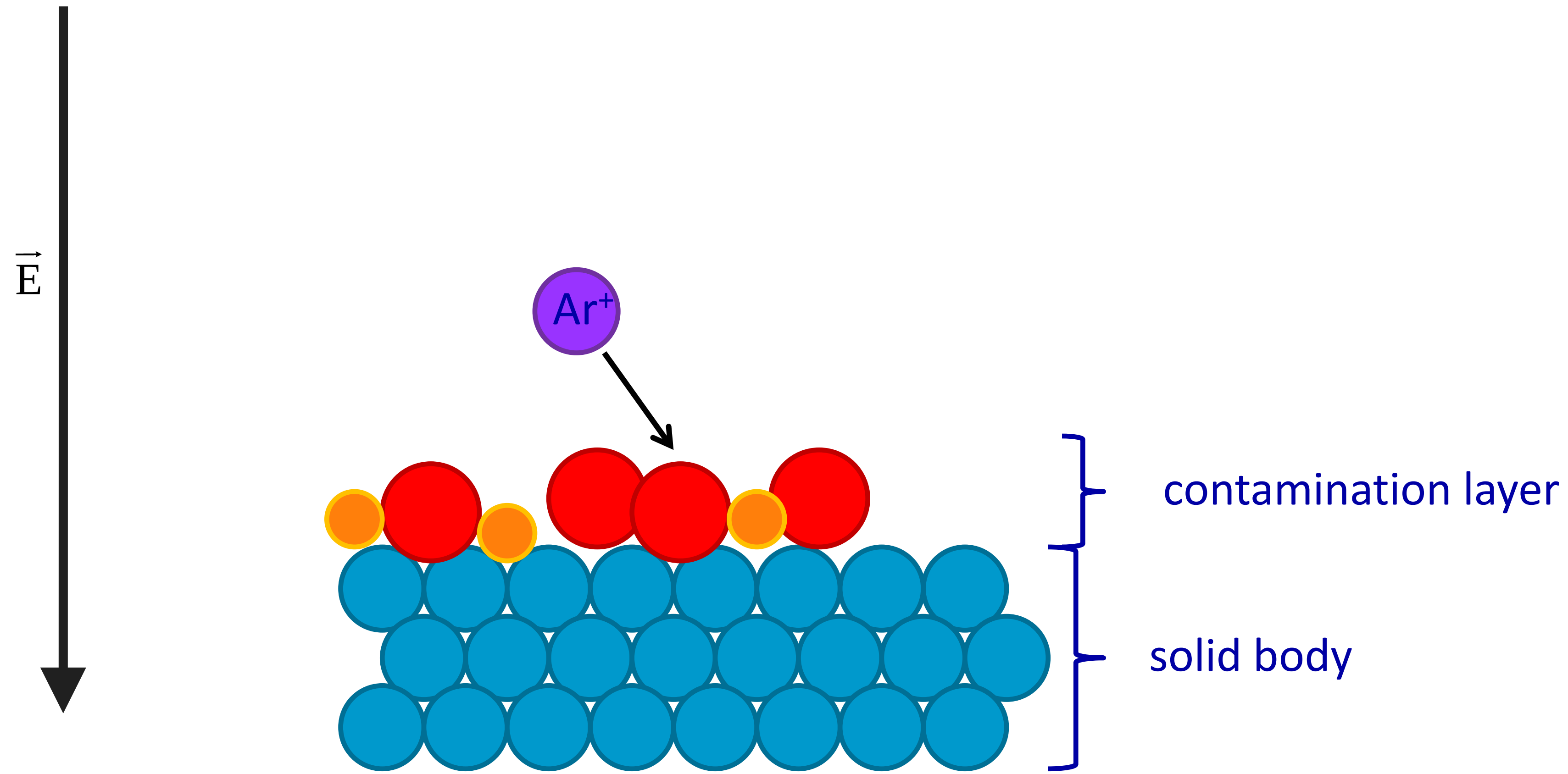
Sputtering



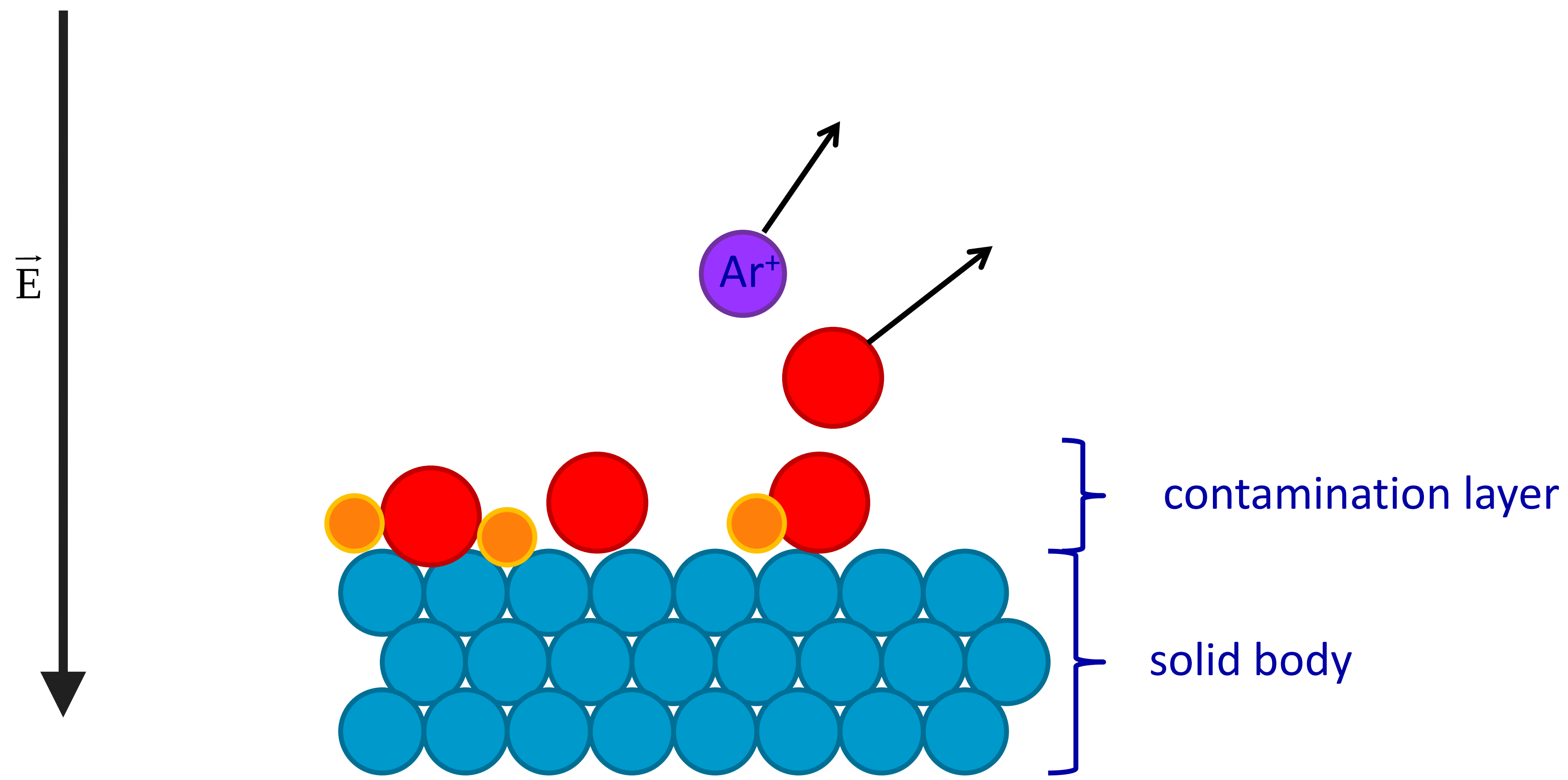
Sputtering



Sputtering



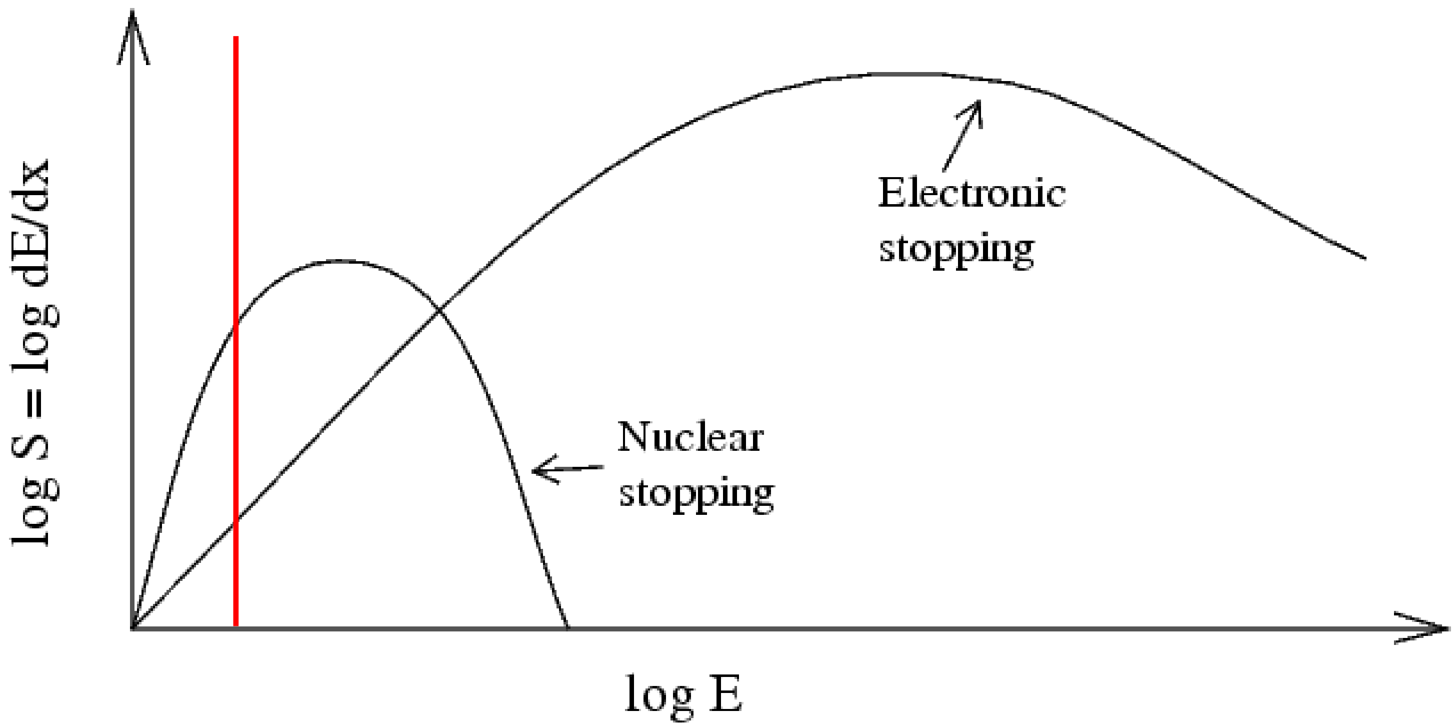
Sputtering



Interactions of Ions with Solids

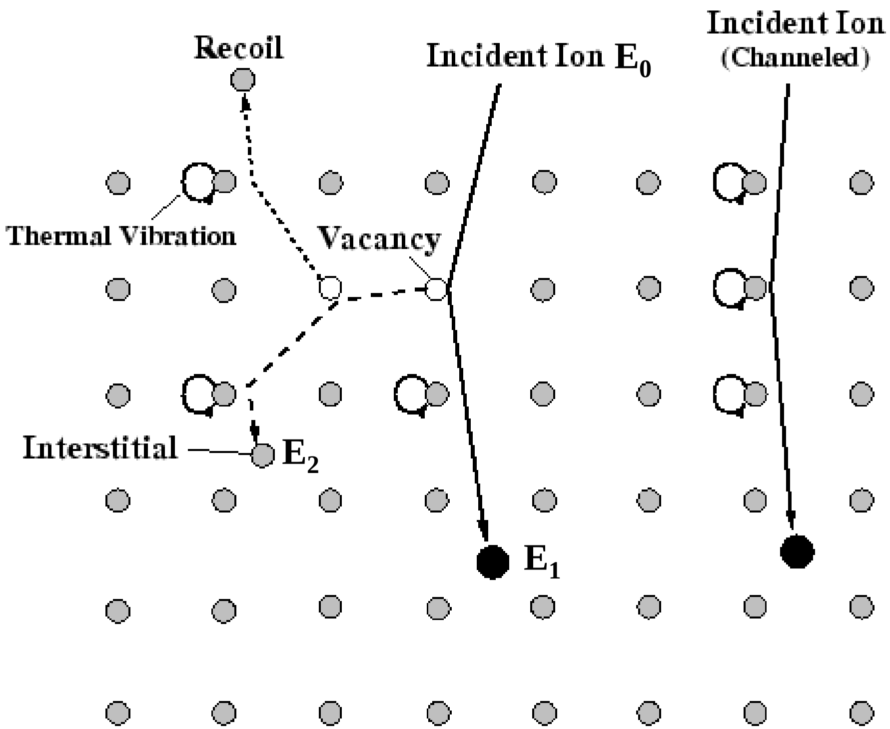
- simple reflection of the incident ion
- creation of secondary electrons
- sputtering of surface atoms
- implantation of the incident ions in a buried layer at the end of the range

Interaction of Ions with Solid Matter



Ratio between nuclear and electronic stopping power

Energy Transfer from Ion to Target



nuclear stopping of ions in solids

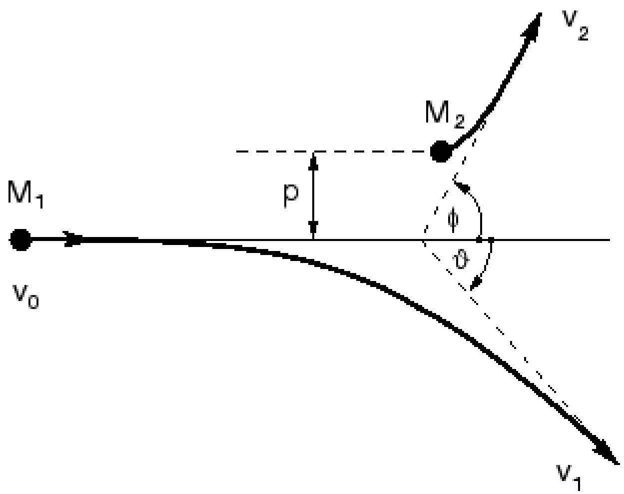
$E_2>E_d$	single displacement occurs
$E_1>E_d$ and $E_2>E_d$	multiple displacements occur
$E_2<E_d$	phonon dissipation
$E_1<E_d$, $E_2>E_d$ and $Z_1=Z_2$	replacement collision and phonon dissipation
$E_1<E_d$, $E_2>E_d$ and $Z_1 \neq Z_2$	Z_1 becomes interstitial atom

displacement energy: E_d

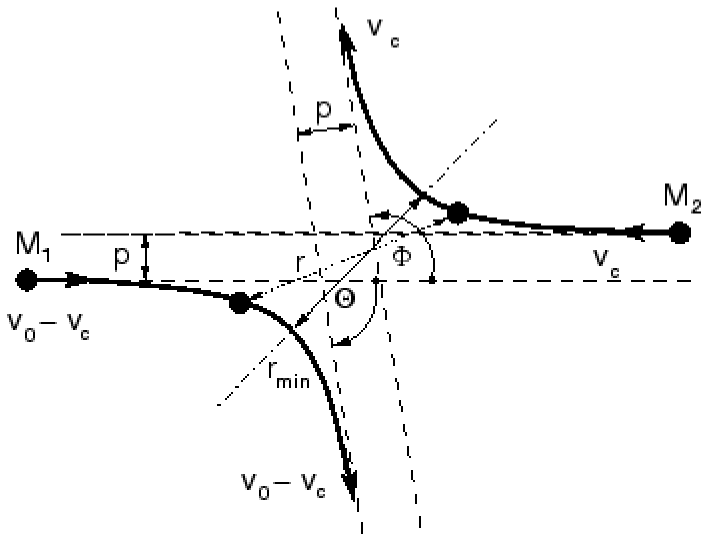
$E_0=E_1+E_2$

Binary Collision Approximation

Laboratory System



Center–of–Mass System



$$\frac{1}{2}M_1 v_0^2 = \frac{1}{2}M_1 v_1^2 + \frac{1}{2}M_2 v_2^2$$

$$M_1 v_0 = M_1 v_1 \cos\varphi + M_2 v_2 \cos\phi$$

$$0 = M_1 v_1 \sin\varphi + M_2 v_2 \sin\phi$$

$$M_1 v_0 = (M_1 + M_2) v_c$$

$$E_c = \frac{M_2}{M_1 + M_2} E_0$$

$$M_c = \frac{M_1 M_2}{M_1 + M_2}$$

Binary Collision Approximation

scattering angle of the center of mass system

$$\Theta(p,E_c)=\pi-2p\int_{r_{\min}}^{\infty}\frac{dr}{r^2\sqrt{1-\frac{V(r)}{E_c}-\frac{p^2}{r^2}}}$$

direction after the hit of the incident ion

$$\tan\vartheta=\frac{\sin\Theta}{\frac{M_1}{M_2}+\cos\Theta}$$

direction after the hit of the target atom

$$\cos\phi=\sin\frac{\Theta}{2}$$

energy of the target atom

$$\Delta E=\frac{4M_1M_2}{(M_1+M_2)^2}E_0\sin^2\frac{\Theta}{2}$$

Interaction Potential

Coulomb Potential: $$V(r) = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{Z_1Z_2e^2}{r}$$

screening of the nucleus surrounding electrons taken into account :

$$V(r) = \frac{1}{4\pi\varepsilon_0}\frac{Z_1Z_2e^2}{r}\Phi(r)$$

$\Phi(r)$ screening function

Interaction Potential

The following contributions have to be considered for the potential:

- The classical terms of Coulomb interaction between
  - the nuclei of the particles
  - the electrons of the particles
  - the nuclei and the electrons of the other particle
- Quantum mechanical corrections due to the Pauli principle in the overlapping area and the interaction energy of electrons

Universal Screening Potential

universal screening potential:

$$\Phi(x) = 0.1818e^{-3.2x} + 0.5099e^{-0.9423x} + 0.2802e^{-0.4028x} + 0.02817e^{-0.2016x}$$

x dimensionless reduced radius

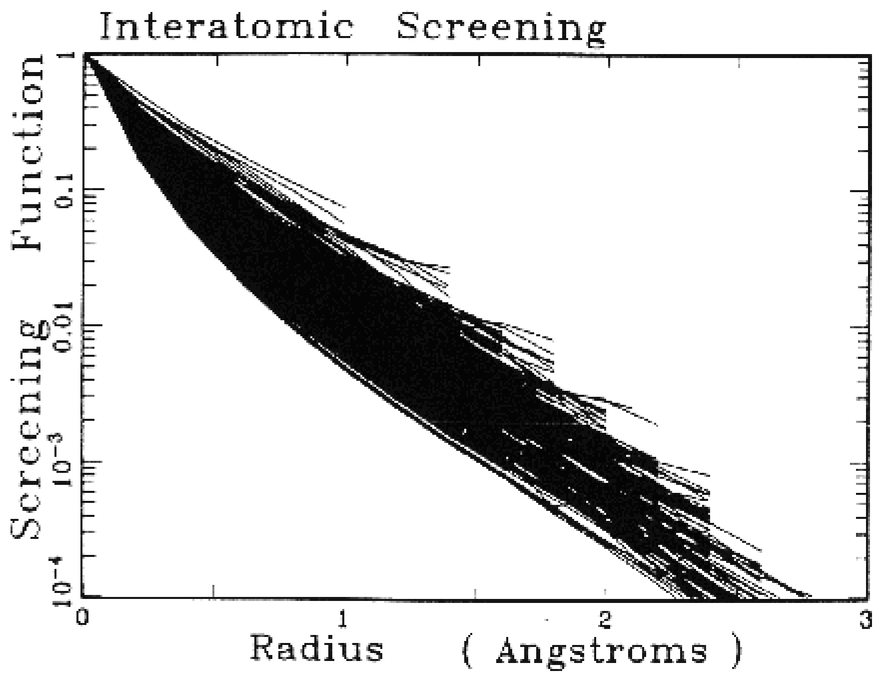
$$x = \frac{r}{a_I}$$

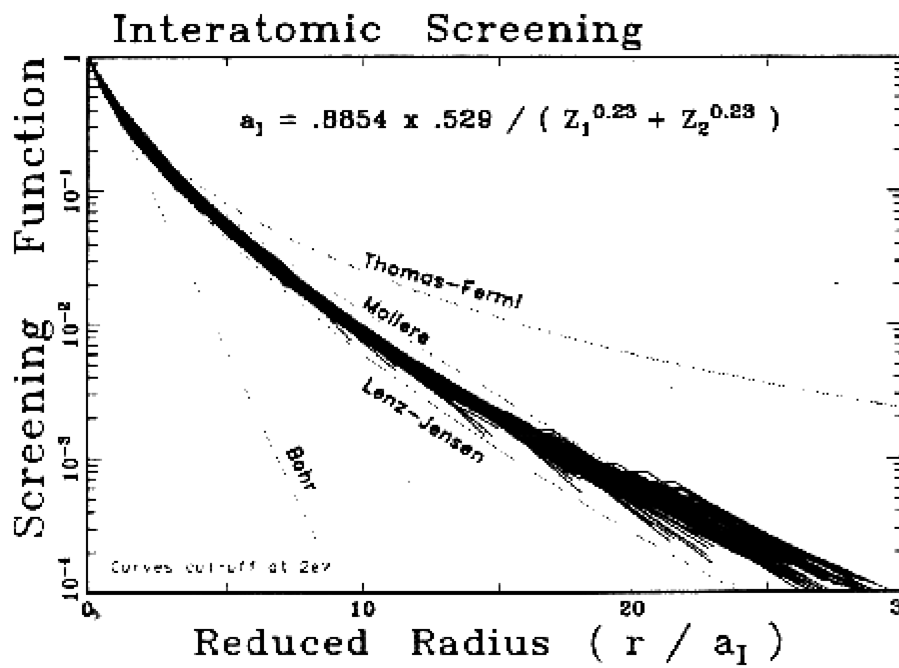
scaling length suggested by Ziegler, Biersack and Littmark, depending on the charges of the involved atoms

$$a_I = 0.8854 \frac{a_0}{Z_1^{0.23} + Z_2^{0.23}}$$

$$[a_I] = 10^{-10} m$$

Screening Function





screening potential with radius for many atom pairs

screening potential with reduced radius for many atom pairs

Binary Collision Approximation

scattering angle of the center of mass system

$$\Theta(p,E_c) = \pi - 2p \int_{r_{\min}}^{\infty} \frac{dr}{r^2 \sqrt{1 - \frac{V(r)}{E_c} - \frac{p^2}{r^2}}}$$

direction after the hit of the incident ion

$$\tan \vartheta = \frac{\sin \Theta}{\frac{M_1}{M_2} + \cos \Theta}$$

direction after the hit of the target atom

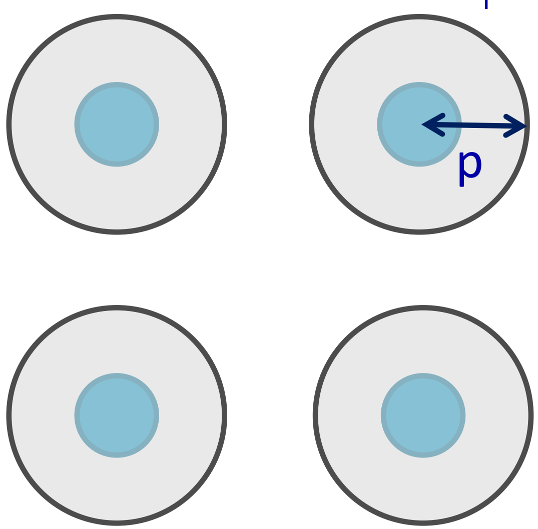
$$\cos \phi = \sin \frac{\Theta}{2}$$

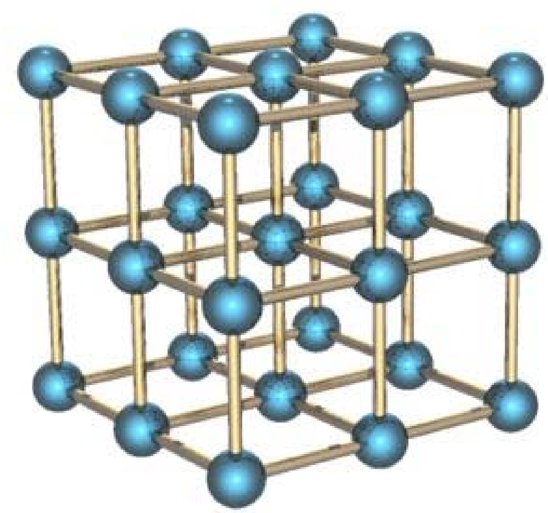
energy of the target atom

$$\Delta E = \frac{4 M_1 M_2}{(M_1 + M_2)^2} E_0 \sin^2 \frac{\Theta}{2}$$

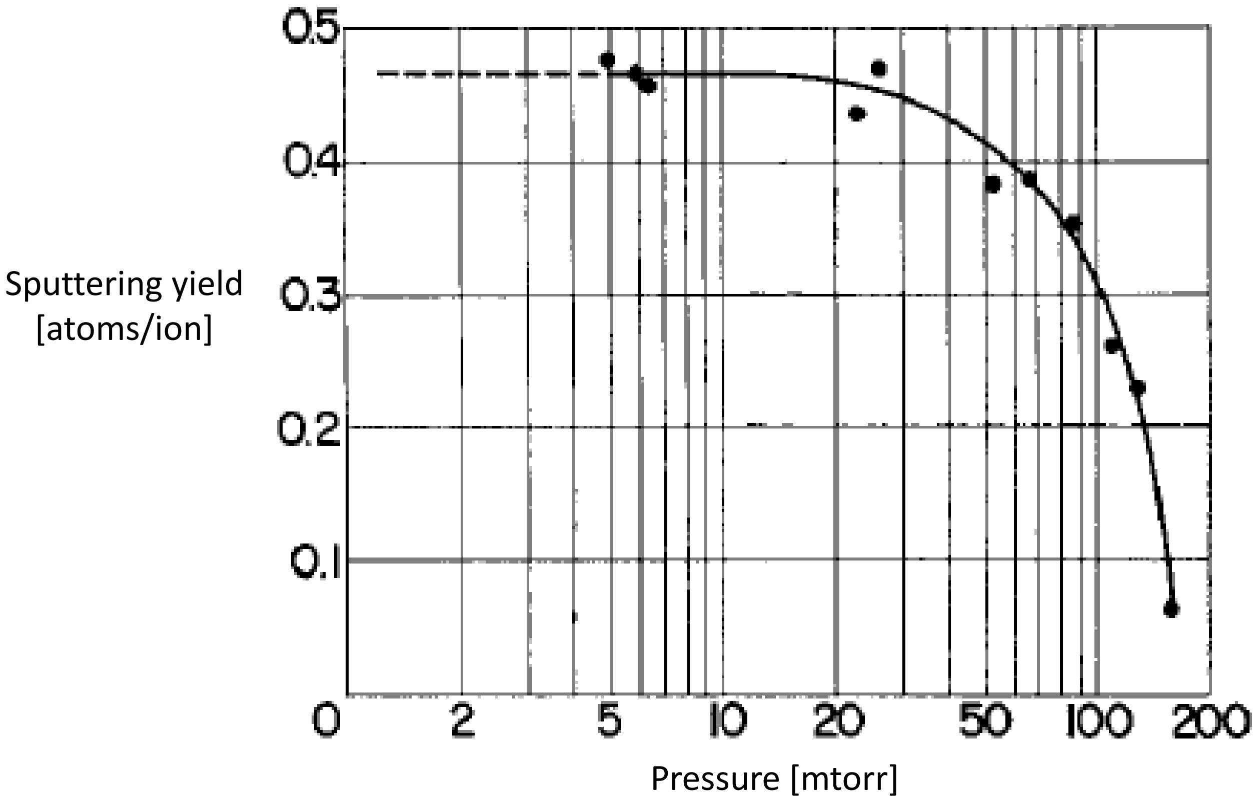
Probability of Displacing an Atom

displacement energy threshold for Ni	$\Delta E = E_d = 17eV$
mass Ni	$M_{Ni} = 26.982u$
mass Ar	$M_{Ar} = 39.948u$
energy of incoming ion	$E_0 = 150eV$
$\sin^2(\Theta/2)$	>0.228
impact parameter p	$<1.14 \cdot 10^{-10}m$
lattice parameter a	$3.52 \cdot 10^{-10}m$
probability of hitting an ion with more than the displacement energy threshold	**33%**



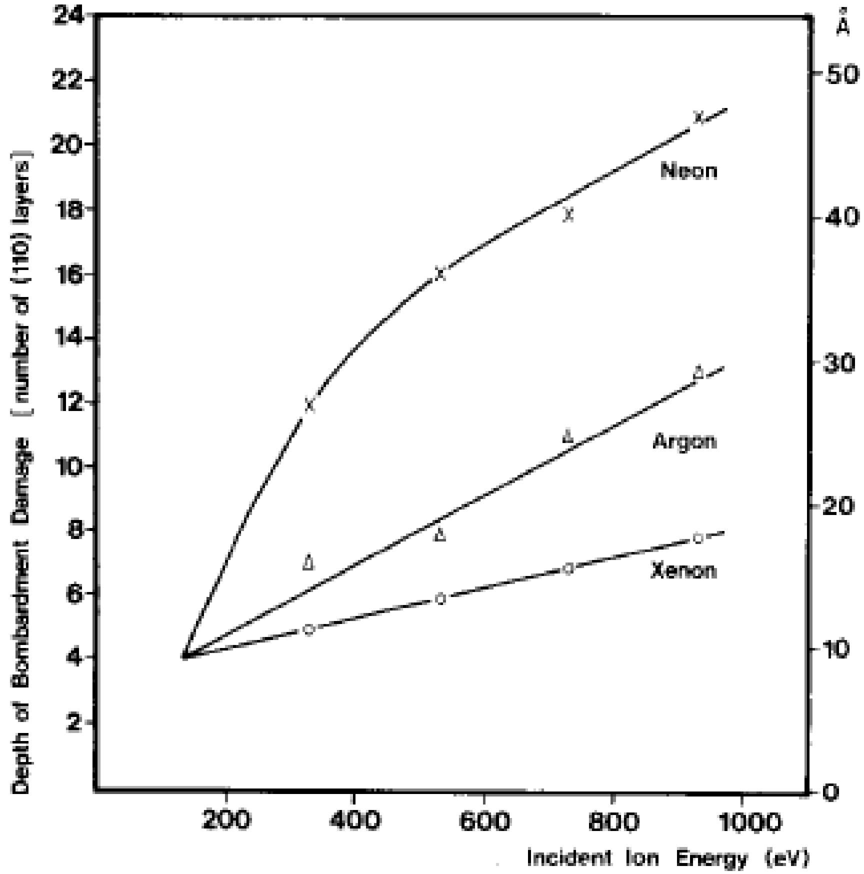


Experimental Sputtering Yield



Sputtering yields of nickel at 150eV ion energy vs argon gas pressure

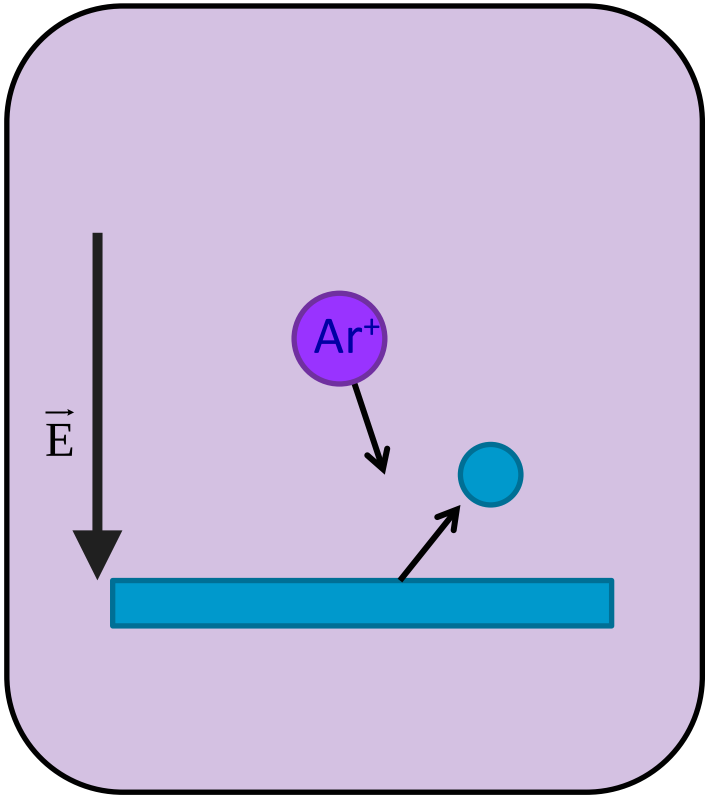
Depth of Damage



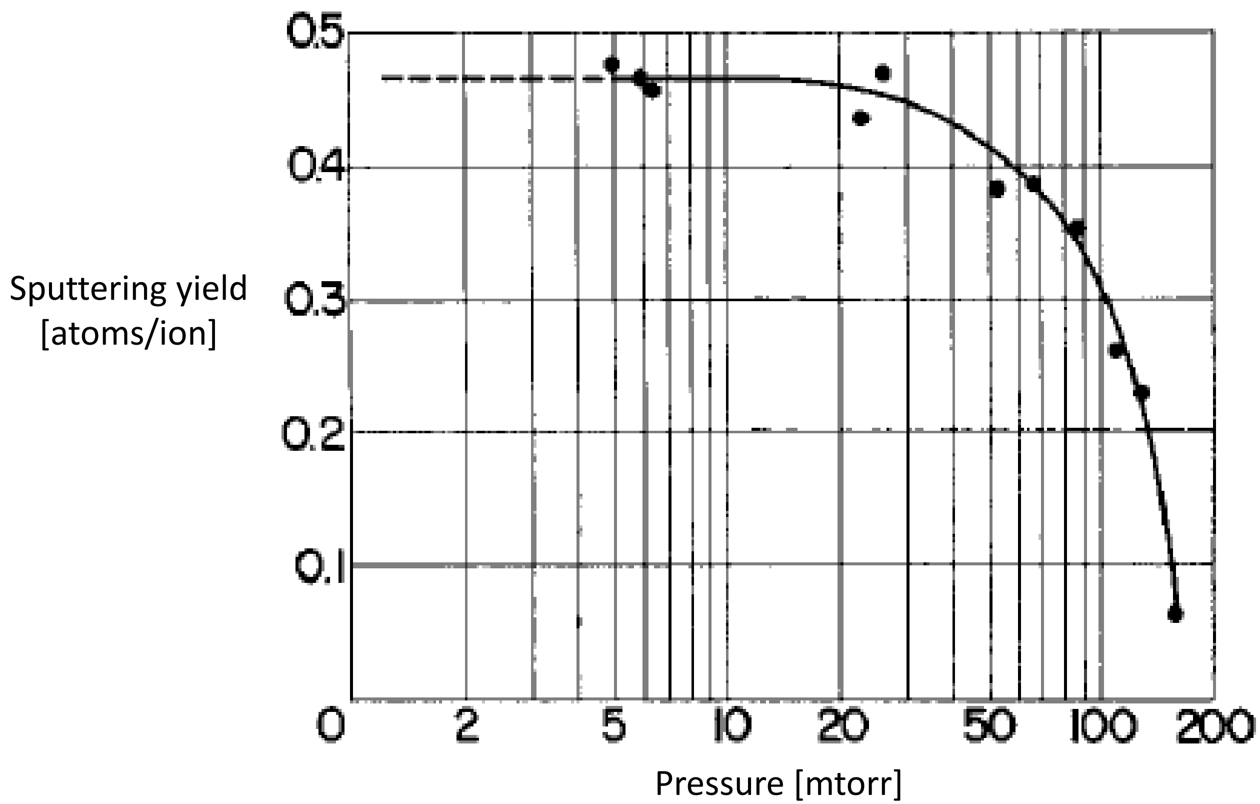
The depth of damage caused to tungsten following bombardment with low energy neon, argon and xenon ions.

Parameters of Sputtering in a Glow Discharge

- material of the target
- type of gas
- pressure of gas
- electrical parameters
- temperature of the target



Pressure



Sputtering yields of nickel at 150eV ion energy vs argon gas pressure

Measurement of the Sputtering Rate

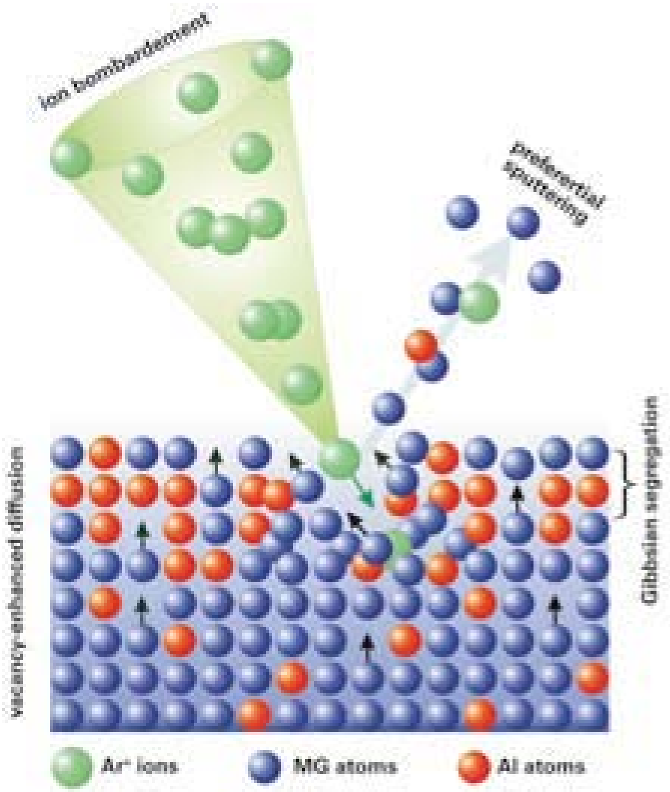
sputtering rate R

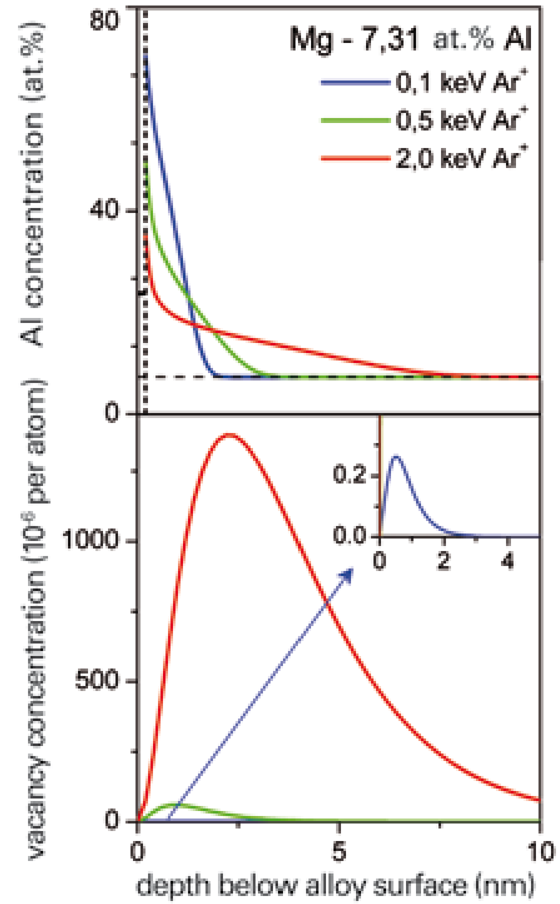
$$R = \frac{h}{t} = \frac{\text{depth of removed material}}{\text{time}}$$

Measuring R is difficult because:

- removal of only a few layers
- variations of the gas pressure
- the composition of the gas
- the incident ion flux
- problems due to difficulties in measuring the depth
- compositional changes of the target
- degradation

Compositional Changes of the Target





preferential sputtering

Possible Measurements

sputtering yield Y

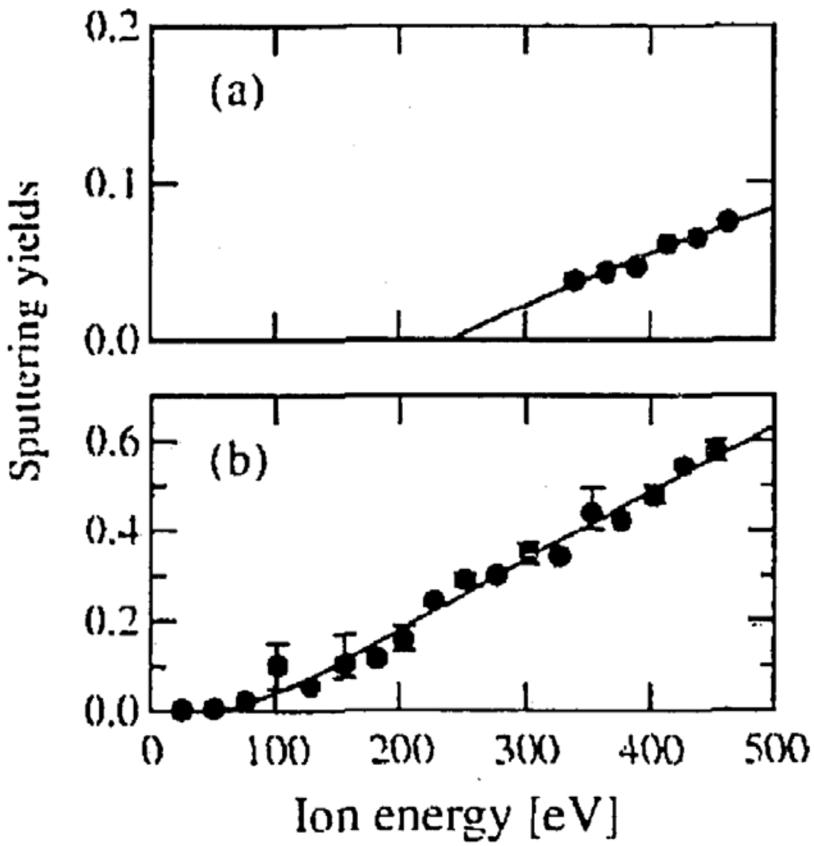
$$Y = \frac{N_s}{N_i} = \frac{\text{number of removed atoms from the target}}{\text{number of injected ions}}$$

- unit: atoms/ ion or grams/ion
- assumption for the calculation of N_i: one argon ion is generated by one electron
- assumption: pure material without contamination

$$N_i = \frac{I \cdot t}{Q_{e^-}} = \frac{\text{current} \cdot \text{time}}{\text{charge of e}^-}$$

$$N_S = \frac{\Delta m \cdot N_A}{M_{mol}} = \frac{\text{change of mass} \cdot \text{Avogadro constant}}{\text{molar mass}}$$

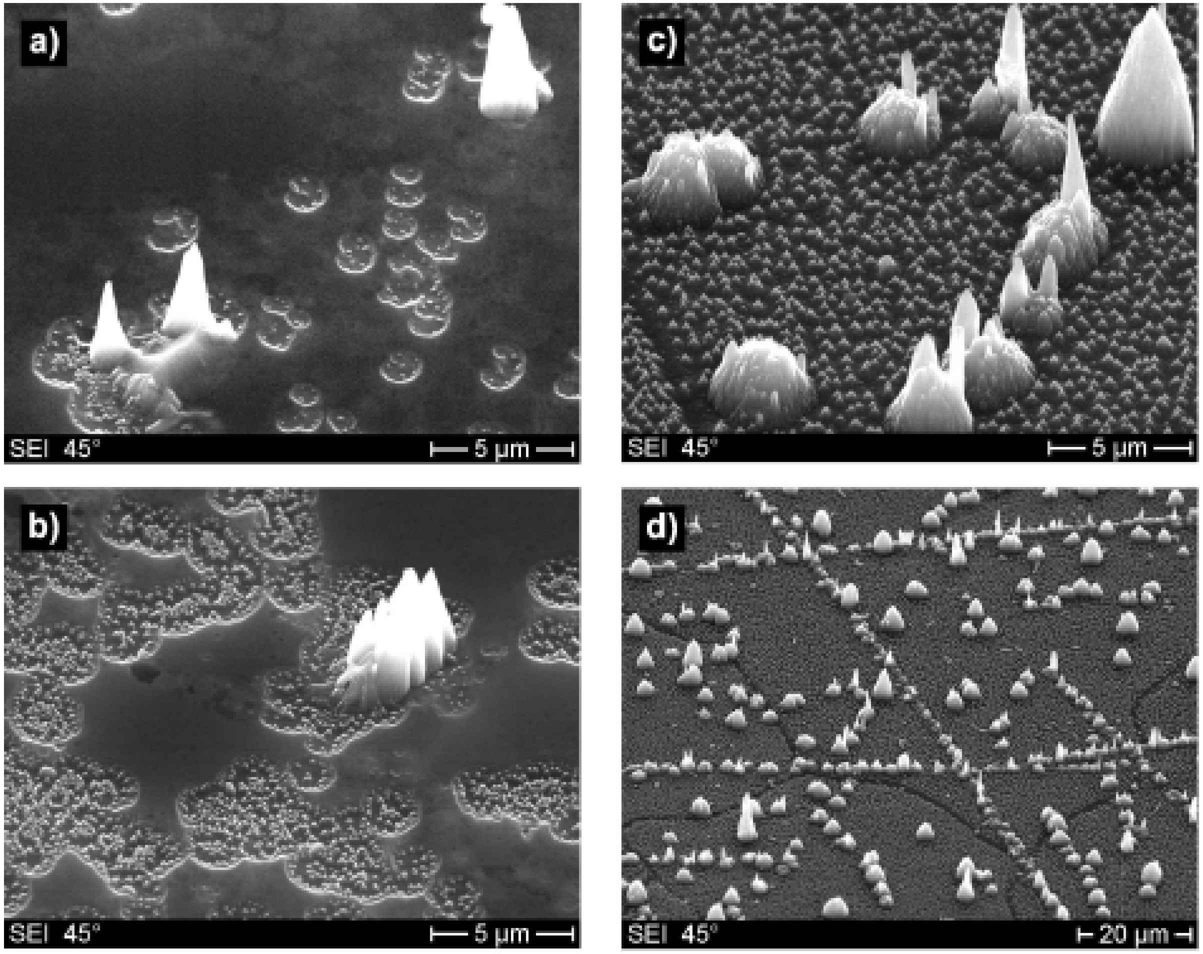
Sputtering Yield



Sputtering yield of MgO by a) He and b) Ar ion beams.

The solid lines correspond to the fitted function to the measured data.

Sputtered Aluminum Samples



SEM micrographs of sputtered aluminum covered with an oxide layer (0.2mbar Ar, 400°C) after a) 30min, b) 45min, c) and d) 60min

THE DEVIL IS IN THE DETAILS