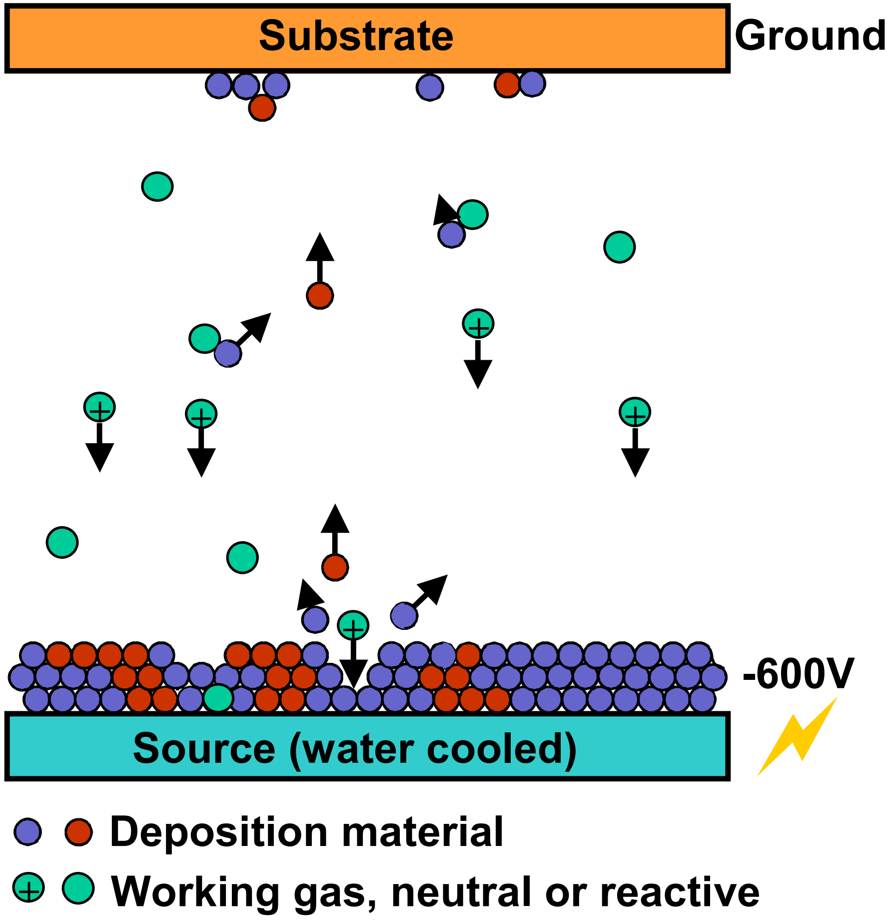
Repetition: Sputtering

Elementary Processes:

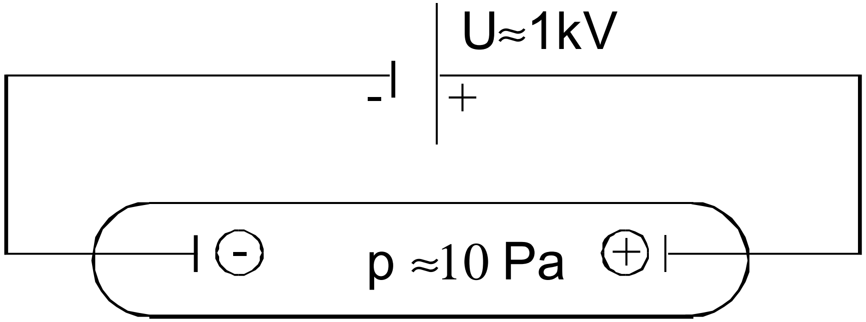


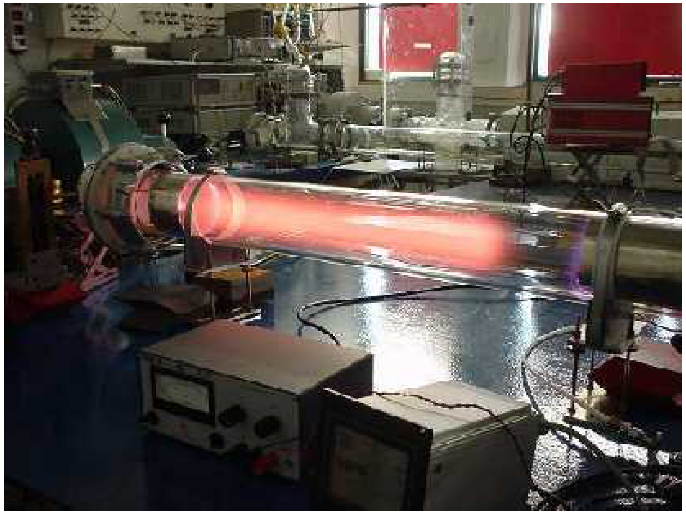
Characteristics:

- *Solid source, i. e. arbitrary source geometry*
- *Low deposition temperature*
- *High deposition rates can be reached*
- *Wide parameter field*
- *Coating composition = source composition*
- *Good coating adhesion*
- *Interesting film properties*

Repetition: Gas Discharge

Experiment:



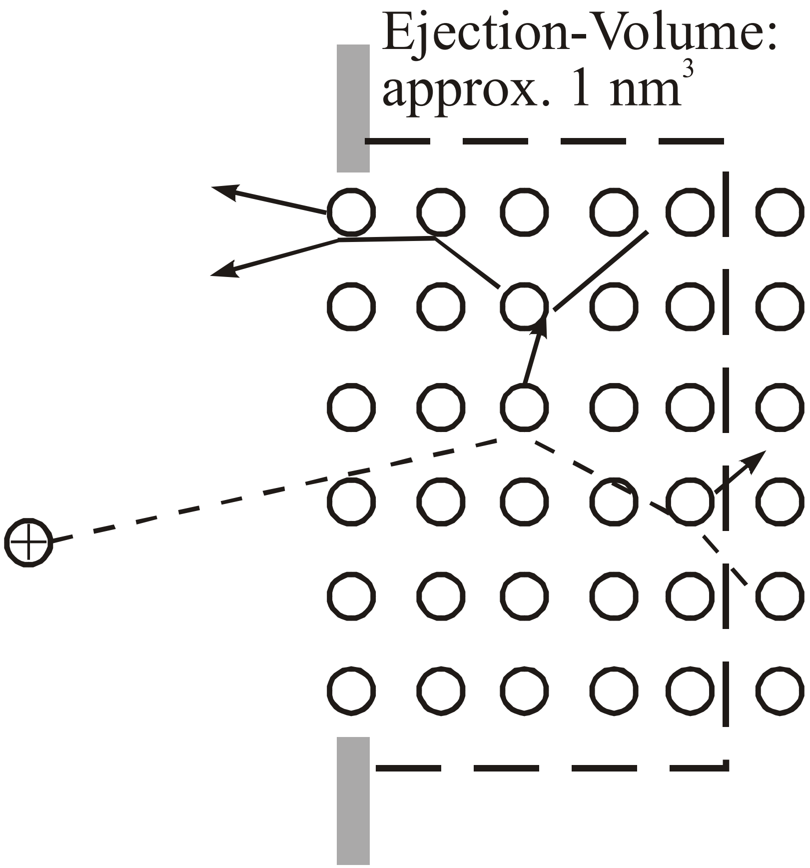


Criteria for a self sustained discharge:

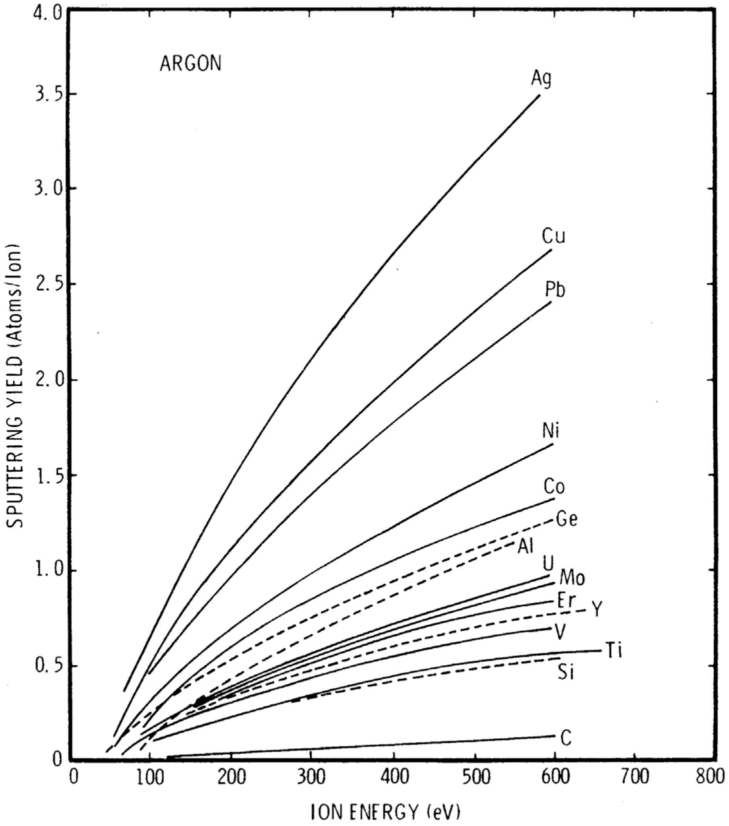
It is possible to sustain a gas discharge if.:

- the mean free path of electrons is long enough to ionize neutral gas particles
  → diluted gas necessary
- if there are enough gas molecules to trigger a ionization cascade
  → no high vacuum possible or necessary

Repetition: Global Charakteristics

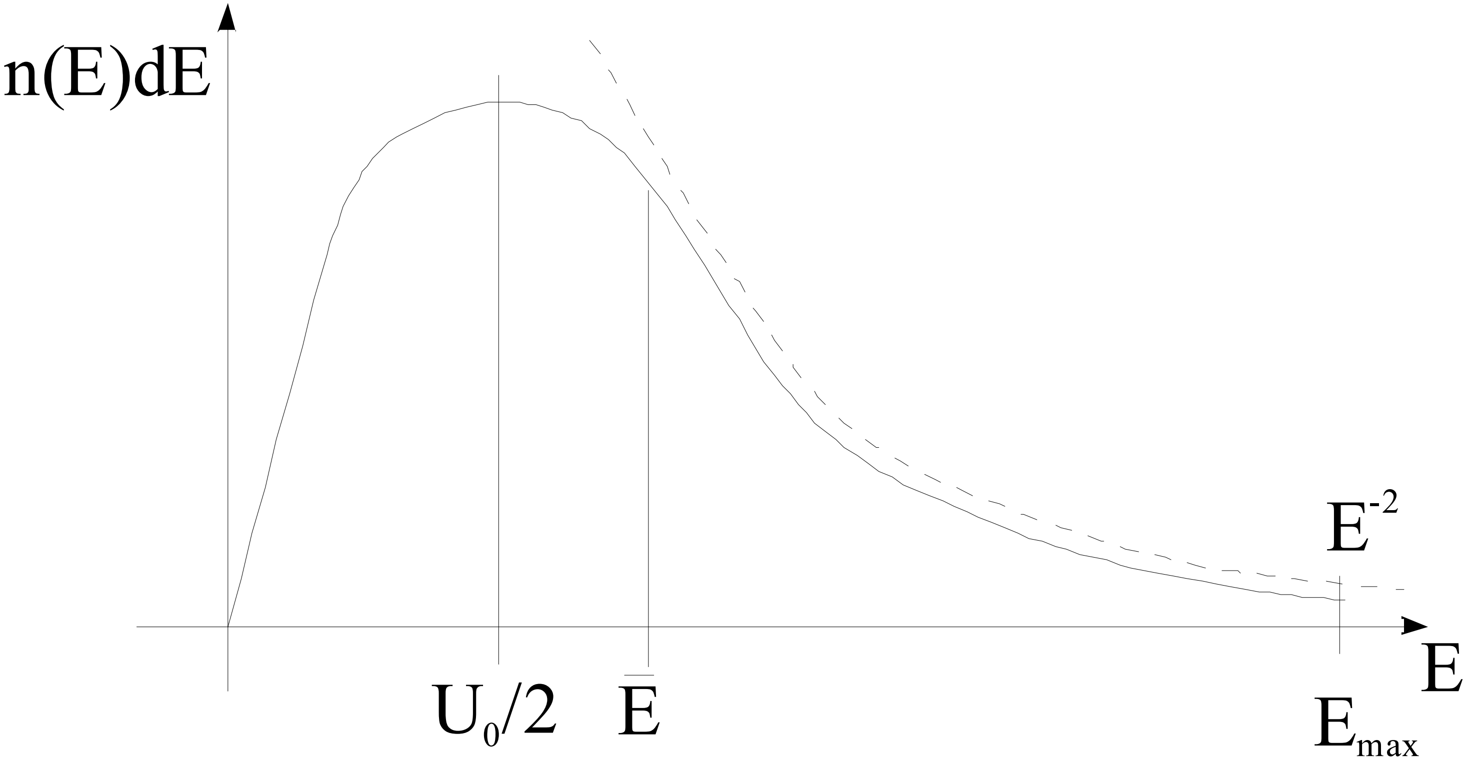


Ejection-Volume:
approx. 1 nm^3



$$\boxed{Y = 0{,}5 - 4}$$

Repetition: Energy Distribution

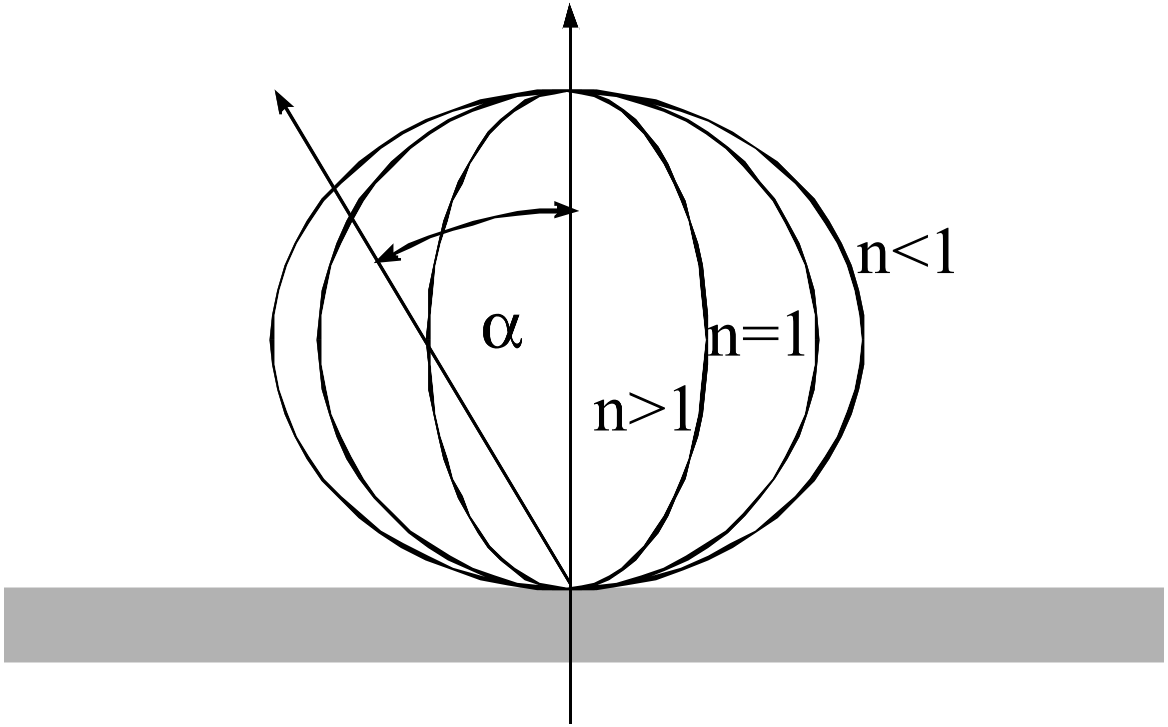


$$n(E)dE \propto \frac{E}{(E+U_0)^3}\,dE$$

E_{max} = Maximum energy, $E_{max} \propto E^{+}$

$\bar{E}$ = Average emission energy

Repetition: Angular Distribution

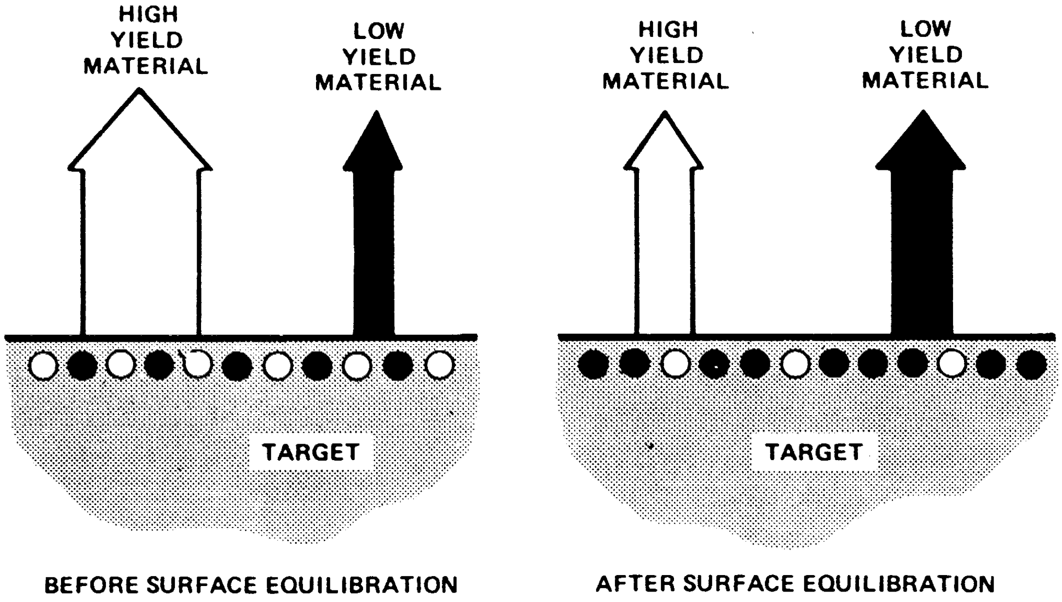


$$n(\alpha) \propto \cos^n \alpha$$

$n \leq 1$ E < 1 keV

$n > 1$ E > 1 keV

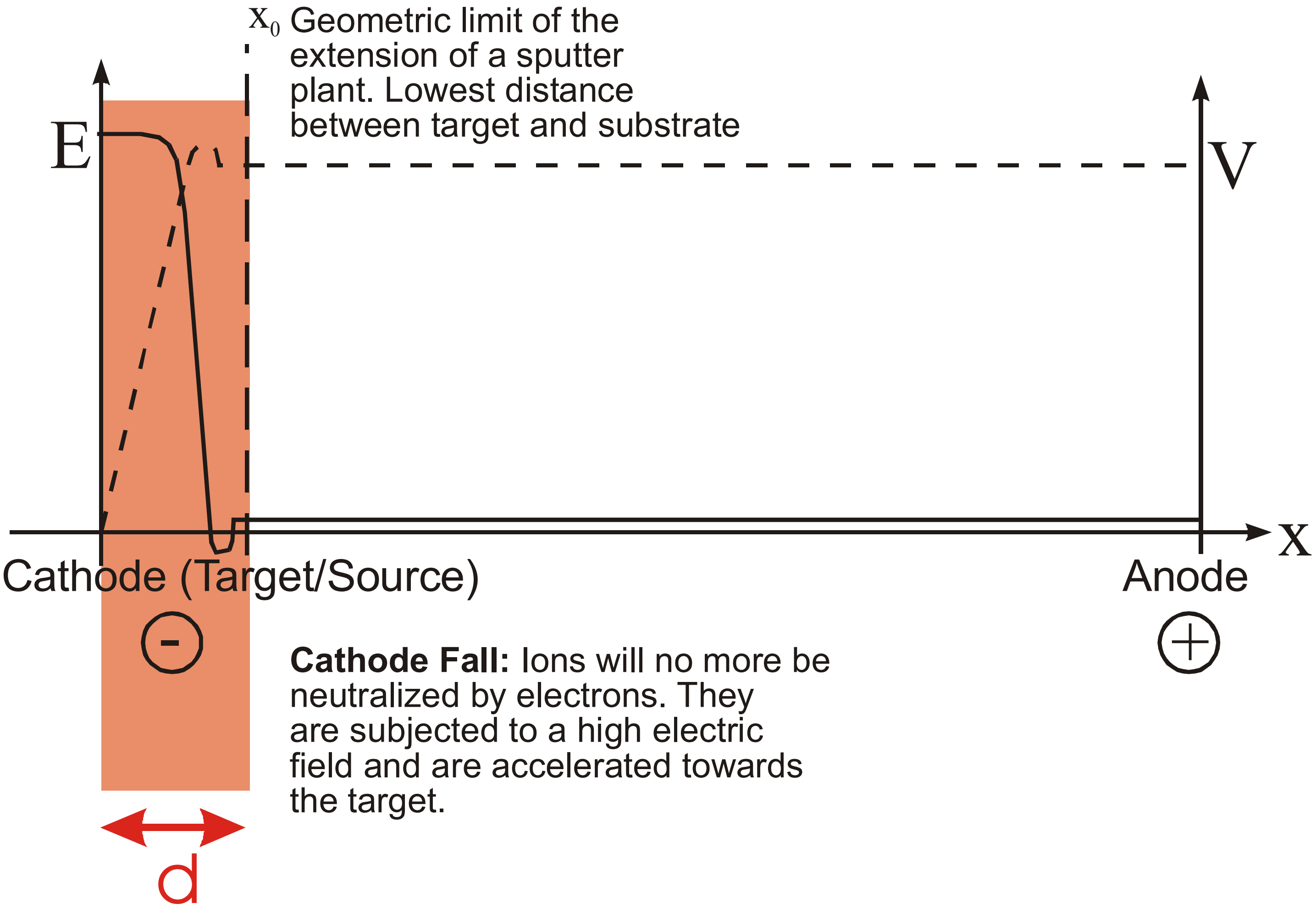
Repetition: Sputtering of Alloys



In the case of the homogenous distribution of the constituents the vapor composition is (after a transient regime) identical to the target composition.

Practical Aspects of Sputtering

Reduction of the Cathode Dark Space!



x_0 Geometric limit of the extension of a sputter plant. Lowest distance between target and substrate

Cathode Fall: Ions will no more be neutralized by electrons. They are subjected to a high electric field and are accelerated towards the target.

Modifications of the Diode Discharge

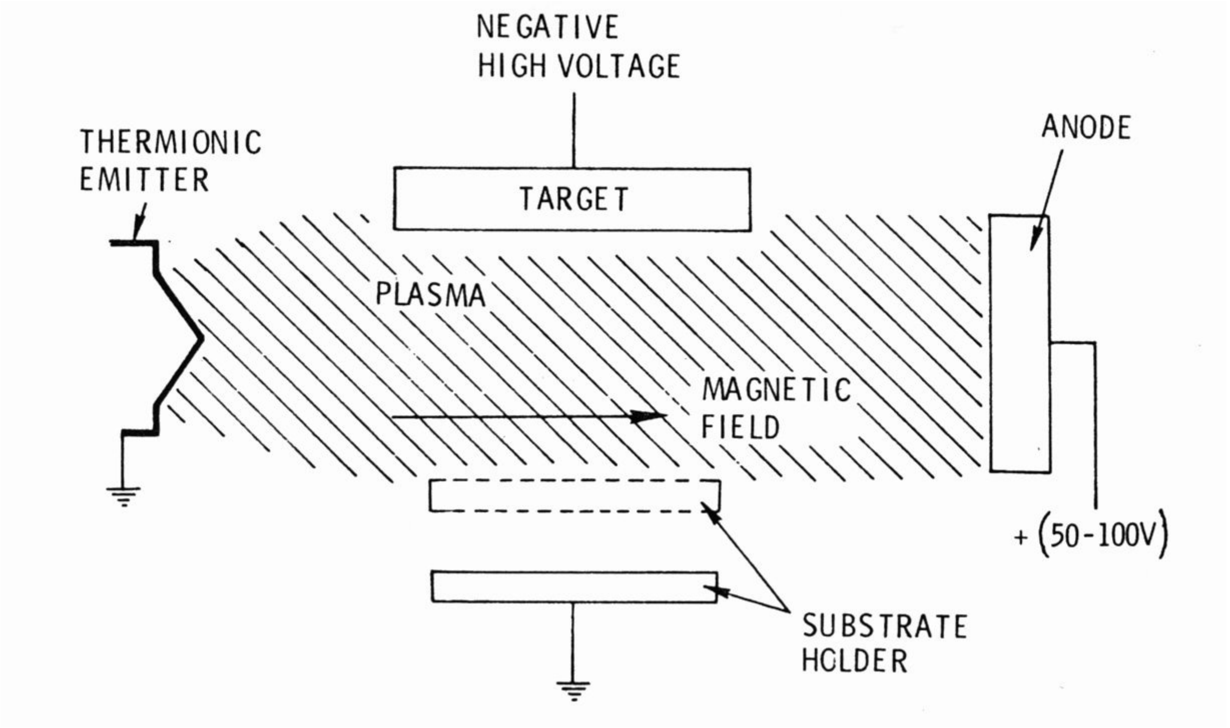
Aims:

a) Reduction of the cathode dark space
b) Increase of the ion current to increase erosion rate
c) Reduction of working gas pressure (purity)
d) Extension of the material palette
(Semiconductors/Insulators)

Methods:

- RF-sputtering: c/d
- Triode sputtering: a-c
- Magnetron sputtering a-c
- RF-Magnetron: a-d
- Ion beam sputtering: c; free choice of ion energy

Triode Discharge (Thermionic Emitter)



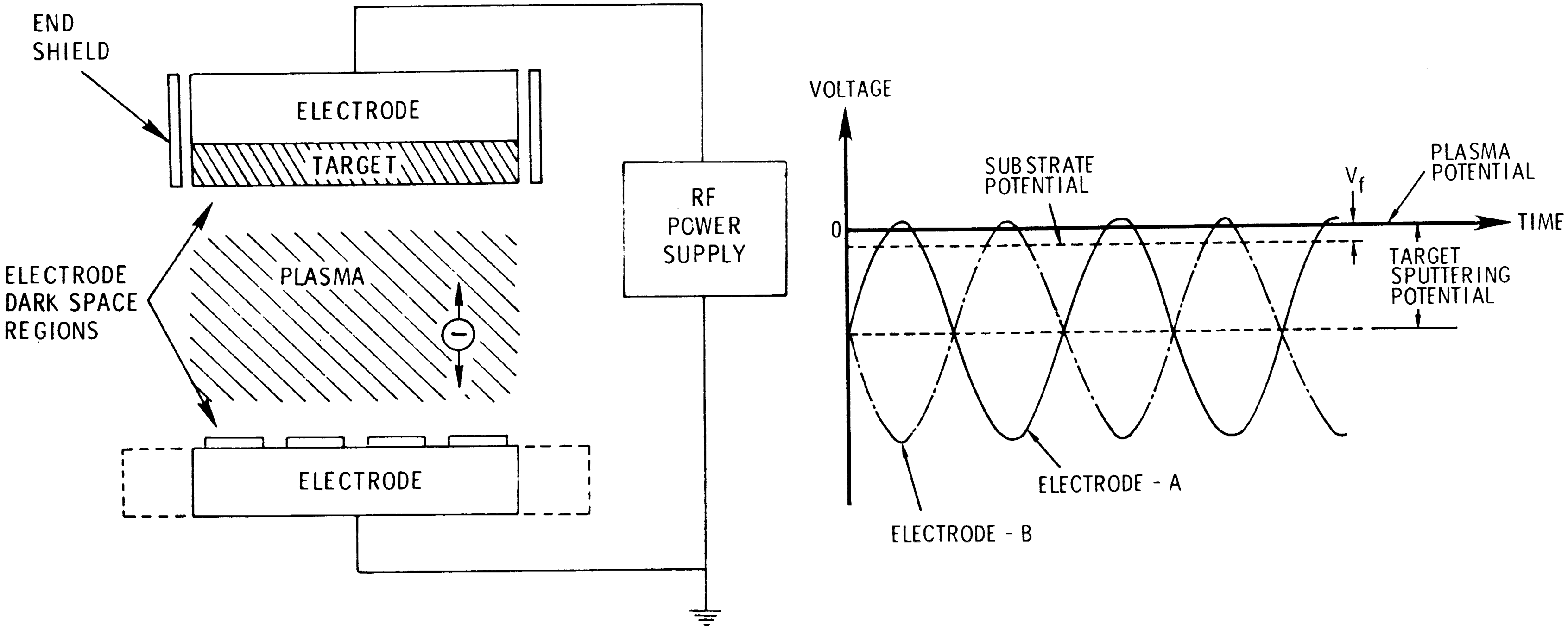
Electrons are injected by thermal emission

*** Higher electron density**

*** Reduction of working gas pressure**

*** But: filament can be unstable (coating/alloying)**

RF-Sputtering I



f = 13,56 MHz (free industry frequency)

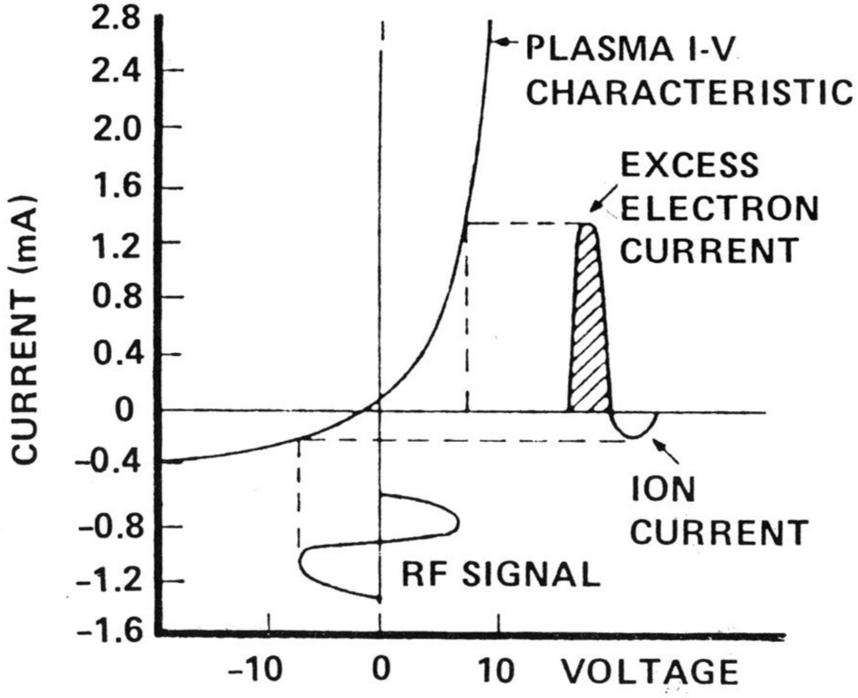
*** Higher electron density**

*** Sputtering of insulators possible**

*** Lower working gas pressure**

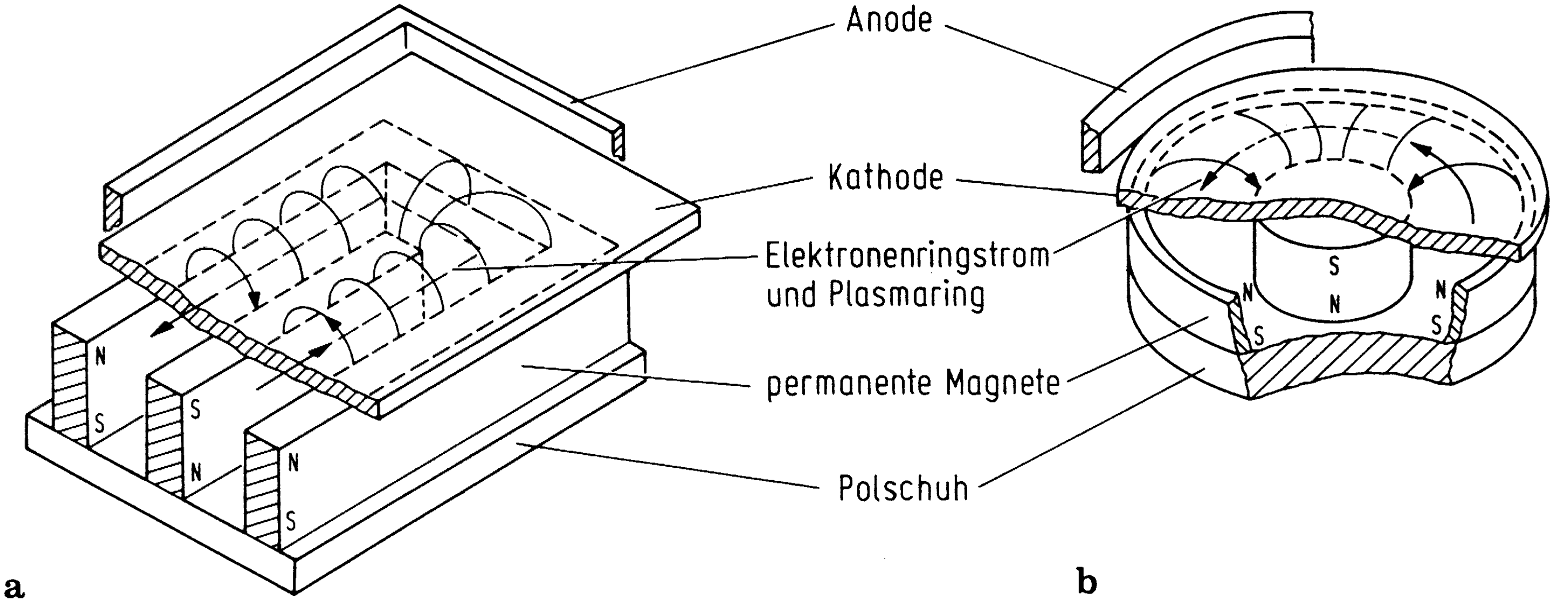
*** Different plasma characteristics (EEDF, plasma potential)**

RF-Sputtering II



An excess current is created by the higher electron mobility. It causes a negative net-voltage at the target, independent from its conductivity.

Magnetron-Sputtering, Fundamentals I



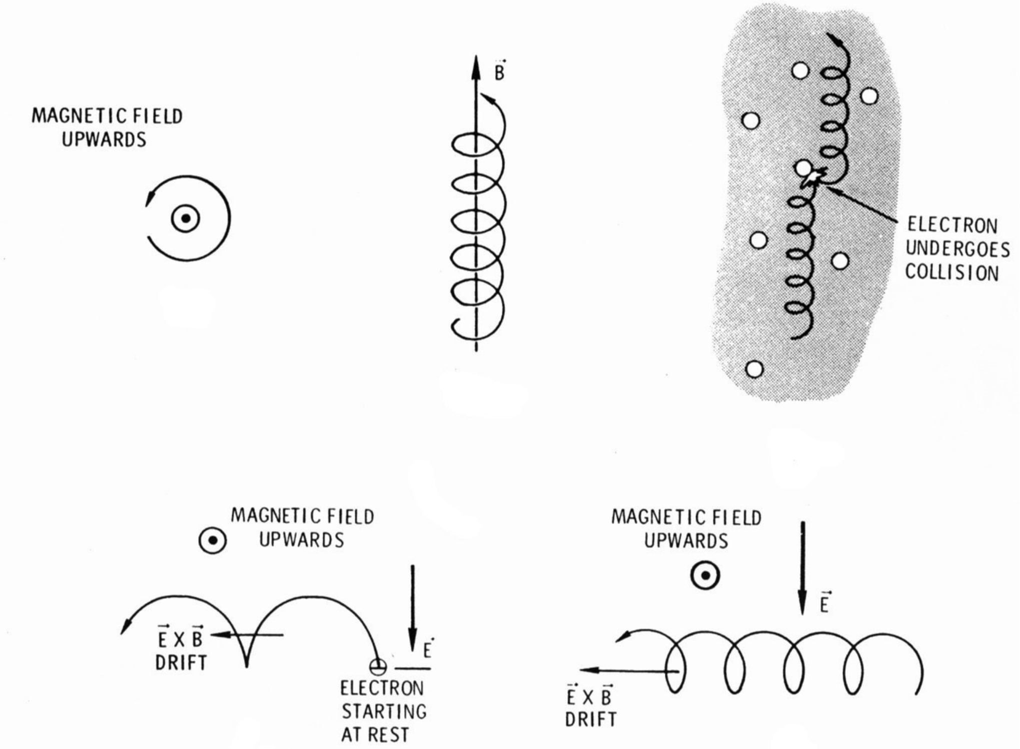
Permanent magnets below the target concentrate the plasma in the vicinity of the target.

*** Smaller dark space**

*** Higher ion density**

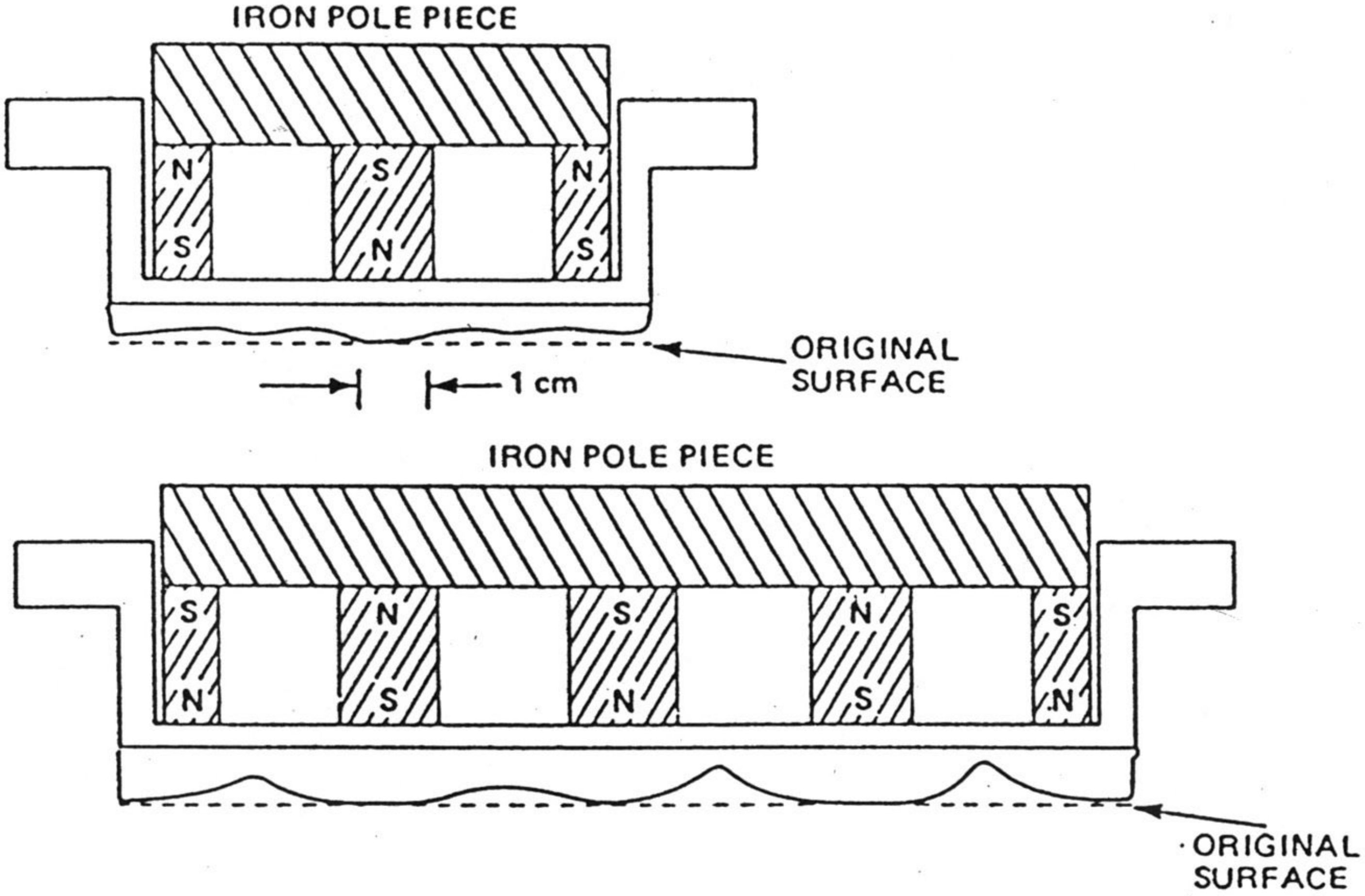
*** Reduction of working gas pressure**

Magnetron-Sputtering, Fundamentals II

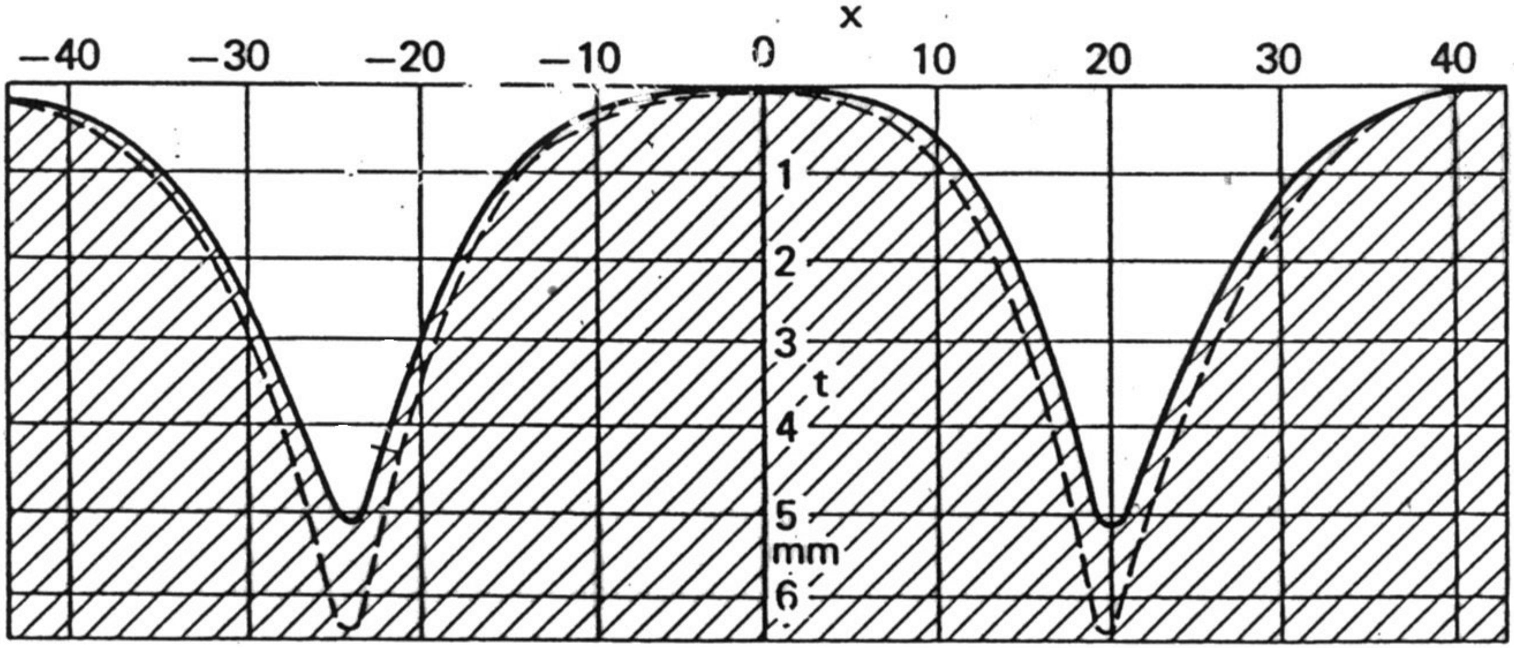


The magnetic field keeps the light electrons close to the target and forces them to helical trajectories (Lorentz-force). A single electron can therefore cause many more ionization events in the vicinity of the target.

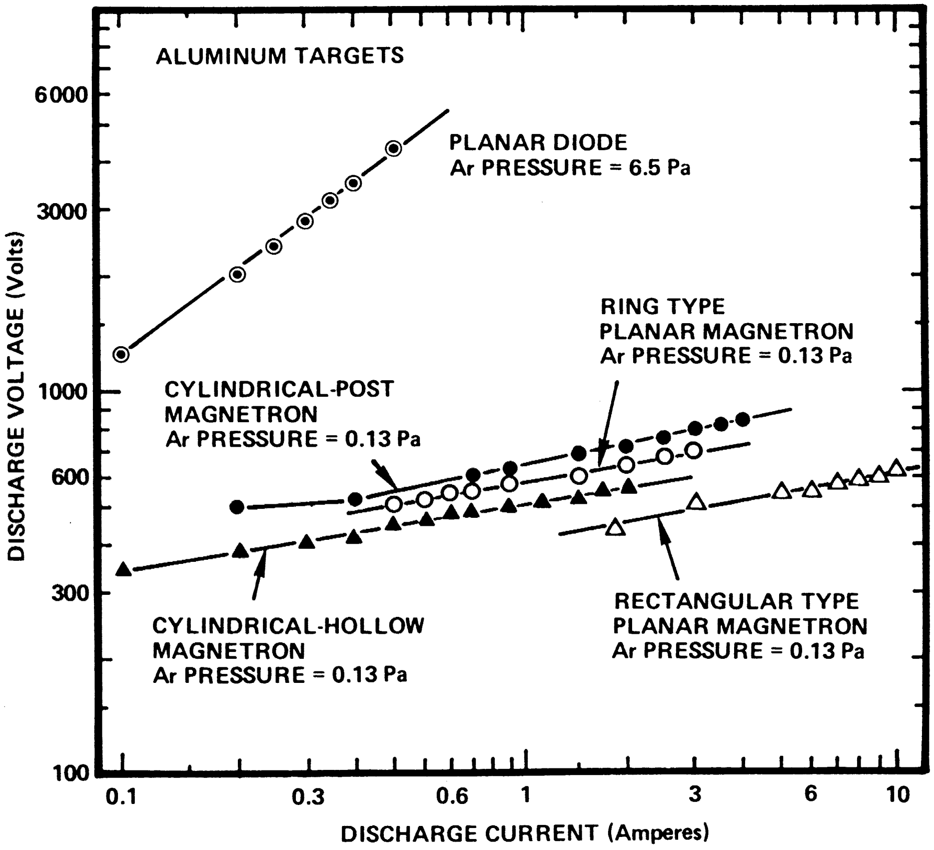
Magnetron-Sputtering: Magnetic Systems



Magnetron- Sputtering : Target Erosion



Magnetron- Sputtering : Characteristics



Empirical relation:

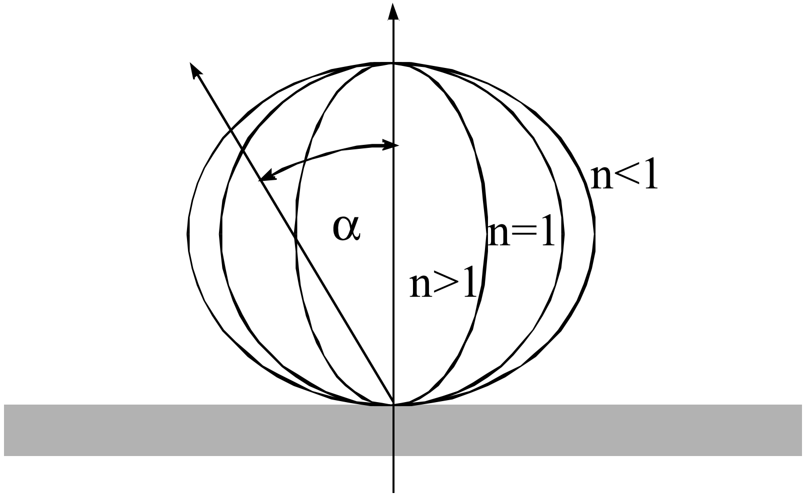
$$R \propto I(k \cdot \ln U)$$

R = Erosion rate
I = Discharge current
U = Discharge voltage

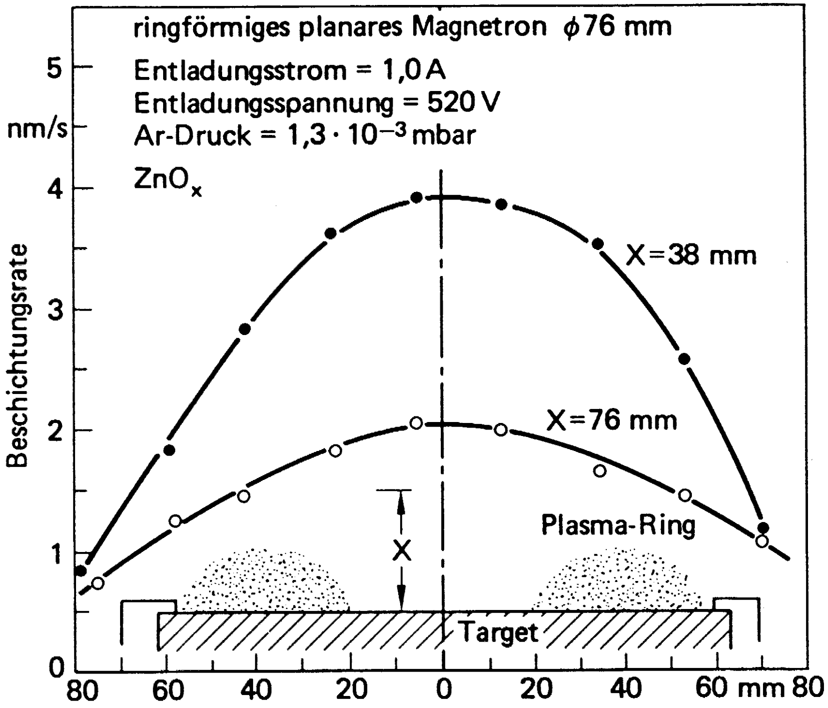
Magnetron discharges are working at significantly lower gas pressures!

Magnetron- Sputtering : Thickness Distribution

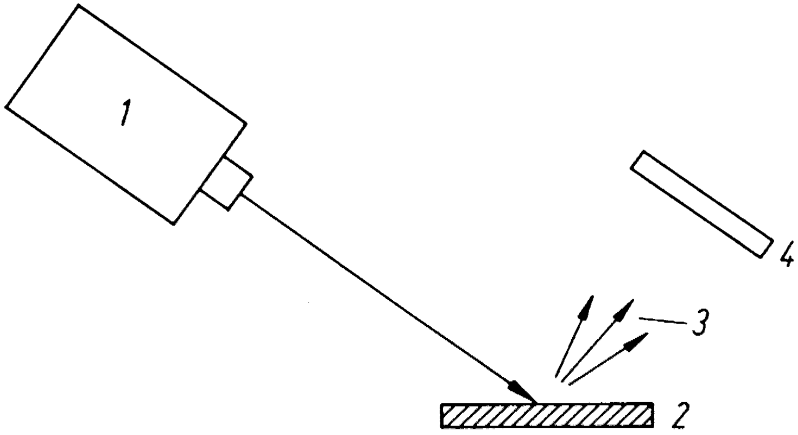
Angular distribution in one target point



Integrated film thickness distribution:



Ion Gun

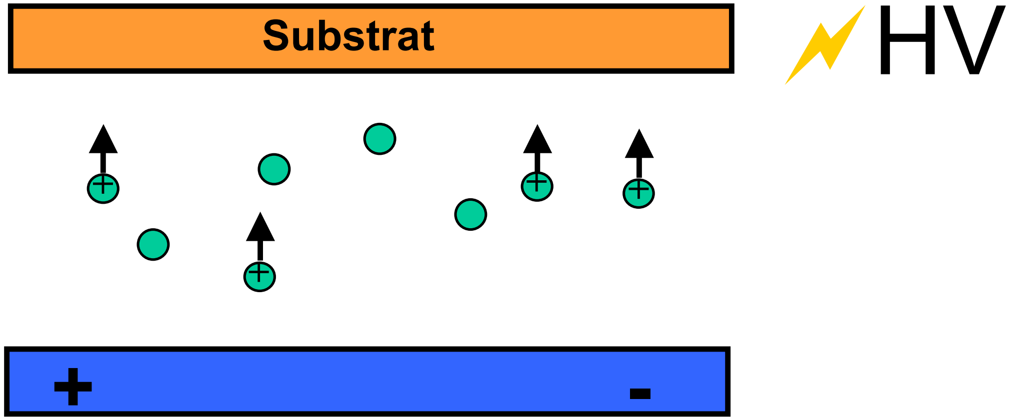


Advantages of the ion gun:

- * Control of ion energy
- * Control of ion impingement angle
- * No working gas, i. e. UHV-capable

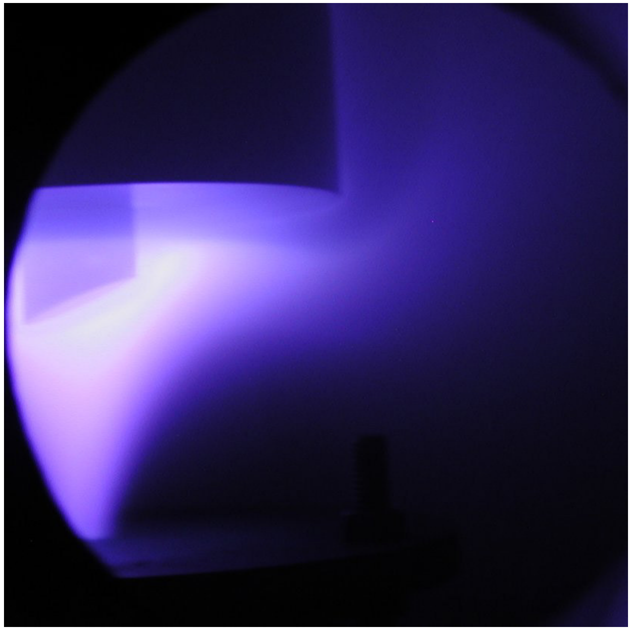
1. Ion source
2. Target
3. Sputtered species
4. Substrate

Sputter-Cleaning



⊕ ● Working gas, ionized or neutral

🟦 Magnetic field assistance (optional)



Sputtering can also be used to clean surfaces, if the substrate, which then acts as "target", is biased with negative high voltage.