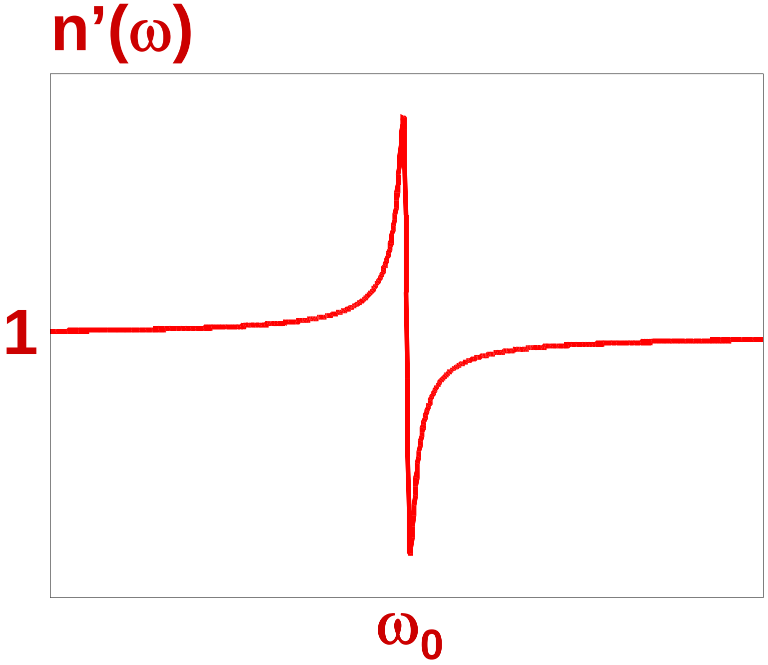
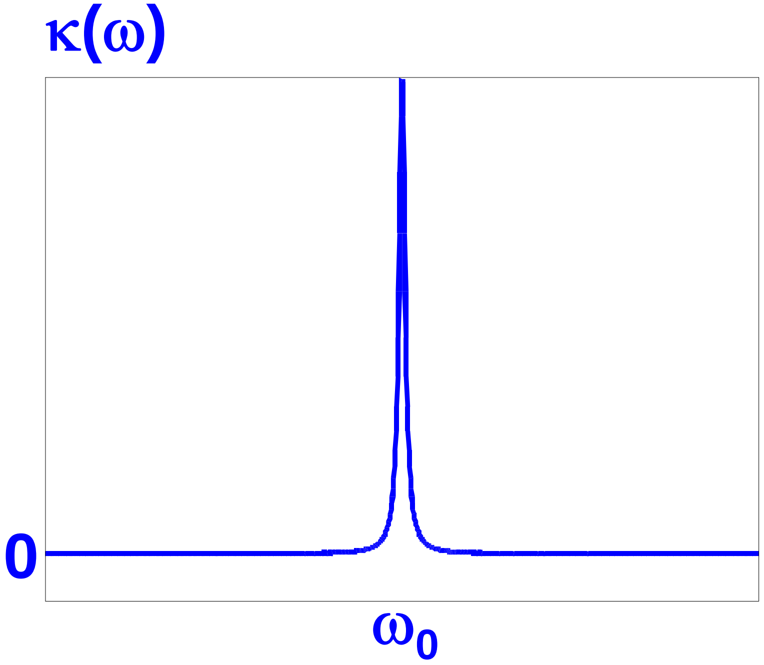
Repetition: Refractive Index





The real part of the refractive index corresponds to refractive index n, as it appears in Snellius law of refraction.

The imaginary part corresponds to the absorption of energy in the medium.

Repetition: Optics - Conservation Law

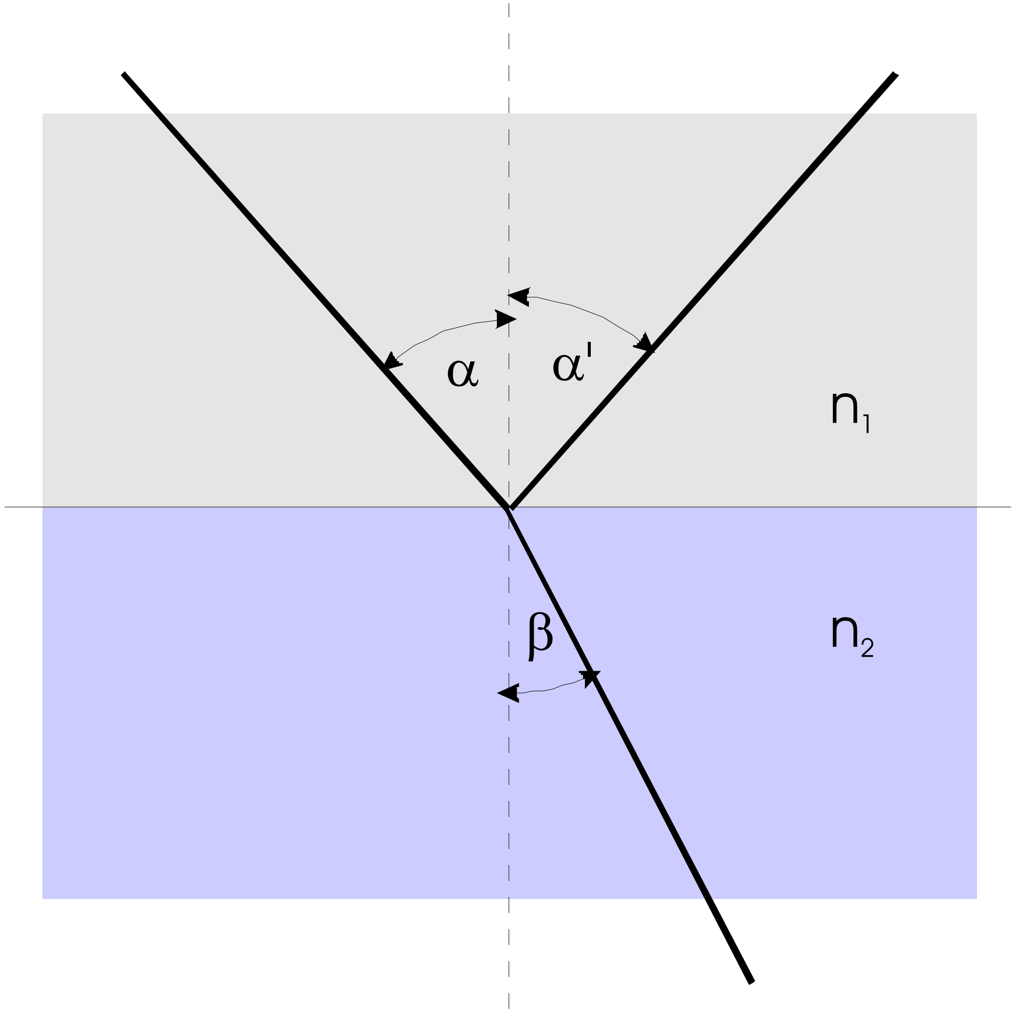
For optics the following conservation law is valid:

$$\boxed{T + R + A + S = 1}$$

T … Transmission
R … Reflection
A … Absorption
S … Scattering

For geometric optics the refraction index n can be considered as frequency independent.

Repetition: Optics - Interfaces



Reflection:

$$\boxed{\alpha = \alpha'}$$

Refraction:

$$\boxed{\frac{\sin\alpha}{\sin\beta} = \frac{n_2}{n_1}}$$

Wavelength:

$$\boxed{\lambda_i = \frac{\lambda_{Vak}}{n_i}}$$

Repetition: Fresnel's Equations

2 Media, indices of refraction n_1, n_2, perpendicular impingement, i. e.: $\varphi_1 = \varphi_2 = 0°$

Reflection:

$$\boxed{r_k^p = r_k^n = \frac{n_1 - n_2}{n_1 + n_2}}$$

Transmission:

$$\boxed{t_k^p = t_k^n = \frac{2n_1}{n_1 + n_2}}$$

Repetition: Optical Film Thickness

Electromagnetic radiation passes from Vacuum into a Medium with refractive index n:

Frequency ω:

$$\omega_n = \omega_{Vak}$$

Wavelength λ:

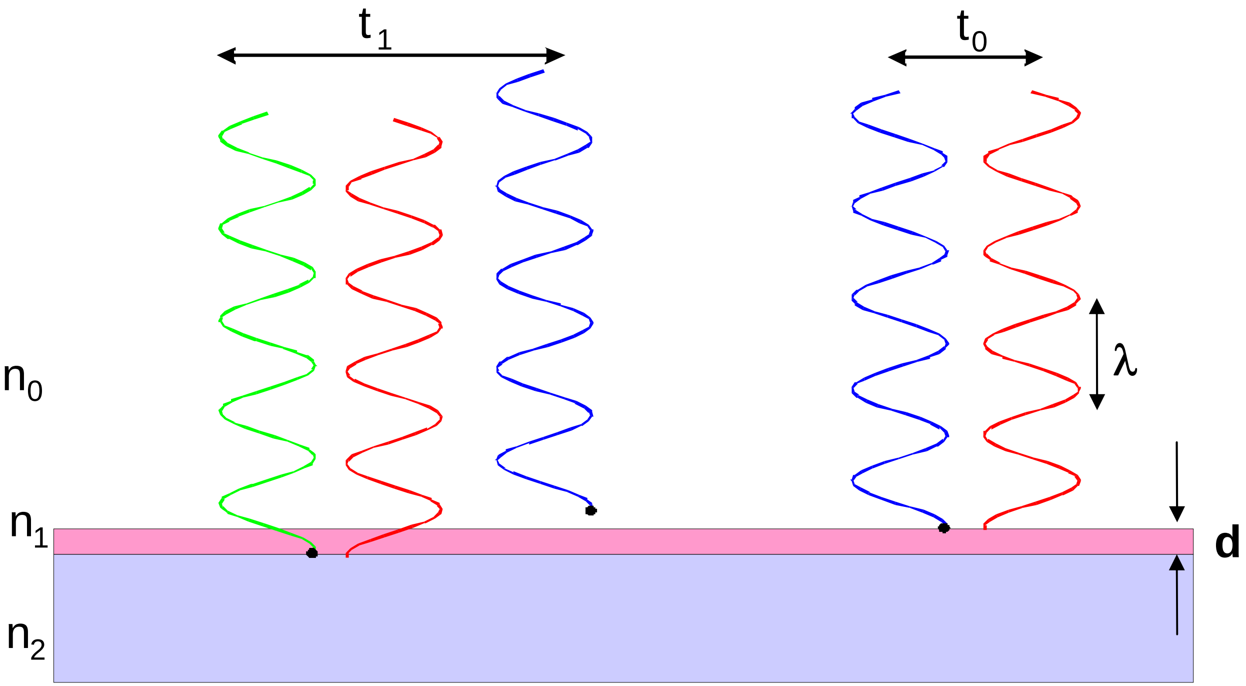
$$\lambda_n = \frac{\lambda_{Vak}}{n}$$

If a film thickness is given as the multiple of a wavelength, λ_n is meant. This film thickness is called "optical film thickness", d_{opt}.

It is:

$$\boxed{d_{Opt} = n \cdot d}$$

Repetition: Reflection Suppression



$n_0 < n_1$

$n_1 > n_2$

$d = \lambda/4$

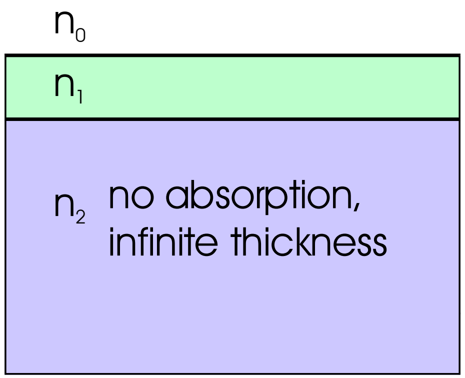
Intensities of reflected radiation:

$$I_r^0 = \frac{(n_0 - n_1)^2}{(n_0 + n_1)^2} \qquad I_r^2 = \frac{(n_1 - n_2)^2}{(n_1 + n_2)^2}$$

$$I_r^0 = I_r^2 \Rightarrow n_1 = \sqrt{n_0 \cdot n_2}$$

Amplitude requirement

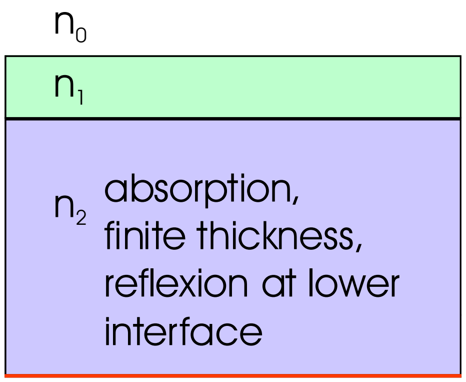
Repetition: Single Layer



n_0

n_1

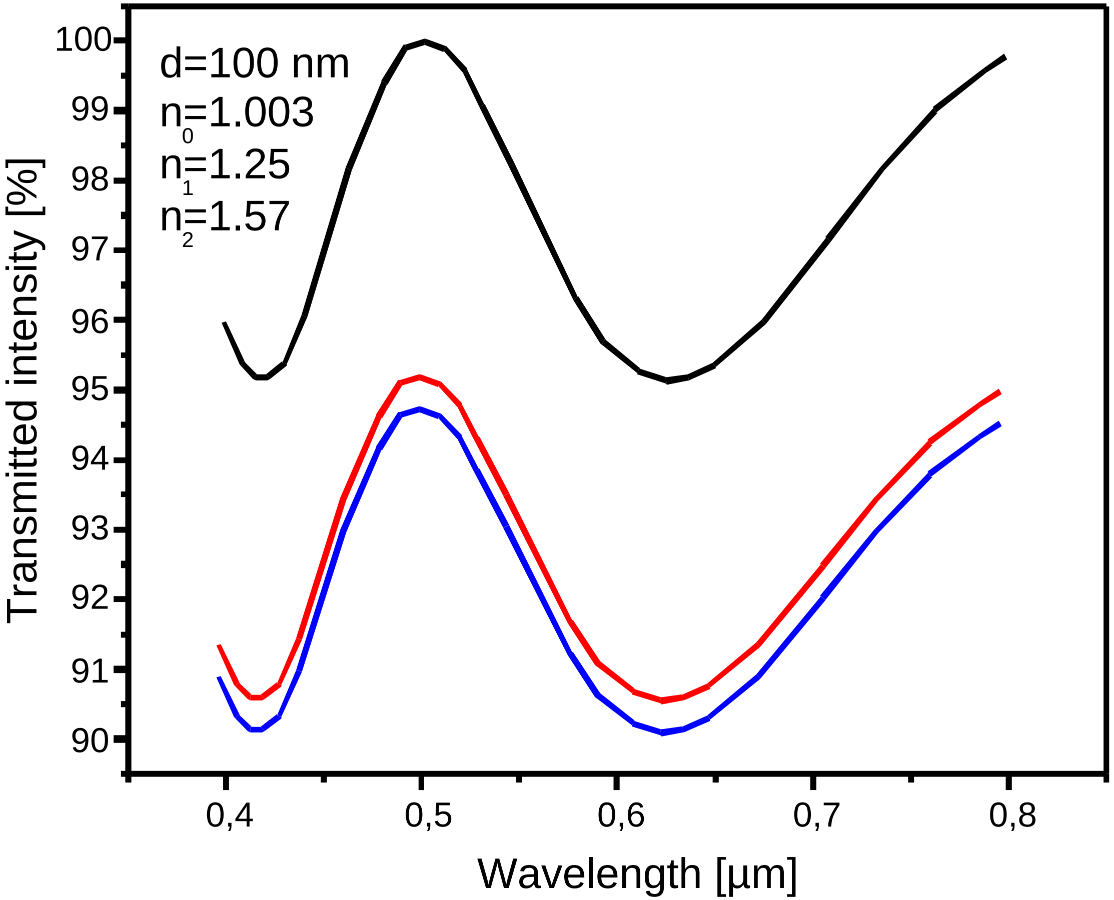
n_2 no absorption, infinite thickness



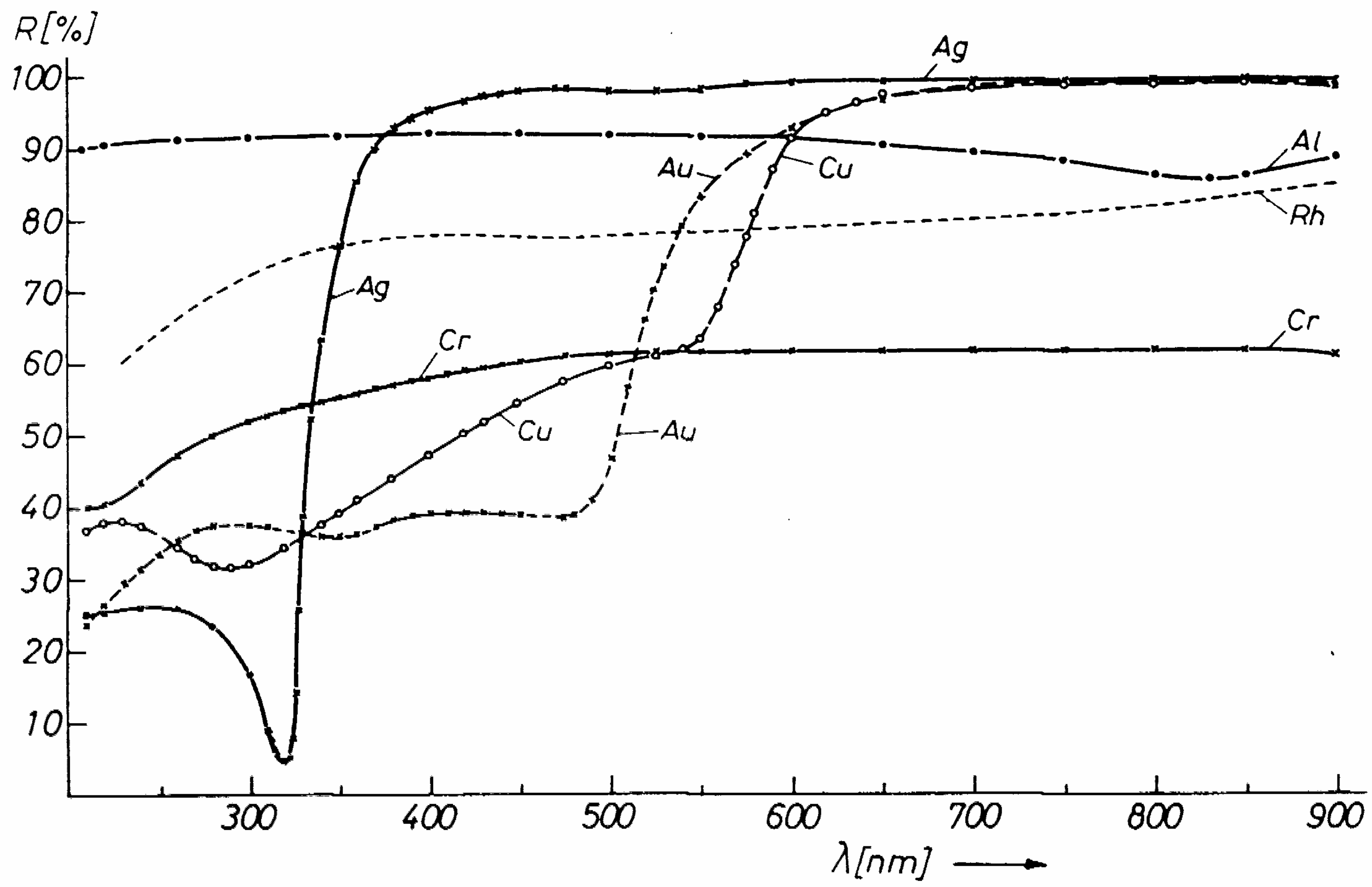
n_0

n_1

n_2 absorption, finite thickness, reflexion at lower interface

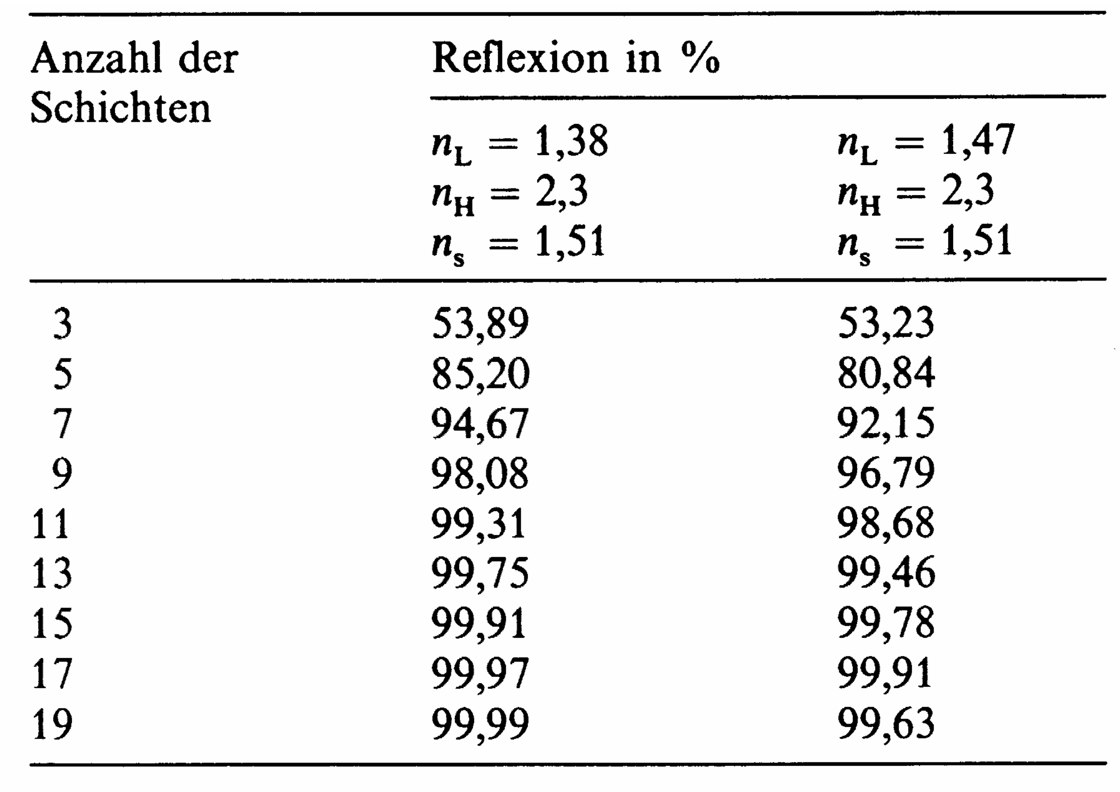


Repetition: Reflection Enhancement I



Repetition: Reflection Enhancement II

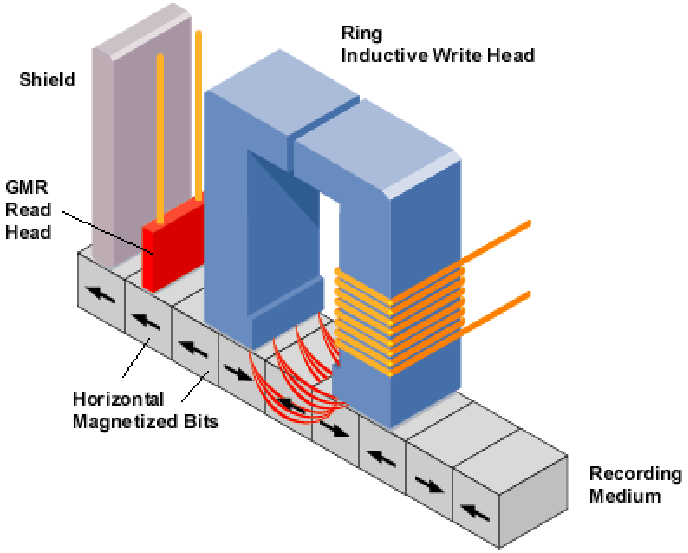
A dielectric mirror consists of a multilayer made from λ/4-coatings with alternating high (H) and low (L) indices of refraction.



Anzahl der Schichten	Reflexion in %	
	$n_L = 1{,}38$ $n_H = 2{,}3$ $n_s = 1{,}51$	$n_L = 1{,}47$ $n_H = 2{,}3$ $n_s = 1{,}51$
3	53,89	53,23
5	85,20	80,84
7	94,67	92,15
9	98,08	96,79
11	99,31	98,68
13	99,75	99,46
15	99,91	99,78
17	99,97	99,91
19	99,99	99,63

Magnetic Properties I

Motivation: permanent data storage



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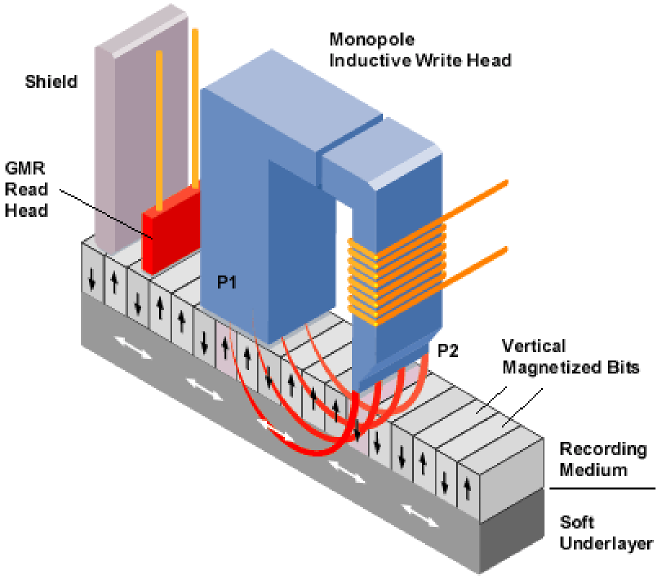
Longitudinal Recording



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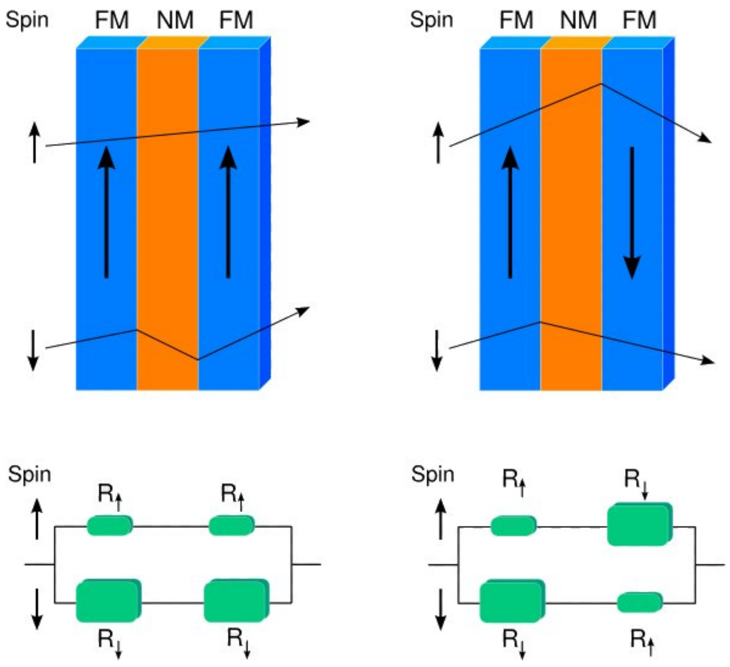
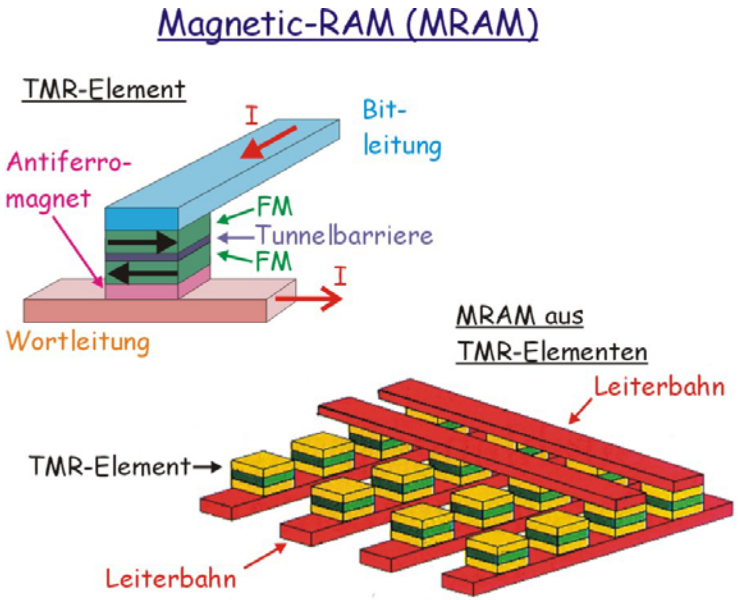
Perpendicular Recording

Magnetic Properties II

Motivation: volatile data storage



Spin Valve



Magnetic Random Access Memory (MRAM)

Switching

"Switching" of a magnetic element means the complete reversal of the magnetization M by an external field H. To obtain the equilibrium position of M in dependence on H, the total energy E resulting from the relative orientation of M and H has to be minimized.

Energy contributions:

- **External field**
- **Stray field**
- **Anisotropy**
- **Exchange energy**
- **Domain walls**

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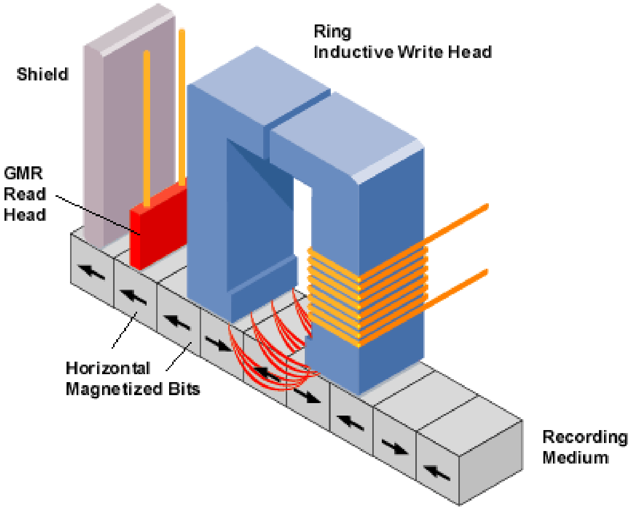
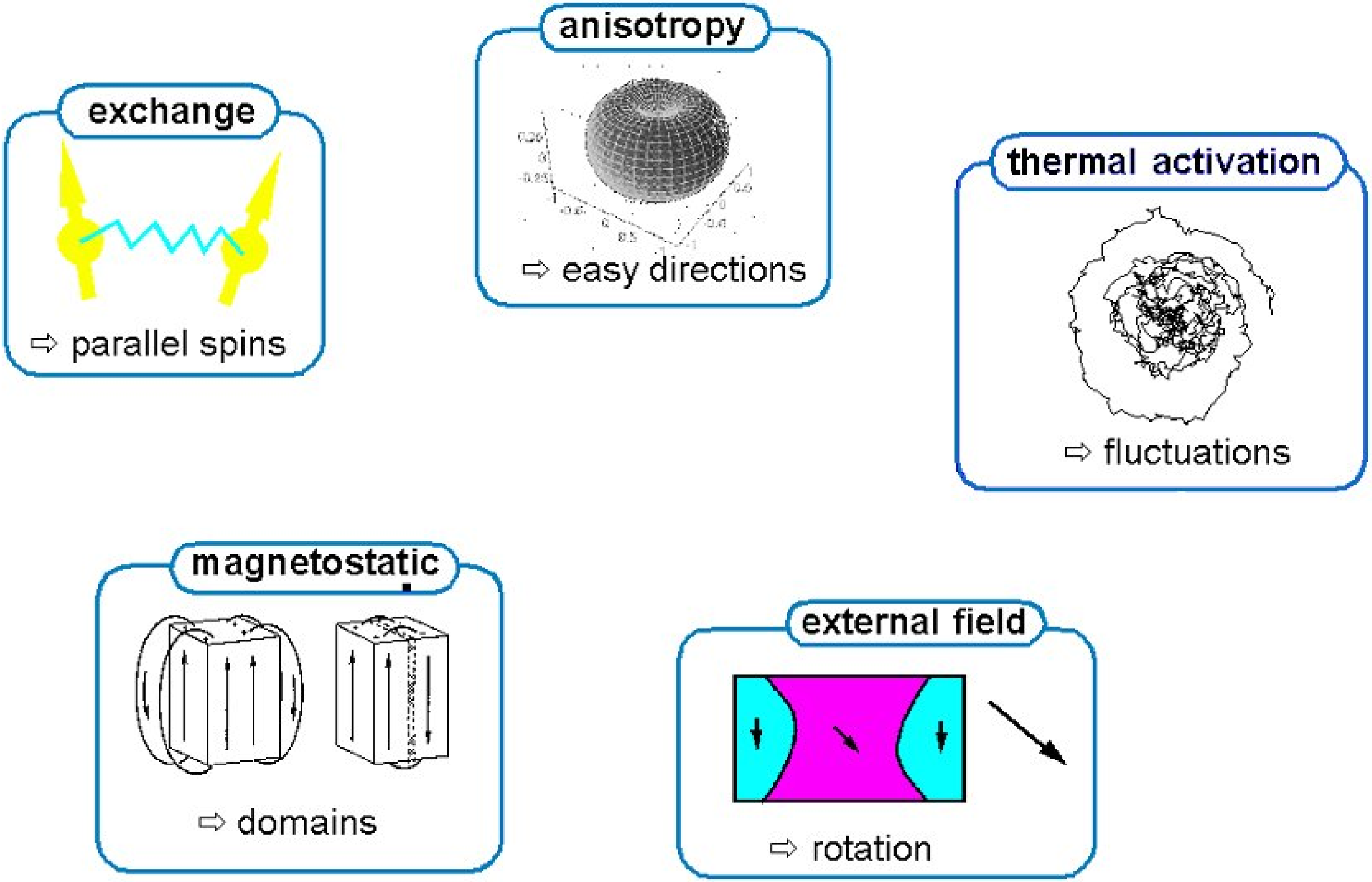


Energy Contributions



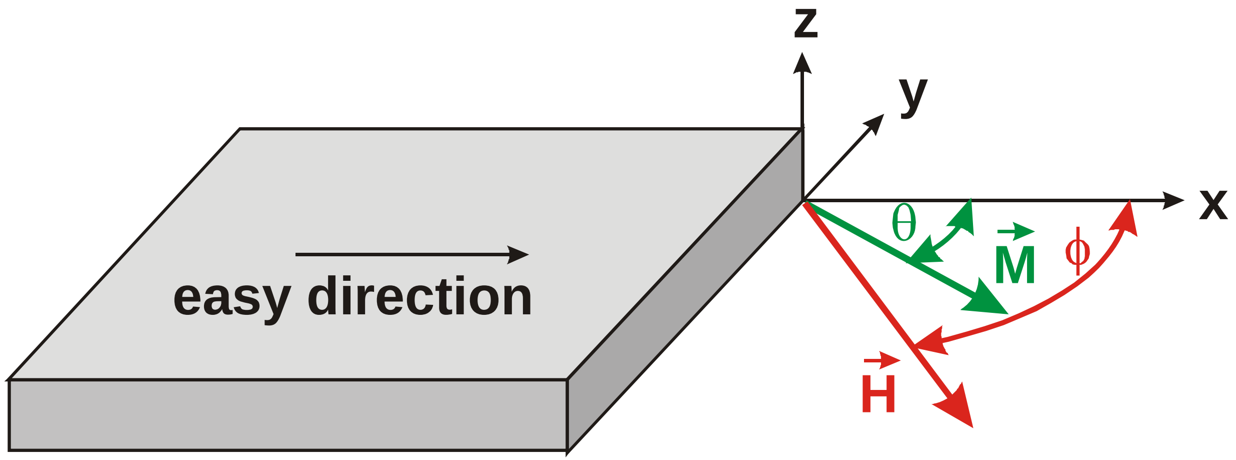
Grafik: Arbeitsgruppe Mikromagnetismus, T. Schrefl http://magnet.atp.tuwien.ac.at/

Energy Consideration I

Focus on the energy contributions from:

- **External field**
- **Anisotropy**

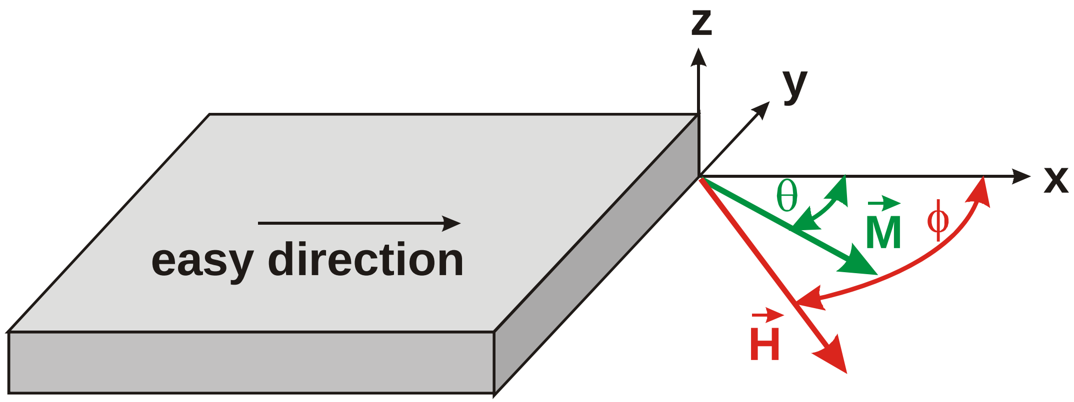
Magnetically anisotropic medium:



Magnetization considered to rotate coherently!

Energy Consideration II

Total magnetic energy (referred to unit volume); anisotropy constant K:



$$\boxed{E =} -\vec{M}\cdot\vec{H} + K\cdot\sin^2\theta = -|M|\cdot|H|\cdot\cos(\phi-\theta) + K\cdot\sin^2\theta =$$

$$= \boxed{-M\cdot H_x\cdot\cos\theta - M\cdot H_y\cdot\sin\theta + K\cdot\sin^2\theta}$$

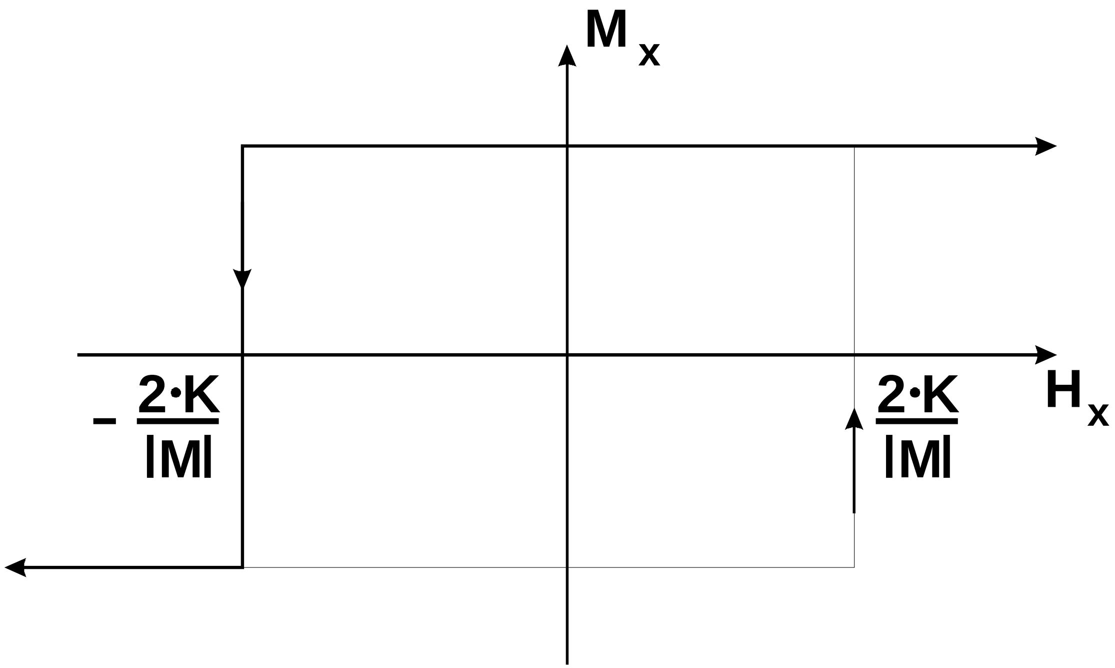
Adition theorem

$$\cos(\phi-\theta) = \cos\theta\cdot\cos\phi + \sin\theta\cdot\sin\phi$$

$$H_x = |H|\cdot\cos\phi \quad H_y = |H|\cdot\sin\phi$$

Magnetic Reversal I

H parallel to easy direction:



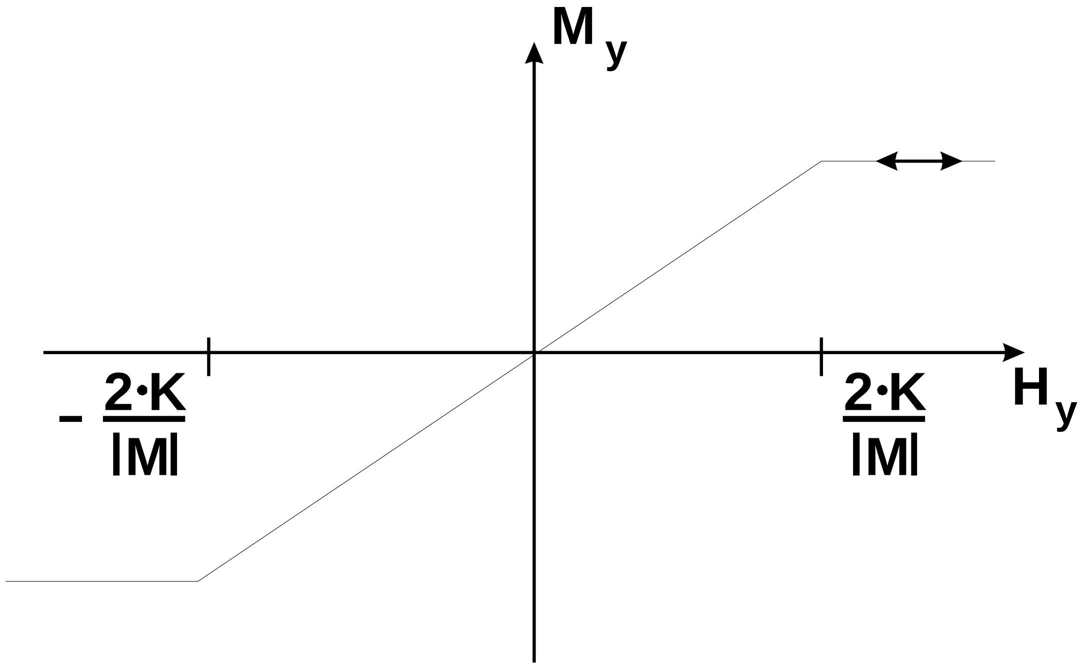
A hysteresis loop is observable.

$$\boxed{H_K = \frac{2\cdot K}{|M|}}$$

External Coercitivity H_K

Magnetic Reversal II

H perpendicular to easy direction:



There is no hysteresis loop. M turns continously.
Each intermediate position is stable.

Further Considerations

Magnetic reversal may not occur via coherent rotation of M in all cases.
Further influences:

- **Domain nucleation**
- **Domain wall mobility**
- **Volume of magnetized regions**

→ Superparamagnetic limit:

Volumes of magnetized regions (bit size)
can become so small, that the anisotropy
energy can be surpassed by thermal fluctuations
→ instability

Superparamagnetic Limit

Estimate:

Typical anisotropy energies:

$$\boxed{E_{\text{Anis}} = 10^4 - 10^5 \ \text{J} \cdot \text{m}^{-3}}$$

Thermal energy within a grain of volume V:

$$k_B \cdot T = E_{\text{Anis}} \cdot V \Rightarrow V = l^3 = \frac{k_B \cdot T}{E_{\text{Anis}}} \Rightarrow l = \sqrt[3]{\frac{k_B \cdot T}{E_{\text{Anis}}}}$$

$$T = 300\text{K}:$$

$$\boxed{l = 7.5 - 3.5 \ \text{nm}}$$

Giant Magneto Resistance (GMR)

Magneto Resistance is the phenomenon that the electric resistivity can be influenced by the direction of the magnetization.

The effect is based on different scattering probabilities between electrons of equal and opposite spins. It has extremely important technological and scientific applications (Nobel prize 2007!):

- **Hard disk reading heads**
- **Spin valves**

Chemical Composition

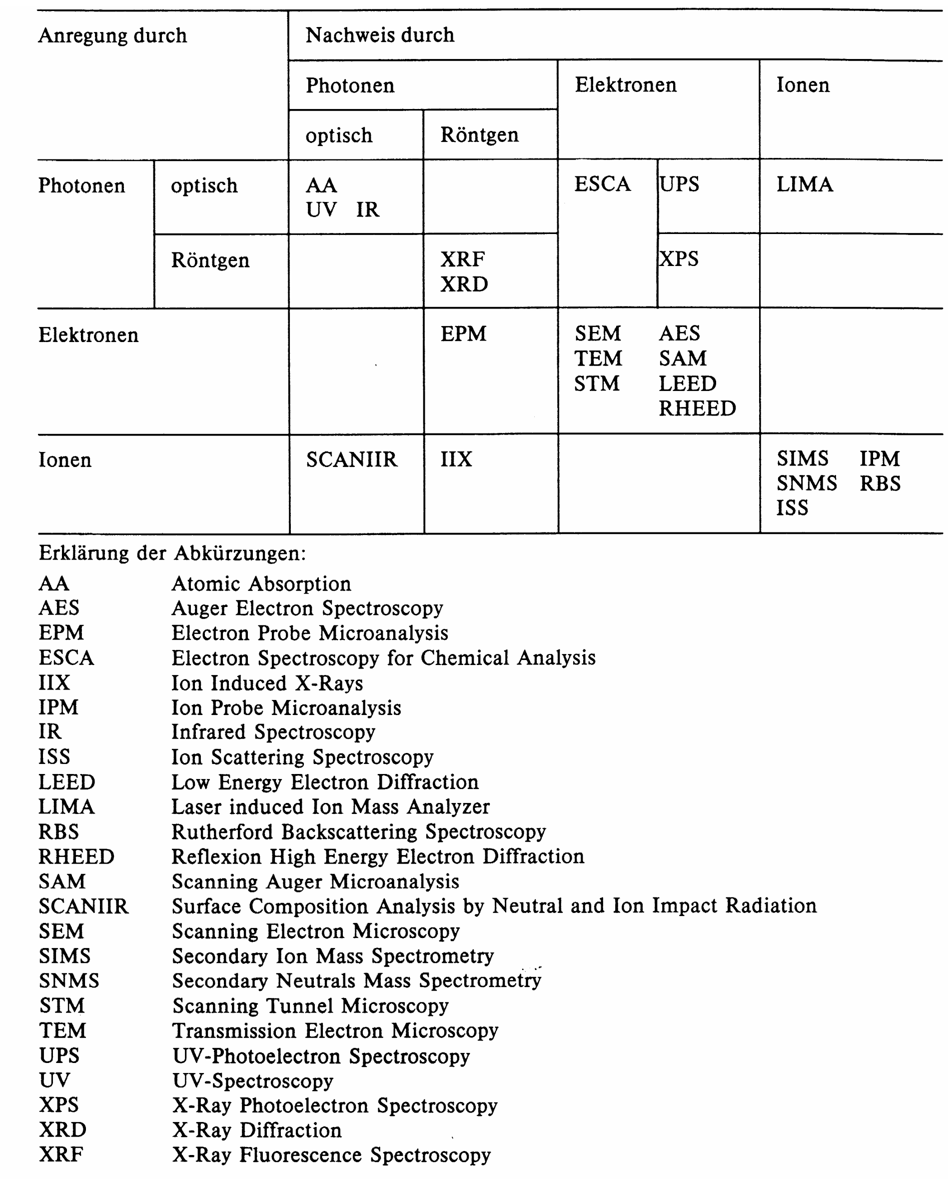
For the chemical analysis of thin films as well as for the analysis of the surface of bulk materials a wide range of physical analysis methods is available.

Most of these methods are based on the following principle:

+ Bombardement of the material with probe particles
+ Detection of the generated radiation or of the generated particles

Only electron optic methods (TEM, LEED, RHEED) and scanning probe methods (STM, AFM, ...) do not necessarily involve this principle.

Physical Analytics - Survey

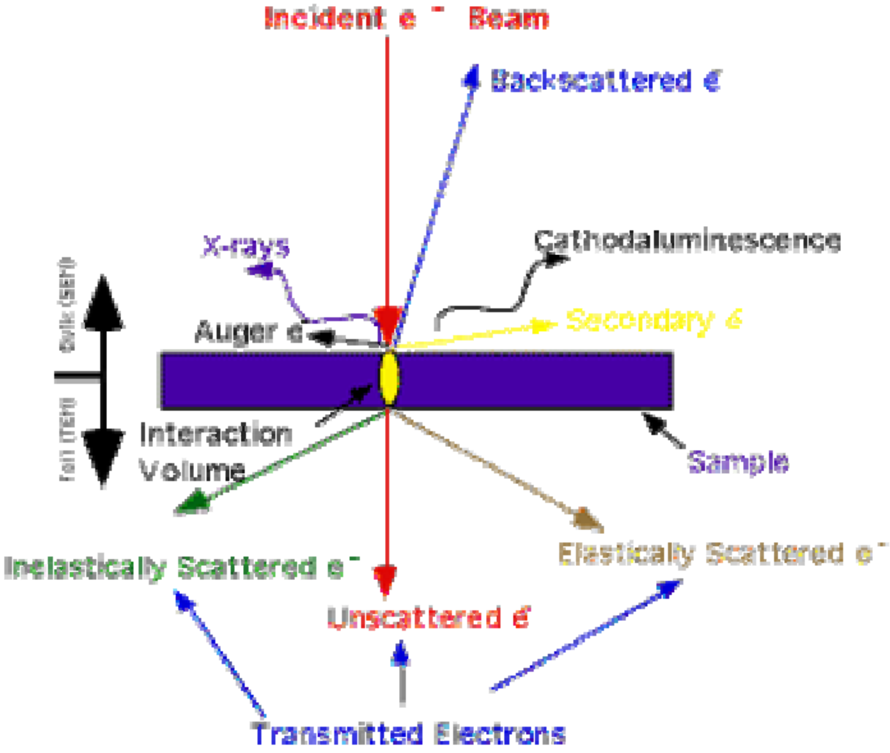


Anregung durch		Nachweis durch				
		Photonen		Elektronen		Ionen
		optisch	Röntgen			
Photonen	optisch	AA UV IR		ESCA	UPS	LIMA
	Röntgen		XRF XRD		XPS	
Elektronen			EPM	SEM TEM STM	AES SAM LEED RHEED	
Ionen		SCANIIR	IIX			SIMS IPM SNMS RBS ISS

Erklärung der Abkürzungen:

AA	Atomic Absorption
AES	Auger Electron Spectroscopy
EPM	Electron Probe Microanalysis
ESCA	Electron Spectroscopy for Chemical Analysis
IIX	Ion Induced X-Rays
IPM	Ion Probe Microanalysis
IR	Infrared Spectroscopy
ISS	Ion Scattering Spectroscopy
LEED	Low Energy Electron Diffraction
LIMA	Laser induced Ion Mass Analyzer
RBS	Rutherford Backscattering Spectroscopy
RHEED	Reflexion High Energy Electron Diffraction
SAM	Scanning Auger Microanalysis
SCANIIR	Surface Composition Analysis by Neutral and Ion Impact Radiation
SEM	Scanning Electron Microscopy
SIMS	Secondary Ion Mass Spectrometry
SNMS	Secondary Neutrals Mass Spectrometry
STM	Scanning Tunnel Microscopy
TEM	Transmission Electron Microscopy
UPS	UV-Photoelectron Spectroscopy
UV	UV-Spectroscopy
XPS	X-Ray Photoelectron Spectroscopy
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence Spectroscopy

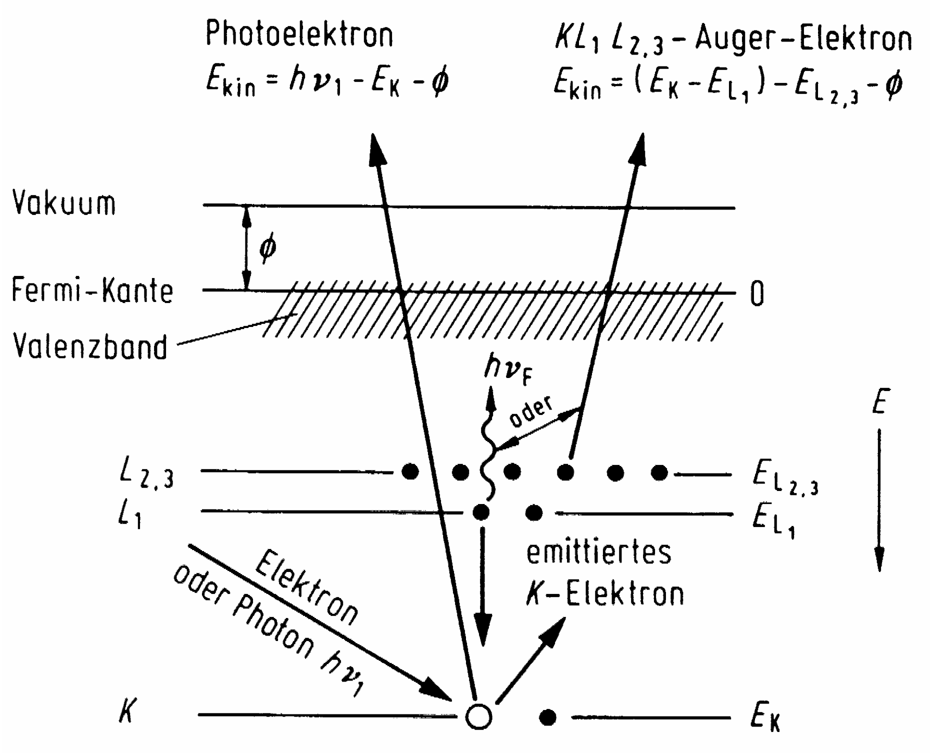
Electron Beam Micro Analysis



Interaction volumes:

Backscattered electrons:
approx. 1-5µm ejection depth
Secondary electrons:
near surace region
Auger electrons:
approx. 10 mn ejection depth
X-rays:
approx. 1-5µm ejection depth

Auger Electron Spectroscopy (AES)

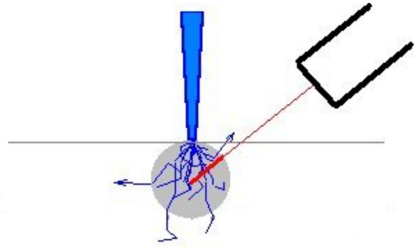


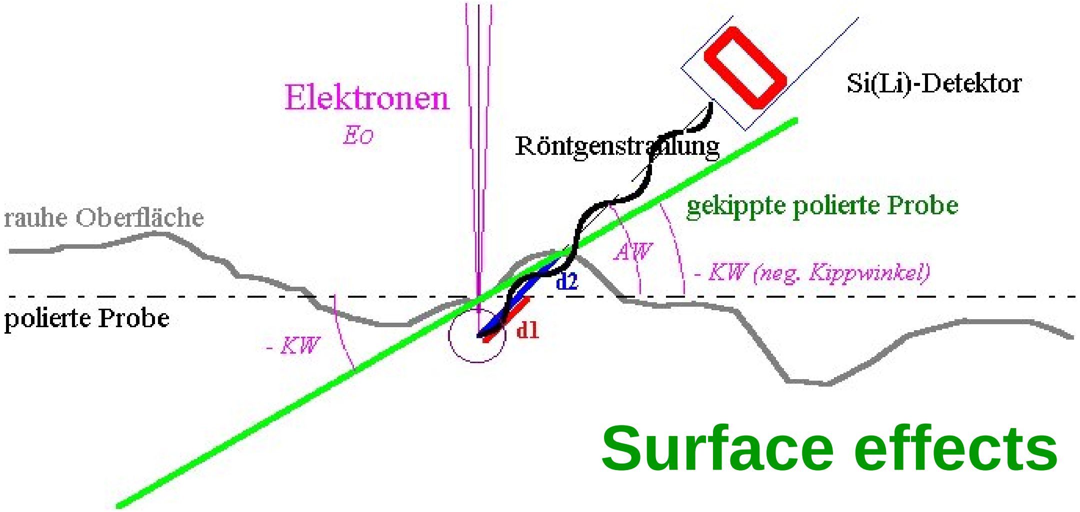
Characteristics:

+ **Surface sensitive (ejection depth 1 – 10 nm)**
+ **Sensitive to light elements**
+ **Sensitivity limit: approx. 0.1 At%**

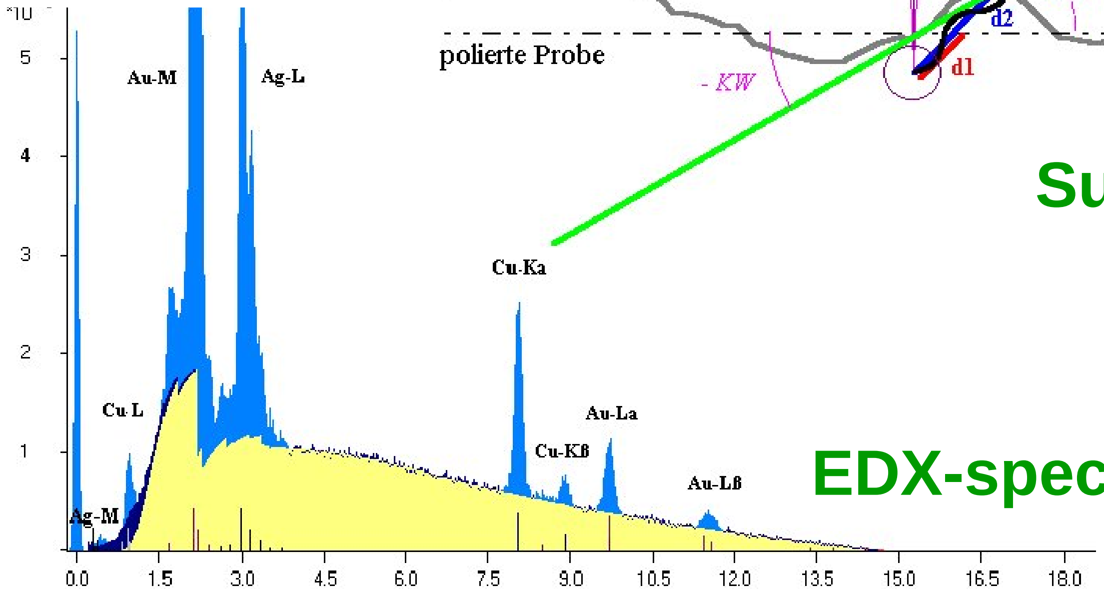
Energy Cispersive X-Ray Analysis (EDX)

Ejection volume





Surface effects

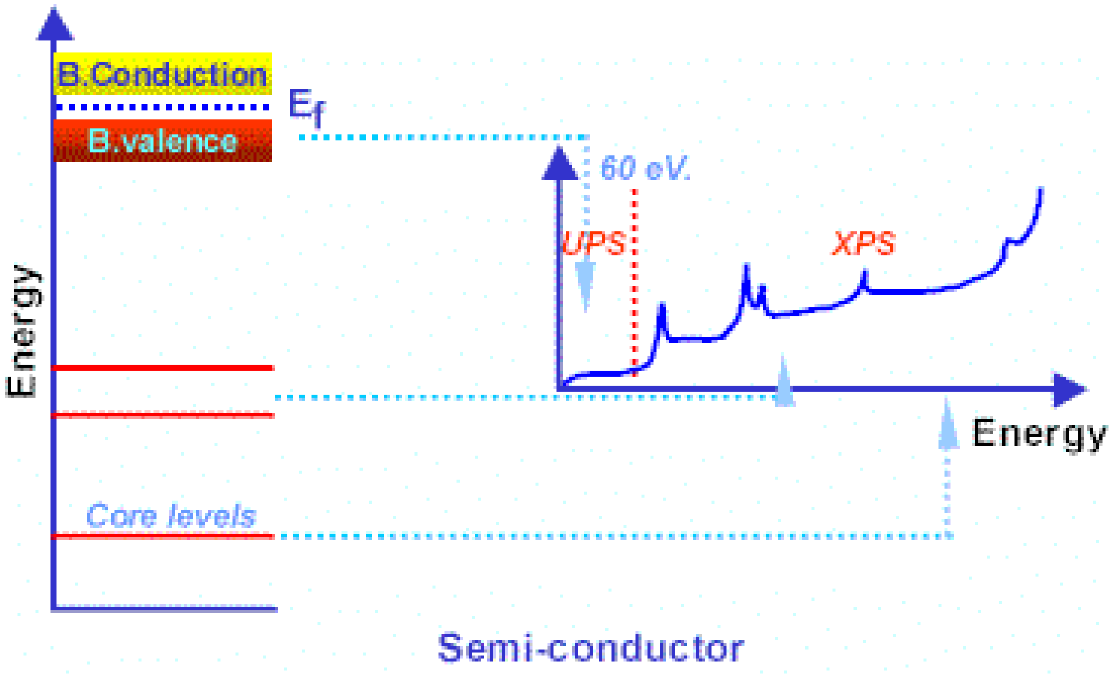


EDX-spectrum

Detection limit: ca. 0.1 At%

XPS, UPS

Photoelectron spectroscopy by excitation with X-rays (XPS) or UV-radiation (UPS)

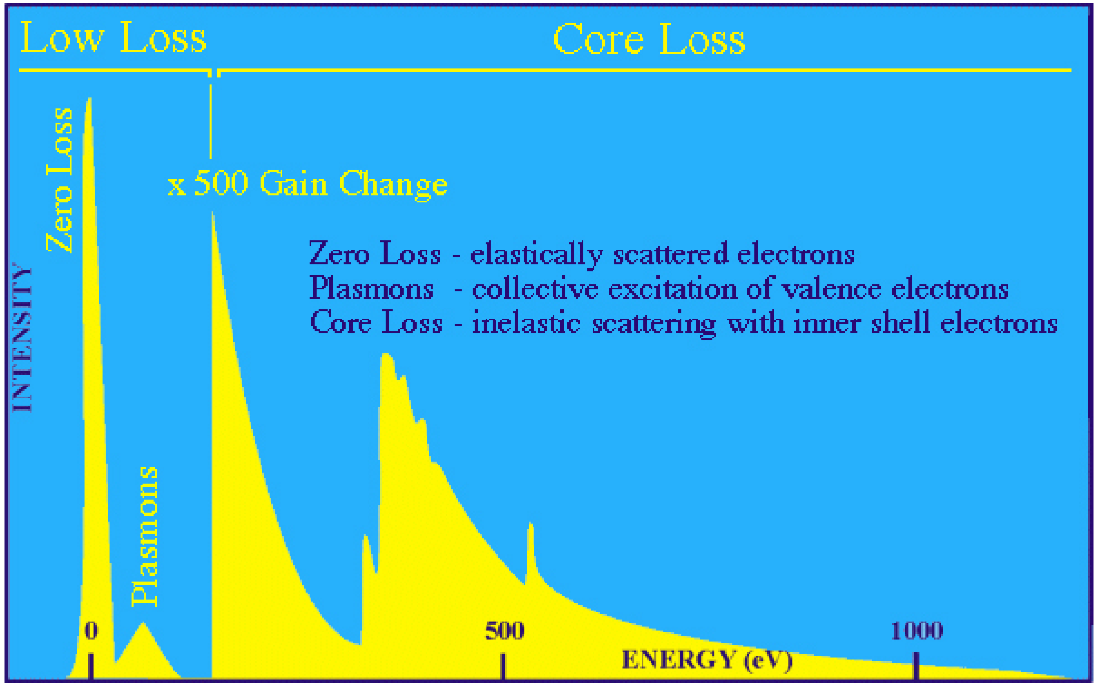


Observable properties:

- **+ Electron work function**
- **+ Density of states**

EELS

Electron Energy Loss Spectroscopy

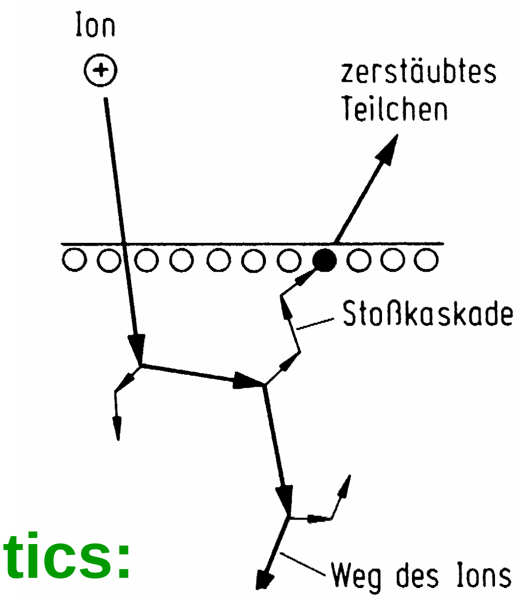


Characteristics:

+ High lateral resolution (TEM)
+ Sensitivity limit: ca. 1 at%
+ Possibility of local chemical mapping

SIMS, SNMS

Secondary Ion Mass Spectroscopy (SIMS) or Secondary Neutral Mass Spectroscopy (SNMS): Mass spectroscopy of directly sputtered ions (SIMS) or post ionized neutrals (SNMS):



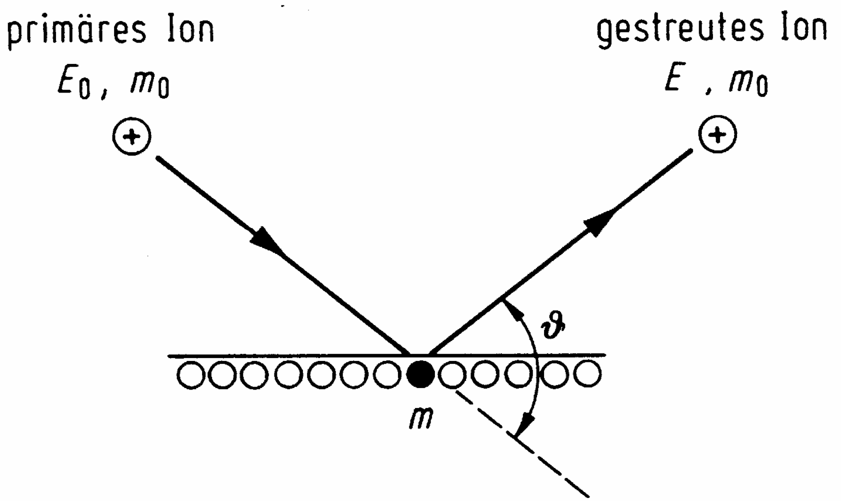
Caution:
Ionization cross section within the bulk does not correspond to the one of a single atom
➔ " matrix effect "

Characteristics:

- **+ High chemical sensitivity (mass spectroscopy)**
- **+ Quantification possible (SNMS)**
- **+ Sensitivity limit: ppm**

LEISS

Low Energy Ion Surface Spectroscopy



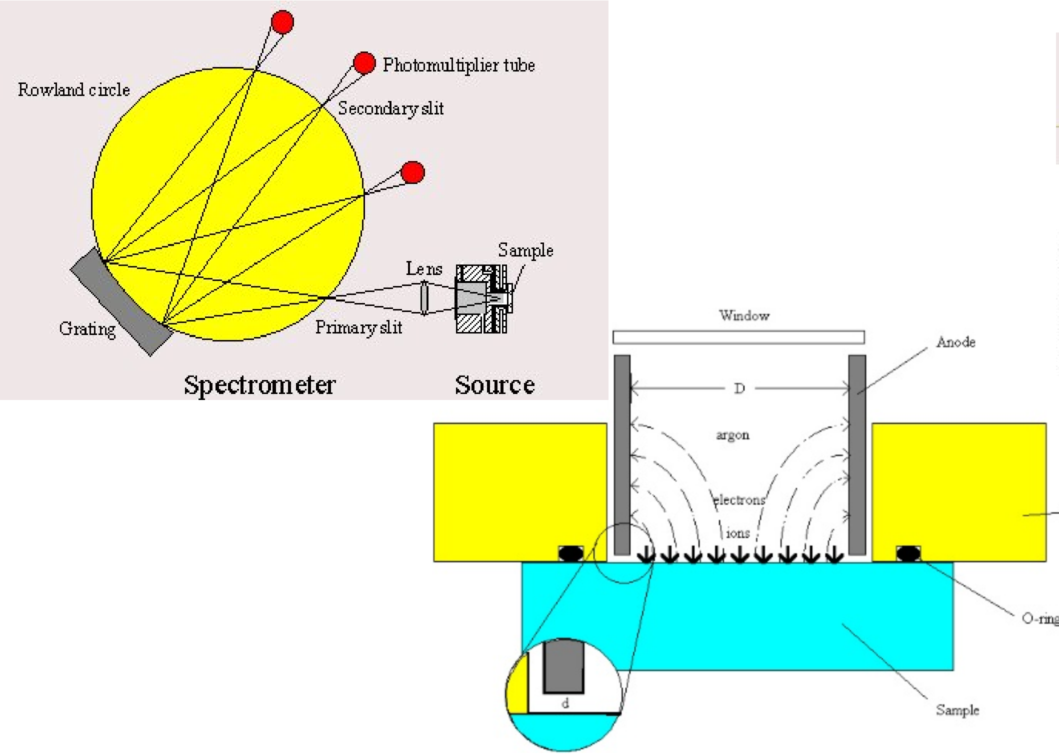
$$\frac{E}{E_0} = \frac{m_0^2}{(m_0 + m)^2} \left[\cos\vartheta + \left(\frac{m^2}{m_0^2} - \sin^2\vartheta \right)^{1/2} \right]^2$$

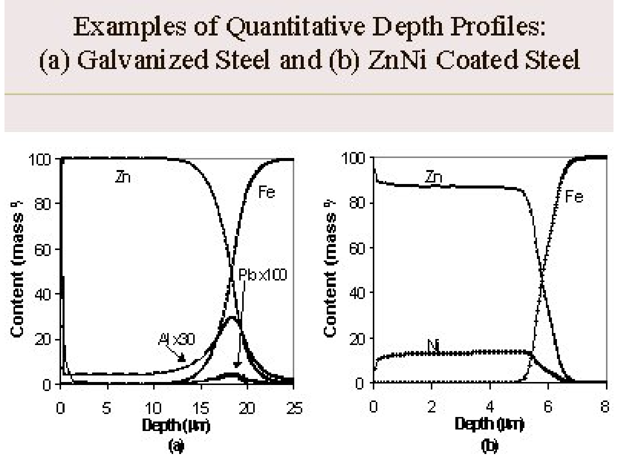
Characteristics:

+ **High surface sensitivity (1. Monolayer)**
+ **Absolute quantification possible (simple collision mechanism)**

GDOS

Glow Discharge Optical Spectroscopy





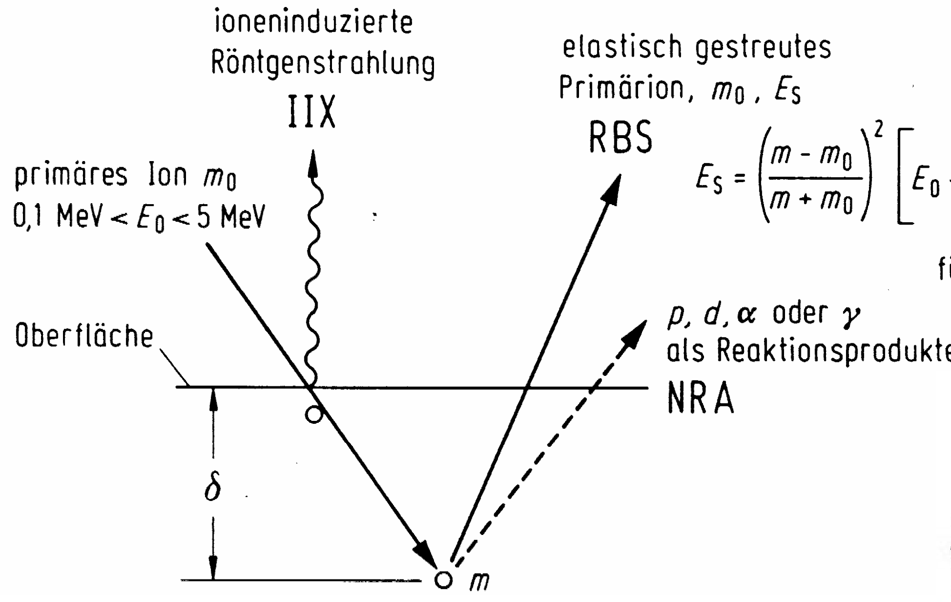
Examples of Quantitative Depth Profiles:
(a) Galvanized Steel and (b) ZnNi Coated Steel

Characteristics:

- + Fast depth profiling
- + Good chemical sensitivity
- + Reasonable quantification possible (Spectroscopy)

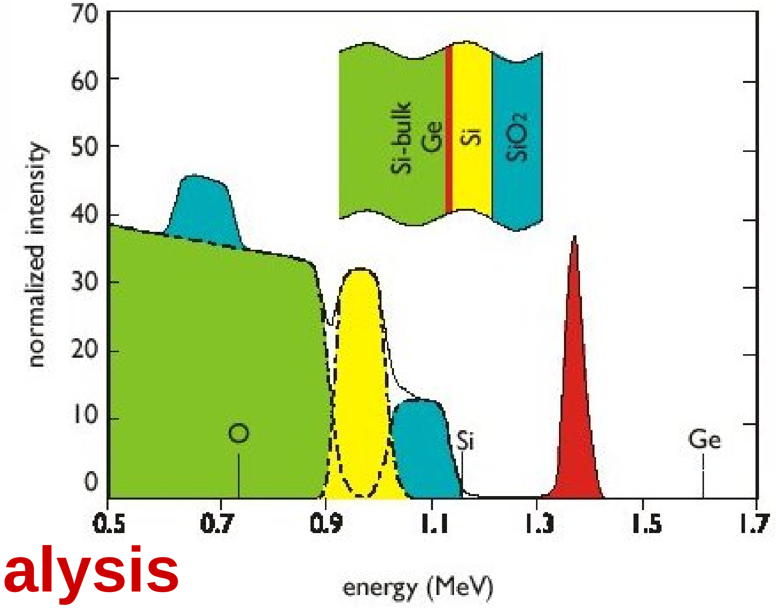
RBS

Rutherford Backscattering



$$E_S = \left(\frac{m - m_0}{m + m_0}\right)^2 \left[E_0 - \delta \left\langle \frac{dE}{dx} \right\rangle\right] - \delta \left\langle \frac{dE}{dx} \right\rangle$$

für $\vartheta = 180°$



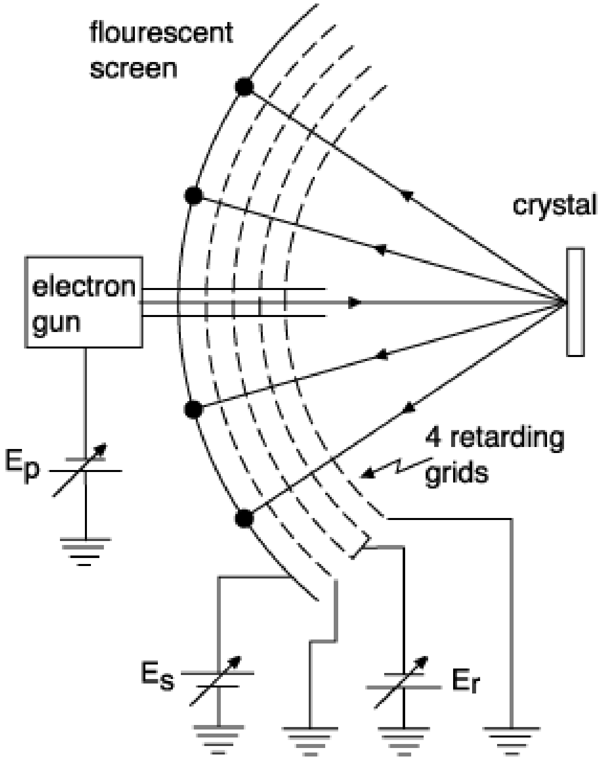
Characteristics:

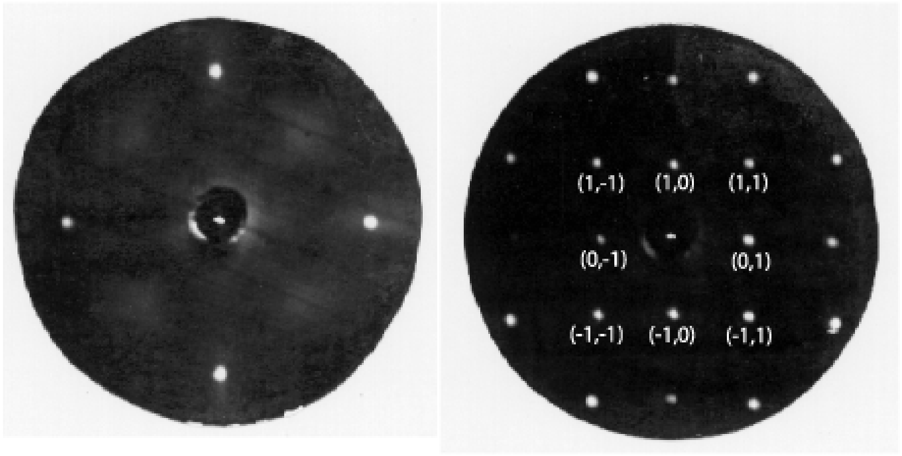
+ Non destructive depth analysis

+ Quantification possible (Coulomb potential)

LEED

Low Energy Electron Diffraction





W(100)

45 eV **145 eV**

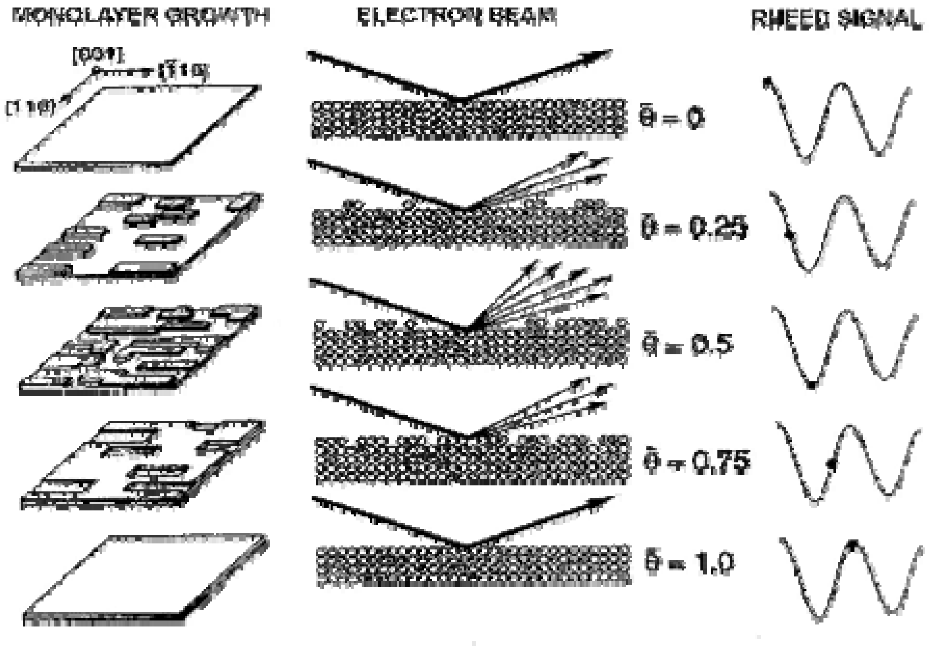
Characteristics:

- + Surface sensitive
- + Yields surface crystallography and adsorbate positions

RHEED

Reflected High Energy Electron Diffraction

Ideal situation:



Characteristics:

- + Surface sensitive
- + Yields detailed informations about growth modes (Layer By Layer/roughening/stochastic)