

Thin Films

Preparation – Characterization – New physics

*Joint Bonn-Cologne Seminar
in Solid State Physics*

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Thin Films

- Motivation
- Crystal growth
- Preparation techniques
- Characterization
- Examples and properties



Motivation

Thin film research is interesting for:

- Physics:
 - New materials (not or hard to make in bulk)
 - New effects (QHE, CMR, TMR)
 - Low dimensional systems ↔ theory
- Industry
 - Less material / Less power consumption (CPU's)
 - New technologies (TFT, CPU's, D-RAM)

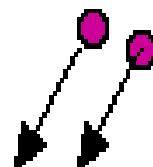


Crystal growth

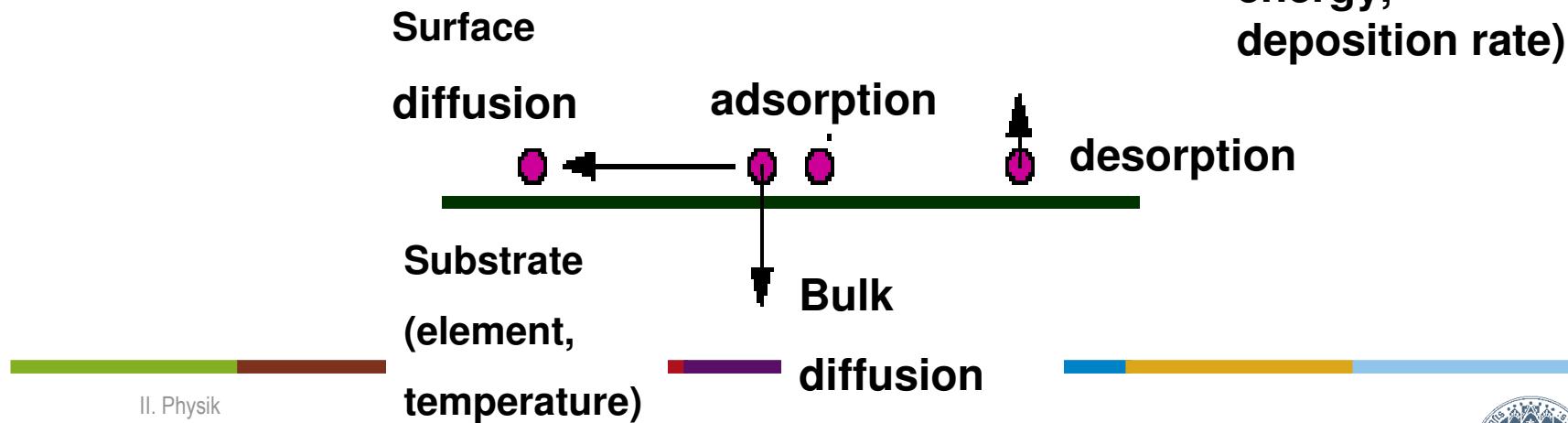
1. Adsorption
2. Surface migration
3. Incorporation
4. Desorption

- Substrate
- Temperature
- Growth rate
- UHV

$$Z \propto p \cdot \frac{1}{\sqrt{M^* \cdot T}}$$

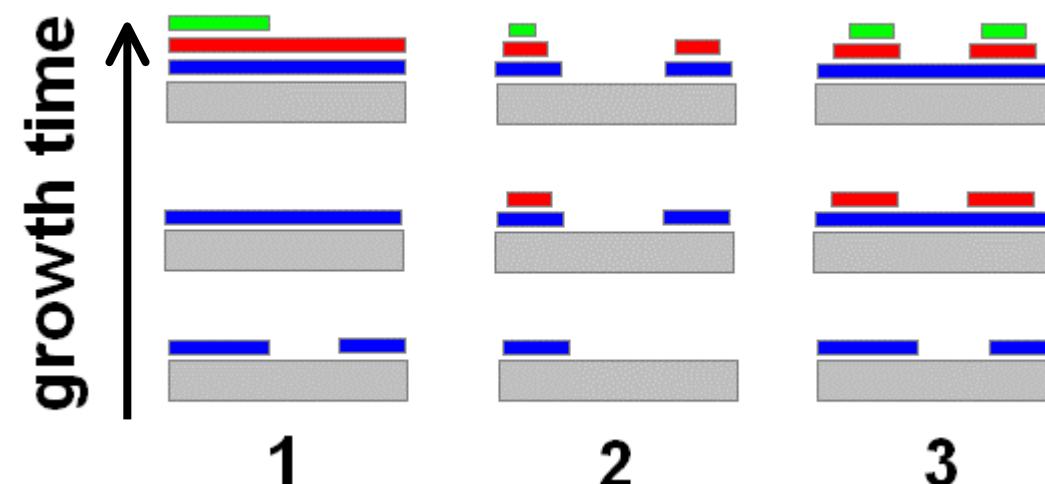


Impinging
material (element,
energy,
deposition rate)



Growth modes

1. Layer by layer (Frank Van Der Merve)
2. Islands (Volmer Weber)
3. Layer plus island (Stranski Krastanov)



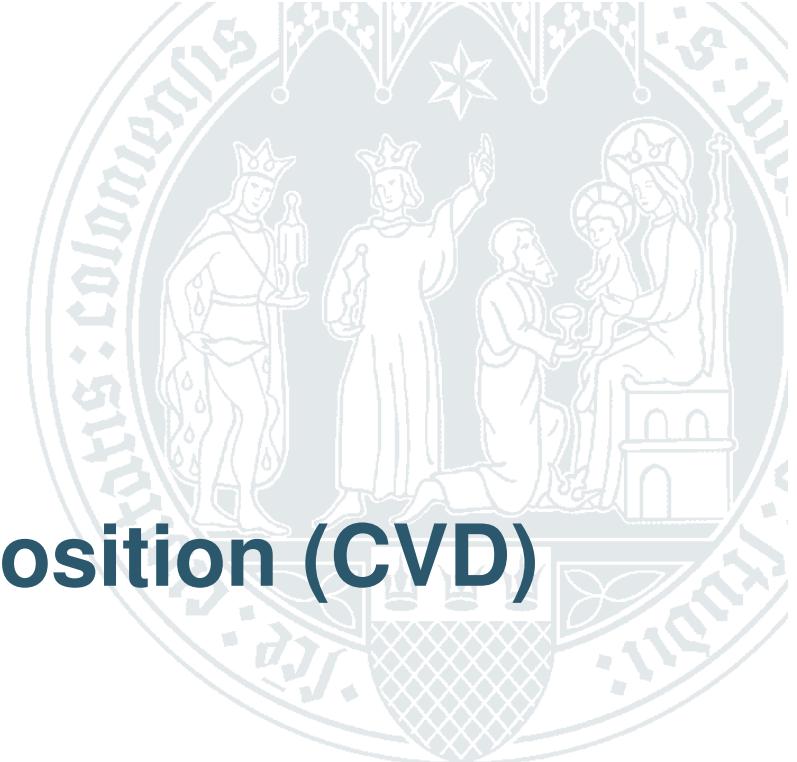
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Techniques

- Spin Coating
- Chemical Vapour Deposition (CVD)
- Sputter Deposition
- Pulsed Laser Deposition (PLD)
- Molecular Beam Epitaxy (MBE)



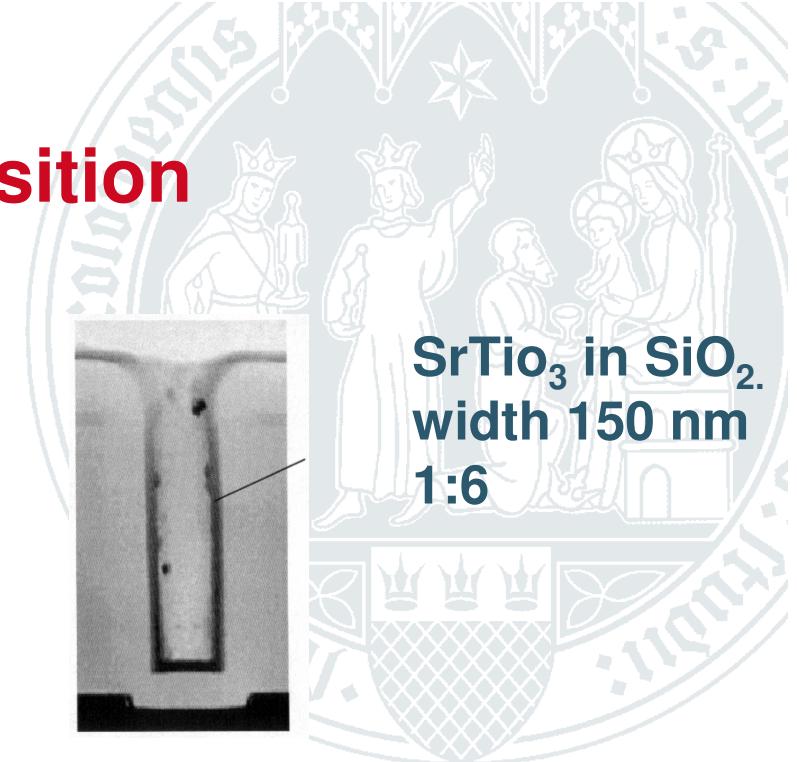
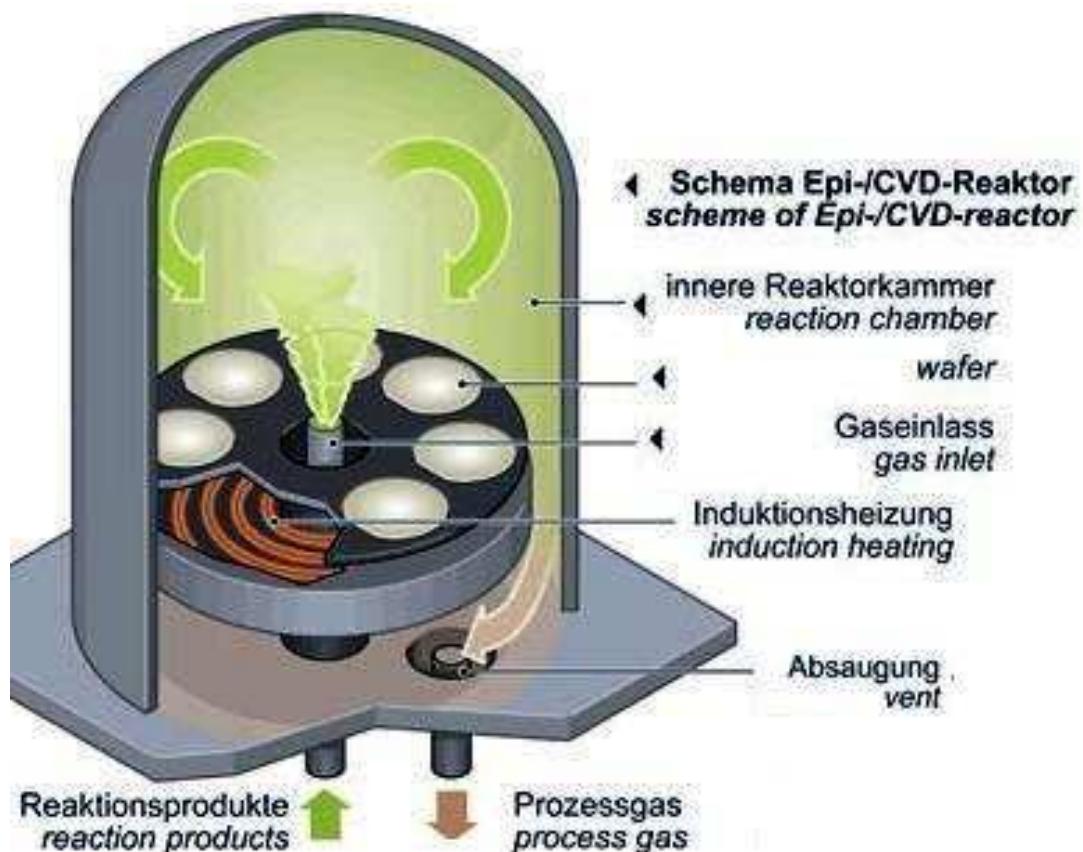
Spin coater



- **Thickness depends on:**
 - Spinning velocity, acceleration
 - Concentration
 - Viscosity, surface tension
- **Typical speed 3000 rpm**

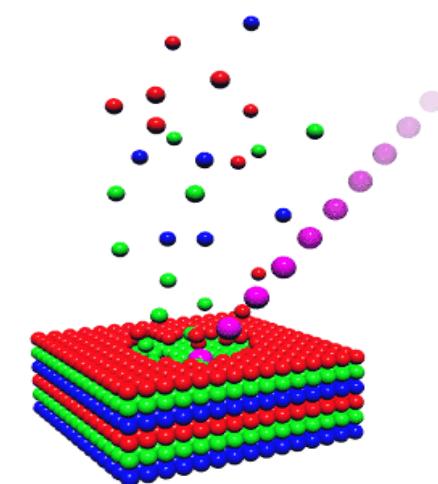
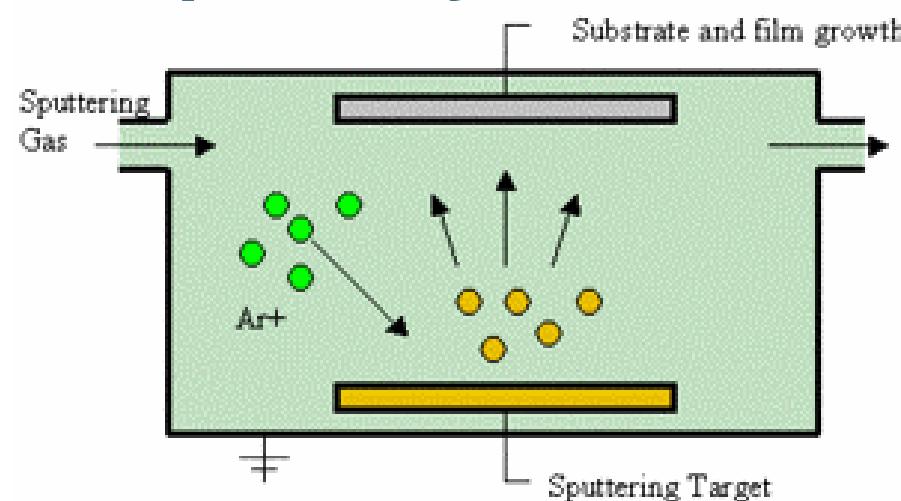
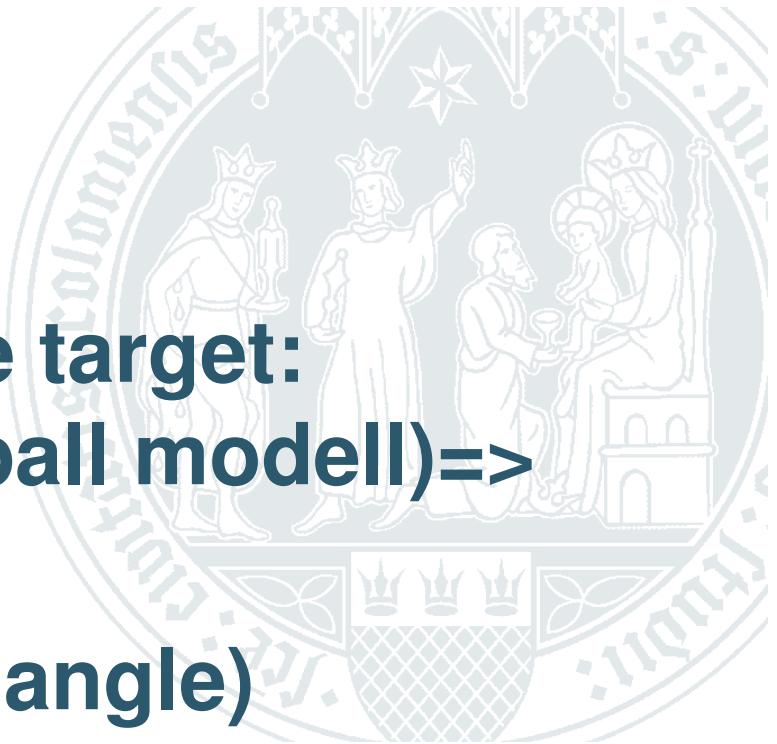


CVD Chemical vapour deposition

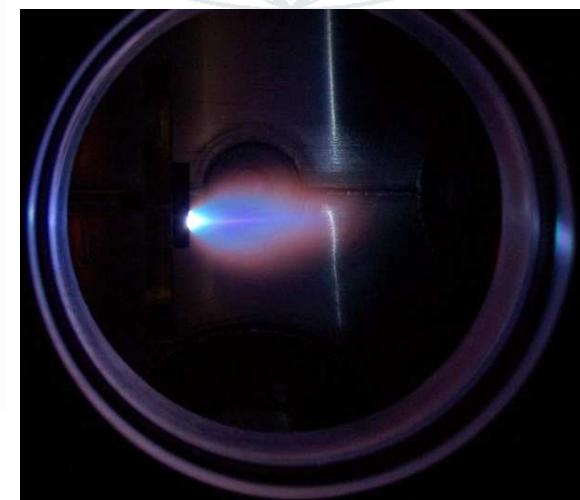
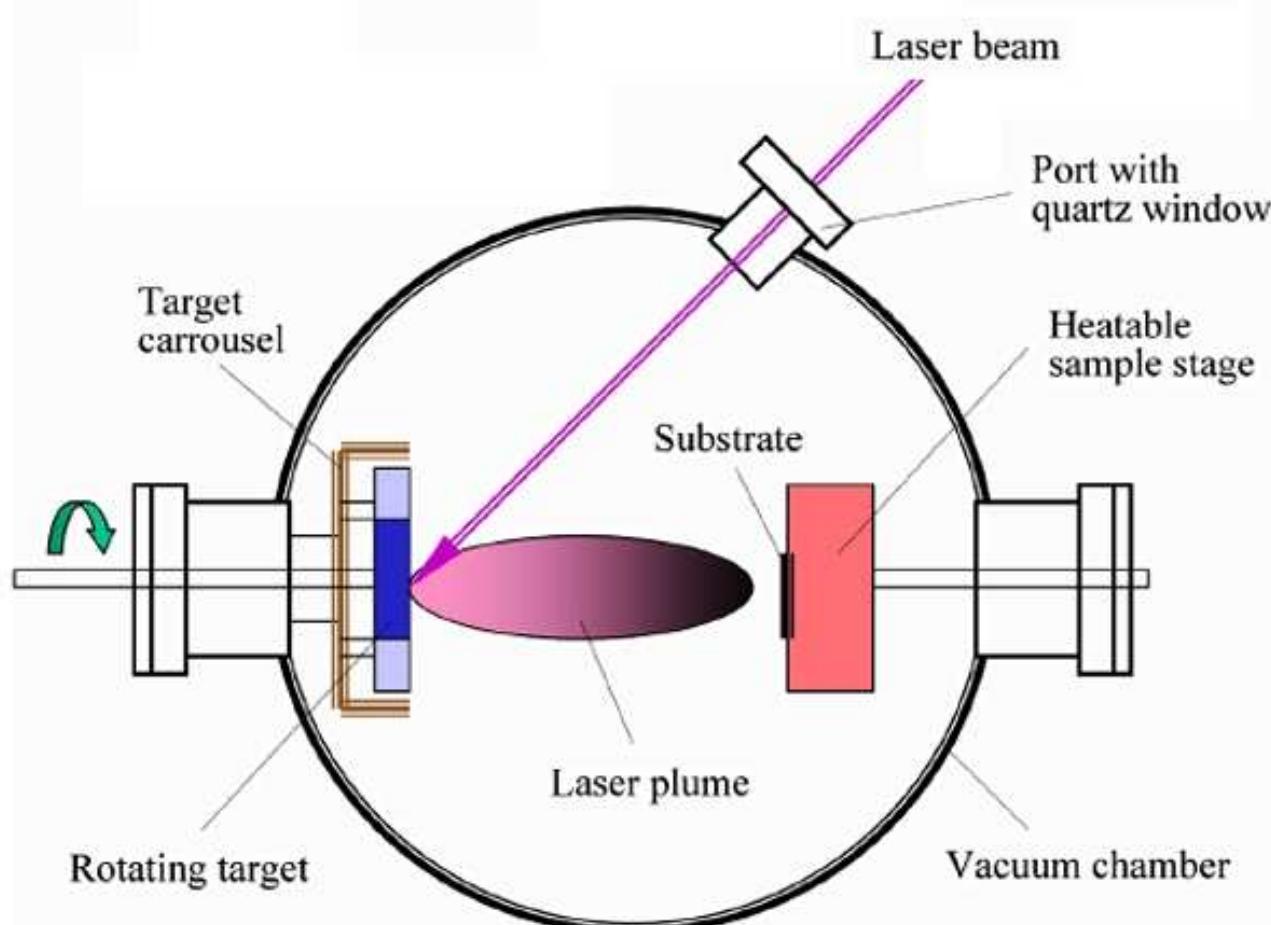


Sputter deposition

- Accelerated ions strike target:
bulk material (billiard ball modell)=> ejection
- **Sputter yield ~ f (E, m, angle)**



PLD Pulsed Laser Deposition



MBE Molecular Beam Epitaxy

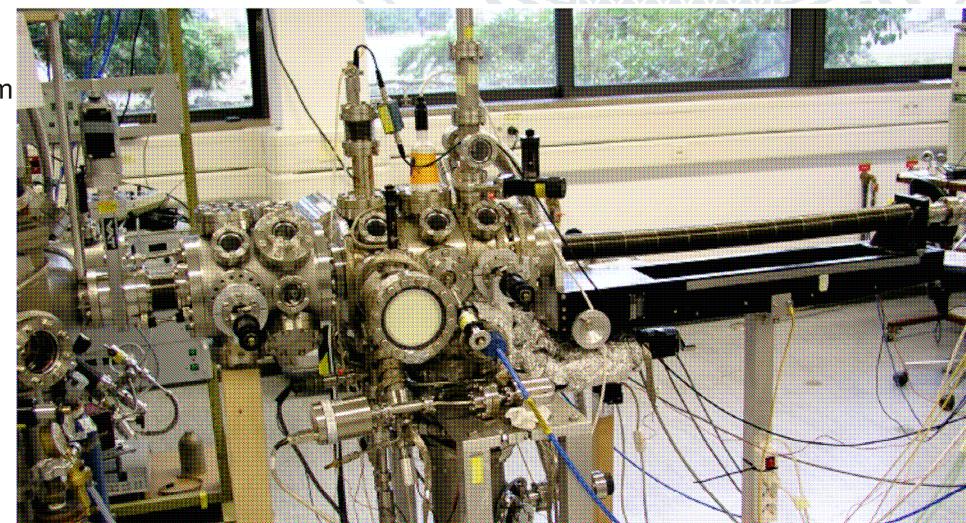
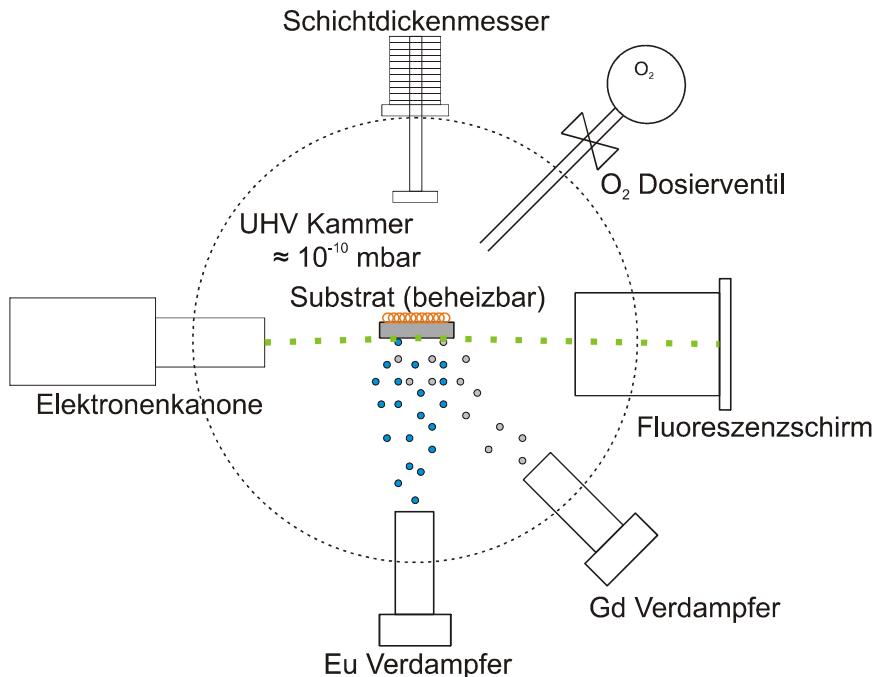


Fig. 1.6: Mini-MBE setup in Cologne





	Physical Vapor Deposition			Chemical Deposition Methods		
	Evap./MBE	Sputtering	PLD	CVD / MOCVD	CSD	Langmuir-Blodgett
Mechanism of production of depositing species	Thermal energy	Momentum transfer	Thermal energy	Chemical reaction	from solution	from floating film
Deposition rate	High, up to 750,000 Å/min	Low, except for pure metals	Moderate	Moderate Up to 2,500 Å/min	several cycles necess.	molecular monolayers per step
Deposition species	Atoms and ions	Atoms and ions	Atoms, ions and clusters	precursor molecules dissociate into atoms	solute molecules	molecules
Energy of deposited species	Low 0.1 to 0.5 eV	Can be high 1- 100 eV	Low to high	Low; can be high with plasma-aid	low	low
Throwing power a) Complex shaped object b) Into blind hole	Poor, line of sight	Nonuniform thickness	Poor	Good	poor	----
b) Into blind hole	Poor	Poor	Poor	Limited	very poor	----
Scalable to wafer size	up to large	up to large	limited	up to large	up to large	up to large

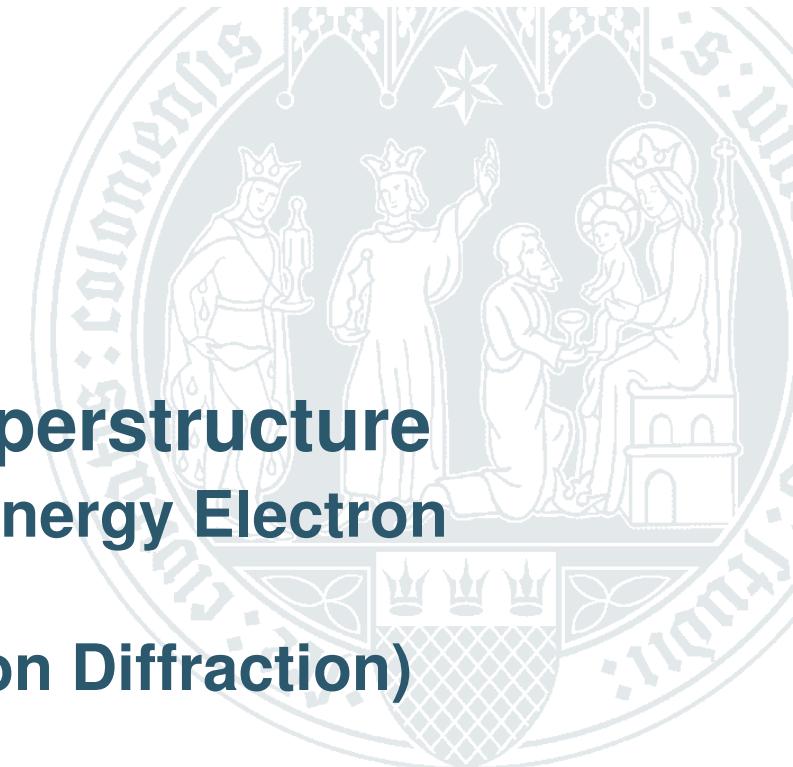
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- Characterization
 - Examples and properties



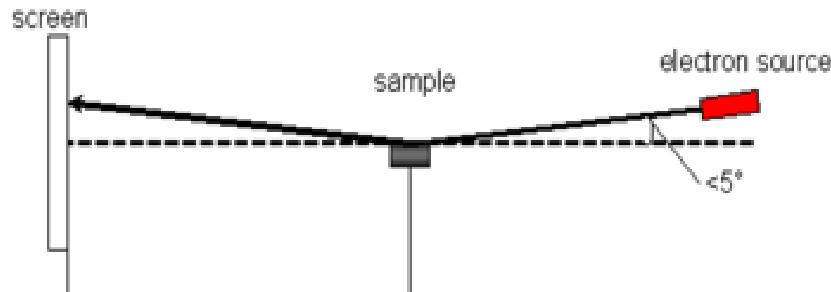
Characterization

- **Structure/Orientation/Superstructure**
 - RHEED (Reflection High Energy Electron Diffraction)
 - LEED (Low Energy Electron Diffraction)
- **Electronic Structure**
 - XPS (X-ray Photoelectron Spectroscopy)
 - XAS (X-ray Absorption Spectroscopy)
- **Magnetic Properties**
 - MOKE (Magneto-Optic Kerr Effect)

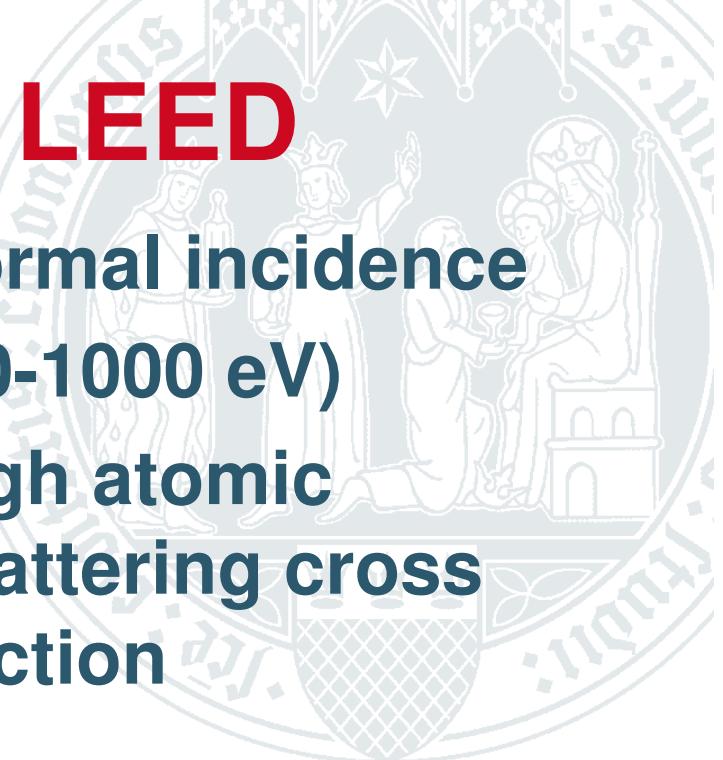


RHEED

- Grazing angle
- (10-50 keV)
- => strong forward elastic scattering

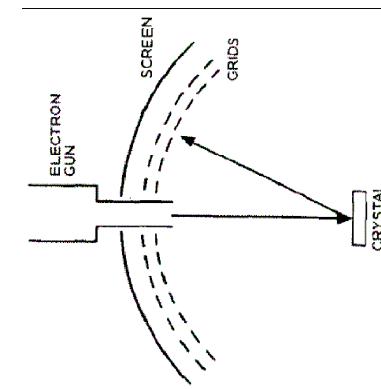


=> surface sensitivity

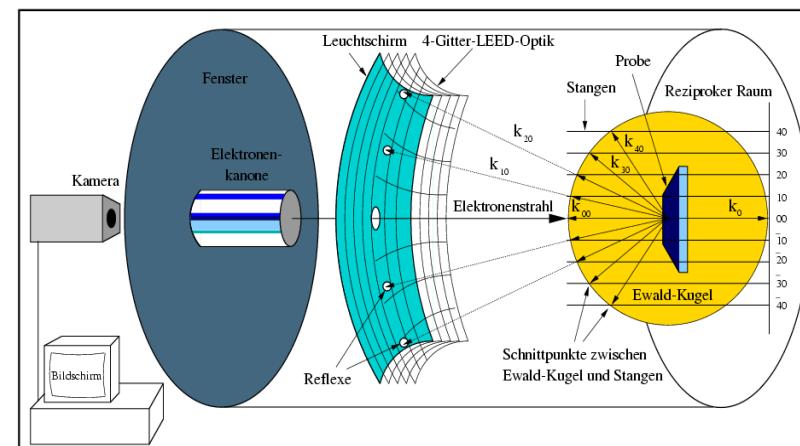
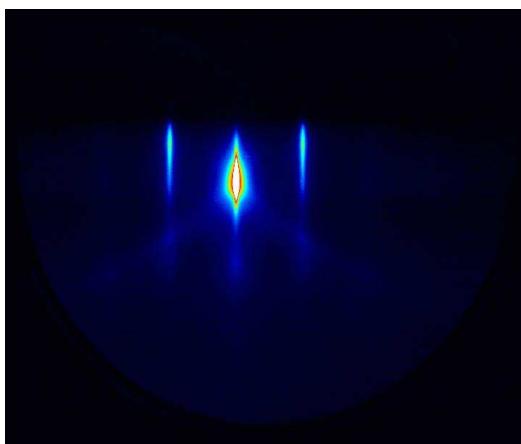
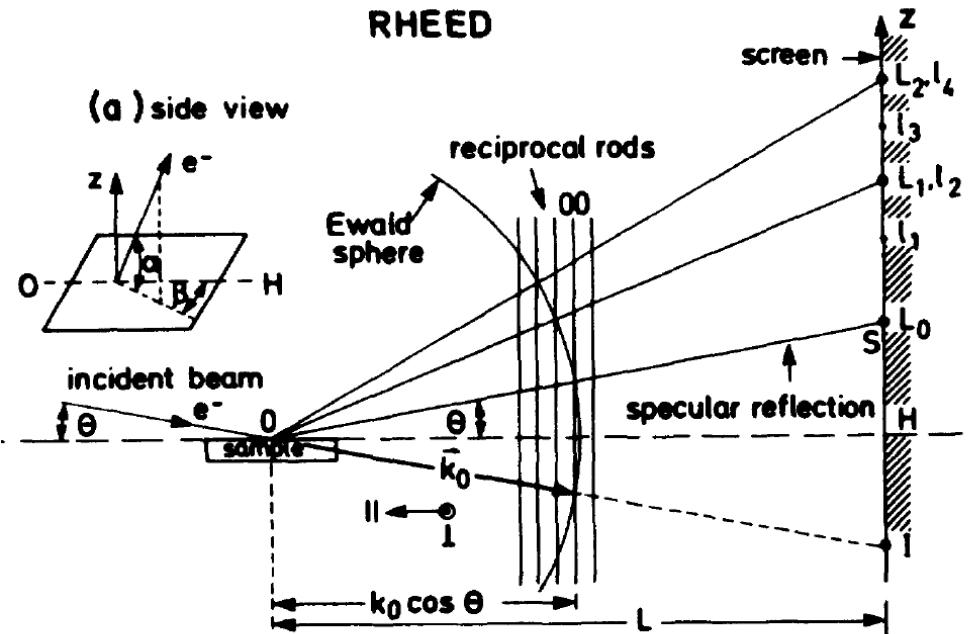


LEED

- Normal incidence
- (10-1000 eV)
- High atomic scattering cross section



RHEED

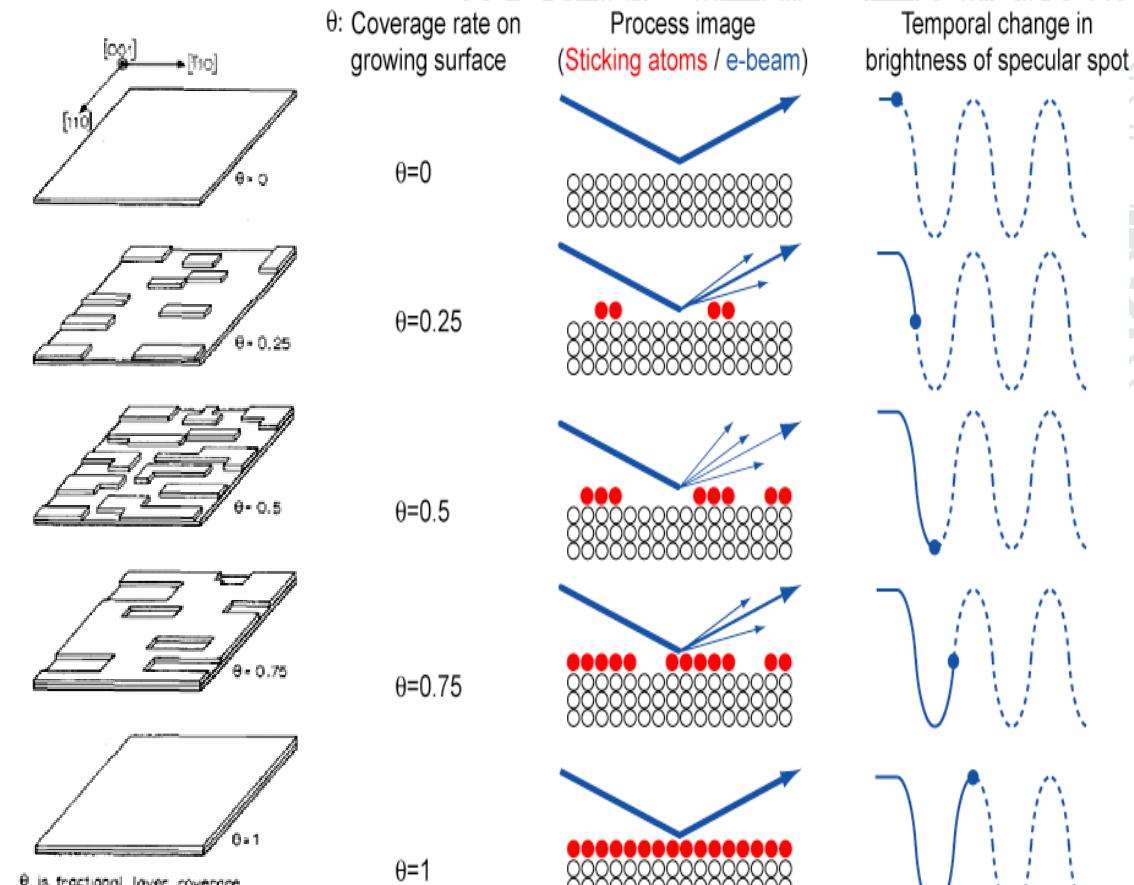
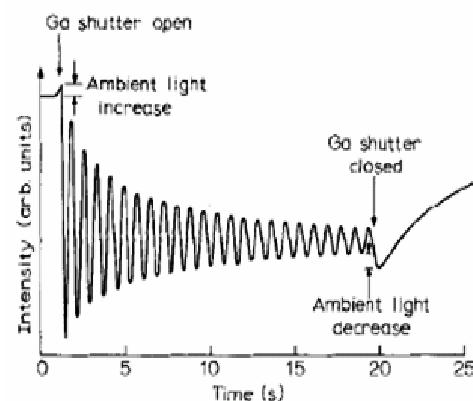


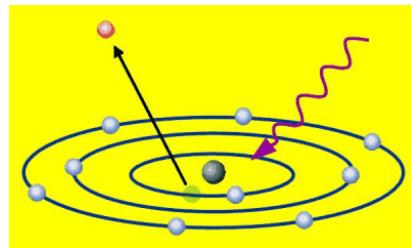
250 nm Ag on MgO (001)



RHEED Oscillations

Intensity ~ coverage

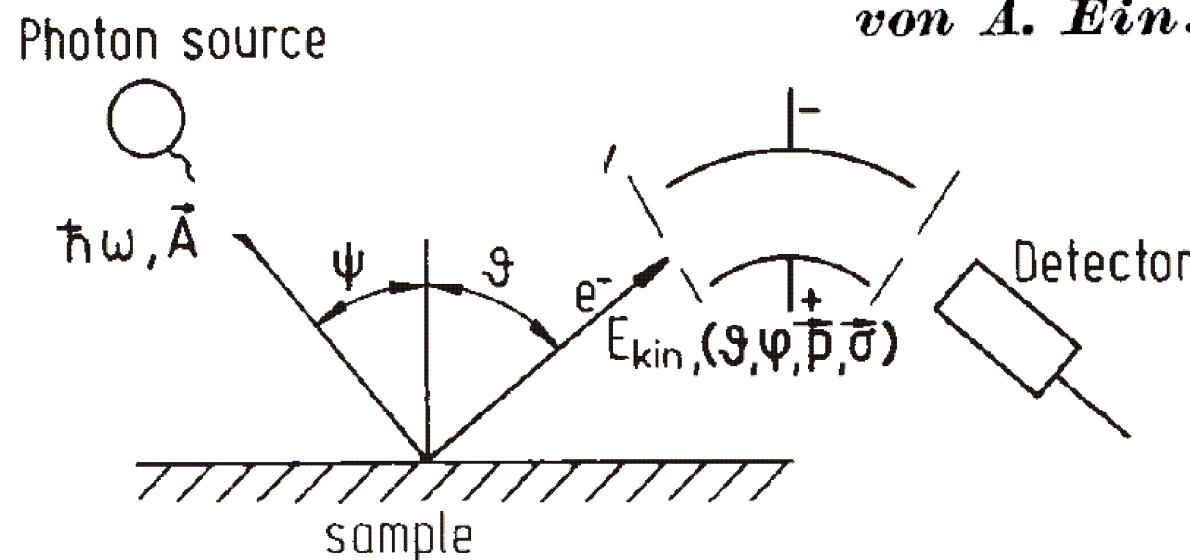




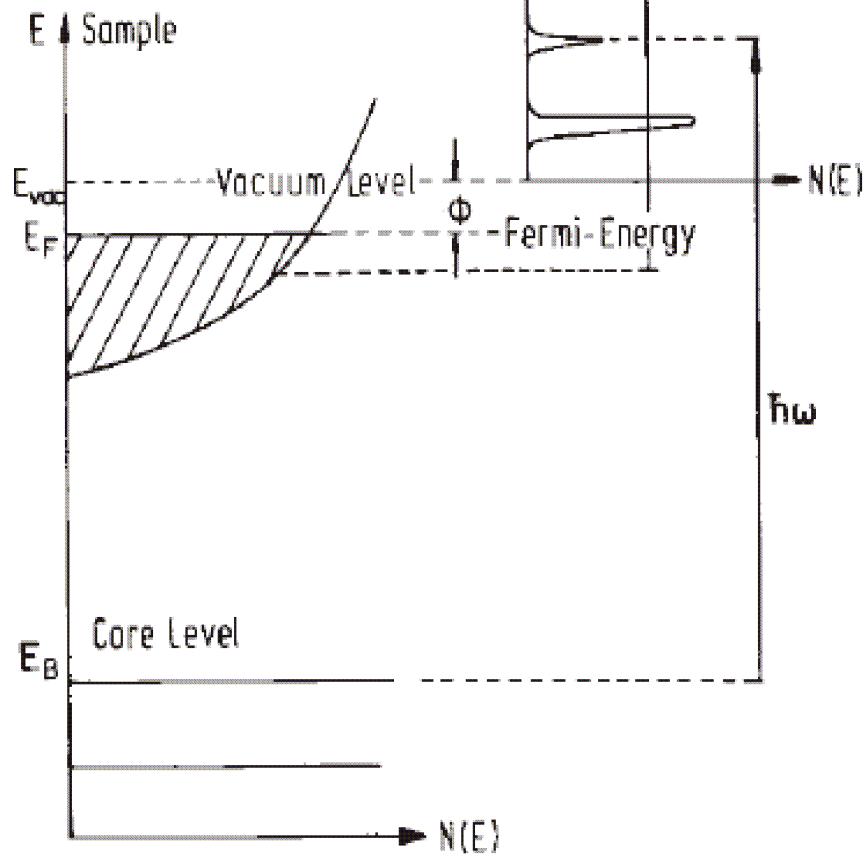
XPS x-ray Photoelectron Spectroscopy



*Über einen
die Erzeugung und Verwandlung des Lichtes
betreffenden heuristischen Gesichtspunkt;
von A. Einstein.*



XPS



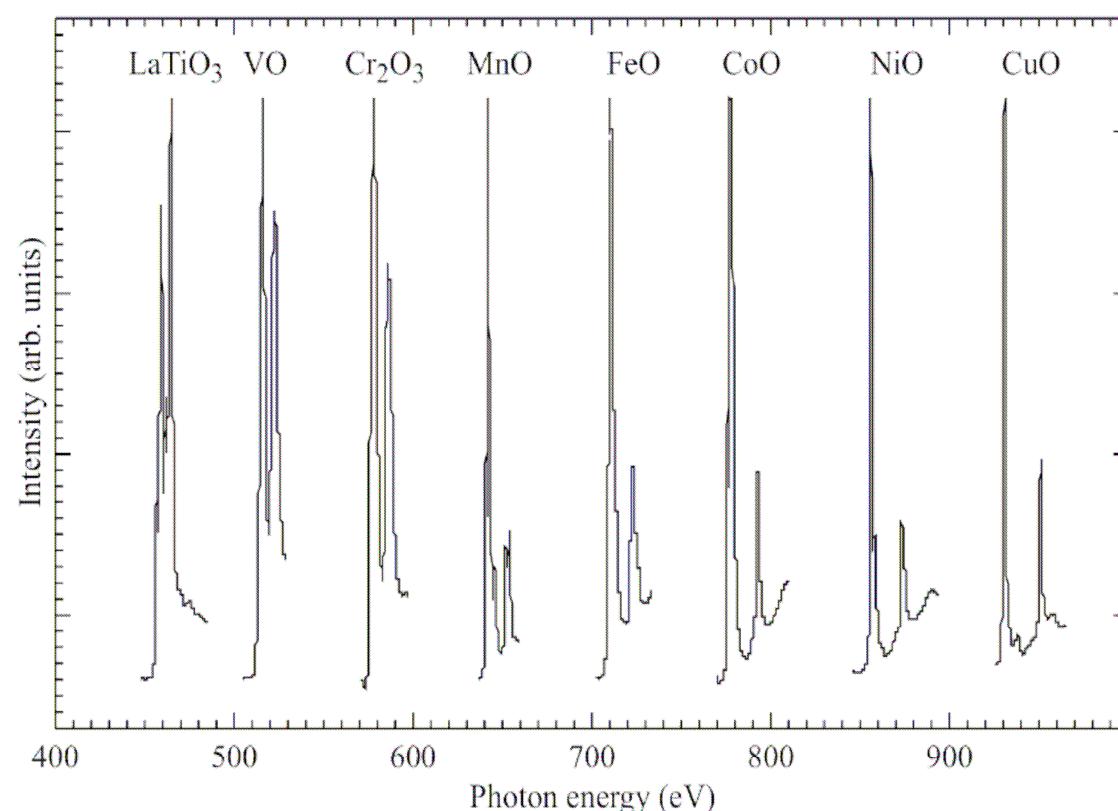
- Characteristic binding energies identify chemical composition
- Strong e-e interaction => small probing depth.

$$E_{kin} = \hbar\omega - |E_B| - \Phi$$



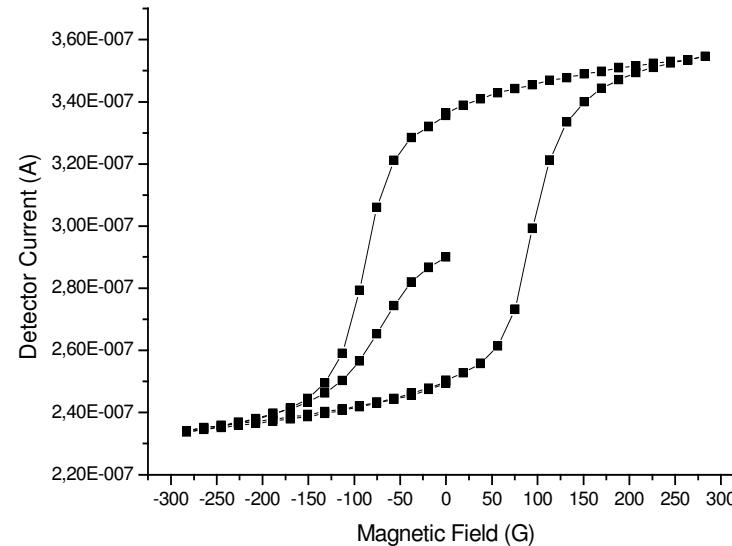
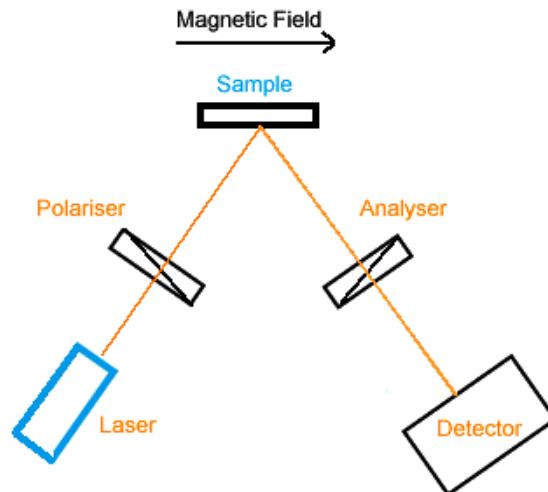
XAS X-ray Absorption Spectroscopy

- **Absorption is energy (300 to 3500 eV) dependent**
- **Site and symmetry selective**
- **Dipole selection rule**



L absorption edges of different transition metal compounds

MOKE Magneto-optic Kerr effect



- **Rotation of polarization axis of linear polarized light reflected from magnetic surface**

$$I = I_0 \sin^2 \varphi + I_{background}$$



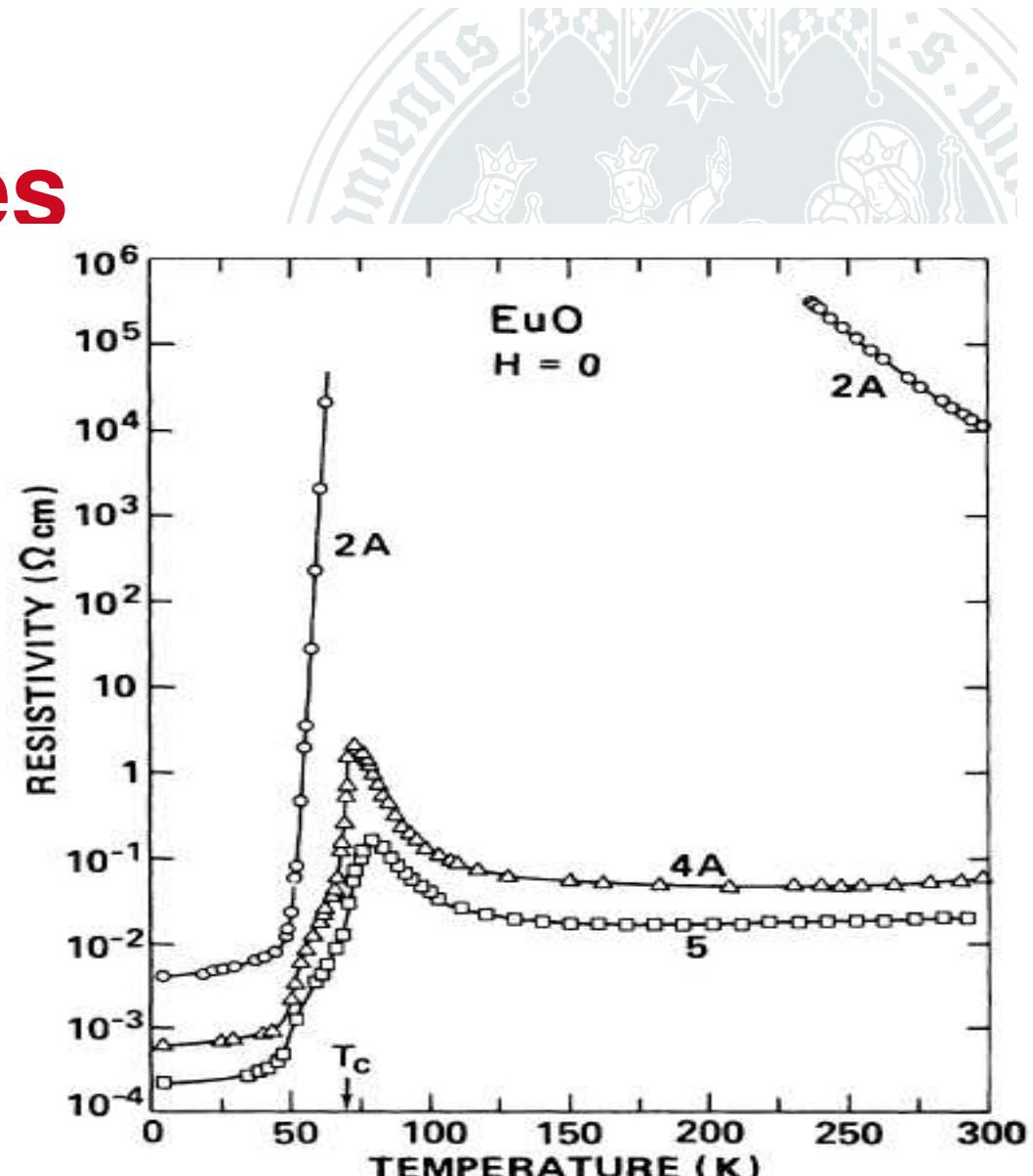
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EuO properties

- Ferromagnetic semiconductor ($T_c=69\text{K}$)
- NaCl - Structure ($a=5.14\text{\AA}$)
- Band gap = 1.2 eV
- CMR, large magneto-optic effects
- Huge MIT



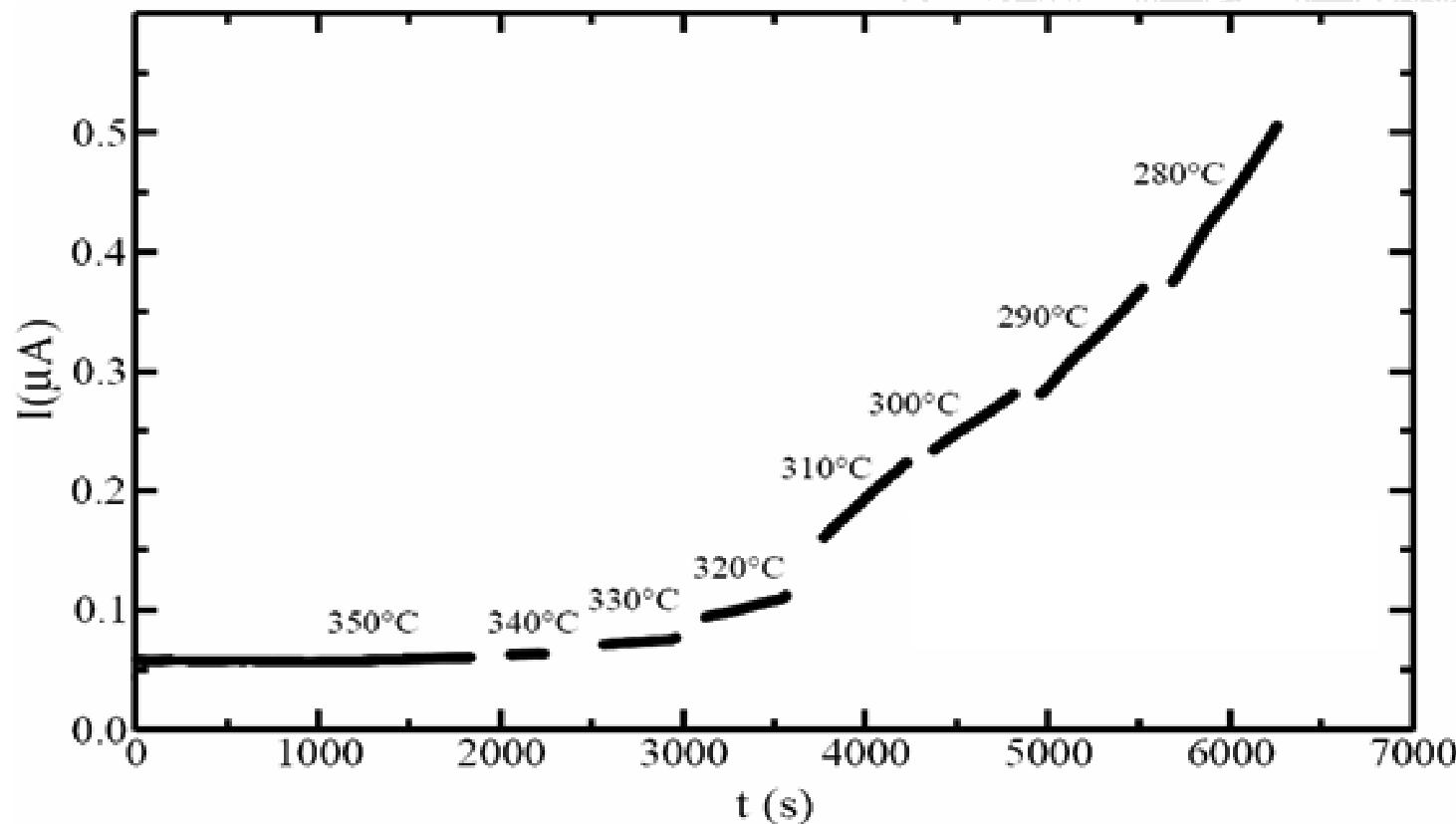
- EuO as thin film?
 - Preparation as bulk crystal needs high temperatures
 - Difficult to make stoichiometric



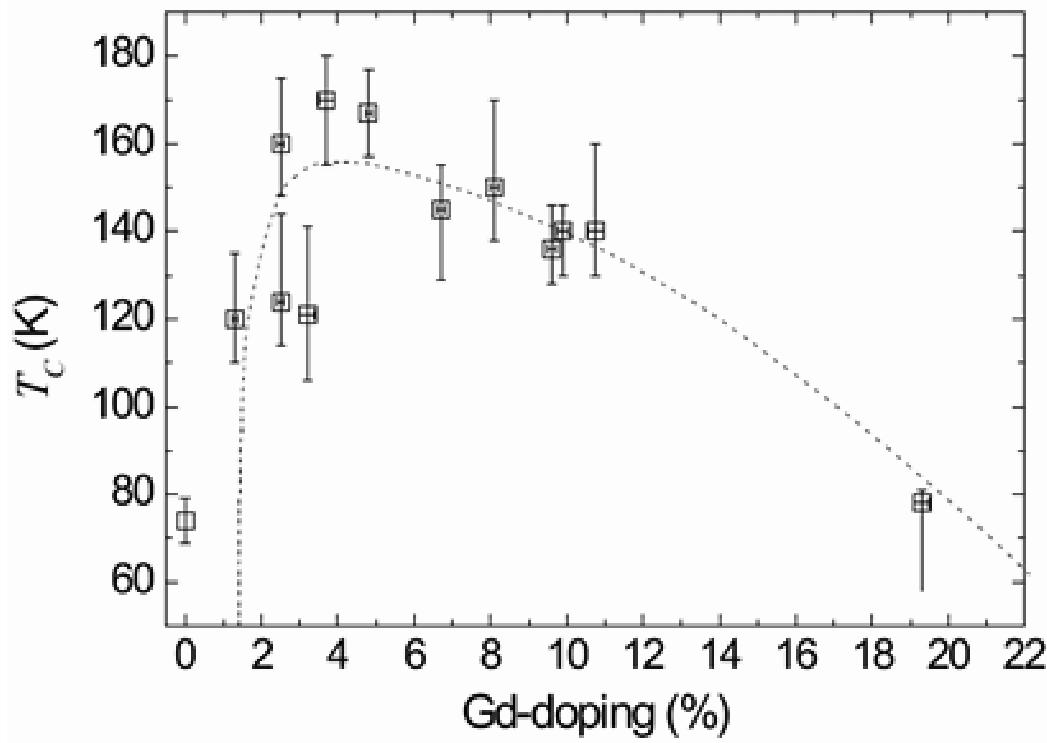
=> Thin films => distillation method



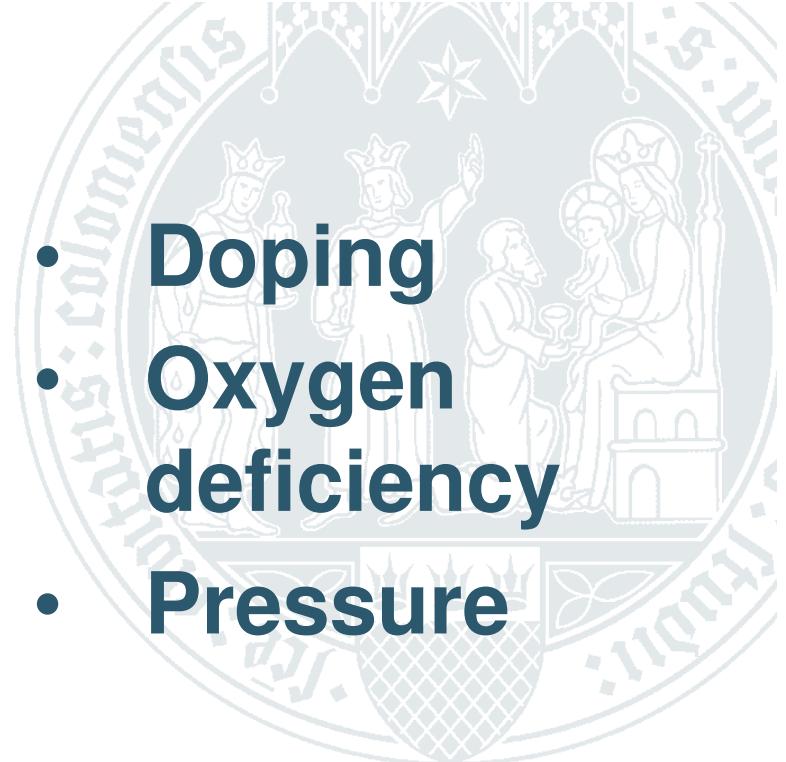
Distillation method



Tc Tuning



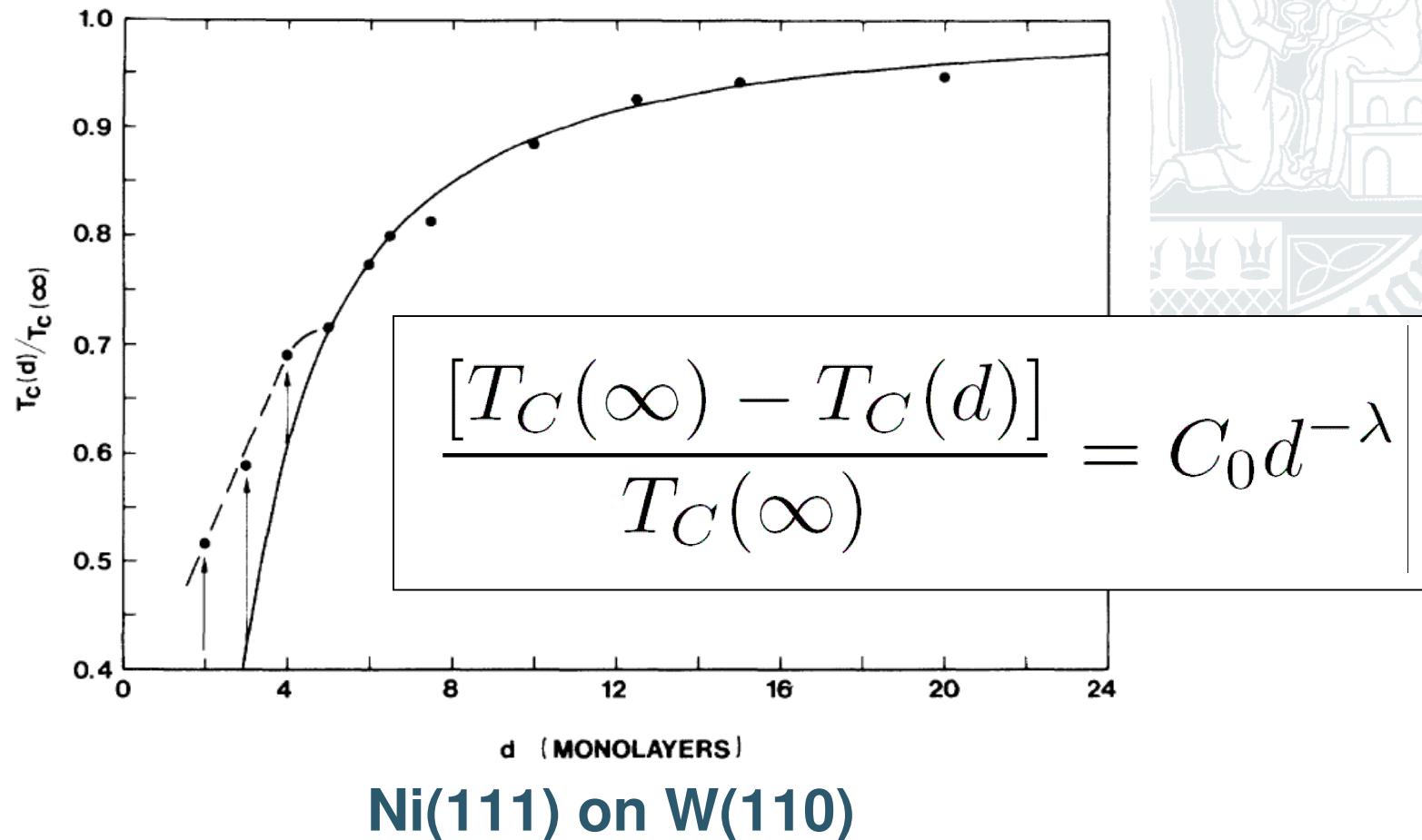
PRB 73, 094407 (2006)



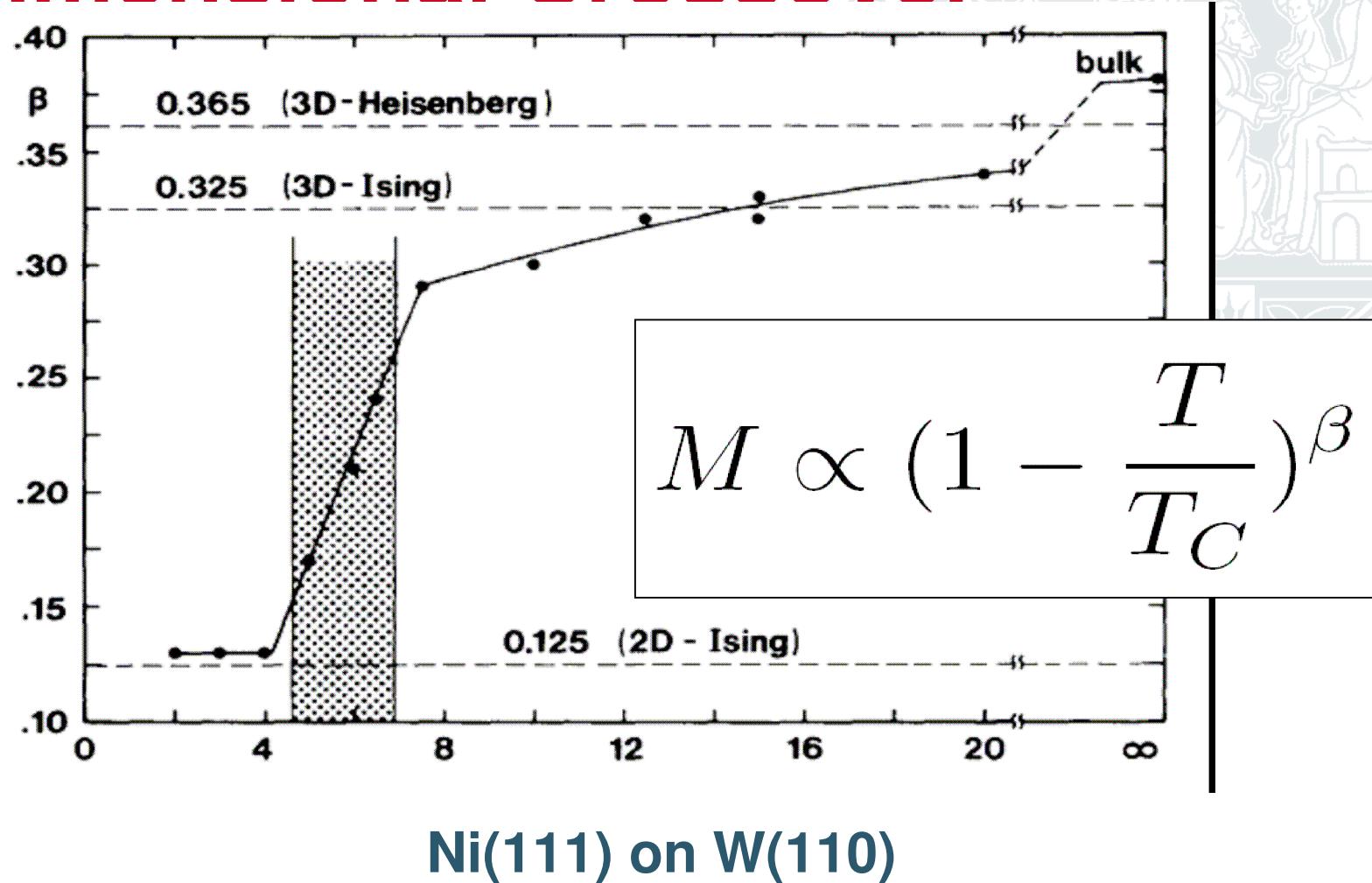
$\text{Eu}_{1-x}\text{Gd}_x\text{O}$



Dimensional Crossover



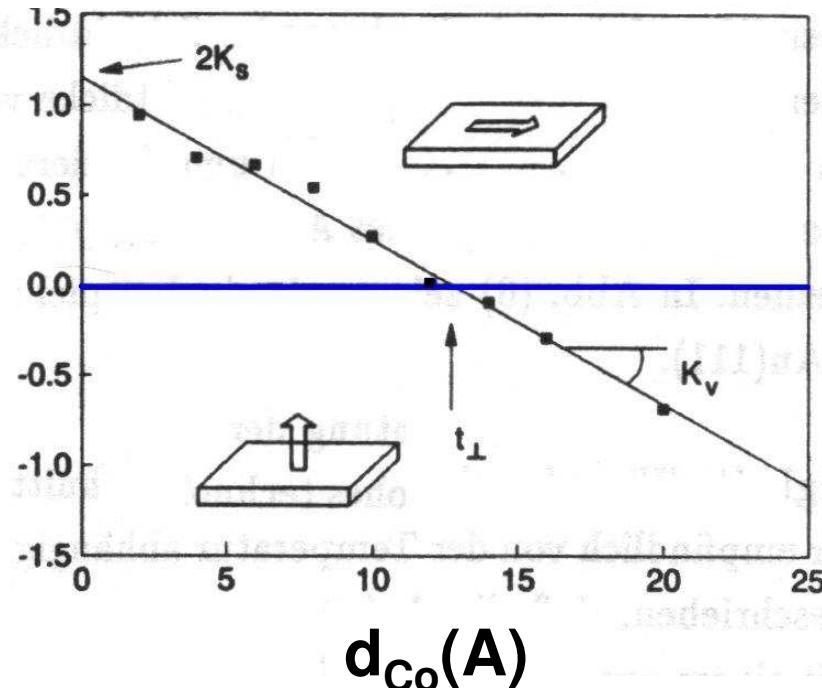
Dimensional Crossover



Ni(111) on W(110)

Spinorientation transition

$$K^{\text{eff}} \times d_{\text{Co}} (\text{mJ/m}^2)$$

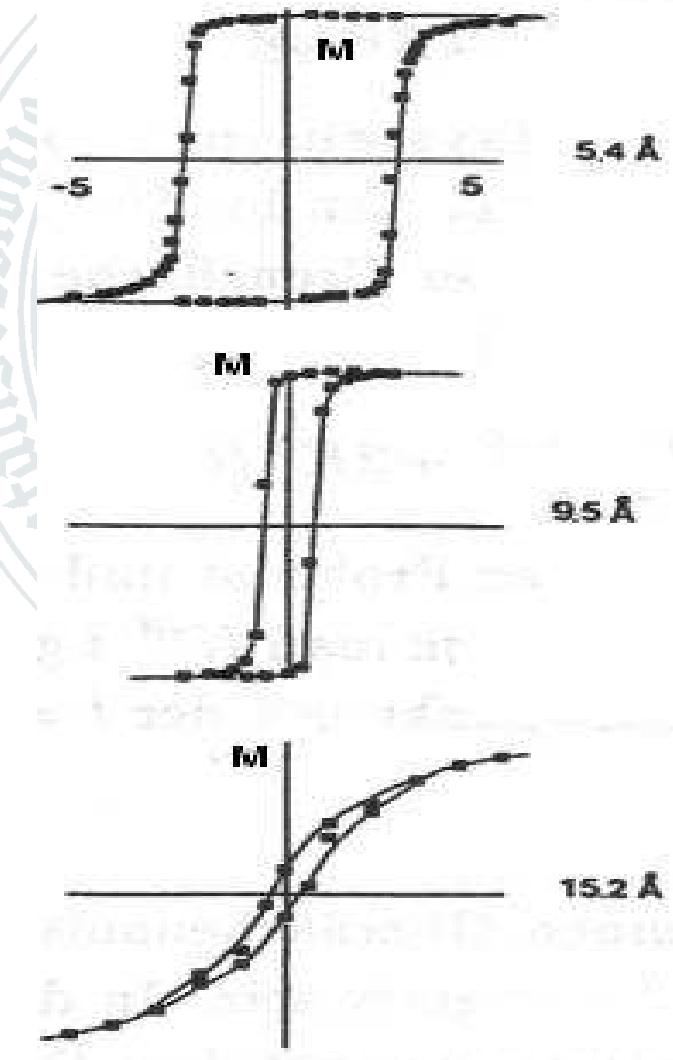


Magnetic anisotropy

$$K^{\text{eff}} = K^v + 2K^s / d_{\text{Co}}$$

$$K^{\text{eff}} \cdot d_{\text{Co}} = K^v \cdot d_{\text{Co}} + 2K^s$$

Co/Pd



Magnetization of
Au/Co(001)/Au(111) at T= 10K

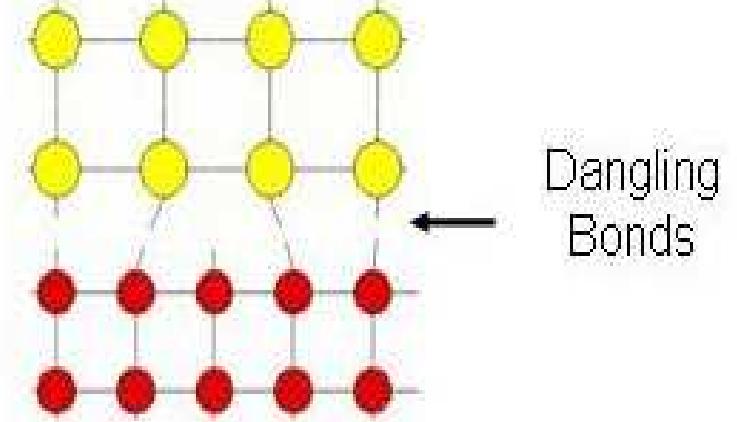
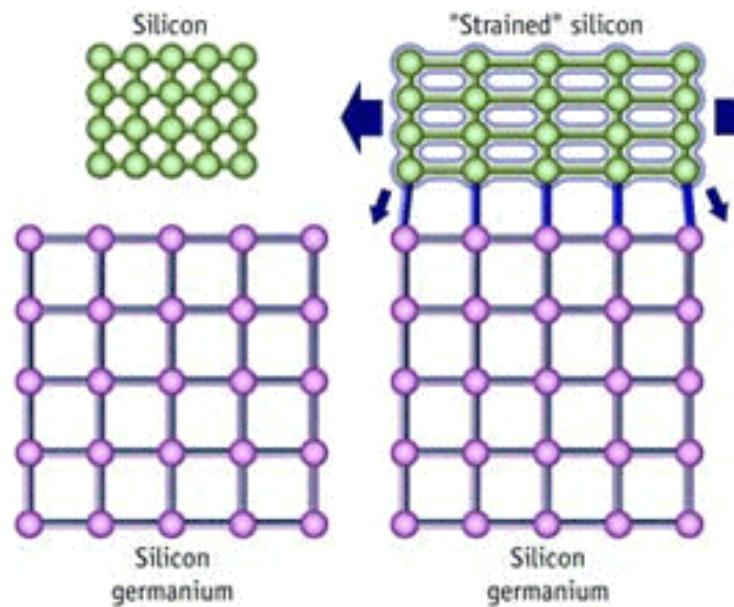


Summary

- **Different preparation methods**
- **New materials , new effects**
- **Surface physics multilayer**



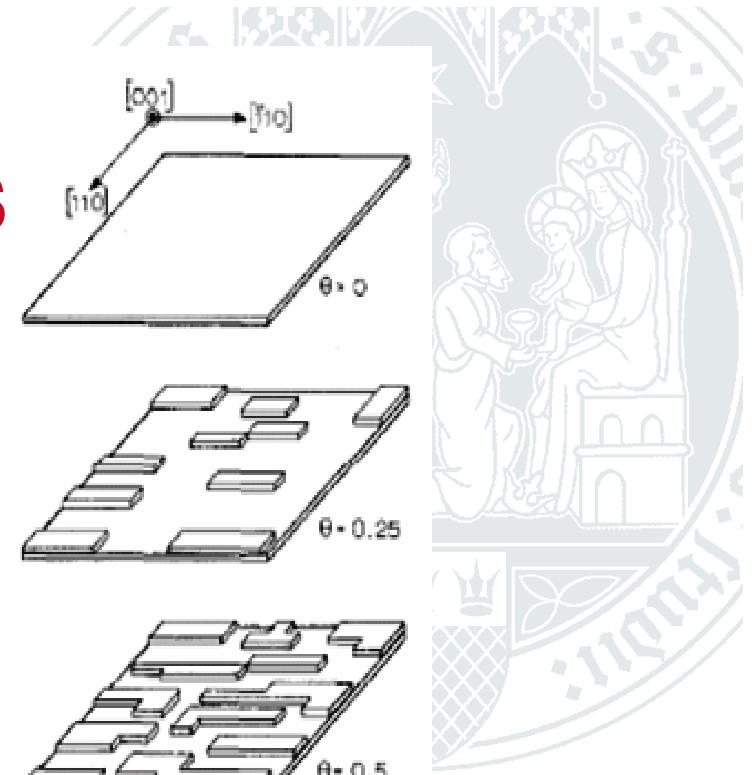
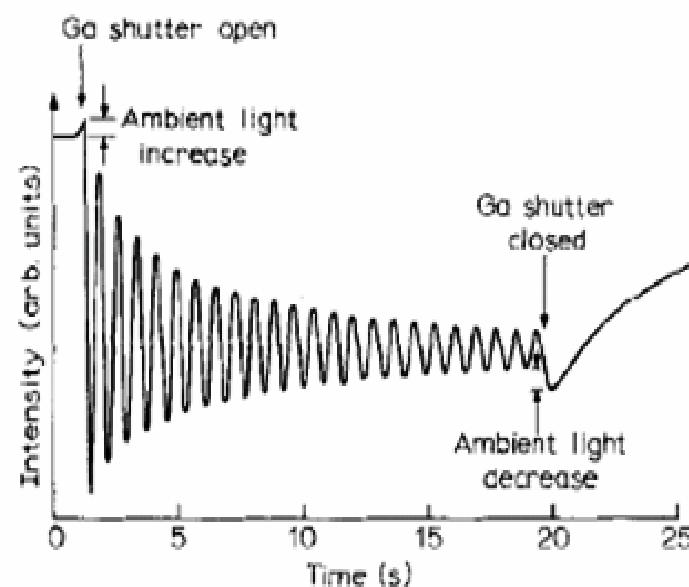
Lattice mismatch



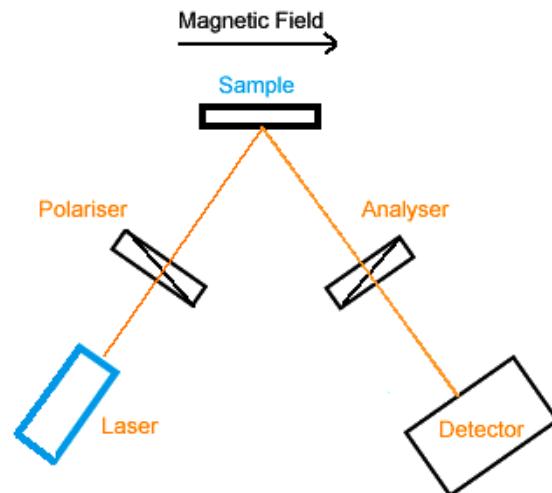
RHEED Oscillations

Intensity ~ coverage

Intensity decrease due to multilayer statistic averaging



MOKE Magneto-optic Kerr effect



The Kerr effect manifests itself in the **change of**

- **polarization** (polar and longitudinal effect)
- **intensity** (transverse effect)

of polarized light when reflected from the surface of a magnetized medium.

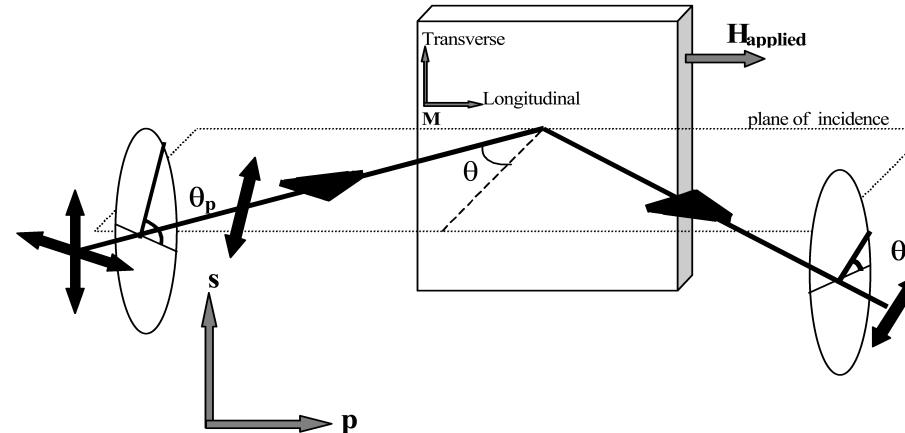
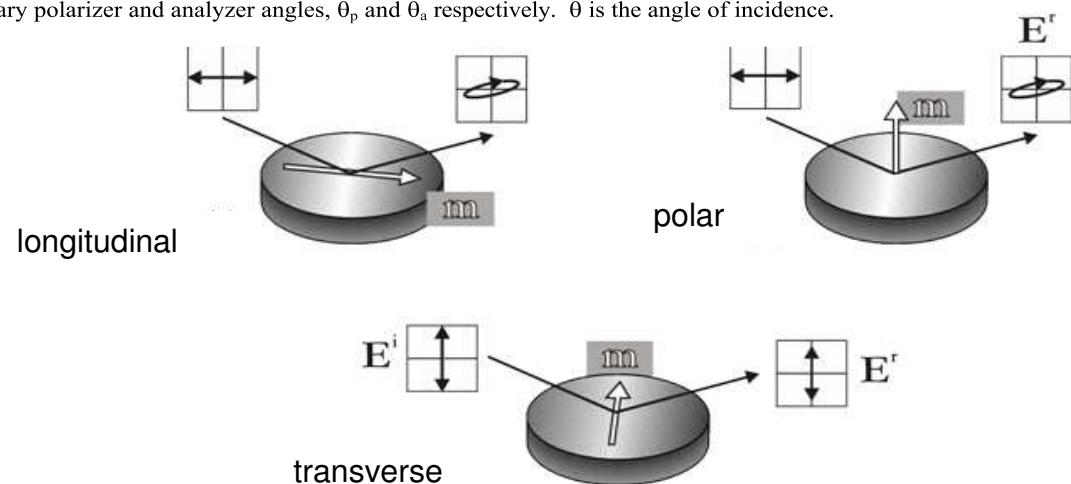


Figure 1: Geometry of reflection off a magnetized sample with magnetization components in the transverse and longitudinal directions. Orientation of the $\hat{\mathbf{p}}$ and $\hat{\mathbf{s}}$ directions is shown, as well as arbitrary polarizer and analyzer angles, θ_p and θ_a respectively. θ is the angle of incidence.

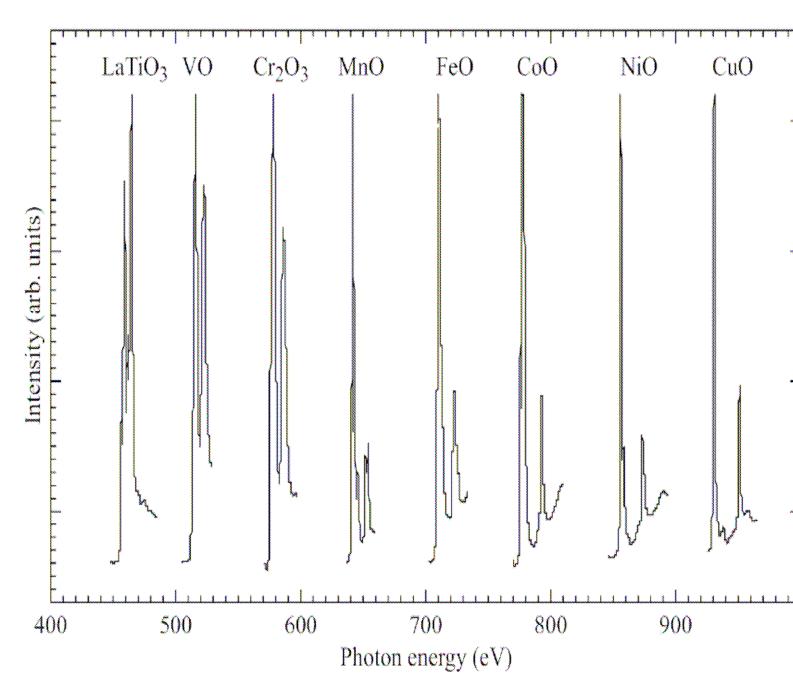


XAS X-ray Absorption Spectroscopy



- **Absorption is energy (300 to 3500 eV) dependent**
- **Symmetry and site selective**

$$w = \frac{2\pi}{\hbar} \sum_f |\langle f | P | i \rangle|^2 \delta(E_i - E_f - \hbar\omega)$$
$$P = e^{i\frac{\omega}{c}\hat{\mathbf{n}} \cdot \mathbf{r}} \mathbf{p} \cdot \hat{\mathbf{e}} \quad \approx \quad \mathbf{p} \cdot \hat{\mathbf{e}}$$

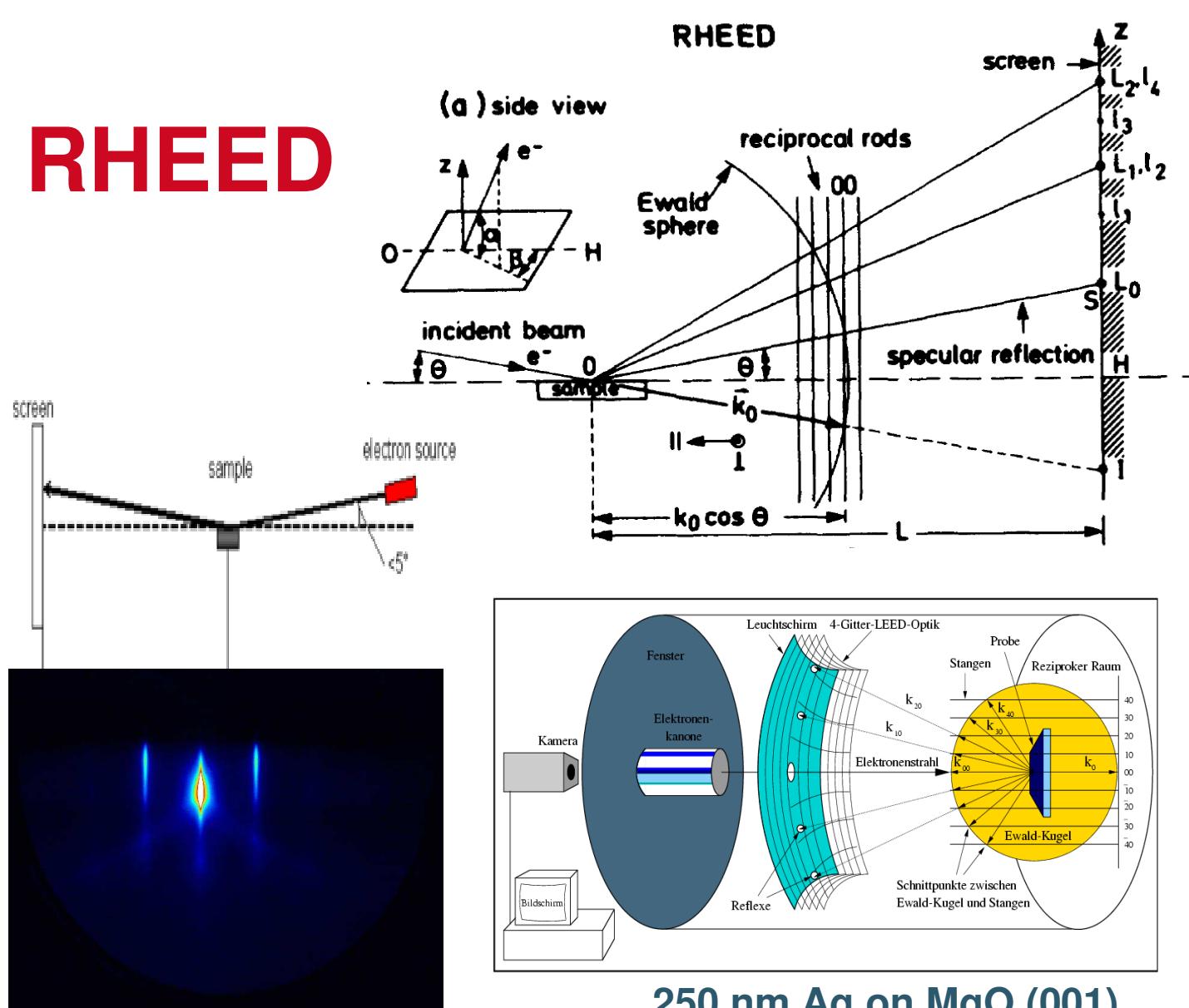


L absorption edges of different transition metal compounds

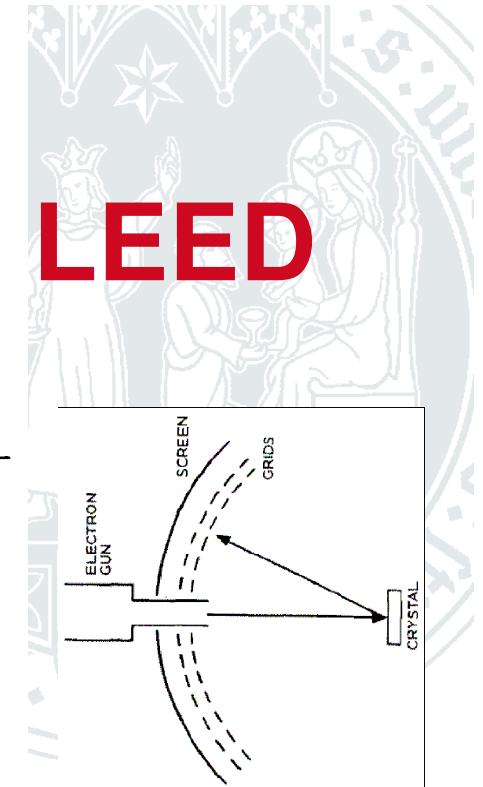
- **Dipole selection rule**



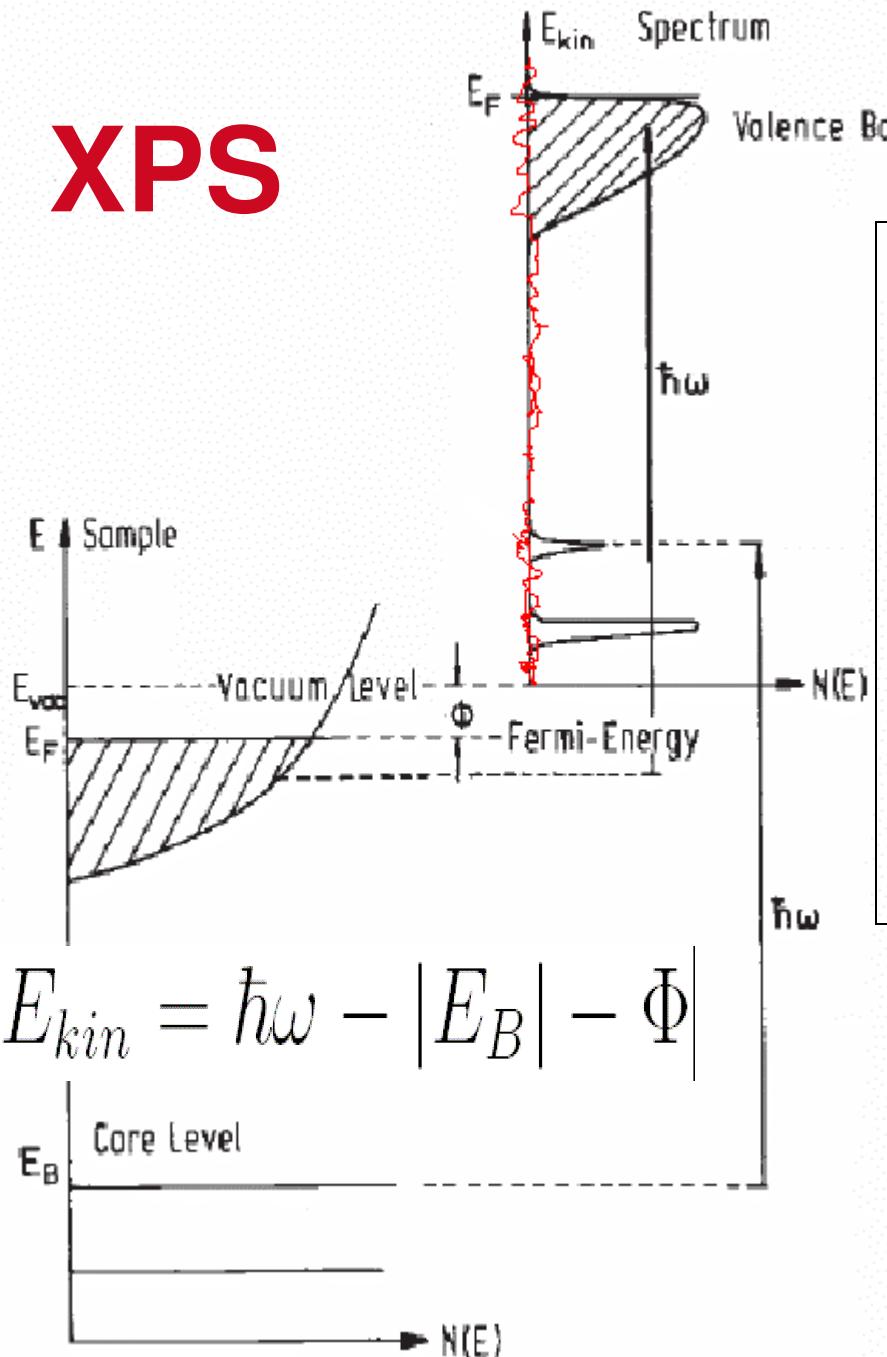
RHEED



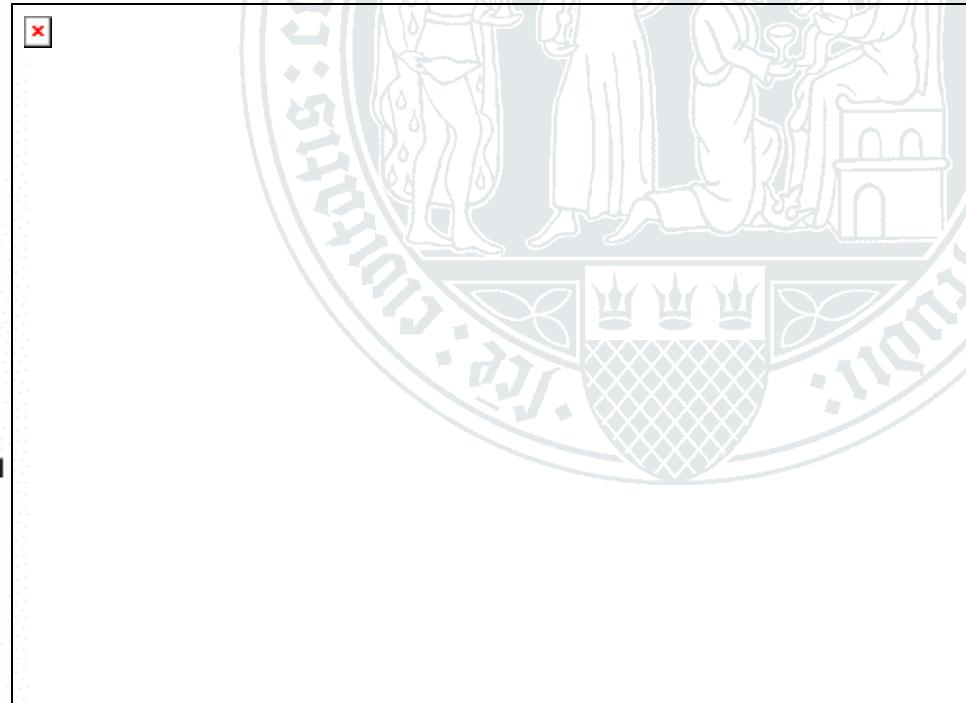
250 nm Ag on MgO (001)



XPS



- Probing depth mean free path dependent.



- statistic distribution of inelastic scattered electrons.