

# Moderní experimentální metody

## Rentgenová a elektronová spektroskopie I

Spektroskopie absorpční hrany rtg záření

- Principy, experimentální realizace
- Metody: XANES, EXAFS
- Postupy vyhodnocení dat, příklady
- Magnetismus – XMCD
- RIXS

# Moderní experimentální metody

## Rentgenová a elektronová spektroskopie II

### Anomální rtg difrakce

- Kramersovy-Kronigovy relace
- Anomální difrakce – principy, použití
- DAFS

### Fluorescenční spektroskopie

- Spektroskopie charakteristického záření (XRF, EDS, WDS)
- Kvalitativní a kvantitativní analýza
- TRXRF
- Fluorescence ve stojaté vlně (SW-XRF) – rtg reflexe, difrakce

# Moderní experimentální metody

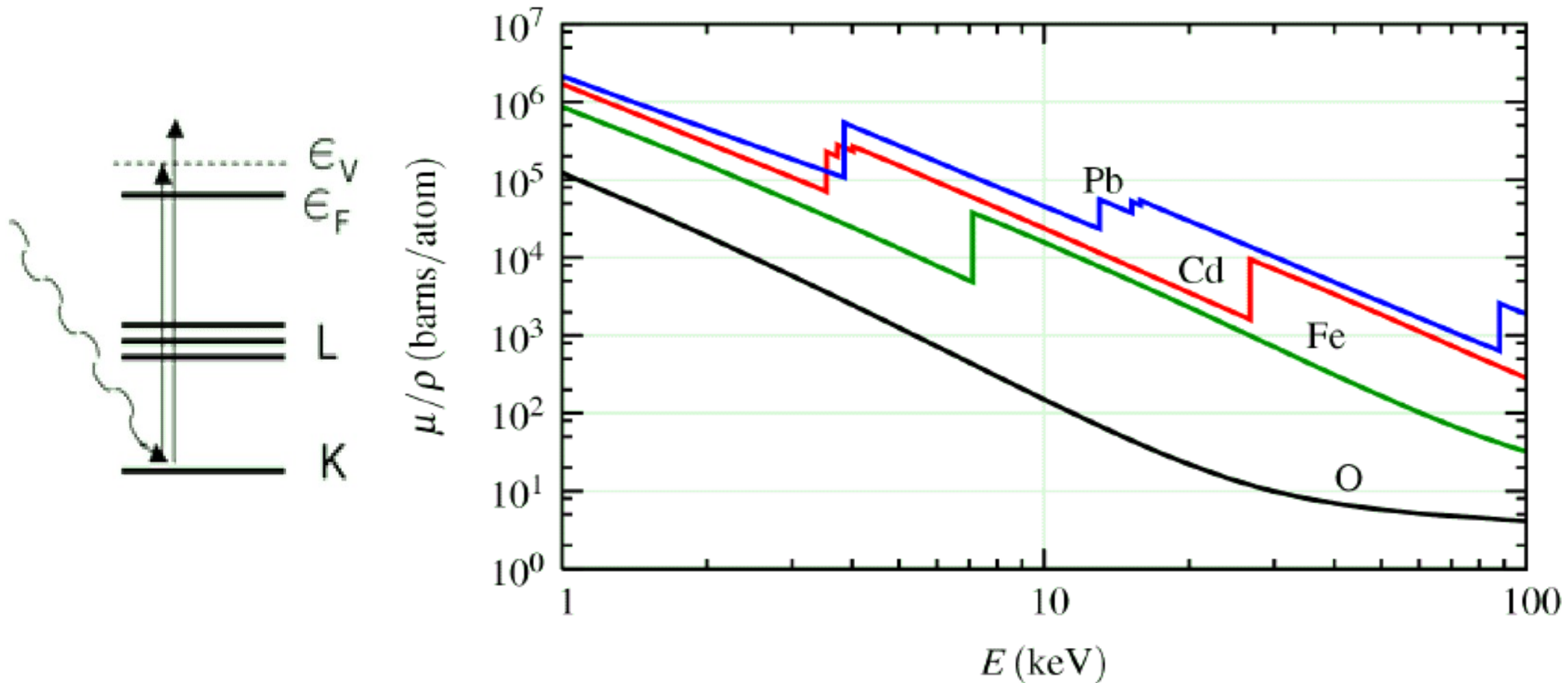
## Rentgenová a elektronová spektroskopie III

### Fotoelektronová spektroskopie

- Fotoelektronová spektroskopie (XPS) a spektroskopie Augerových elektronů (AES)
- Úhlově rozlišená fotoelektronová spektroskopie (ARPES)
- Experimentální aspekty
- Zdroje: ARPES, ARUPS
- Detektory
- Příprava vzorků

# Absorpce rtg záření

Ionizace hluboké elektronové hladiny – absorpční hrana.



Závislost absorpce na vlnové délce pro olovo ( $Z=82$ ).

Empirická závislost absorpce na energii mimo absorpční hranu:

$$\alpha(\epsilon) = \frac{a}{\epsilon^3} + \frac{b}{\epsilon^4},$$

# Index lomu pro rtg

- Filtrace záření – Ni filtr pro Cu, buď jako vrstva různé tloušťky, nebo v multivrstvě
- $n(\lambda) = 1 - \delta(\lambda) = 1 - \delta'(\lambda) + i\beta(\lambda)$
- Indexu lomu: reálná část – refrakce  
imaginární část – absorpce
- $E = E_0 \exp(iKnr) = E_0 \exp(iKr) \exp(-iK\delta'r) \exp(-K\beta r)$
- Intenzita při absorpci:  
 $I = I_0 \exp(-\mu z) = |E|^2 = I_0 \exp(-2K\beta z)$   
 $\mu(\lambda) = 4\pi\beta(\lambda) / \lambda$

# X-ray optical properties

Dielectric function (Drude):

$$\varepsilon(\omega) = 1 - ne^2 / [\varepsilon_0 m \omega (\omega + i/\tau)]$$

High frequency limit:

$$\varepsilon(\omega) \approx 1 - ne^2 / [\varepsilon_0 m_e \omega^2]$$

$$\varepsilon(\omega) \approx 1 - NZr_e \lambda^2 / \pi < 1$$

$$r_e = e^2 / [4\pi\varepsilon_0 m_e c^2] = 2.8179 \cdot 10^{-15} \text{ m}$$

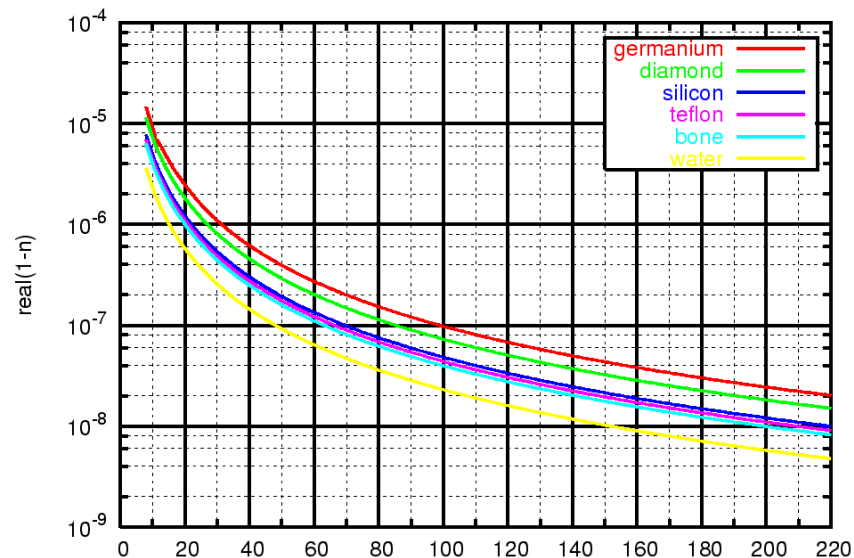
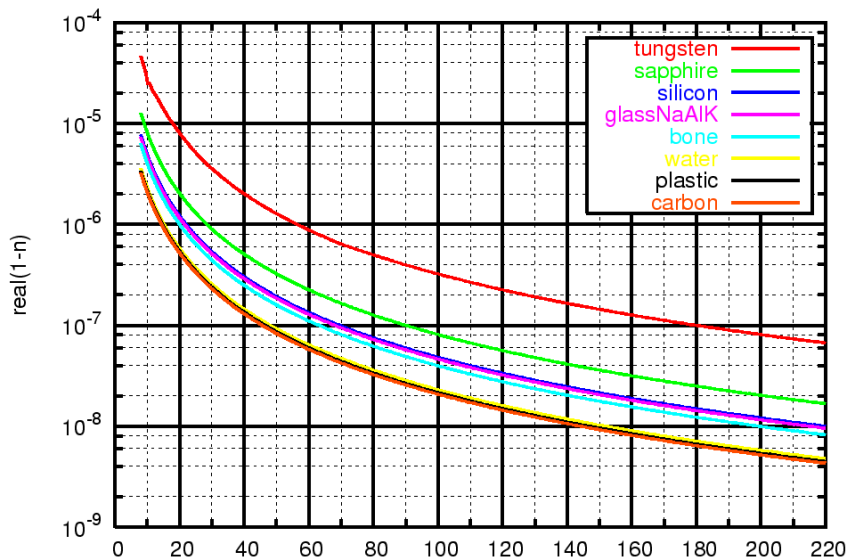
$$n = 1 - \delta + i\beta = 1 - (\delta_0 - i\beta_0) \rho_{\text{rel}}$$

$$\delta \approx -NZr_e \lambda^2 / \pi$$

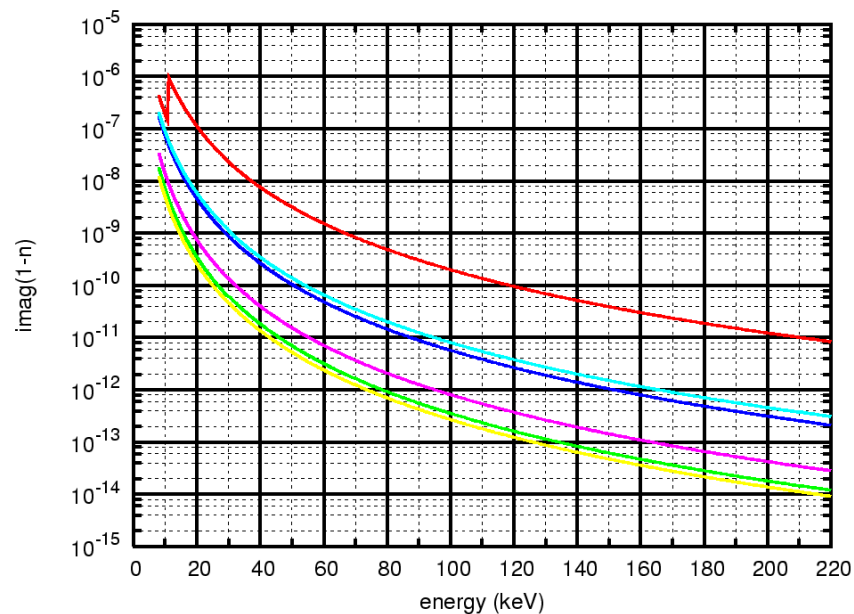
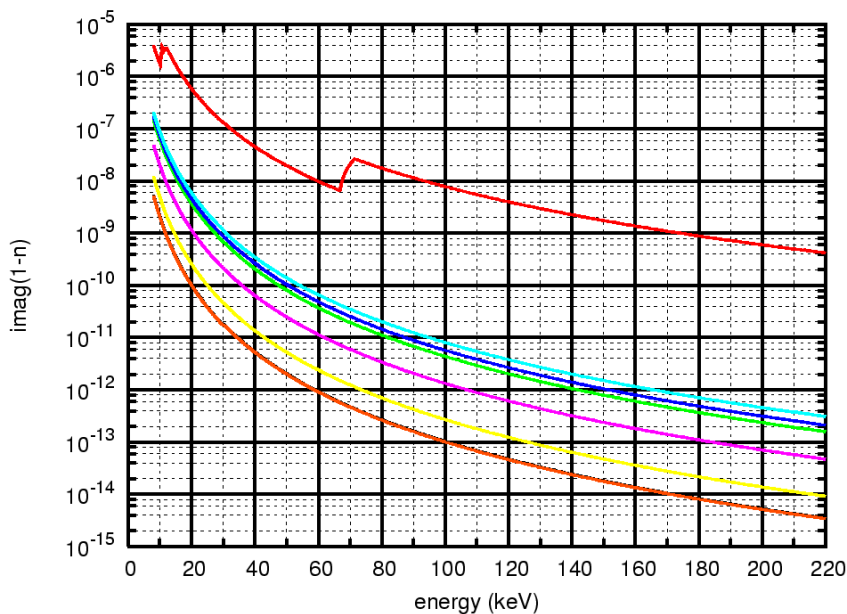
Electron density = proton density  $\sim$  mass density

# Dekrement indexu lomu $\delta(E)=1-n(E)$ : závislost reálné a imaginární části na energii

Reálná  
část  
 $\delta \sim E^{-2}$

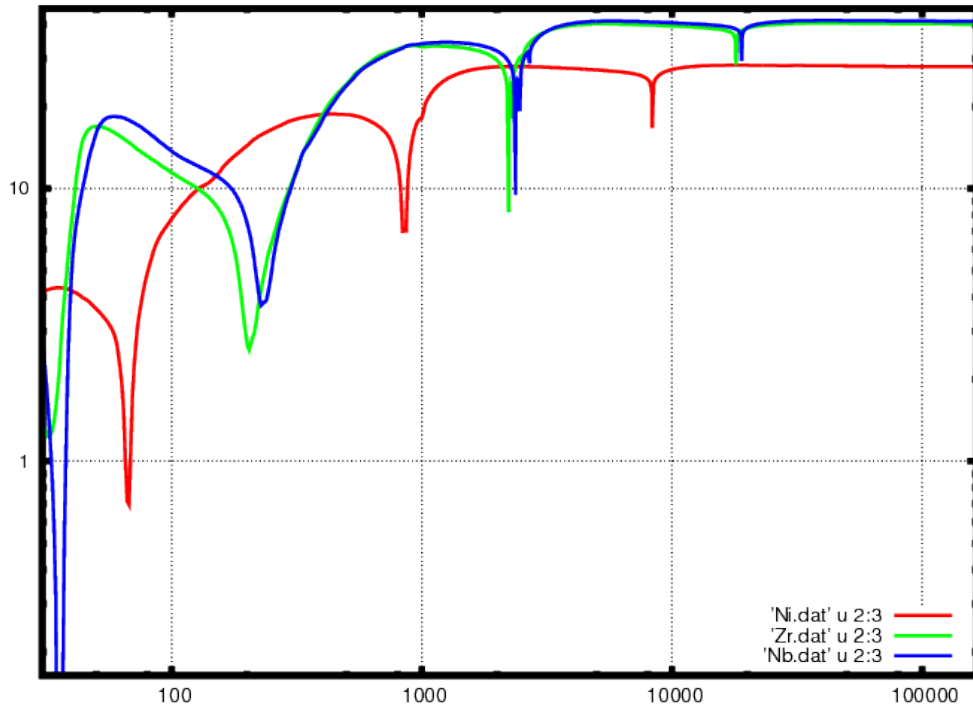


Imaginár  
ní část  
 $\delta \sim E^{-3}$   
→ *Dávka*  
*z ozáření*  
*klesá!*

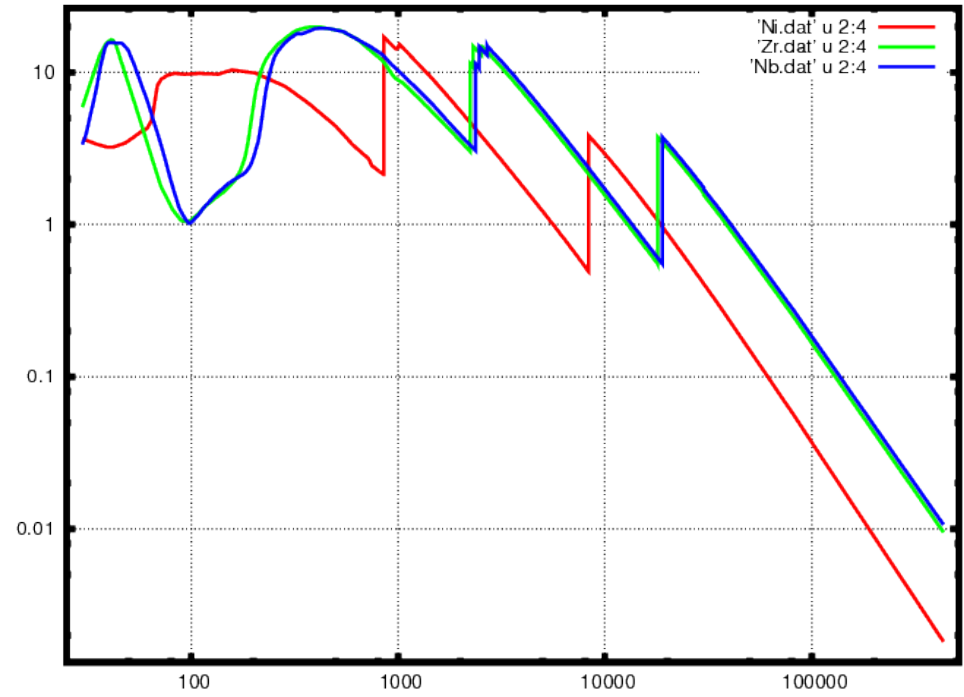


Atomový strukturální faktor  $f(E) = Z + f_1(E) + i f_2(E)$ :

log-log závislost  $f_1$



a  $f_2$  na energii



Výpočet: a.s.f. pro všechny atomy ve vzorci nebo elementární buňce  
 → strukturální faktor → susceptibilita → index lomu

Dopředná vlna – jeden atom:

$$E^{\text{forw}} = f(r_e/r) E^{\text{inc}}$$

Vlnový vektor:

$$k(\mathbf{r}) = n(\mathbf{r}) K, \quad K=2\pi/\lambda$$

$$\rho_{\text{el}} = \text{suma}(f) / V_{\text{elem.b.}}$$

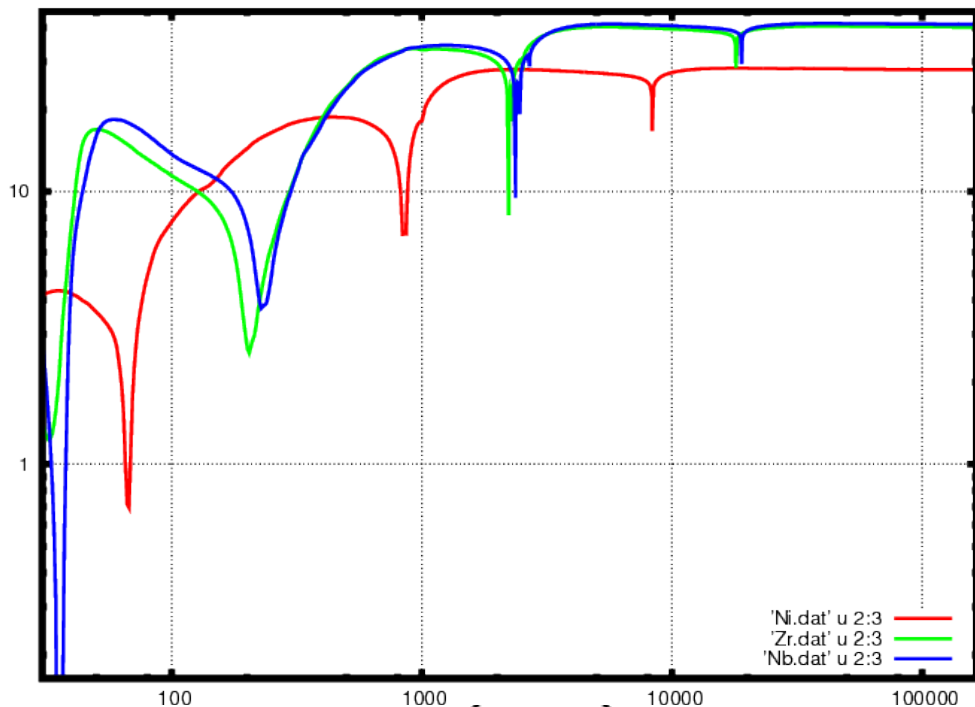
$$\chi = - (r_{\text{el}} \lambda^2/\pi) \rho_{\text{el}}$$

$$n^2 = \epsilon_r = 1 + \chi \rightarrow \delta = -\chi/2$$



Atomový strukturální faktor  $f(E) = Z + f_1(E) + i f_2(E)$ :

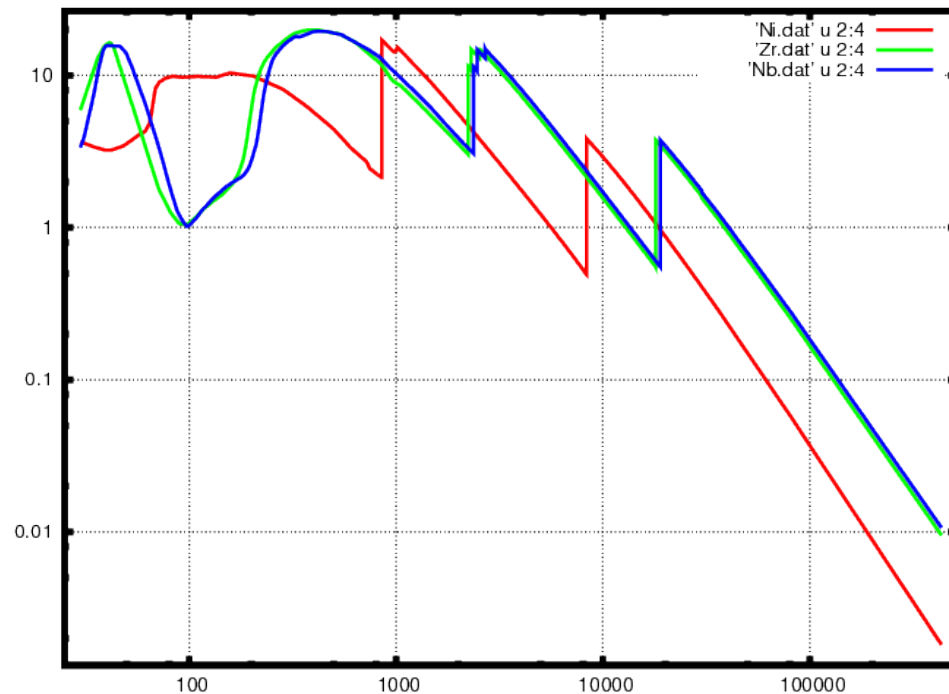
log-log závislost  $f_1$



$$f''(E) = \left( \frac{mcE}{2e^2h} \right) \sigma(E)$$

$$f'(E_0) = \frac{2}{\pi} \int_0^{\infty} \frac{E f''(E)}{(E_0^2 - E^2)} dE$$

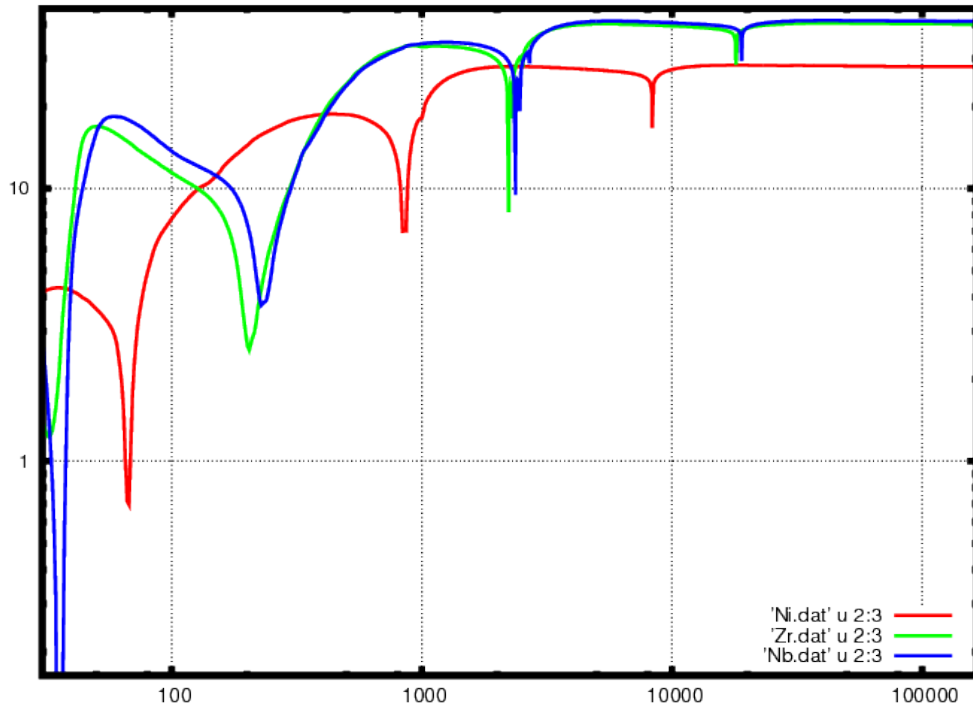
a  $f_2$  na energii



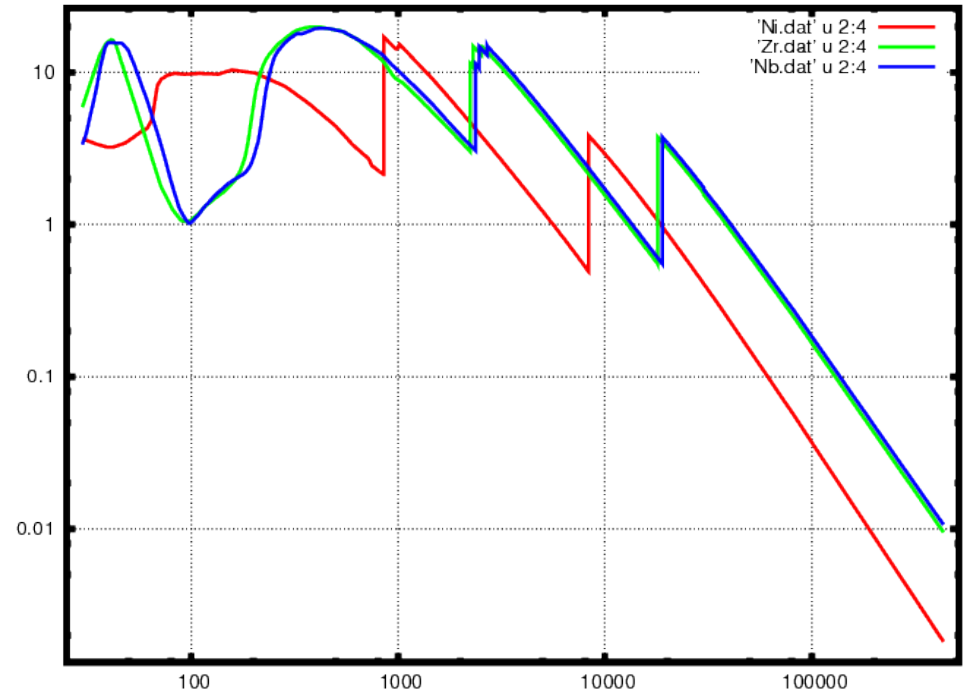
$$f''(E_0) = -\frac{2E_0}{\pi} \int_0^{\infty} \frac{f'(E)}{(E_0^2 - E^2)} dE$$

Atomový strukturní faktor  $f(E) = Z + f_1(E) + i f_2(E)$ :

log-log závislost  $f_1$



a  $f_2$  na energii



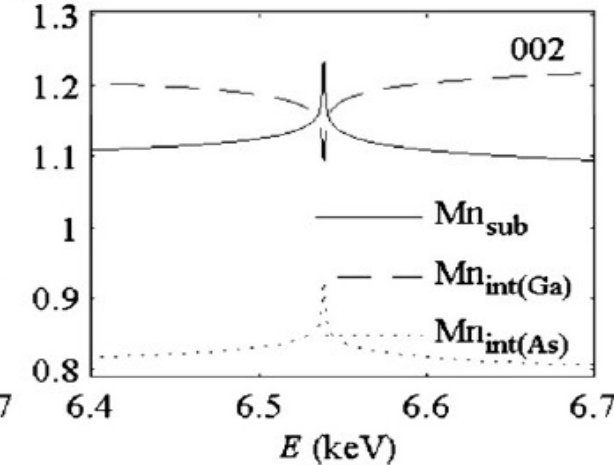
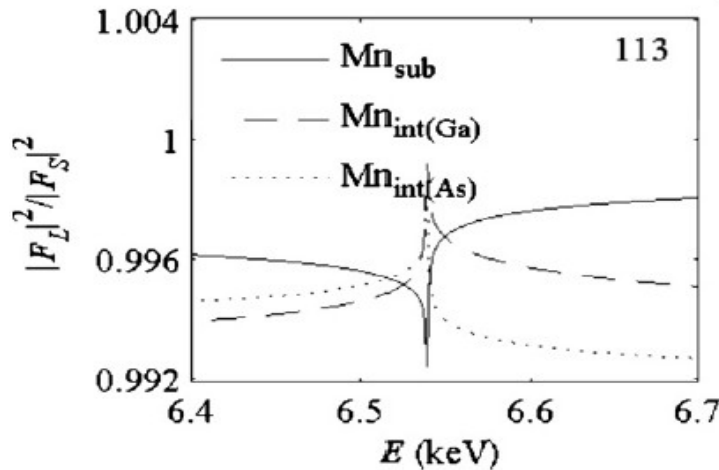
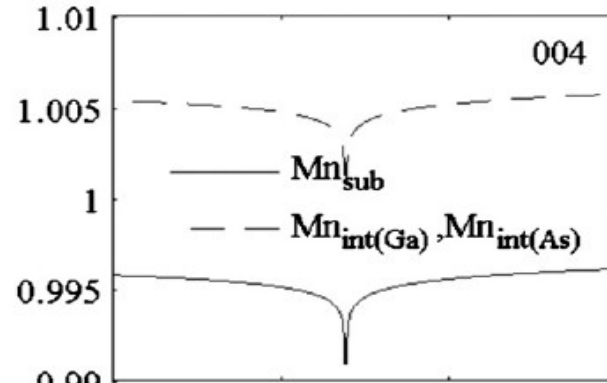
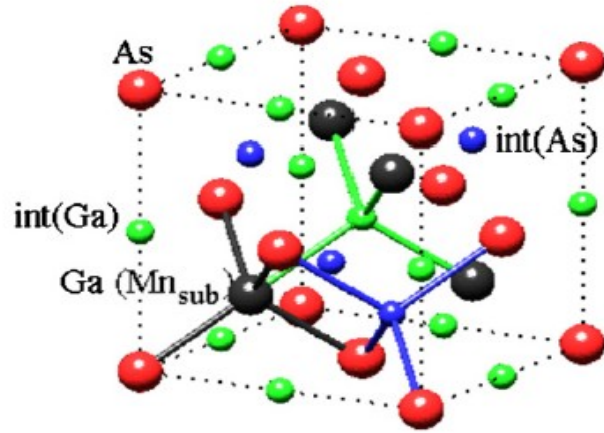
Difrakce: atomový rozptylový faktor se obvykle aproximuje jako

$$f_{at}(Q, E) = f_0(Q) + f_1(E) + i f_2(E)$$

$$F = \sum_n f_n(Q, E) e^{i Q \cdot r_n}$$

# Anomální rtg difrakce

$$F(\mathbf{h}) = 4\left\{(1 - c_{\text{sub}})f_{\text{Ga}}(\mathbf{h}) + c_{\text{sub}}f_{\text{Mn}}(\mathbf{h}) + \phi(\mathbf{h})f_{\text{As}}(\mathbf{h}) + (-1)^h f_{\text{Mn}}(\mathbf{h})[c_{\text{int(As)}} + c_{\text{int(Ga)}}\phi(\mathbf{h})]\right\},$$

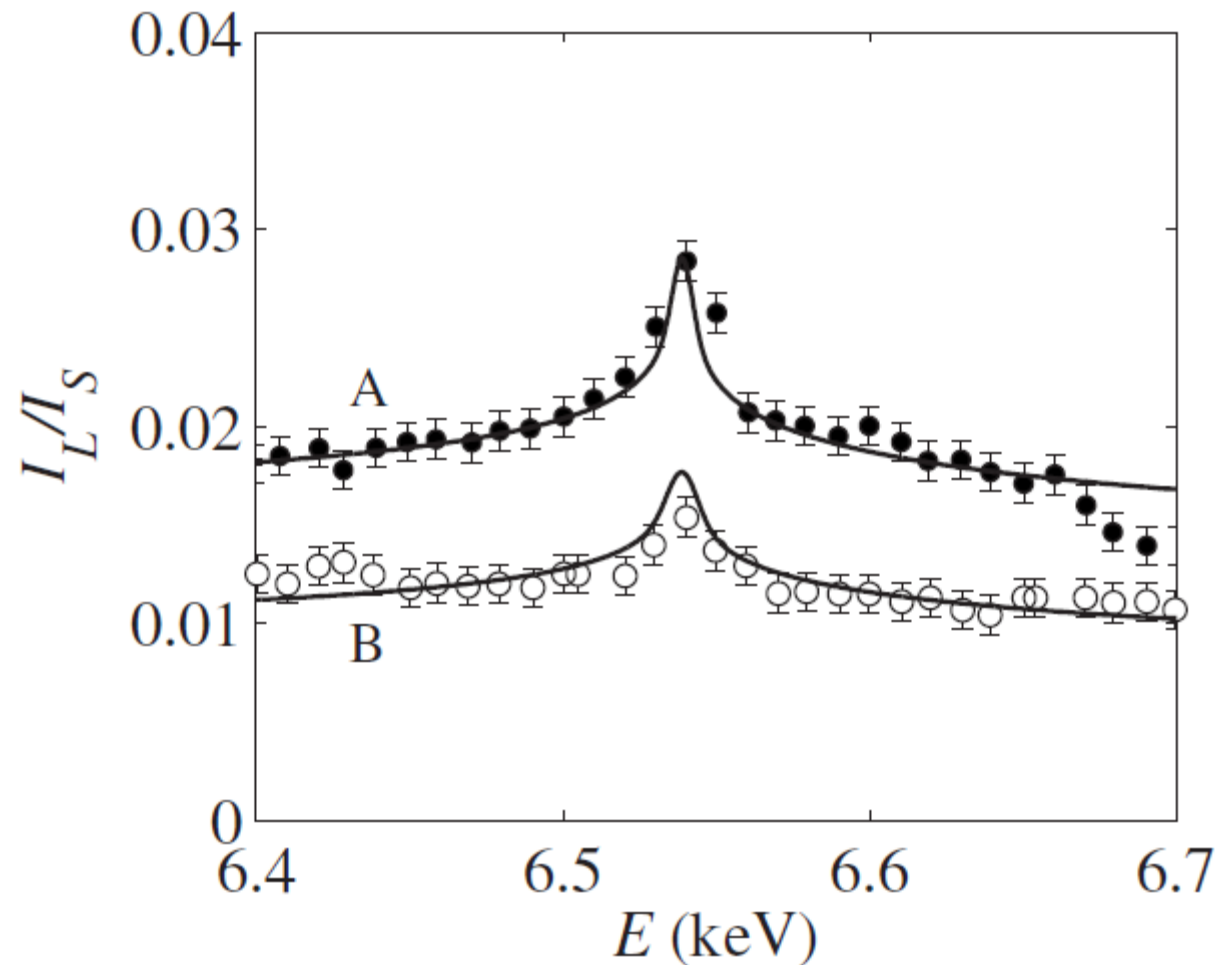


APPLIED PHYSICS LETTERS 97, 181913 (2010)

## Density of Mn interstitials in (Ga,Mn)As epitaxial layers determined by anomalous x-ray diffraction

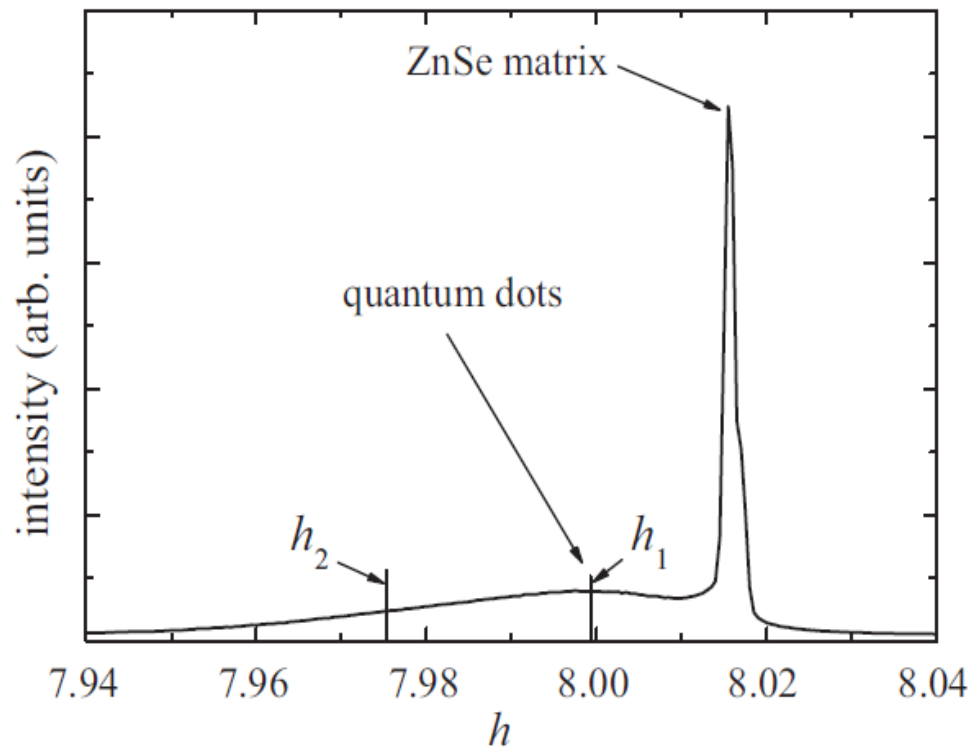
V. Holý,<sup>1,a)</sup> X. Martí,<sup>1</sup> L. Horák,<sup>1</sup> O. Caha,<sup>2</sup> V. Novák,<sup>3</sup> M. Cukr,<sup>3</sup> and T. U. Schüllí<sup>4</sup>

## Anomální rtg difrakce



From the fit we obtained for all values of  $n$  the following concentrations  $c_{\text{sub}} = (8.2 \pm 1.1)\%$ ,  $(c_{\text{int(As)}} - c_{\text{int(Ga)}})^{(A)} = (1.6 \pm 0.3)\%$ , and  $(c_{\text{int(As)}} - c_{\text{int(Ga)}})^{(B)} = (2.4 \pm 0.3)\%$ . Fortu-

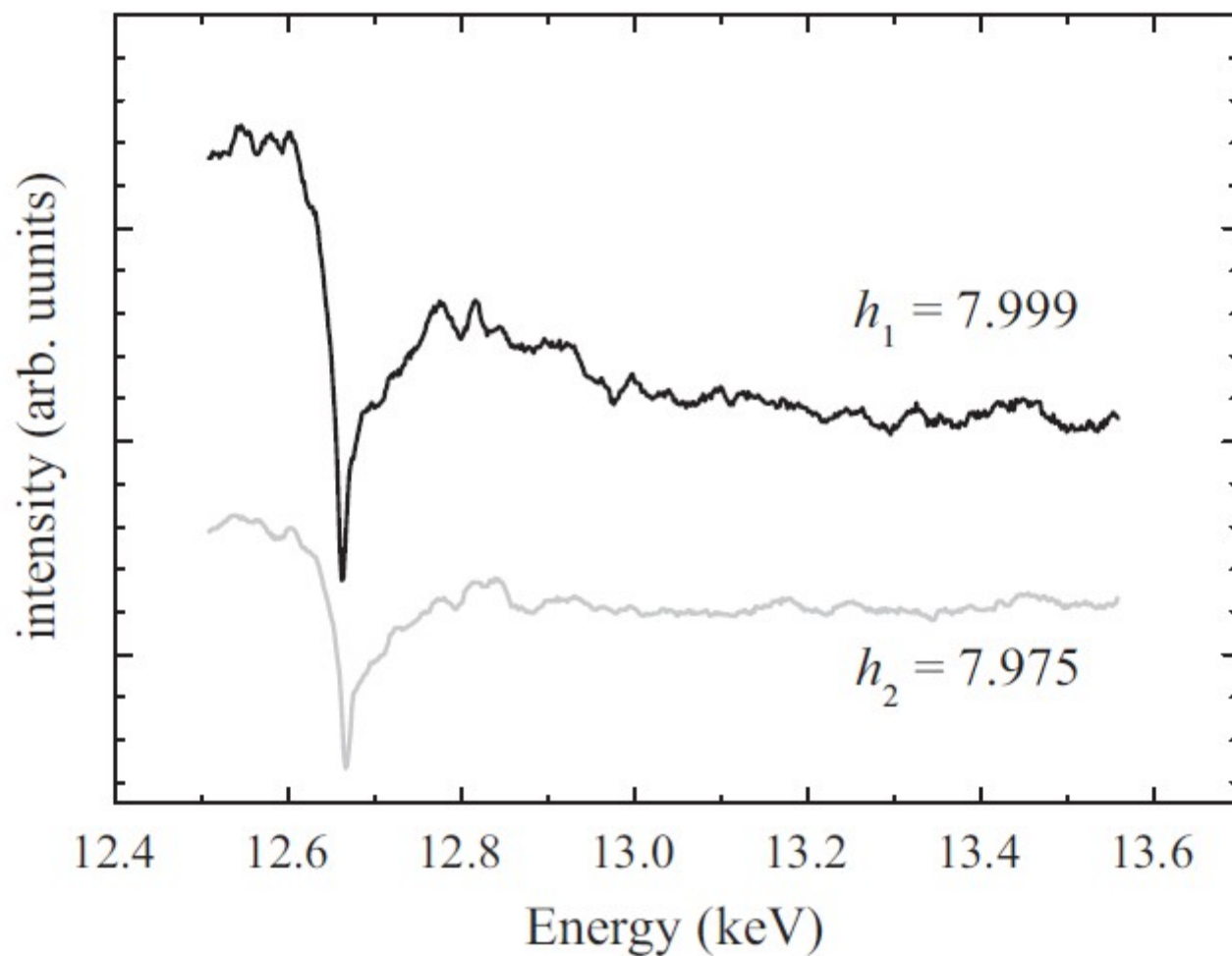
# Anomální rtg difrakce



**Fig. 3.** The diffraction profile measured in radial (800) direction. The  $h_1$  and  $h_2$  indicate the radial positions in reciprocal space where the DAFS data were collected.

Complementary information on CdSe/ZnSe quantum dot local structure from extended X-ray absorption fine structure and diffraction anomalous fine structure measurements

# Anomální rtg difrakce



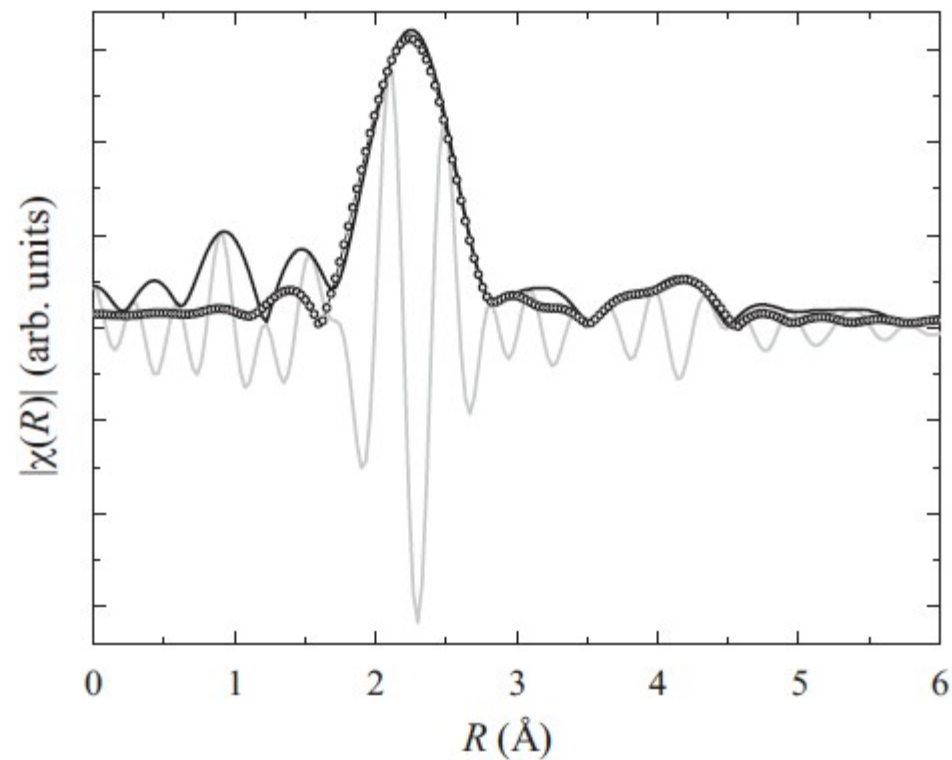
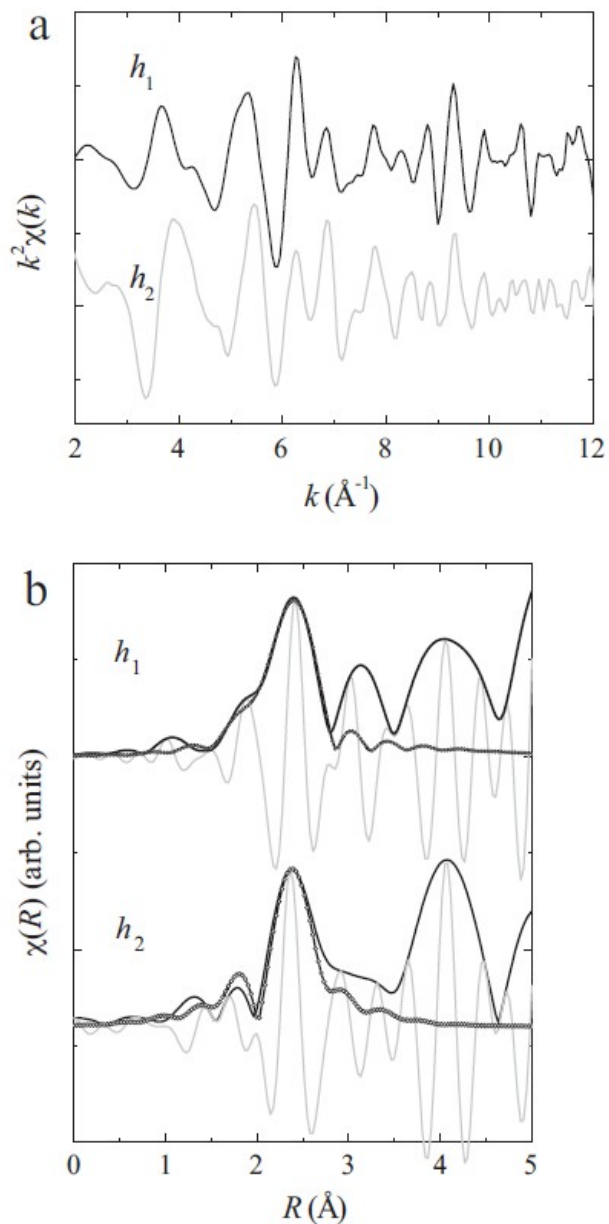
**Fig. 4.** Raw DAFS spectra collected at the Se K-edge at two different values of  $h$  indicated in Fig. 3.

Complementary information on CdSe/ZnSe quantum dot local structure from extended X-ray absorption fine structure and diffraction anomalous fine structure measurements

Journal of Alloys and Compounds 523 (2012) 155–160

E. Piskorska-Hommel<sup>a,b,\*</sup>, V. Holý<sup>c</sup>, O. Caha<sup>d</sup>, A. Wolska<sup>b</sup>, A. Gust<sup>a</sup>, C. Kruse<sup>a</sup>, H. Kröncke<sup>a</sup>, J. Falta<sup>a</sup>, D. Hommel<sup>a</sup>

# Anomální rtg difrakce



**Fig. 2.** The magnitude (black line) and the real part (grey line) of the Fourier transformation of the EXAFS oscillations presented in Fig. 1 and the best fit (circles) of the first and second coordination shells for CdSe quantum dots.

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# Anomální rtg difrakce

**Table 1**

The EXAFS and DAFS fitting results determined for Cd and Se K-edge, respectively.  $R$  are the distances between the absorbing atom and its near-neighbors,  $N$  is the coordination number,  $\sigma^2$  is the Debye–Waller factor, respectively.

	EXAFS (Cd K-edge; 2 shells)		DAFS (Se K-edge; one shell)	
	CdSe	Sample	$h_1$	$h_2$
$N_{\text{Se}}$	4	4	–	–
$N_{\text{Cd}}$	12	5(2)	1.6 (0.4)	2.8 (0.8)
$N_{\text{Zn}}$	–	7(2)	2.4 (0.4)	1.2 (1)
$R_{\text{Cd-Se}} (\text{Å}) (2.62)$	2.62 (0.01)	2.61 (0.01)	2.62 (0.02)	2.54 (0.03)
$R_{\text{Cd-Cd}} (\text{Å}) (4.28)$	4.31 (0.02)	4.37 (0.02)	–	–
$R_{\text{Cd-Zn}} (\text{Å}) (4.01)$	–	4.18 (0.04)	–	–
$R_{\text{Se-Zn}} (\text{Å}) (2.45)$	–	–	2.45 (0.02)	2.45 (0.03)
$\sigma^2_{\text{Cd-Se}} (\text{Å}^2)$	0.003 (0.001)	0.002 (0.001)	0.004 (0.002)	0.009 (0.003)
$\sigma^2_{\text{Cd-Cd}} (\text{Å}^2)$	0.014 (0.002)	0.012 (0.005)	–	–
$\sigma^2_{\text{Cd-Zn}} (\text{Å}^2)$	–	0.015 (0.003)	–	–
$\sigma^2_{\text{Se-Zn}} (\text{Å}^2)$	–	–	0.008 (0.005)	0.023 (0.009)

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# Anomální rtg difrakce

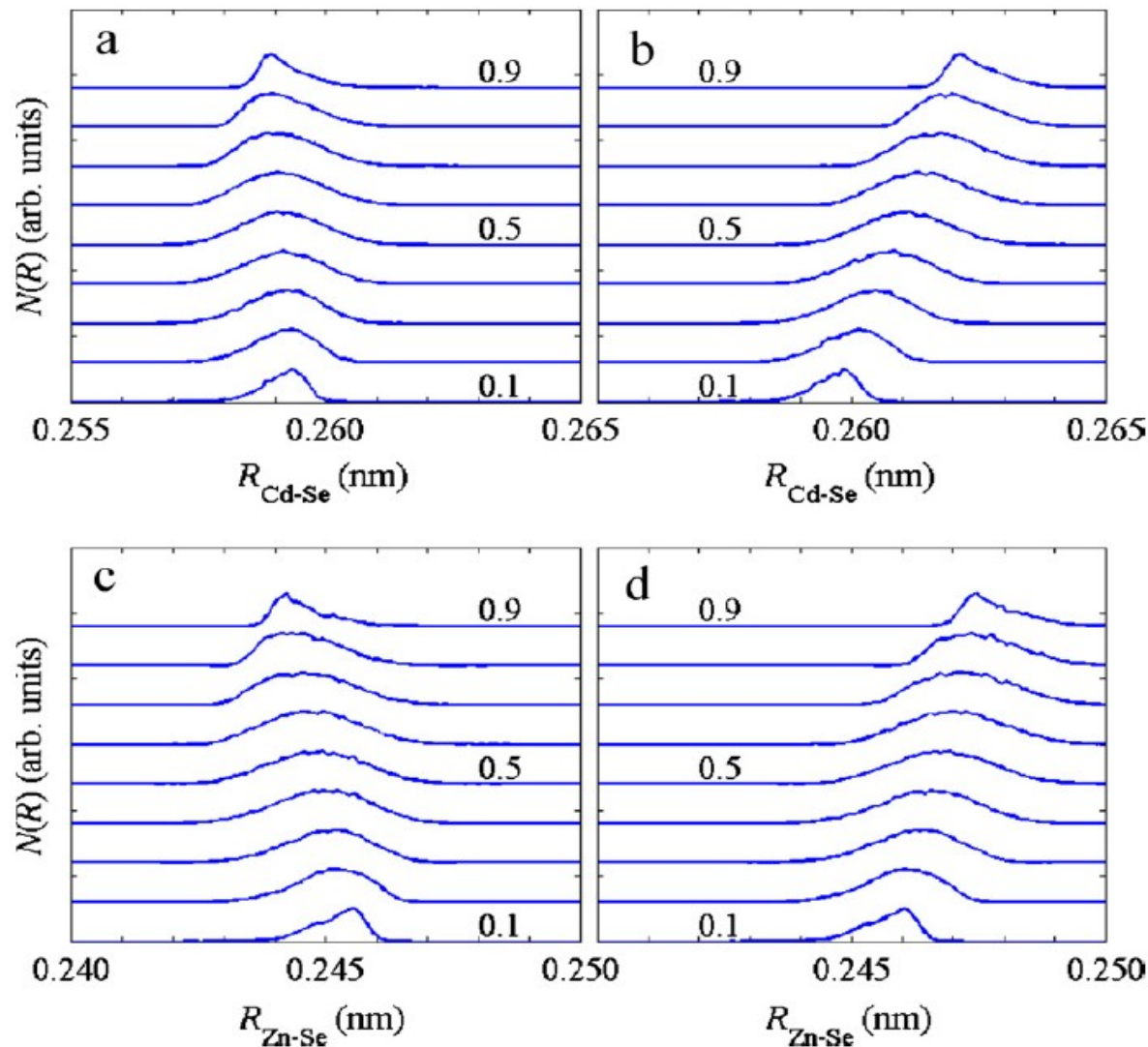


Fig. 6. The distribution of the Cd–Se (a and b) and Zn–Se (c and d) bond lengths calculated by the valence-field model assuming fully relaxed (b and d) and biaxially strained (a and c)  $\text{Cd}_x\text{Zn}_{1-x}\text{Se}$  lattice (see the text for details). The parameter of the curves is the concentration  $x$  of Cd. The curves are shifted vertically for clarity.

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# Vznik charakteristického rtg záření

Přechody mezi hlubokými elektronovými hladinami ( $Z > 3$ )

Výběrová pravidla:  $\Delta n \neq 0$ ,  $\Delta l = \pm 1$ ,  $\Delta j = 0, \pm 1$

Energie přechodu:  $\epsilon_{fi} = \hbar\omega = R_y(Z - \sigma_f)^2 \left( \frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$

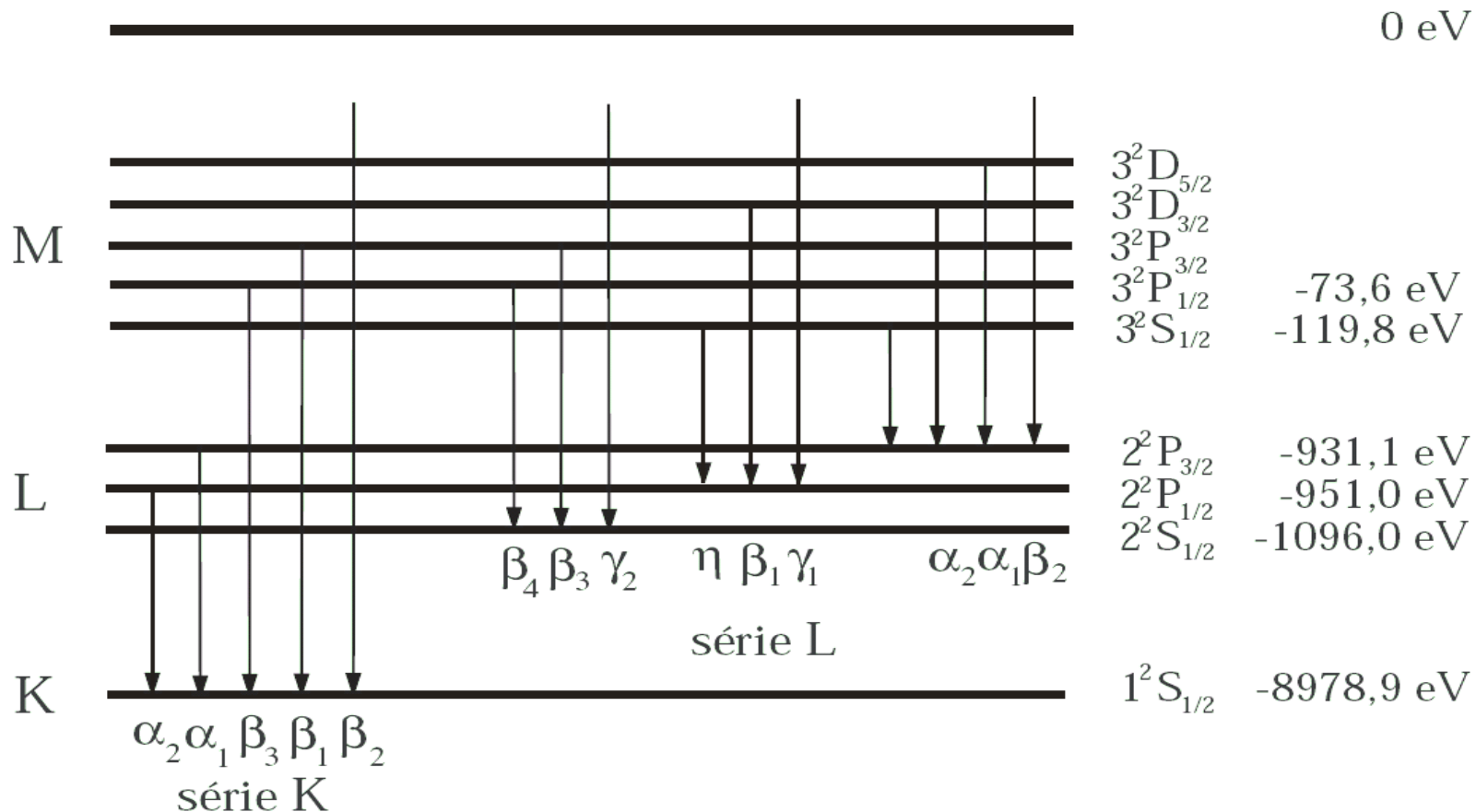
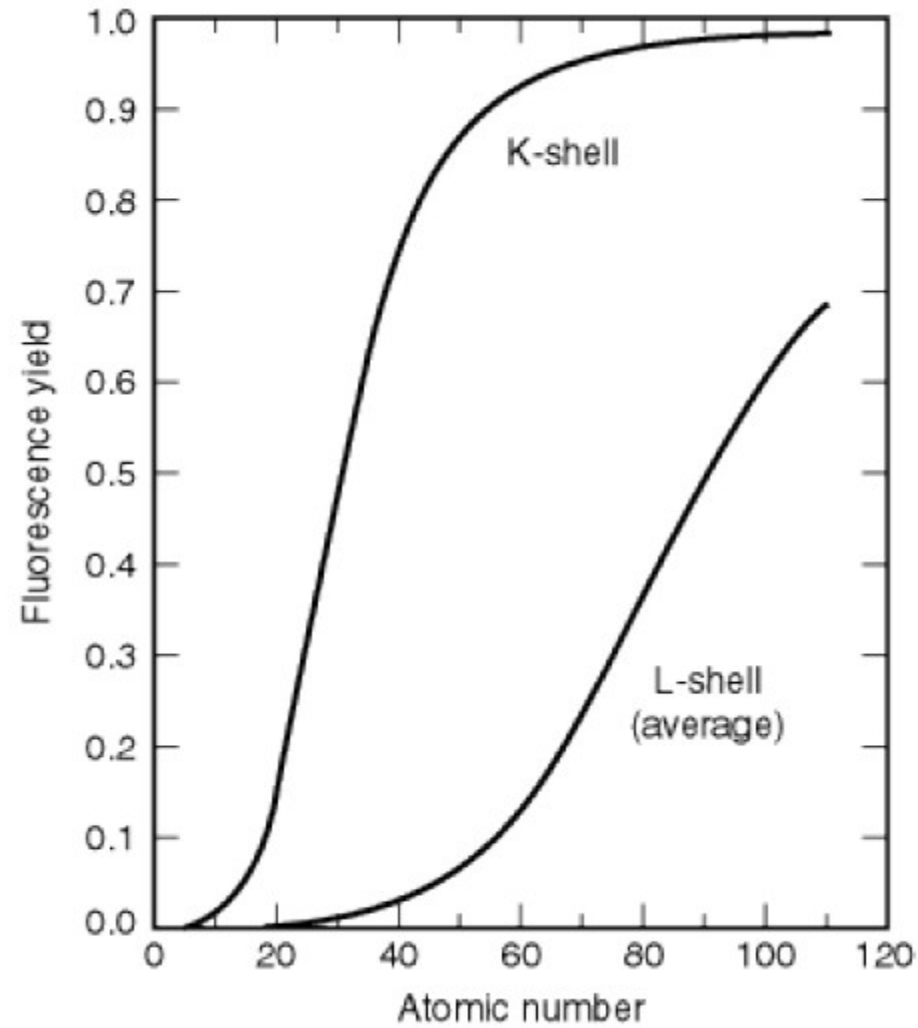


Schéma přechodů pro měď ( $Z=29$ ).

# Charakteristické rtg záření



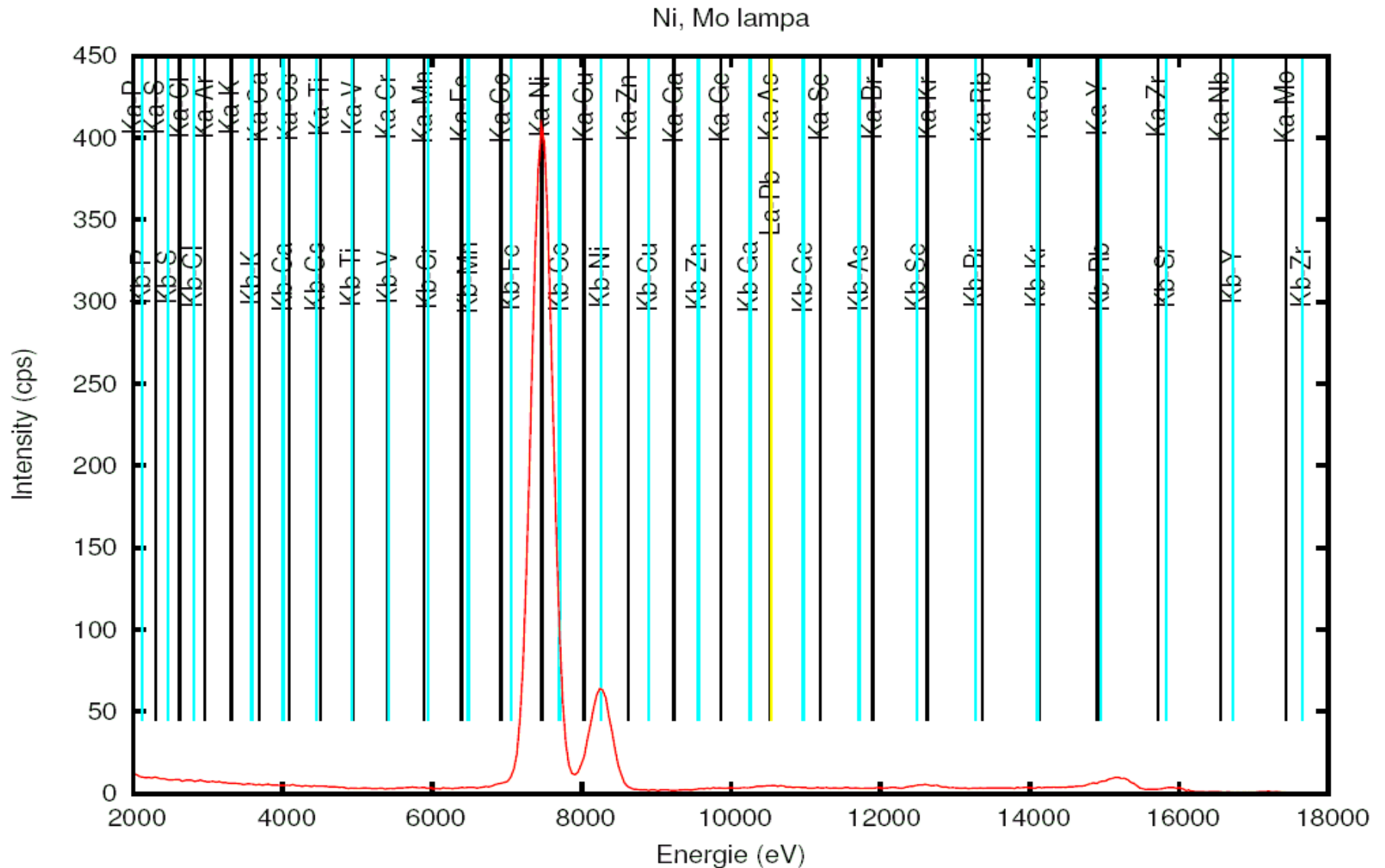
# XRF

Rentgenová fluorescenční spektroskopie

X-ray Fluorescence spectroscopy – XRF

Ionizace atomů vzorku rtg svazkem a měření spektra

sekundárního rtg záření. Nezávisí na chemickém stavu atomu.



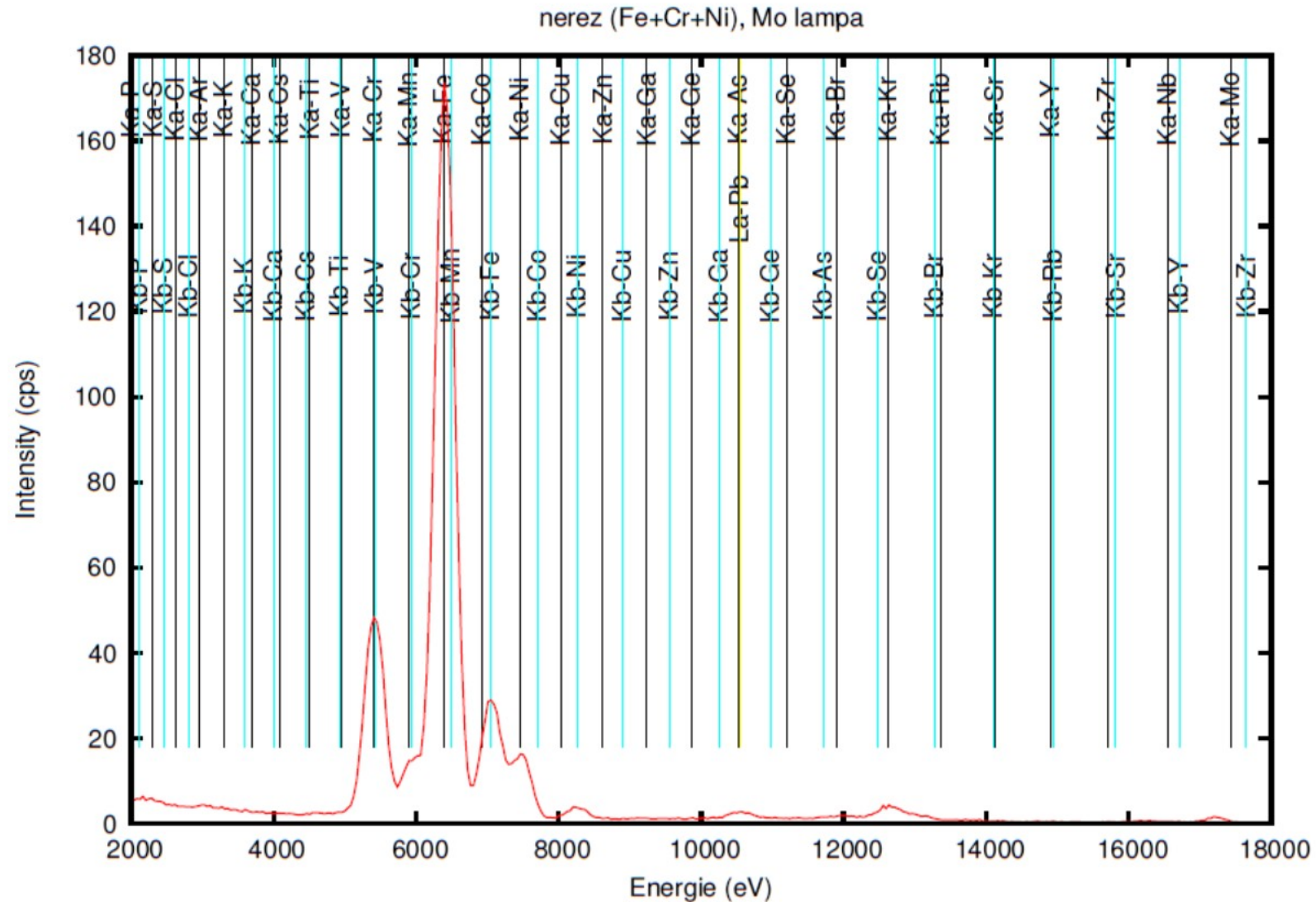
# XRF

Rentgenová fluorescenční spektroskopie

X-ray Fluorescence spectroscopy – XRF

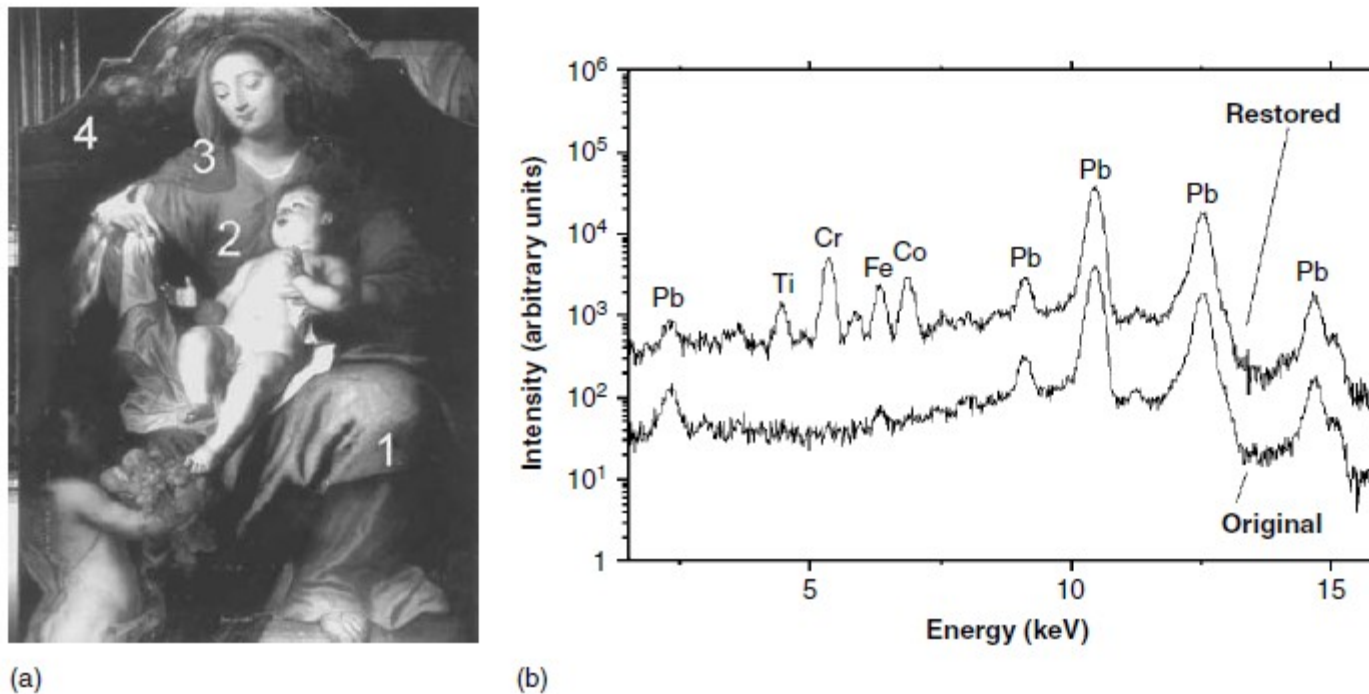
Ionizace atomů vzorku rtg svazkem a měření spektra

sekundárního rtg záření. Nezávisí na chemickém stavu atomu.



# XRF

## Rentgenová fluorescenční spektroskopie Kvantitativní analýza:



**Figure 3.3.15** (a) Micro-XRF analysis of a baroque painting (attributed to P. Thys). The area marked '1' shows Fe, Pb but no Co or Cu, suggesting the use of indigo (an organic pigment), the area marked '2' contains Fe, Hg, Sr, Pb (vermillion), area '3' Ca, Mn, Zn, Pb (umber), and area '4' contains Ca, Mn, Fe, Zn, Pb (umber). (b) Two XRF spectra from adjacent spots in the area marked '1' in (a). Positions where more recent paint (containing Ti, Cr and Co) was applied during past restoration activities can clearly be distinguished from positions with original seventeenth century paint

# XRF

Rentgenová fluorescenční spektroskopie

Kvantitativní analýza s použitím  $j$  standardů podobného složení,  
zanedbány rozdíly absorpce mezi vzorek a standardem:

$$I_i = k_i W_i \quad \text{weight fraction of analyte } W_i$$

$$k_i = \frac{n \sum_{j=1}^n W_{ij} I_{ij} - \sum_{i=1}^n W_{ij} \sum_{i=1}^n I_{ij}}{n \sum_{i=1}^n W_{ij}^2 - \left( \sum_{i=1}^n W_{ij} \right)^2}$$

# XRF

Rentgenová fluorescenční spektroskopie  
Kvantitativní analýza obecně:

$$I_i = \frac{d\Omega}{4\pi \sin \phi_1} Q_i q_i W_i \int_{\lambda_{\min}}^{\lambda_{\text{edge}}} \tau_i(\lambda) I_0(\lambda) \frac{1 - \exp[-\chi(\lambda, \lambda_i) \rho t]}{\chi(\lambda, \lambda_i)} \left( 1 + \sum_j W_j S_{ij} \right) d\lambda$$

$d\Omega$  is the differential solid angle for the characteristic radiation

$Q_i$  is the sensitivity of the spectrometer

$\lambda_{\min}$  and  $\lambda_{\text{edge}}$  are short-wavelength limit and wavelength of analyte absorption edge,  
 $\tau_i(\lambda)$  is the photoelectric absorption coefficient for analyte  $i$

$I_0(\lambda)$  is intensity of the primary radiation

$q_i$  is sensitivity of the analyte  $i$

$q_i = \omega_{K,i} f_{i,K} (1 - 1/J_{i,K})$ , where  $\omega_{K,i}$  is fluorescence yield of K radiation;

$J_{i,K}$  is absorption edge jump ratio

$\chi(\lambda, \lambda_i)$  is total mass-attenuation coefficient of the sample

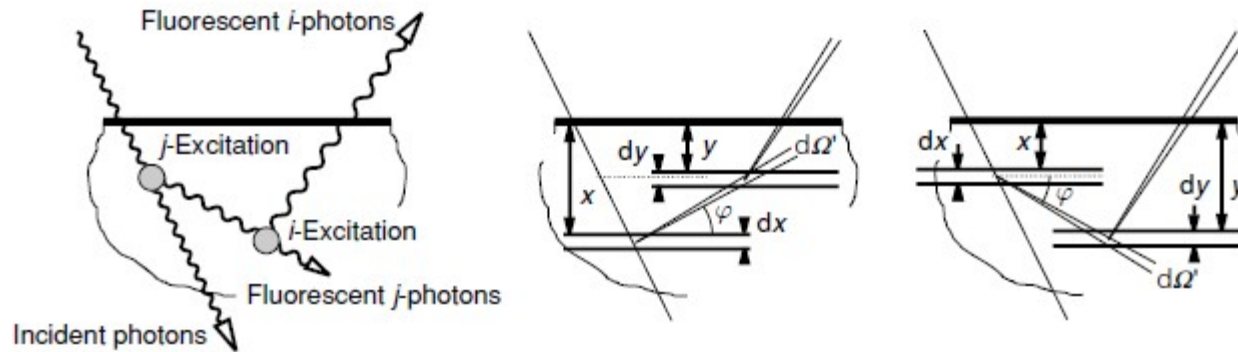
$$\chi(\lambda, \lambda_i) = \frac{\mu(\lambda)}{\sin \phi_1} + \frac{\mu(\lambda_i)}{\sin \phi_2} \quad \mu(\lambda) = W_i \mu_i(\lambda) + \sum_j W_j \mu_j(\lambda)$$

$$\mu(\lambda_i) = W_i \mu_i(\lambda_i) + \sum_j W_j \mu_j(\lambda_i)$$



# XRF

Rentgenová fluorescenční spektroskopie  
Kvantitativní analýza efekty self-absorpce:



$$S_{ij} = \frac{1}{2} q_j \tau_j(\lambda) \frac{\tau_i(\lambda_j)}{\tau_i(\lambda)} \frac{\chi(\lambda, \lambda_i)}{1 - \exp[-\chi(\lambda, \lambda_i)\rho t]} D_{ij}$$

$$D_{ij} = \int_0^{\pi/2} \tan(\theta) \left[ \frac{1 - \exp[-\chi_1(\lambda_i, \lambda_j)\rho t]}{\chi_1(\lambda_i, \lambda_j)\chi_2(\lambda, \lambda_j)} - \frac{1 - \exp[-\chi(\lambda, \lambda_i)\rho t]}{\chi(\lambda, \lambda_i)\chi_2(\lambda, \lambda_j)} \right] d\theta +$$

$$\int_{\pi/2}^{\pi} \tan(\theta) \left[ \frac{\exp[-\chi_2(\lambda, \lambda_j)\rho t] - \exp[-\chi(\lambda, \lambda_i)\rho t]}{\chi_1(\lambda_i, \lambda_j)\chi_2(\lambda, \lambda_j)} - \frac{1 - \exp[-\chi(\lambda, \lambda_i)\rho t]}{\chi(\lambda, \lambda_i)\chi_2(\lambda, \lambda_j)} \right] d\theta$$

$$\chi_1(\lambda_i, \lambda_j) = \frac{\mu(\lambda_i)}{\sin \phi_1} + \frac{\mu(\lambda_j)}{\cos \theta}$$

$$\chi_2(\lambda, \lambda_j) = \frac{\mu(\lambda)}{\sin \phi_1} - \frac{\mu(\lambda_j)}{\cos \theta}$$

# XRF

Rentgenová fluorescenční spektroskopie  
Kvantitativní analýza limita pro tlustý vzorek:

$$I_i = \frac{d\Omega}{4\pi \sin \phi_1} Q_i q_i W_i \int_{\lambda_{\min}}^{\lambda_{\text{edge}}} \frac{\tau_i(\lambda) I_0(\lambda)}{\chi(\lambda, \lambda_i)} \left( 1 + \sum_j W_j S_{ij} \right) d\lambda$$

$$S_{ij} = \frac{1}{2} q_j \tau_j(\lambda) \frac{\tau_i(\lambda_j)}{\tau_i(\lambda)} \left[ \ln \left( 1 + \frac{\mu(\lambda)}{\mu(\lambda_j) \sin \phi_1} \right) \frac{\sin \phi_1}{\mu(\lambda)} + \ln \left( 1 + \frac{\mu(\lambda_i)}{\mu(\lambda_j) \sin \phi_2} \right) \frac{\sin \phi_2}{\mu(\lambda_i)} \right]$$

$$t \geq \frac{4.61}{\chi(\lambda, \lambda_i) \rho}$$

Limita pro tenký vzorek:

$$I_i = \frac{d\Omega}{4\pi \sin \phi_1} Q_i q_i W_i \rho t \int_{\lambda_{\min}}^{\lambda_{\text{edge}}} \tau_i(\lambda) I_0(\lambda) d\lambda$$

$$\rho t \leq \frac{0.1}{\chi(\lambda, \lambda_i)}$$

# XRF

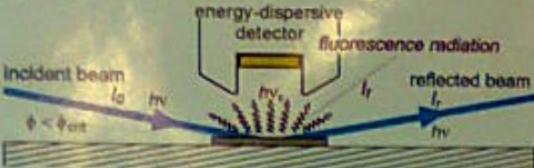
Rentgenová fluorescenční spektroskopie

Total reflexion x-ray fluorescence

monochromatický zdroj, malý úhel dopadu, platí limita tenkého vzorku

analýza povrchové kontaminace polovodičů

• The TXRF-measurements were performed at the PTB beamline for undulator radiation at the electron storage ring BESSY II [2].



**High surface layer sensitivity under total reflection geometry**

• Based on radiometrically calibrated instrumentation and knowledge of relevant instrumental and atomic fundamental parameters

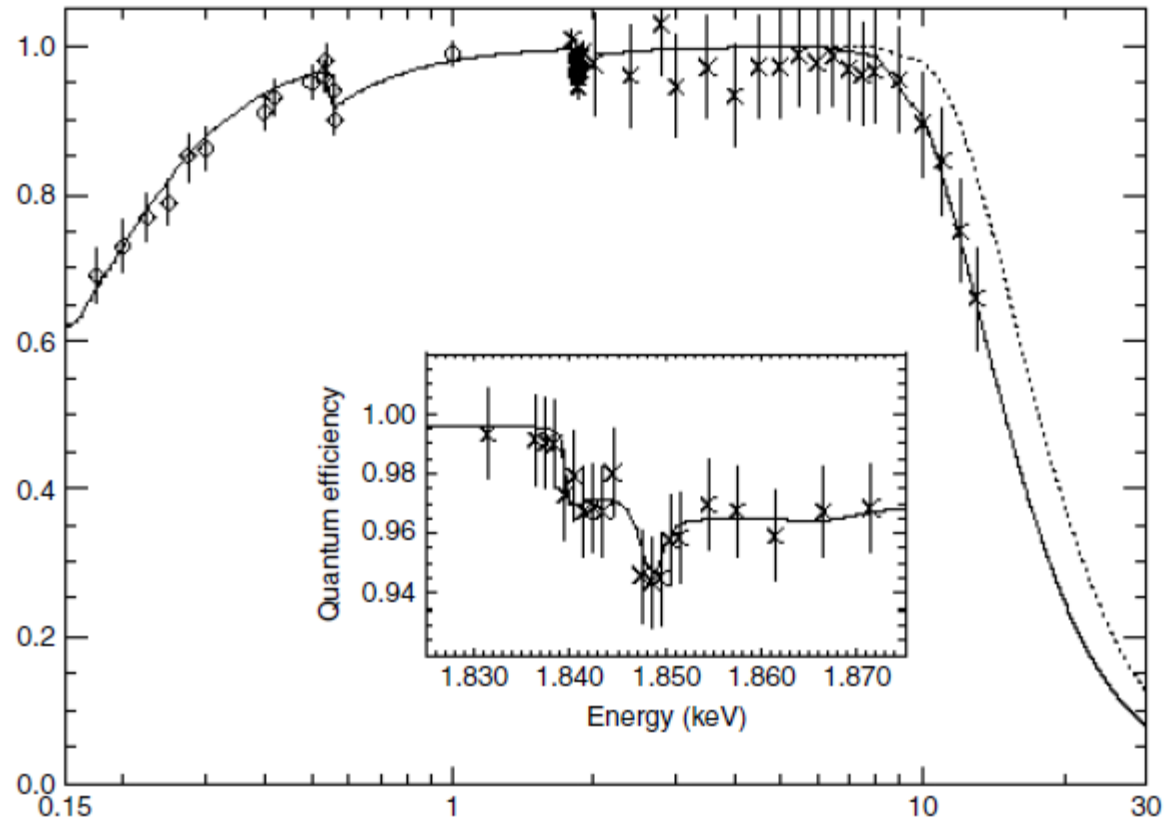
$$\frac{m_i}{F_i} = \frac{-1}{\mu_{\text{tot},i}} \ln \left\{ 1 - \frac{P_i}{P_0 W_{\text{surf}} \tau_{i,E_0} Q} \frac{\Omega_{\text{det}}}{4\pi} \frac{1}{\sin \psi_{\text{in}}} \frac{1}{\mu_{\text{tot},i}} \right\}$$

$P$ : radiant power  
 $\Omega$ : solid angle of detection  
 $\mu, \tau, Q$ : fundamental materials parameters  
 $\psi_{\text{in}}$ : Incident Angle of radiation

Mass deposition of the element  $i$  can be directly calculated [3]

# XRF

## Rentgenová fluorescenční spektroskopie Kvantitativní analýza:



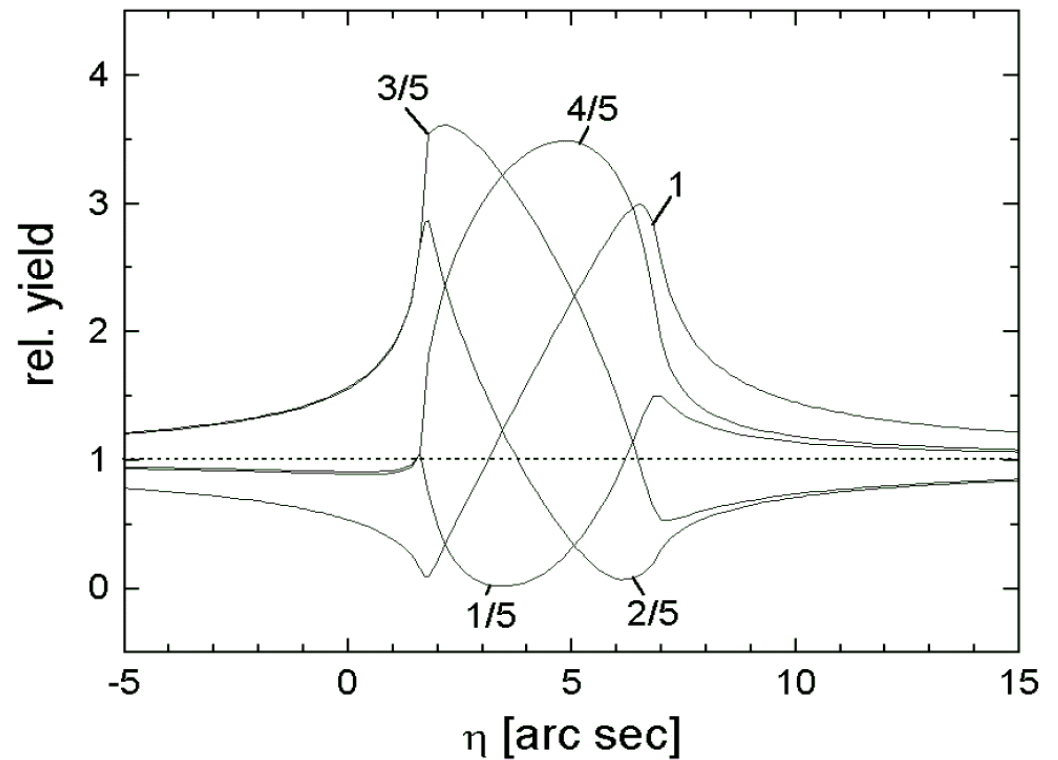
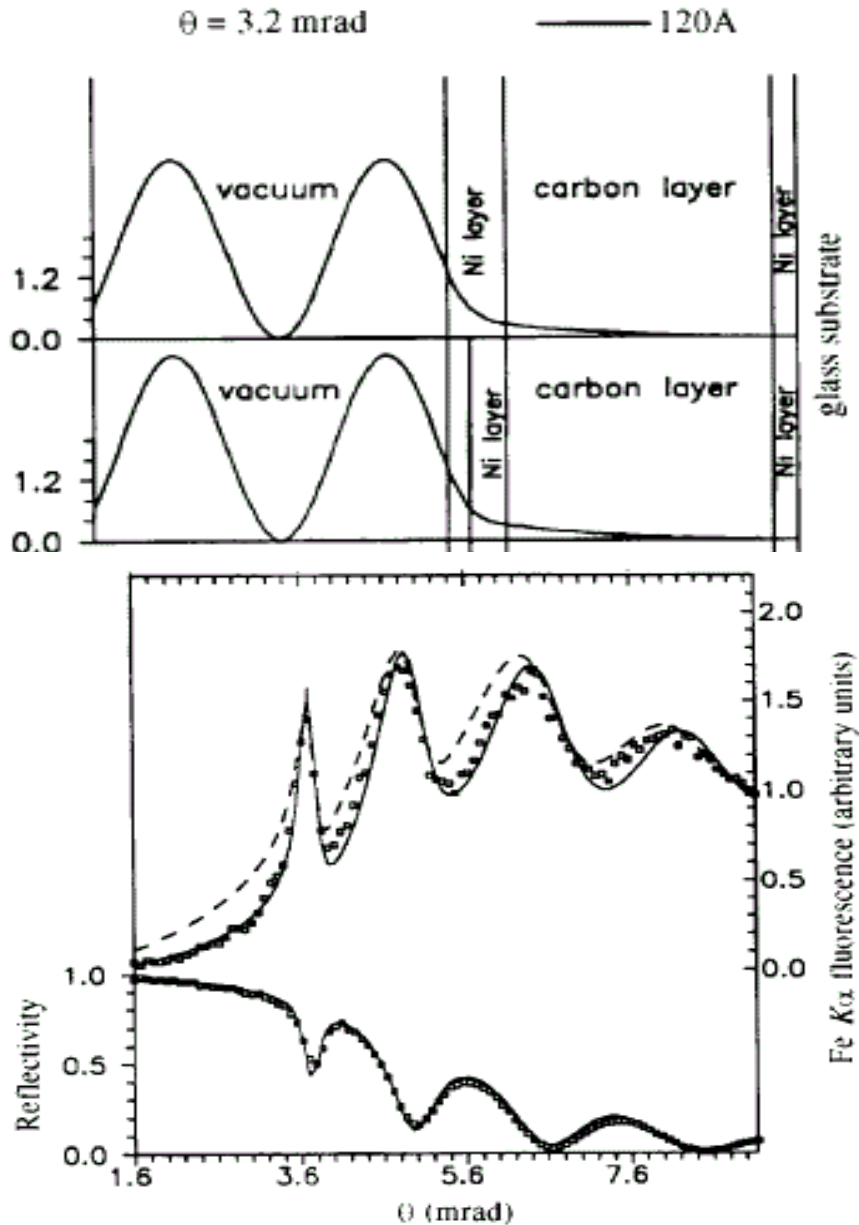
**4.1.14** Quantum efficiency for X-rays in the range of 150 eV to 30 keV energy of a pn-CC of 300 μm thickness (rements and solid line) equipped with a thin optimized radiation entrance window. Close to 100% quantum efficiency is achieved over most of the range. Remarkable is the high efficiency at low energies. The falloff at high energy is due to the thickness. The dotted line represents an extrapolation to 500 μm thick sensitive volume

# Fluorescence ve stojaté vlně

Stojatá vlna vzniká interferencí dopadající a odražené (difraktované) vlny.

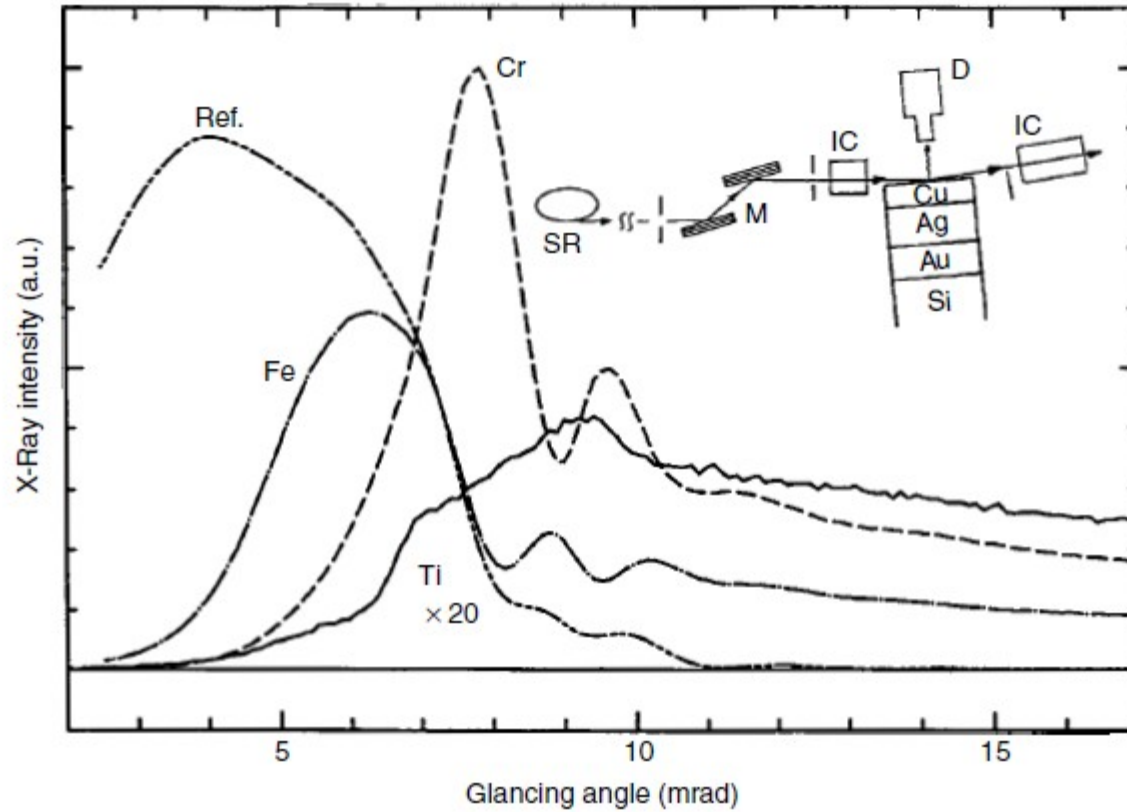
Použití: v reflexi (vlevo)

v difrakci (vpravo)



# Fluorescence ve stojaté vlně

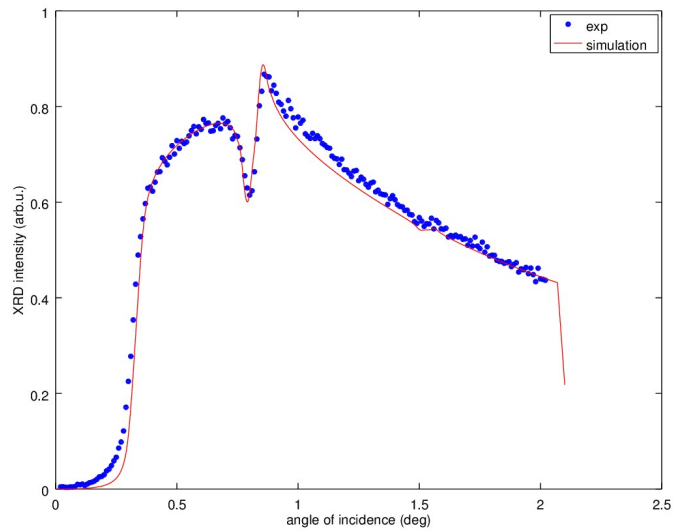
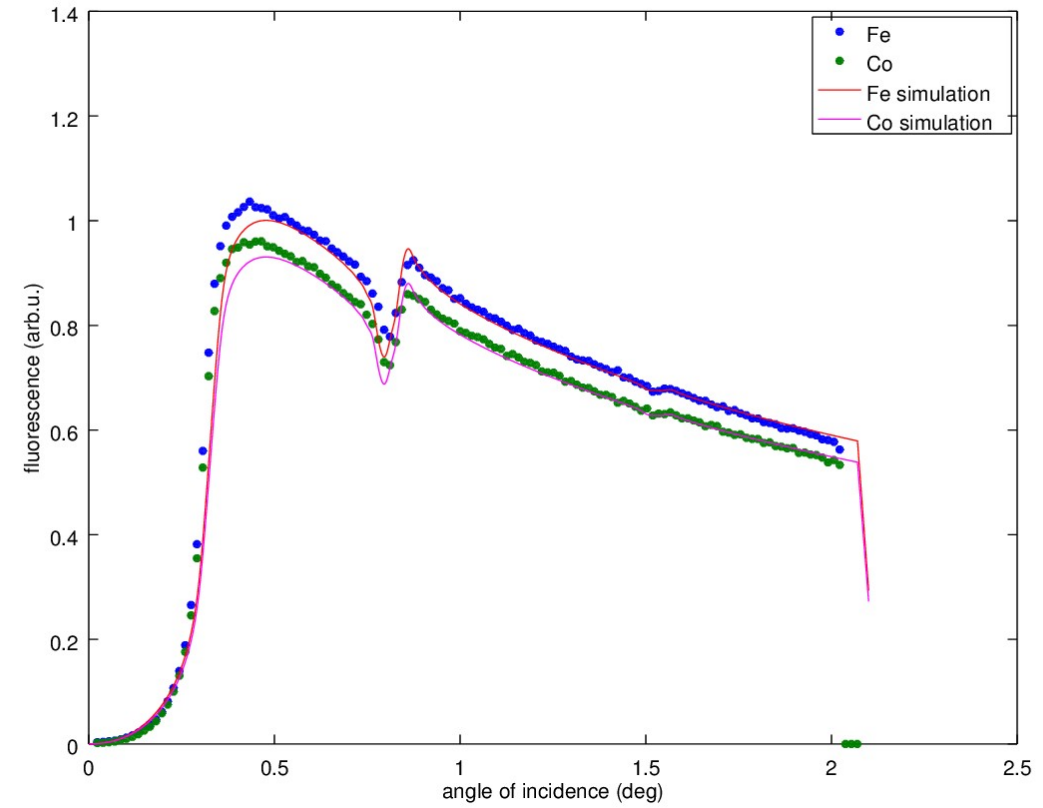
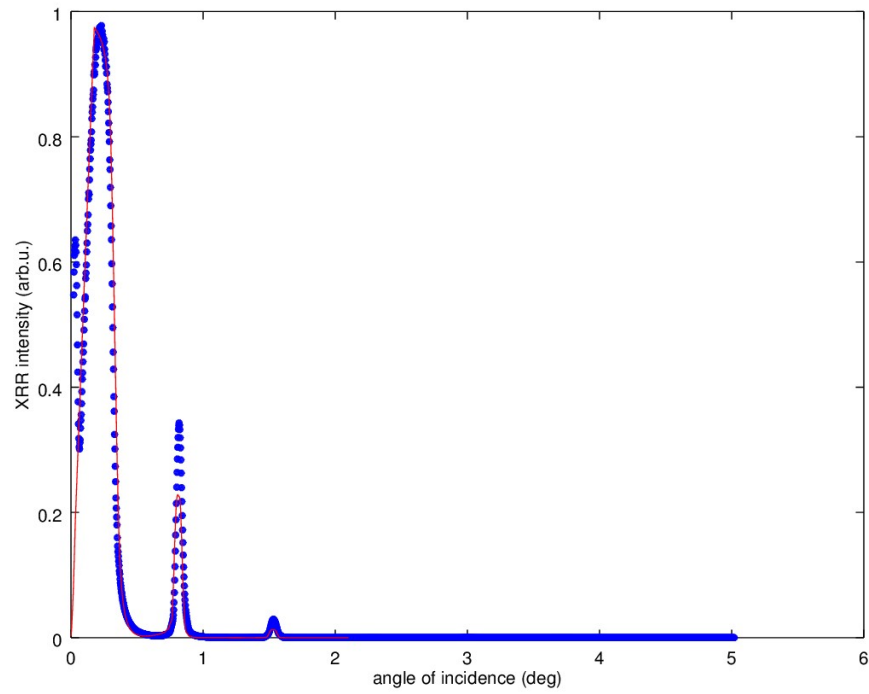
V reflexi



**Figure 5.1.8** Experimental angular plot of reflectivity and integrated X-ray fluorescence intensities of iron, chromium and titanium from the surface and interfaces of a Cu/Ag/Au thin film. (Reproduced with permission of Plenum Press,<sup>44</sup> Figure 4)

# Fluorescence ve stojaté vlně

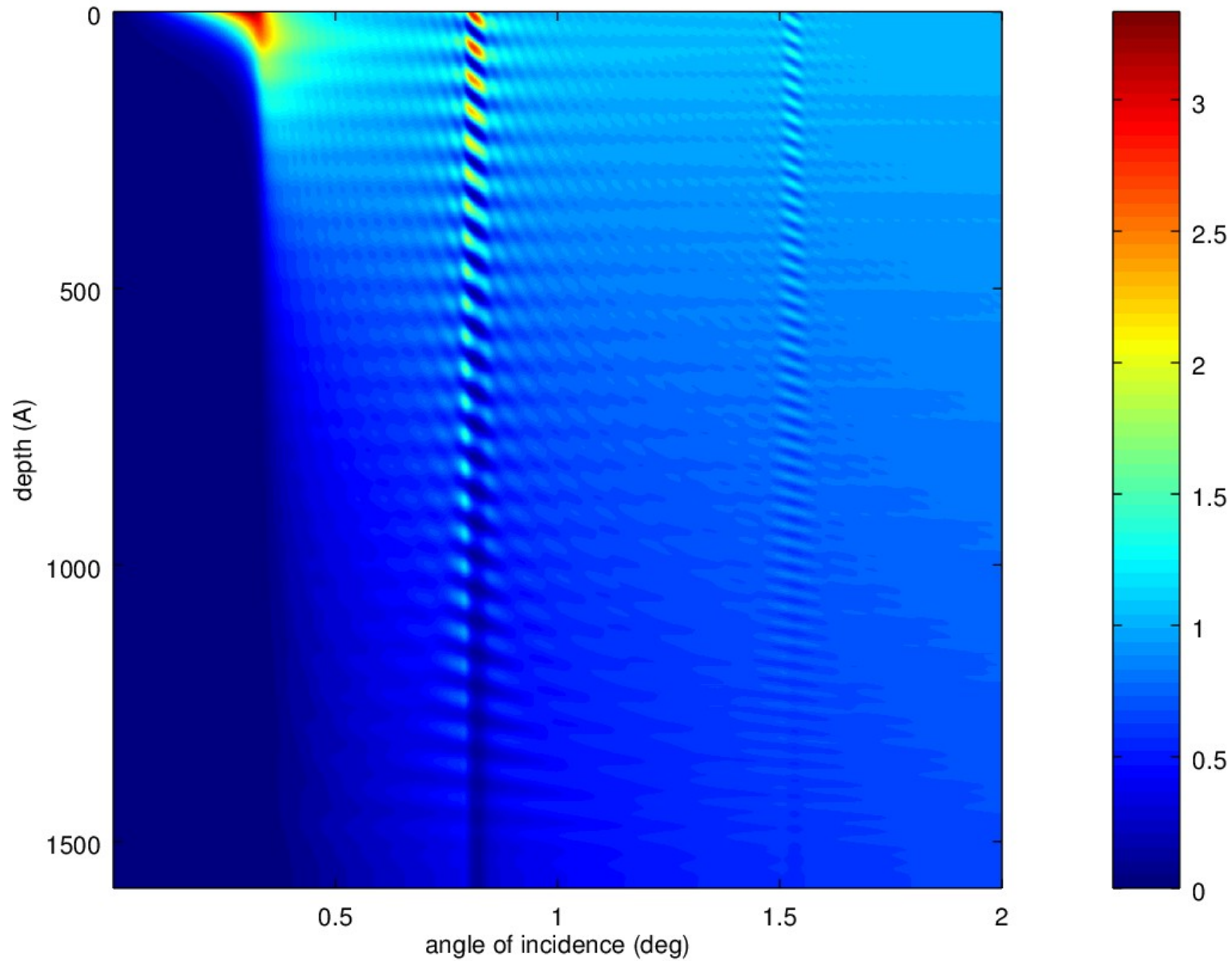
## V reflexi





# Fluorescence ve stojaté vlně

V reflexi





# Fluorescence ve stojaté vlně

## V reflexi

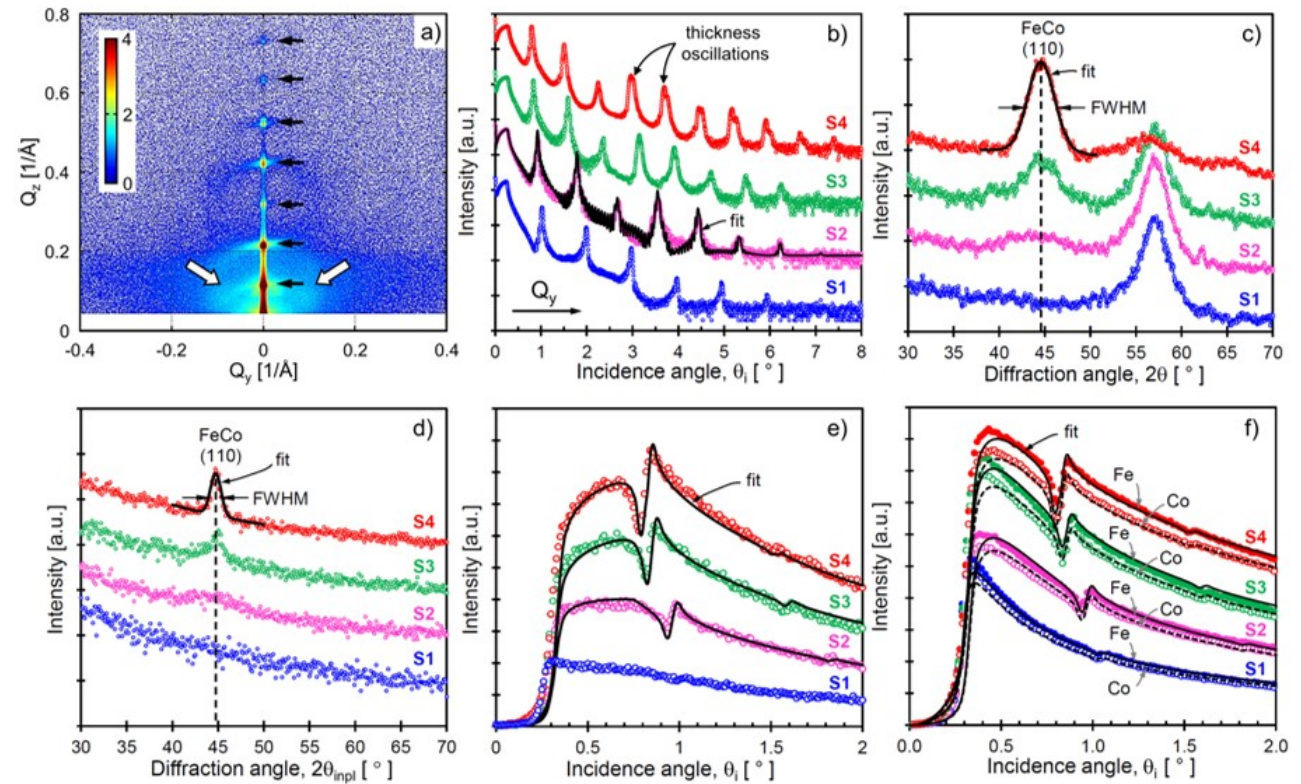


FIG. 5. a) Reflectivity reciprocal space map (RSM) of 25-period FeCo/Al<sub>2</sub>O<sub>3</sub> multilayer with FeCo layers having 2 nm nominal thickness (sample S4). The peaks along  $Q_z$  direction for  $Q_y = 0$  (depicted by black arrows) arise from the constructive interference of X-rays scattered at various buried interfaces. The white arrows indicate the diffused scattering due to the granular FeCo layers (see also Fig. 4a). b) Specular XRR scans (shifted vertically for clarity) for samples S1, S2, S3 and S4 in Table I. c) Detector  $2\theta$  scans (shifted vertically for clarity) in the AXRD scattering geometry for samples S1 to S4 (incidence angle  $\theta_i = 6^\circ$ ); the black line is a Gaussian fit of the FeCo (110) diffraction peak. d) Detector  $2\theta_{imp}$  scans (shifted vertically for clarity) in the GID geometry for samples S1 to S4 (incidence angle  $\theta_i = 1^\circ$ ); the black line is a Gaussian fit of the FeCo (110) diffraction peak. e) Incidence angle  $\theta_i$  scans (shifted vertically for clarity) in the GID geometry for samples S1 to S4 (detector angle  $2\theta_{imp} = 1^\circ$ ); the black lines represent ... f) Incidence angle  $\theta_i$  scans (shifted vertically for clarity) of Fe and Co XRF signals; the black lines represent ...

# Fluorescence ve stojaté vlně

## V reflexi

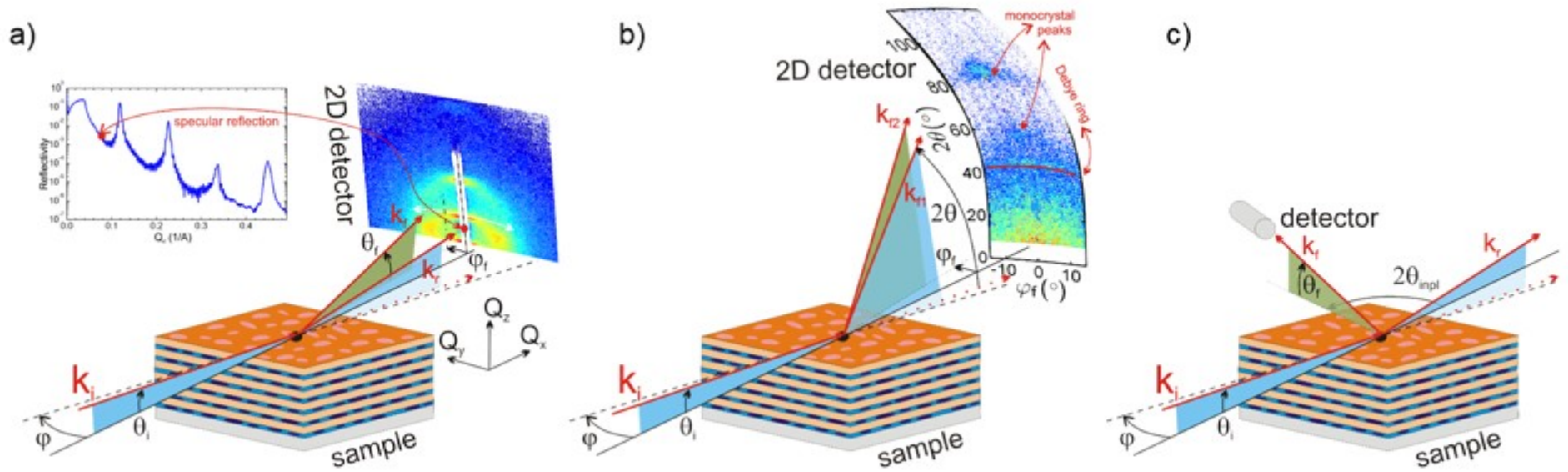
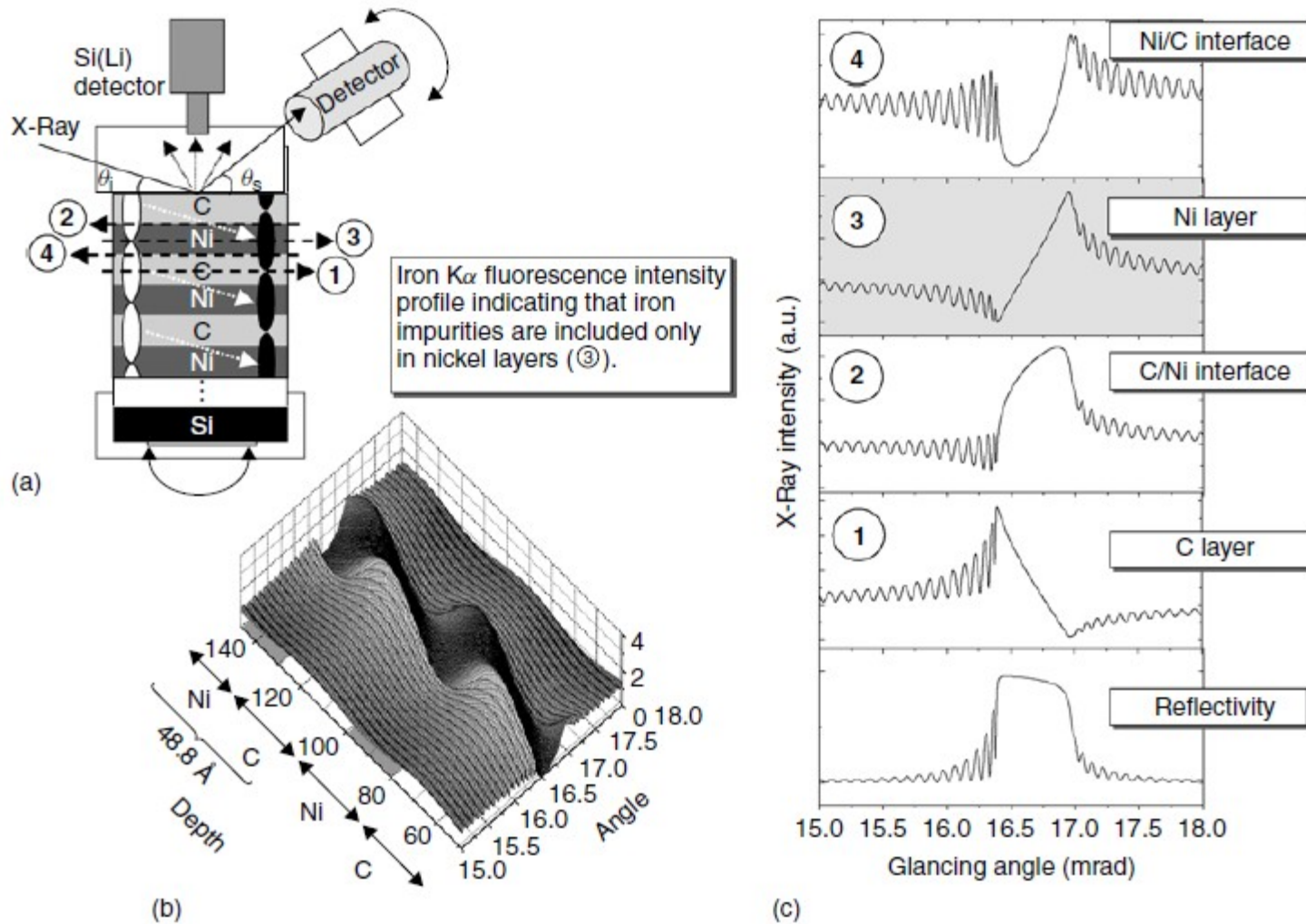


FIG. 2. Schematics of the X-ray scattering experiments performed to obtain structural information (e.g. layer thickness, vertical and lateral grain size, separation between the grains) in the  $\text{FeCo}/\text{Al}_2\text{O}_3$  multilayers: a) X-ray reflectivity (XRR) and grazing incidence small angle X-ray scattering (GISAXS); b) highly asymmetric X-ray diffraction (AXRD); c) non-coplanar grazing incidence diffraction (GID).

# Fluorescence ve stojaté vlně

V reflexi



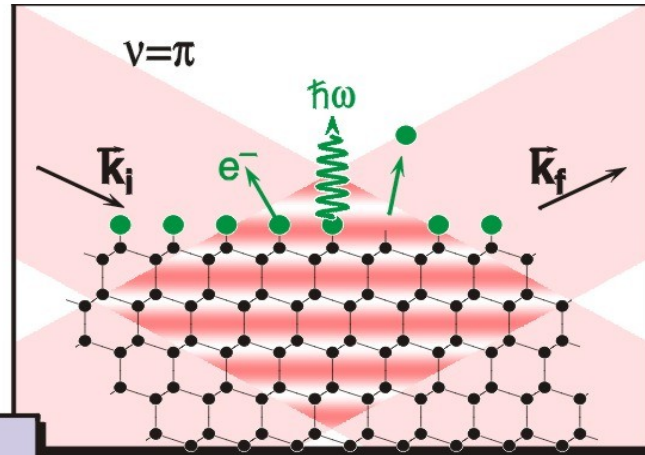
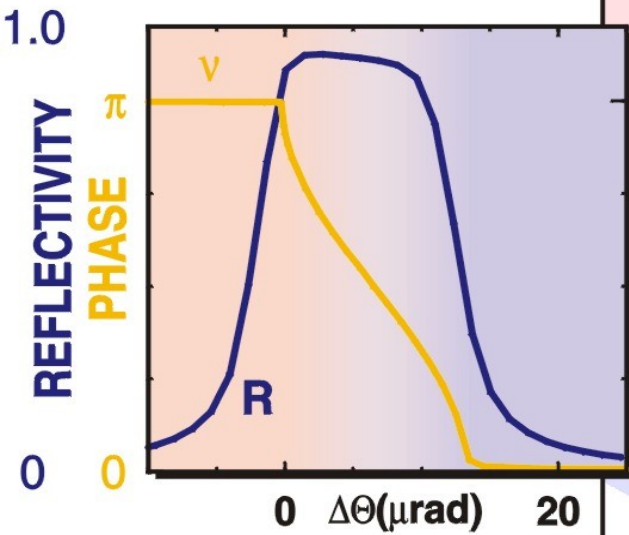
**Figure 5.1.10** Calculation of angular dependence of X-ray fluorescence. (a) Basic idea of the X-ray standing wave technique. (b) Three-dimensional map for X-ray electric field intensity in the multilayer. (c) Angular profile for X-ray fluorescence for impurity iron segregated at: (1) center of the C layer; (2) C/Ni interface; (3) center of the Ni layer; (4) Ni/C interface



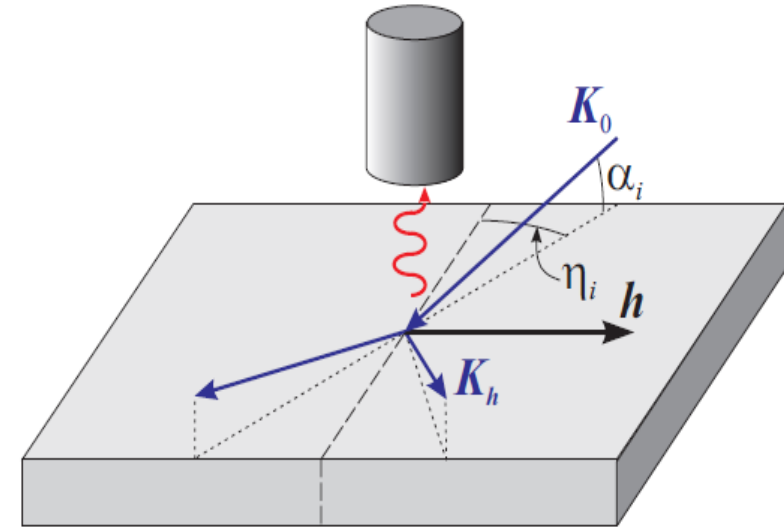
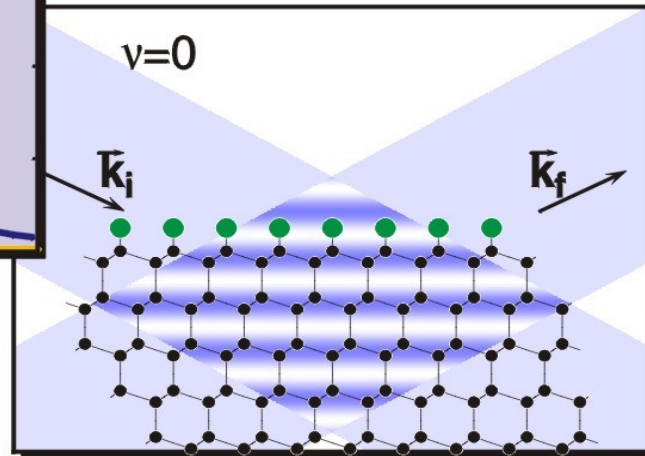
# Fluorescence ve stojaté vlně

## XSW

## X-ray Standing Waves

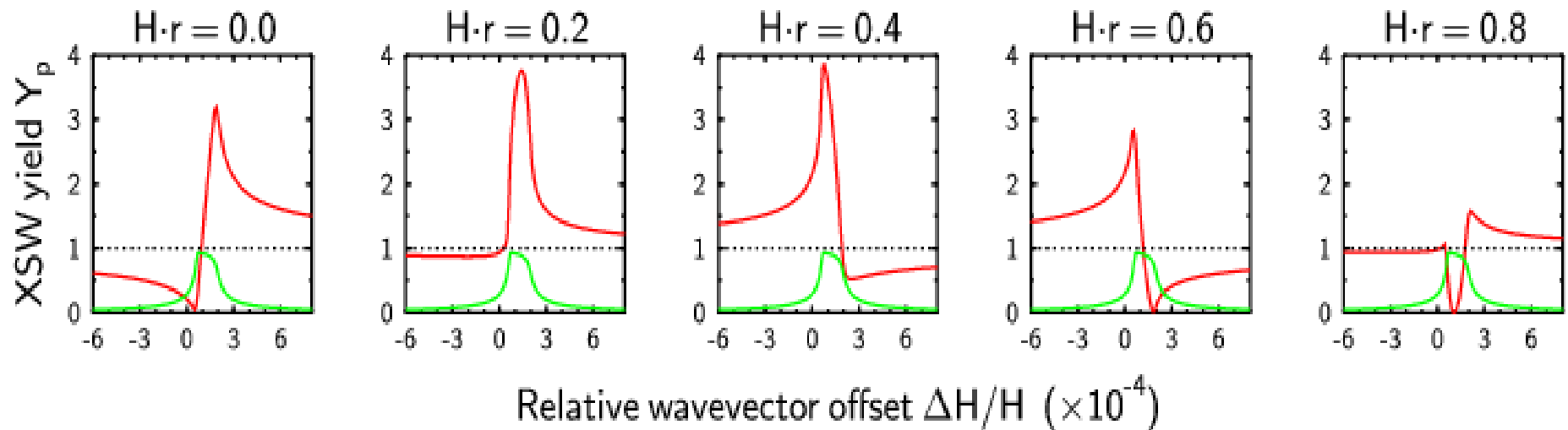


- substrate
- adsorbate

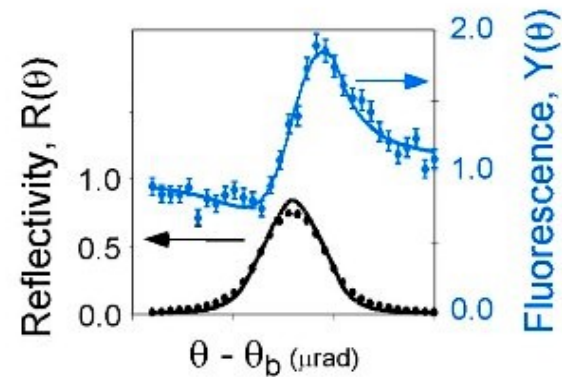
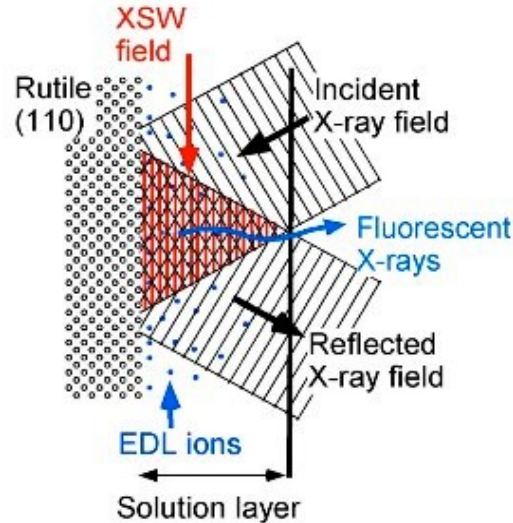
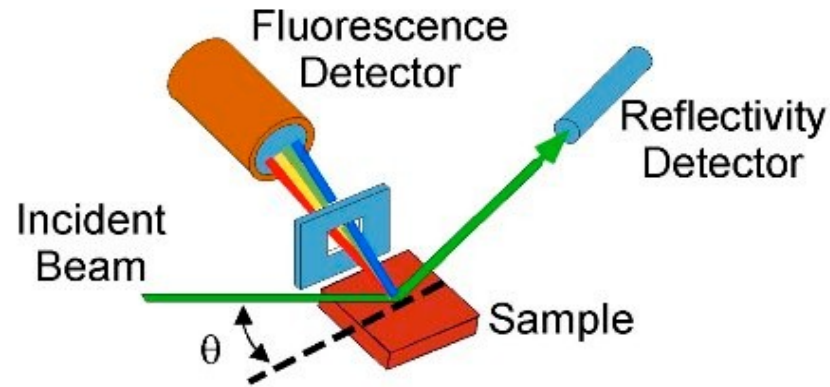


# Fluorescence ve stojaté vlně

$$Y_p(\Omega) = 1 + R + 2C\sqrt{R}f_H \cos(\nu - 2\pi P_H)$$



# Fluorescence ve stojaté vlně



Fluorescent yield:

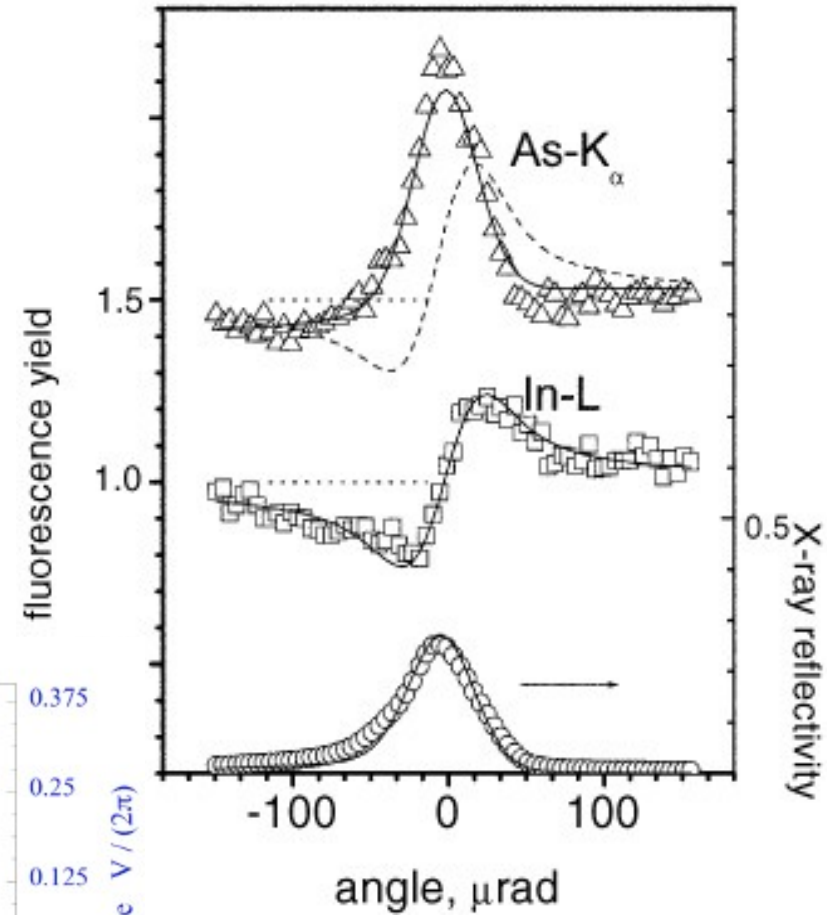
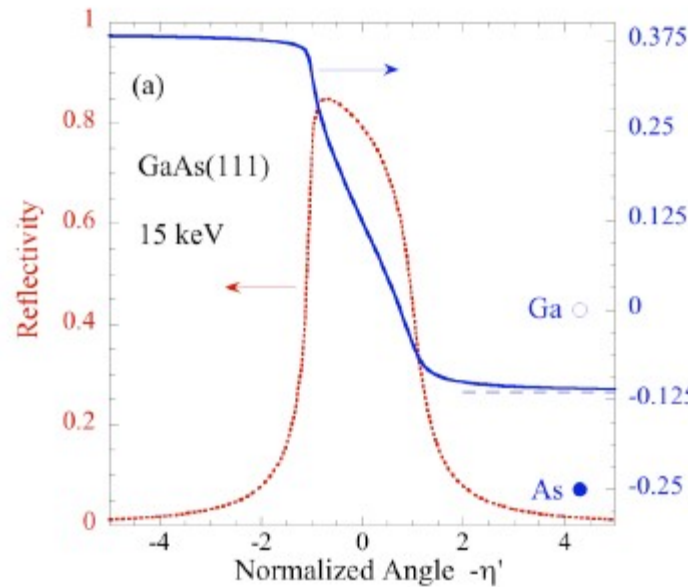
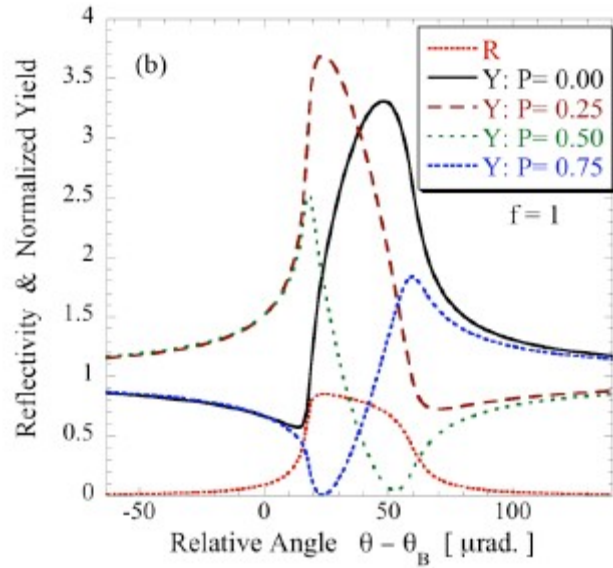
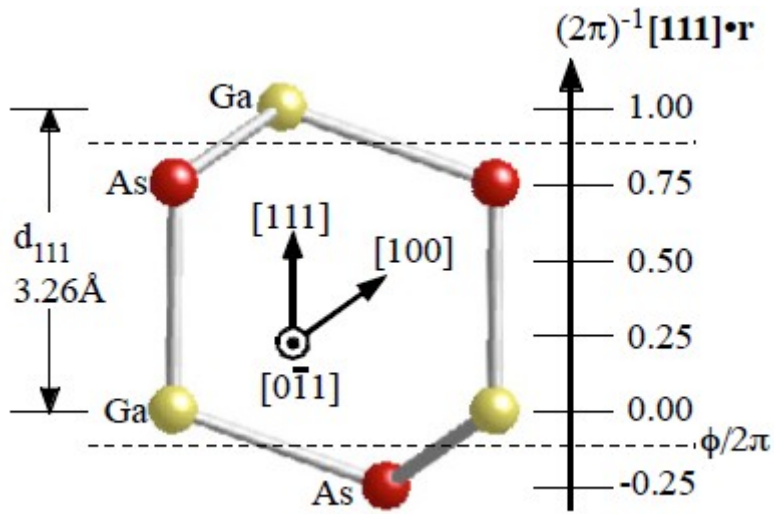
$$Y_H(\theta)/Y_{OB} = 1 + R(\theta) + 2F_H [R(q)]^{1/2} \cos[\nu(\theta) - 2\pi P_H]$$

$P_H$  ("coherent position") and  $F_H$  ("coherent fraction") describe the ion distribution. A first-order analysis of these parameters with respect to EDL structure yields:

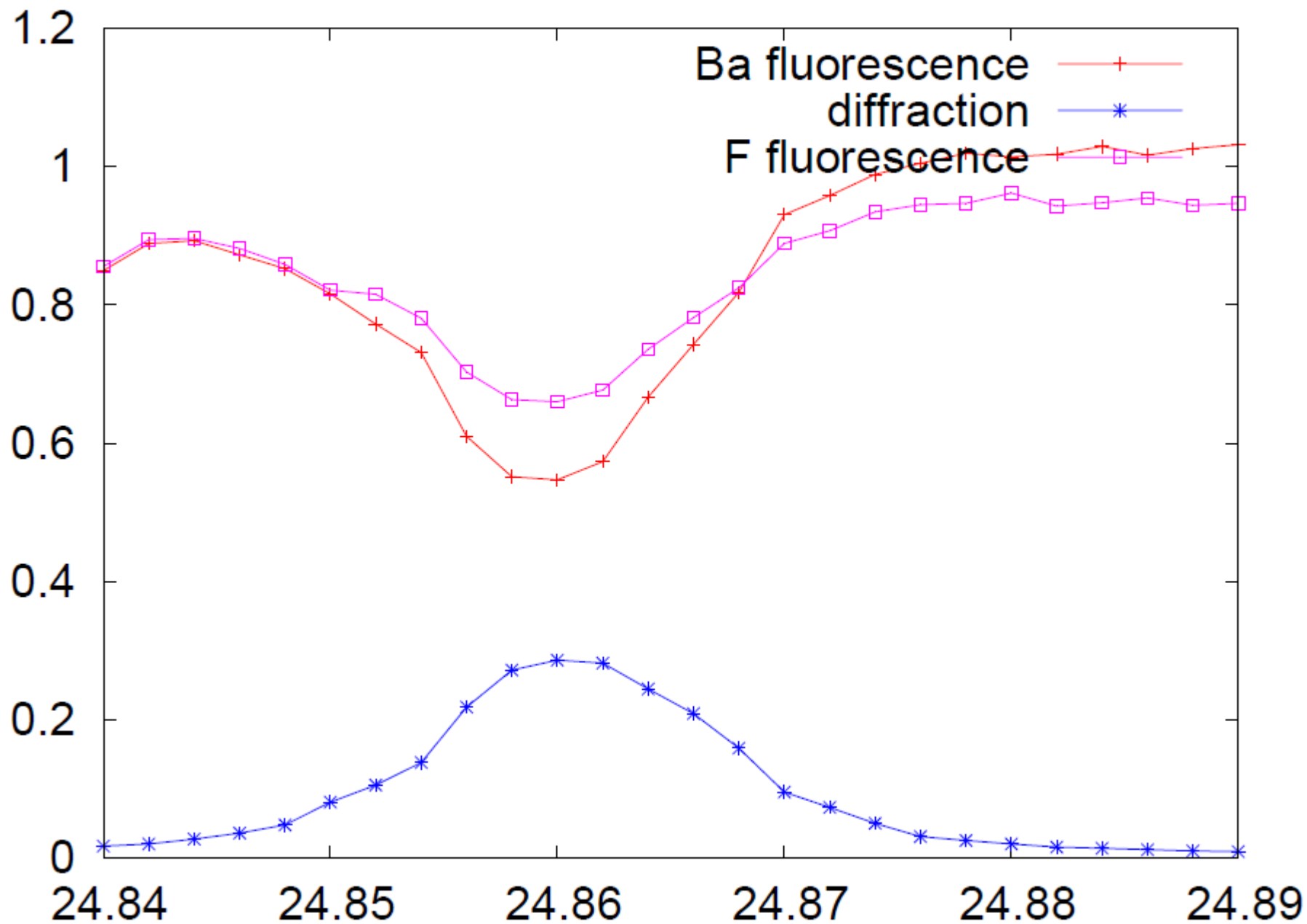
$$P \sim h/d_H, \text{ (h is ion height w/r to } H^{\text{th}} \text{ Bragg plane)}$$

$$F \sim \text{fraction of double layer ions in adsorbed condensed layer}$$

# Fluorescence ve stojaté vlně

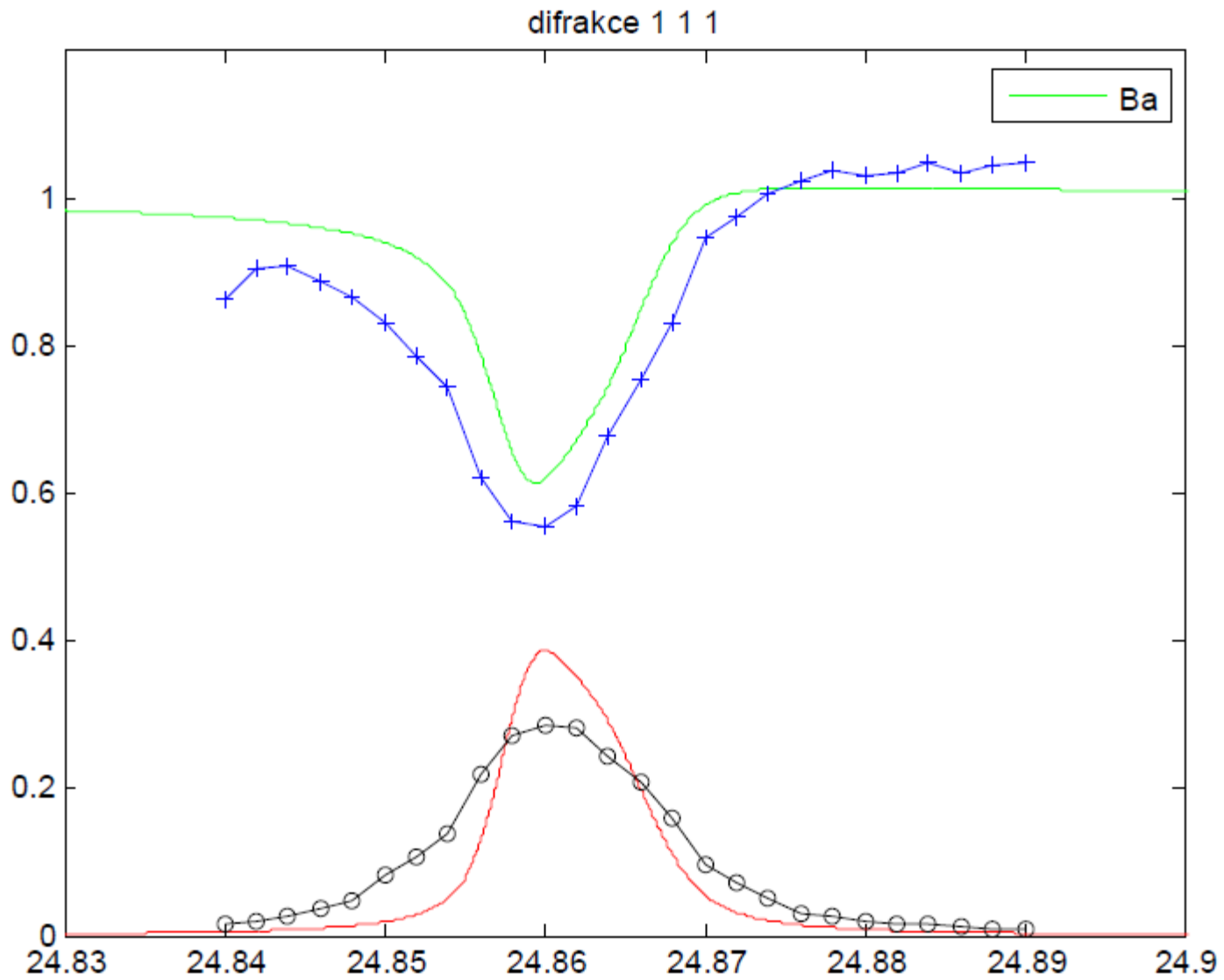


# Fluorescence ve stojaté vlně



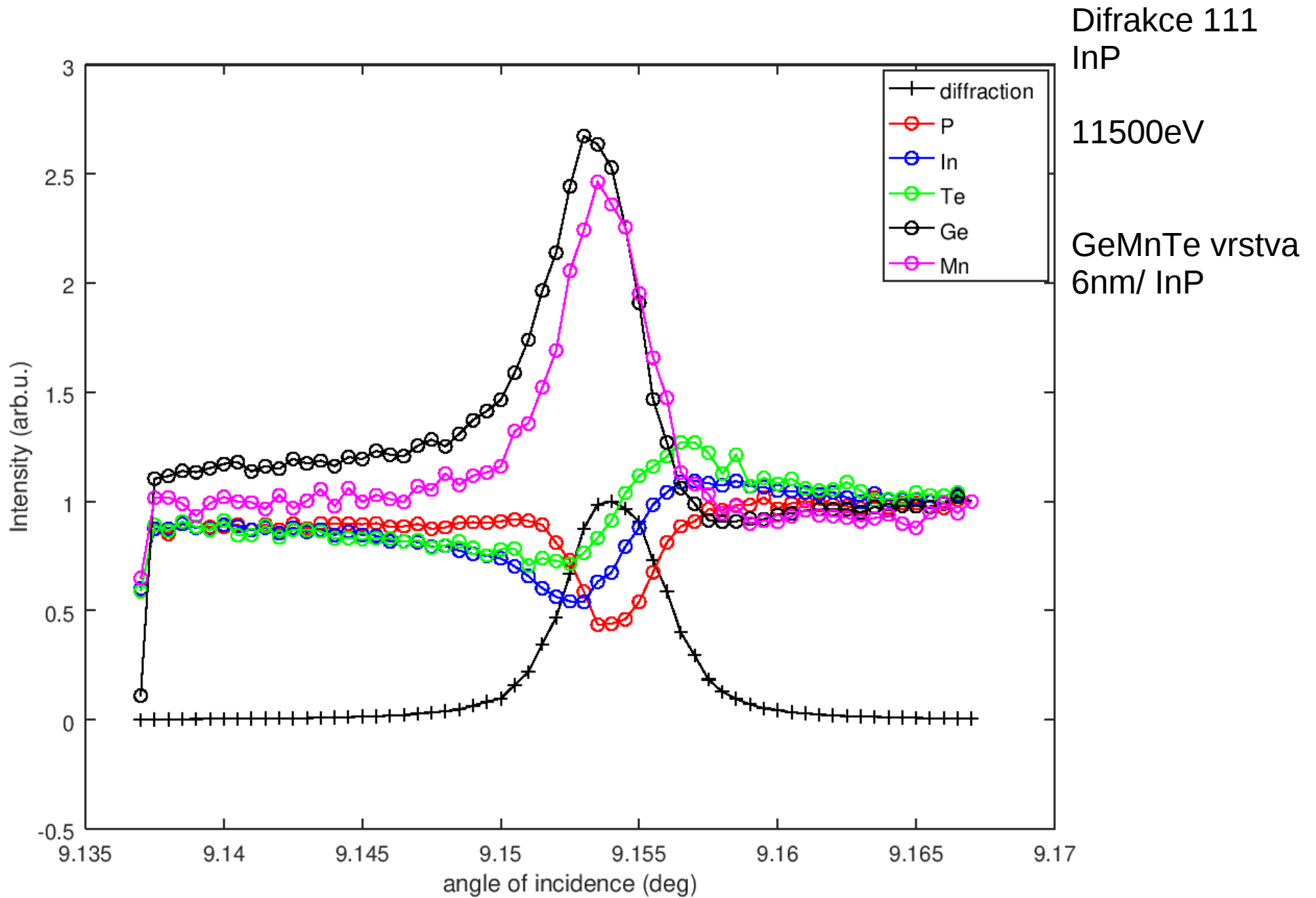


# Fluorescence ve stojaté vlně

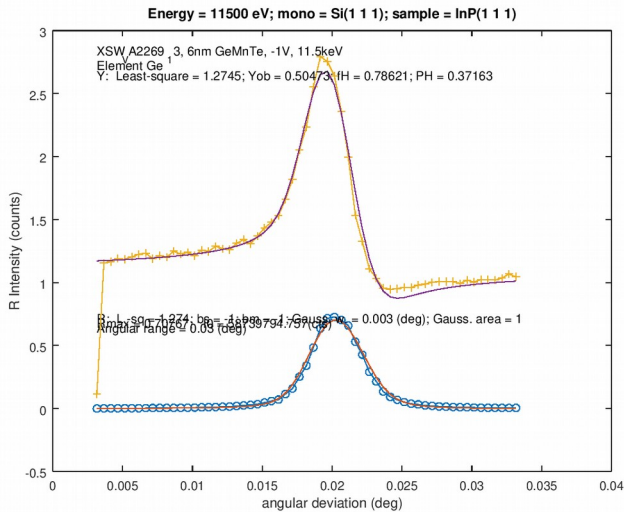
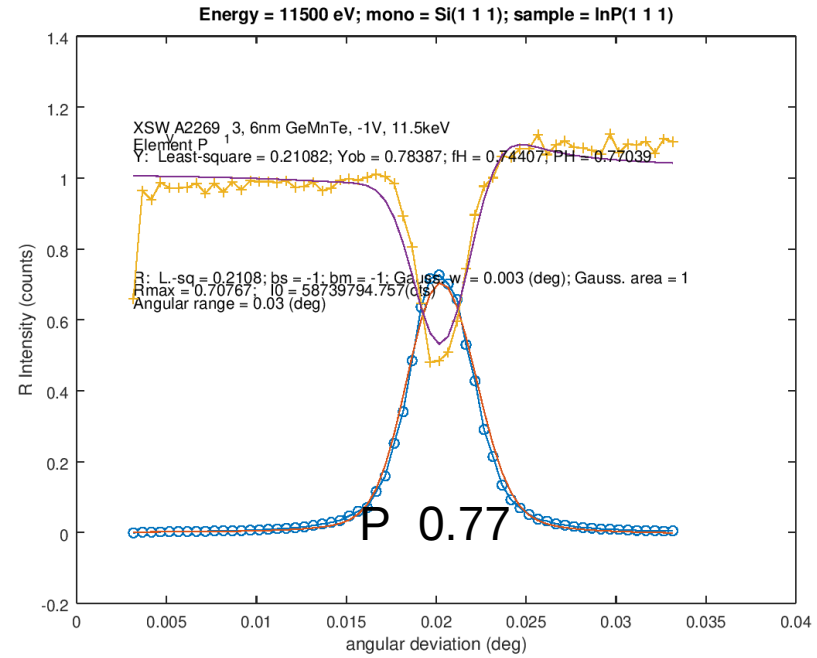
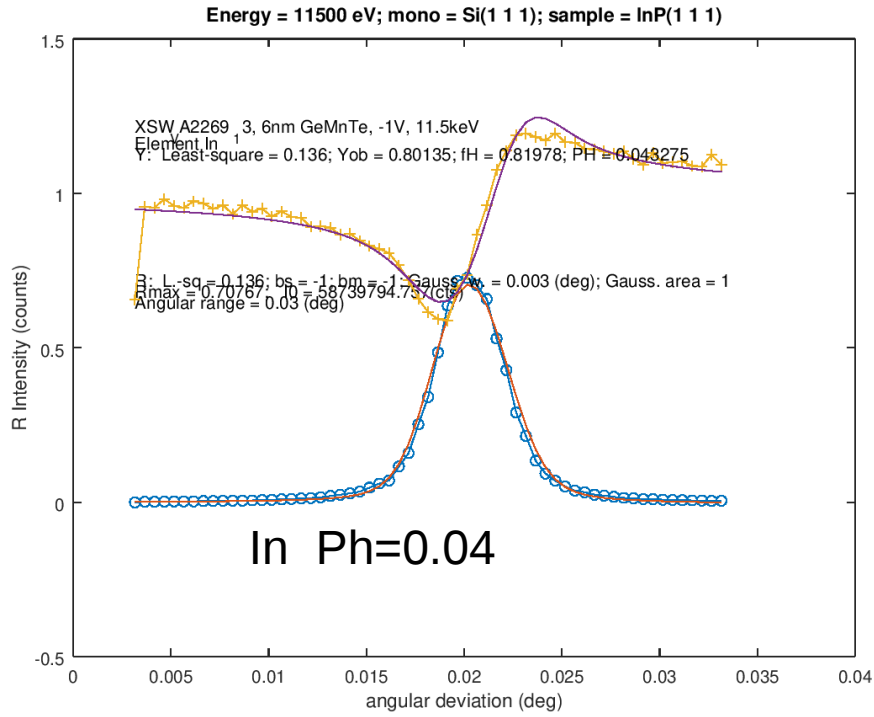


# Fluorescence ve stojaté vlně

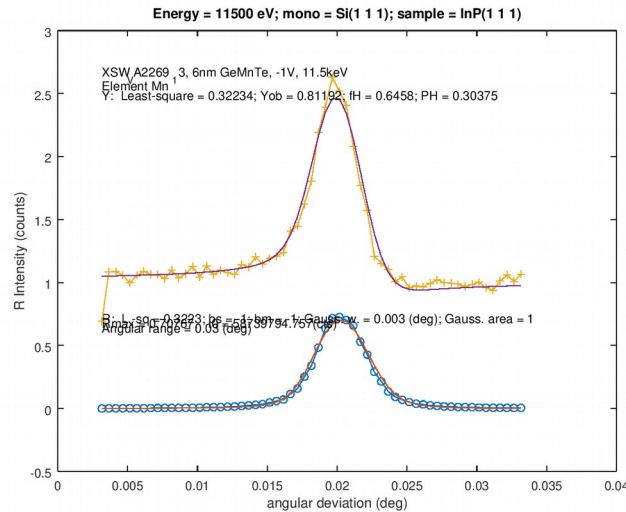
Difrakce



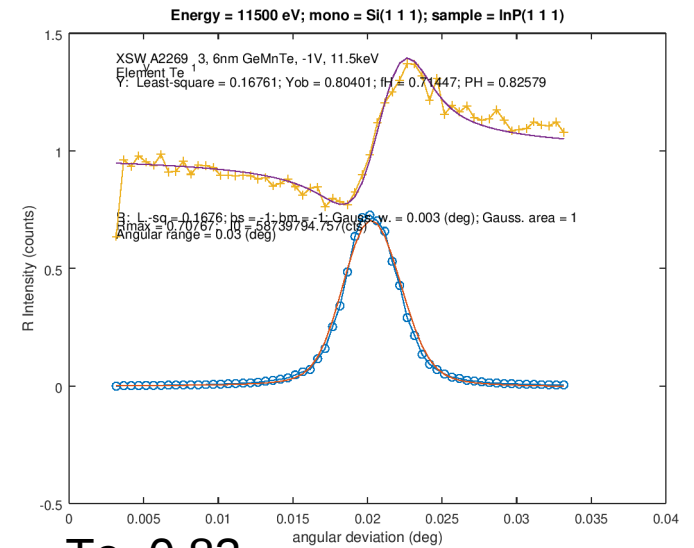
# Fluorescence ve stojaté vlně



Ge 0.37

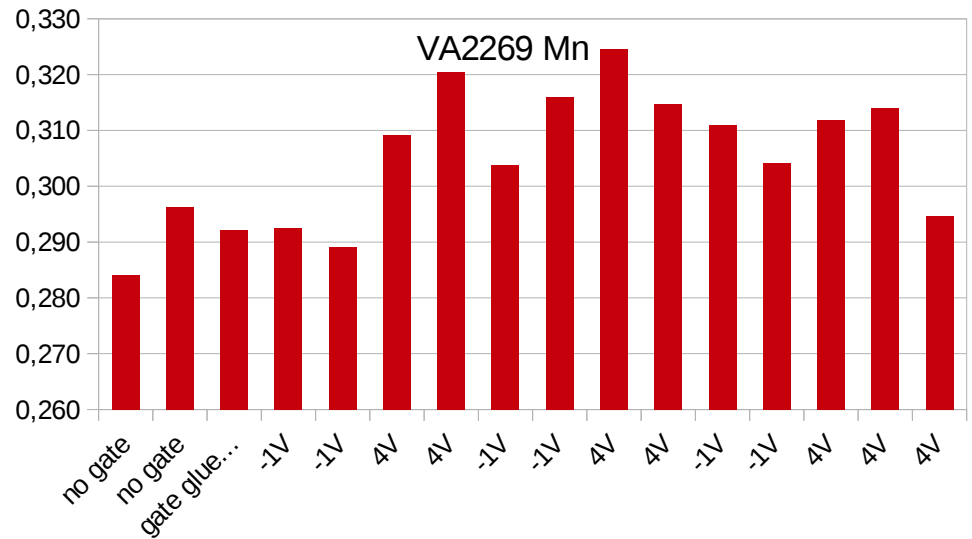
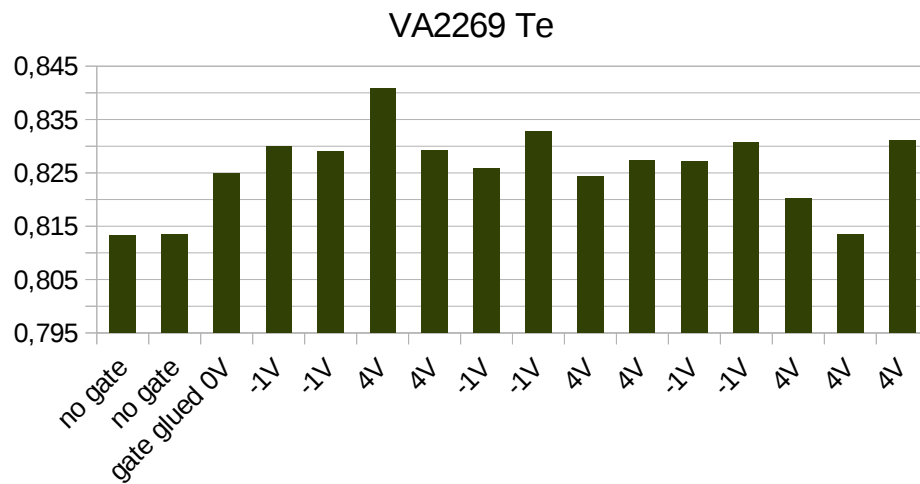
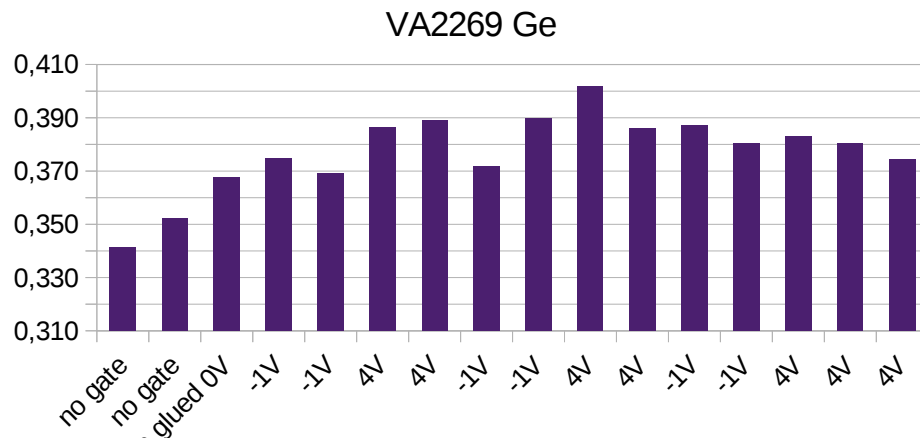


Mn 0.30



Te 0.83

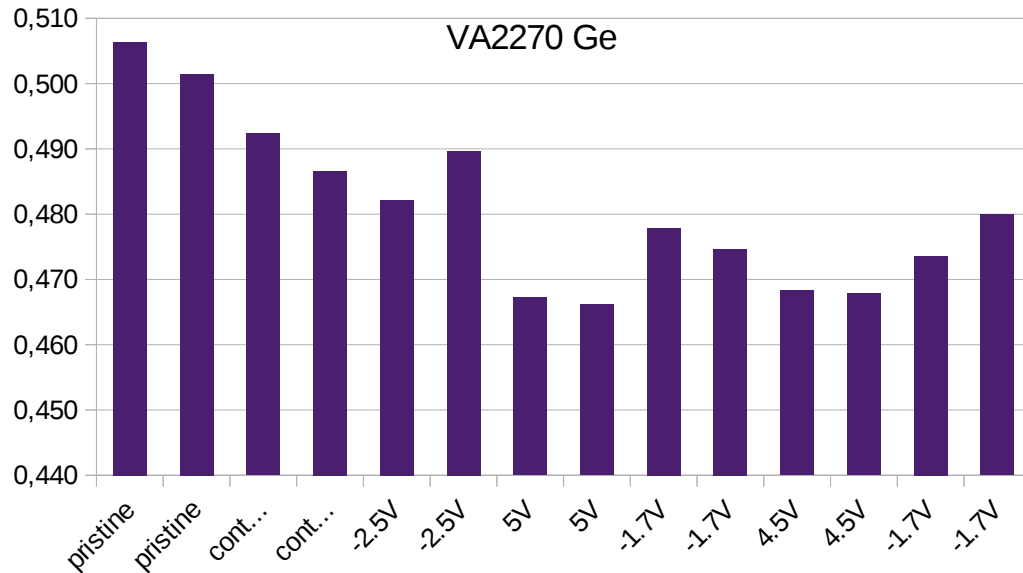
# Fluorescence ve stojaté vlně



Atomic position in fraction of standing wave period (0.3388 nm – InP 111)

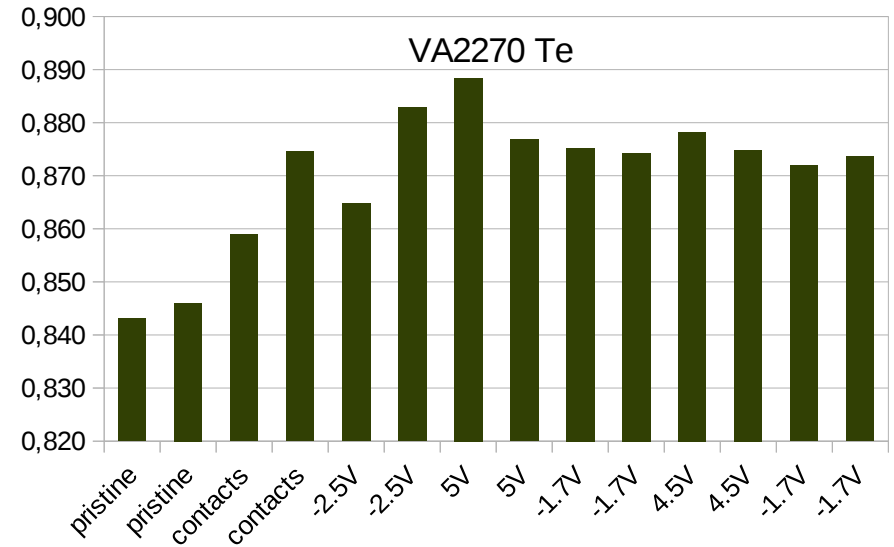
GeMnTe feroelektrické – piezoelektrické posuny pokud připojíme napětí na vzorek.

# Fluorescence ve stojaté vlně



Very obvious poling effect –  
ferroelectric shift of germanium

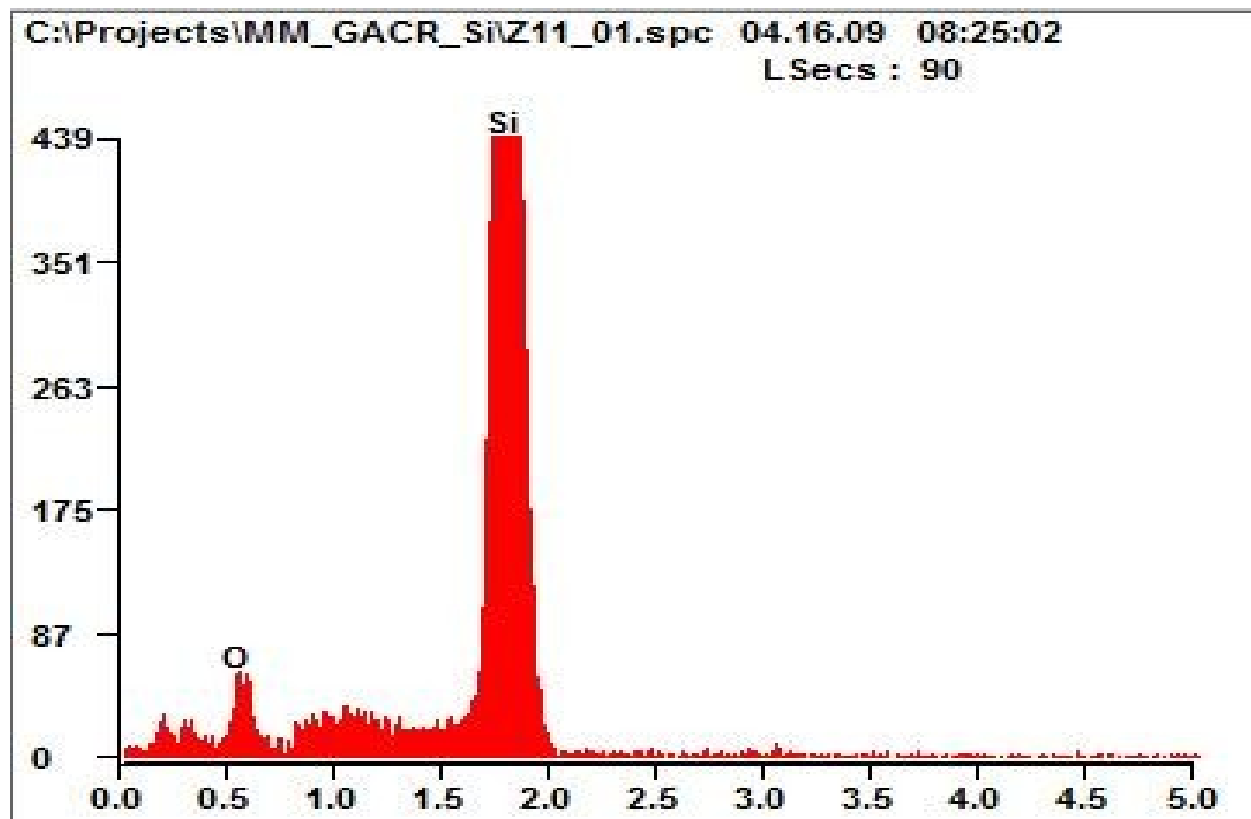
In Te not so obvious



GeTe feroelektrické – piezoelektrické posuny pokud připojíme napětí na vzorek.

# EDS, WDS

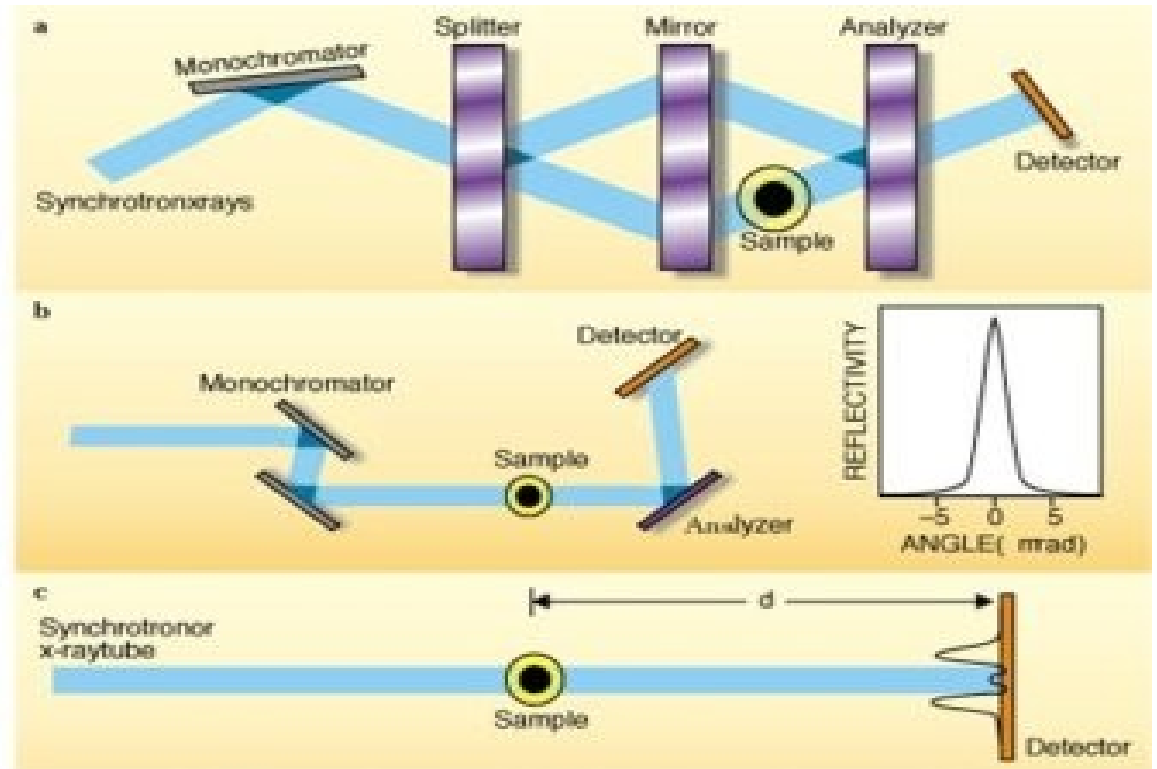
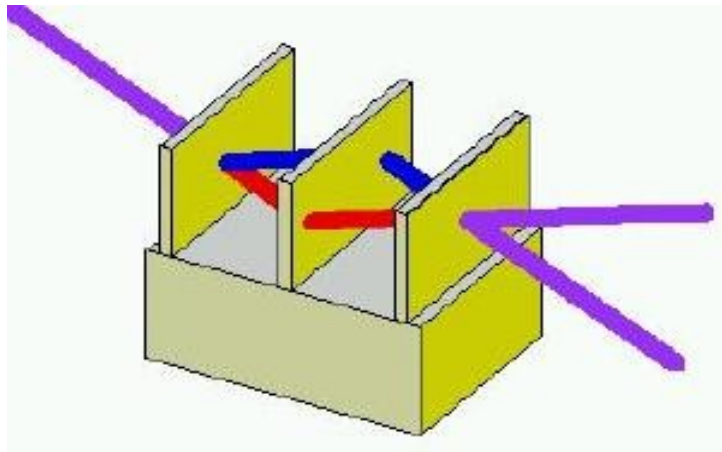
Energiově (vlnově) disperzní rentgenová spektroskopie  
Energy Dispersive X-ray Spectroscopy – EDS (EDAXS)  
Wavelength Dispersive X-ray Spectroscopy – WDS  
Často s elektronovou mikroskopií.  
Lokální chemické složení vzorku. Povrchově citlivé.



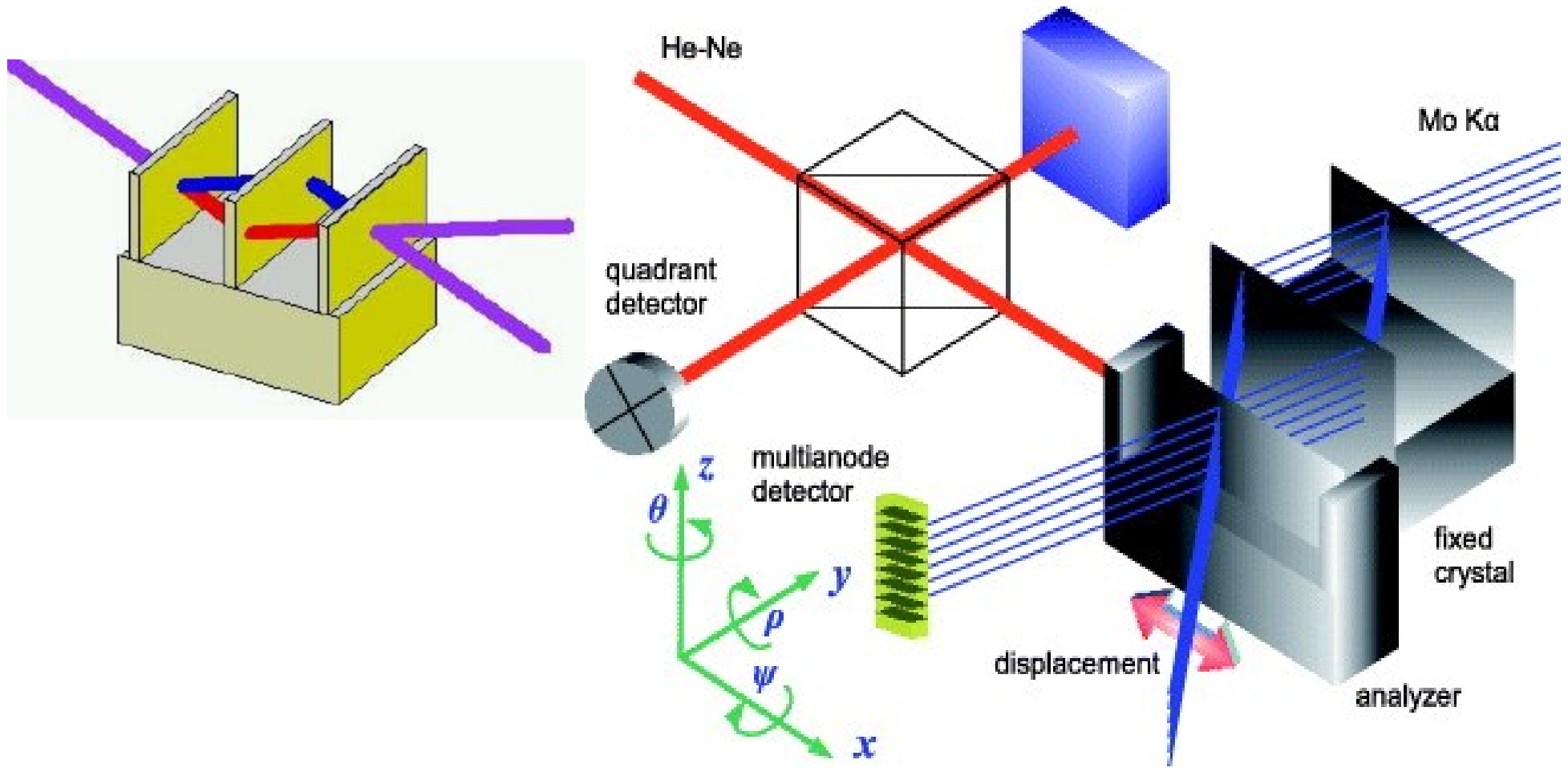
## Další podobné metody

PIXE – Particle Induced X-ray Emission – buzení iontovým svazkem

# Interferometrie



# Interferometrie





# Interferometrie

