

F7030 Rentgenový rozptyl na tenkých vrstvách

O. Čaha
PřF MU

Prezentace k přednášce
Numerické simulace
Příklady experimentů
Vybrané vztahy

Syllabus

1. Experimentální technika: zdroje, vznik rtg záření, goniometry, optické prvky (monochromátory, kolimátory, zrcadla, fokusační optika), detektory. Základní experimenty: polykrystalové a monokrystalové metody, mapování reciprokého prostoru
2. Kinematická teorie rozptylu: úvod do teorie rozptylu, rozptyl na elektronu, izolovaném atomu, krystal, strukturní a geometrický faktor, omezená velikost krystalu
3. Difrakce na polykrystalech I: strukturní faktor, velikost krystalitu (Scherrerova formule), vliv deformace na polohy a šířky difrakčních maxim, zbytková napětí, kvantifikace fázového složení (vnitřní normál)
4. Polykrystaly II: Full profile fitting; Texture, ODF (orientation distribution function); Debyeův vztah, PDF (pair distribution function).
5. SAXS: teoretický popis, řídké roztoky – Guinierův a Porodův vztah, uspořádané částice – long range a short-range order
6. Dokonalé, téměř dokonalé krystaly, epitaxní vrstvy: Kinematická teorie na monokrystalu a epitaxní vrstvě – polohy difrakcí, truncation rod, deformace v epitaxní vrstvě, relaxace. Mozaikový krystal
7. Dynamická teorie rtg reflexe: Jednovlnná aproximace – hloubka vniku, reflexe na hladkém rozhraní, multivrstvy (formalismus přenosové matice), TRXRF
8. Dynamická teorie rtg difrakce: Dvojevlnná aproximace: případ Bragg a Laue, Borrmannův jev, stojatá vlna, GID, epitaxní vrstvy
9. Semikinematická teorie I: DWBA, Rozptyl na drsných rozhraních – popis drsného rozhraní, příklady: fraktálové rozhraní, dvouúrovňové, vicinální, spekulární odraz a nespekulární rozptyl, drsné multivrstvy
10. Semikinematická teorie II: GISAXS na částicích na povrchu a uvnitř vzorku, Difuzní rozptyl na defektech v krystalu v okolí difrakce
11. Experimentální rozlišení Experimentální rozlišení v reciprokém prostoru: analyzer streak, detector streak, monochromator streak, DuMondovy grafy, disperzní a nedisperzní uspořádání, koherenční šířka a délka
12. Další rentgenové metody: Fluorescenční spektroskopie, absorpční spektroskopie – XAFS, XMCD.

Dynamická teorie

$$(\Delta + K^2)E(\mathbf{r}) = \hat{V}(\mathbf{r})E(\mathbf{r})$$

$$\hat{V}(\mathbf{r}) = \text{graddiv} - K^2\chi(\mathbf{r})$$

Řešení v periodickém potenciálu
ve tvaru Blochovy vlny

$$D(\mathbf{r}) = \varepsilon_0(1 + \chi(\mathbf{r}))E(\mathbf{r})$$

$$E(\mathbf{r}) = \sum_{\mathbf{g}} E_{\mathbf{g}} e^{i\mathbf{k}_{\mathbf{g}} \cdot \mathbf{r}}$$

$$K^2 E_{\mathbf{g}} - \mathbf{k}_{\mathbf{g}} \times (E_{\mathbf{g}} \times \mathbf{k}_{\mathbf{g}}) = -K^2 \sum_{\mathbf{p}} \chi_{\mathbf{p}} E_{\mathbf{g}-\mathbf{p}}$$

$$(K^2 - k_{\mathbf{g}}^2) D_{\mathbf{g}} = \mathbf{k}_{\mathbf{g}} \times (\mathbf{k}_{\mathbf{g}} \times \sum_{\mathbf{p}} \chi_{\mathbf{p}} D_{\mathbf{g}-\mathbf{p}})$$

Dynamická teorie

Okrajové podmínky

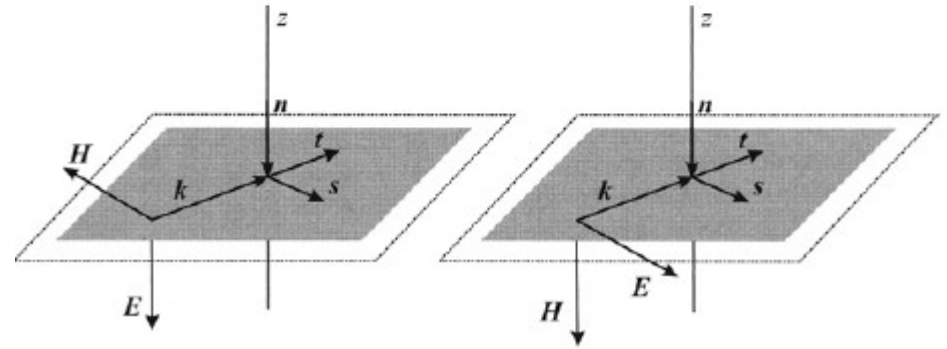
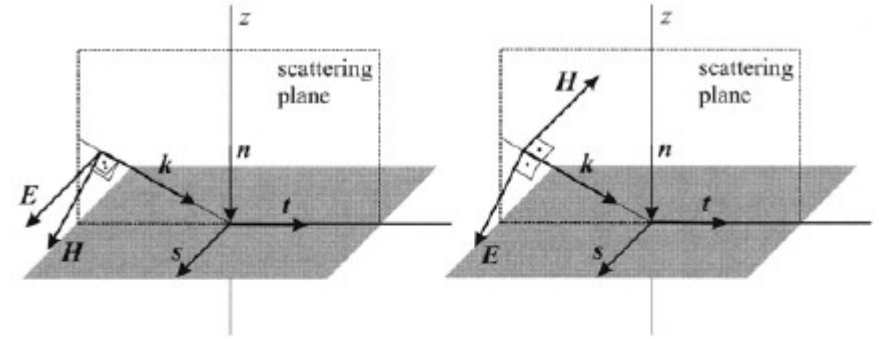
$$\mathbf{H} = \frac{c\epsilon_0}{K} \mathbf{k} \times \mathbf{E};$$

S-polarizace

$$E_{\parallel} = Es, \quad H_{\parallel} = \frac{k_z}{K} \epsilon_0 c E t.$$

P-polarizace

$$E_{\parallel} \approx \frac{k_z}{K} E t, \quad H_{\parallel} \approx -\epsilon_0 c E s.$$



$$\sum_n E_n^a \mathbf{s}_n e^{i\mathbf{k}_n^a \cdot \mathbf{r}} \Big|_{\mathbf{r} \in S} = \sum_n E_n^b \mathbf{s}_n e^{i\mathbf{k}_n^b \cdot \mathbf{r}} \Big|_{\mathbf{r} \in S},$$

$$\sum_n E_n^a k_{zn}^a t_n e^{i\mathbf{k}_n^a \cdot \mathbf{r}} \Big|_{\mathbf{r} \in S} = \sum_n E_n^b k_{zn}^b t_n e^{i\mathbf{k}_n^b \cdot \mathbf{r}} \Big|_{\mathbf{r} \in S},$$

Koplanární symetrická zjednodušení:

$$\sum_n E_n^a e^{i\mathbf{k}_n^a \cdot \mathbf{r}} \Big|_{\mathbf{r} \in S} = \sum_n E_n^b e^{i\mathbf{k}_n^b \cdot \mathbf{r}} \Big|_{\mathbf{r} \in S}$$

Dynamická teorie

Dvouvlnná aproximace

$$\mathbf{E}(\mathbf{r}) = \mathbf{E}_0 e^{i\mathbf{k}_0 \cdot \mathbf{r}} + \mathbf{E}_h e^{i\mathbf{k}_h \cdot \mathbf{r}}, \quad \mathbf{k}_h = \mathbf{k}_0 + \mathbf{h},$$

S-polarizace

$$(k_0^2 - k^2) E_0 = K^2 \chi_{-h} E_h$$

$$k = nK$$

$$(k_h^2 - k^2) E_h = K^2 \chi_0 E_h,$$

Dynamická teorie

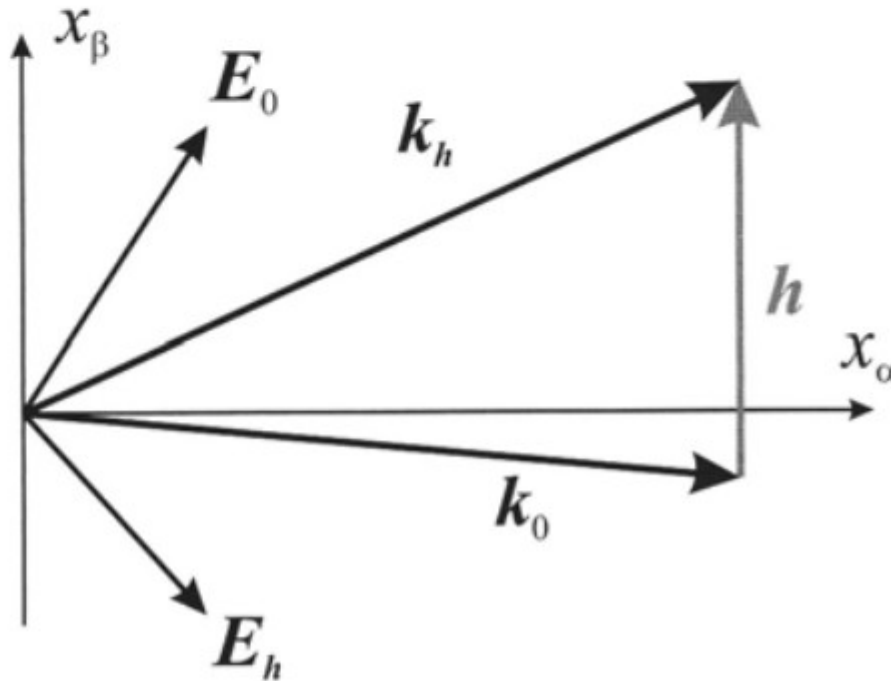
P-polarizace

$$(k_0^2 - k^2)E_{0\alpha} - k_{0\alpha}(k_{0\alpha}E_{0\alpha} + k_{0\beta}E_{0\beta}) = K^2\chi_{-h}E_{h\alpha}$$

$$(k_0^2 - k^2)E_{0\beta} - k_{0\beta}(k_{0\alpha}E_{0\alpha} + k_{0\beta}E_{0\beta}) = K^2\chi_{-h}E_{h\beta}$$

$$(k_h^2 - k^2)E_{h\alpha} - k_{h\alpha}(k_{h\alpha}E_{h\alpha} + k_{h\beta}E_{h\beta}) = K^2\chi_h E_{0\alpha}$$

$$(k_h^2 - k^2)E_{h\beta} - k_{h\beta}(k_{h\alpha}E_{h\alpha} + k_{h\beta}E_{h\beta}) = K^2\chi_h E_{0\beta}$$



Dynamická teorie

$$(k_0^2 - k^2)(k_h^2 - k^2) = K^4 \chi_h \chi_{-h} \left(1 - P \frac{k_{0\alpha}^2 h^2}{k^4 - K^4 \chi_h \chi_{-h}} \right)$$

$P = 0$ for the S-polarization and $P = 1$ for the P-polarization.

$$1 - p \frac{k_{0\alpha}^2 h^2}{k^4 - K^4 \chi_h \chi_{-h}} \approx C^2$$

S-polarizace $C=1$

P-polarizace $C = \cos(2\Theta)$

Dynamická teorie

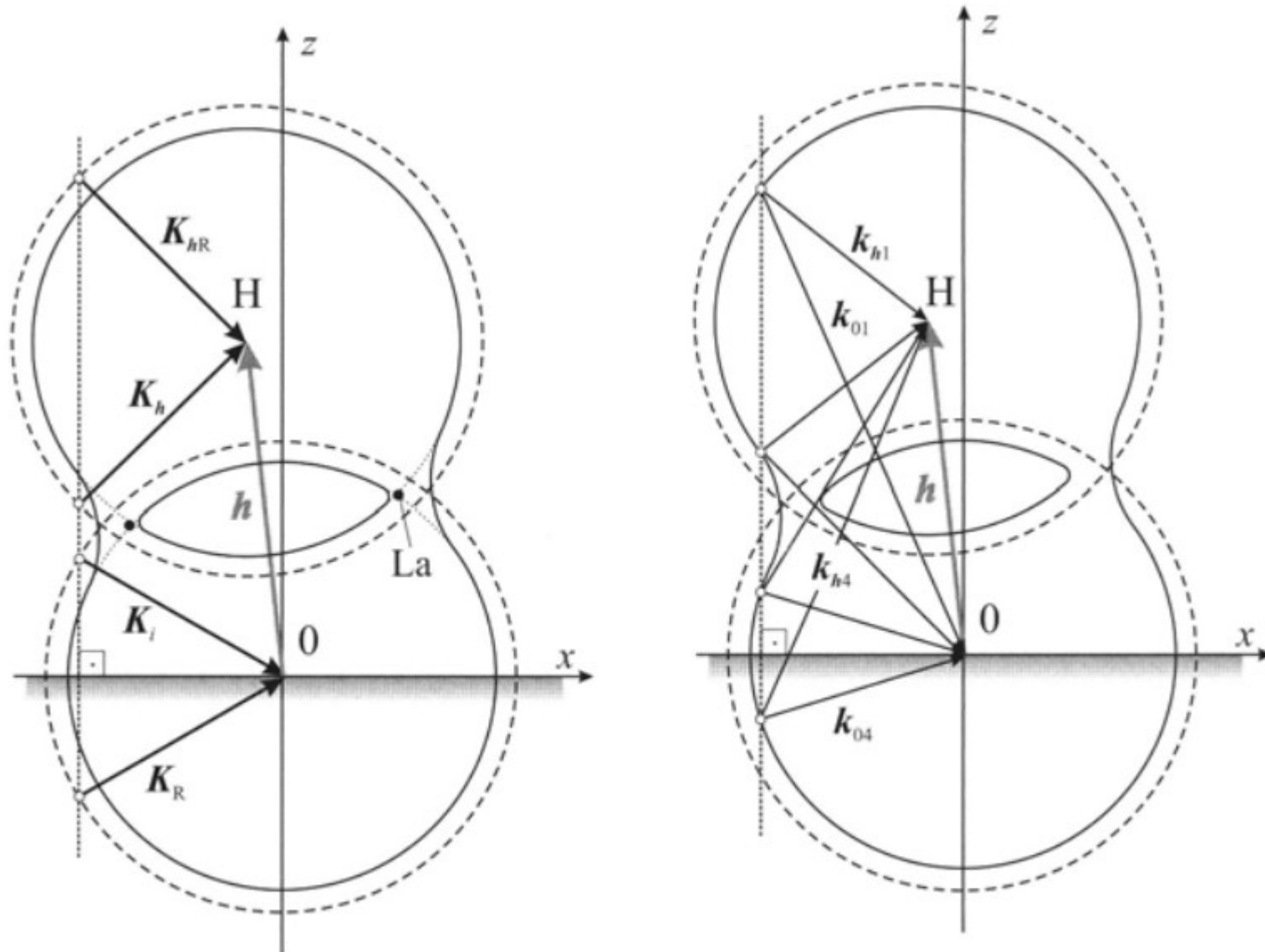


Fig. 6.5. Dispersion surface of the coplanar two-beam case: *left* the wave vectors of the vacuum waves, *right* the wave vectors of the waves in the crystal. In the right panel, the tie-points are denoted by small empty circles. La denotes the Laue point.

Dynamická teorie

$$k_{0hn}, n = 1, \dots, 4,$$

$$(k_0^2 - k^2) E_0 = K^2 \chi_{-h} E_h$$

Soustava je lineárně závislá

$$(k_h^2 - k^2) E_h = K^2 \chi_0 E_h,$$

$$c_n = \frac{E_{hn}}{E_{0n}}$$

Okrajové podmínky

$$\sum_{n=1,4} E_{0n} = \text{const}, \quad \sum_{n=1,4} c_n E_{0n} = \text{const},$$

$$\sum_{n=1,4} k_{0nz} E_{0n} = \text{const}, \quad \sum_{n=1,4} c_n k_{hzn} E_{0n} = \text{const}.$$

$$\mathbf{K}_{R\parallel} = \mathbf{K}_{0\parallel}, \quad \mathbf{K}_{h\parallel} = \mathbf{K}_{hR\parallel} = \mathbf{K}_{0\parallel} + \mathbf{h}_{\parallel}.$$

Dynamická teorie

Vynecháme málo přispívající řešení,
Kde velikosti vlnových vektorů jsou příliš velké k_{01} a k_{h4} .

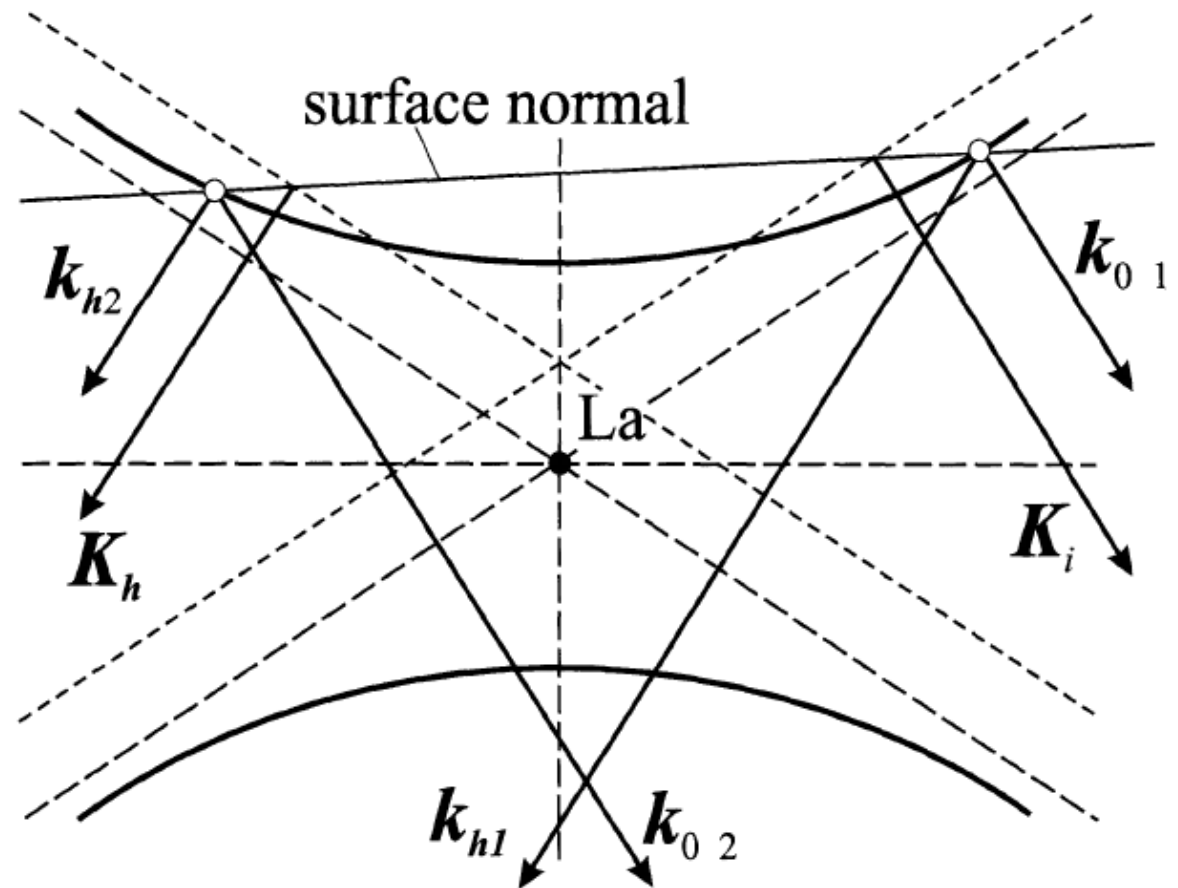
$$E_i + E_R = E_{01} + E_{02}, \quad K_{0z}(E_i - E_R) = k_{0z1}E_{01} + k_{0z2}E_{02}$$

$$E_h = c_1E_{01} + c_2E_{02}, \quad K_{hz}E_h = k_{hz1}c_1E_{01} + k_{hz2}c_2E_{02};$$

$$(k_0 - k)(k_h - k) = \frac{1}{4}K^2C^2\chi_h\chi_{-h}$$

$$(k_0 - k)E_0 = \frac{1}{2}KC\chi_{-h}E_h$$

$$(k_h - k)E_h = \frac{1}{2}KC\chi_hE_0.$$



Dynamická teorie

Okrajové podmínky pro polonekonečný vzorek:

Nulová intenzita ve velké hloubce (správné znaménko imaginární části k_{0z})

Jediný relevantní kořen:

$$E_i = E_{01}, E_h = c_1 E_{01}$$

$$I_h = I_i |c_1|^2$$

Změna plochy svazku:

$$\mathcal{R}_h = \frac{\Psi_h}{\Psi_i} = \frac{|\gamma_h|}{\gamma_0} |c_1|^2$$

Dynamická teorie

$$\cos \alpha_{\mathbf{h}} = \cos \alpha_i - 2 \sin \Theta_B \cos \phi$$

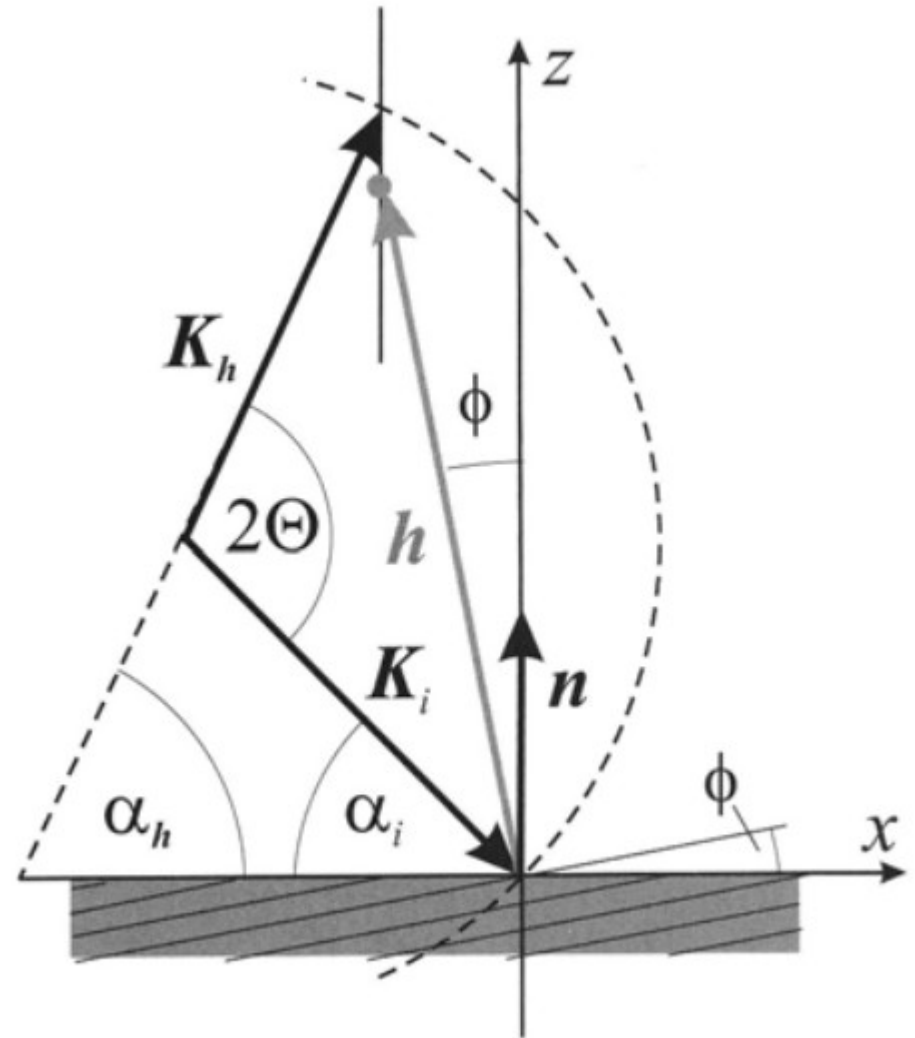
$$\sin \Theta_B = \frac{|\mathbf{h}|}{2K}$$

$$\alpha_i = \alpha_{iB} + \eta_i, \quad |\eta_i| \ll \alpha_{iB}$$

$$\alpha_{\mathbf{h}} = \alpha_{\mathbf{h}B} + \eta_{\mathbf{h}}, \quad |\eta_{\mathbf{h}}| \ll \alpha_{\mathbf{h}B}$$

$$\frac{\eta_{\mathbf{h}}}{\eta_i} = -\frac{\gamma_0}{\gamma_{\mathbf{h}}}$$

$$b = \gamma_{\mathbf{h}}/\gamma_0$$



$$\gamma_0 = \sin \alpha_{iB} = \sin(\Theta_B - \phi), \quad \gamma_{\mathbf{h}} = -\sin \alpha_{\mathbf{h}B} = -\sin(\Theta_B + \phi)$$

where γ_0 and $\gamma_{\mathbf{h}}$ denote the direction cosines of the primary and diffracted waves in the Bragg maximum with respect to the *internal* surface normal:

Dynamická teorie

$$\gamma_0 = \sin \alpha_{iB} = \sin(\Theta_B - \phi), \quad \gamma_h = -\sin \alpha_{hB} = -\sin(\Theta_B + \phi)$$

$$\Delta\alpha_h = \frac{1}{|b|} \Delta\alpha_i$$

$$A_i \Delta\alpha_i = A_h \Delta\alpha_h$$

Dynamická teorie

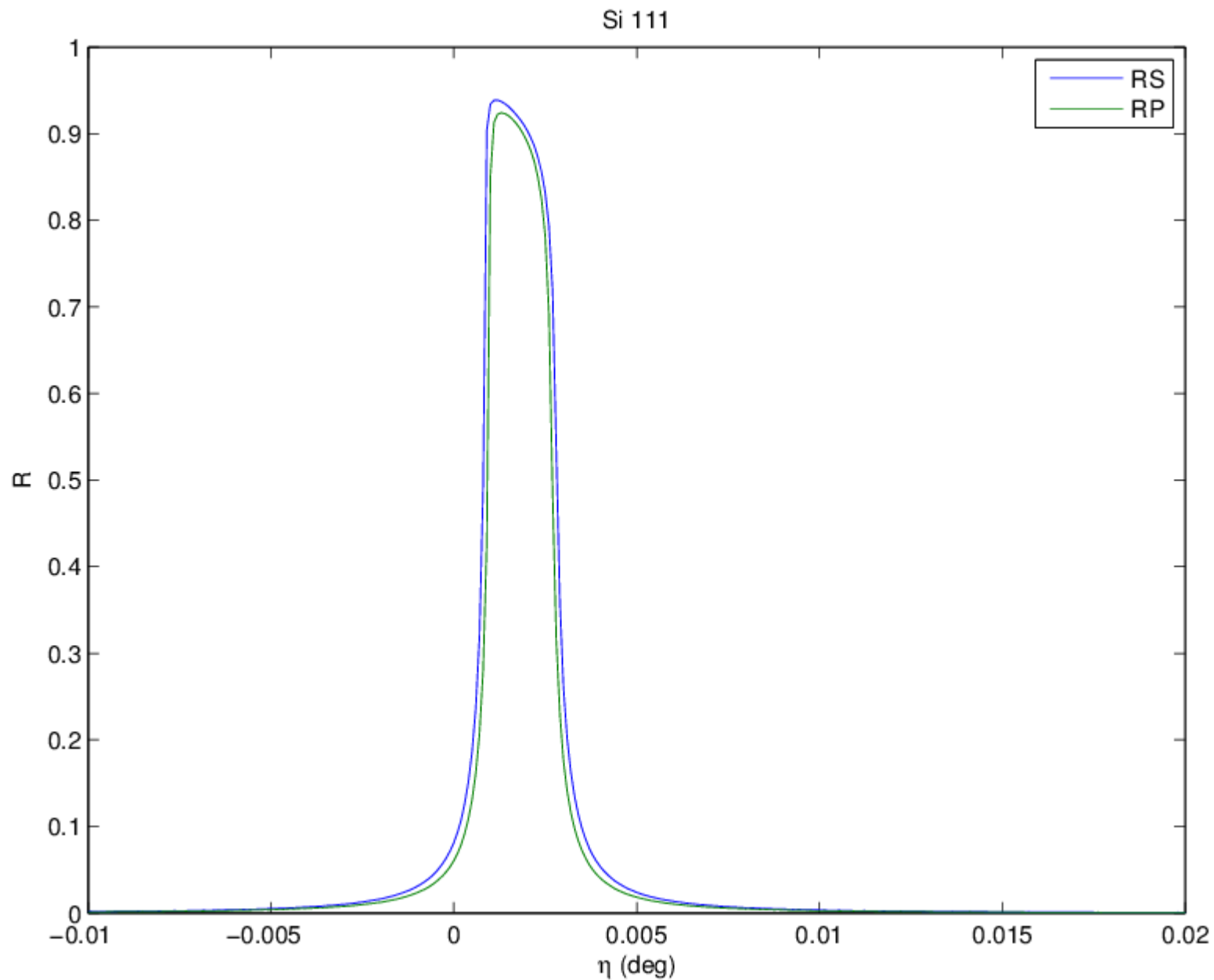
$$\beta = 2\eta \sin(2\theta_B) + \chi_0 \left(1 - \frac{\gamma_0}{\gamma_h}\right)$$

$$y = \frac{\beta}{2C \sqrt{\chi_h \chi_{-h}} \sqrt{|\gamma_h/\gamma_0|}}$$

$$\mathcal{R}(\eta) = \left| \frac{\chi_h}{\chi_{-h}} \right| \left| y \pm \sqrt{y^2 - 1} \right|^2$$

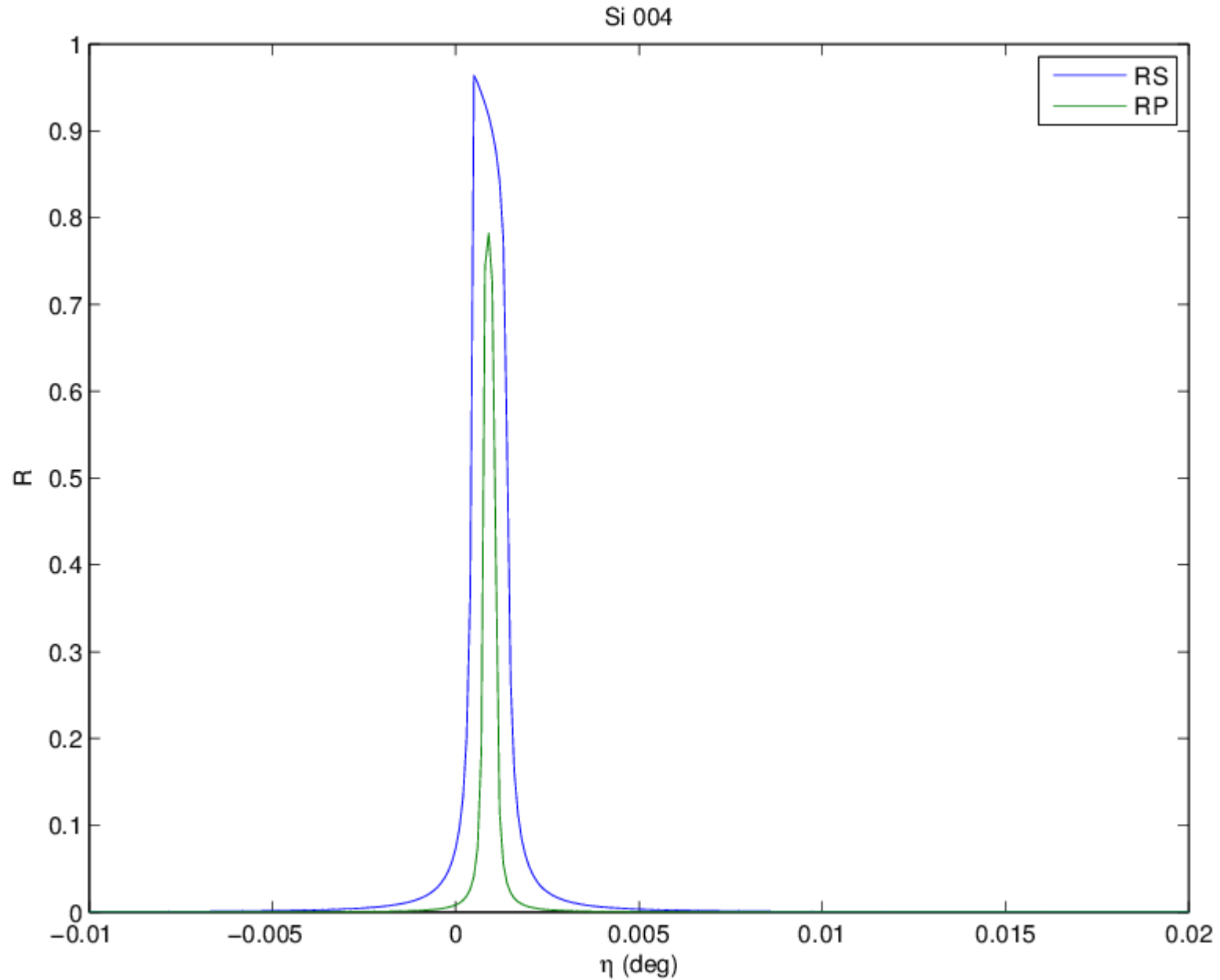
Dynamická teorie

Difrakce na polonekonečném krystalu v dvouvlonné aproximaci



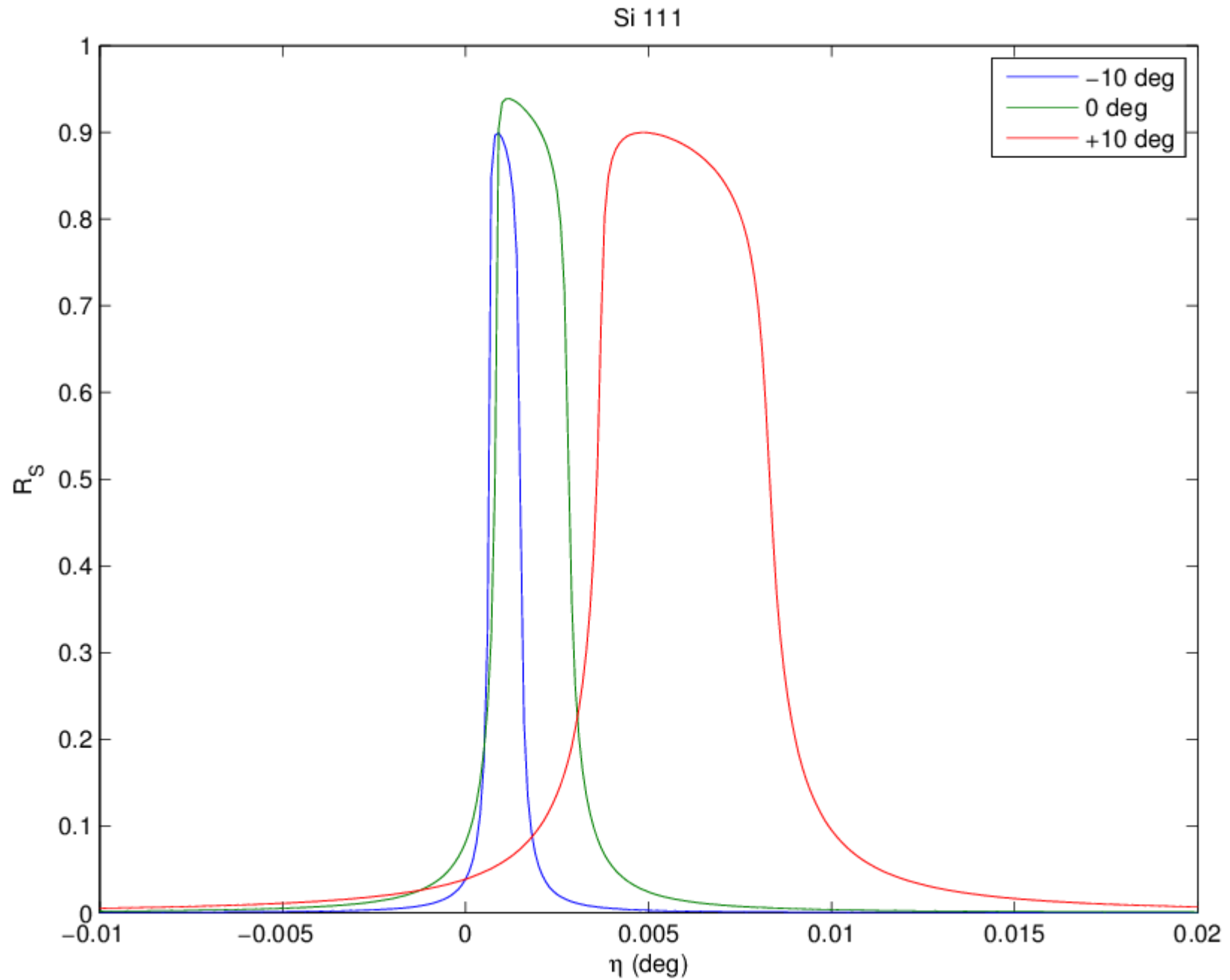
Dynamická teorie

Difrakce na polonekonečném krystalu v dvouvlnné aproximaci



Dynamická teorie

Difrakce na polonekonečném krystalu v dvouvlnné aproximaci



Dynamická teorie

Difrakce na průchod

$$W = \frac{KT}{2} C \sqrt{\frac{\chi_h \chi_{-h}}{\gamma_0 \gamma_h}}$$

$$I_h^{(e)} = |D_h^{(e)}|^2 = I_0^{(i)} \frac{\gamma_0}{\gamma_h} \left| \frac{\chi_h}{\chi_{-h}} \right| \left| W \operatorname{sinc}(W \sqrt{1 + y^2}) \right|^2$$

$$I_0^{(e)} = |D_0^{(e)}|^2 = I^{(i)} \left| \frac{y^2 + \cos^2(W \sqrt{1 + y^2})}{1 + y^2} \right|$$

Dynamická teorie

$$\eta_{max} = -\frac{\operatorname{Re}(\chi_0)}{2 \sin(2\theta_B)} \left(1 - \frac{\gamma_0}{\gamma_h} \right)$$

The angular width of the reflection curve can be defined by the points $y = \pm 1$

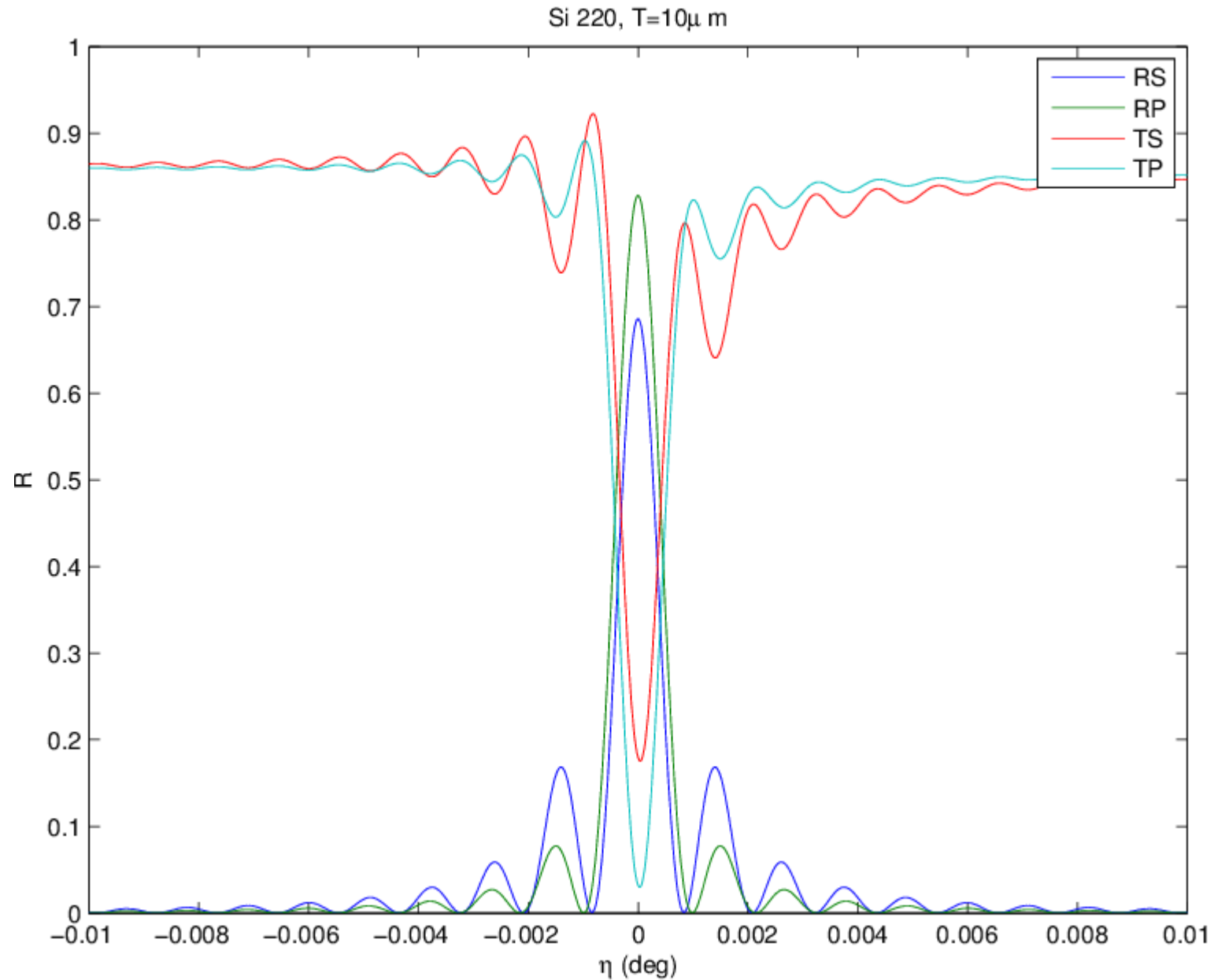
$$\Delta\eta = \frac{2C \sqrt{\chi_h \chi_{-h}}}{\sin(2\theta_B)} \frac{\gamma_h}{\gamma_0}$$

The reflectivity for $\eta = \eta_{max}$ is an oscillating function of the crystal thickness T

$$\tau = \frac{\lambda}{C} \sqrt{\frac{\gamma_0 \gamma_h}{\chi_h \chi_{-h}}}$$

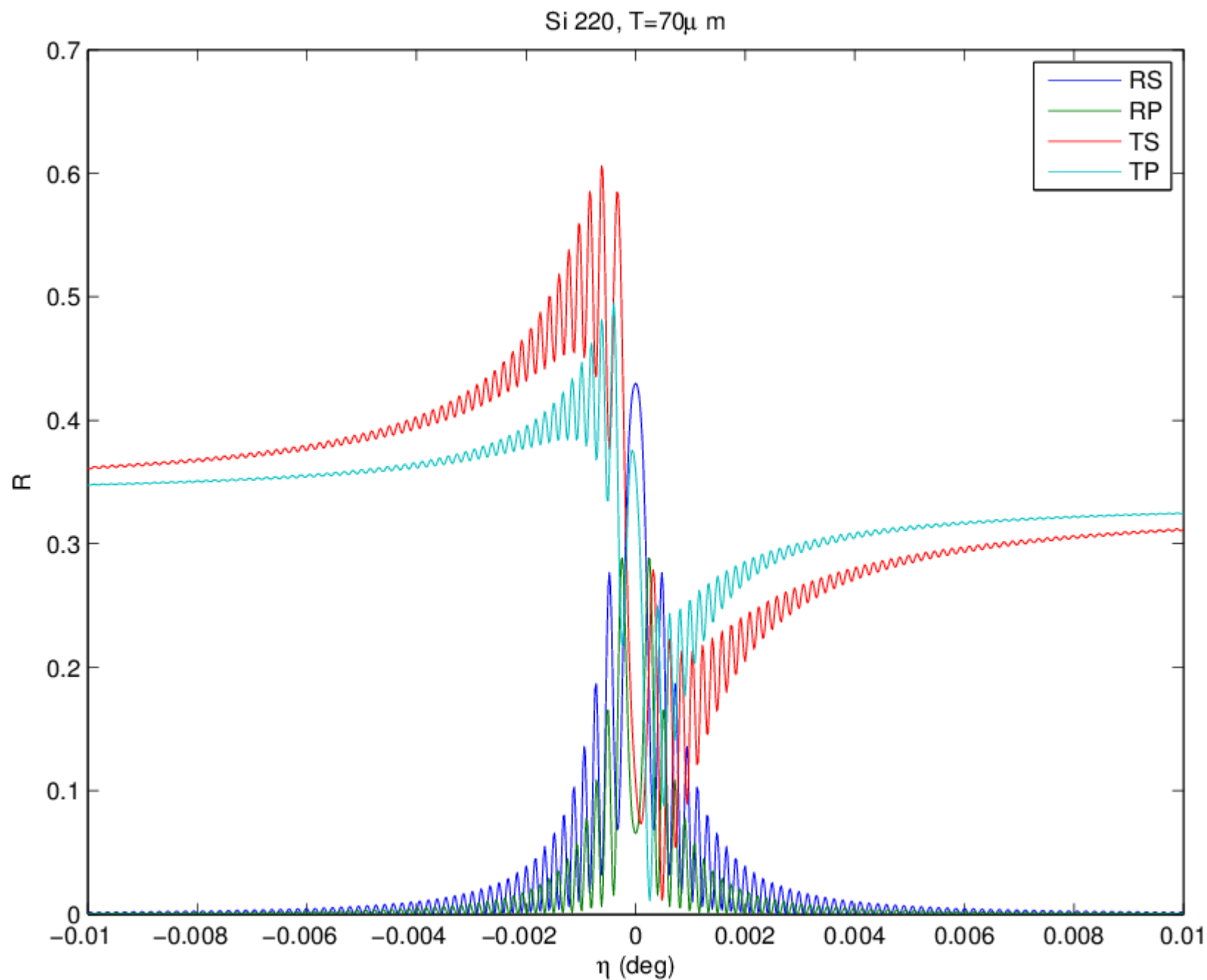
Dynamická teorie

Difrakce na tenkém krystalu v dvouvlonné aproximaci



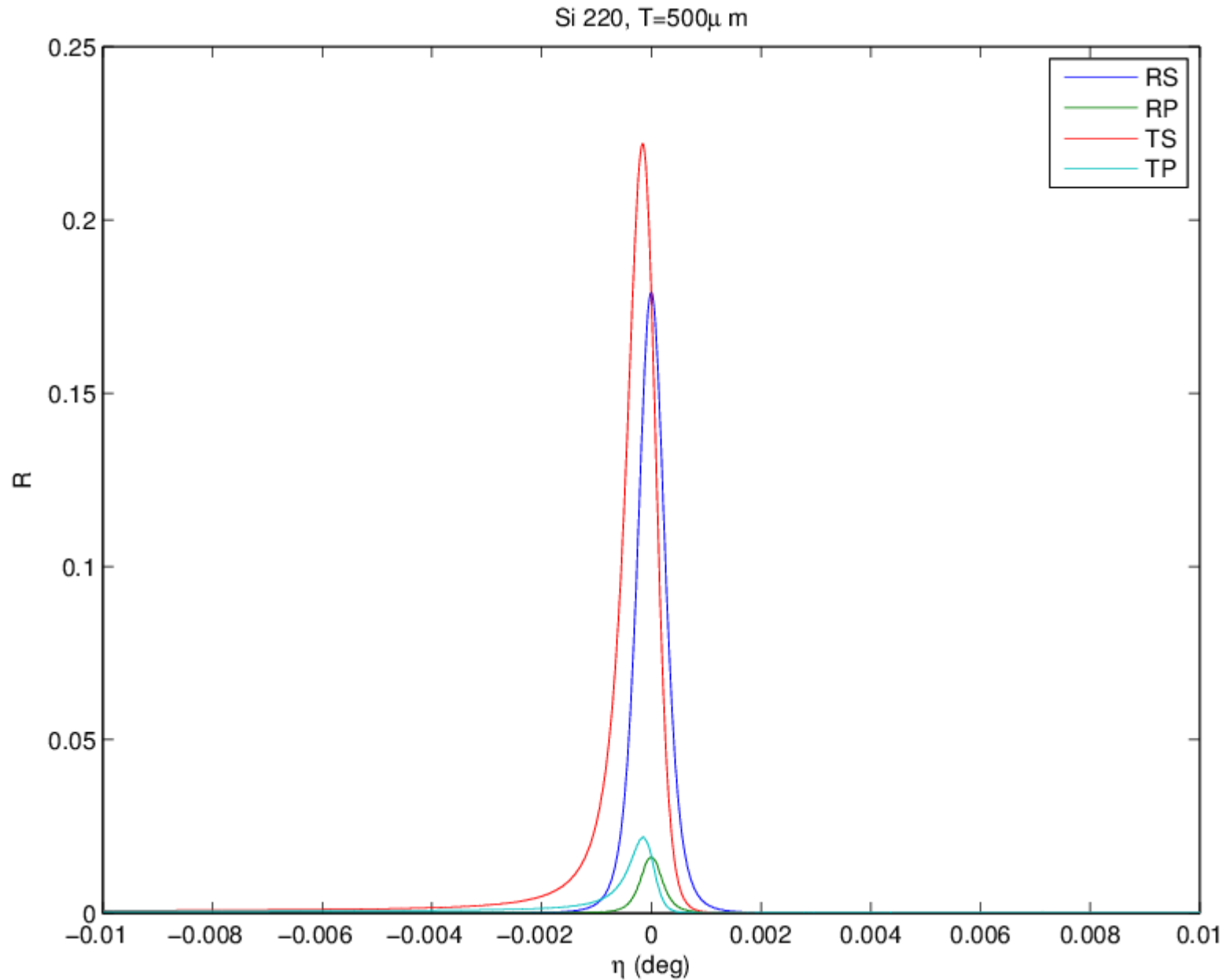
Dynamická teorie

Difrakce na tenkém krystalu v dvouvlonné aproximaci



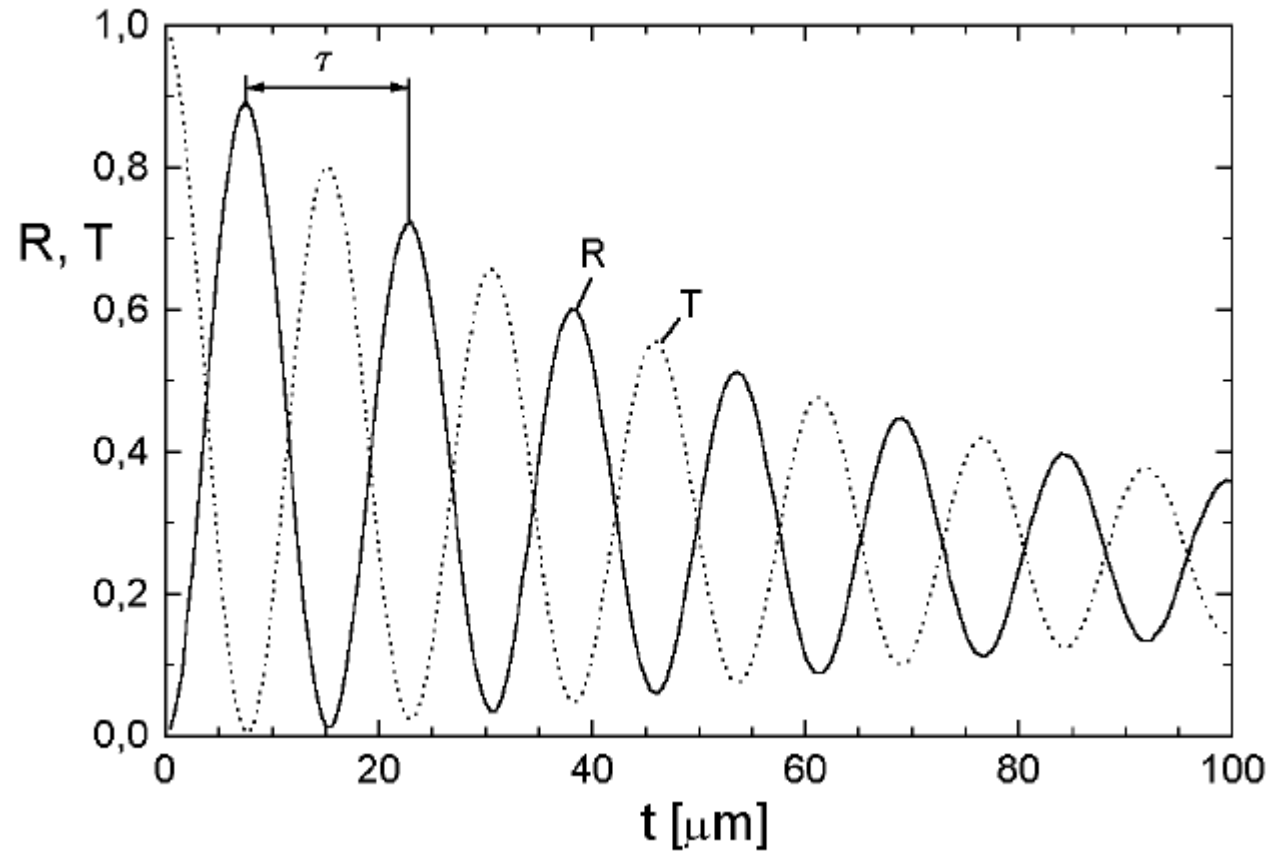
Dynamická teorie

Difrakce na tenkém krystalu v dvouvlonné aproximaci



Dynamická teorie

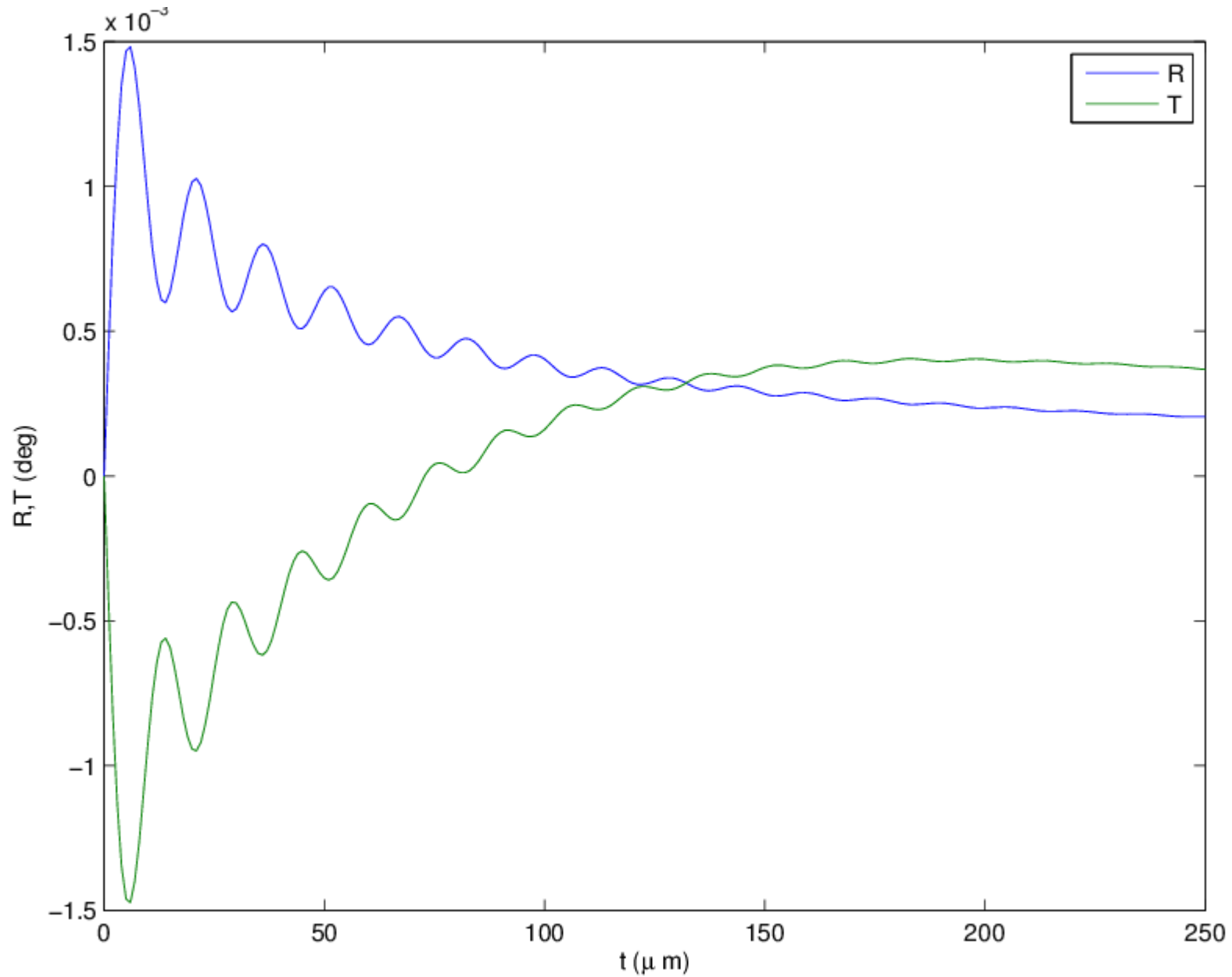
Difrakce na tenkém krystalu v dvouvlnné aproximaci



“Pendelösung” oscilace

Dynamická teorie

Difrakce na tenkém krystalu v dvouvlonné aproximaci, závislost integrální intenzity na tloušťce vzorku



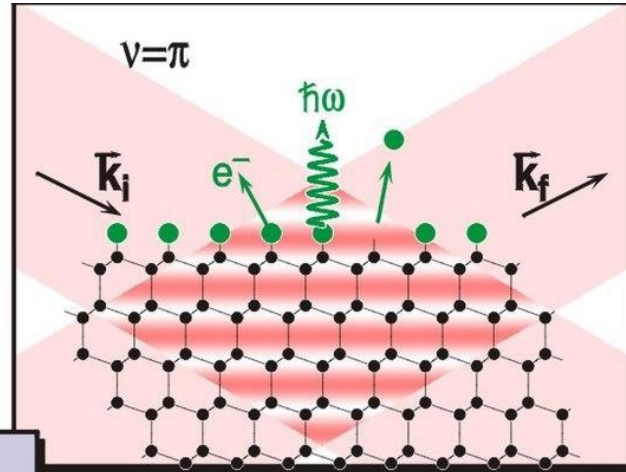
X-ray standing waves

X-ray diffraction

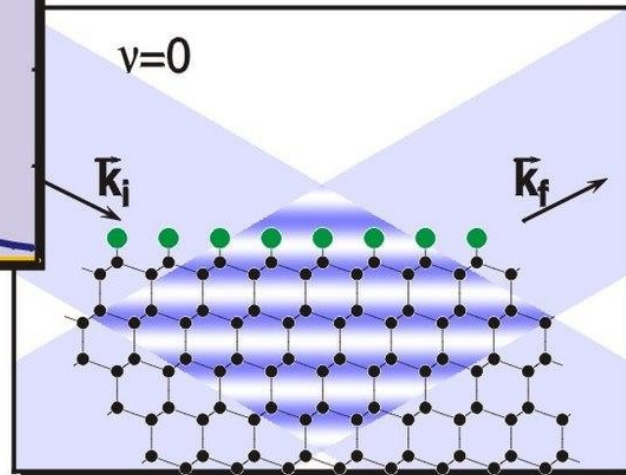
Gerhard Borrmann



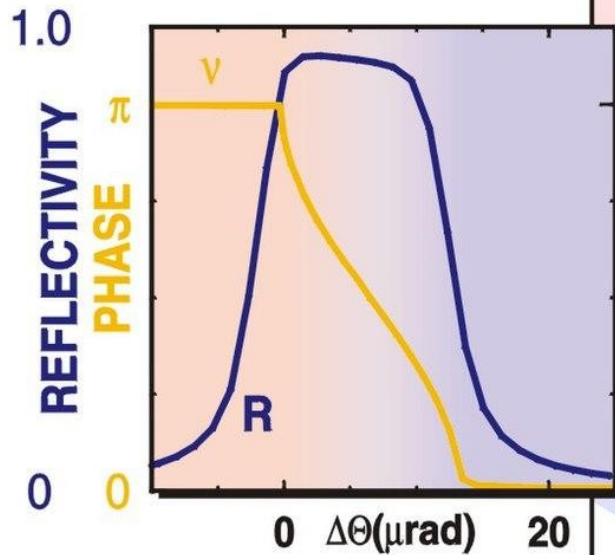
XSW
X-ray Standing Waves



• substrate
• adsorbate



Boris Batterman

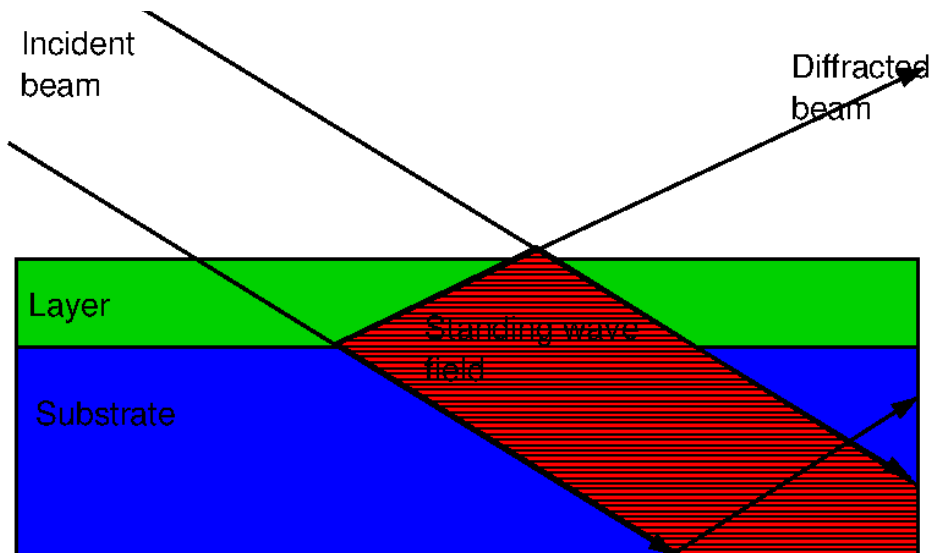
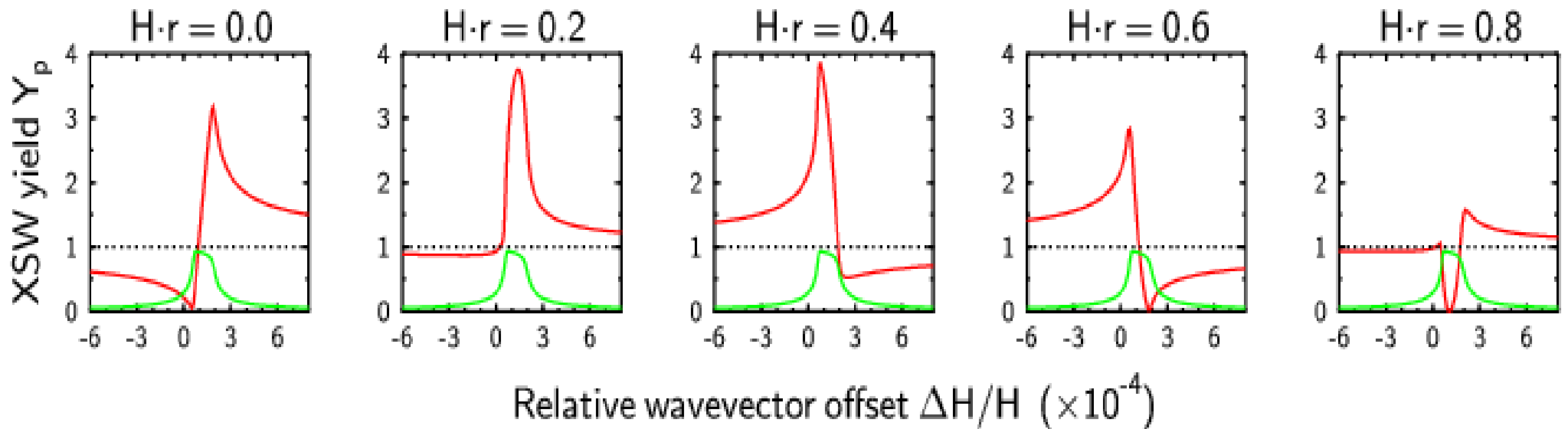


Th. Schmidt, J.J. Flége

X-ray standing waves

X-ray diffraction

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

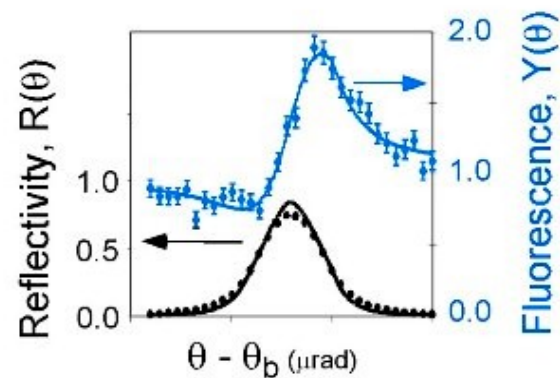
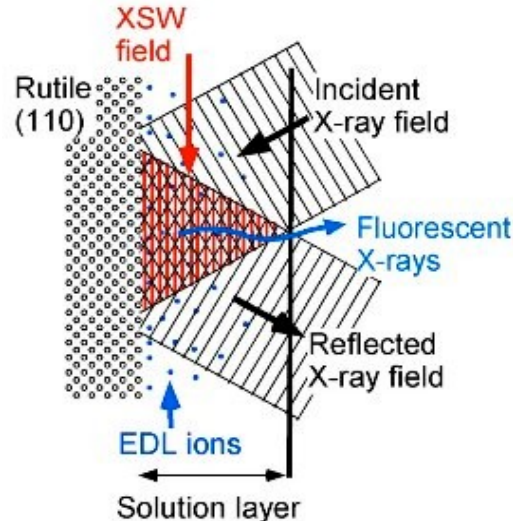
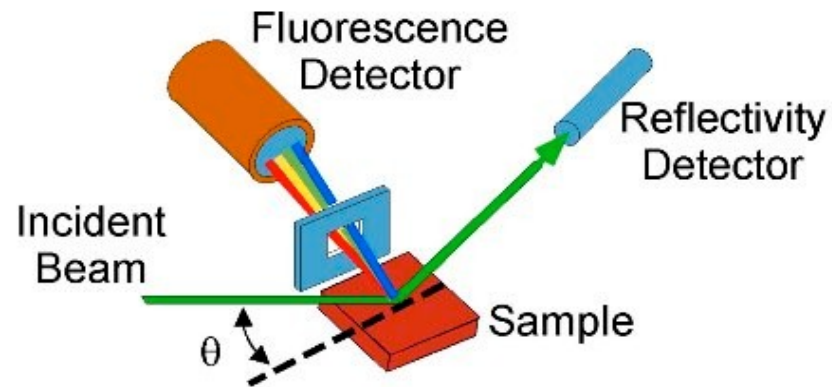


Standing wave in thin film induced by substrate

Period of standing wave defined by monocrystalline substrate:
InP (111) $d=3.39 \text{ \AA}$

Film thickness limited by lattice mismatch!

Fluorescence ve stojaté vlně



Fluorescent yield:

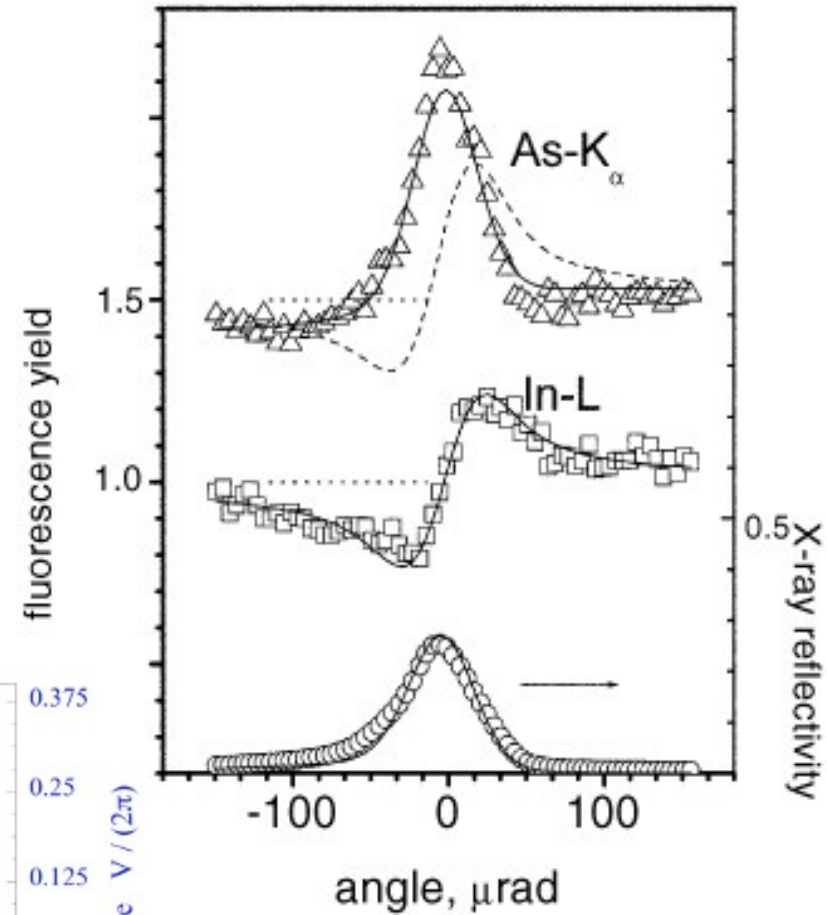
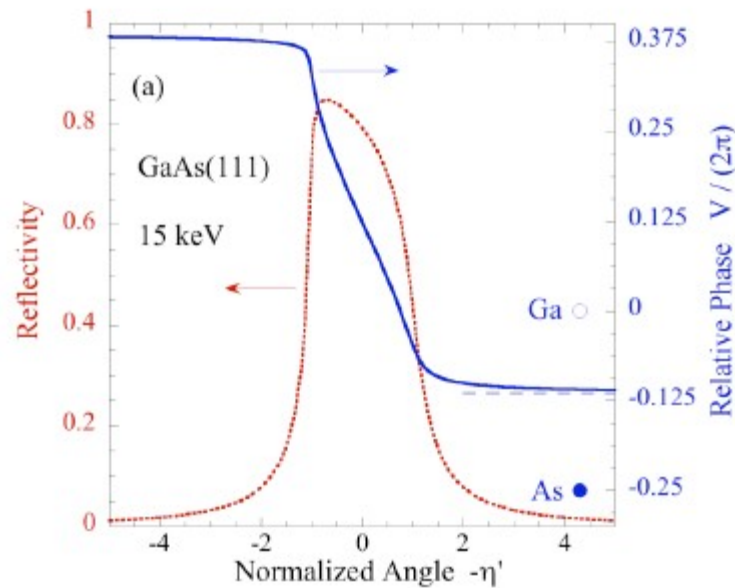
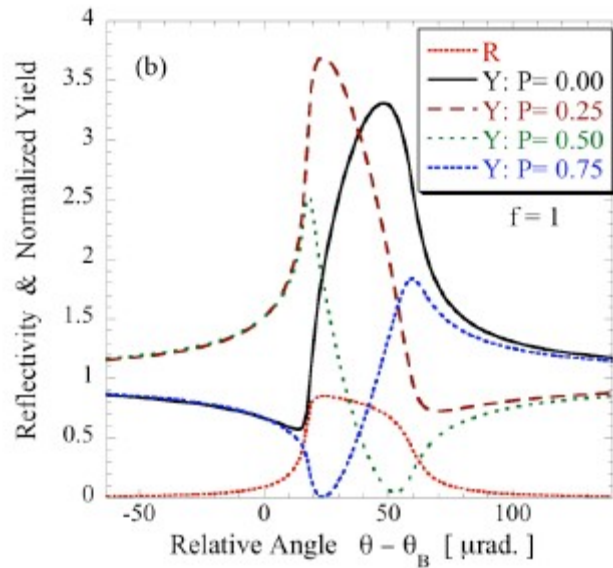
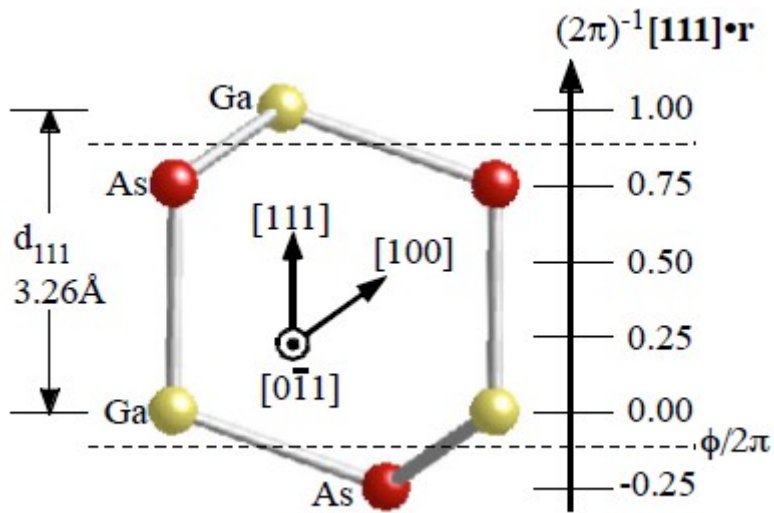
$$Y_H(\theta)/Y_{OB} = 1 + R(\theta) + 2F_H [R(q)]^{1/2} \cos[\nu(\theta) - 2\pi P_H]$$

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:

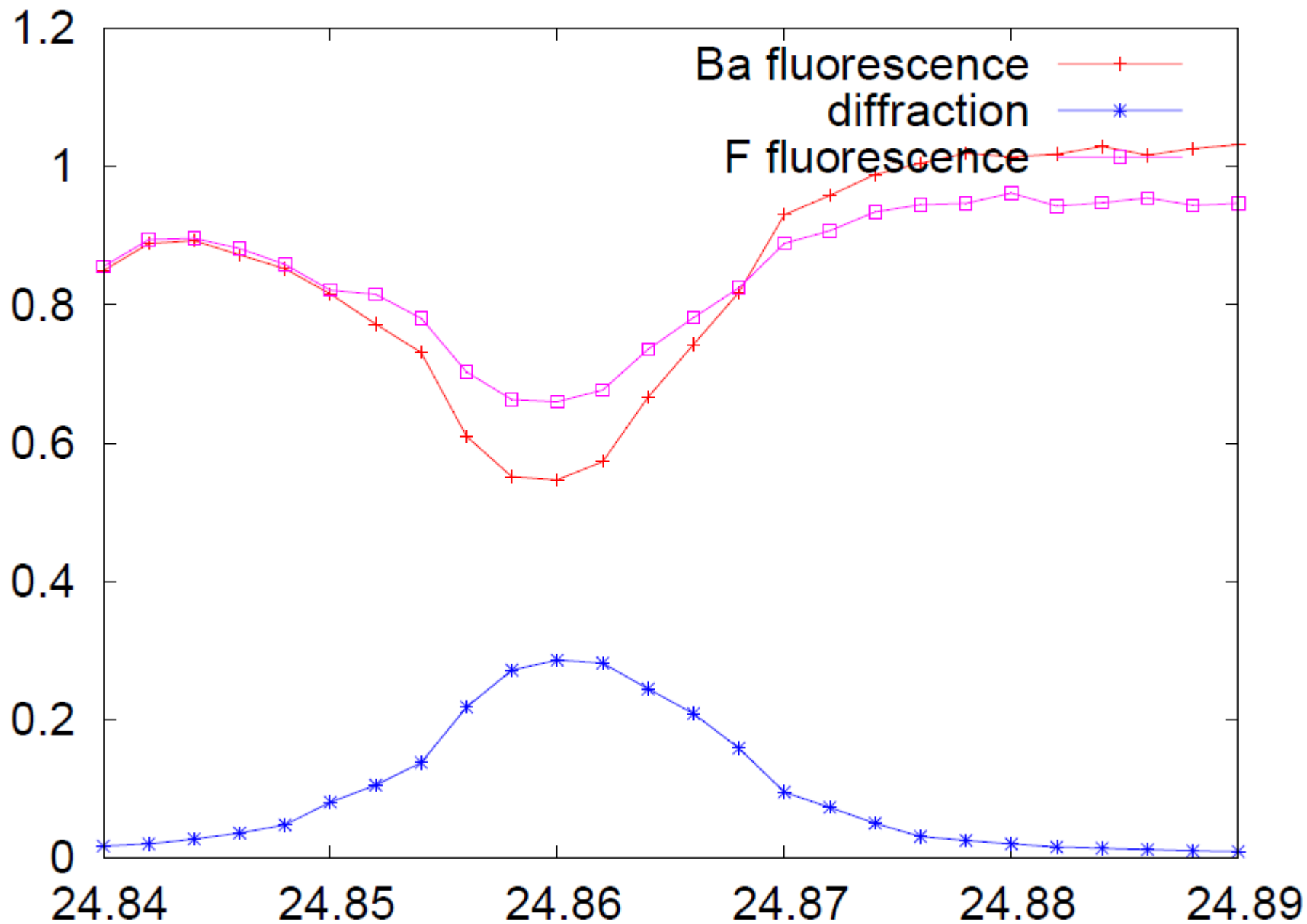
$$P \sim h/d_H, \text{ (h is ion height w/r to } H^{\text{th}} \text{ Bragg plane)}$$

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

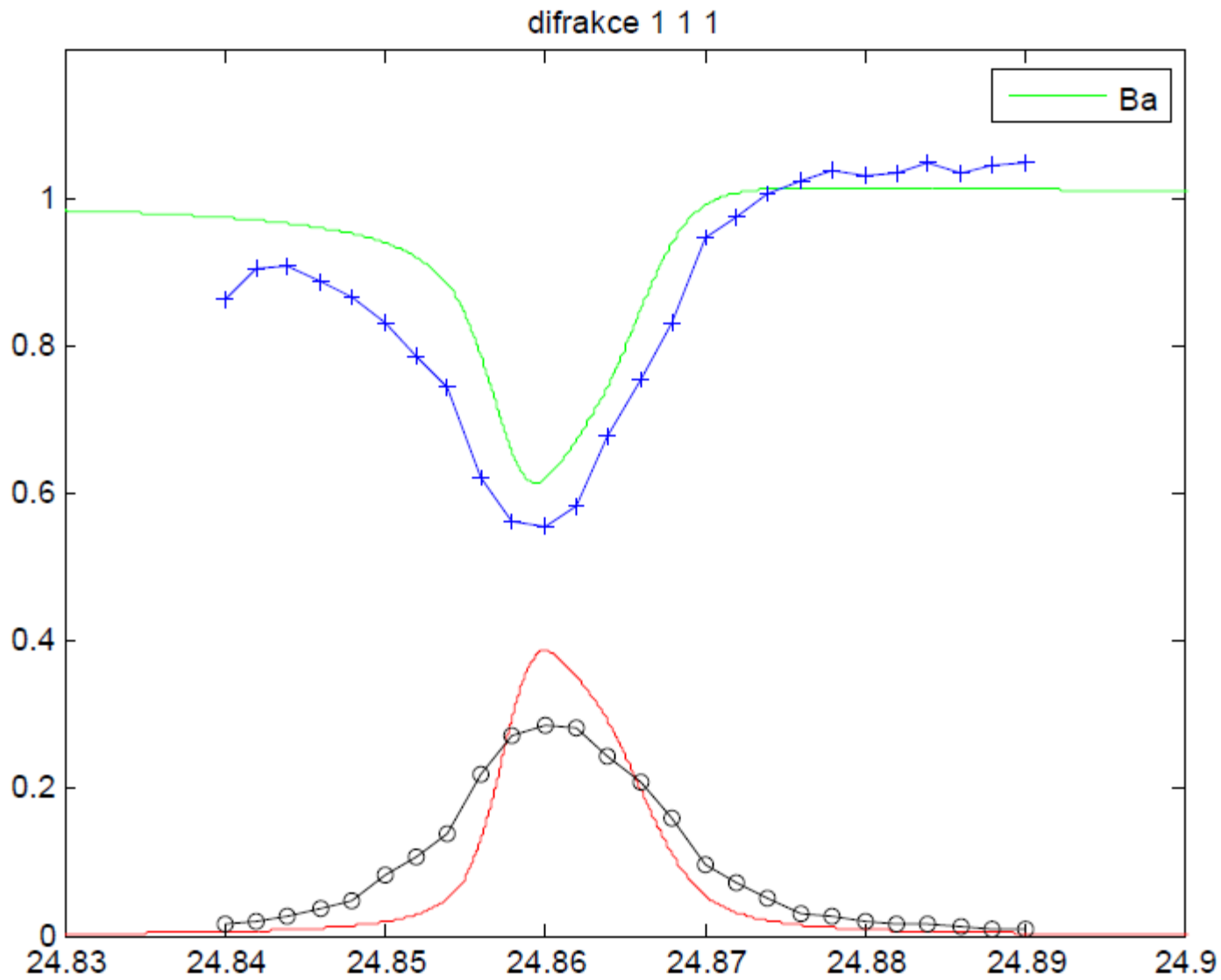
Fluorescence ve stojaté vlně



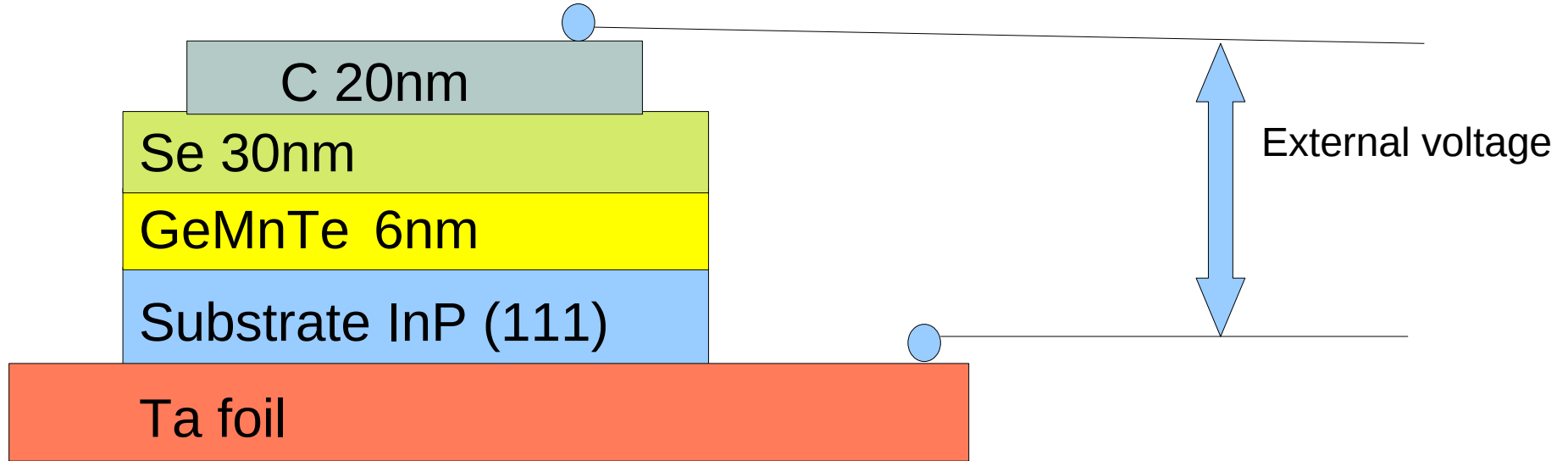
Fluorescence ve stojaté vlně



Fluorescence ve stojaté vlně



Standing waves in (Ge,Mn)Te



Sample preparation:
JKU Linz

VA2268 6nm
GeTe/InP(111)A
+ 30nm Se cap
+ 20nm carbon (one piece)

VA2269 6nm
GeMnTe/InP(111)A
+ 30nm Se cap
+ 20nm carbon (one piece)

VA2270 6nm
GeTe/InP(111)A
+ 30nm Se cap
+ 20nm carbon (one piece)

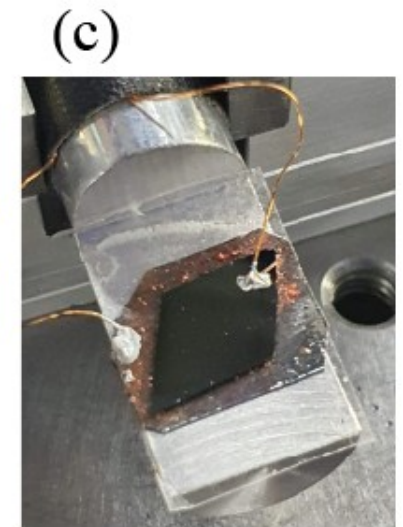
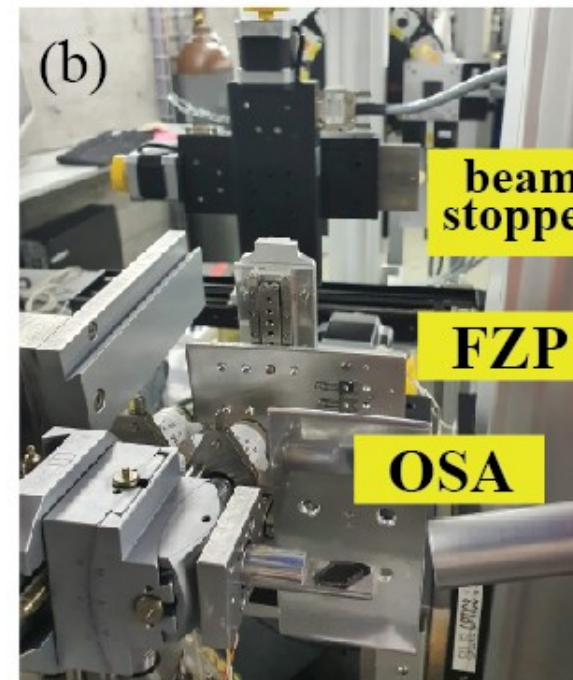
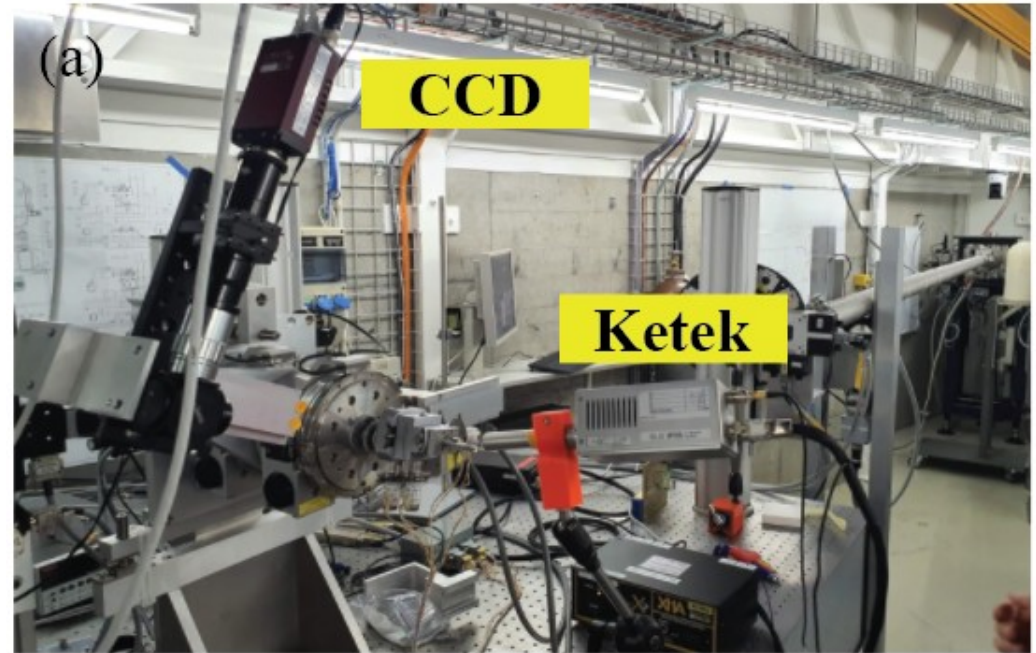


Standing waves in (Ge,Mn)Te

Experiment at synchrotron
swiss light source – SLS

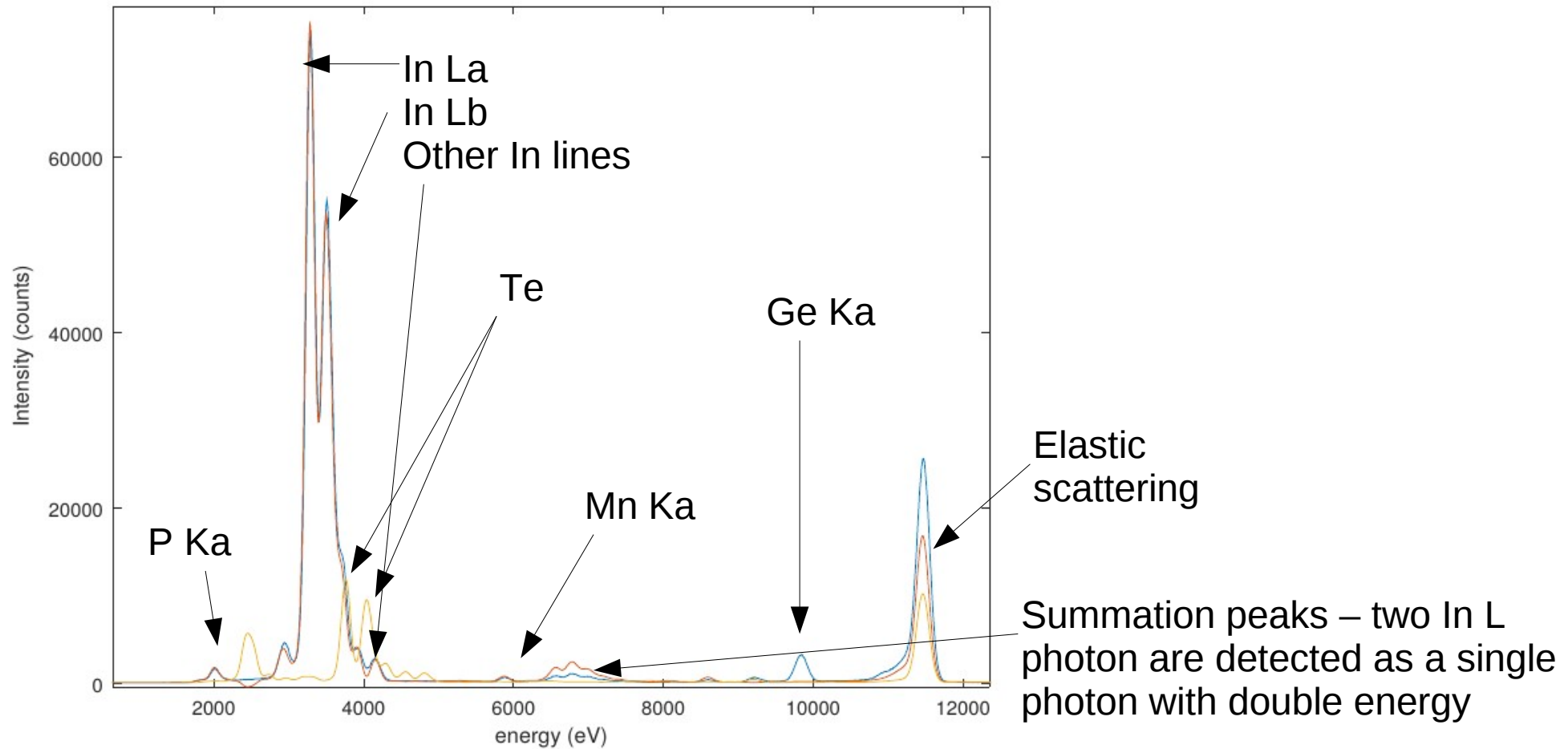
Beamline X05DA

Photon energy 11.5 keV
above Ge Kedge
to excite Ge K lines

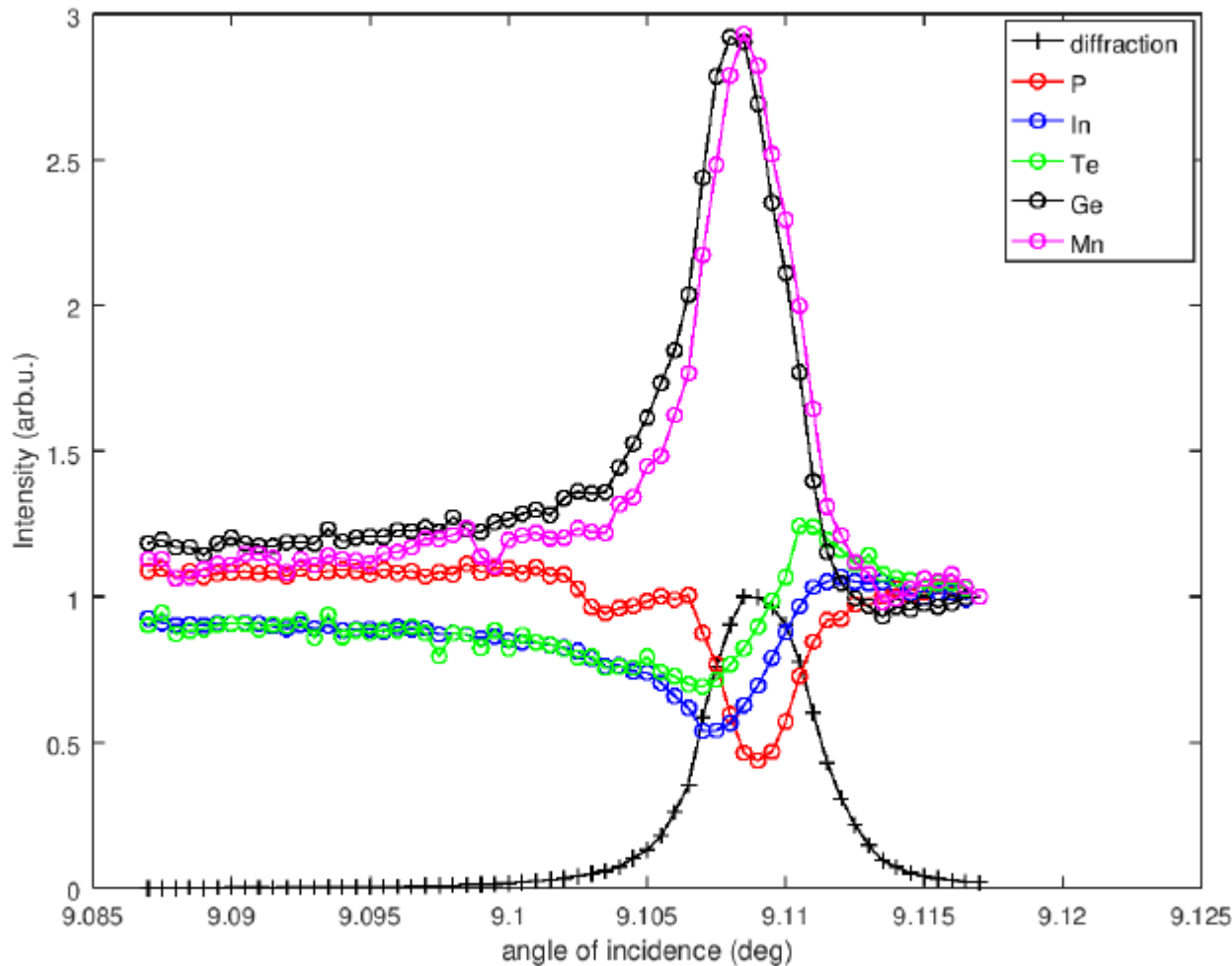


Standing waves in (Ge,Mn)Te

X-ray fluorescence spectrum



Standing waves in (Ge,Mn)Te



Average positions in fraction of standing wave period –
 InP (111) interplanar distance
 3.39 Å

GeTe and GeMnTe

In: 0.05

P: 0.77

In and P distance confirms
 InP (111)A – In terminated
 orientation

GeMnTe:

Te: 0.86

Ge: 0.37

Mn: 0.32

Te-Ge planes 1.52 Å

GeTe:

Te: 0.86

Ge: 0.45

Te-Ge planes 1.40 Å

Distance of Ge-Te planes:
 High temperature rocksalt 1.7 Å
 Ferroelectric rhombohedral 1.4 Å or 2.0 Å

Dynamická teorie

$$\mathbf{E}_j = \begin{pmatrix} E_{01}^{(j)} \\ E_{02}^{(j)} \\ E_{03}^{(j)} \\ E_{04}^{(j)} \end{pmatrix} \quad \hat{\mathbf{C}}_{j-1} \hat{\Phi}_{j-1} \mathbf{E}_{j-1} = \hat{\mathbf{C}}_j \mathbf{E}_j, \quad j = 1, \dots, N+1,$$

$$\hat{\mathbf{C}}_j = \begin{pmatrix} 1 & 1 & 1 & 1 \\ k_{01z}^{(j)} & k_{02z}^{(j)} & k_{03z}^{(j)} & k_{04z}^{(j)} \\ c_1^{(j)} & c_2^{(j)} & c_3^{(j)} & c_4^{(j)} \\ k_{hz1}^{(j)} c_1^{(j)} & k_{hz2}^{(j)} c_2^{(j)} & k_{hz3}^{(j)} c_3^{(j)} & k_{hz4}^{(j)} c_4^{(j)} \end{pmatrix} \quad \hat{\Phi}_j = \begin{pmatrix} e^{-ik_{01z}^{(j)} T_j} & 0 & 0 & 0 \\ 0 & e^{-ik_{02z}^{(j)} T_j} & 0 & 0 \\ 0 & 0 & e^{-ik_{03z}^{(j)} T_j} & 0 \\ 0 & 0 & 0 & e^{-ik_{04z}^{(j)} T_j} \end{pmatrix}$$

$$\mathbf{E}_0 = \hat{\Phi}_0^{-1} \hat{\mathbf{C}}_0^{-1} \hat{\mathbf{C}}_1 \hat{\Phi}_1^{-1} \hat{\mathbf{C}}_1^{-1} \hat{\mathbf{C}}_2 \hat{\Phi}_2^{-1} \hat{\mathbf{C}}_2^{-1} \dots \hat{\Phi}_N^{-1} \hat{\mathbf{C}}_N^{-1} \hat{\mathbf{C}}_{N+1} \hat{\Phi}_{N+1}^{-1} \mathbf{E}_{\text{sub}}$$

$$\equiv \hat{\mathbf{M}} \mathbf{E}_{\text{sub}}.$$

$$\mathcal{R}_h = \frac{I_h A_h}{I_i A_i} \equiv \left| \frac{E_h}{E_i} \right|^2 \frac{|\gamma_h|}{\gamma_0}$$

$$\hat{\mathbf{C}}_0 = \begin{pmatrix} 1 & 1 & 0 & 0 \\ K_{0z} & K_{Rz} & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & K_{hz} & K_{hz} \end{pmatrix}, \quad \mathbf{E}_0 = \begin{pmatrix} E_i \\ E_R \\ E_h \\ 0 \end{pmatrix}$$

$$\mathcal{R}_R = \left| \frac{E_R}{E_i} \right|^2$$

Dynamická teorie

Jedna vrstva

$$\mathcal{R} = \left| \frac{\Re_{\text{sub}}(c_1 - Mc_2) + c_1c_2(M - 1)}{\Re_{\text{sub}}(1 - M) + c_1M - c_2} \right|^2$$

$$M = E^{-i(k_{0z1} - k_{0z2})T}$$

$$\Re_j = \frac{c_1^{(j)} E_{01}^{(j)} + c_2^{(j)} E_{02}^{(j)}}{E_{01}^{(j)} + E_{02}^{(j)}} \equiv \frac{A_2}{A_1}$$

$$\mathbf{A} = \begin{pmatrix} A_1 \\ A_2 \end{pmatrix} = \hat{\mathbf{C}}_j \mathbf{E}_j$$

$$\Re_j = \frac{\Re_{j+1}(c_1^{(j)} - M_j c_2^{(j)}) + c_1^{(j)} c_2^{(j)} (M_j - 1)}{\Re_{j+1}(1 - M_j) + c_1^{(j)} M_j - c_2^{(j)}},$$

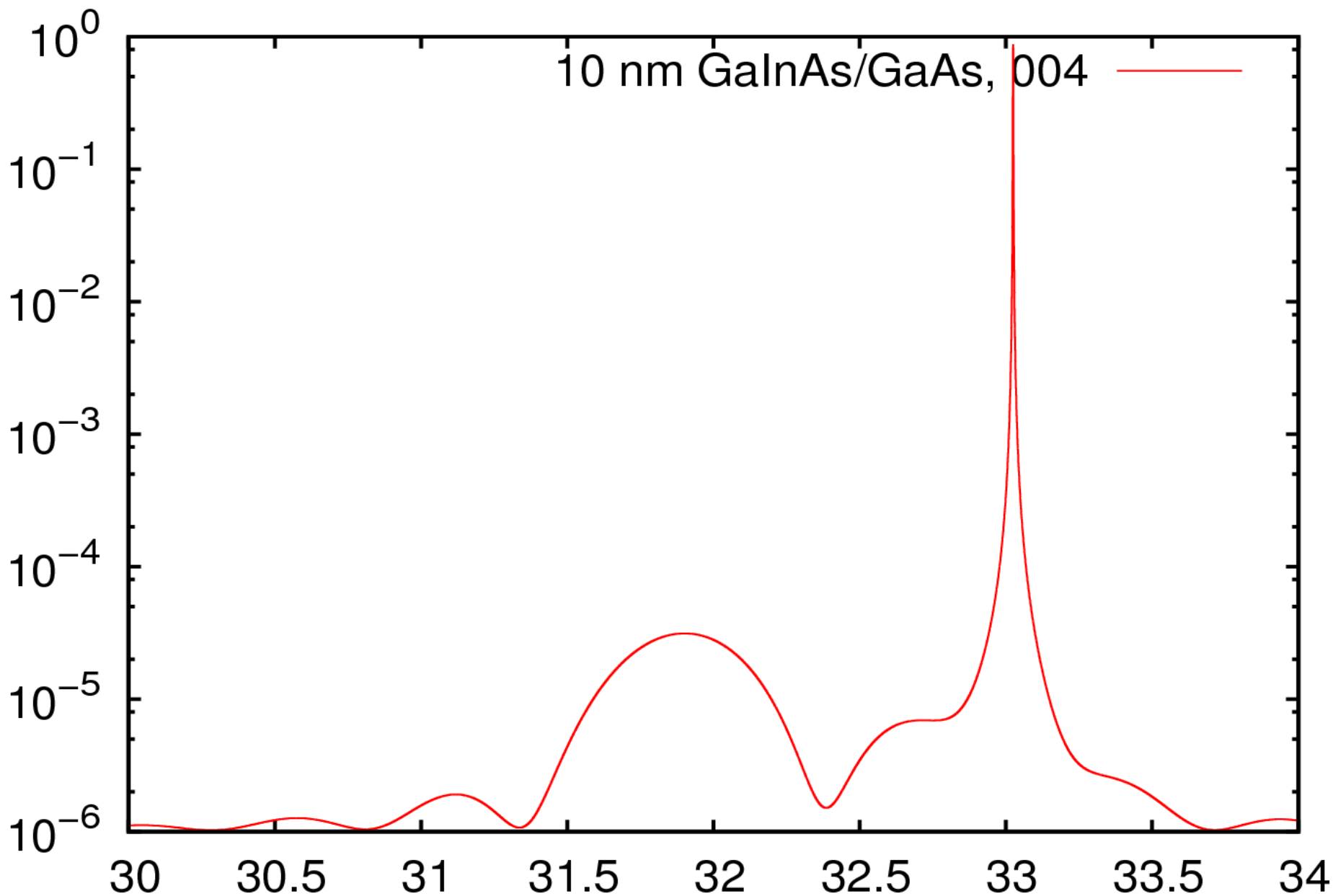
$$M_j = e^{-i(k_{0z1}^{(j)} - k_{0z2}^{(j)})T_j}, \quad j = 0, \dots, N.$$

$$\Re_{\text{sub}} \equiv \Re_{N+1} = c_s^{(N+1)}$$

$$\mathcal{R} = |\Re_0|^2 \frac{|\gamma \mathbf{h}|}{\gamma_0}.$$

Dynamická teorie

Pseudomorfní vrstva na substrátu



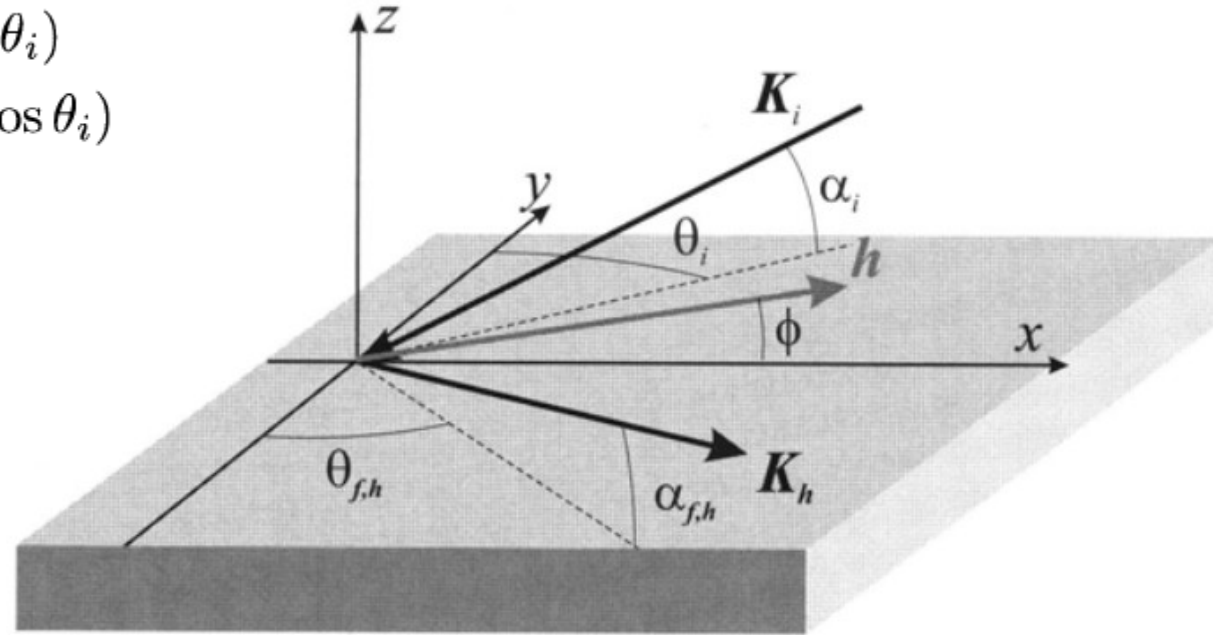
Dynamická teorie

Grazing incidence difrakce

$$Q_x = K(\cos \alpha_f \sin \theta_f + \cos \alpha_i \sin \theta_i)$$

$$Q_y = -K(\cos \alpha_f \cos \theta_f - \cos \alpha_i \cos \theta_i)$$

$$Q_z = K(\sin \alpha_f + \sin \alpha_i).$$



$$\Delta Q_{\parallel} = K \sqrt{\sin^2 \Theta_{B\parallel} [\alpha_f^2 (\Delta \alpha_f)^2 + \alpha_i^2 (\Delta \alpha_i)^2] + \cos^2 \Theta_{B\parallel} [(\Delta \theta_i)^2 + (\Delta \theta_f)^2]}$$

$$\Delta Q_z = K \sqrt{(\Delta \alpha_f)^2 + (\Delta \alpha_i)^2}.$$

Dynamická teorie

Grazing incidence difrakce

$$\begin{aligned}\cos \alpha_{\mathbf{h}} \sin \theta_{\mathbf{h}} + \cos \alpha_i \sin \theta_i &= 2 \sin \Theta_B \cos \phi \equiv 2 \sin \Theta_{B\parallel} \\ \cos \alpha_{\mathbf{h}} \cos \theta_{\mathbf{h}} &= \cos \alpha_i \cos \theta_i,\end{aligned}$$

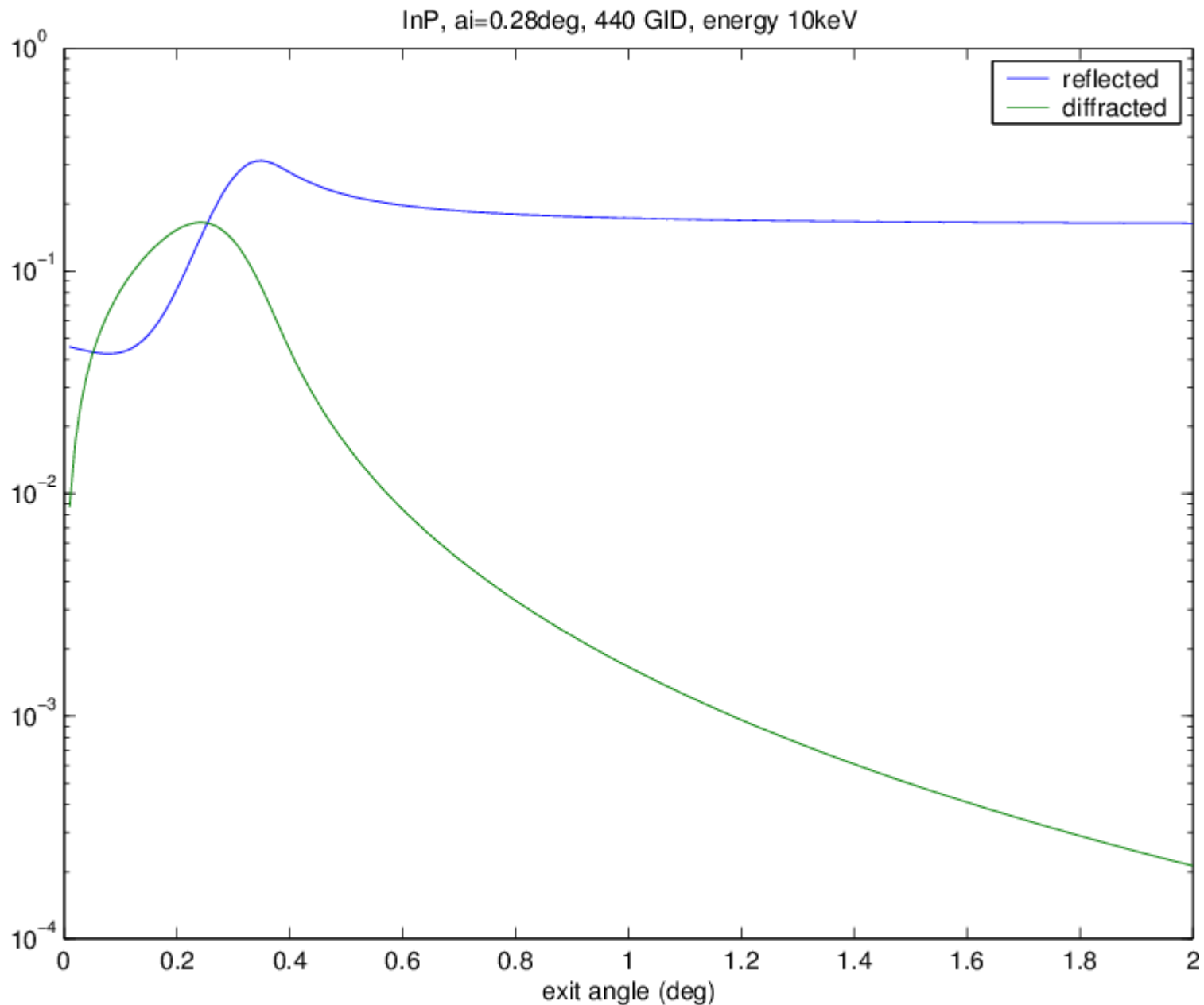
$$\delta\theta_s = \theta_s - \theta_{sB}, \quad s = i, \mathbf{h},$$

$$\begin{aligned}\alpha_{\mathbf{h}}^2 &= \alpha_i^2 \cos(2\Theta_{B\parallel}) + 2\delta\theta_i \sin(2\Theta_{B\parallel}) \\ \delta\theta_{\mathbf{h}} &= \frac{1}{2}\alpha_i^2 \sin(2\Theta_{B\parallel}) - \delta\theta_i \cos(2\Theta_{B\parallel})\end{aligned}$$

$$\begin{aligned}\Delta\alpha_i &= 0 \\ \Delta\alpha_{\mathbf{h}} &= \frac{\Delta(\delta\theta_i)}{\alpha_{\mathbf{h}}} \sin(2\Theta_{B\parallel}).\end{aligned}$$

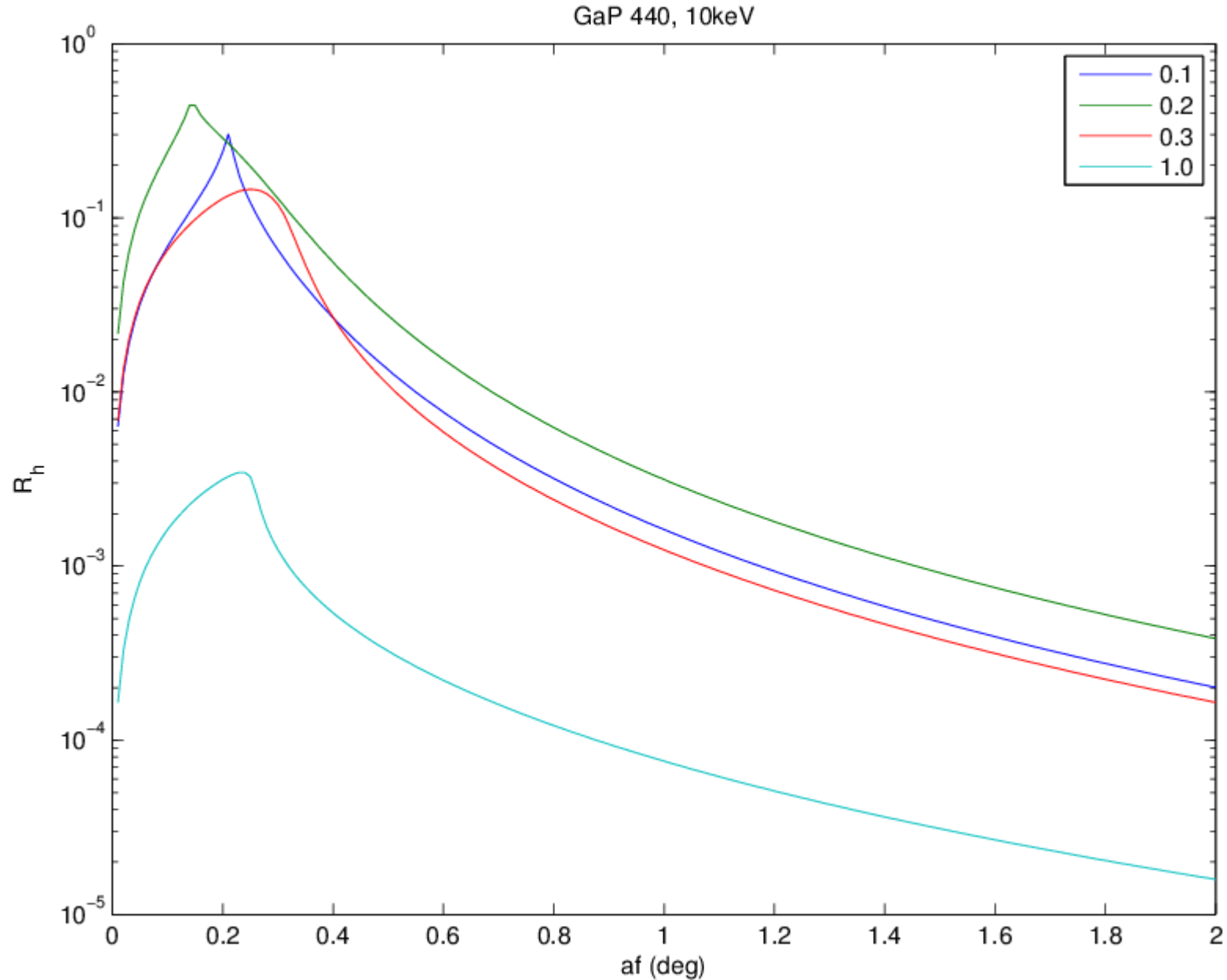
Dynamická teorie

Grazing-incidence difrakce



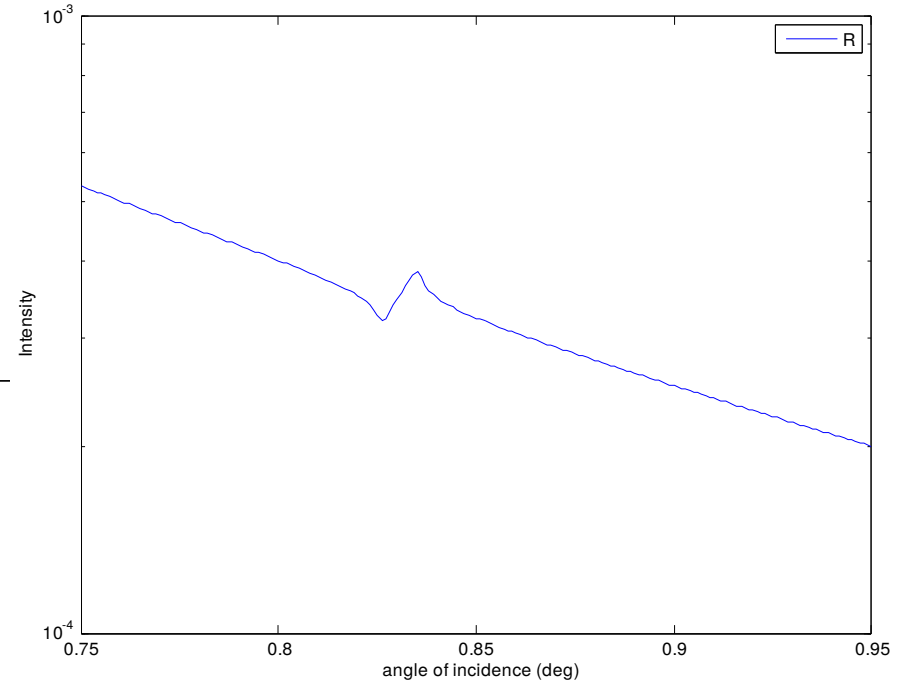
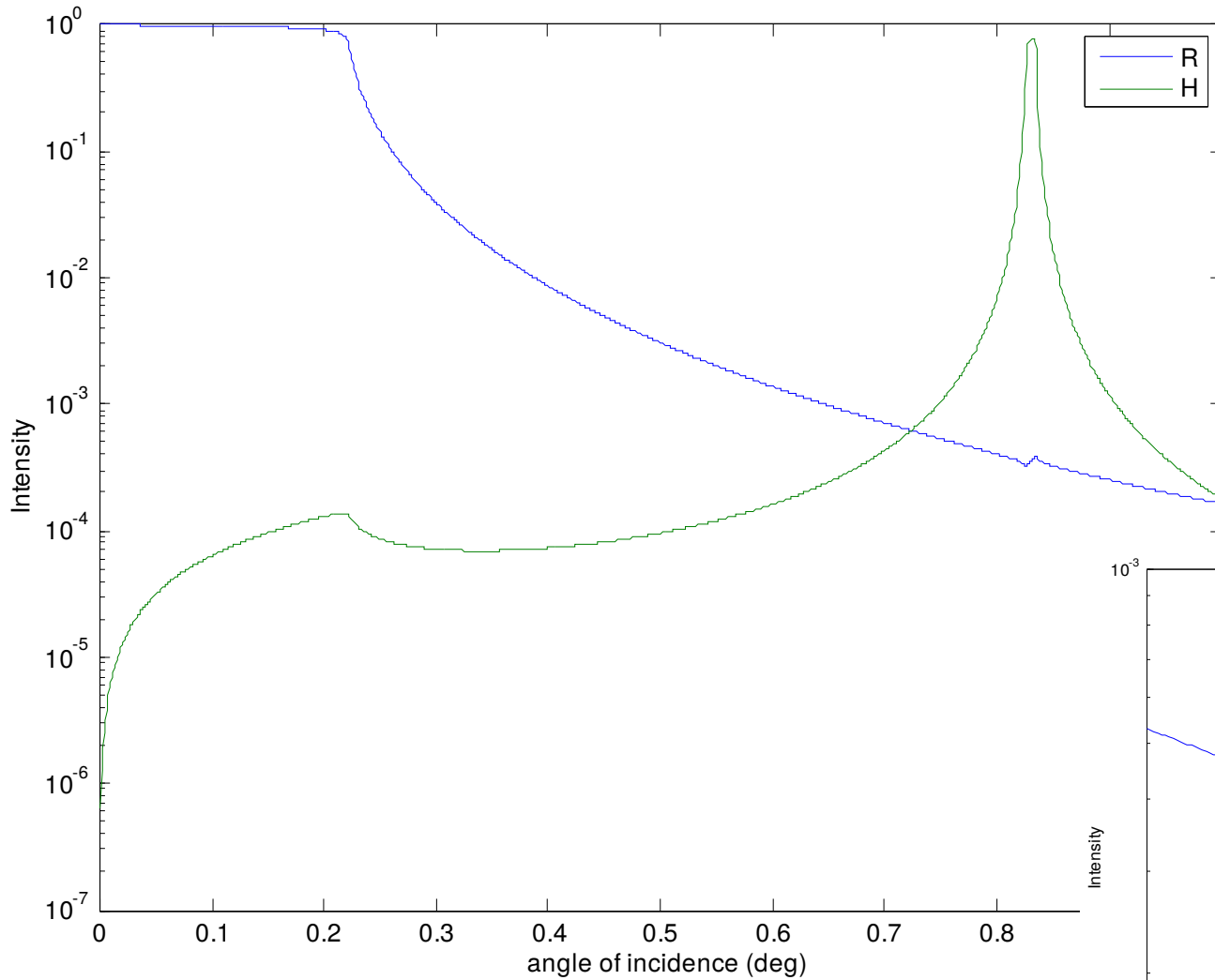
Dynamická teorie

Grazing-incidence difrakce, závislost na úhlu výstupu pro různé úhly dopadu



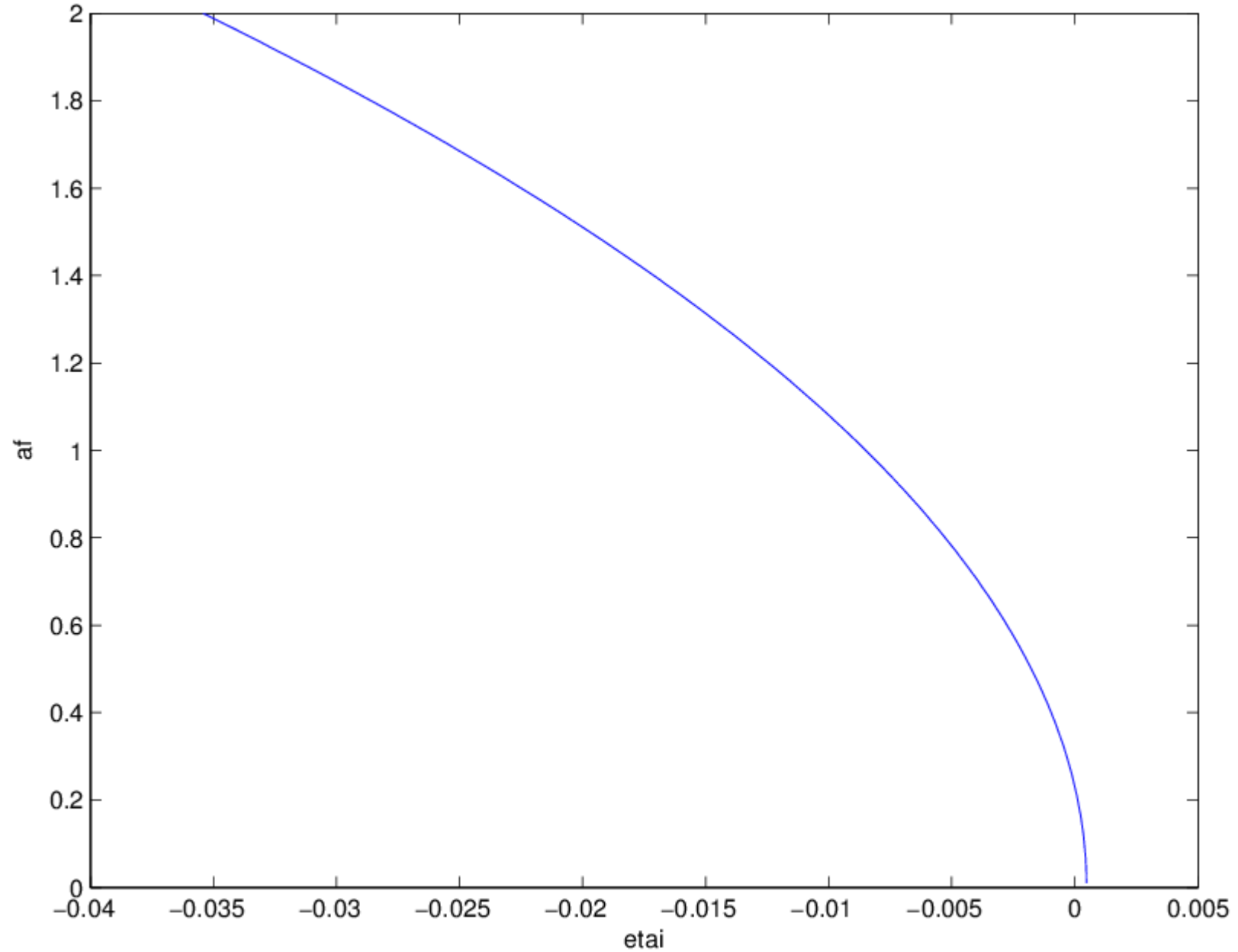
Dynamická teorie

Silně asymetrická difrakce, záření CuK α , difrakce Si 220, úhel asymetrie 22.8



Dynamická teorie

Grazing-incidence difrakce



Dynamická teorie

Grazing-incidence difrakce

