Characterization of Solid State Materials Using Synchrotron Radiation

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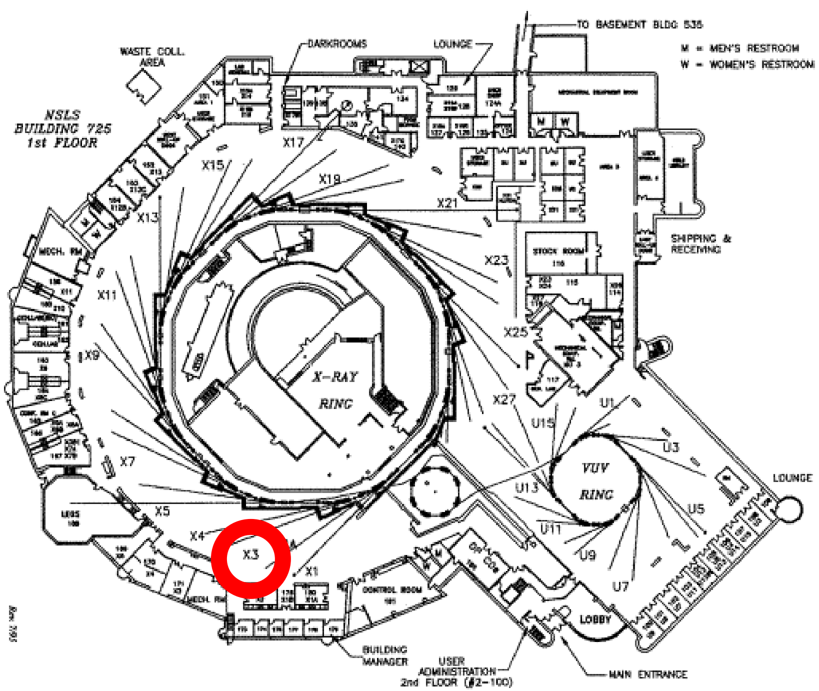
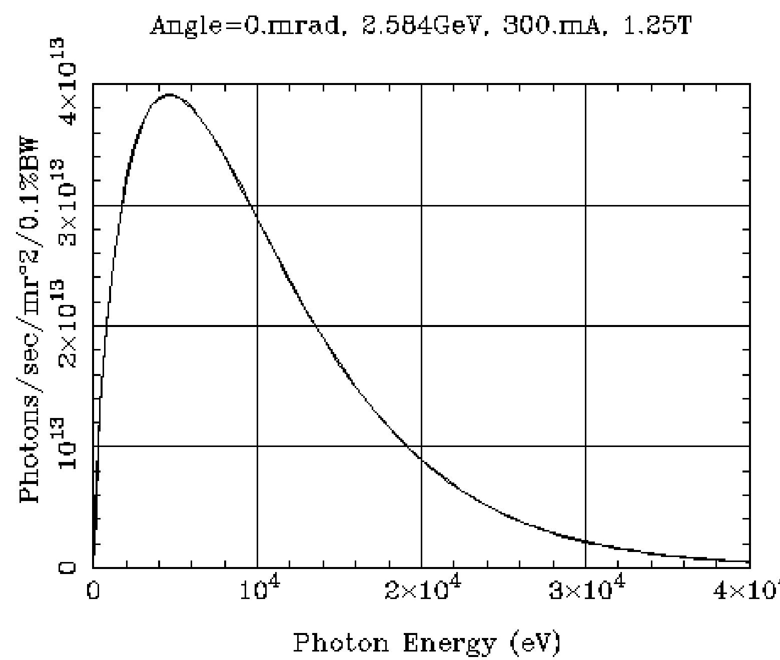
National Synchrotron Light Source



- **Synchrotron Radiation**
  - –High-intensity
  - –Tunable
  - –Collimated
  - –Polarized

Bend Magnet Spectrum

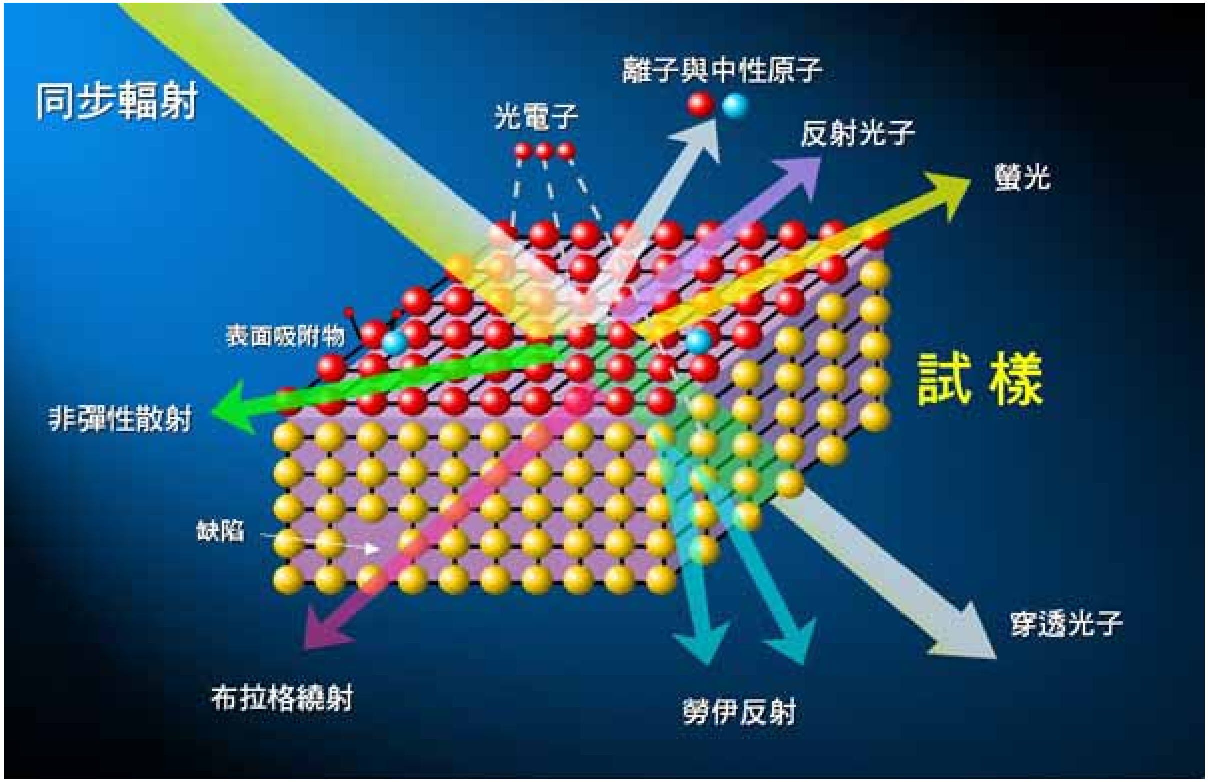


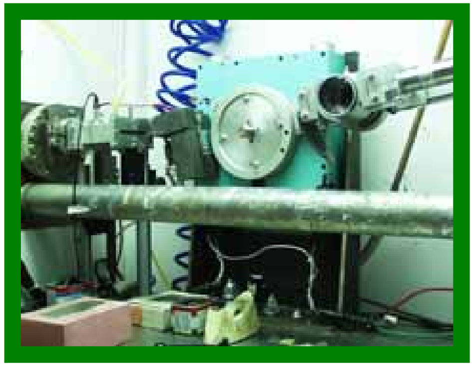
X-rays

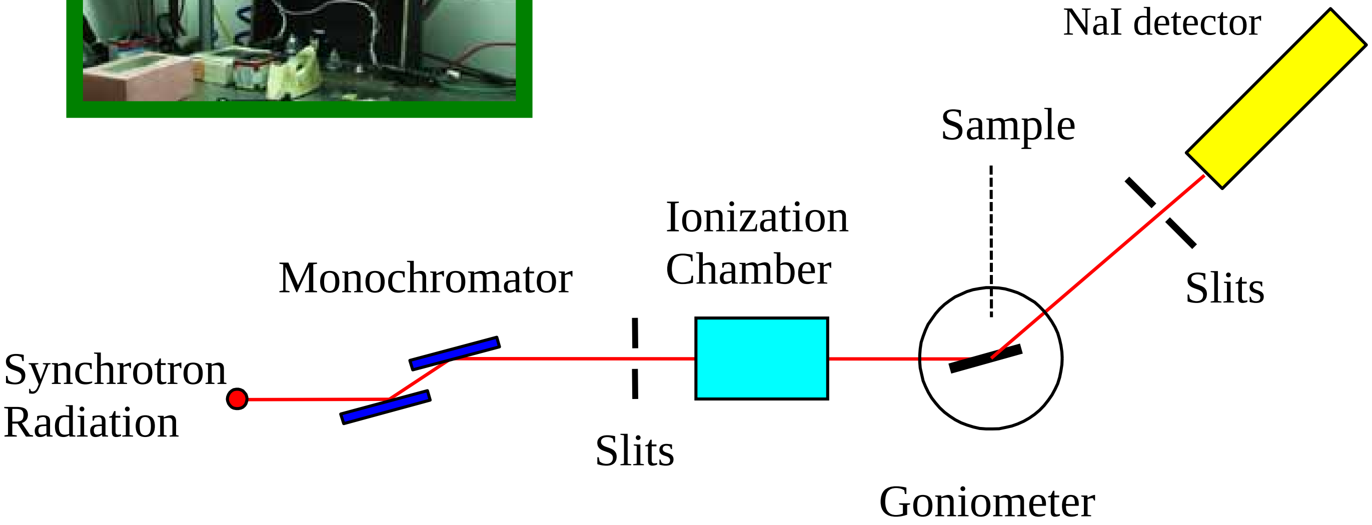
- Soft X-rays (Vacuum Ultraviolet) and Hard X-rays

- Typical photon energy 100eV-100keV
  - K level of Be to Rn

- Typical wavelength 0.1Å-100Å
  - Size of Atom to Protein


同步輻射
離子與中性原子
光電子
反射光子
螢光
表面吸附物
試 樣
非彈性散射
缺陷
穿透光子
布拉格繞射
勞伊反射

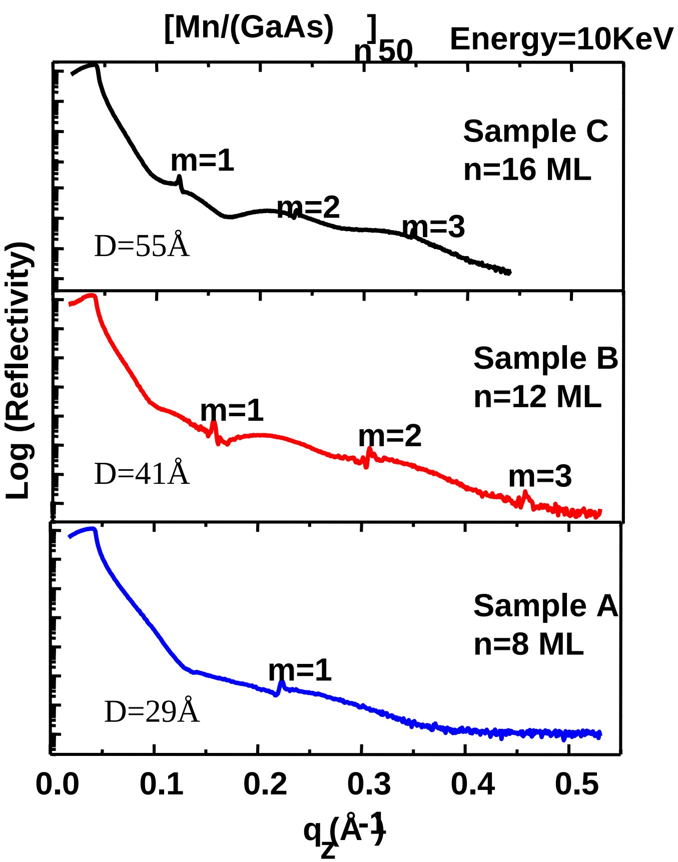




Experimental setup for GIXS and XRD at beamline X3B1 NSLS

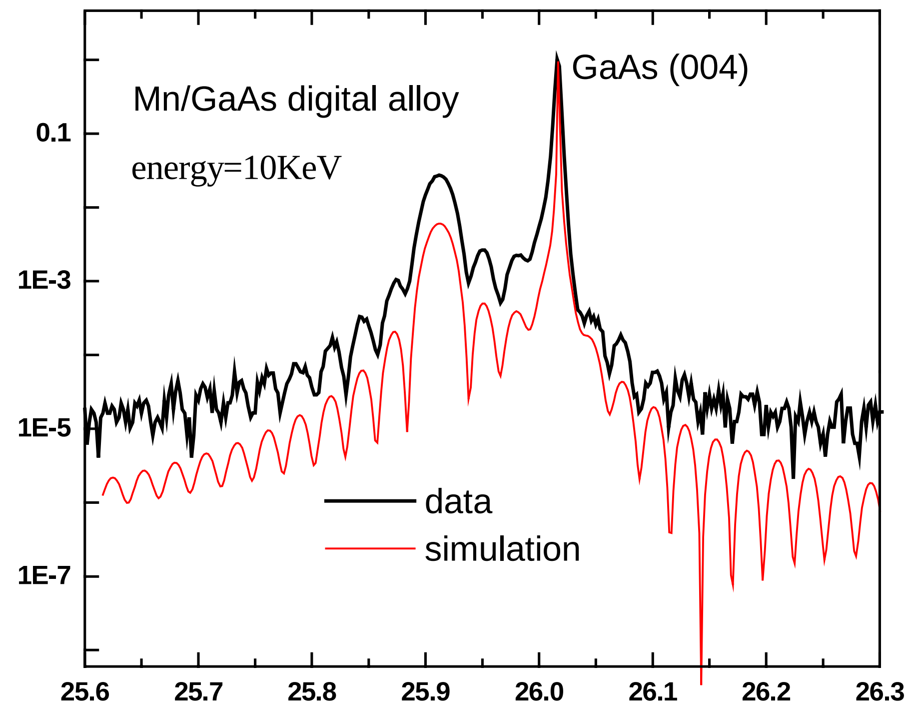
Mn/GaAs digital alloys

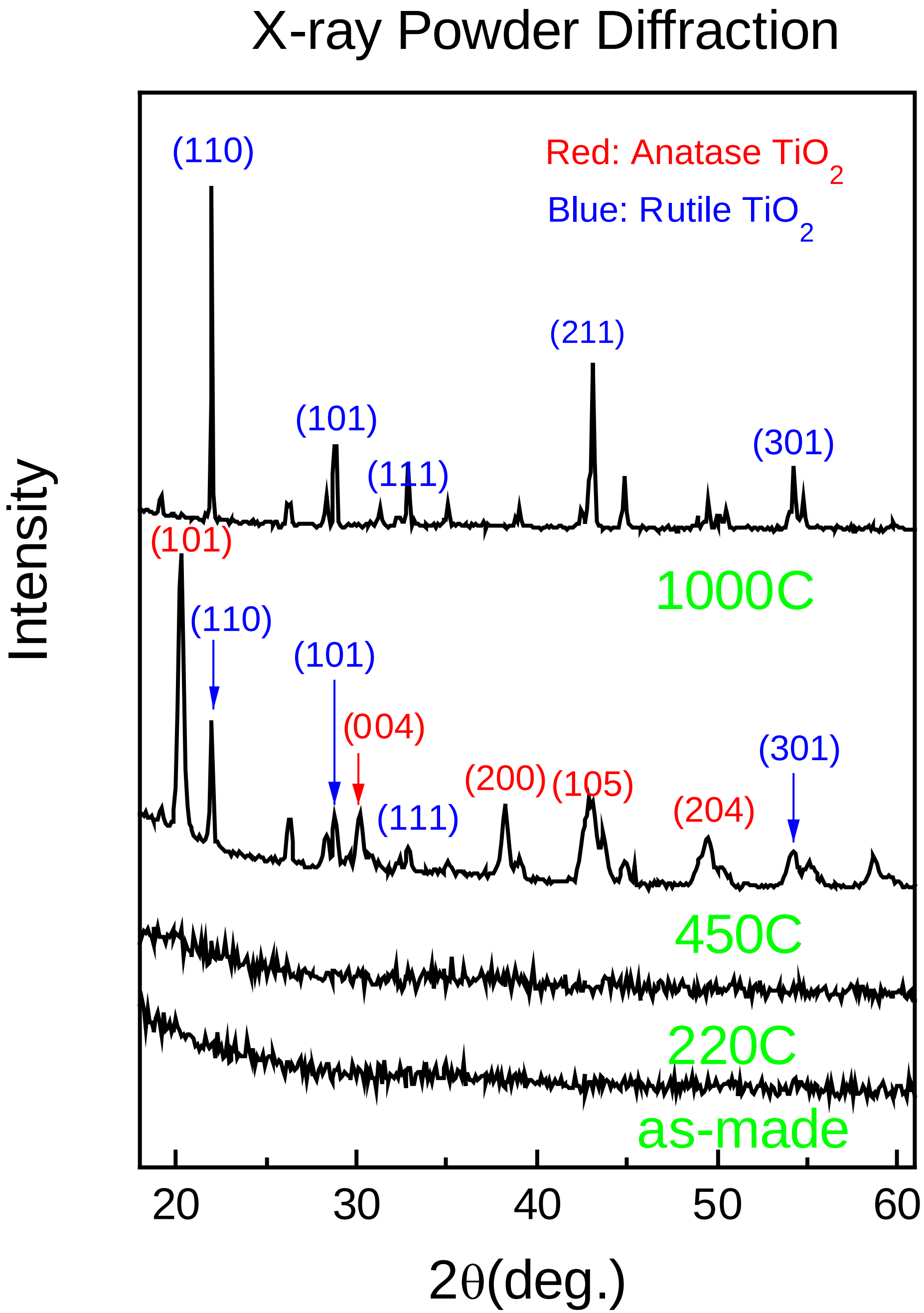
[G. Kioseoglou *et al.* APL **80**, 1150(2002)]

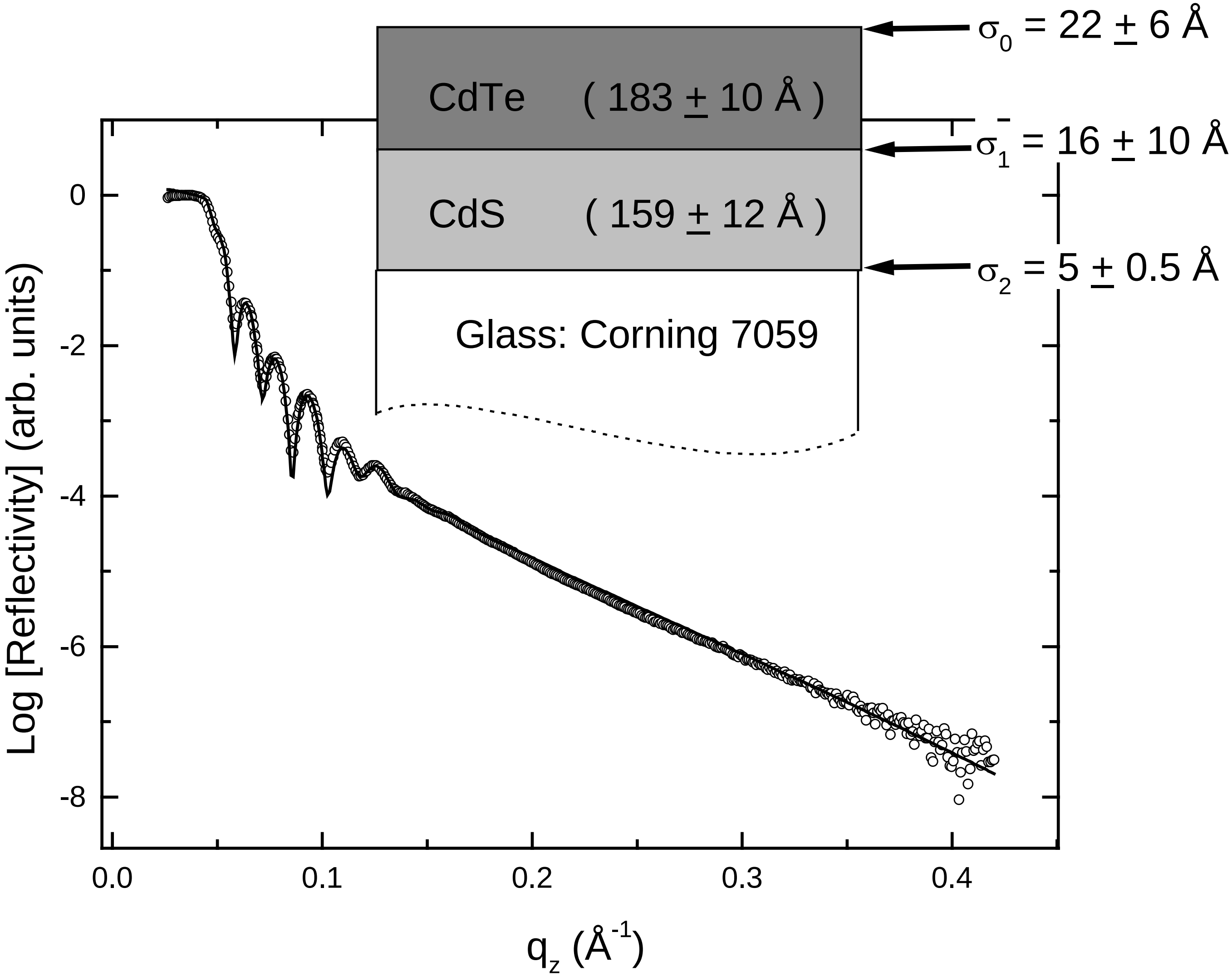


Bragg condition
$q_z = 2\pi m/D$

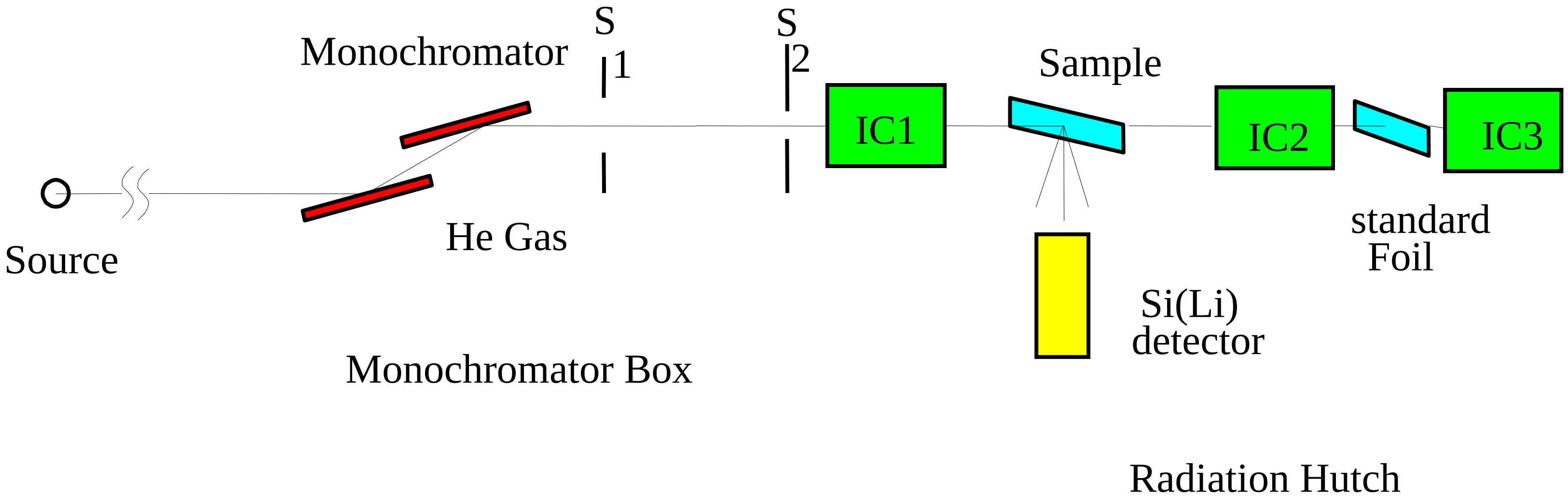
X-ray Diffraction of single-crystal thin films




X-ray Powder Diffraction
Red: Anatase TiO2
Blue: Rutile TiO2
(110)
(101)
(111)
(211)
(301)
1000C
(101)
(110)
(101)
(004)
(111)
(200)
(105)
(204)
(301)
450C
220C
as-made
Intensity
20
30
40
50
60
2θ(deg.)



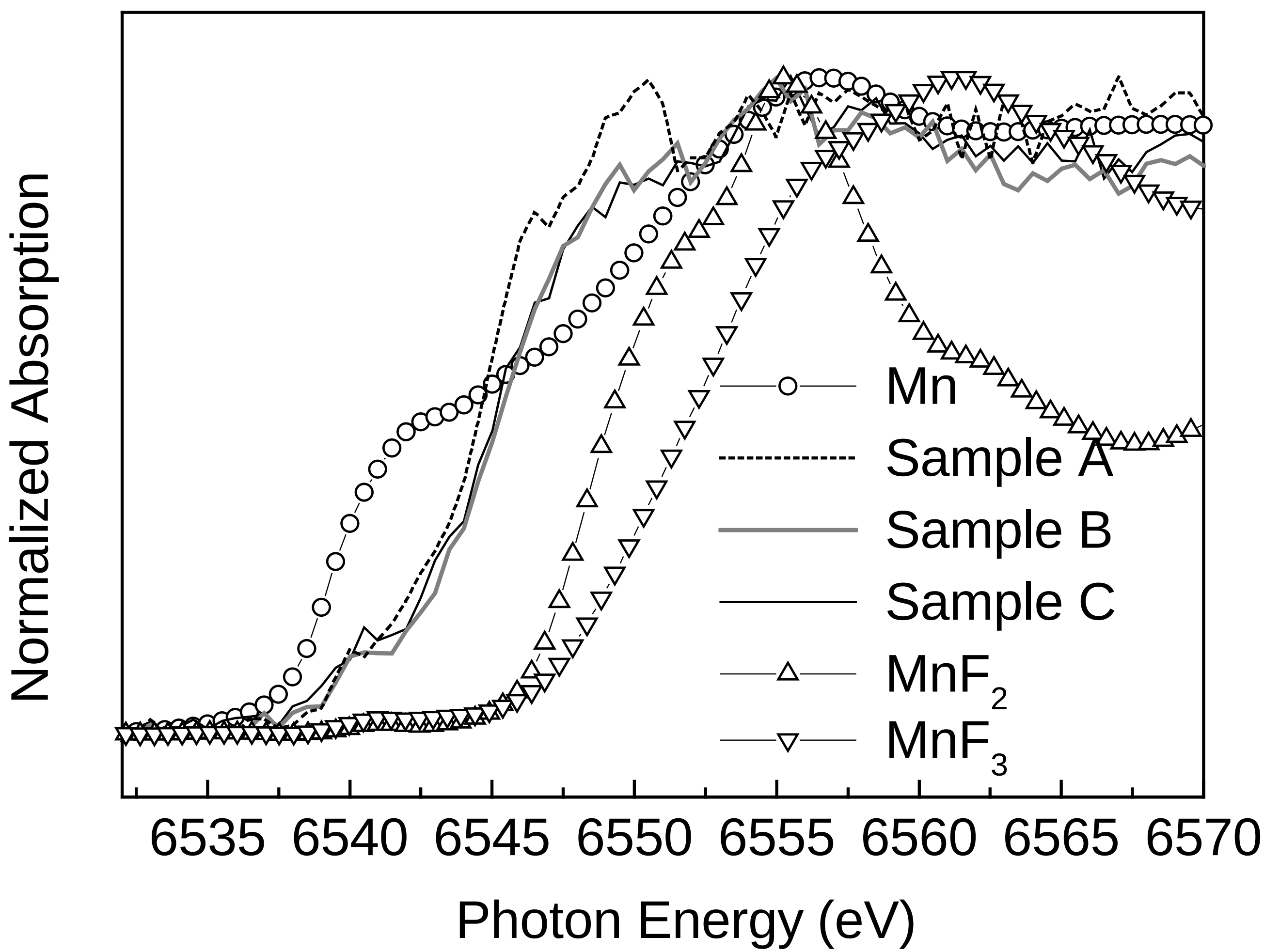
$\sigma_0 = 22 \pm 6$ Å
CdTe (183 ± 10 Å)
$\sigma_1 = 16 \pm 10$ Å
CdS (159 ± 12 Å)
$\sigma_2 = 5 \pm 0.5$ Å
Glass: Corning 7059
Log [Reflectivity] (arb. units)
0
-2
-4
-6
-8
0.0
0.1
0.2
0.3
0.4
q_z (Å^{-1})

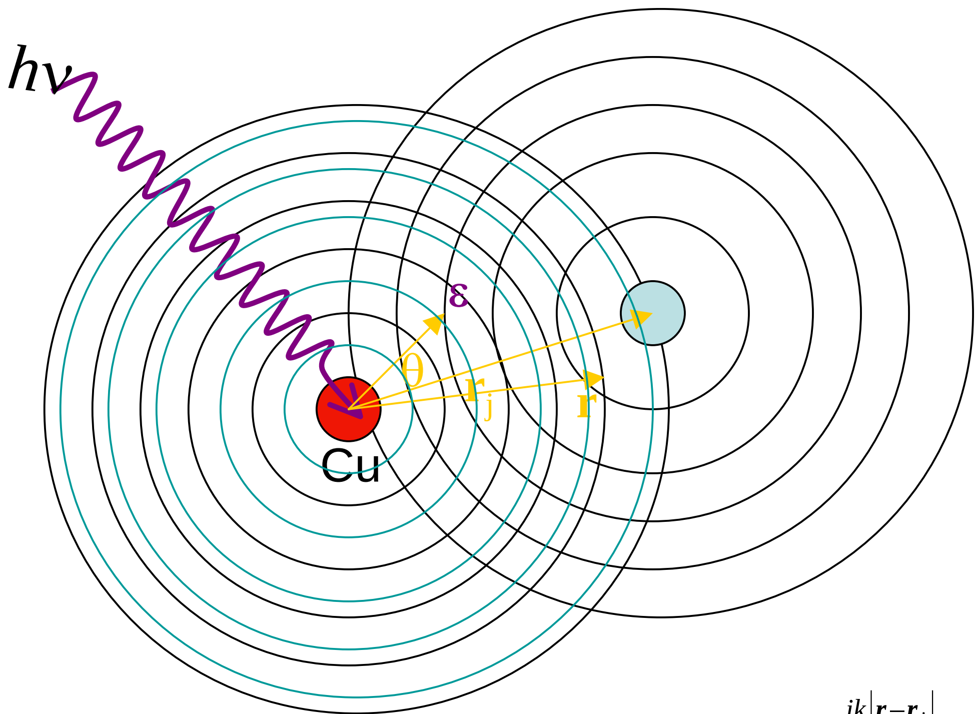


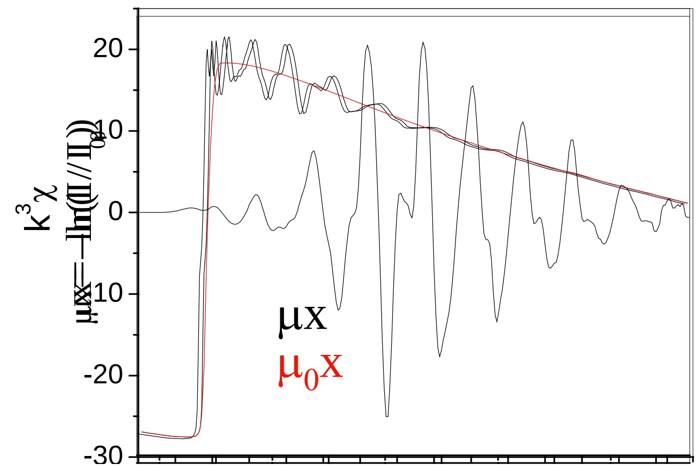
Experimental Setup for X-ray Absorption Spectroscopy at Beamline X3B1

National Synchrotron Light Source

Near Edgde X-ray Absorption Fine Structure (NEXAFS)





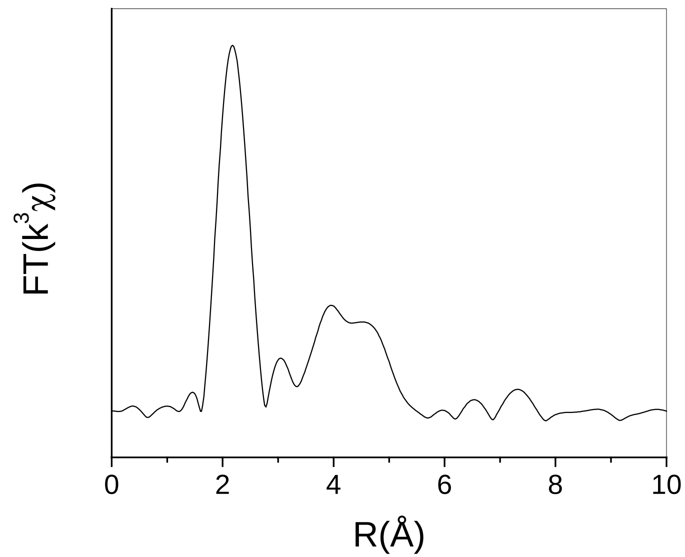


$$|f\rangle = h_1^+(kr)\cos\theta \;+\; 3i[[h_1^+(kr_j)]^2\cos^2\theta_j\, f(\pi)]h_1^+(k$$

$$h_1^+(kr_j)\cos\theta_j \frac{e^{ik|\mathbf{r}-\mathbf{r}_j|}}{|\mathbf{r}-\mathbf{r}_j|}$$

$(l=1, m=0$ partial wave, inc

$$|f_0\rangle \qquad\qquad |f_{EXAFS}\rangle$$

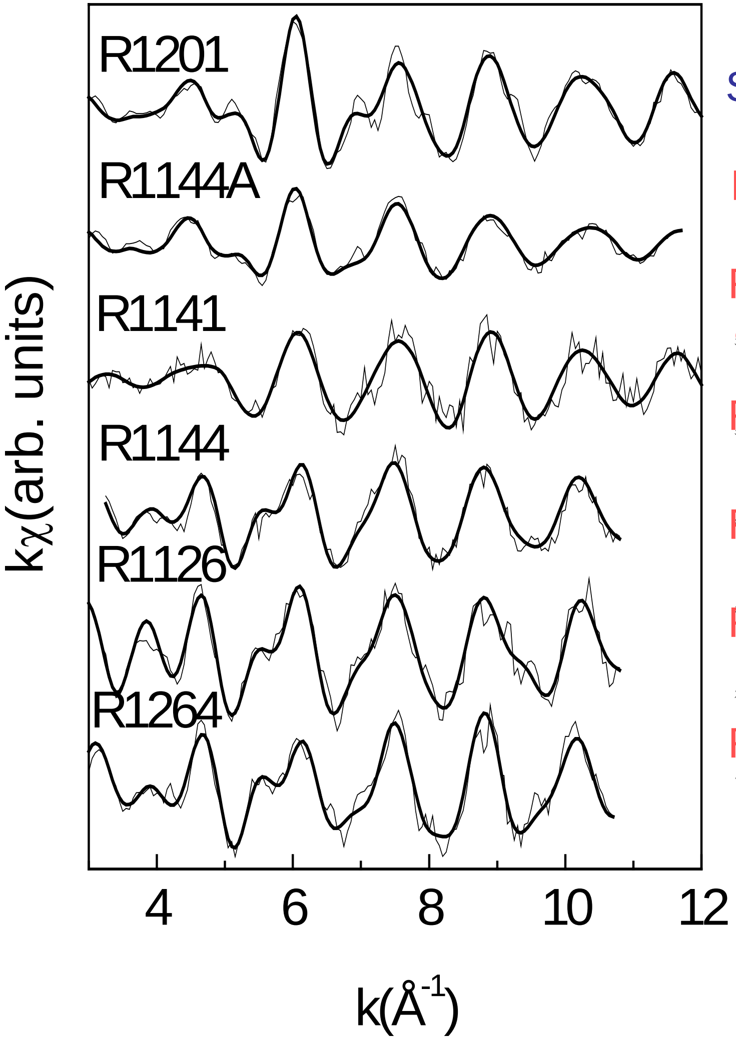


$$\mu = \frac{4\pi^2\omega e^2}{c} N_a |\langle i|\vec{r}\cdot\hat{\varepsilon}|f\rangle|^2 \rho(E_f); \quad \mu_0 = \frac{4\pi^2\omega e^2}{c} N_a |\langle i|\vec{r}$$

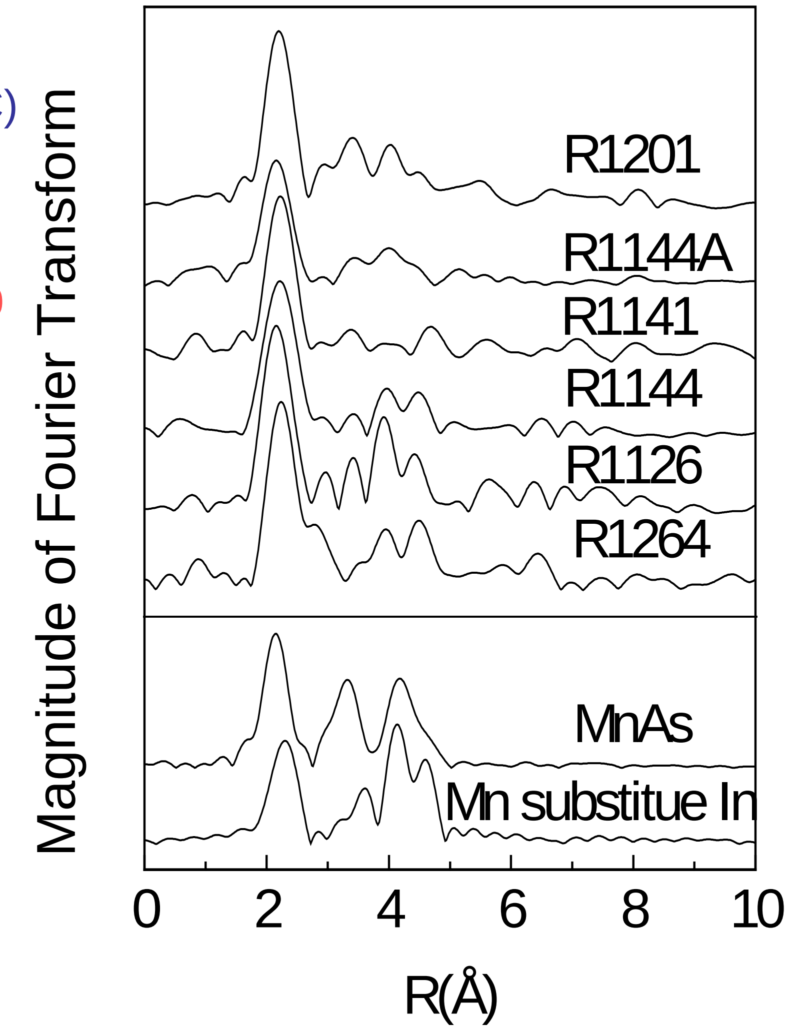
$$\boxed{\chi(k) = \frac{\mu-\mu_0}{\mu_0} = S_0^2 \sum_j \frac{N_j}{kr_j^2} F_j(k)\exp(-2k^2\sigma_j^2)\exp\left(\frac{-2(r_j-\Delta)}{\lambda}\right)\sin[2kr_j+\delta_j(k)]}$$

$\rightarrow$ N, R, σ^2

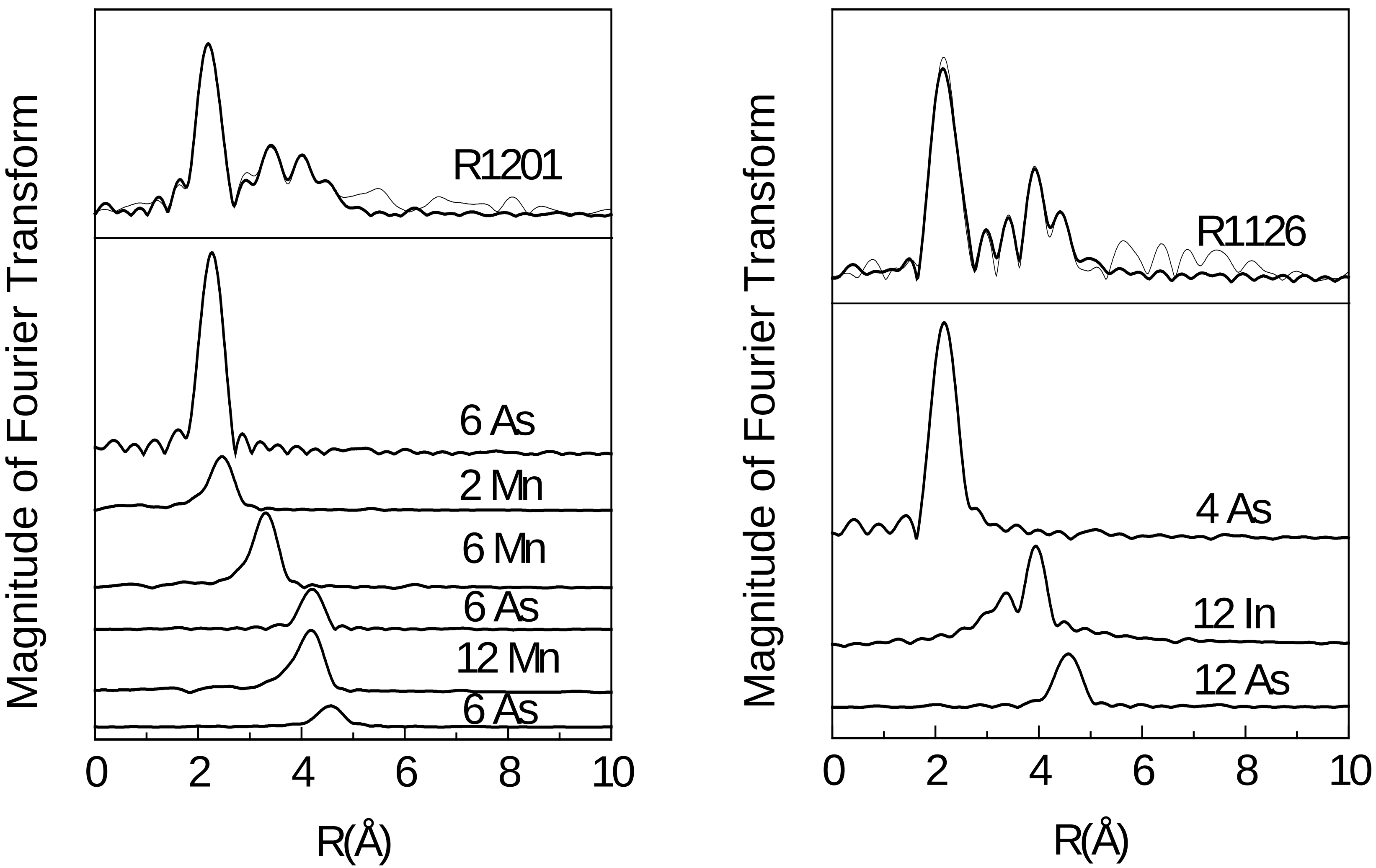
MBE grown (In,Mn)As



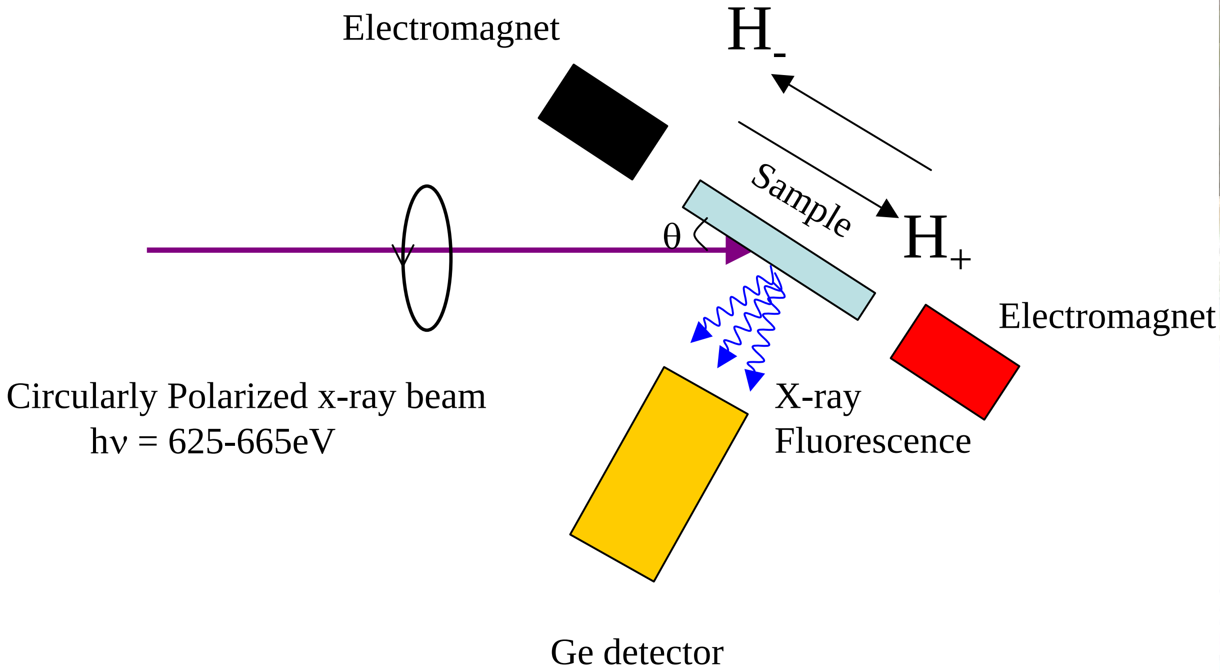
Sample	x	Ts(ºC)
R1201	(MnAs)	
R1144A	0.12	210
annl. at 480ºC		
R1141	0.12	280
R1144	0.12	210
R1126	0.014	200
R1264	0.017	300



MBE grown (In,Mn)As



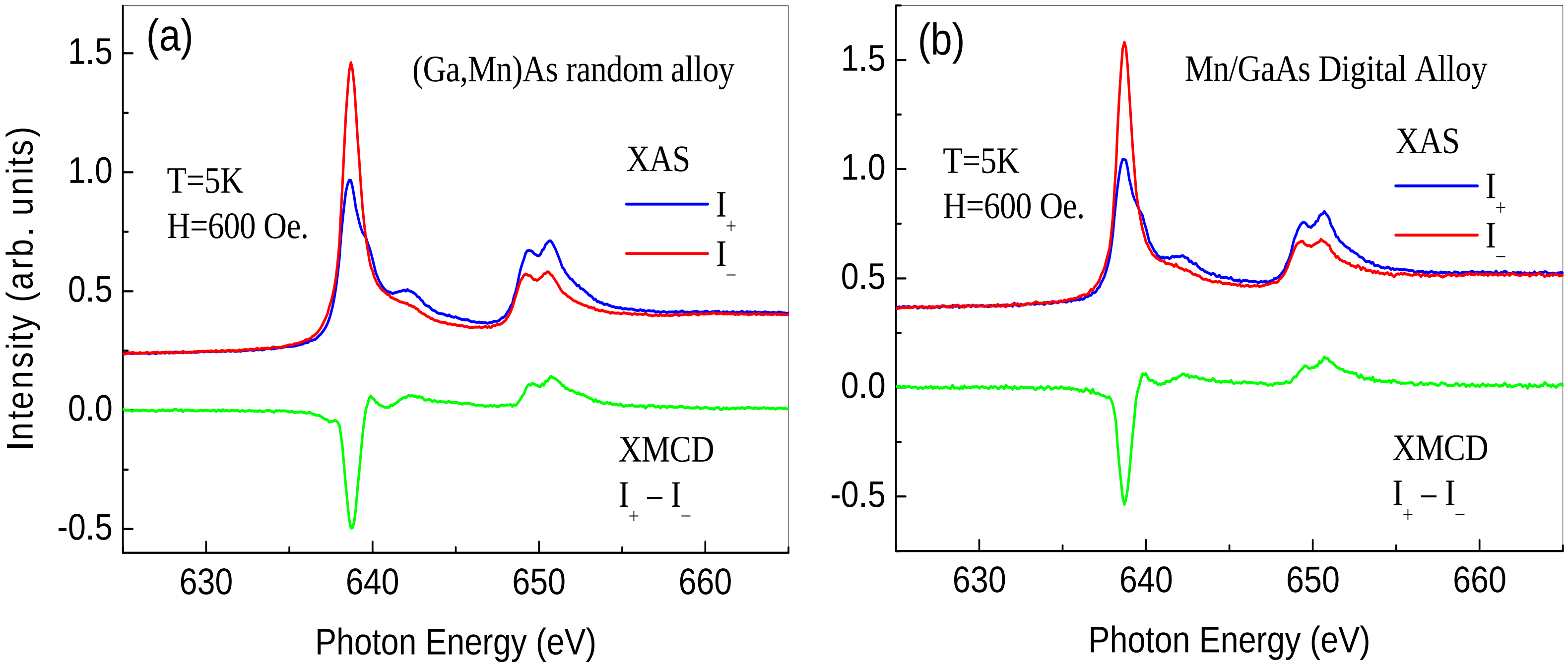
X-ray Magnetic Circular Dichroism (XMCD)



Dragon Beamline SRRC, Taiwan

XMCD of (Ga,Mn)As random alloy and Mn/GaAs digital alloy

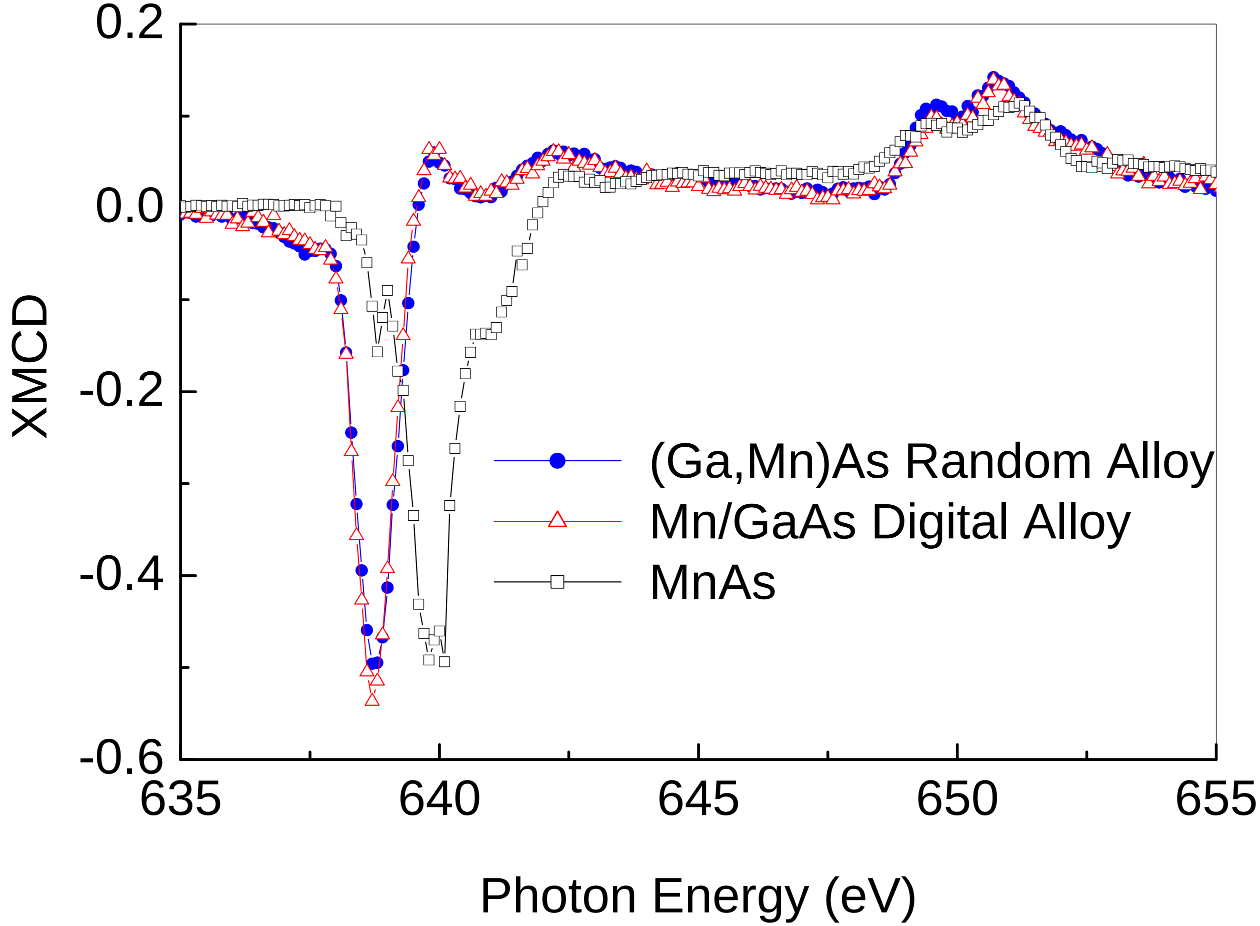
[Y. L. Soo et al. PRB **67**, 214401 (2003)]



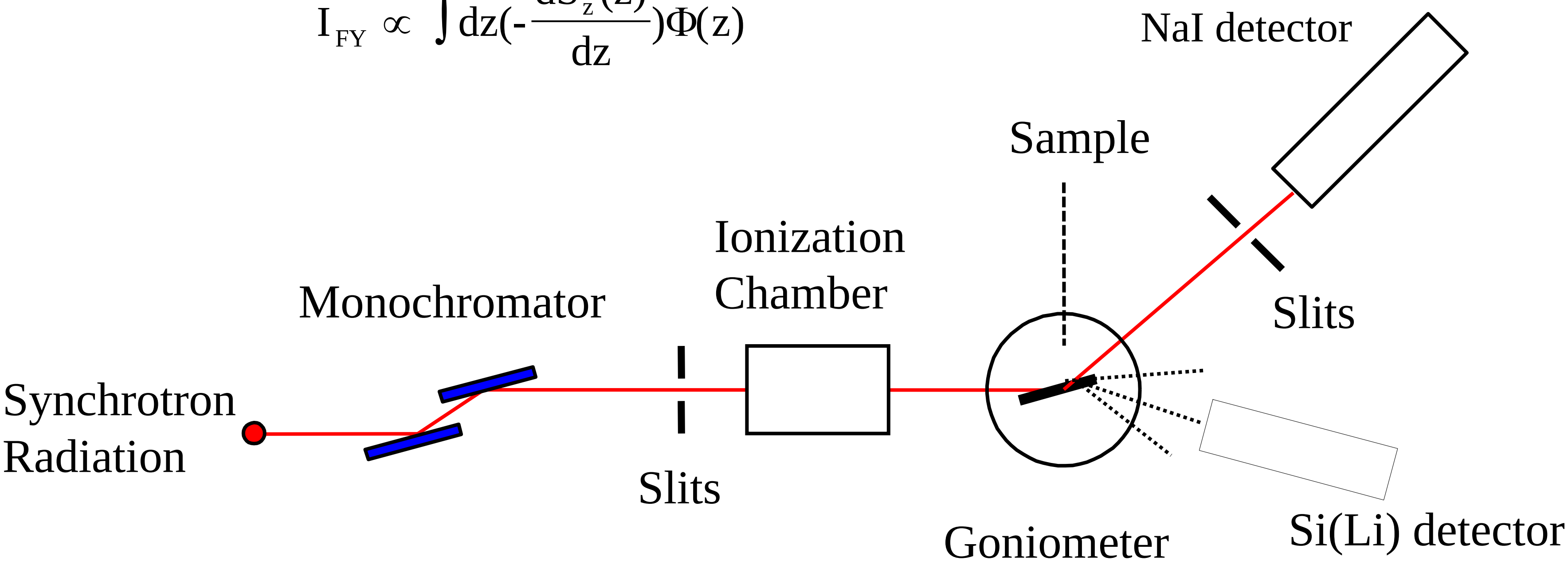
Maximum asymmetry rate $(I_- - I_+)/(I_+ + I_-)$ at 638.7eV:

(Ga,Mn)As: 39%; Mn/GaAs: 42% ;Theoretical: 58%

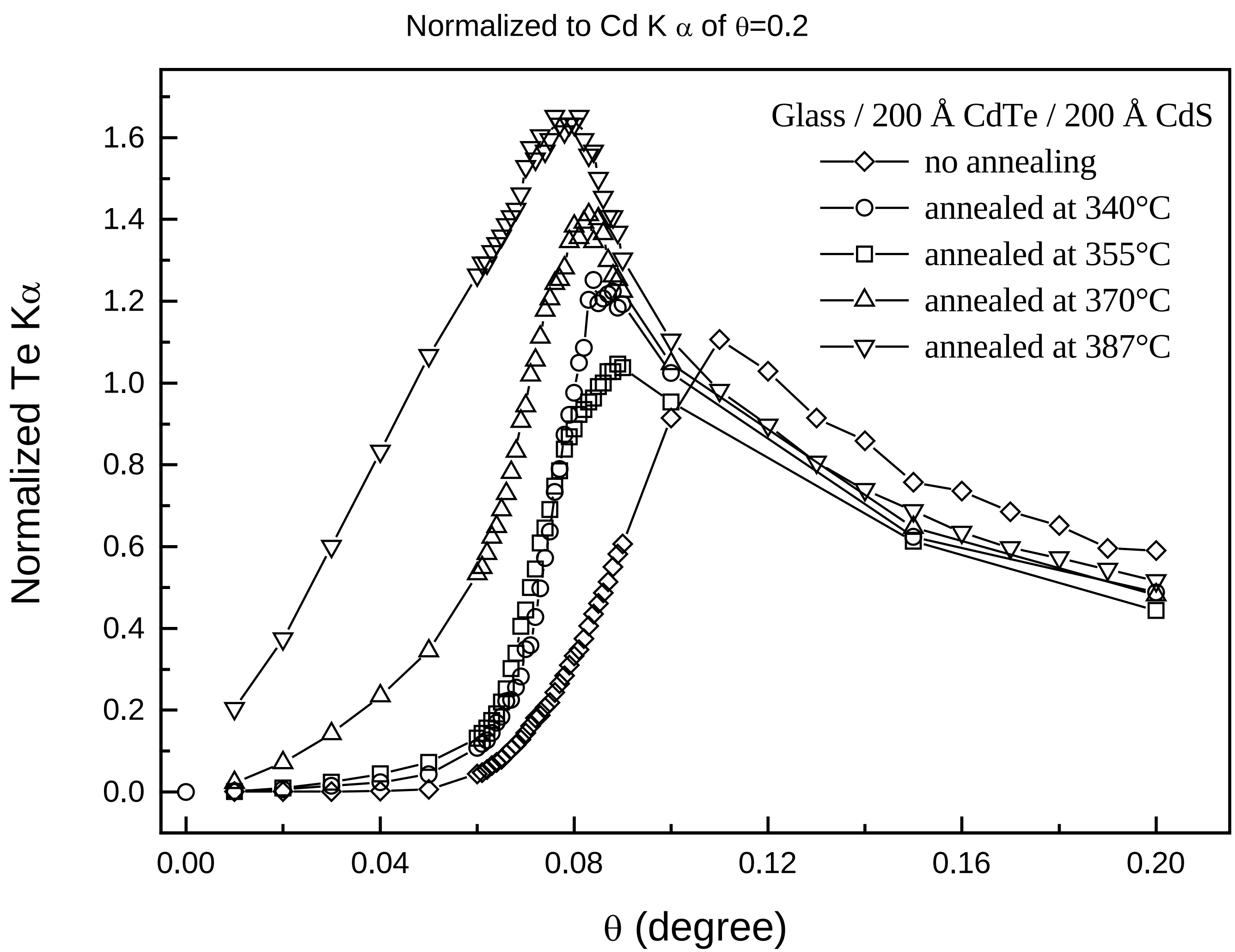
Ferromagnetically ordered Mn: (Ga,Mn)As:>66%; Mn/GaAs:>71%


0.2
0.0
-0.2
-0.4
-0.6
XMCD
635
640
645
650
655
Photon Energy (eV)
(Ga,Mn)As Random Alloy
Mn/GaAs Digital Alloy
MnAs

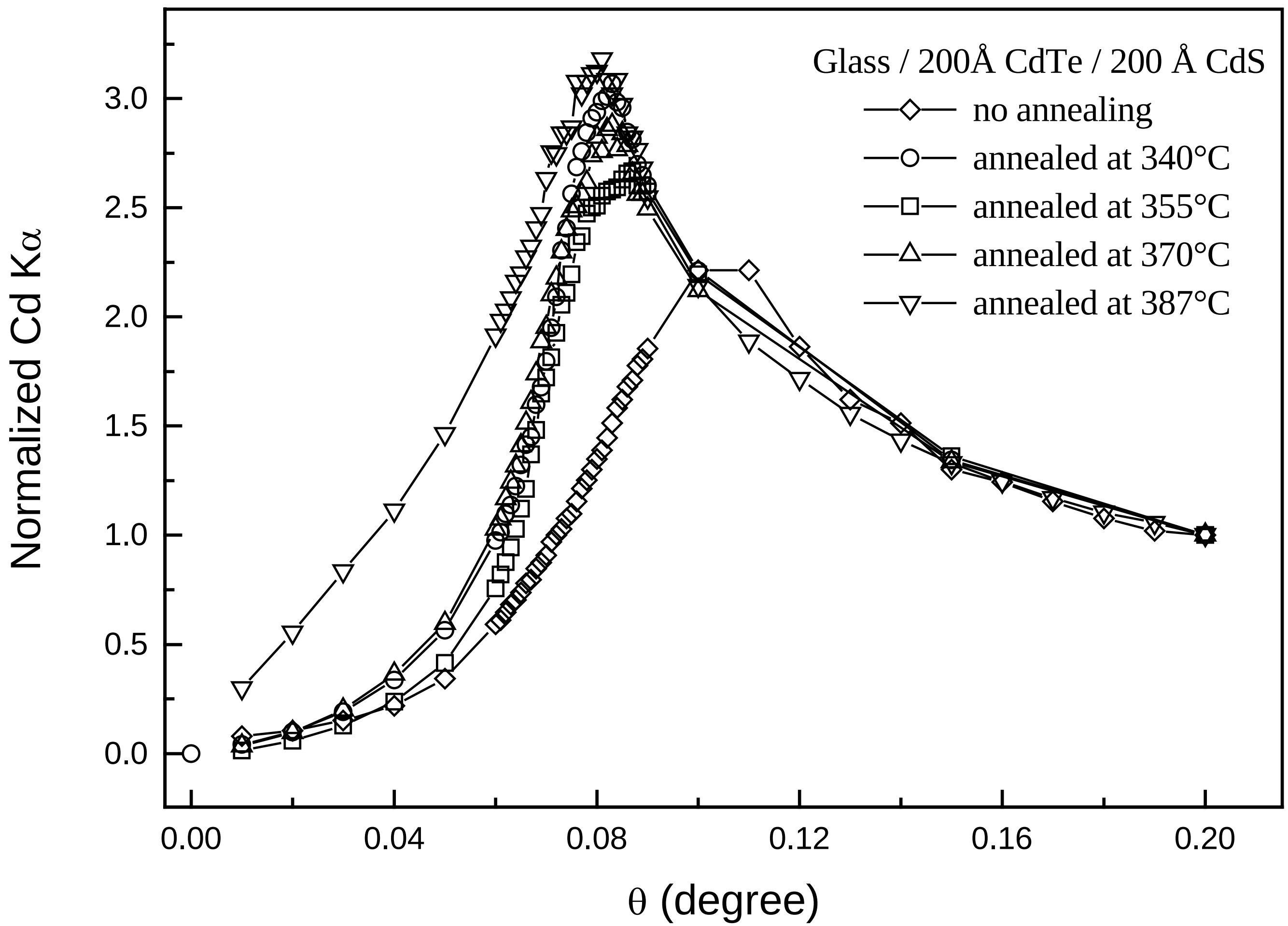
$$I_{FY} \propto \int dz\left(-\frac{dS_z(z)}{dz}\right)\Phi(z)$$



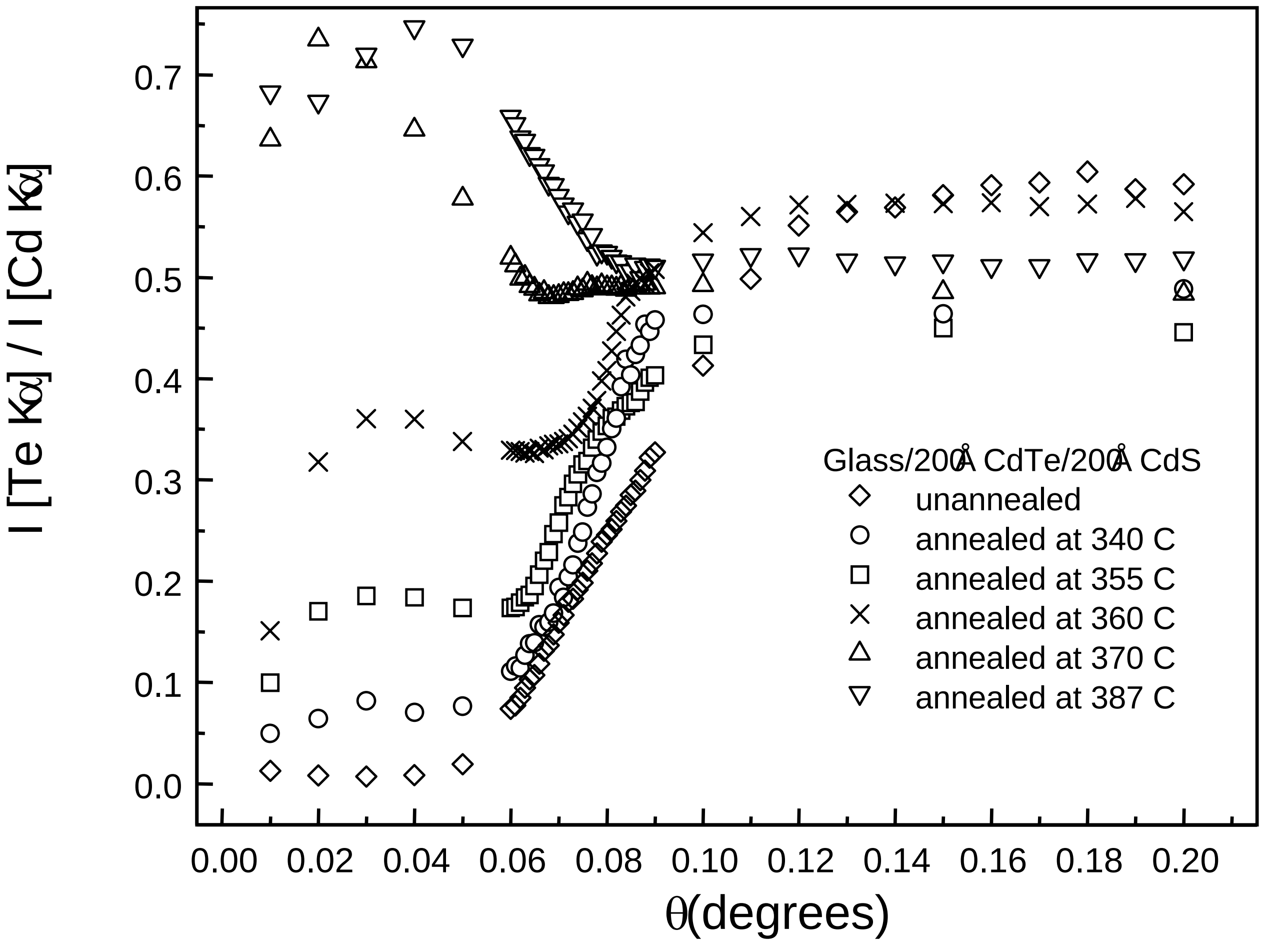
Experimental setup for ADXRF at beamline X3B1 NSLS



Normalized to Cd K α of θ=0.2
Glass / 200 Å CdTe / 200 Å CdS
no annealing
annealed at 340°C
annealed at 355°C
annealed at 370°C
annealed at 387°C
Normalized Te Kα
θ (degree)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0.00
0.04
0.08
0.12
0.16
0.20

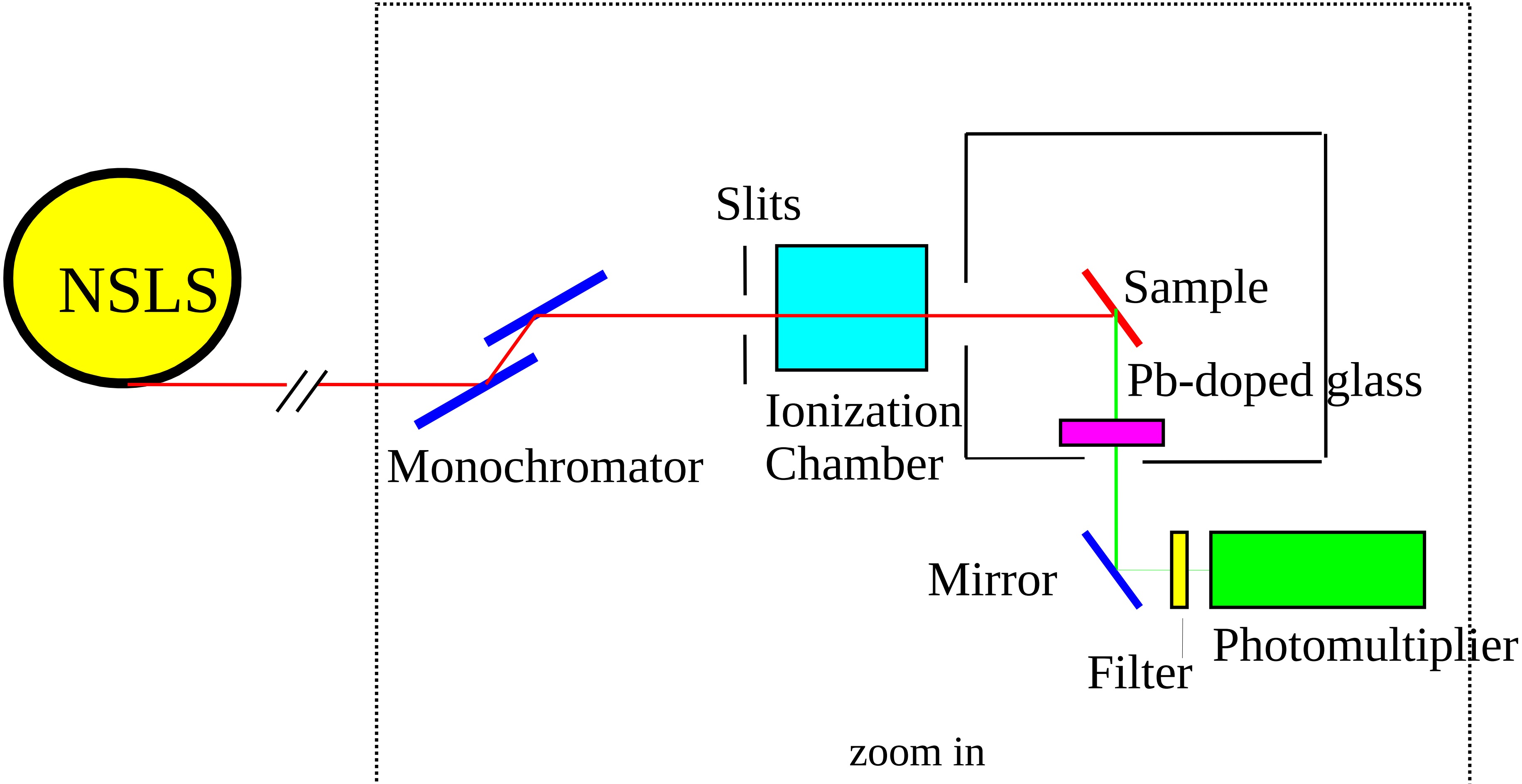


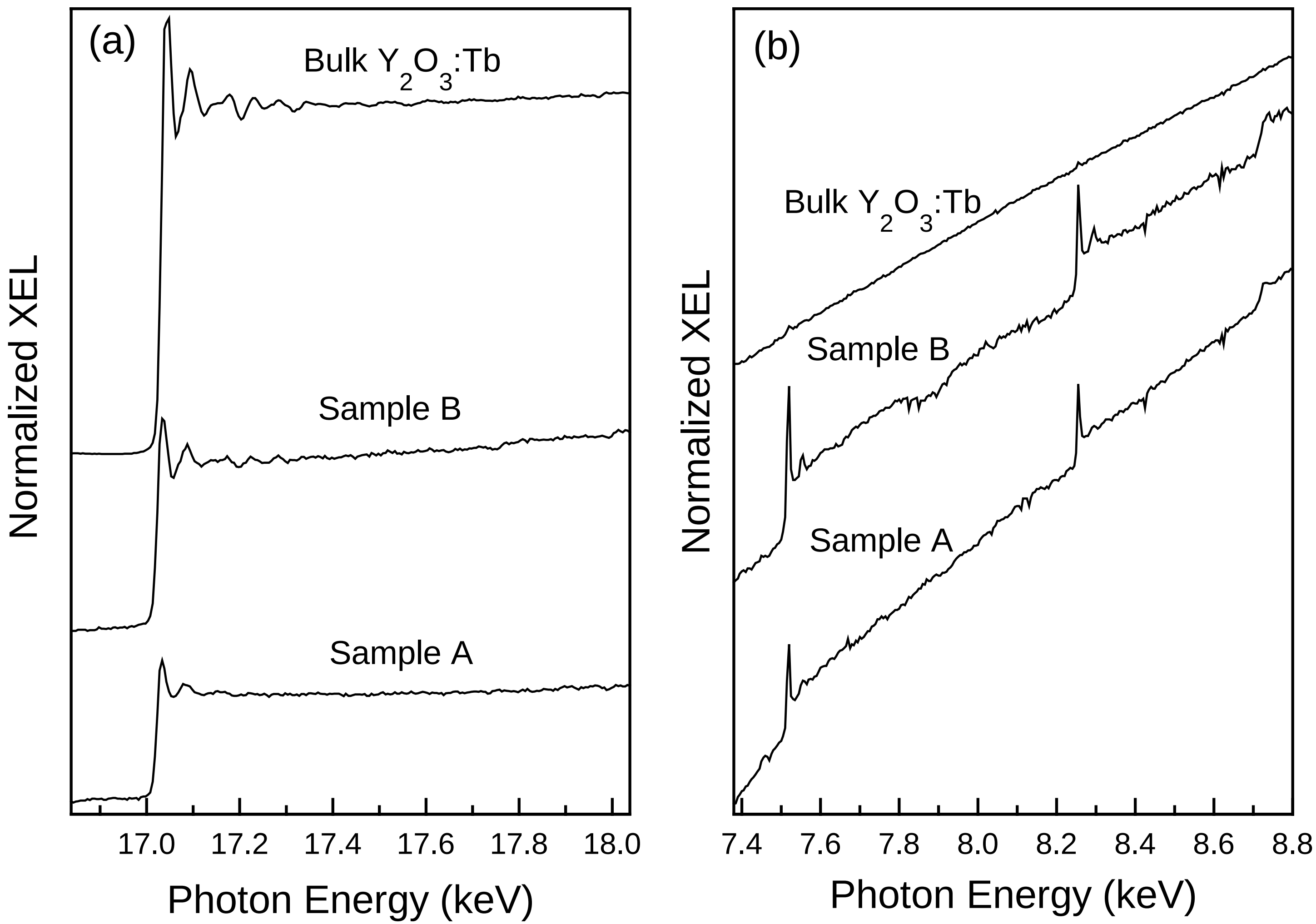
Glass / 200Å CdTe / 200 Å CdS
no annealing
annealed at 340°C
annealed at 355°C
annealed at 370°C
annealed at 387°C
Normalized Cd Kα
θ (degree)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0.00
0.04
0.08
0.12
0.16
0.20



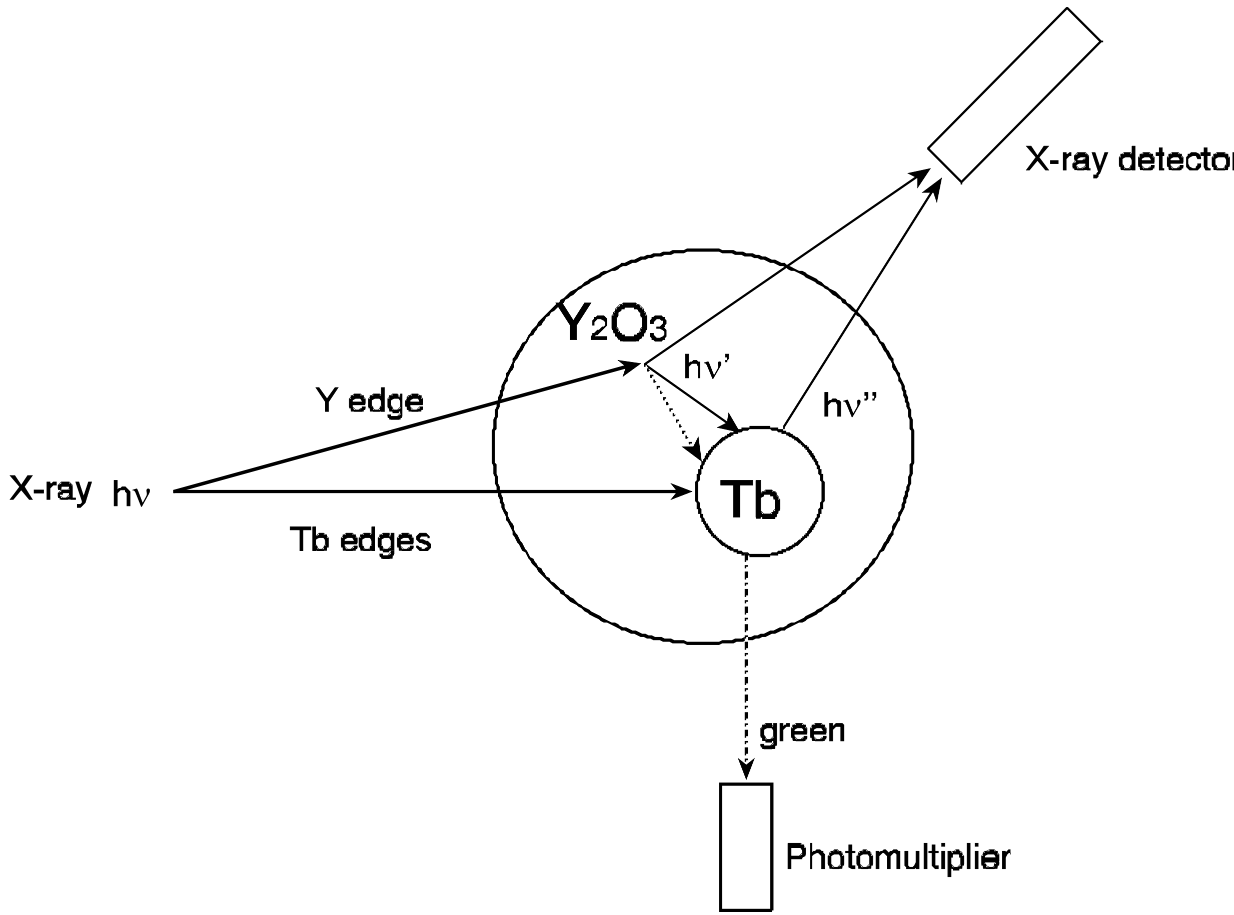
I [Te Kα] / I [Cd Kα]
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
θ(degrees)
Glass/200Å CdTe/200Å CdS
unannealed
annealed at 340 C
annealed at 355 C
annealed at 360 C
annealed at 370 C
annealed at 387 C

Experimental setup for XEL measurements at Beamline X3B1 NSLS





(a)
Bulk Y_2O_3:Tb
Sample B
Sample A
Normalized XEL
17.0
17.2
17.4
17.6
17.8
18.0
Photon Energy (keV)
(b)
Bulk Y_2O_3:Tb
Sample B
Sample A
Normalized XEL
7.4
7.6
7.8
8.0
8.2
8.4
8.6
8.8
Photon Energy (keV)



X-ray detector
Y2O3
hν'
Y edge
hν''
X-ray
hν
Tb
Tb edges
green
Photomultiplier

Synchrotron Radiation X-ray techniques

- Long-range-order (LRO) structure: XRD
- Short-range-order (SRO) structure: EXAFS, NEXAFS
- Probing selective element in ferromagnetic ordering: XMCD
- Variations of density profiles of constituent elements in solid: ADXRF
- Interfacial morphology: GIXS
- Probing x-ray to visible down conversion route/ relation between specific elements and itinerant electrons: XEL