Recent development of HAXPES instrumentations at BL-47XU/SPring-8

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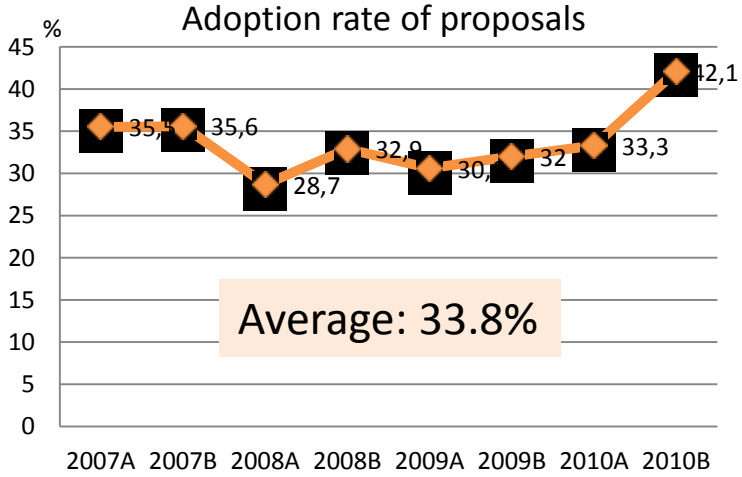
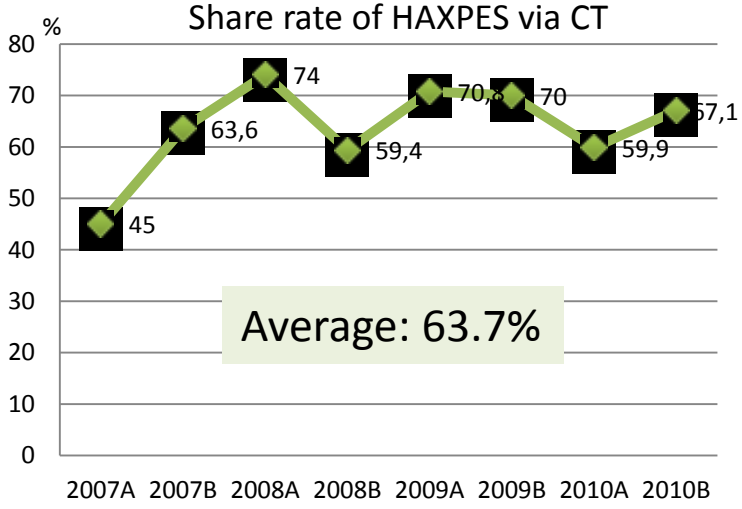
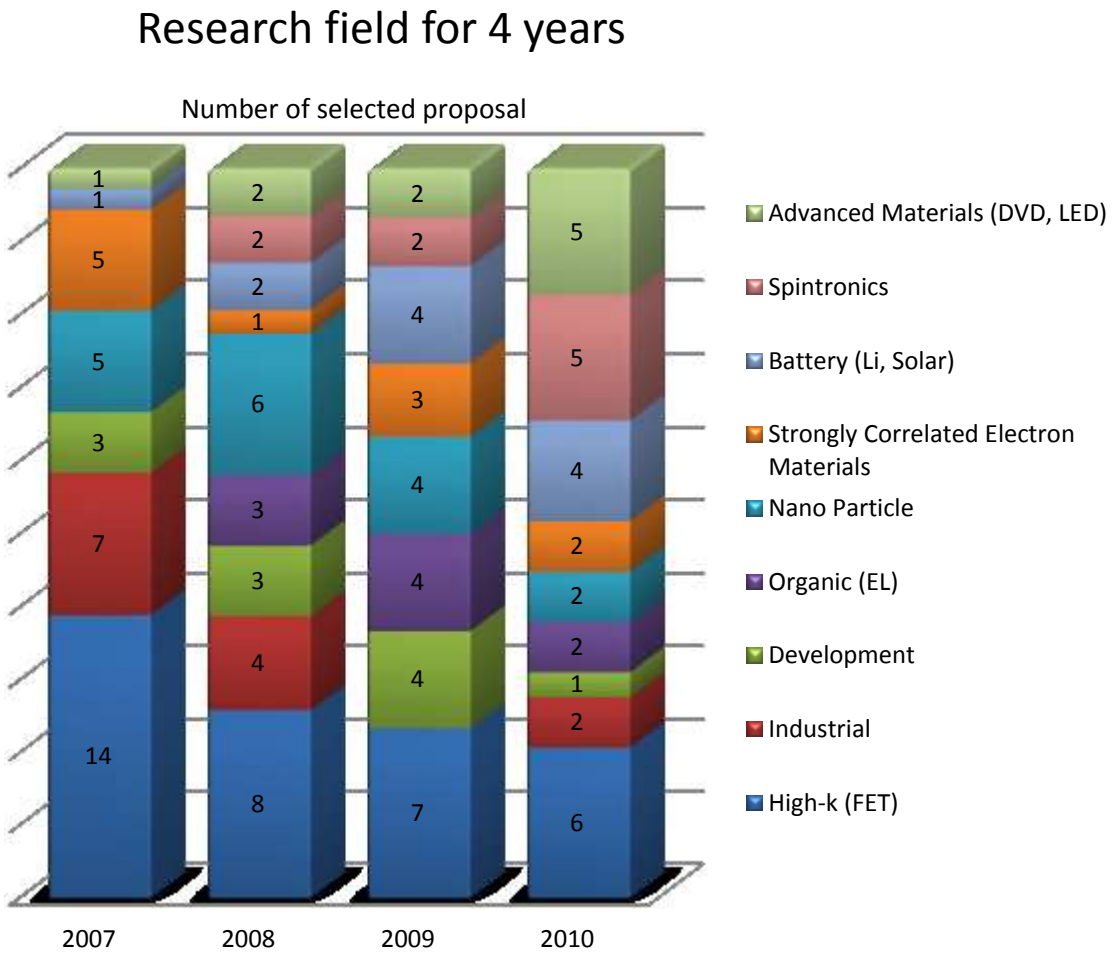
14, Sep. 2011, HAXPES workshop

Research Market in HAXPES : BL47XU





HAXPES of BL47 has high popularity.



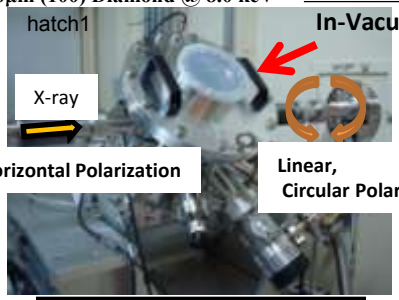
Researches in Battery(Li, Solar), Spintronics, Advanced Materials(DVD, LED) are increasing.

Recent Developments of HAXPES : BL47XU

MCD-HAXPES for Spintronics

200μm (100) Diamond @ 8.0 keV

Phase Retarder In-Vacuum



- Rapid helicity reversal
- Pc > 0.95
- Plin > 0.90

These development was supported by DFG-JST.

Project Leader: Prof. C. Felser

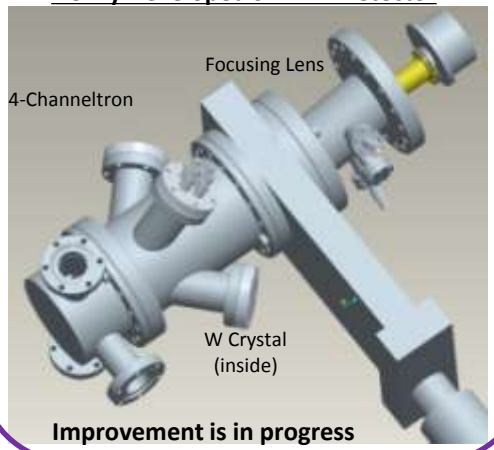
Aims :

#Development of a new method, spin-resolved HAXPES, for magnetic properties

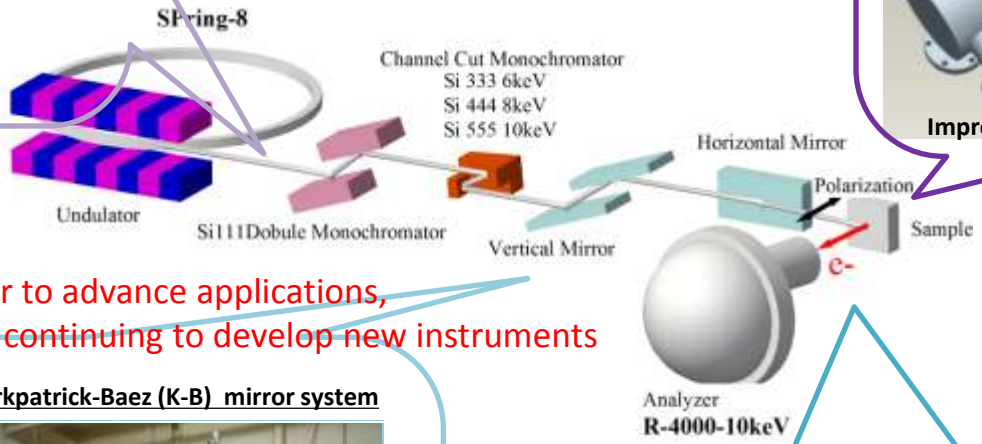
The SPLEED detector detects the spin polarized secondary electron emitted from the tungsten crystal

SPIN resolved HAXPES

Newly Developed SPLEED Detector



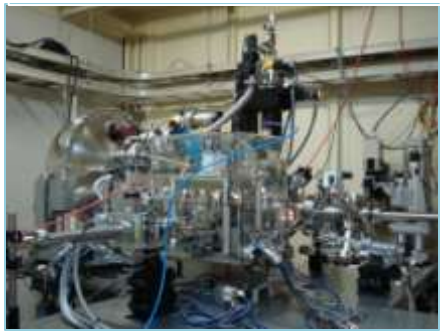
Improvement is in progress



In order to advance applications,
we are continuing to develop new instruments

Focusing optics

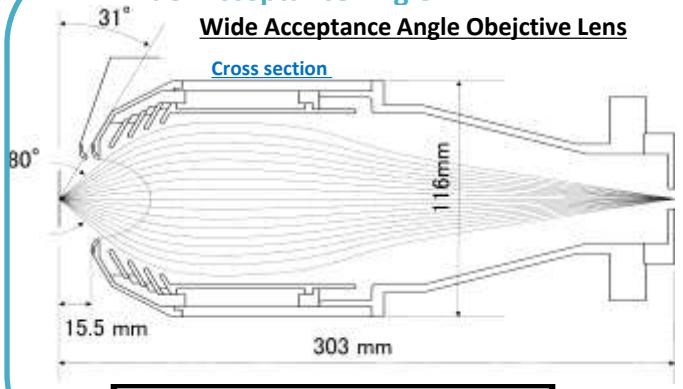
Kirkpatrick-Baez (K-B) mirror system



- Focusing size: φ1μm

Wide Acceptance Angle

Wide Acceptance Angle Obejctive Lens

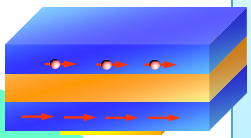


- Acceptance Angle: ±30° ←±7°

These development was supported by SENTAN, JST.
Project Leader: Prof. K. Kobayashi.

Public BL47XU

Our targets

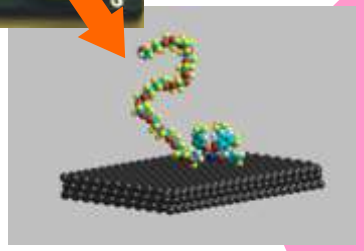


Strained Manganite Thin Films

Fundamental Science

Industrial application

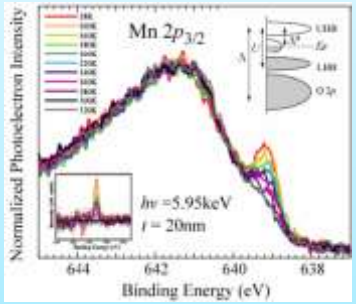
Applied Science

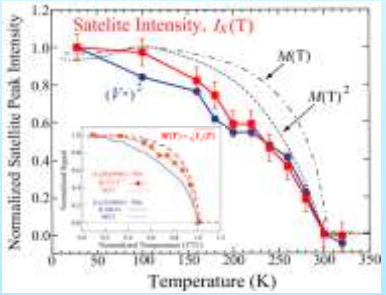


Organic Materials

Typical result

Electronic Structure of Strained Manganite Thin Films with Room Temperature Ferromagnetism （$LaBaMn_3/SrTiO_3$）

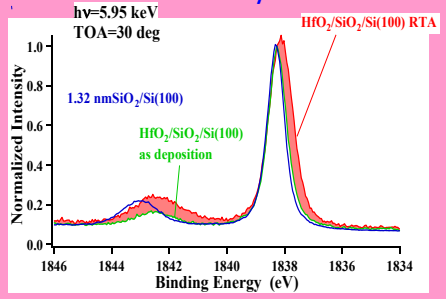




The relation that corresponds to temperature-magnetization curve is experimentally clarified.

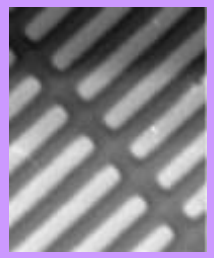
Typical result

Interface reaction of poly-Si/high-k insulator systems



The depth probe is analyzed in high accuracy.

Applied nanotechnology



Transition Metal of Ferromagnetic Oxide

Nano-DNA Chips

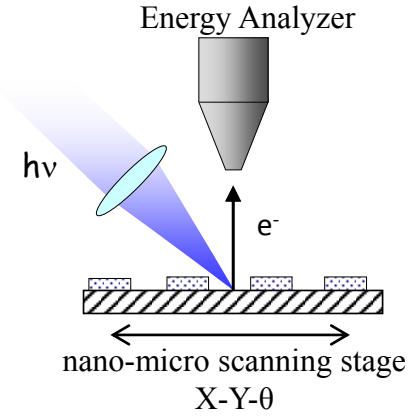
(Kawai-Lab nano-bio-chip group)

- These advanced materials has nano or micro structures.
  Request of observation in the microscopic area is increased.

Purpose

Achievement of the 3D chemical states analysis by scanning sample in microscopic area and taking depth profiles

Scanning (in-plane 2D) + take-off angle (depth 1D)



Plan

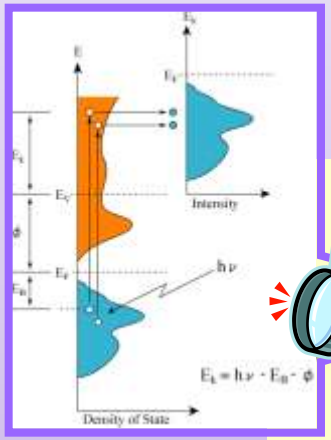
Scanning type microscope

1. Introduce focusing optics

- Standard beam size **V: 40μm & H: 30μm**

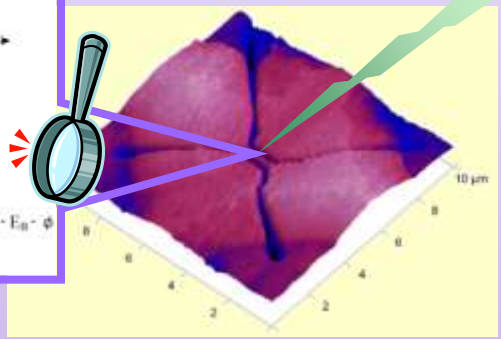
After installation K-B Mirror, Status of beam spot size

⇒ϕ1μm～submicron



Electronic state of microscopic area

K-B Mirror

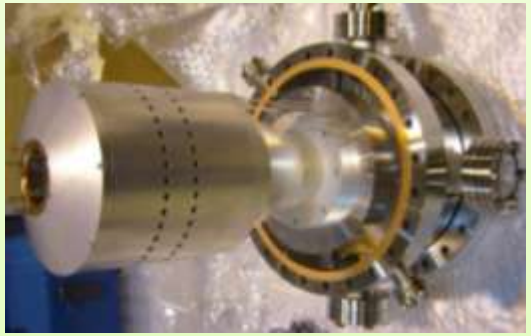


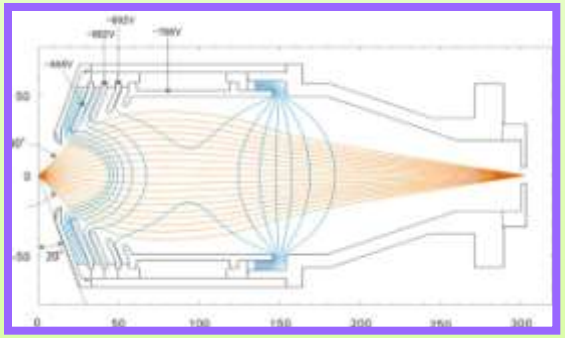
This development of scanning type of photoemission microscope can obtain the electronic states and images in microscopic area.

2. Development of Objective lens

Analyzer lens of solid angle: ±7°

Wide acceptance angle

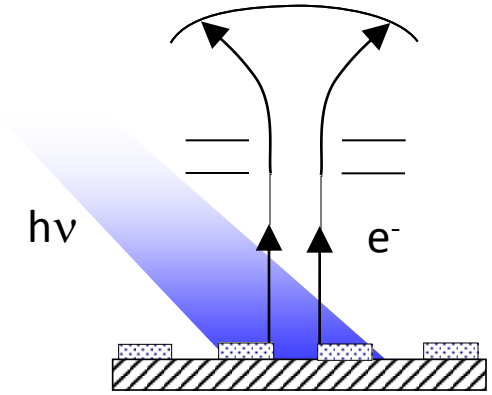




What is the difference with PEEM ?

Photoelectron emission microscope (PEEM)

Magnification/Energy selection

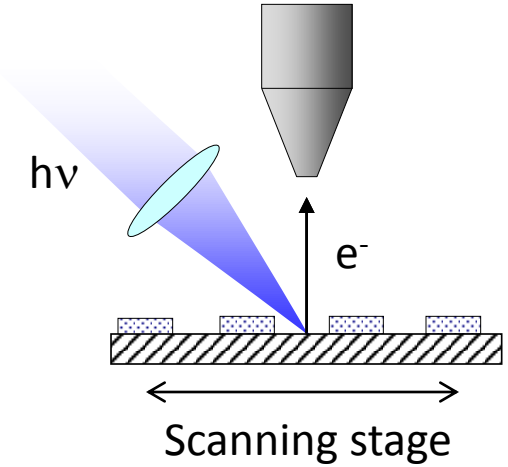


- High lateral resolution < 10 nm
- Moderate energy resolution > 0.3 eV

Scanning type microscope

Sample scanning (x-y)

Energy Analyzer



- Lateral resolution is limited by spot size
- Advantage for the scanning type microscope (High energy resolution)

High-energy resolution is required for resolving lateral dependence of electronic structure.

Lateral Resolution of Analyzer Photoelectron Detection

Au micro Dot on Si wafer

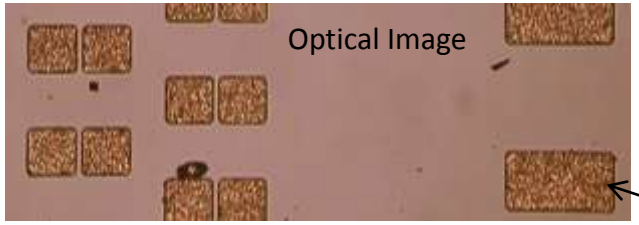
Transmission Mode

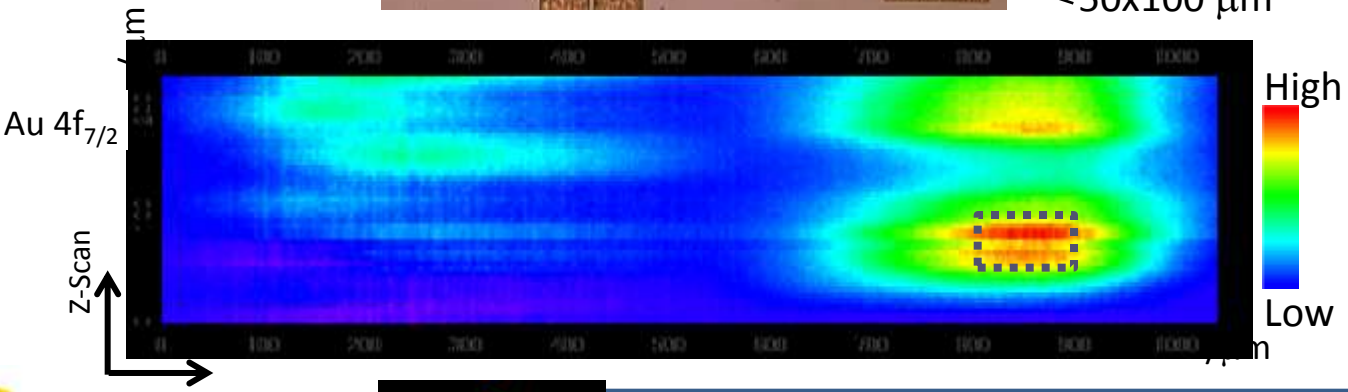
Focusing size: **V: 40μm H: 30μm**

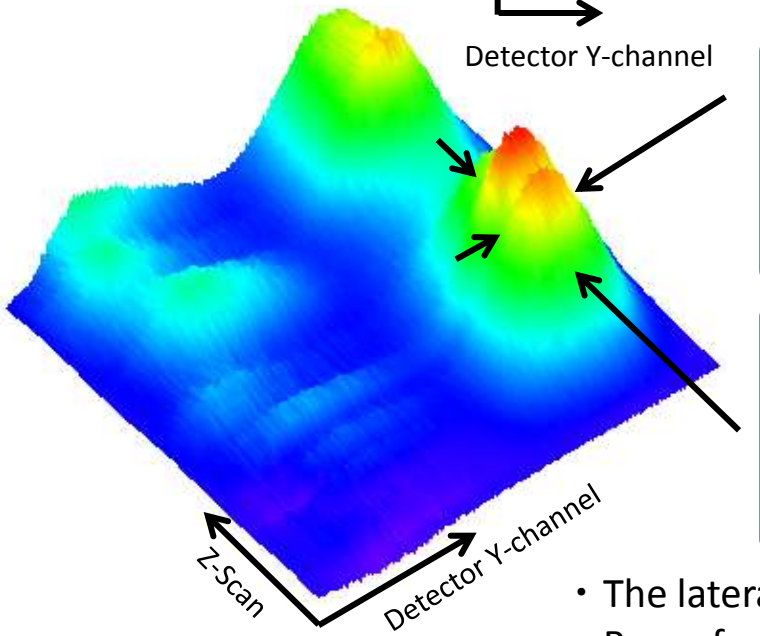
TOA: 88.5, Scan Step: 5 μm,

CCD Y-channel array:

1.35 μm/pixel







Broadening by Lateral Resolution of Analyzer Photoelectron Detection

magnification: 25 with Objective Lens, Phosphor Screen & CCD Detection System)

Convolution of

Au Dot Size & Beam focusing Size

50 μm 40μm(FWHM)

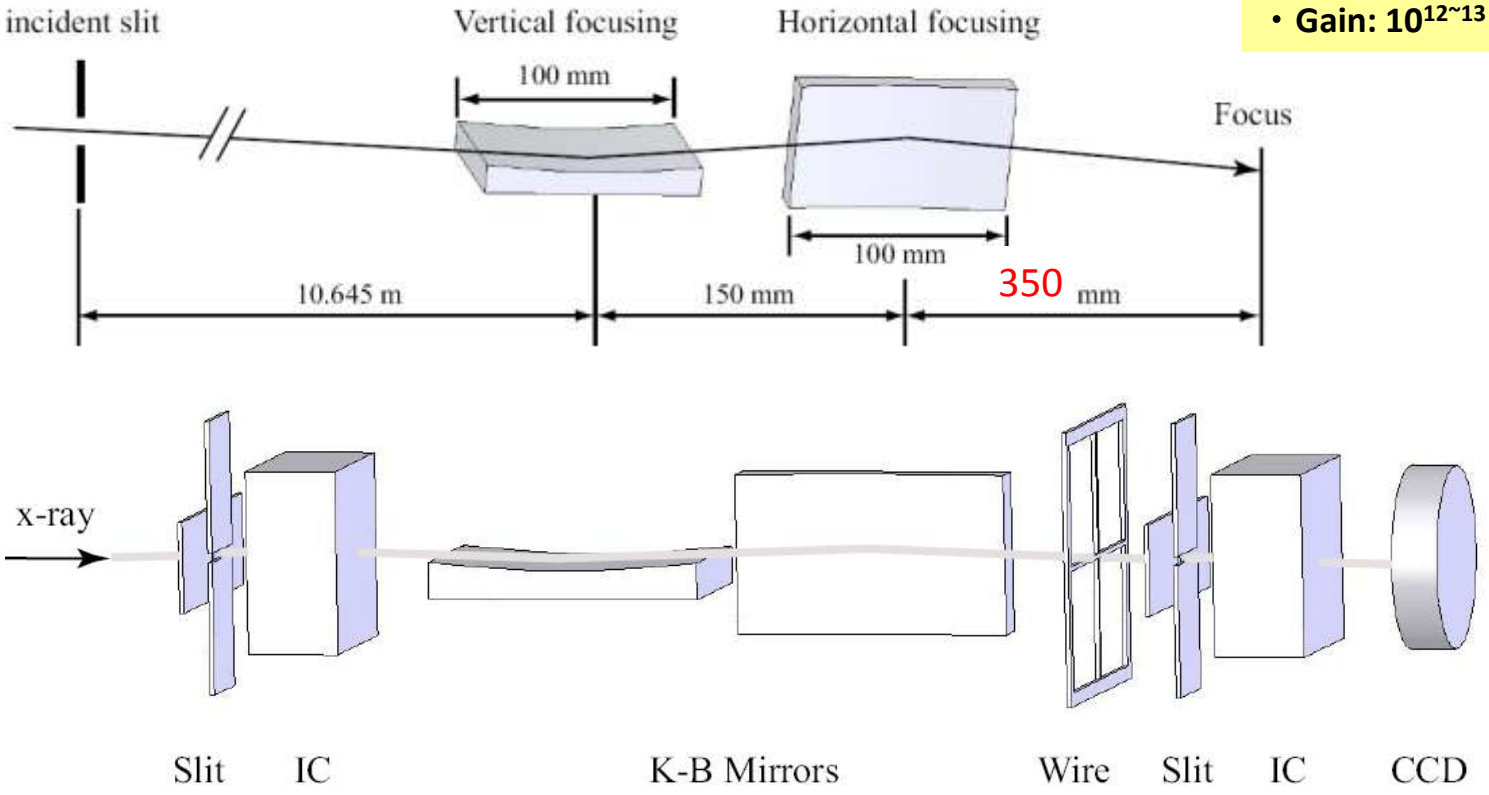
- The lateral resolution of 2-D detection system is poor
- Beam focusing is important for well-resolved image with high energy resolution.

Development of K-B mirror system

K-B mirror system

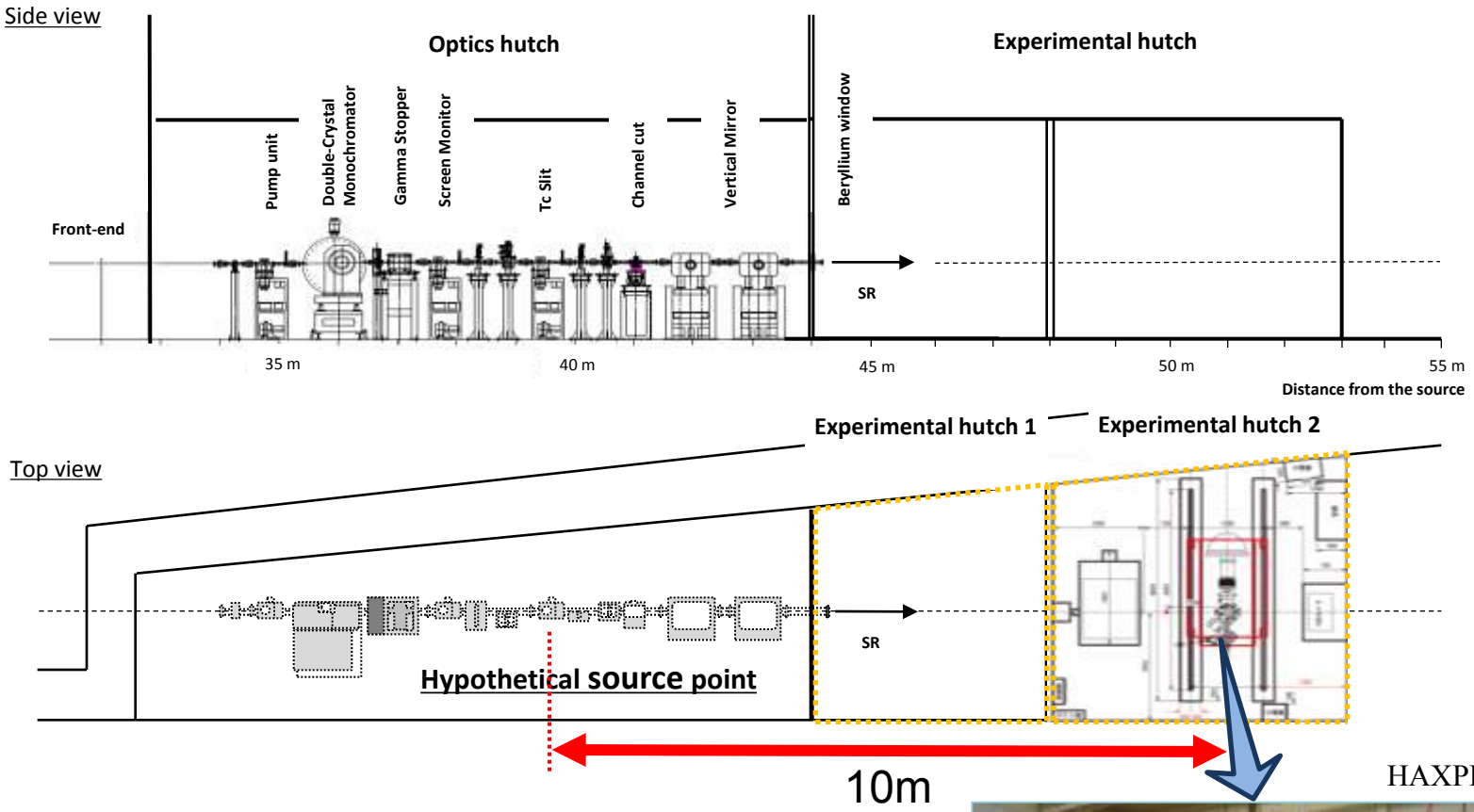
elliptical mirrors; figure errors ~ 2 nm; platinum coating;
glancing angle ~ 3 mrad; incident slit: 300 × 300 μm

- **Working distance:**
  350mm (BL47XU)
- **Beam size: 1um**
- **Demagnification : 1000**
- **Gain: $10^{12\sim13}$**

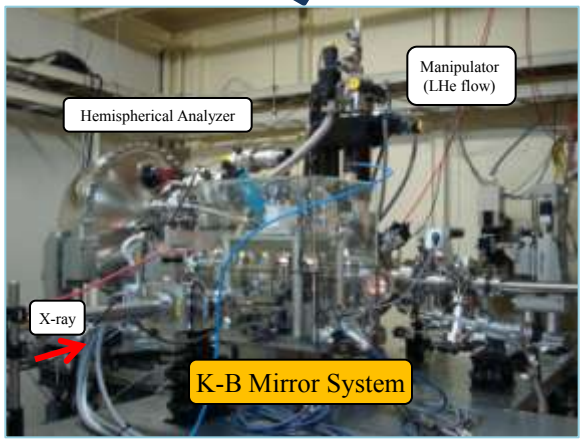


Extended working distance leads to wide space around sample

Development of K-B mirror system



HAXPES



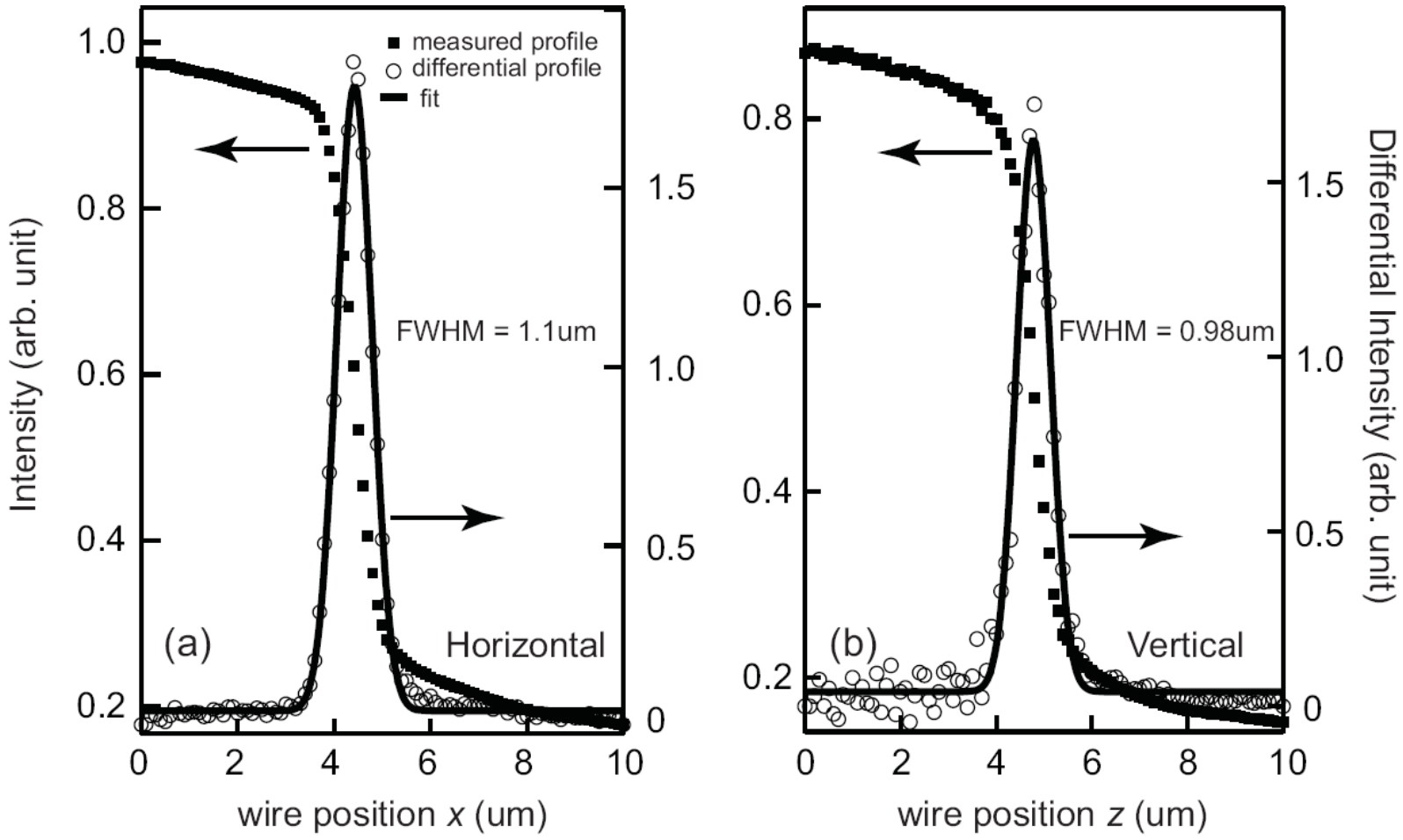
- In-vacuum planar undulator, 5.9 ~18.9 keV
- Si (111) double crystal monochrometer
- liquid nitrogen cooling (not closed cycle system)
- Si (333) channel cut

High Energy Resolution (Band Width=60meV @8keV)

Development of K-B mirror system

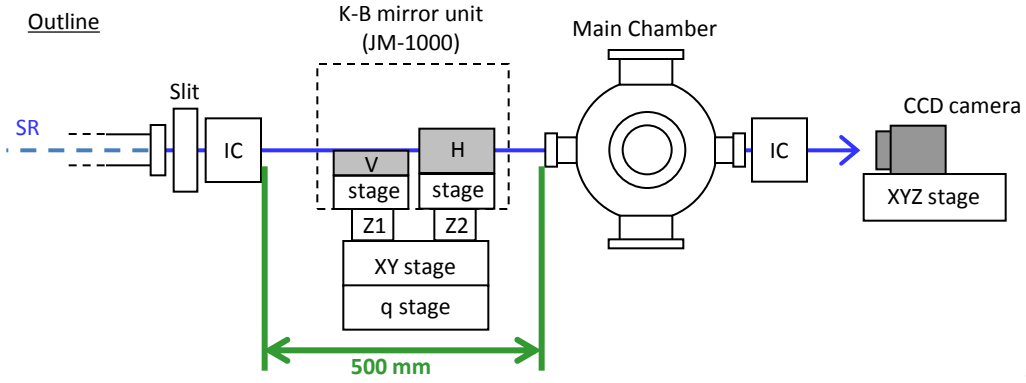
Focusing Result (Photon Energy=7.94keV)

Using Wire Scan monitor



Beam size: 1.1μm (H) × 0.98μm (V)

Development of K-B mirror system

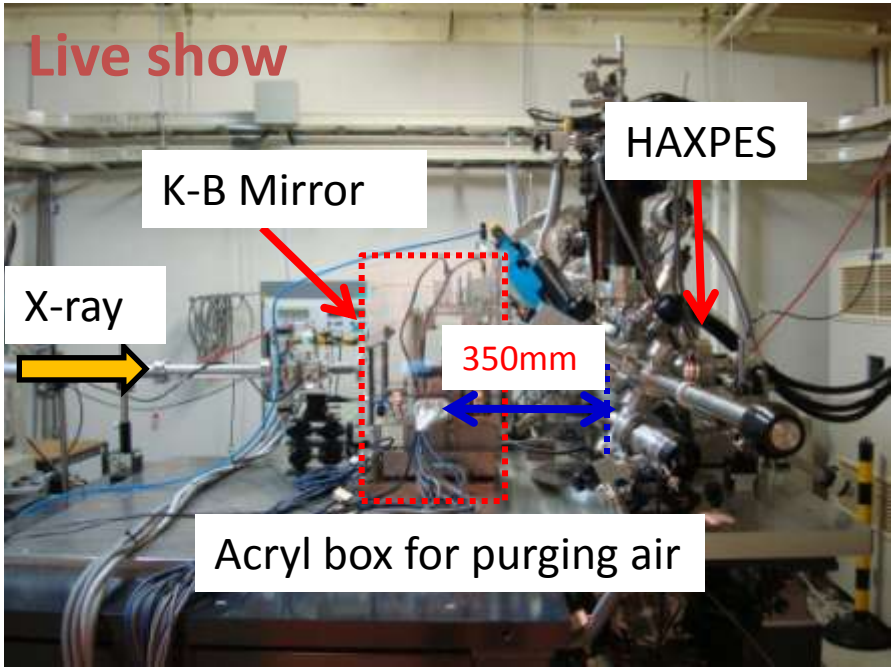


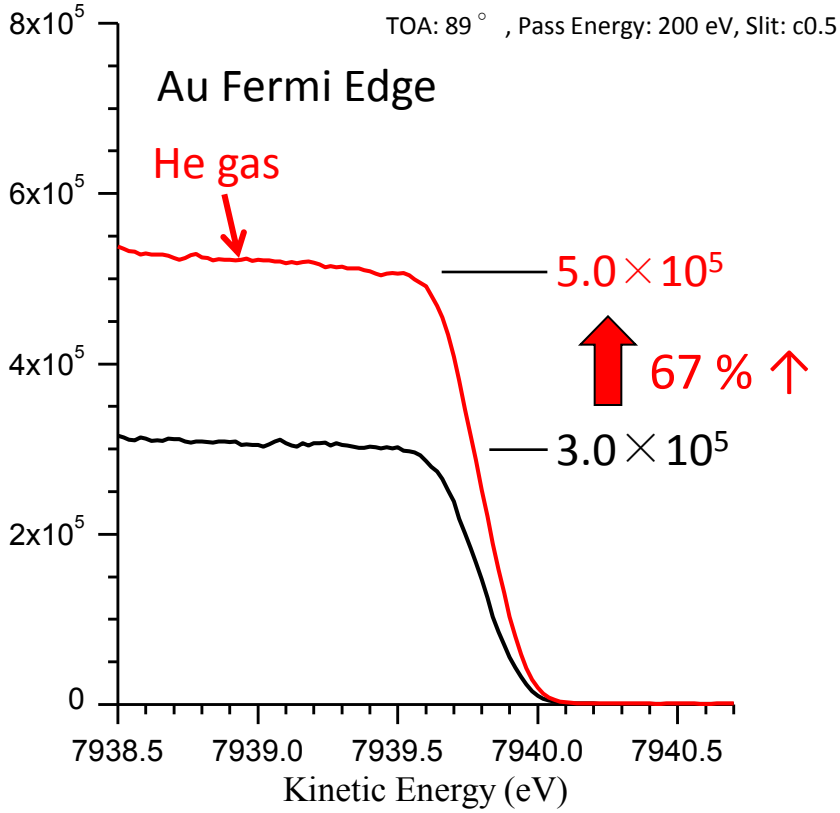
Increasing of Photon Flux

8.1e+10 → 1.3e+11 (photons/s)

63 % ↑

Improvement of signal intensity by replacing the air path of the KB mirror with helium gas





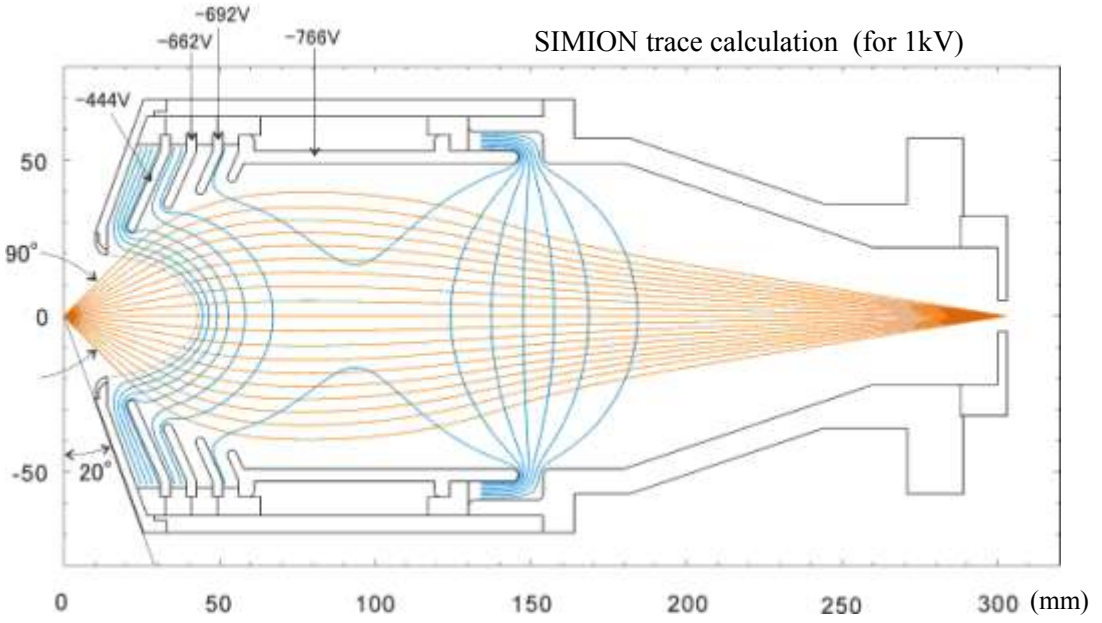
This result confirms linearity of signal intensity against photon flux is good enough.

Wide Acceptance Angle Objective Lens

In Collaborate with Drs. Daimon and Matsuda

About withstanding voltage・・・

Stable operation under 8kV application without discharge.



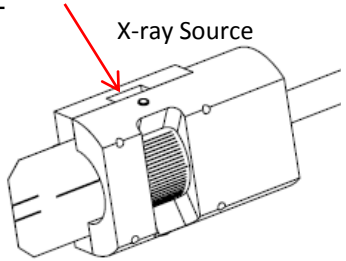
Main feature・・・

- **Discharge prevention measures by simplification of correction electrode part structure**
- **The entrance shape mesh of a spheroid type**
- **Working Distance=15mm**
- **Magnification factor: 5**
- **Total magnification factor becomes 25**
  by combination of this objective and the analyzer lenses

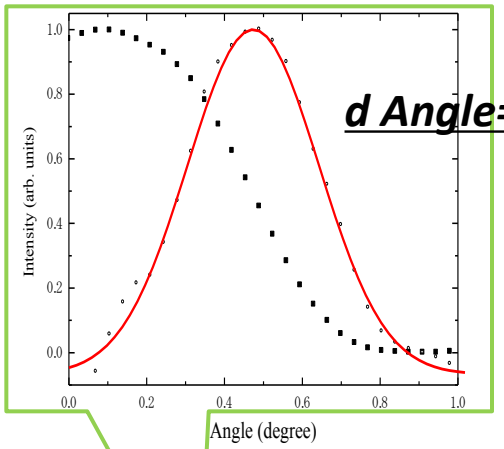
Wide Acceptance Angle Objective Lens

（Evaluation of acceptance angle）

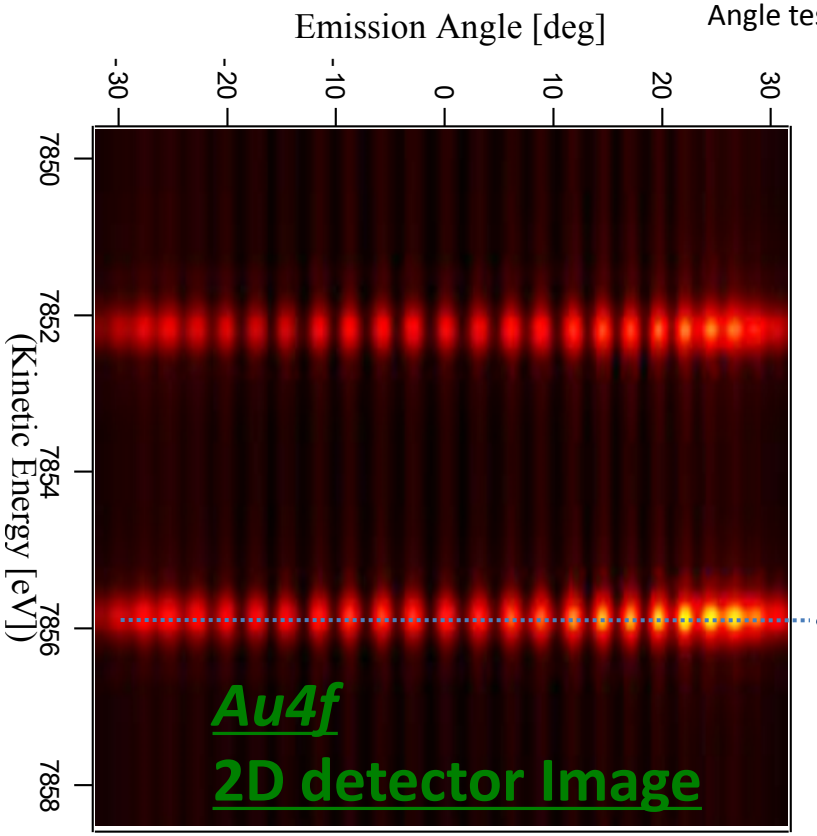
Photon Energy=7.94keV
PE=200eV, C0.5
TOA85deg, Lens mode: Angular

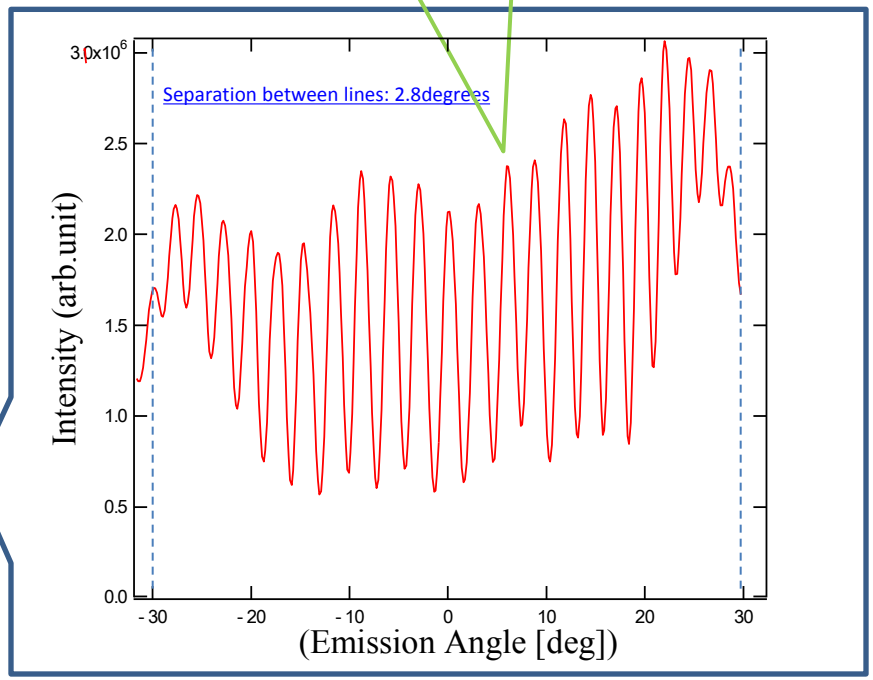


Angle test device(VG SCIENTA)



d Angle=0.34(deg)

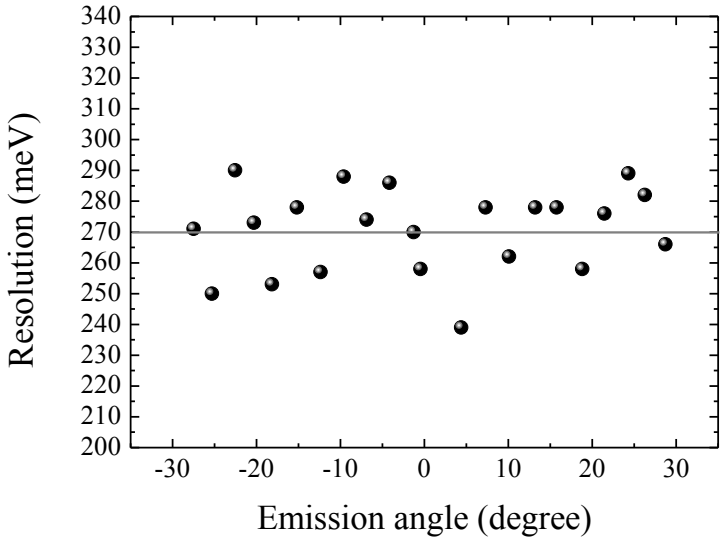




Total Acceptance angle ±30 degrees

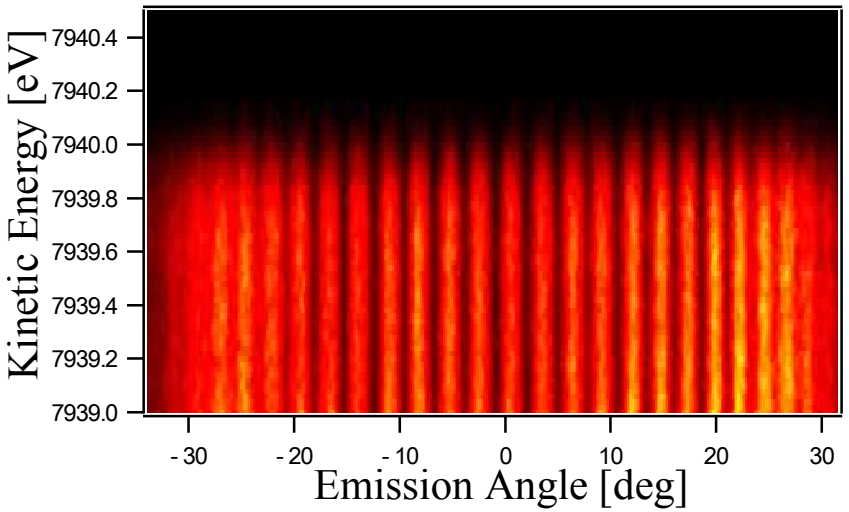
Wide Acceptance Angle Objective Lens

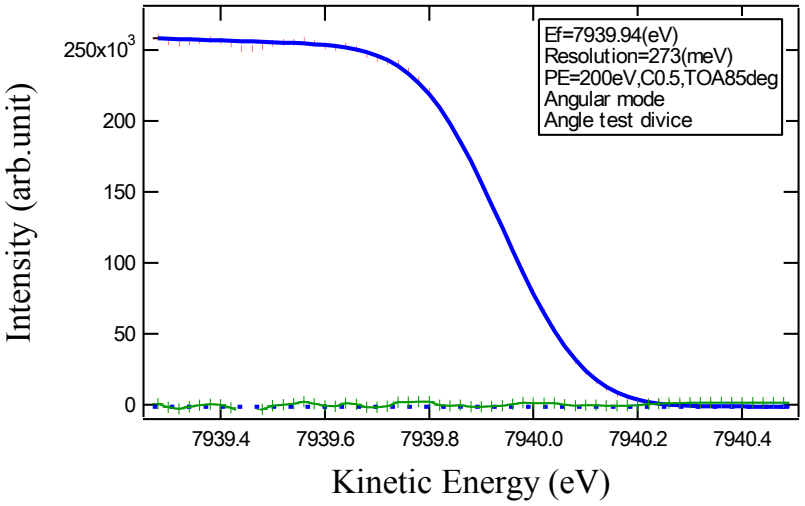
（Evaluation of Energy Resolution - aberration）



270±20 （meV)

Fermi edge of Au





Total Resolution=275meV

Aberration due to the bend of shape mesh in lens

Decrease of energy resolution

Decrease of energy resolution with objective lens is suppressed within 20 meV !

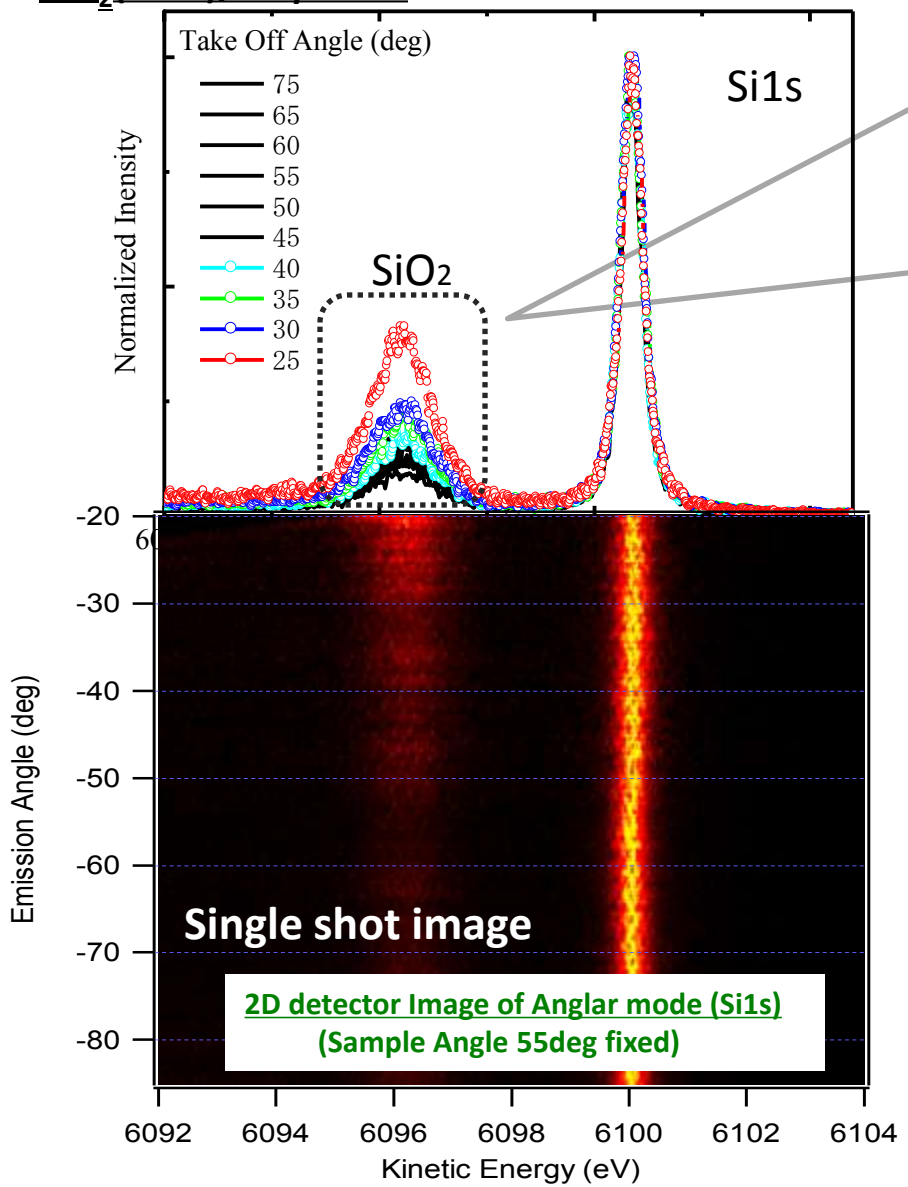
Wide Acceptance Angle Objective Lens

(Evaluation of Depth Probing)

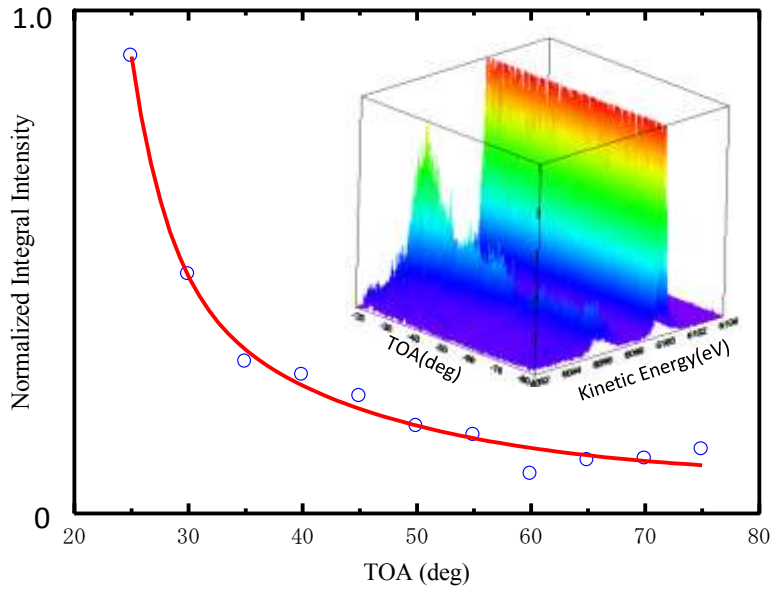
SiO_2(4nm)/Si *spectra*

depth probing in Si 1s spectra of 4nm SiO layer on Si substrate.
Normalized by substrate Si1s intensity

Photon Energy=7.94KeV
Pass Energy=200eV
Slit:=C 0.5



TOA Dependence of Si Oxide



Oxide component increases with decreasing TOA

Wide Depth profiles can be acquired at once without changing the angle of the sample!

- **Wide Depth Profiles -single shot image**
- **Efficiency 30times↑**
- **10 min acquisition**

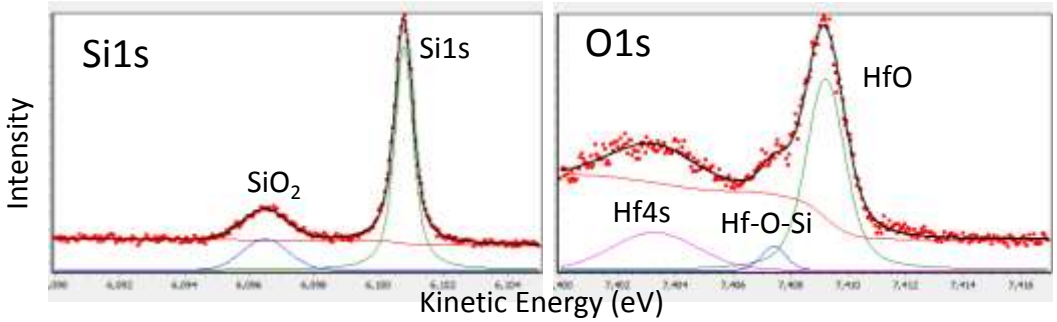
NIM in Physics Research A 601 (2009)

Wide Acceptance Angle Objective Lens

Photon Energy=7.94KeV
Pass Energy=200eV
Slit:=C 0.5

（quantitative analysis of thickness）

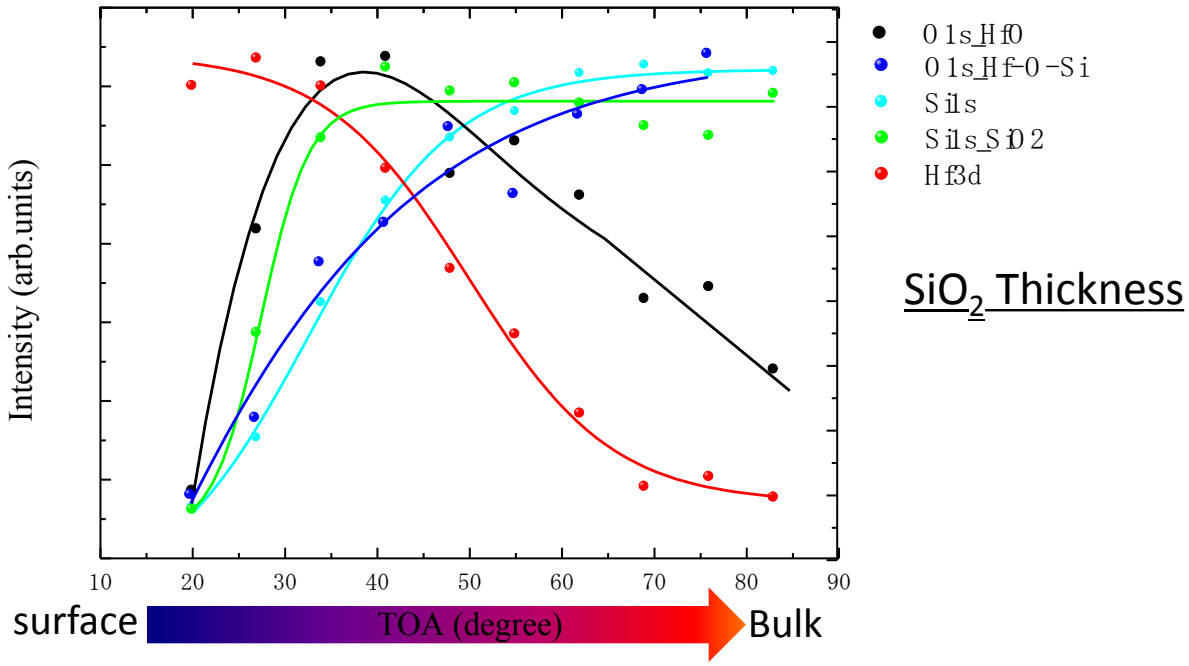
HfO_2(4nm)/SiO_2(1nm)/Si　（The SiO 1nm thickness has been inspected by RBS）



$$d = \sin\theta \ln\left(\frac{Ns\lambda sIf}{Nf\lambda fIs} + 1\right)$$

Atomic density	N/cm^3
$Si(N_s)$	5E+22
$SiO_2(N_f)$	2.27E+22
The attenuation length ※TPP2M Formula	(nm)
$Si(\lambda_s)$	6.4
$SiO_2(\lambda_f)$	9

Angle dependence of each components



SiO_2 Thickness

Thickness	Angle	
d(nm)	θ	If:SiO2/Is:Si
1.092	83	0.0831
0.996	76	0.0772
0.941	69	0.0757
0.941	62	0.0802
0.969	55	0.0897
0.925	48	0.0947
0.991	41	0.1166
1.037	34	0.1461
1.125	27	0.2024
1.021	20	0.2512

This is well consistent with the thickness result of RBS.

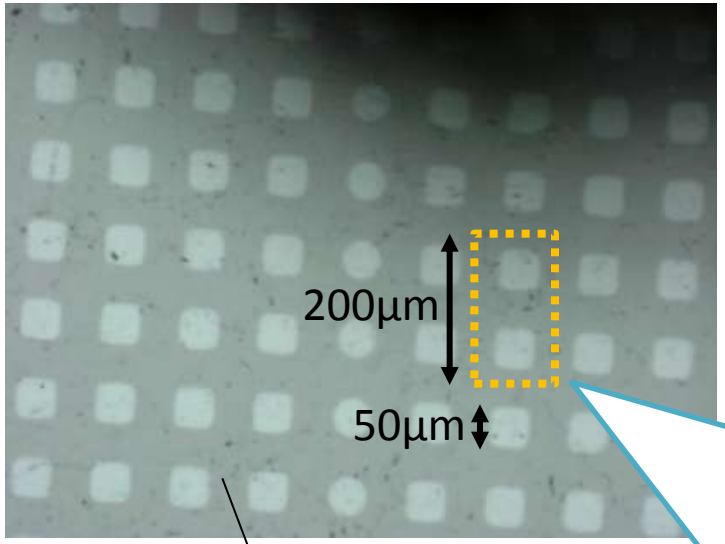
Average Thickness：1.004nm

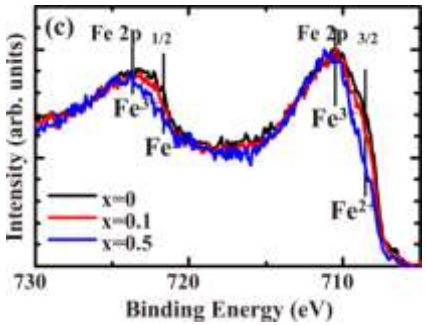
Combination of K-B mirror and Objective Lens

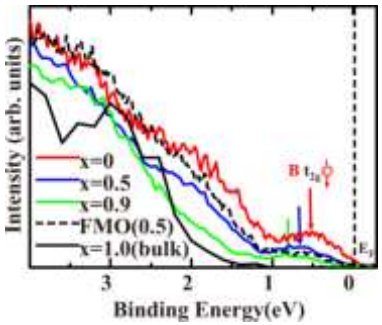
(sample scanning -2D mapping)

Photon Energy=7.94KeV
Pass Energy=200eV
Slit:=C 0.5

$(Fe_{2.5}Mn_{0.5})O_4$ dot 50×50μm thickness : 20nm)







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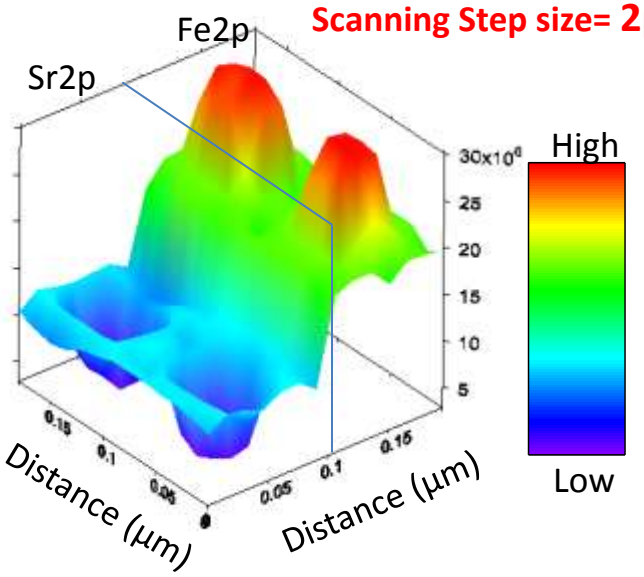
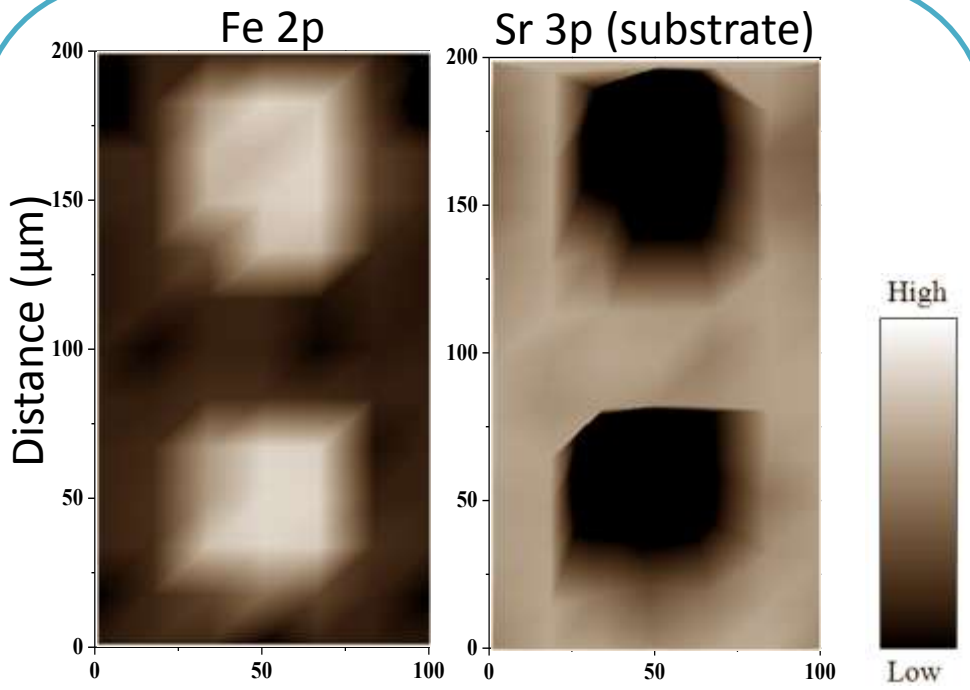
Scanning Step size= 2μm





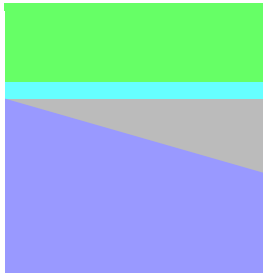
reversal distribution of the chemical states

Micro dot is well resolved by using beam size of 1 μm.

Combination of K-B mirror and Objective Lens

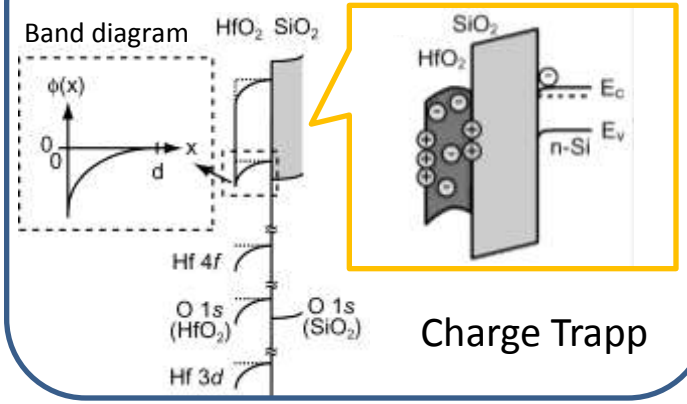
Ir(8nm)/HfO_2(2.2nm)/SiO_2 (0-10 nm)/Si(100)

[4mm] ← [0mm] Scanning 200μm step



Ir(8nm)
HfO_2(2.2nm)
SiO_2(0-10nm)
thickness-graded
Si(100)

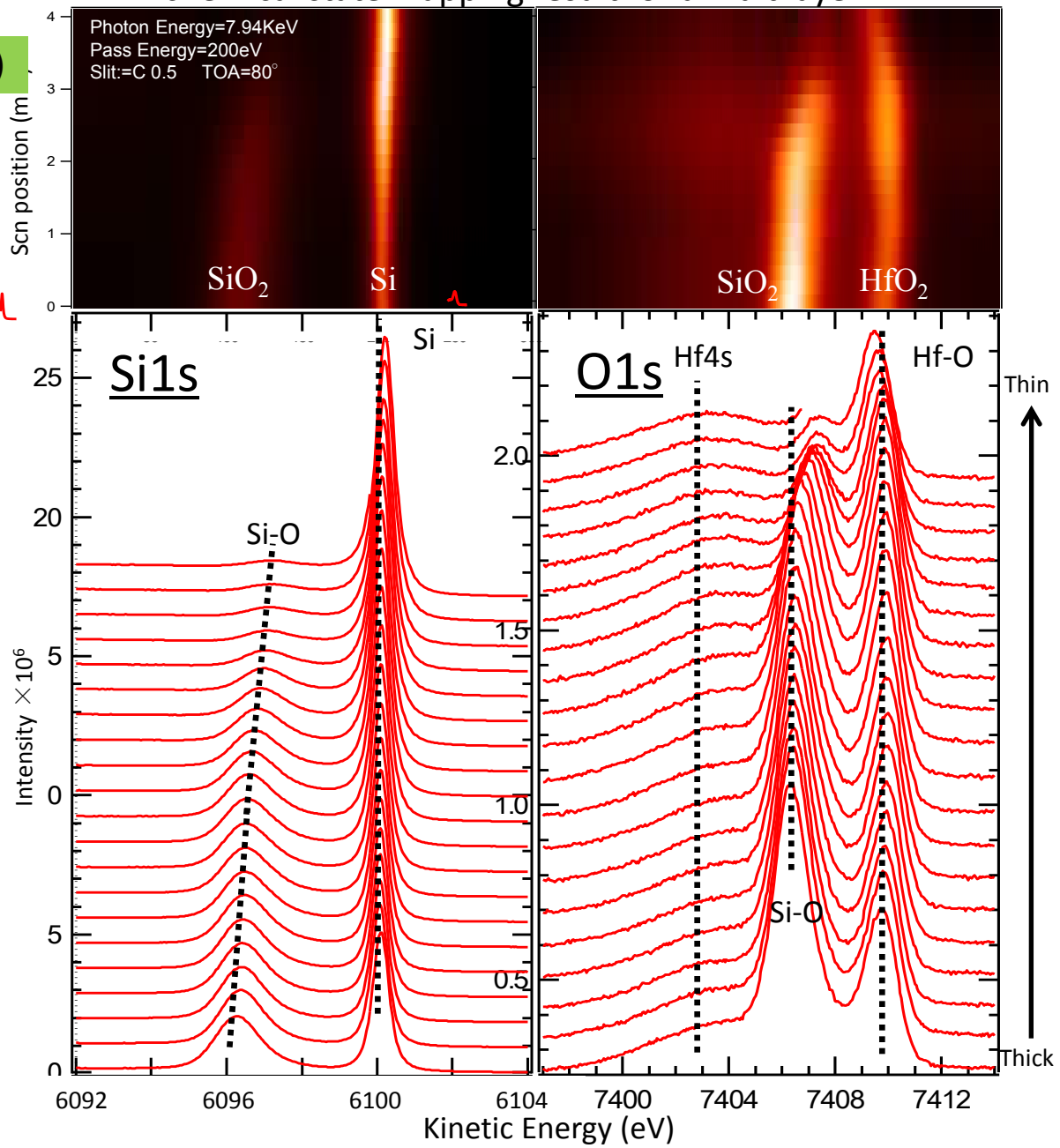
Band Bending in thickness dependence



Charge Trapp

These results indicate the band bending in thickness dependence caused by charge trap of interlayer

chemical state mapping result for a multilayer film

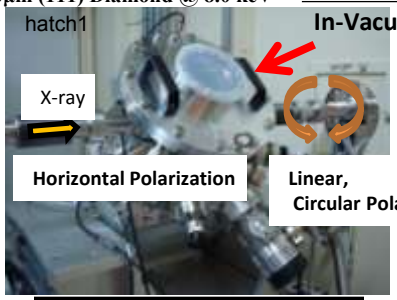


These development was supported by DG-JST.
Project Leader: Prof. C. Felser

MCD-HAXPES for Spintronics

200μm (111) Diamond @ 8.0 keV

Phase Retarder
In-Vacuum



- Pc > 0.95
- Plin > 0.90
- Rapid helicity reversal

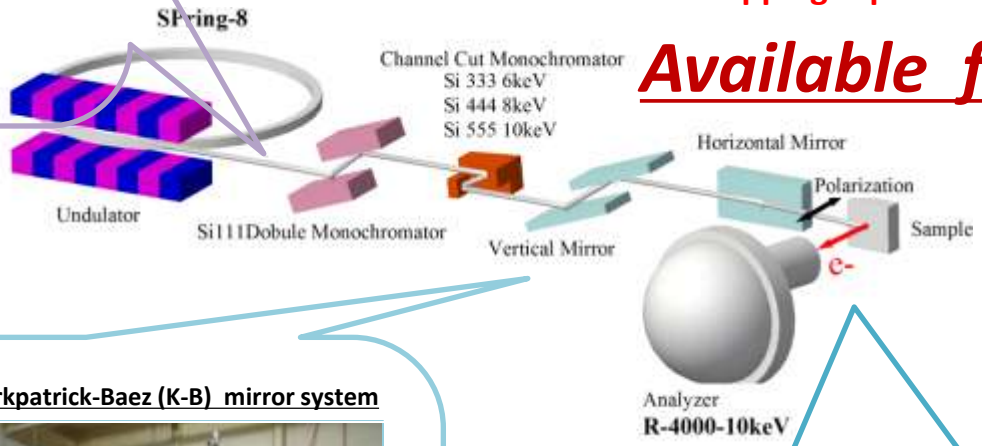
Summary

(1) Objective Lens
- Total Acceptance angle = ±30 degrees

(2) K-B mirror
- Beam Size = Φ1μm

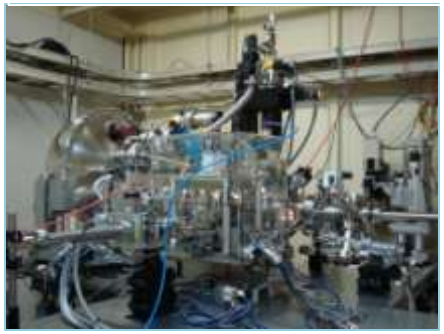
(3) Combination
- Chemical states mapping is possible!

Available for all users !!



Focusing optics

Kirkpatrick-Baez (K-B) mirror system

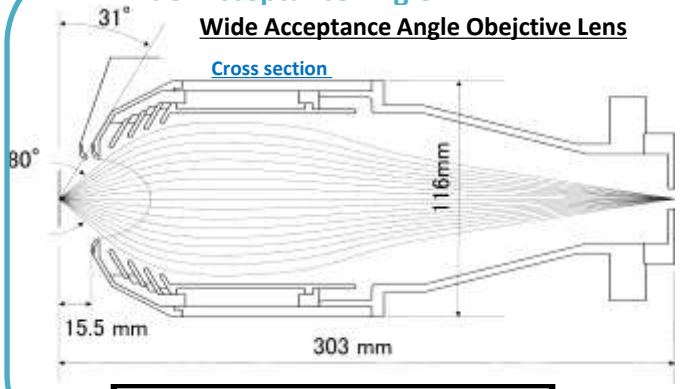


- Focusing size: φ1μm

These development was supported by SENTAN, JST.
Project Leader: Prof. K. Kobayashi.

Wide Acceptance Angle

Wide Acceptance Angle Obejctive Lens



- Acceptance Angle: ±30° ←±7°

Thank you for attention !