Surface and Interface Studies at Photon Factory

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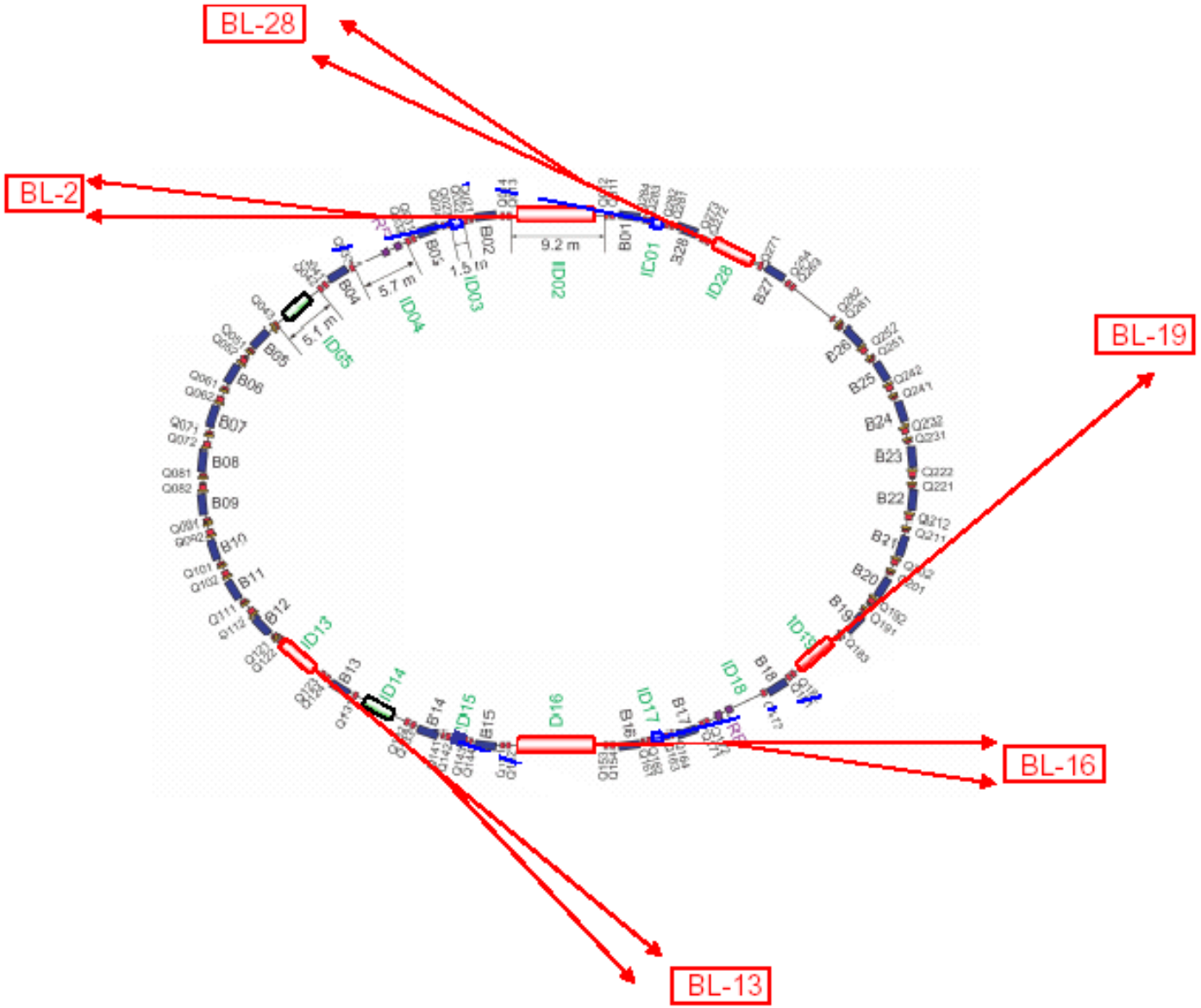
PF & CMRC, IMSS, KEK

1. Depth-resolved X-ray absorption spectroscopy of magnetic thin films
2. Real-time observation of surface chemical reaction
3. Future prospects

Soft X-ray Undulator Beamlines at Photon Factory



A soft X-ray beamline BL-16A

Light Source: Twin APPLE II Undulators with Kicker Magnets

Variable Polarization: Circular and Linear (Horizontal/Vertical) Polarization

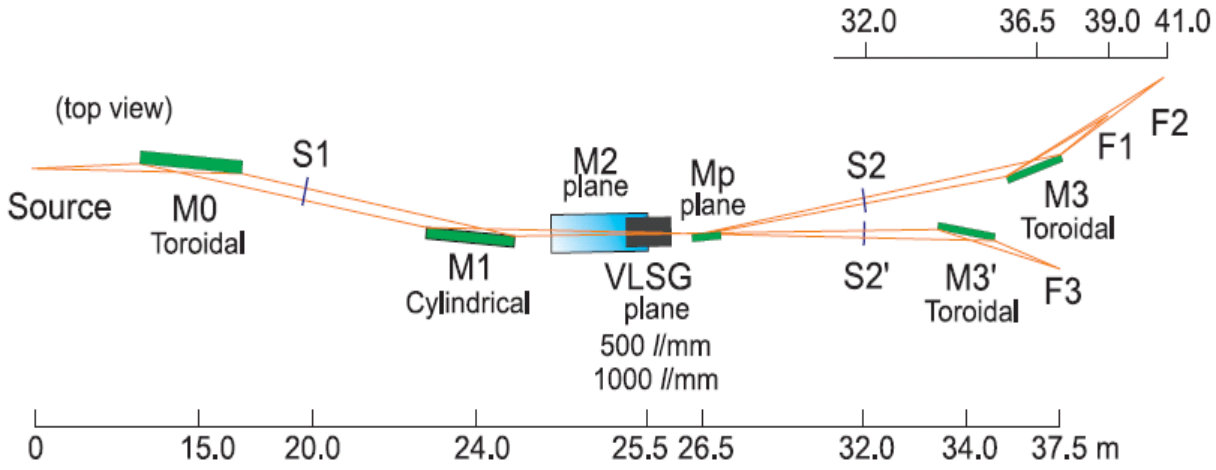
Fast Polarization Switching (~10 Hz)

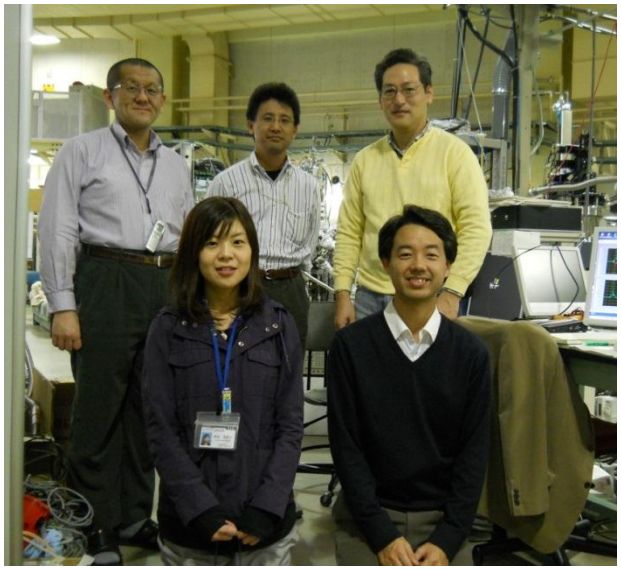
1st Undulator: Mar-Apr 2008, 2nd Undulator: 2010 Summer

Monochromator: Variable-Included-Angle Varied-Line-Spacing Grating

200-1500 eV (3d Transition Metals, Light Elements, and Rare-earth Elements)

Installation: 2007 Summer, Commissioning: Oct 2007-





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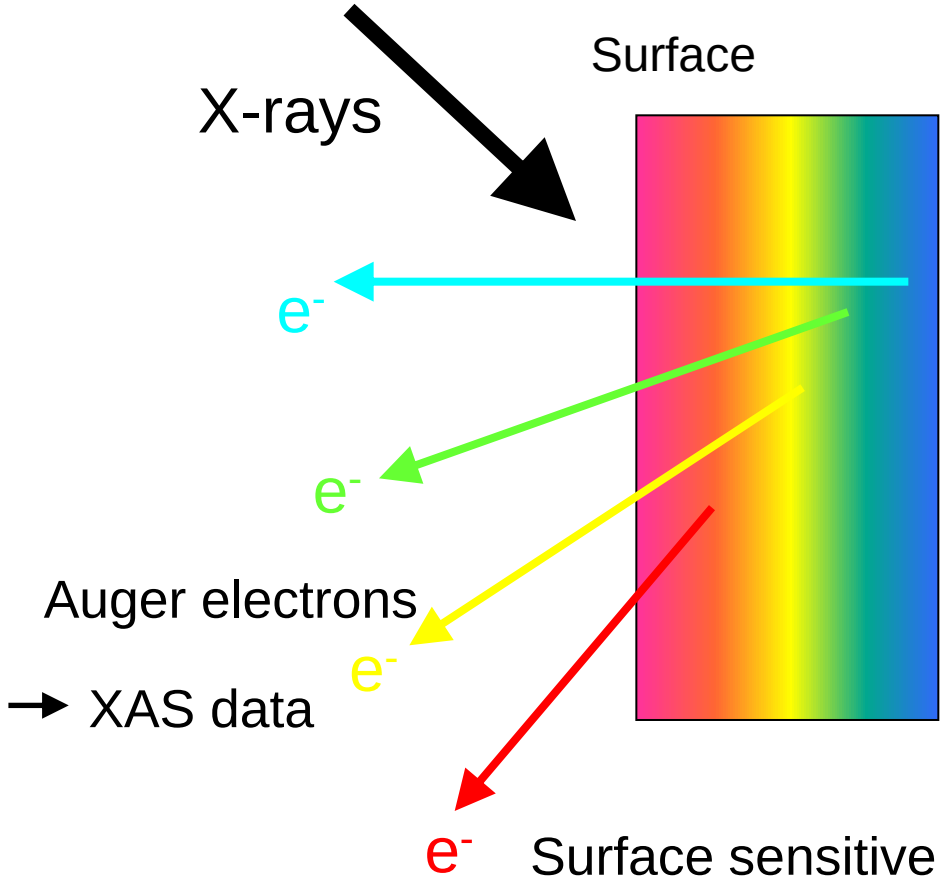
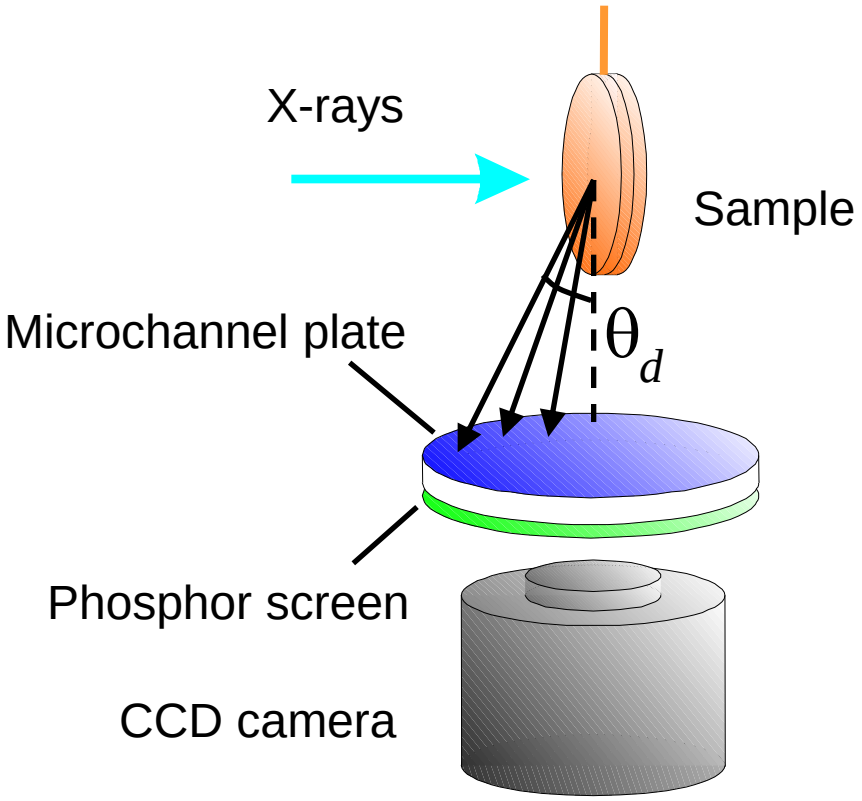
Principle of Depth-resolved XAS





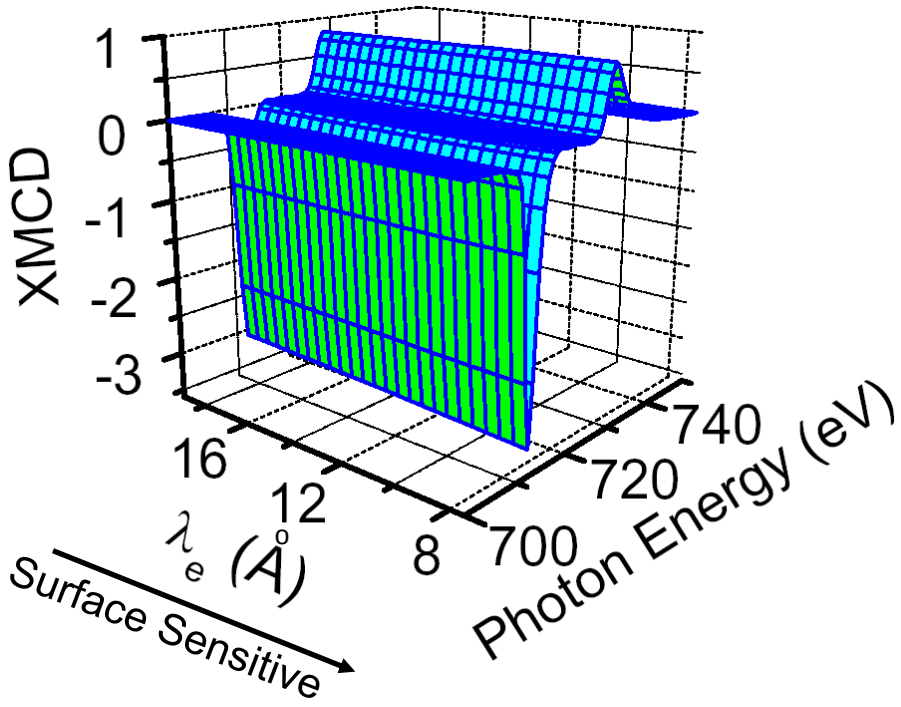
Electron yield XAS measurements at different detection angles

→ A set of XAS data with different probing depths

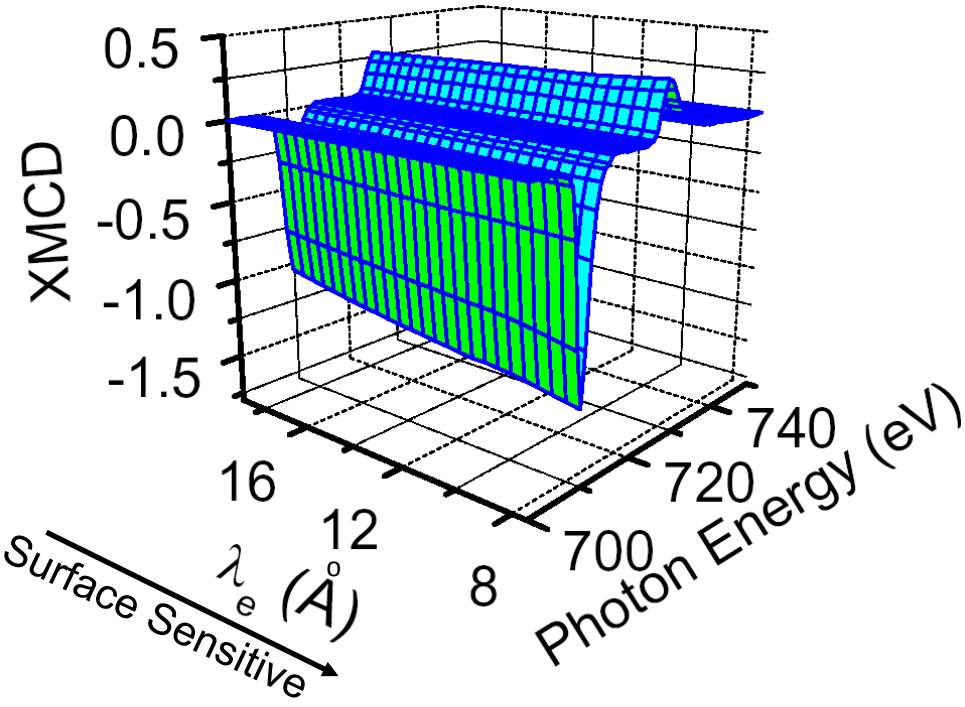
Feasibility Study: Depth-resolved XMCD of Fe/Cu(100)

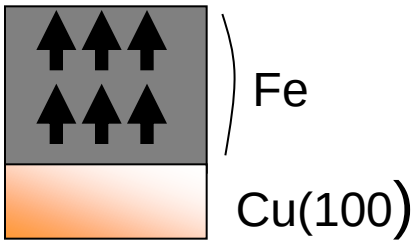
Amemiya et al., Appl. Phys. Lett. 84 (2004) 936. Normal Incidence, 130 K

3 ML Fe

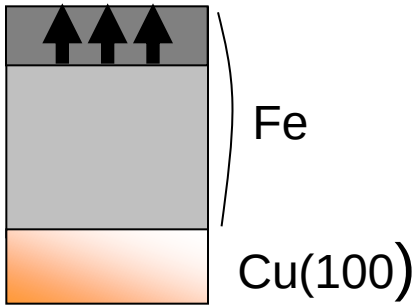


7 ML Fe





Uniform Magnetization

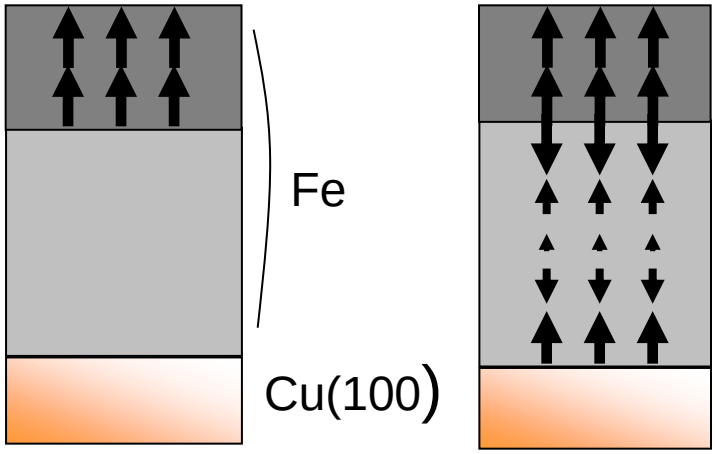


Surface Magnetization

Fe/Cu(100)

>200 K

<200 K

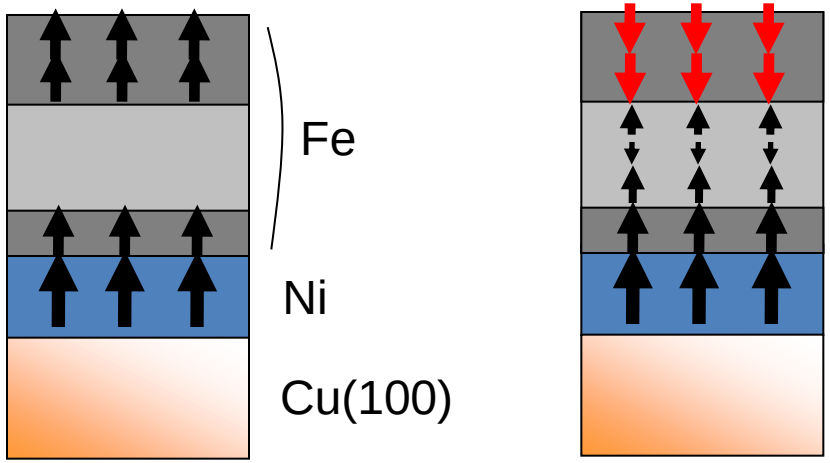


Surface (FM)

Inner layers (AFM or SDW)

No (little) magnetic interaction between Cu and interface (bottom) Fe

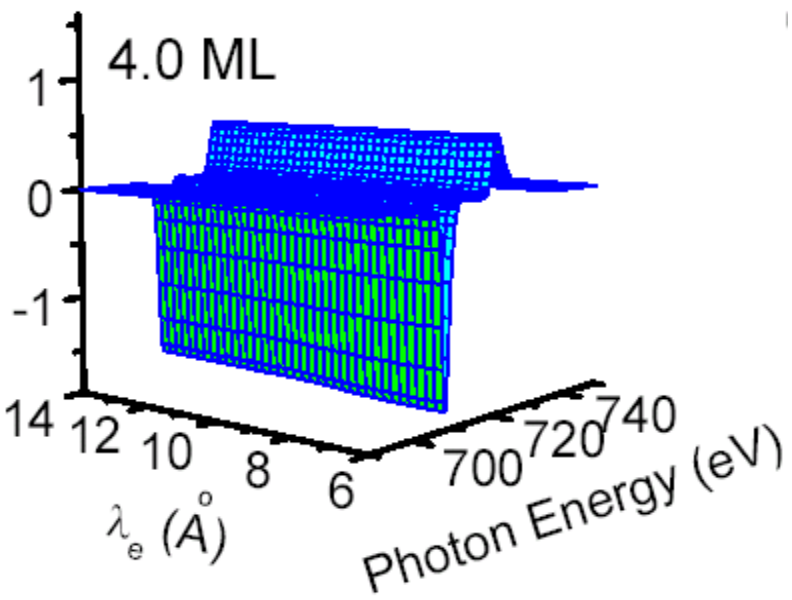
Fe/Ni/Cu(100)

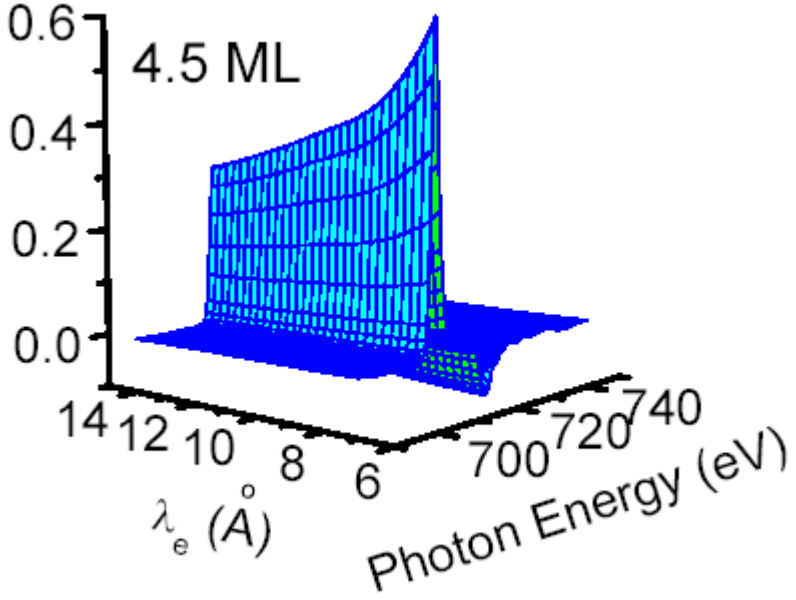


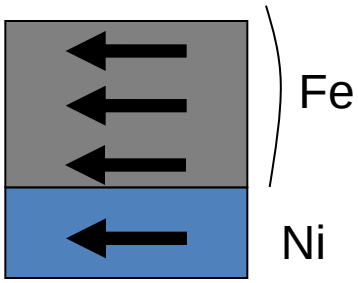
Any magnetic interaction among surface, inner layers and interface ?

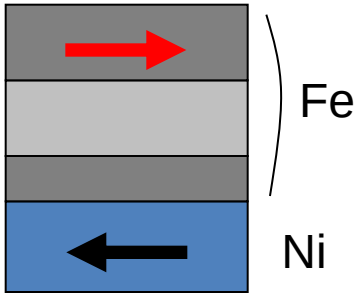
Fe(x ML)/Ni(6 ML)/Cu(100)

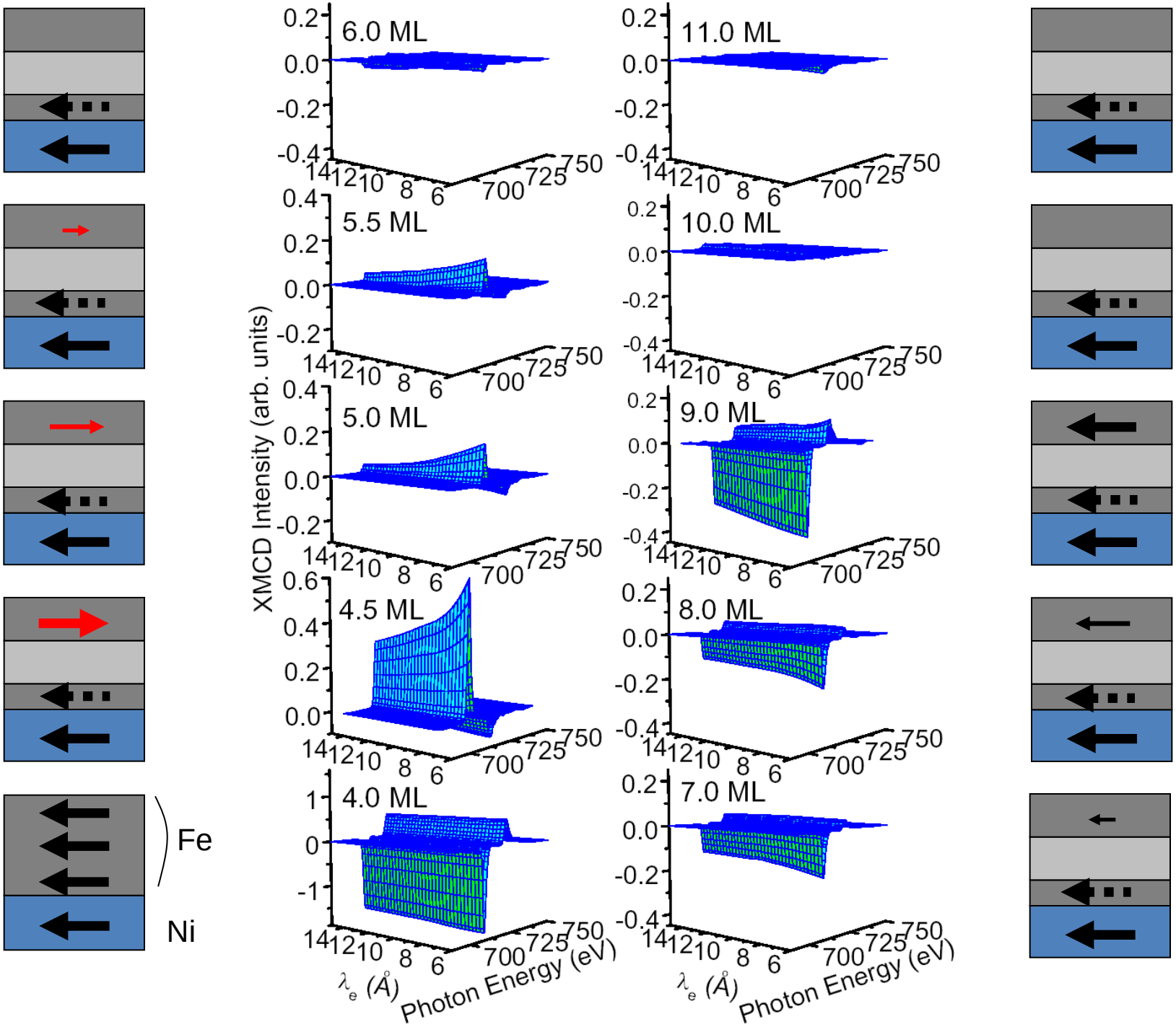
Fe L-edge Depth-resolved XMCD
Grazing Incidence (200 K)



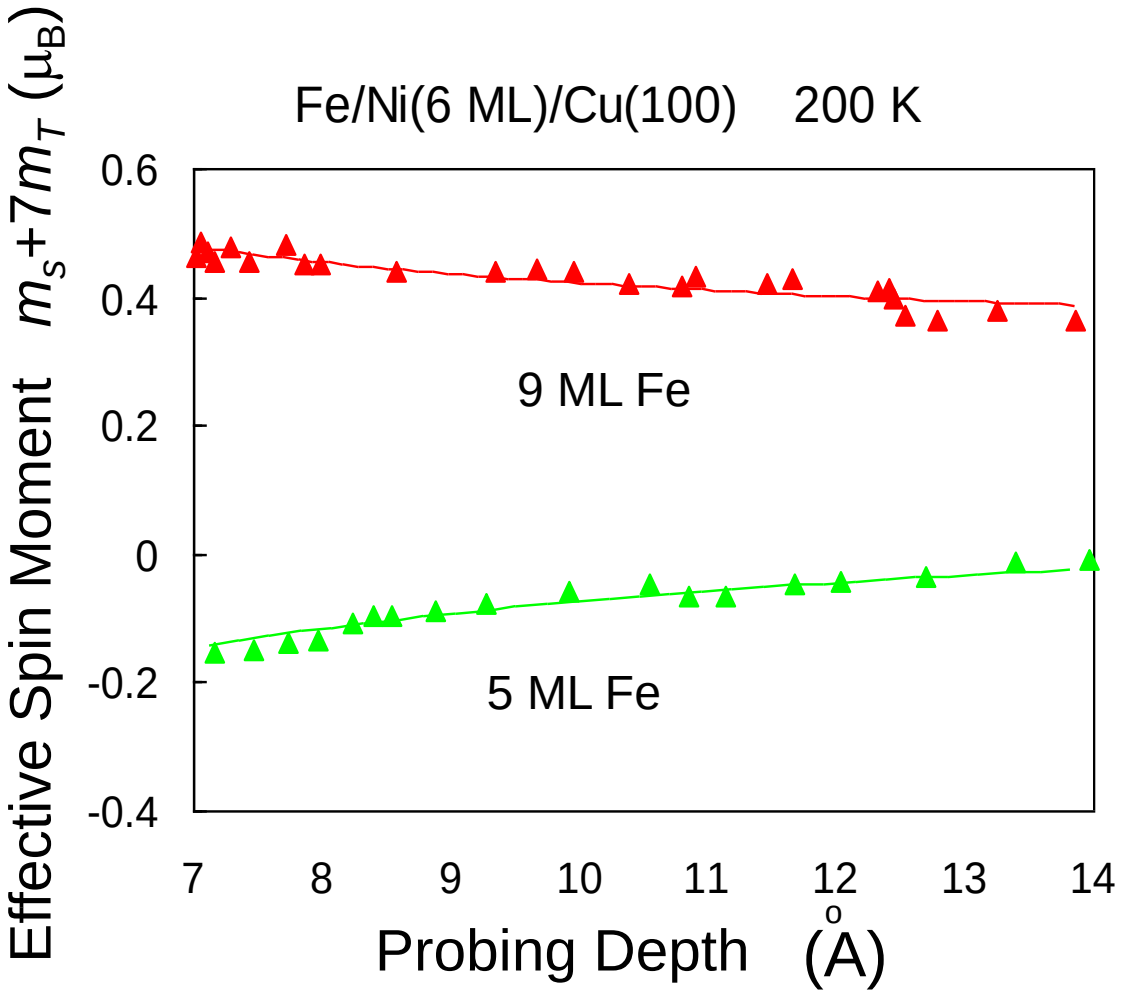


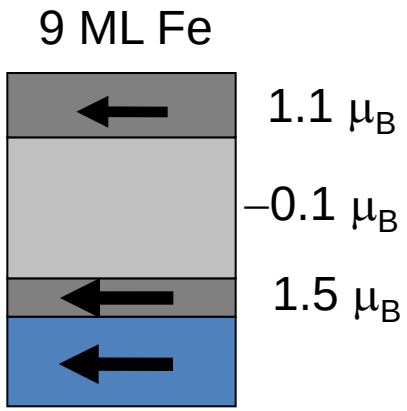


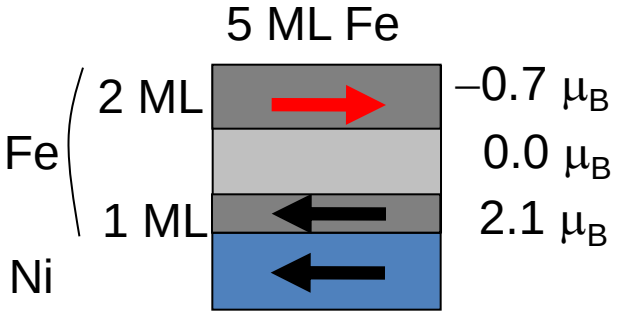



6.0 ML
11.0 ML
5.5 ML
10.0 ML
5.0 ML
9.0 ML
4.5 ML
8.0 ML
4.0 ML
7.0 ML
XMCD Intensity (arb. units)
λe (Å)
Photon Energy (eV)
Fe
Ni

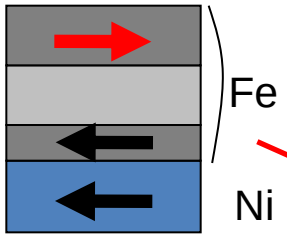
Curve fitting with a three-region model

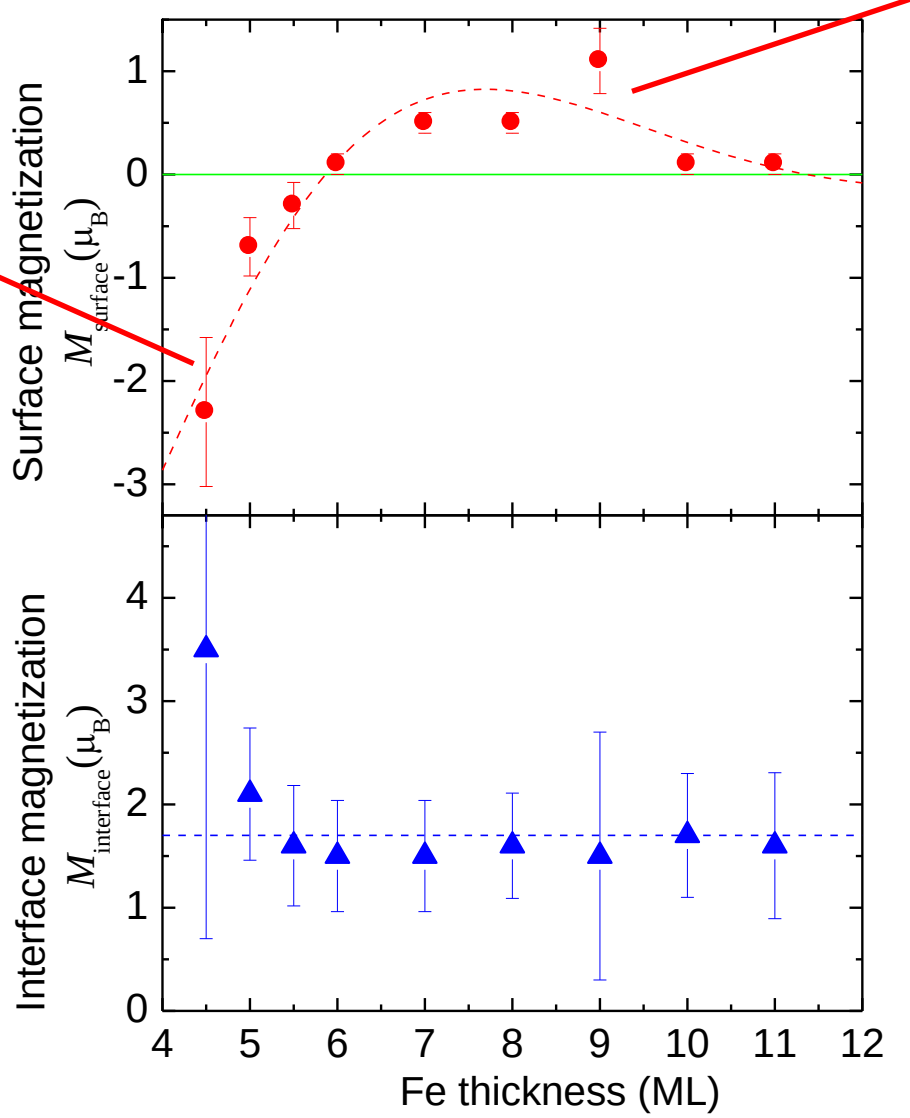


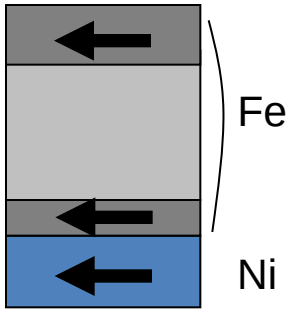




Fe thickness dependence at 200 K







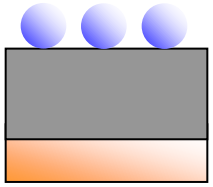
Oscillatory
surface magnetization

Positive
interface magnetization

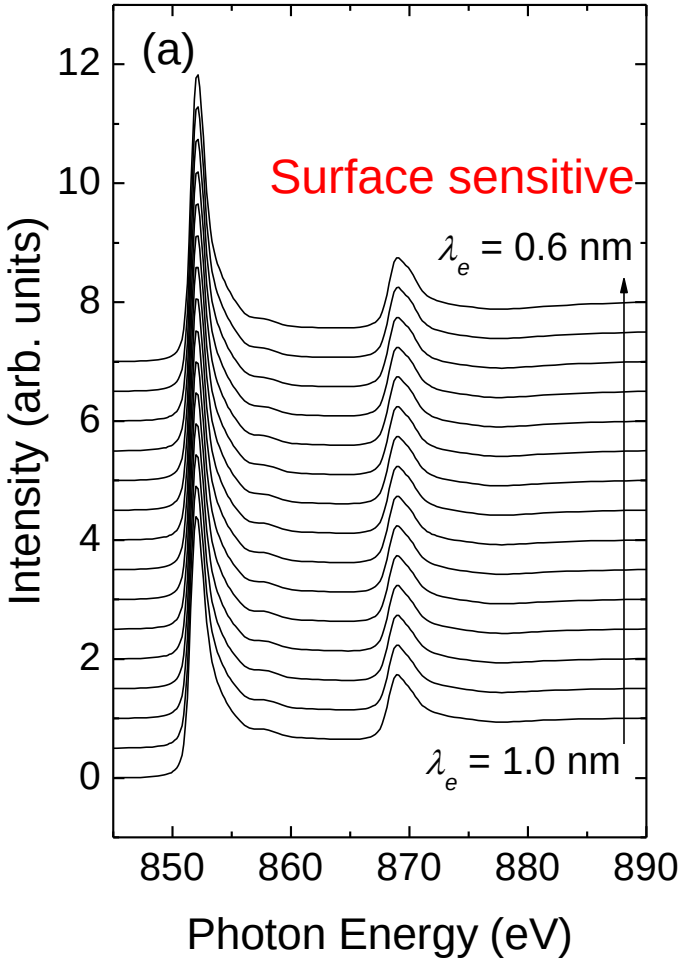
Oscillatory
magnetic coupling
between
surface and interface

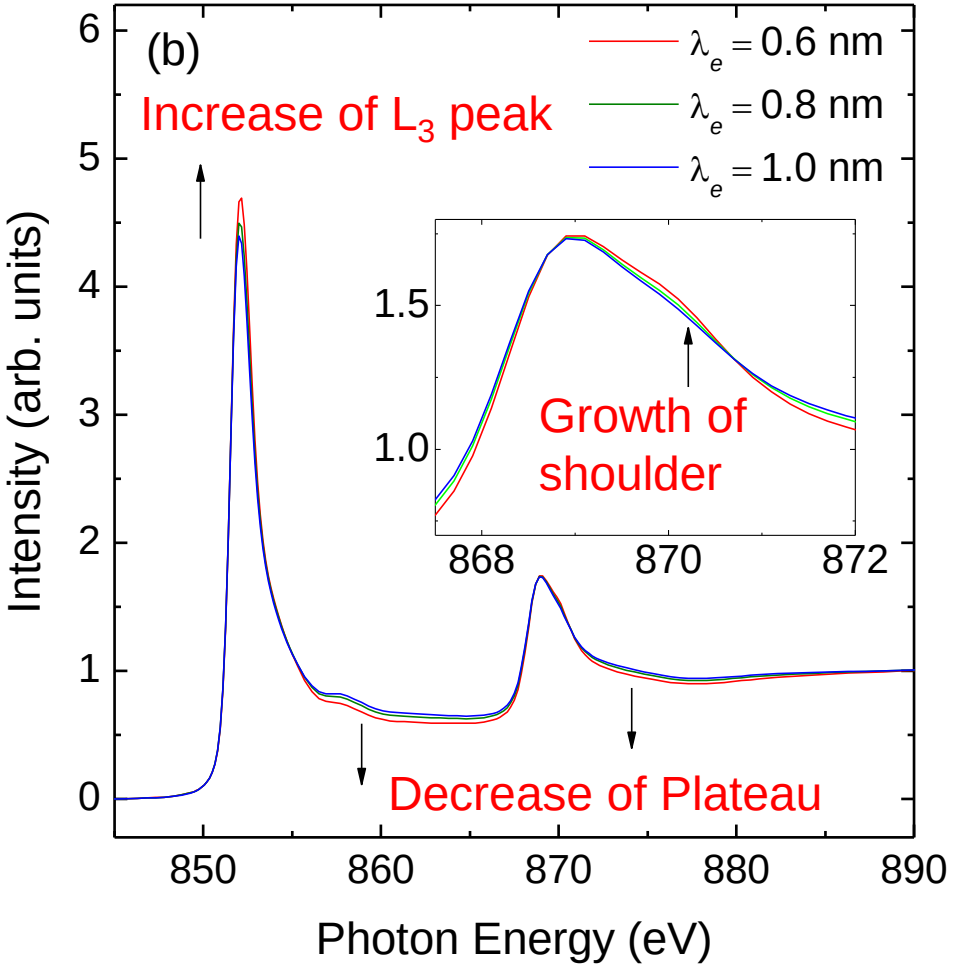
Amemiya et al., Phys. Rev. B 70 (2004) 195405.

Depth-resolved XAS for O/Ni/Cu(100)



O/Ni(5.5 ML)/Cu(001) Ni L-edge XAS (X-ray Absorption Spectrum)

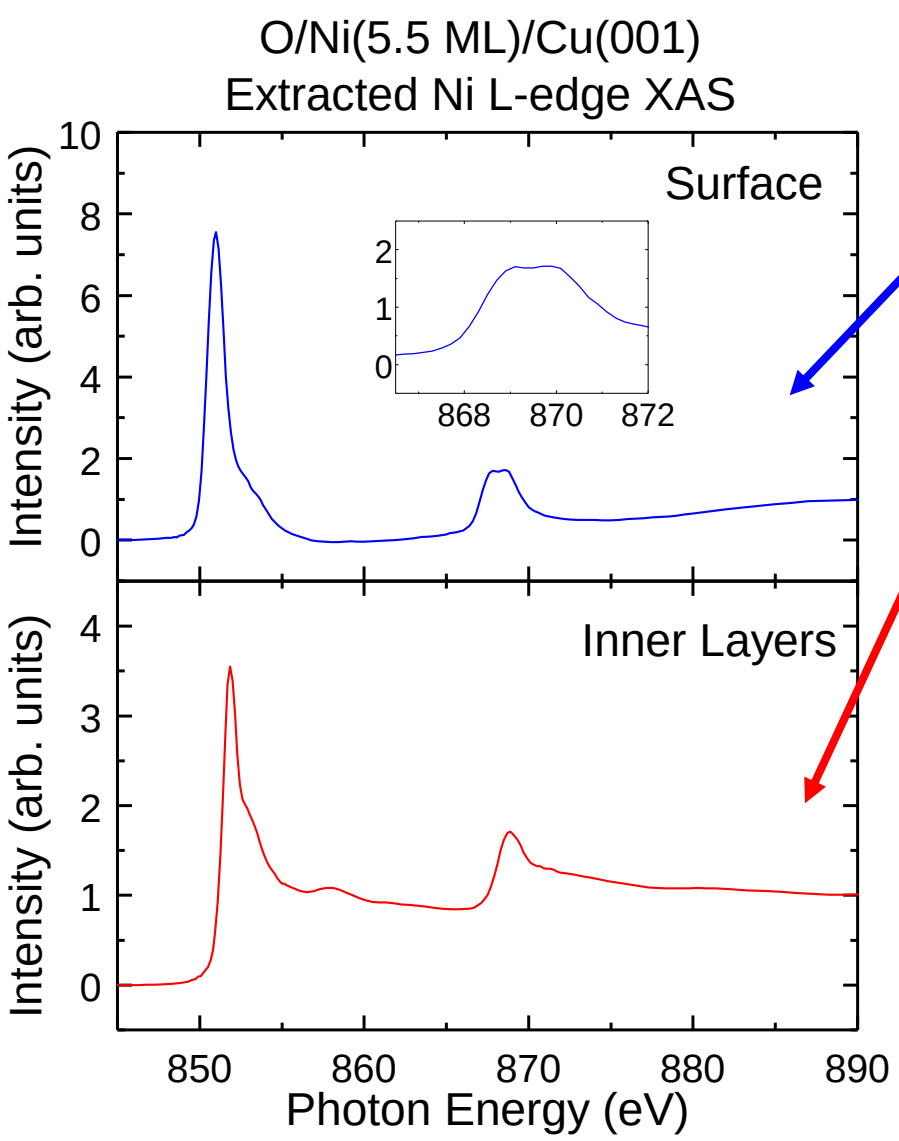


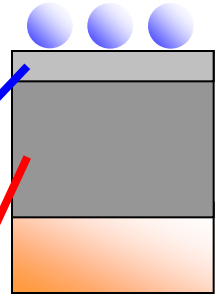


Extracted X-ray absorption Spectra

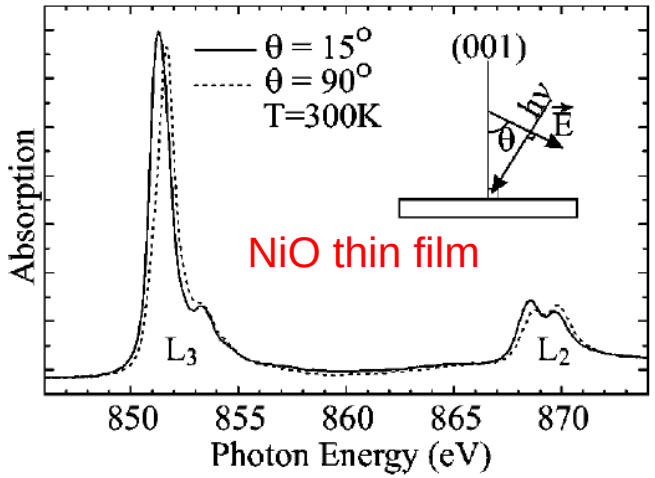
K. Amemiya and M. Sakamaki,

Appl. Phys. Lett. 98 (2011) 012501.



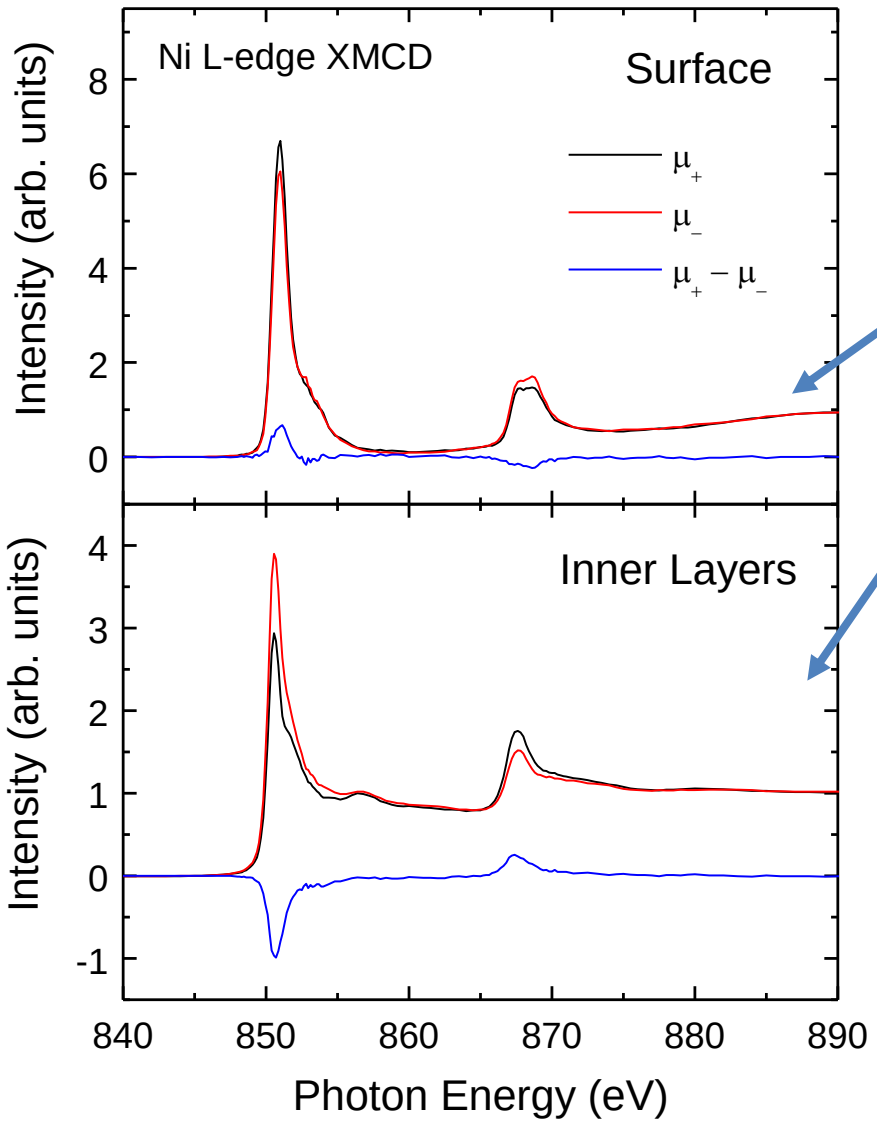


XAS spectra at surface shows NiO-like features



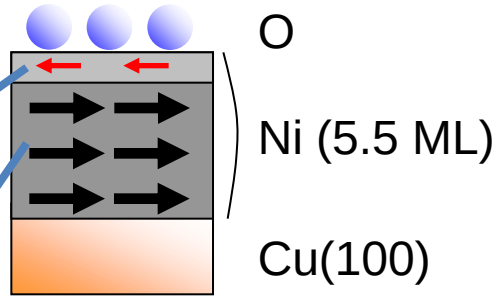
Haverkort et al., Phys. Rev. B 69, 020408(R).

Extracted XMCD spectra



K. Amemiya and M. Sakamaki,

Appl. Phys. Lett. 98 (2011) 012501.



Surface layer shows small negative magnetization.

Uncompensated spin at the interface?

1. Depth-resolved X-ray absorption spectroscopy of magnetic thin films

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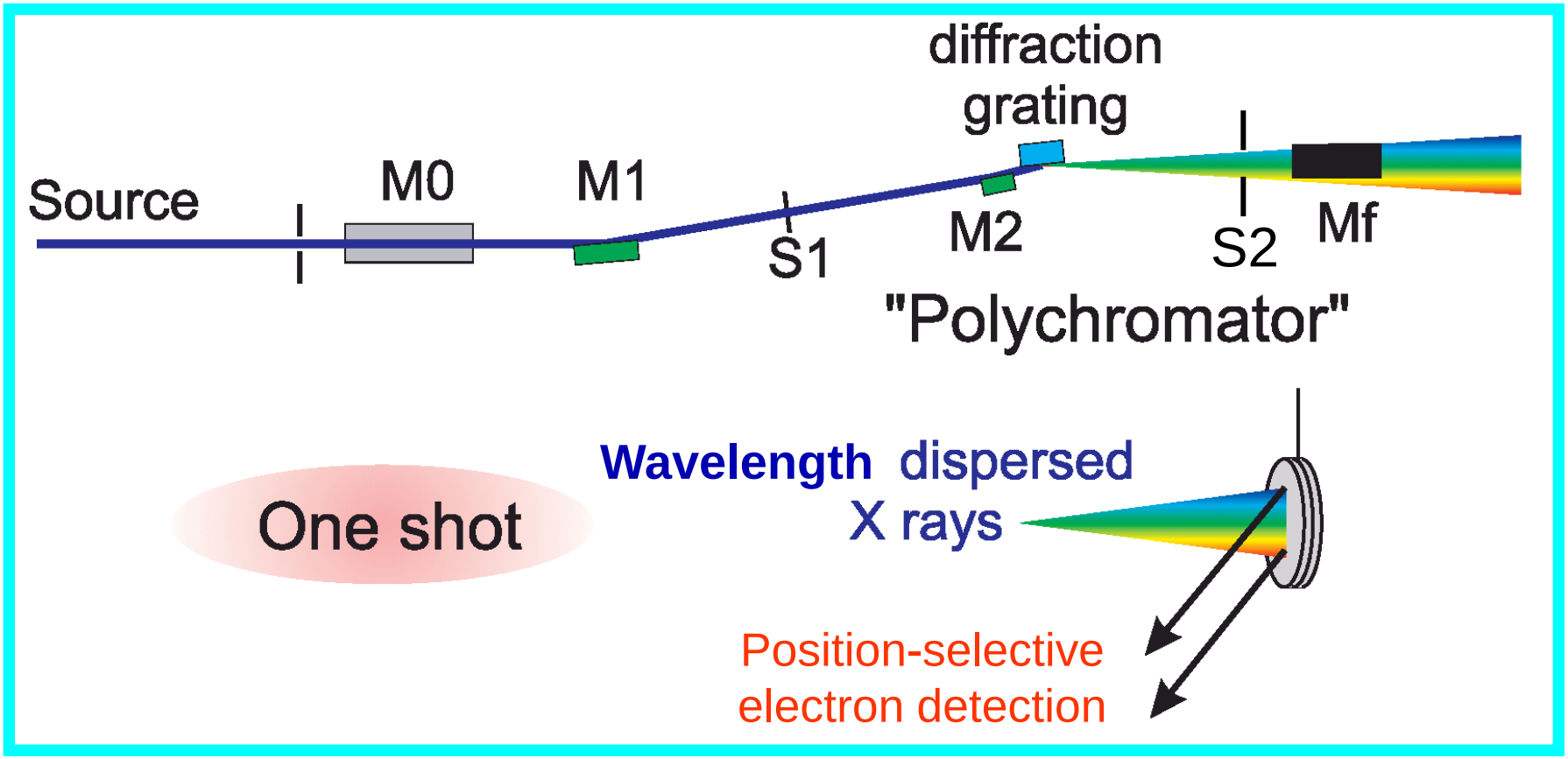
Development of Wavelength-dispersive XAS

XAS: Element selectivity, Chemical species determination, Structural information,…

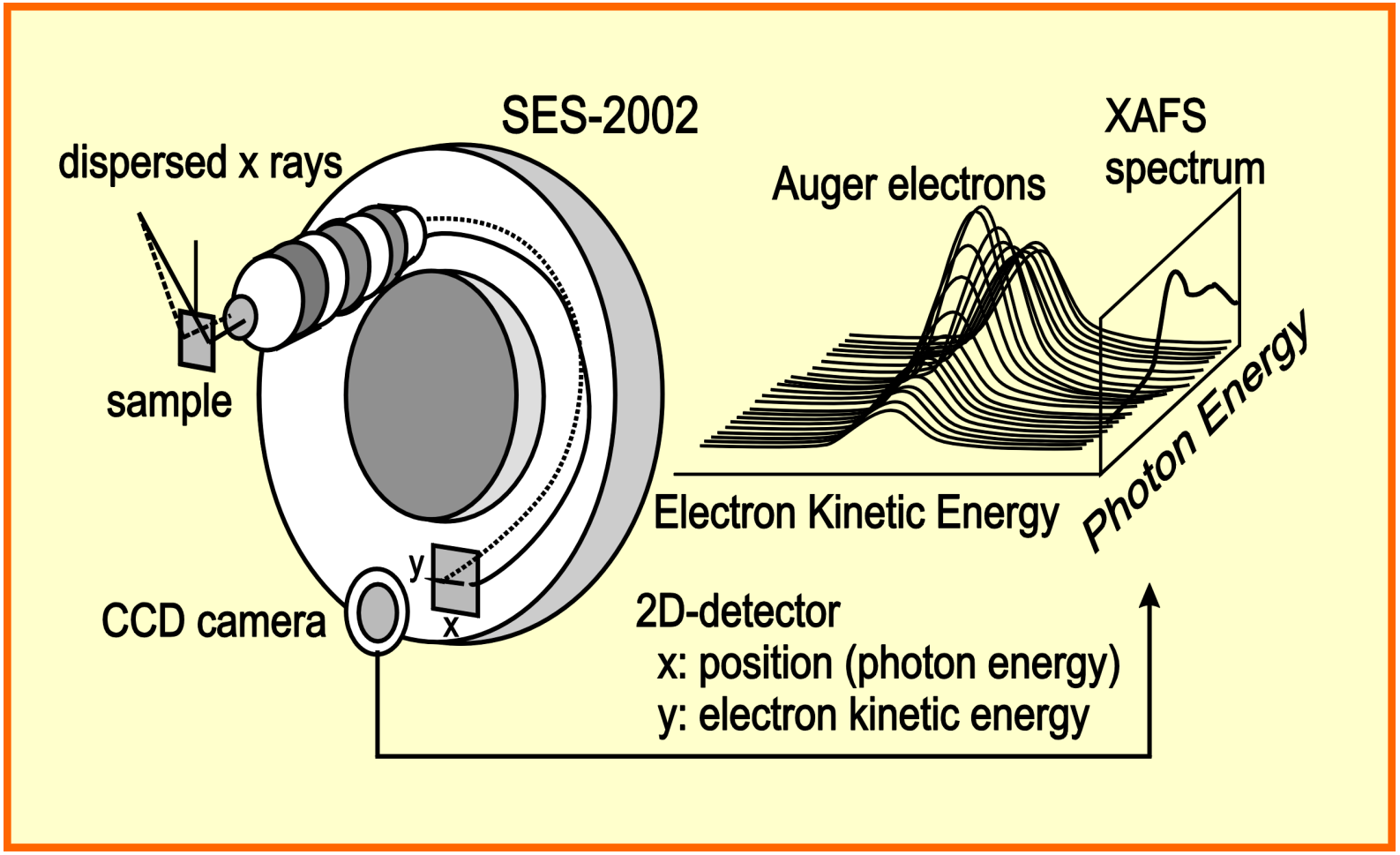
Takes long time (~5 min/spectrum) for a measurement.

"Real-time (without pump-probe)" measurement is necessary.



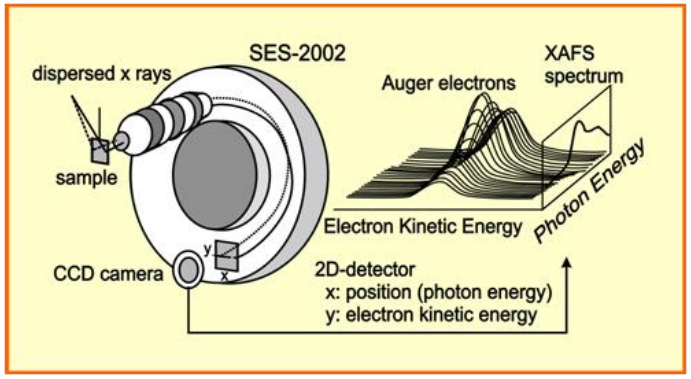
Experimental setup for wavelength-dispersive XAS

- Wavelength-dispersed X rays + Position-sensitive electron detector

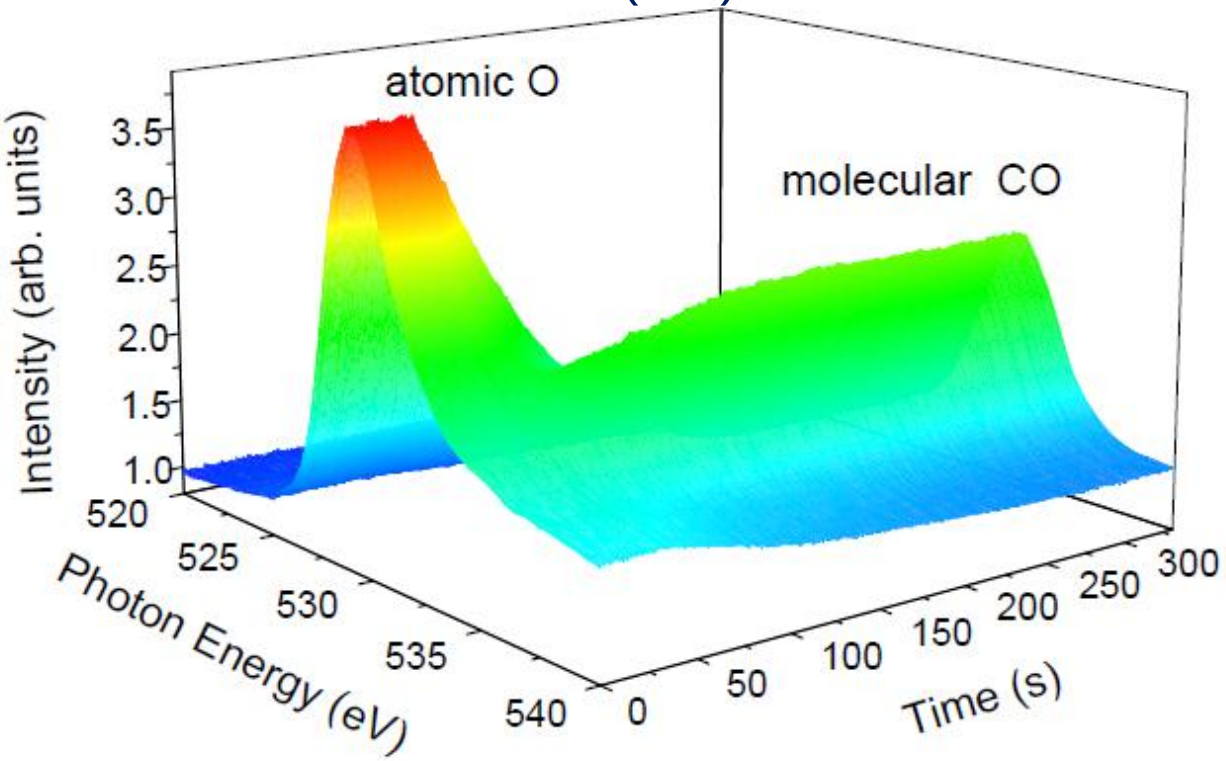


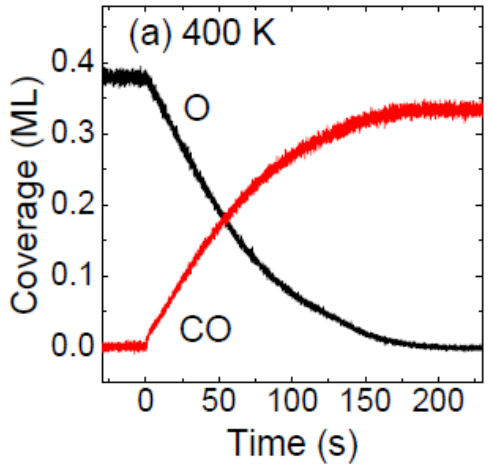
Observation of chemical reaction

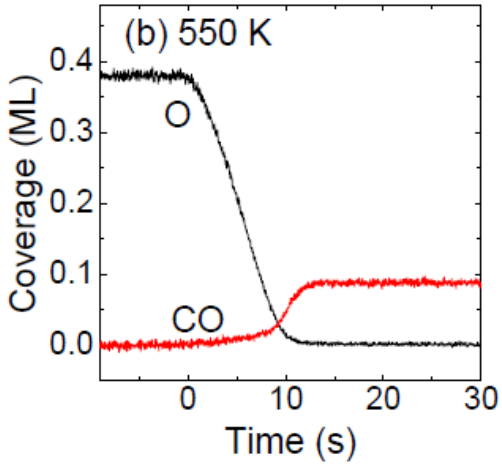
Wavelength-dispersive XAFS:
XAFS spectrum measurement
without monochromator scan



CO + O reaction on Ir(111)



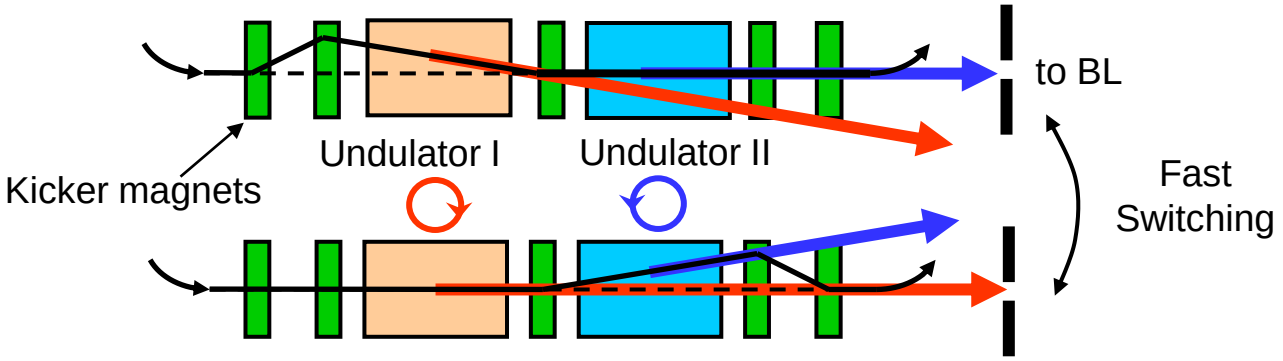




Present time resolution: 33 ms
without pump-probe technique (no repetition)

Amemiya et al., Appl. Phys. Lett. **99** (2011) 074104.

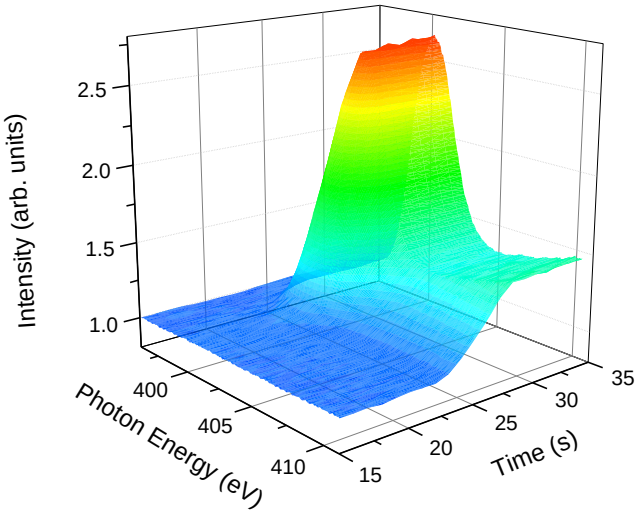
Combination with fast polarization switching



T. Muro et al., AIP Conf. Proc. 705, 1051 (2004); 879, 571 (2007).
T. Muro et al., J. Electron Spectrosc. Relat. Phenom. 144-147, 1101 (2005).

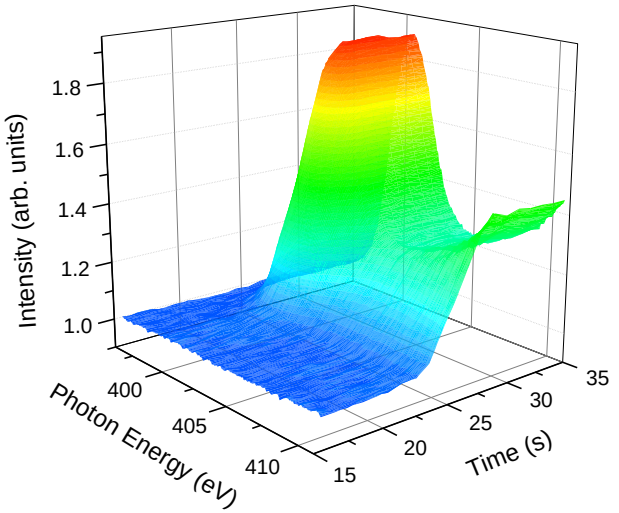
Determination of molecular orientation by polarization dependence

Vertical Polarization



1 Hz switching

Horizontal Polarization



Real-time observation of molecular orientation

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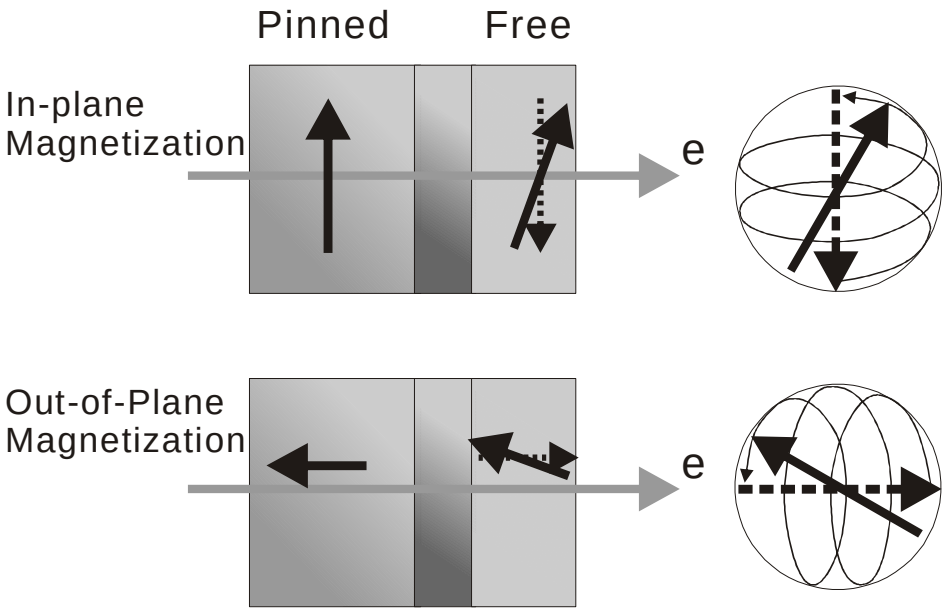
2. Real-time observation of surface chemical reaction

3. Future prospects

Spin dynamics of magnetic thin films



Magnetic Random Access Memory (MRAM)

Spin switching by <u>electric current</u>:

Spin precession

Time scale (at present): ~ ns

Observation and control of spin dynamics especially at the interface

-> Time & depth-resolved XMCD

Faster spin switching with lower current

$$\frac{d\vec{M}_2}{dt} = \gamma \vec{M}_2 \times \vec{H} + \vec{m}_2 \times \alpha \frac{d\vec{M}_2}{dt} + I\beta_{ST}\vec{m}_2 \times (\vec{m}_1 \times \vec{m}_2).$$

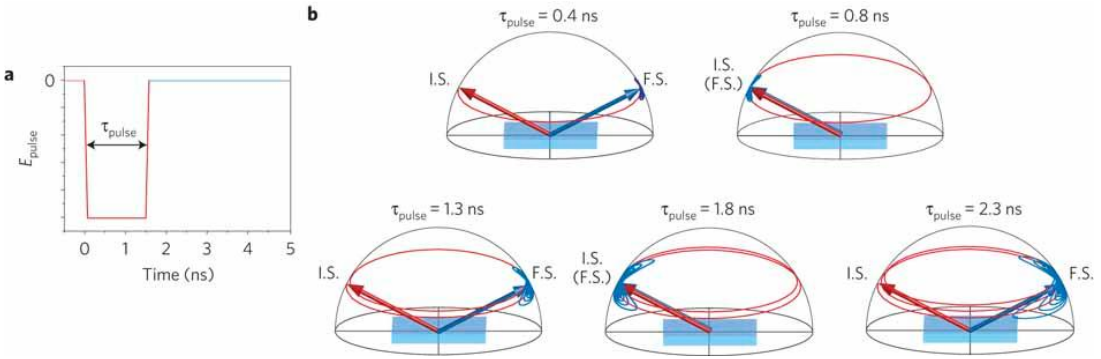
In future:

Spin switching by <u>electric field</u>

-> faster switching

lower energy consumption

First demonstration: ~0.4 ns



Y. Shiota et al., Nature Materials 11 (2012) 39.