Possibility of Magnetic Imaging Using Photoelectron Emission Microscopy with Ultraviolet Lights

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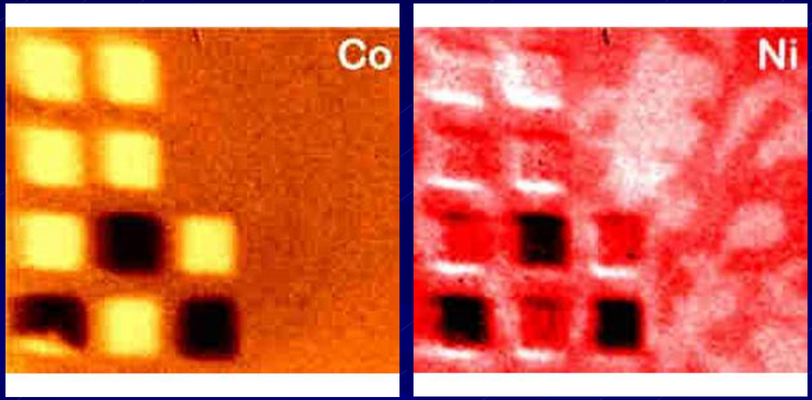
XMCD PEEM and UV MLD/MCD PEEM

XMCD PEEM

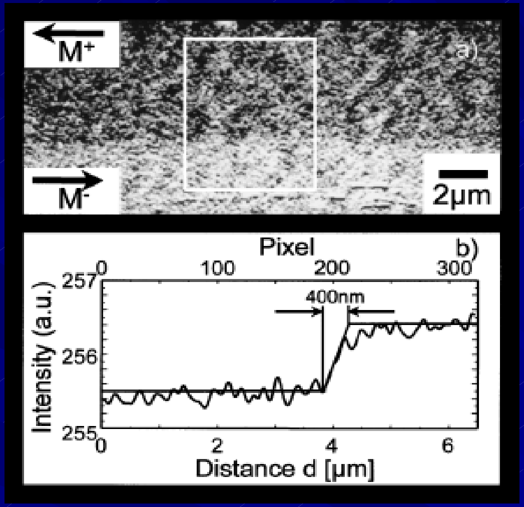


Ni(8ML)/Co(15ML)/Cu(001)

Omicron HP http://www.omicron.de/index2.html
C. M. Schneider *et al*.

- Strong MCD >10%
  due to large LS coupling in the core shell
- Easily applicable to ultrathin film
- Need Third Generation Synchrotron Light Sources
- Time resolving power limited by the SR source pulses (>> 1ps)

UV MLD PEEM



G. K. L. Marx, H. J. Elmers, and G. Schönhense, *Phys. Rev. Lett.* **84** (2000) 5888.

Hg arc lamp

polycrystalline Fe thick (~100 nm) film

- Very small MLD 0.37%
  due to small LS coupling in the valence band
- Difficult to apply to ultrathin film
  No UV MCD PEEM images reported
  MCD contrast should be similar
- In-laboratory experiments
- Ultrafast time resolution using lasers

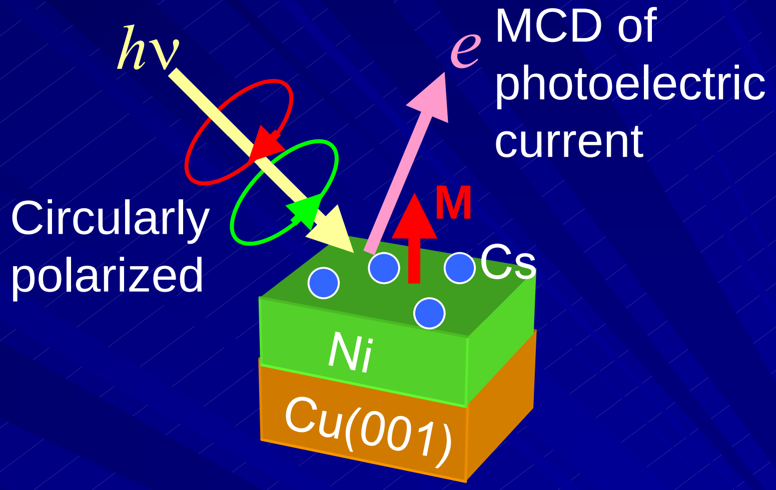
Purpose of this work

1) Try to find out substantially improved contrast in UV-visible photoelectric MCD

Cs-coated magnetic thin films to reduce the work function

Energy dependence of the MCD asymmetry by changing the work function (=Cs amount).

T. Nakagawa and T. Yokoyama, *Phys. Rev. Lett.* **96** (2006) 237402.



2) To eliminate the possibility of the Cs effect

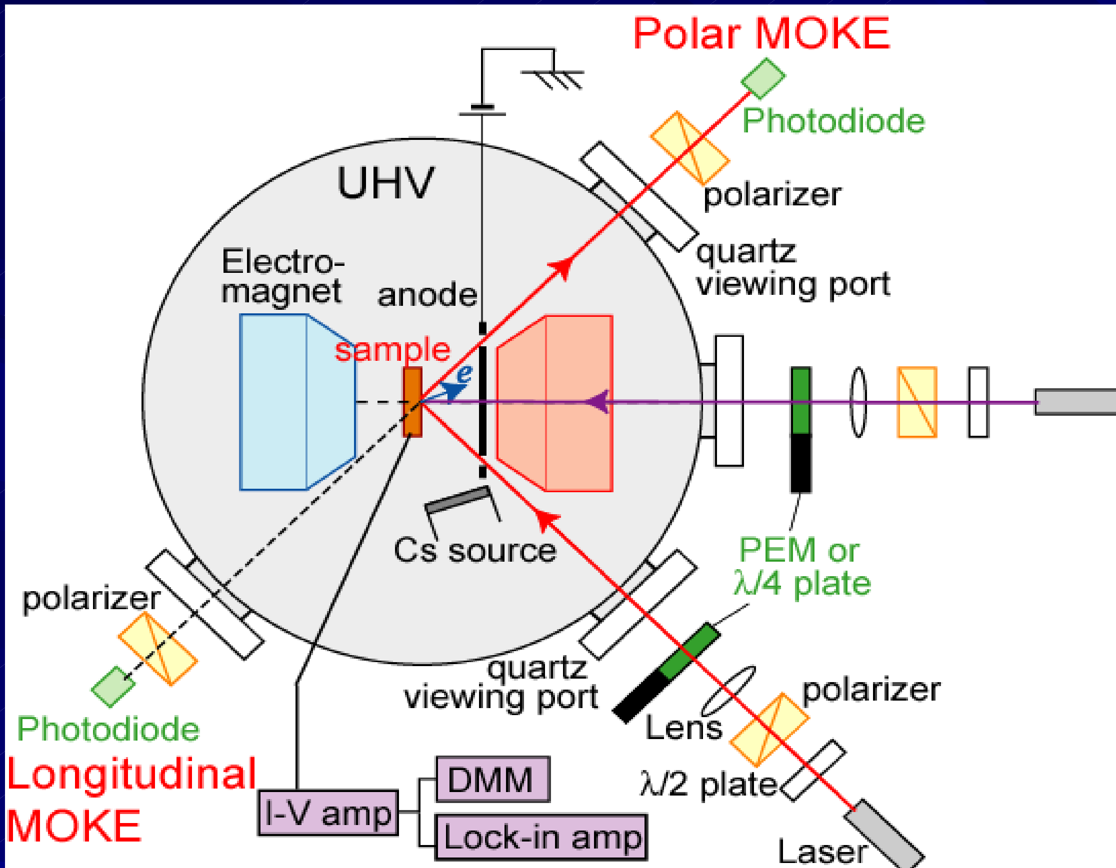
(i) Gd deposition instead of Cs
work function ~ 3.8 eV,
can be excited by a HeCd laser

(ii) Clean films using FEL at UVSOR-II
Photon energy up to 6 eV

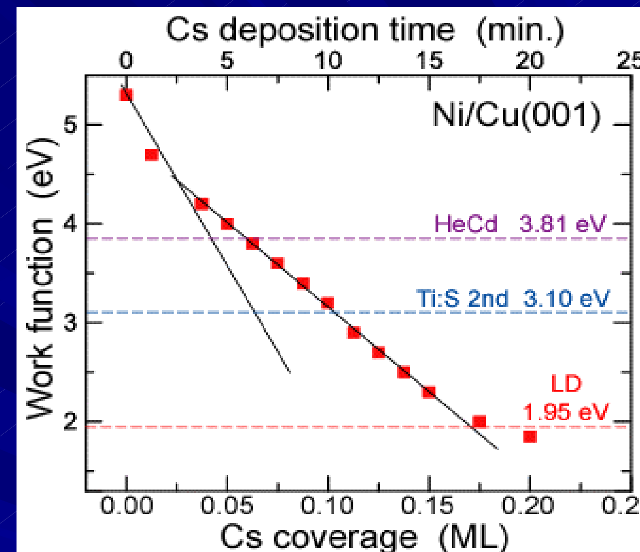
3) MLD

Trial of MLD for in-plane magnetized films

UV-visible MCD & MLD Experimental Setup



Work function variation during Cs dosage



Φ 1.8~5.3 eV (Ni)

UHV ~10^{-10} Torr, Electromagnet 2500 Oe

Laser:

Diode (CW, 5mW) 635nm, 1.95eV

Diode (CW, 10mW) 405nm, 3.06eV

HeCd (CW, 10mW) 325nm, 3.81eV

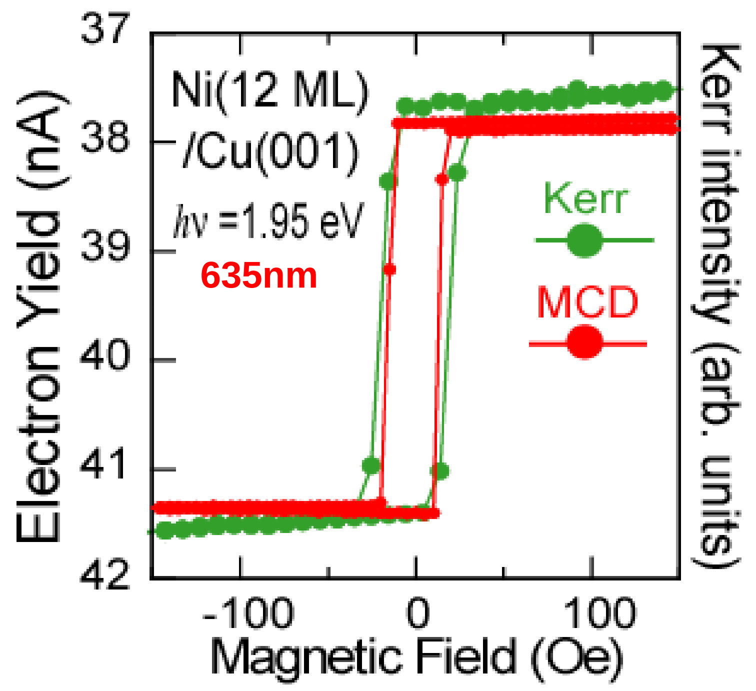
Ti:sapphire 2nd (100fs) 400nm, 3.10eV

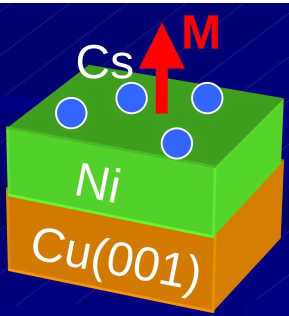
FEL UVSOR-II (100-500mW)

~230nm, ~5.4 eV tunable

Results of Perpendicular Ni/Cu(001)

Magnetization curves



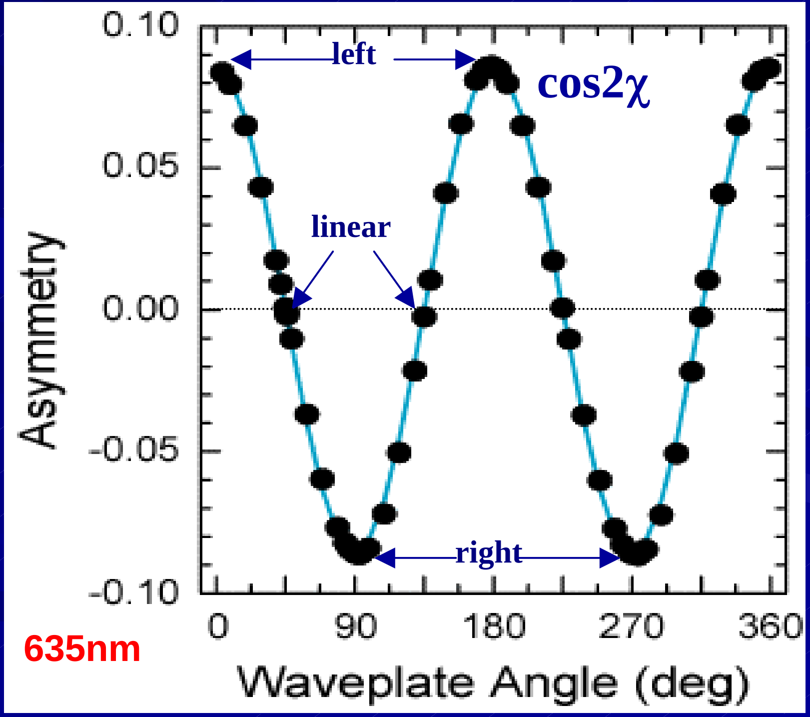


Cs ~0.2 ML
Ni 12ML

Azimuthal angle χ dependece of a quarter-wave plate

MCD asymmetry ***A***

$$A = \frac{I^{left} - I^{right}}{I^{left} + I^{right}}$$

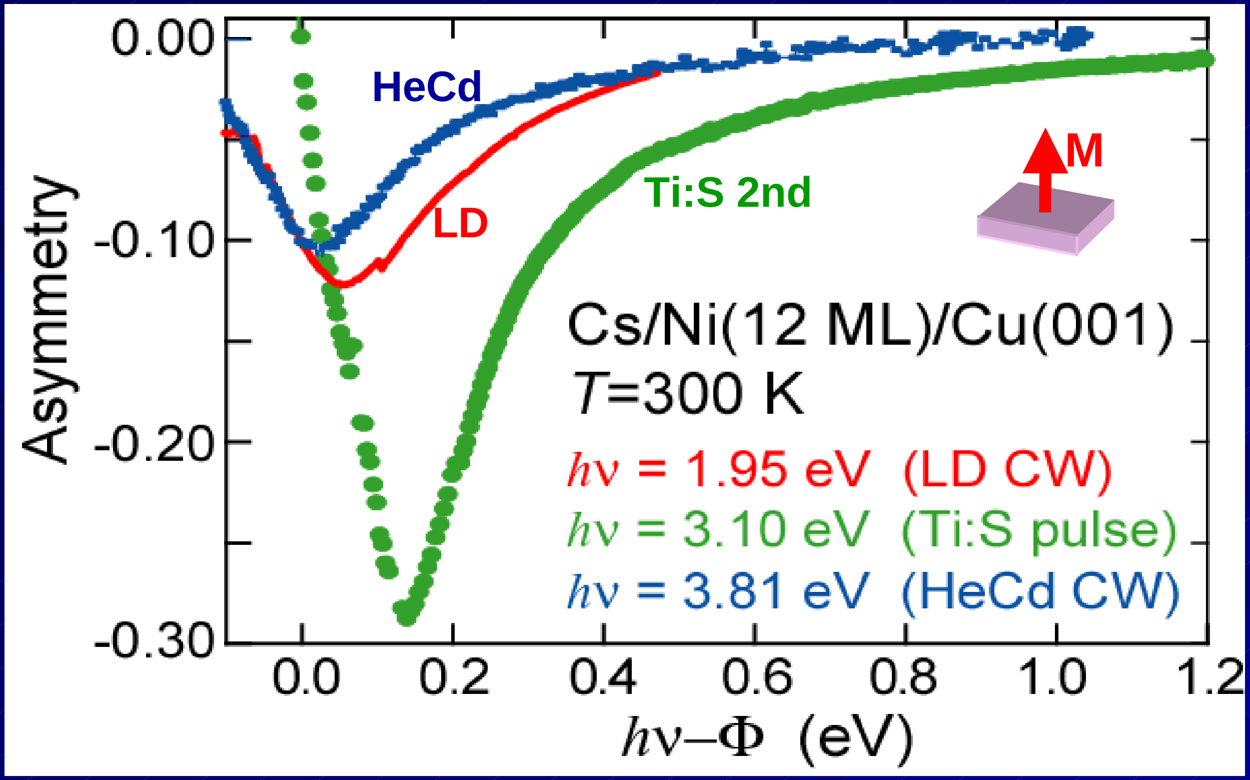


$A \sim \cos 2\chi$

MCD max. ~9% !!

Work Function Dependence in Ni/Cu(001)

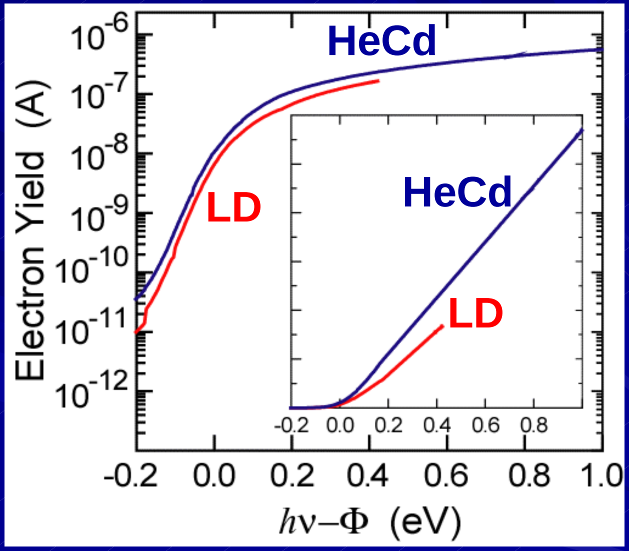
MCD asymmetry



At $h\nu \sim \Phi$

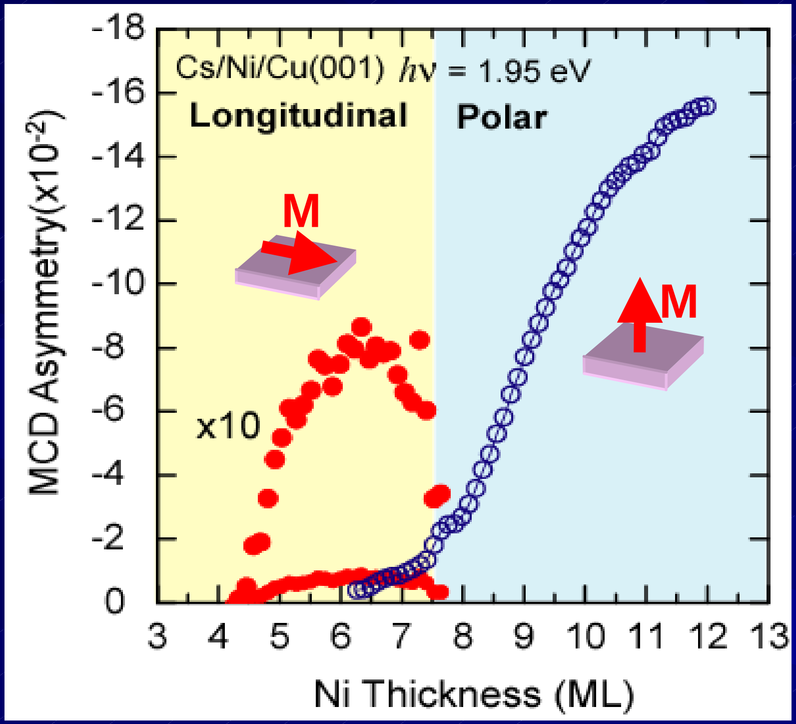
HeCd	Cs	~0.06 ML
Ti:S		~0.10 ML
LD		~0.20 ML

Total Electron Yield

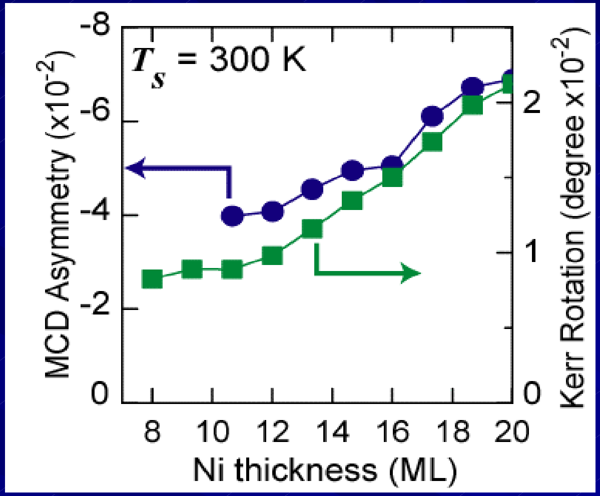


- Maximum MCD asymmetry 10~29% !!
- Strong MCD only at $h\nu \sim \Phi$

Thickness Dependence in Ni/Cu(001)



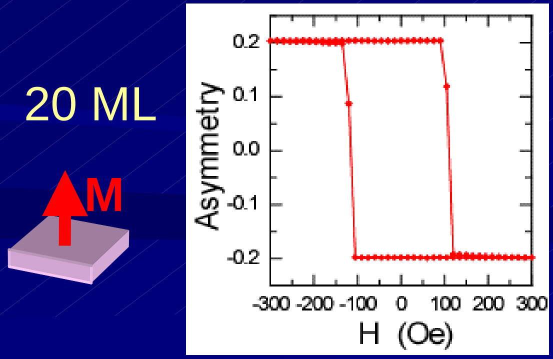
Comparison with Kerr results



Perpendicular magnetization
MCD max. ~1% / ML !!
due to magnification by the presence of reflected lights

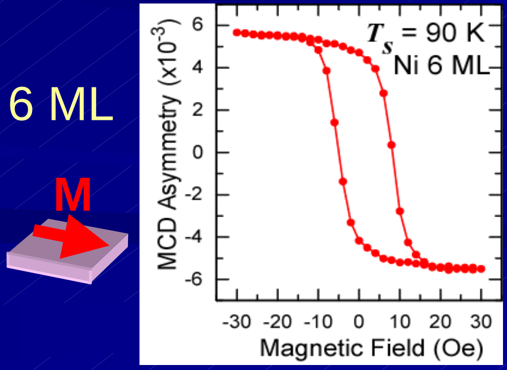
In-plane magnetization
MCD max. ~0.1% / ML
due to compensation by the presence of reflected lights

20 ML



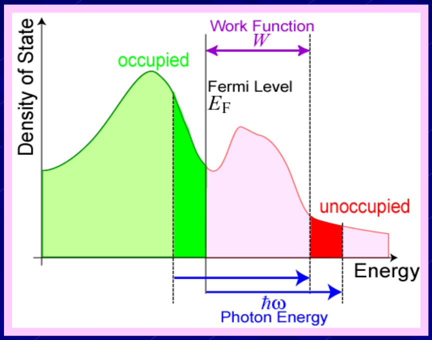
MCD ~20%

6 ML



MCD ~0.6%

Theoretical Evaluation in *fcc* Ni



Band calculations Wien2k

P. Blaha, K. Schwarz, G. K. H. Madsen, D. Kvasnicka, and J. Luitz, Computer code Wien2k (Technische Universität Wien, Vienna, 2002).

Optical conductivity

P. M. Oppeneer, T. Maurer, J. Sticht, and J. Kübler, *Phys. Rev.* **B 45**, 10924 (1992).

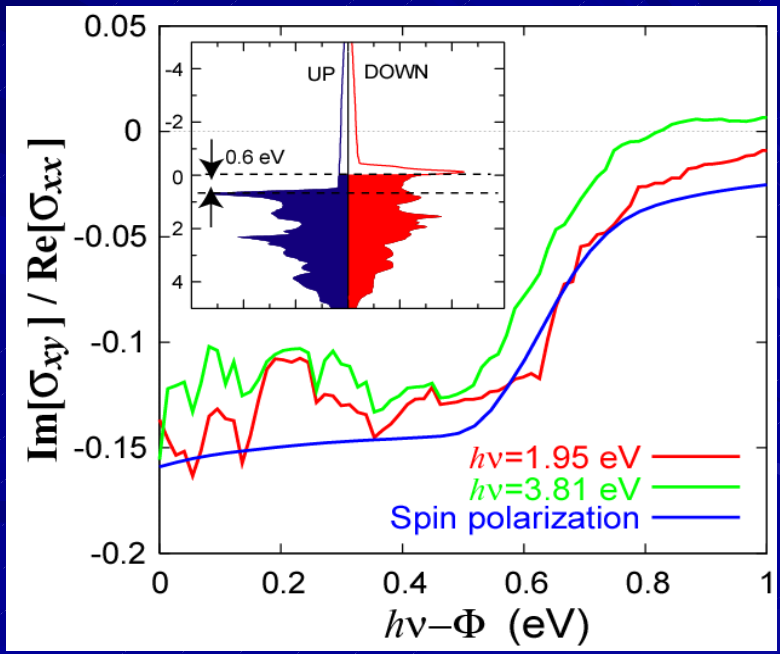
$$\sigma_{\alpha\beta}^{(eff)}(\omega) = \frac{Ve^2}{8\pi^2 m^2 \hbar\omega} \sum_{n}^{\substack{E_F+\Phi-\hbar\omega \\ <E_{\mathbf{k}n}<E_F}} \sum_{n'}^{E_{\mathbf{k}n'}>E_F} \int d^3k \langle \mathbf{k}n | \hat{p}_\alpha | \mathbf{k}n' \rangle \langle \mathbf{k}n' | \hat{p}_\beta | \mathbf{k}n \rangle \delta(E_{\mathbf{k}n'} - E_{\mathbf{k}n} - h\nu)$$

The summation over n (occupied states) is performed only in the energy range of $E_F + \Phi - \hbar\omega < E_{kn} < E_F$.

MCD asymmetry

$$A \propto \mathrm{Im}\left[\sigma_{xy}^{(eff)}\right] \Big/ \mathrm{Re}\left[\sigma_{xx}^{(eff)}\right]$$

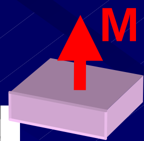
Calculated MCD asymmetry

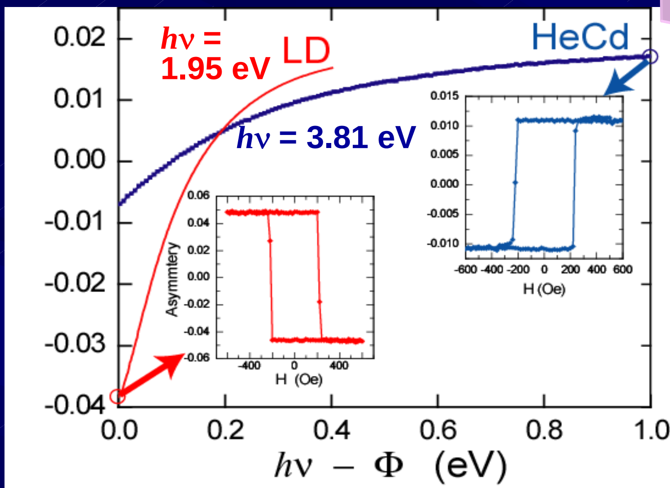


- Reproduce fairly well experimental data
- Close to $h\nu \sim \Phi$, MCD >10%

Results of *fcc* Co and *fcc* & ***bcc*** Fe/Cu(001)

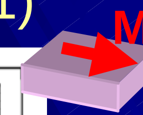
Cs/ *fcc* Fe(3ML)/Cu(001)

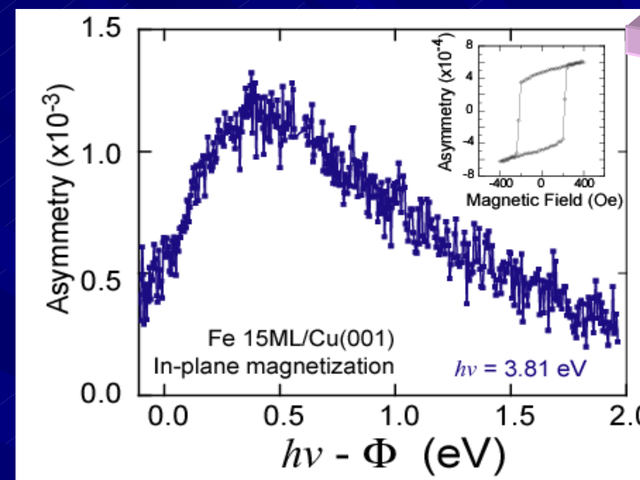




MCD max.
1% / ML !!

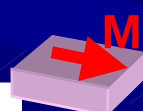
Cs/ *bcc* Fe(15ML)/Cu(001)

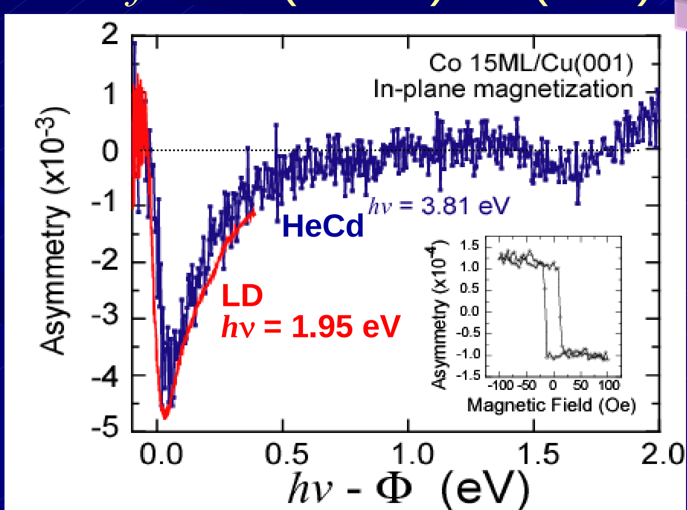




MCD max. 0.01% / ML

Cs/ *fcc* Co(15ML)/Cu(001)





MCD max.
0.03% / ML

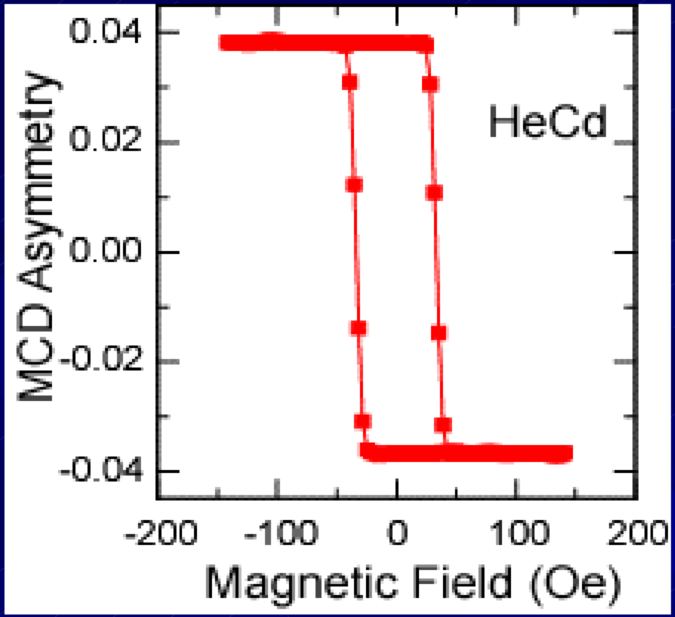
Results of Ni, Co, Fe/Cu(001)

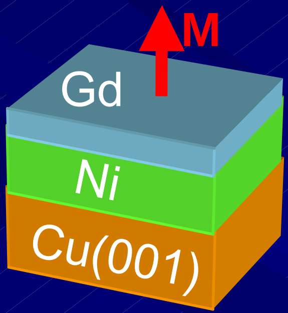
- Close to threshold, MCD maximized
- Perpendicular **M** : Strong (~1%/ML)

  In-plane **M** : Weak (<0.1%/ML)

Gd deposition on Ni/Cu(001)

Gd deposition on Ni/Cu(001) instead of Cs





Gd 2 ML
Ni 10 ML

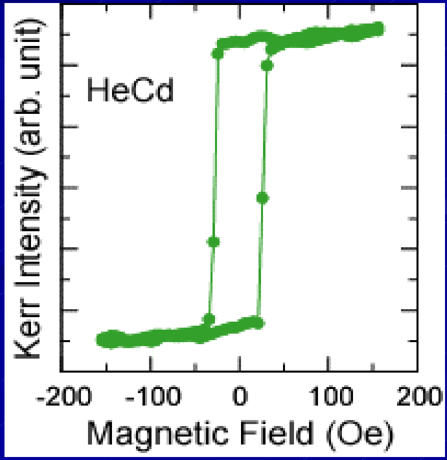
Φ ~ 3.8eV

MCD ~ 4%

Photoelectric MCD can be measured in Gd/Ni/Cu(001) using a HeCd laser (325 nm).

We can eliminate the possibility of the Cs effect for the enhancement of photoelectric MCD.

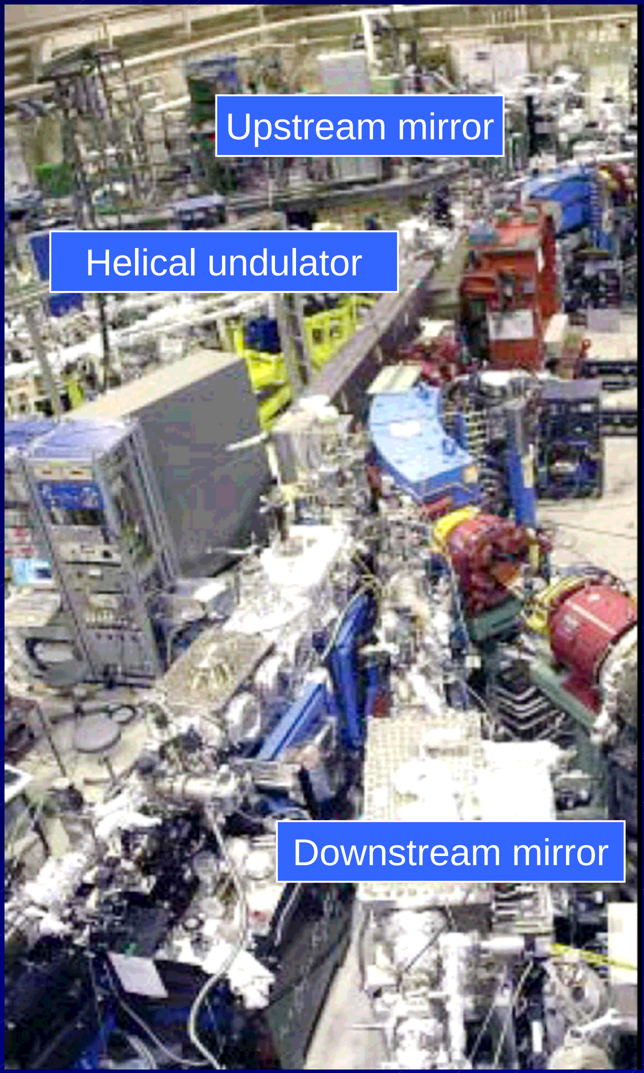
cf. Polar MOKE of the same system using a HeCd laser



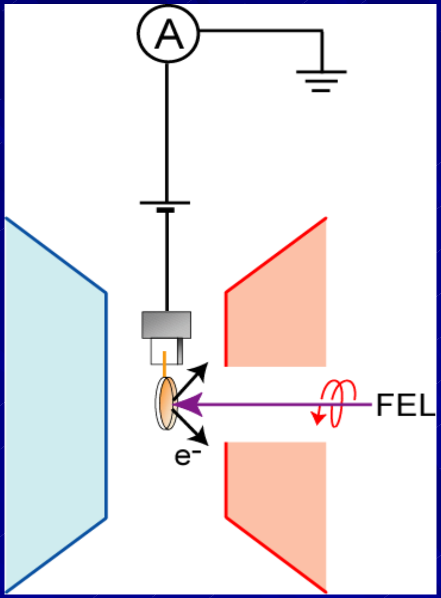
FEL trial experiments

Cs-free Ni/Cu(001) using FEL at UVSOR-II

λ ~ 230nm tunable



Collaboration with UVSOR machine group, Prof. M. Kato & Dr. M. Hosaka *et al.*



FEL from helical undulator

inherently circular polarized

Strong intensity ~100-500 mW

Energy scan

not easy due to limited range of the multilayer mirrors

- ➡ Photon energy tuning not perfect
- ➡ Weaker MCD, worse S/N ratio

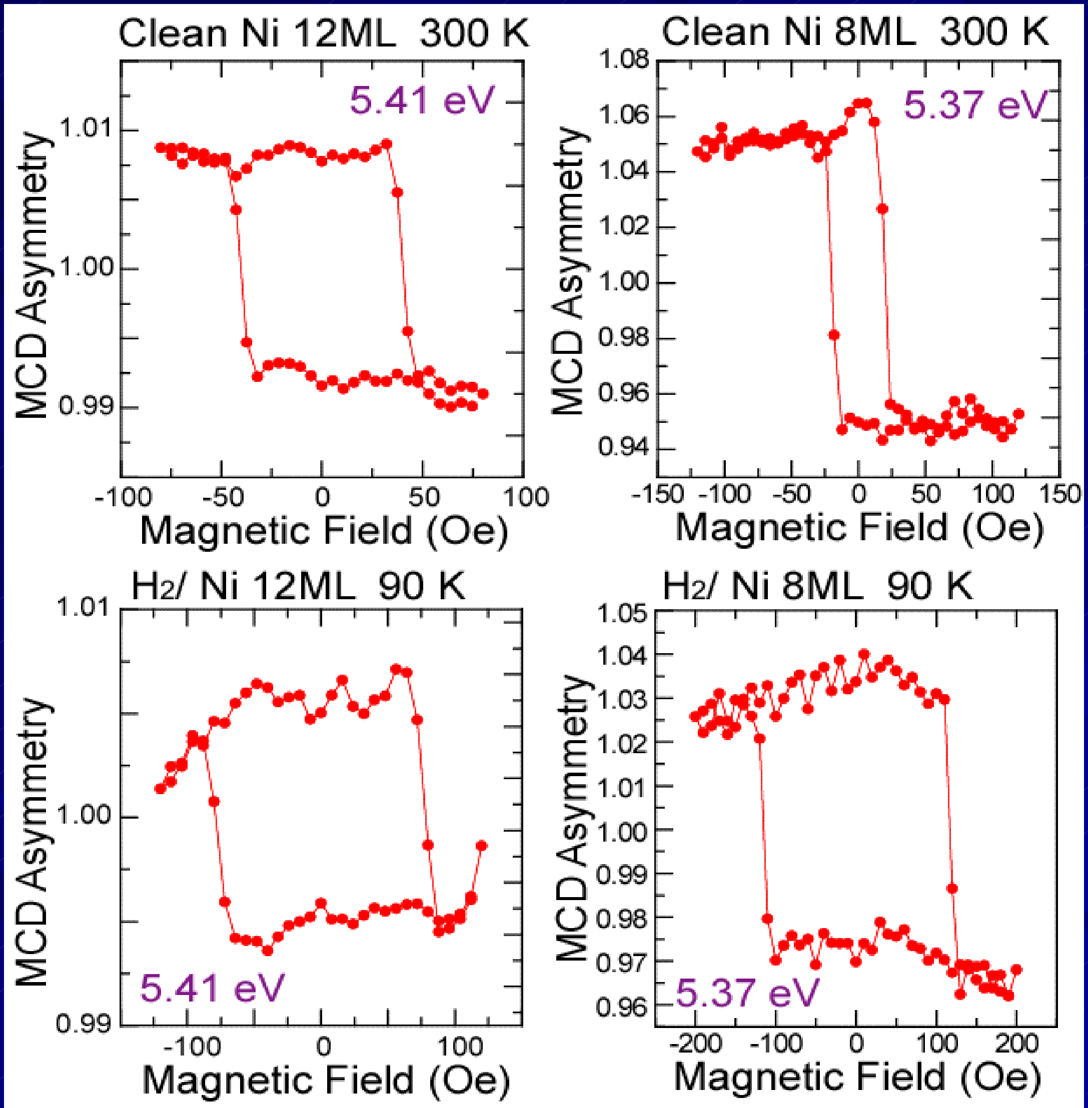
Absence of the electrode

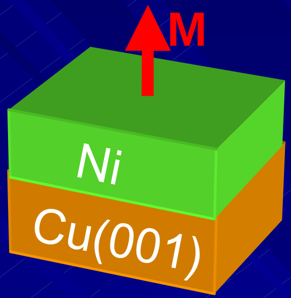
sample biased with a battery

- ➡ Worse S/N ratio

FEL trial experiments

Cs-free clean Ni/Cu(001) using FEL at UVSOR-II





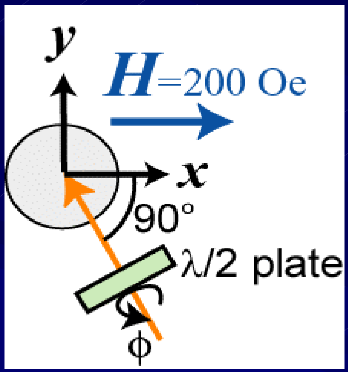
No Cs, no Gd

$h\nu$ = 5.41 (eV) 229.2nm
MCD ~ 0.5-1%

$h\nu$ = 5.37 (eV) 230.9nm
MCD ~ 3-5% !!

MLD of in-plane magnetized films

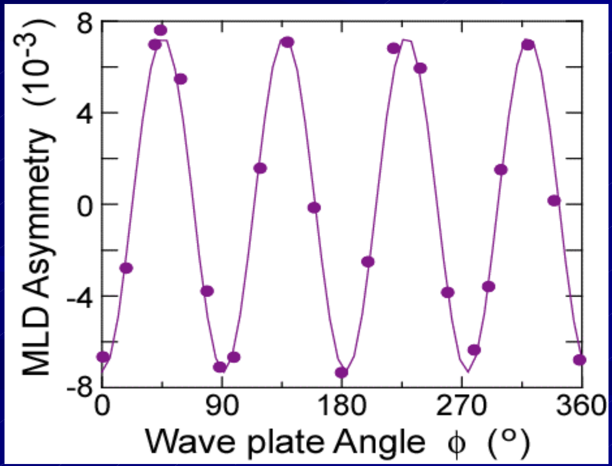
Cs/Co(5ML)/Cu(001)



LD 635 nm

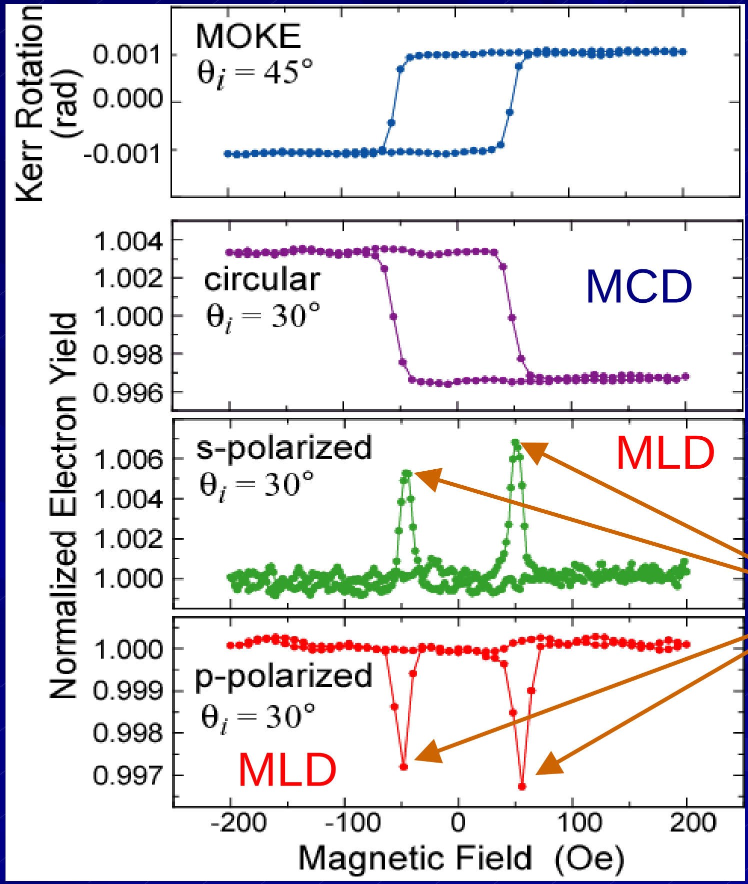
MLD ~ 0.8%

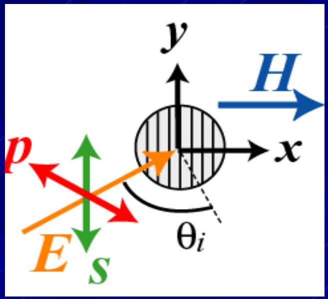
$I(\mathbf{M} \parallel \mathbf{E}) - I(\mathbf{M} \perp \mathbf{E})$



$I(\mathbf{M} \perp \mathbf{E}) - I(\mathbf{M} \parallel \mathbf{E})$

Cs/Co(5ML)/Cu(1 1 17)





M ⊥ H

MCD ~ 0.3%

MLD ~ 0.5%

MCD after suppression of reflected lights may be better.

Conclusions: Possibility of UV MCD PEEM

- We observed substantial enhancements of the photoelectric MCD asymmetries especially in perpendicularly magnetized films when the photon energy was tuned to the work function threshold.
- Although we believed that the valence band MCD is too weak, UV MCD PEEM is possible rather in general.
- We are now preparing UV MCD PEEM experimental setup, and a video-rate measurements will be done by this summer using available lasers. No 3rd SR light sources are necessarily required.
- We are also planning ultrafast spin dynamics measurements using a third-order harmonics of a wavelength-variable Ti:sapphire laser. Time resolving power of 10-100 fs is by far superior to those of third-generation SR light sources.

Elmitec PEEM Spector