PREPARATION AND MAGNETIC CHARACTERIZATION OF Fe/GaAs THIN FILMS FOR XMCD and EMCD EXPERIMENTS

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OUTLINE

- **Motivation and samples description**

- **Sample preparation**
  - **GaAs substrate preparation**
  - **Fe films growth**

- **Magnetic characterization**
  - **Magneto-optic Kerr Effect (MOKE)**
  - **X Rays Magnetic Circular Dichroism (XMCD)**

Center for Electron Microscopy

APE beamline

AIM

Direct comparison between XMCD and Electron Energy Loss Magnetic Circular Dichroism (EMCD)

SYSTEM

Fe thin films on GaAs(001) substrate

Fe	GaAs
❖well known material system ❖large dichroic signal at $L_{2,3}$ edges	❖good lattice match with Fe (mismatch~1.4%) ❖Well known artifact free TEM sample preparation procedures

GaAs SUBSTRATES PREPARATION

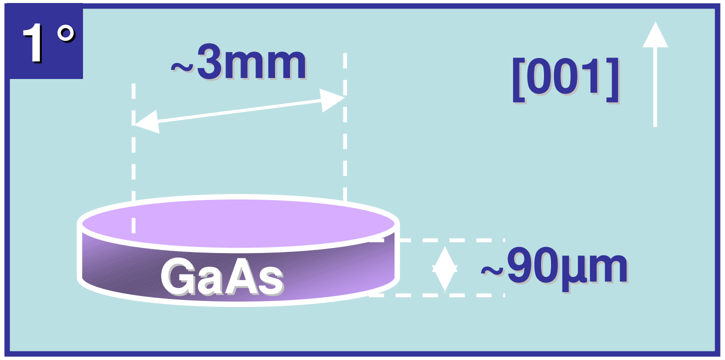
TASC

Substrate

GaAs (001)

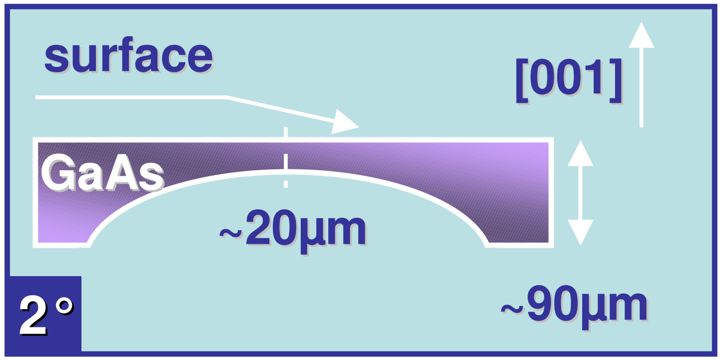
(a_0=0.56nm, space group F-43m)

TEM substrate preparation (plan view)



1° step:

3mm diameter disks pre-thinned down to ~ 90µm



2° step:

Dimpling and polishing of the central area (final thickness ~20µm)

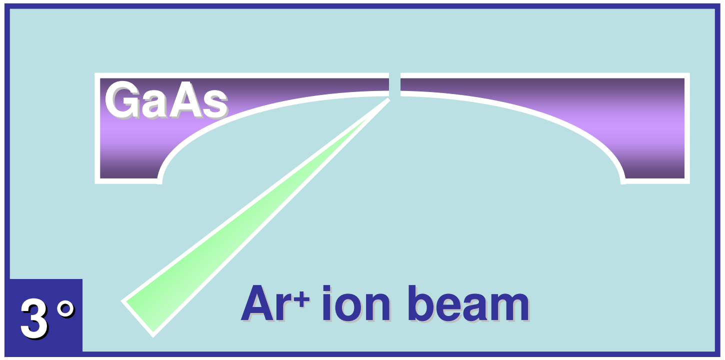
Fe growth surface untouched

GaAs SUBSTRATES PREPARATION

3° step:

Final thinning by low energy ion milling until electron beam trasparency

Ar^+ ions:
- energy 4.5÷1.8 KeV
- Incidence angle ~ 5°



two options:
- Ion milling *before* Fe deposition
- Ion milling *after* Fe deposition

❖Analysis of influence of GaAs substrate on Fe growth

❖Studies of the influence of ion beam milling on Chiral properties of the samples.

GaAs SURFACE PREPARATION BEFORE Fe GROWTH

(2x10^{-10}mbar)

Ar^{+} ions sputtering (750 eV, sputtering pr.1x10^{-6}mbar)

Annealing at 580℃

Substrates' surface analysis

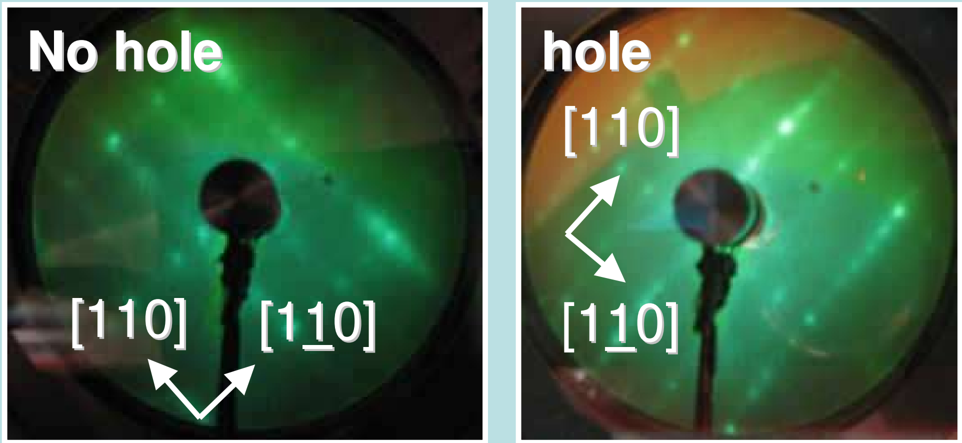
Auger Electron Spectroscopy (AES) → C and O under detection limit (2%); Traces of Mo

Low Energy Electron Diffraction (LEED) → 6x4 surface reconstruction

LEED on GaAs surface

⇩

Surface quality influences Fe growth and its magnetic properties

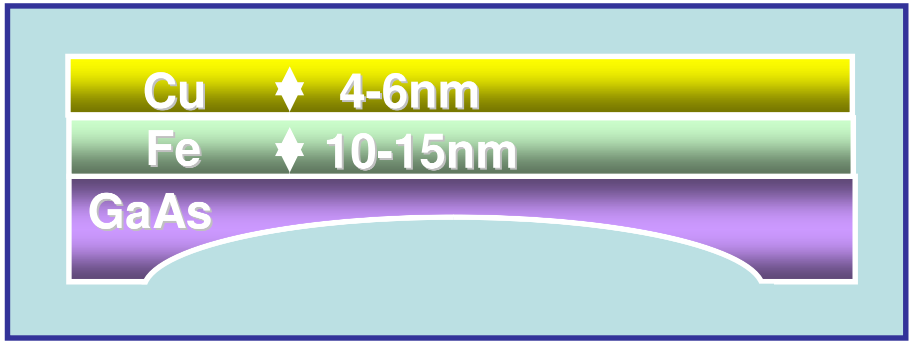


Better surface quality

Fe GROWTH

Fe (bcc, a_0=0.286nm, space group Im-3m)

- Molecular beam epitaxy (MBE) in UHV chamber
- Small lattice mismatch (~1.4%)
- Films thickness 10÷15nm
- Cu capping



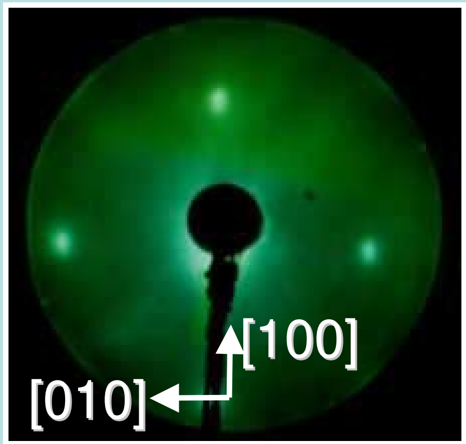
Fe surface analysis

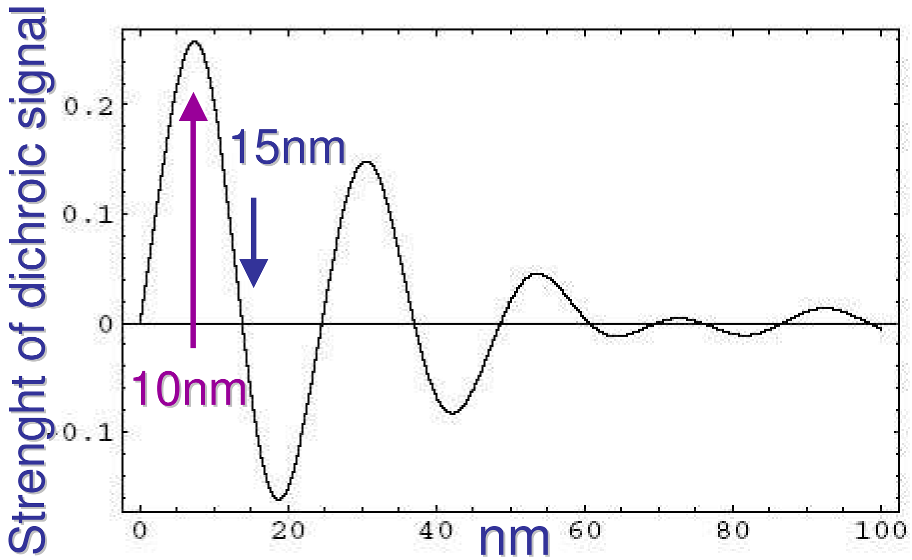
LEED on Fe surface

⇓

Good surface quality

1x1 reconstruction





Why 10 and 15 nm?

❖10 nm: maximum dichroic signal

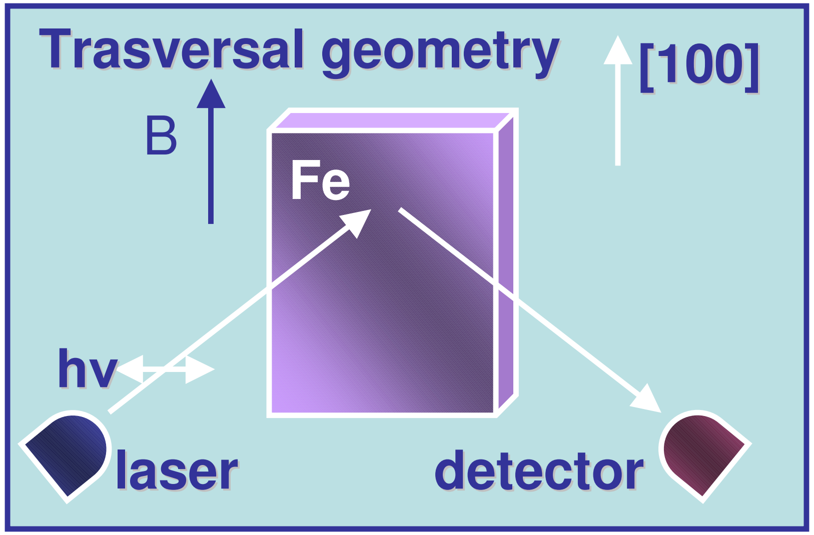
❖15nm: lower dichroic signal

PREPARED SAMPLES

Fe thickness (nm)	Hole	XMCD after EMCD
10	No	In progress
10	Yes	In progress
15	Yes	Yes
15*	No*	Yes*

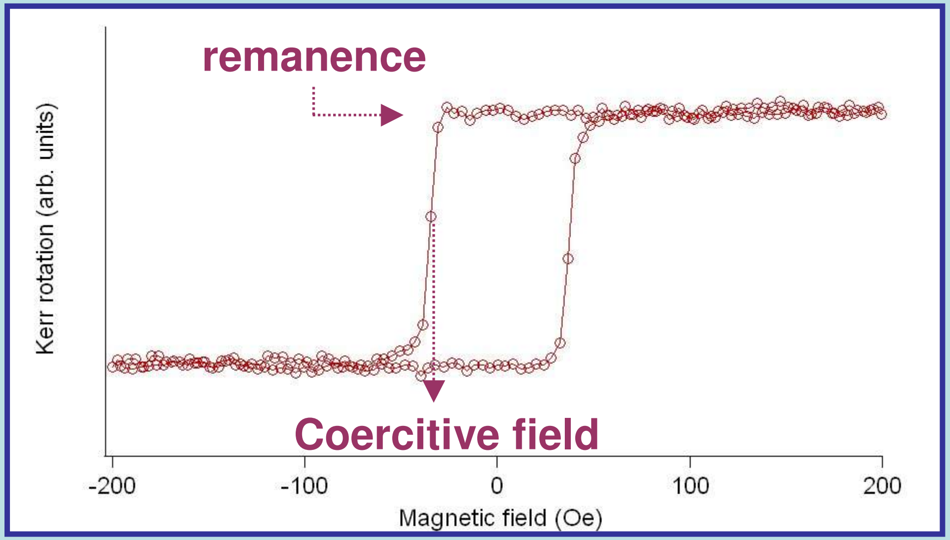
**Sample with no hole was thinned again in Wien because Cu capping was too thick*

MOKE ANALYSIS



Rotation of polarization plane of reflected light is related to magnetization

Measurement of hysteresis loops



100% remanence

⇩

Easy axis along [100]

A LITTLE GLANCE AT XMCD TECHNIQUE

J.Stöhr et a., *New Direction in Research with 3° generation X-ray Synchrotron Radiation Source*, 221-250, Kluwer Academic Publishers (1994)

1° step

Absorption of X-ray

2p core shells → e^- → 3d empty states

2° step

Spin-orbit coupling on 2p levels

→ Polarized X-Rays excite spin polarized e^- with different rate

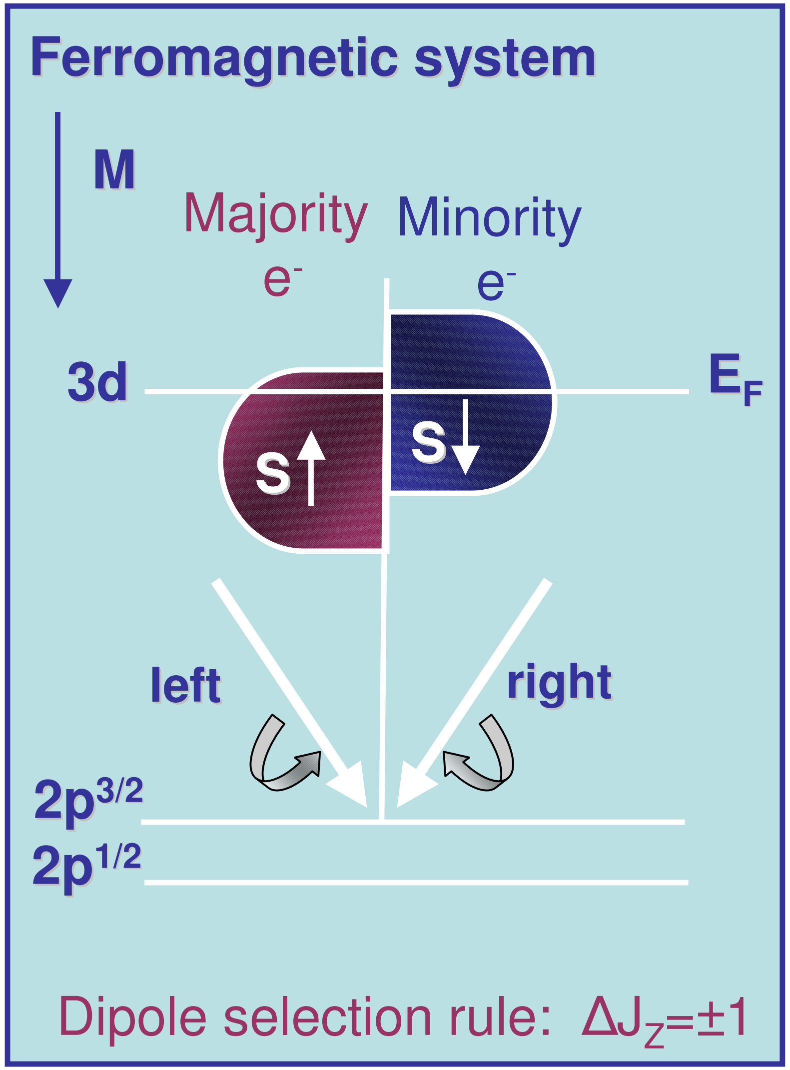
core shells ⟷ source

3° step

Exchange interaction on 3d band

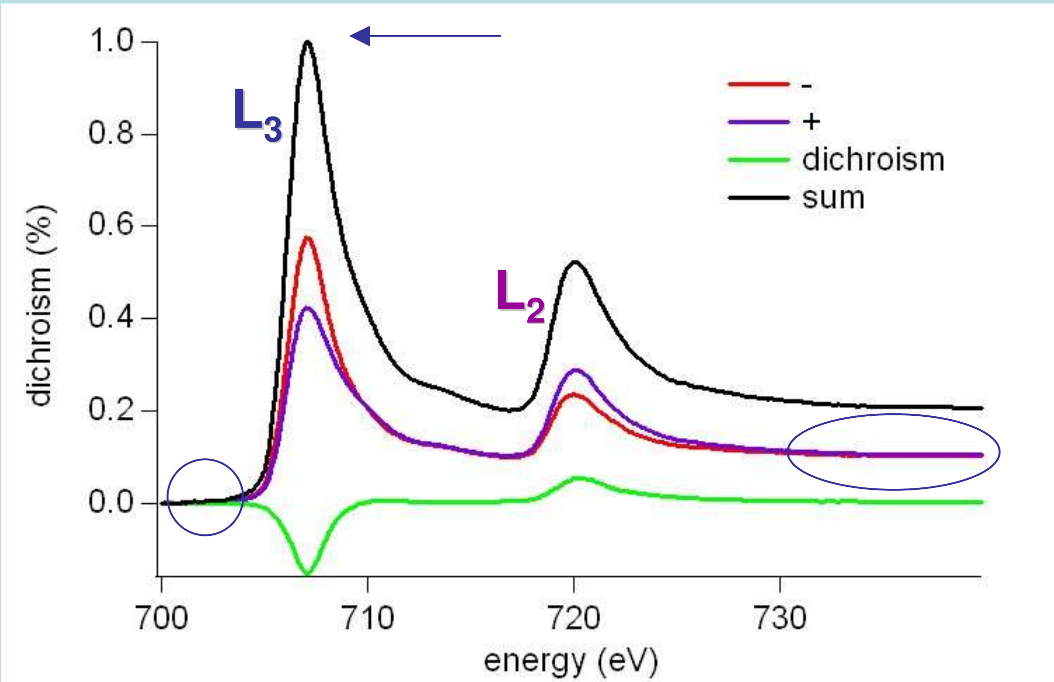
→ Absorption of one spin polarization is favored

Empty levels ⟷ filter



XMCD STEP BY STEP

- ❖ Background removal
- ❖ Normalize post edge of + and - spectra to the same value
- ❖ Normalize sum spectrum maximum to unity
- ❖ Calculate difference spectrum $I^{+}(E)-I^{-}(E)$
- ❖ Rescale difference for polarization and sample orientation



L_3 : $2p^{3/2} \longrightarrow 3d$

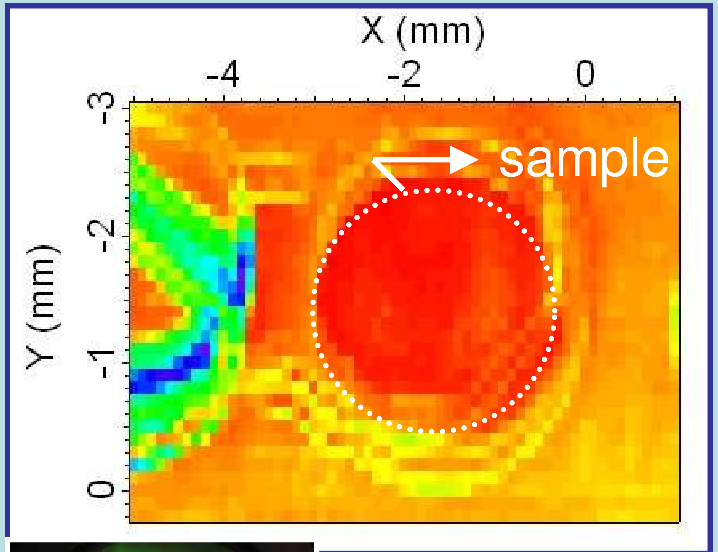
L_2 : $2p^{1/2} \longrightarrow 3d$

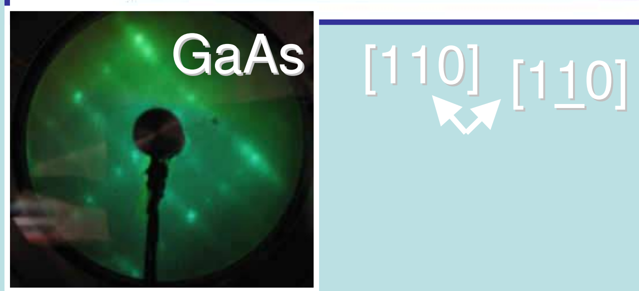
$$\text{Dichr}(\%) = \frac{I^{+}(E)-I^{-}(E)}{I^{-}(E)+I^{+}(E)}$$

XMCD EXPERIMENTS ON 15nm Fe FILMS

Before EMCD

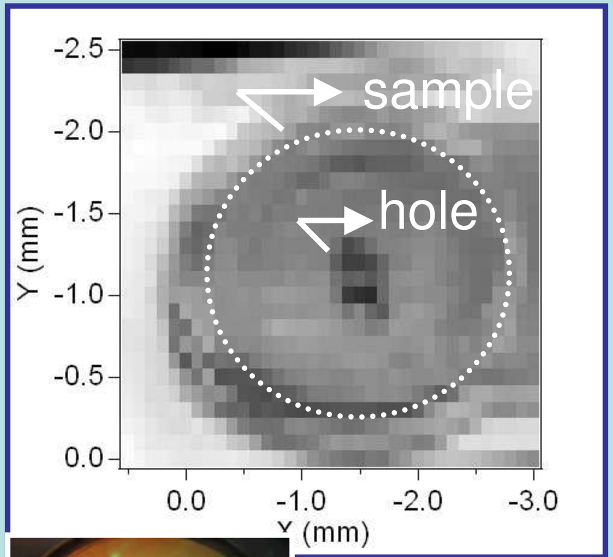
No hole

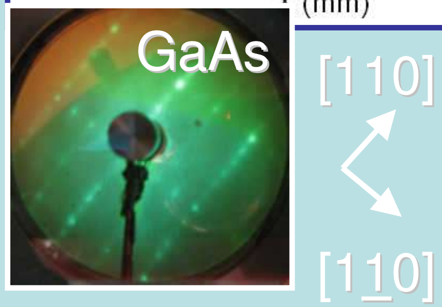




- Lower Fe signal
- % dichroism 12÷16%

Hole





Better surface quality

- Higher Fe signal
- % dichroism 27÷33%

After EMCD

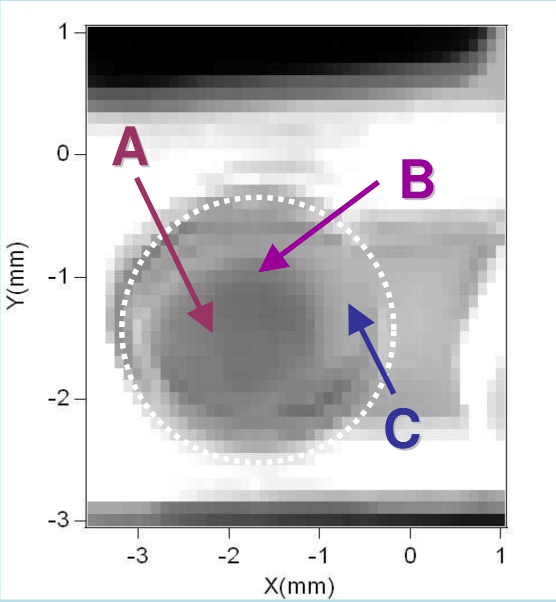
No hole

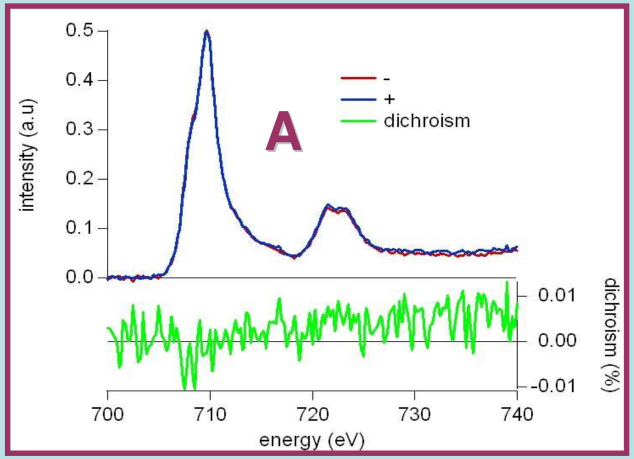
❖ Dichroism :

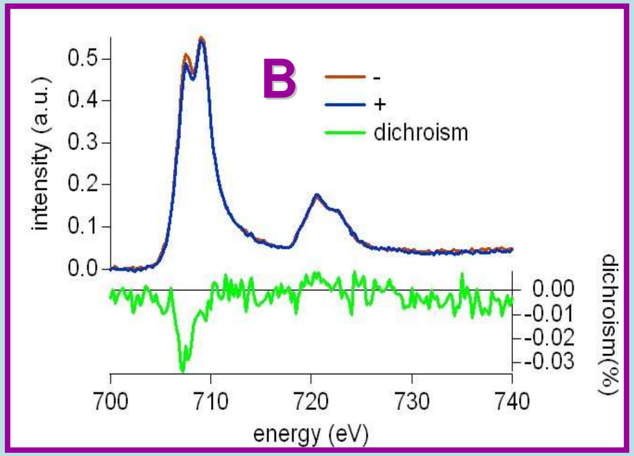
Not uniform over the surface and smaller (~3%)

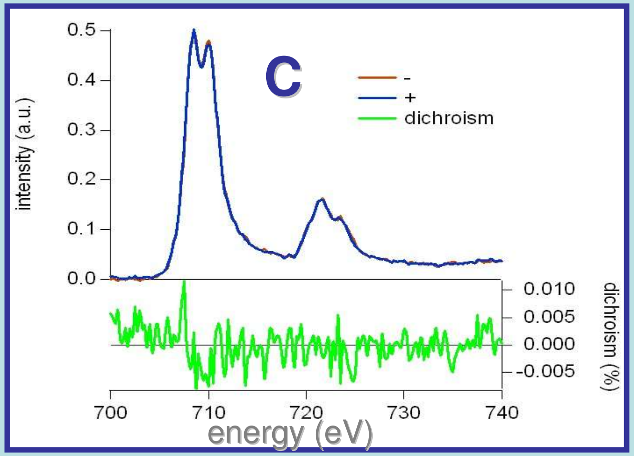
❖ Preliminary analysis :

mixture of different iron oxides (Fe_3O_4 ; Fe_2O_3 ; FeO).

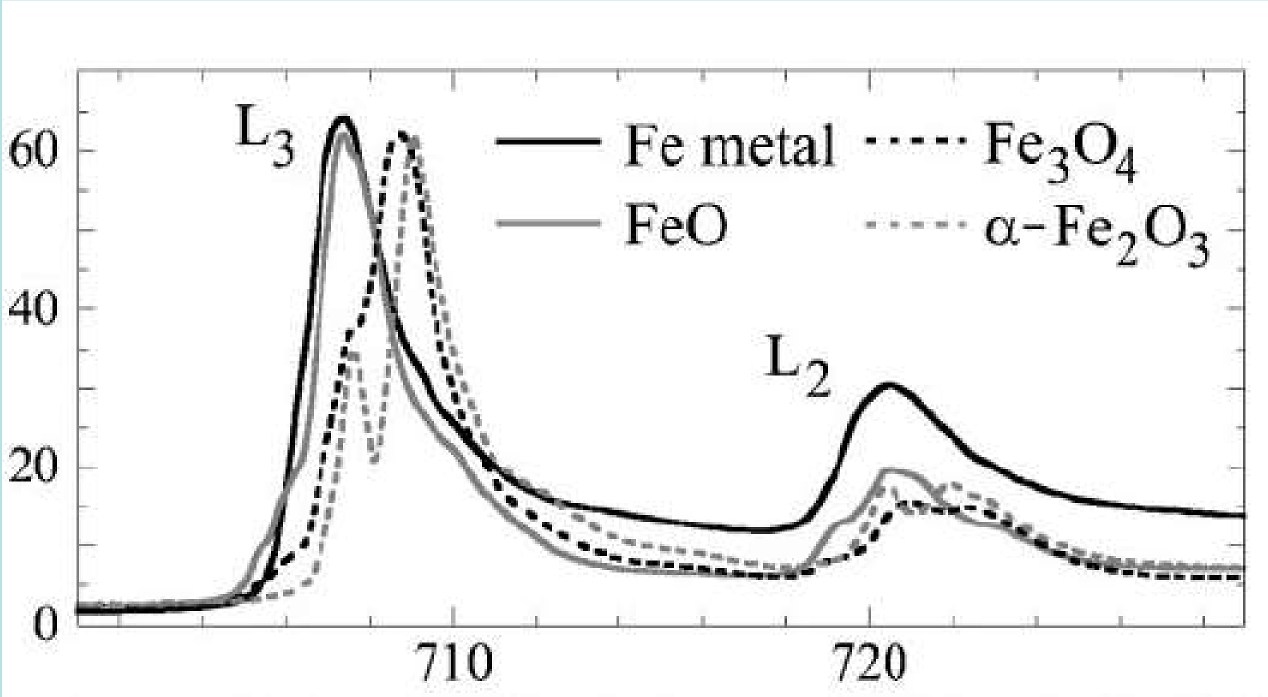








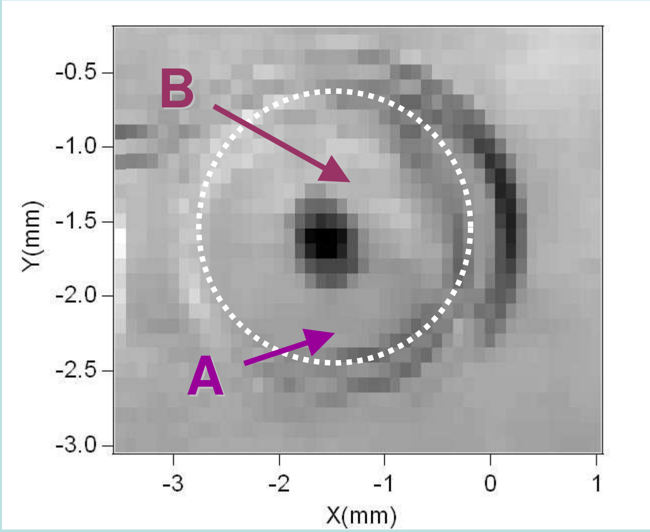
Iron oxides L_3 and L_2

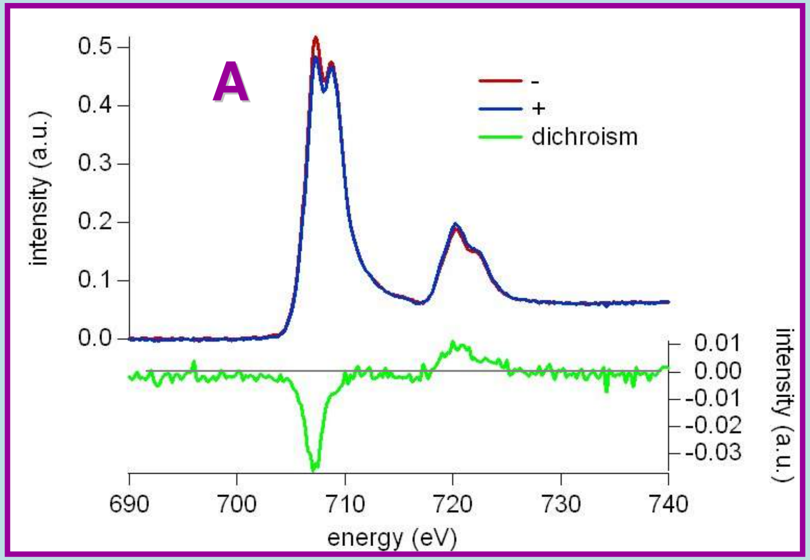


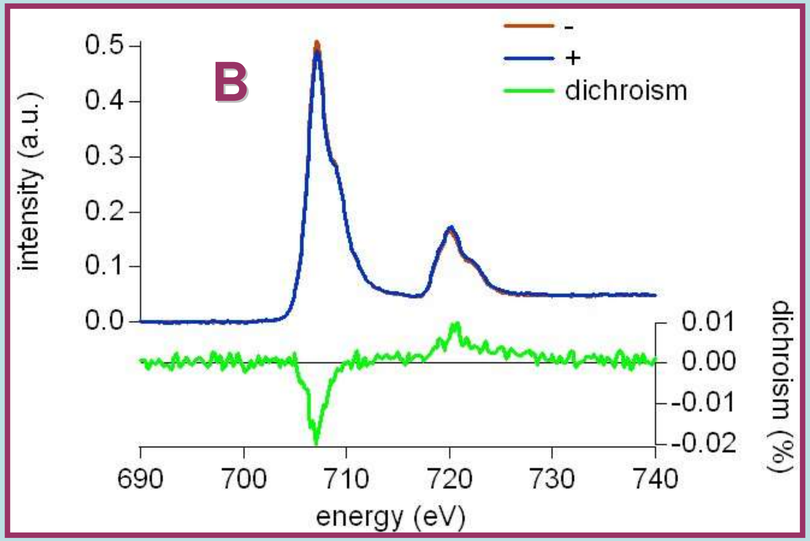
Regan et al., Phys. Rev. B, 64, 214422 (2001)

After EMCD

Hole







- ❖ Dichroism :

uniform over the surface but smaller (~2%)

- ❖ Preliminary analysis :

mixture of different iron oxides (Fe_3O_4 ; Fe_2O_3 ; FeO) and metallic Fe.

CONCLUSIONS

❖ Thin Fe films have been prepared with different thickness to compare the theoretical expectation of EMCD depencence on TEM specimen thickness.

❖ All Fe films show good crystalline quality

❖ XMCD experiments before and after EMCD have been performed to study ion beam milling influence and to test the different probing depth.

FUTURE

❖ Improvment of capping procedures

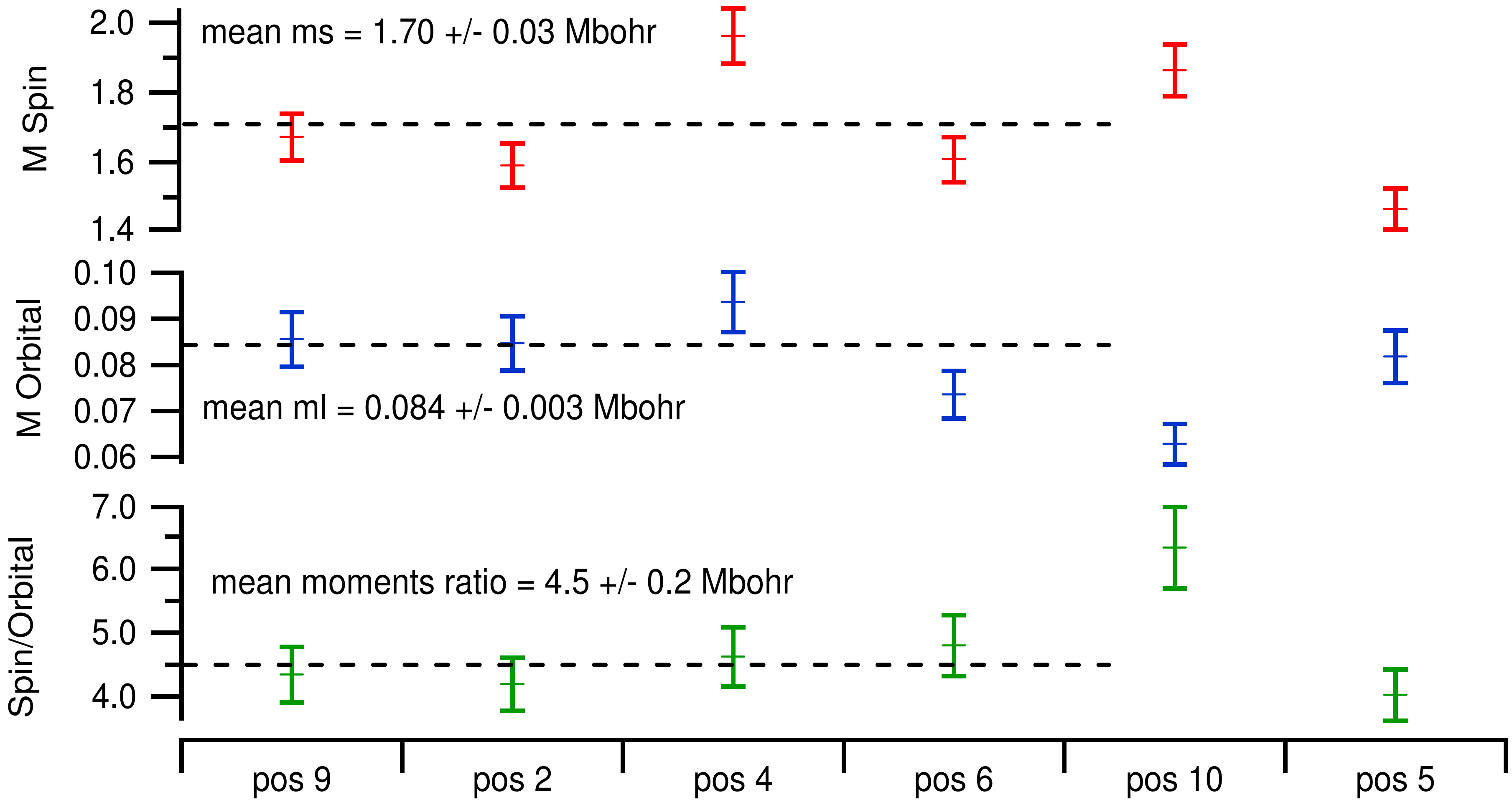
❖ XAS/XMCD microscopy with Fresnel diffractive optic (spot ~100nm)

❖Quantitative comparison between XMCD and EMCD

❖Study of EMCD as a function of applied magnetic fields.

❖ New systems

Calculations of magnetic moments



Total M=1.70+0.084= 1.784 Mbohr