Synchrotron-Based Cathode Lens Microscopy

Tevfik OnurMenteş
Summary

1. X-rays: general considerations, synchrotrons
2. Interaction of x-rays with matter: XPS, XAS, XMCD/XMLD
3. X-ray microscopy methods: XPEEM/LEEM
4. SPELEEM at work: FeNi phase separation
5. X-ray diffraction within an XPEEM setup
Radiation spectrum

**x-rays:**
100 eV to 100 keV
or
10 nm to 10 pm

Science according to wavelength:
- $10^{-15}$ m (fm) nucleus
- $10^{-12}$ m (pm) atoms
- $10^{-9}$ m (nm) mesoscopic physics
  nanotechnology
- $10^{-6}$ m (µm) optics

Wavelength limits the dimension of objects that you can see....

... sort of.... (near field!)
Radiation spectrum

**x-rays:**
100 eV to 100 keV or 10 nm to 10 pm

**Science according to energy:**

- $> 10^9$ eV, high energy physics
- $> 10^6$ eV, nuclear physics
- 1000 eV, electron binding
- 1 eV, valence band, chemical bonds, magnetic exchange energy...
- 1 meV, atomic vibrations
- 1 µeV, magnetic anisotropy
A few words about the Synchrotron Light Source

On the Classical Radiation of Accelerated Electrons

JULIAN SCHWINGER
Harvard University, Cambridge, Massachusetts
(Received March 8, 1949)

EARLY in 1945, much attention was focused on the design of accelerators for the production of very high energy electrons and other charged particles. In connection with this activity, the author investigated in some detail the limitations to the attainment of high energy electrons imposed by the radiative energy loss of the accelerated electrons. Although the results of this work were communicated to various interested persons, no serious attempt at publication was made. However, recent experiments on the radiation from the General Electric synchrotron have made it desirable to publish the portion of the investigation that is concerned with the properties of the radiation from individual electrons, apart from the considerations on the practical attainment of very high energies. Accordingly, we derive various properties of the radiation from a high energy accelerated electron; the comparison with experiment has been given in the paper by Elder, Langmuir, and Pollock.

Figure 4
The 70 MeV General Electric synchrotron in 1947 with clearly visible synchrotron light spot (light splash in the lower left center of the picture).

Figure 5
The General Electric team (from left to right, Langmuir, Elder, Gurewitsch, Charlton and Pollock) looking at the vacuum chamber of the 70 MeV synchrotron – the world's second synchrotron.
**XPS** X-ray Photoemission Spectroscopy
  Chemistry, bonding

**ARPES** Angle Resolved Photoemission Spectroscopy
  Electronic structure

**XPD** or **PED** x-ray photoelectron diffraction
  Short range atomic structure

**XAS** X-ray Absorption Spectroscopy
  Chemistry, magnetism

**EXAFS** Extended X-ray Absorption Fine Structure
  Short range atomic structure

**XRD** X-ray Diffraction
  Crystallography

Infrared Spectroscopy, X-ray Fluorescence, RIXS,
Small Angle X-ray Scattering, X-ray Speckles, etc.
Interaction of light with matter
Interaction of x-rays with matter: **XPS and XAS**

**x-ray photoemission spectroscopy (XPS)**

- Unocc. valence
- Occ. valence
- Core orbital
- Valence Photoemis.
- Core-Level Photoemis.
- Auger decay

vs the kinetic energy of the emitted electron

**x-ray absorption spectroscopy (XAS)**

- Photon
- X-ray Absorption

vs the energy of the absorbed photon
Interaction of x-rays with matter: Probing depth

Photons probe deeper than electrons. Electron-based measurements are surface sensitive.

Henke database, CXRO, Berkeley

Figure 25. Summary plot of calculated IMFPs for the 41 elemental solids (Table 4) as a function of electron energy.

_Surf Interface Anal._ 2011, 43, 589–713
X-ray Photoemission Spectroscopy (XPS)

Stefan Hufner

**Photoelectron Spectroscopy**

Principles and Applications

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Need to determine the kinetic energy of photoelectrons

Typical XPS spectrum
X-ray Photoemission Spectroscopy (XPS)

Transition probability

\[
w \propto \frac{2\pi}{\hbar} |\langle \Psi_f | \Delta | \Psi_i \rangle |^2 \delta(E_f - E_i - \hbar\omega)
\]

\[
\delta(E_{f,\text{kin}} + E_s(N - 1) - E_0(N) - \hbar\omega)
\]

Free electron + atom with a hole

Energy of the photoelectron depends:
- intra-atomic screening
- inter-atomic screening

Core level shifts!

Angle-Resolved Photoemission Spectroscopy (ARPES)

assume free-electron-like final state

\[ E_f = \left( \frac{\hbar^2}{2m^*} \right) (\mathbf{k} + \mathbf{G})^2 - |E_0^\prime| \]

inner potential

Band structure in reciprocal space:

- angle → \( k // \) surface
- energy → \( k \perp \) surface

e.g. fcc(110)
Angle-Resolved Photoemission Spectroscopy Illustration

‘LEED vectors’ for bcc(110) tungsten

Intensity profile as a function of binding energy

Pd + O / W(110)
X-ray Absorption Spectroscopy (XAS)

Experimentally there are different ways to do XAS:

- inelastic scattering, fluorescence
- incident beam
- transmitted beam
- total/partial electron yield
- relevant to XPEEM!

Typical XAS spectrum

- XANES
- EXAFS

near-edge chemistry/magnetism

extended XAFS atomic structure

relevant to XPEEM!
X-ray Absorption Spectroscopy (XAS)

Example: Fe-oxides L edge (2p → 3d)

The «peaks» have much more underneath!

Table 4
The 2p X-ray absorption transitions from the atomic ground state to all allowed final state symmetries, after applying the dipole selection rule: $\Delta J = -1, 0$ or $+1$

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Interaction of x-rays with matter: useful resources

http://henke.lbl.gov/optical_constants/


https://xdb.lbl.gov/
Interaction of x-rays with matter: useful resources

NIST X-ray Photoelectron Spectroscopy Database

NIST Standard Reference Database 20, Version 4.1
Last Update to Data Content: 2012
DOI: http://dx.doi.org/10.18434/T4188K

Data compiled and evaluated by
Alexander V. Naumkin, Anna Kraut-Vass, Stephen W. Gaarenstroom, and Cedric J. Powell

- XPS Home
  - Identify Unknown Spectral Lines
  - Retrieve Data for Selected Elements
  - Retrieve Data for a Selected Element
  - Display Wagner Plot
  - Retrieve Data for Selected Compounds
  - Retrieve Data by Scientific Citation

- Instructions:
  - Click on solid arrows at left to display additional choices.

https://srdata.nist.gov/xps/main_search_menu.aspx
Interaction of light with a magnetic material
X-ray scattering from a magnetic material, beginnings

PHYSICAL REVIEW B
VOLUME 2, NUMBER 9
1 NOVEMBER 1970

Magnetic Scattering of X Rays from Electrons in Molecules and Solids

P. M. Platzman
Bell Telephone Laboratories, Murray Hill, New Jersey

and

N. Tzoar
City College of the City University, New York City, New York
(Received 2 June 1970)

The scattering of moderately high-energy x rays from electrons in magnetic solids is analyzed. We show that (a) the incoherent Compton scattering of polarized x rays can be used to determine the spin-dependent momentum distribution function of electrons in ferromagnetic materials, and (b) the coherent Bragg scattering of unpolarized x rays can be used to determine the magnetic structure of antiferromagnetic solids below their transition temperature.

Recently\textsuperscript{1-3} there has been renewed interest in utilizing x rays to probe the electronic properties of molecules and solids.

In the extreme nonrelativistic limit, the x rays couple exclusively to the charge of the electrons. This implies that for electrons in solids the scattering cross section is independent of the magnetic properties of the medium. However, it is well known that the complete relativistic Compton amplitude does depend on the spin of the electron.\textsuperscript{4}

\begin{equation}
\left( \frac{\hbar \omega}{mc^2} \right)^2 \approx 4 \times 10^{-6}
\end{equation}

Magnetic scattering is a relativistic effect...

dipole reradiation of the scattered field. If one thinks of the electron as a little spinning ball with a radius of the order of the Compton wavelength \( \lambda = \hbar / mc \) then the ratio of magnetic dipole to electric dipole radiation is roughly \( k_0^6 \), i.e., \( \hbar \omega_0 / mc^2 \).

In this paper we will show that mildly relativistic x rays can be used to: (a) measure independently the momentum distributions of spin “up” and spin “down” electrons in magnetic solids, and (b) determine the magnetic crystal structure of antiferro-
Polarization and Resonance Properties of Magnetic X-Ray Scattering in Holmium

Doon Gibbs
Brookhaven National Laboratory, Upton, New York 11973

D. R. Harshman, E. D. Isaacs, and D. B. McWhan
AT&T Bell Laboratories, 600 Mountain Avenue, Murray Hill, New Jersey 07974

D. Mills
Cornell High Energy Synchrotron Source, Cornell University, Ithaca, New York 14853

and

C. Vettier
Institut Laue-Langevin, 38042 Grenoble, Cedex, France

(Received 15 June 1988)

Be measuring the degree of linear polarization we identify the orbital and spin contributions to the x-ray magnetic scattering in holmium. When the incident x-ray energy is tuned through the $L_{III}$ absorption edge, we observe a fivefold resonant enhancement of the magnetic signal, and resonant integer harmonics. The line shapes of the two linear components scattered parallel and perpendicular to the diffraction plane are distinct in energy with a 6-eV splitting.

To get a strong resonant enhancement, the scattering must involve a low-order electric multipole transition ($E1$ or $E2$) between a core level and either an unfilled atomic shell, or a narrow band. In the latter case, the atomiclike nature of the transition is increased because the core hole gives an additional binding of the excited level.

X-Ray Resonance Exchange Scattering

J. P. Hannon and G. T. Trammell
Physics Department, Rice University, Houston, Texas 77251

and

M. Blume and Doon Gibbs
Brookhaven National Laboratory, Upton, New York 11973

(Received 15 June 1988)

Large resonant magnetization-sensitive x-ray scattering is predicted to occur in the vicinity of $L_{II}$, $L_{III}$, and $M_{III}$-$M_{IV}$ absorption edges in the rare-earth and actinide elements, and at the $K$ and $L$ edges in the transition elements. These "magnetic" resonances result from electric multipole transitions, with the sensitivity to the magnetization arising from exchange. For some transitions, the magnetic scattering will be comparable to the charge scattering. The general features of the observed $L_{III}$ resonance in Ho are discussed.

element specific magnetization!
## Relevant absorption thresholds: transition metals

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3d/4d metals, $p \rightarrow d$ transitions
Relevant absorption thresholds: **rare earths**

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Resonant X-Ray Magnetic Scattering, basics

macroscopic view: dielectric constant
\[ n(\lambda) = \sqrt{\epsilon(\lambda)} = 1 - \delta(\lambda) + \imath \beta(\lambda) \]

microscopic view: atomic scattering factors
\[ n(\lambda) = 1 - \frac{\tau_e}{2\pi} \lambda^2 \sum_i N_i f_i(\lambda, \bar{q} = 0) \]

Resonant part of atomic scattering factor in the dipole approximation (\( F_{LM} \) are transition matrix elements)
\[
\begin{align*}
\hat{f}_{E_1}^{(xres)} &= \frac{3}{8\pi} \lambda [\epsilon_f^* \cdot \epsilon_0 (F_{11} + F_{1-1}) \\
&\quad - \imath (\epsilon_f^* \times \epsilon_0) \cdot \hat{m} (F_{11} - F_{1-1}) \\
&\quad + (\epsilon_f^* \cdot \hat{m}) (\epsilon_0 \cdot \hat{m}) (2F_{10} - F_{11} - F_{1-1})],
\end{align*}
\]

Circular dichroism: (forward direction) \( \epsilon_f = \epsilon_0 = \epsilon_L = x + \imath y \). Therefore, \( \epsilon_L^* \times \epsilon_L = z = k \). That is why \( \text{XMCD} \propto k.m \)

X-ray Magnetic Circular Dichroism: Sum Rules

orbital moment

\[ m_{\text{orb}} = -\frac{4 \int_{L_3+L_2} (\mu_+ - \mu_-) \, d\omega}{3 \int_{L_3+L_2} (\mu_+ + \mu_-) \, d\omega} (10 - n_{3d}) \]

spin moment

\[ m_{\text{spin}} = -\frac{6 \int_{L_3} (\mu_+ - \mu_-) \, d\omega - 4 \int_{L_3+L_2} (\mu_+ - \mu_-) \, d\omega}{\int_{L_3+L_2} (\mu_+ + \mu_-) \, d\omega} (10 - n_{3d}) \left( 1 + \frac{7\langle T_z \rangle}{2\langle S_z \rangle} \right)^{-1} \]


---

X-Ray Circular Dichroism and Local Magnetic Fields

Paolo Carra, (1) B. T. Thole, (1,2) Massimo Altarelli, (1) and Xudong Wang (3)

(1) European Synchrotron Radiation Facility, BP 220, F-38043 Grenoble CEDEX, France
(2) Department of Chemical Physics, Materials Science Center, University of Groningen, Nijenborgh 16, 9747 AG Groningen, The Netherlands
(3) Ames Laboratory and Department of Physics and Astronomy, Iowa State University, Ames, Iowa 50011

(Received 13 July 1992)

Sum rules are derived for the circular dichroic response of a core line (CMXD). They relate the intensity of the CMXD signal to the ground-state expectation value of the magnetic field operators (orbital, spin, and magnetic dipole) of the valence electrons. The results obtained are discussed and tested for transition metals and rare earths.
X-Ray Microscopy using low-energy electrons
X-ray Microscopy: Dark ages!

focusing optics

Figure 1. The crossed-1D-lenses focusing scheme developed by Kirkpatrick and Baez using elliptical profile mirrors [6]. At top left is an illustration from Kirkpatrick’s 1949 contribution to *Scientific American* [7], where the editor’s blurb in the table of contents stated “The X-ray Microscope: It would be a big improvement on microscopes using light or electrons, for X-rays combine short wavelengths, giving fine resolution, and penetration. The main problems standing in the way have now been solved.” At bottom is a three-mirror sys-

Point-projection microscopy

The history and future of X-ray microscopy

To cite this article: J Kirz and C Jacobsen 2009 *J. Phys.: Conf. Ser.* 186 012001
A Scanning X-Ray Microscope Using Synchrotron Radiation

Abstract. Focused synchrotron radiation collimated by means of a pinhole has been used to construct a scanning x-ray microscope capable of making stereoscopic element-discriminating pictures of relatively thick specimens in an atmospheric environment.

Paul Horowitz; John A. Howell


Fig. 2. Transmission micrographs of a 200 mesh per inch (80 grids per centimeter) copper grid at three different magnifications. The faint horizontal and vertical lines in these micrographs are from the oscilloscope graticule.

Obtained by scanning a 2 µm pinhole in front of the sample.
PhotoEmission Electron Microscopy (PEEM): history

Electrons produced by UV light, and accelerated to high voltage (30 kV) can be used for imaging using an electron lens.


Fig. 2. PEEM image of a polycrystalline Pt foil after annealing at high temperature, showing work function contrast and grain boundary grooving, taken with the instrument shown in Fig. 1.
Adapted from Ref. [13].

Fig. 5. UVPEEM images. Top: Occlusion in an Al alloy with very fine grains. Bottom: Basalt with augite dendrites.
Adapted from Ref. [36].

Polycrystalline Pt foil.

Same instrument, 1934!

Engel, 1970, group of Ruska
Photoyield spectromicroscopy of silicon surfaces using monochromatic synchrotron radiation

B. P. Tonner and G. R. Harp
Department of Physics and Laboratory for Surface Studies, University of Wisconsin–Milwaukee, Milwaukee, Wisconsin 53211

(Received 23 May 1988; accepted 3 September 1988)

A photoemission electron microscope has been used to generate spatial maps of silicon surfaces, along with chemical spectroscopy of the silicon core levels at micron-scale spatial resolution. The electron optics permits scanned photon energy imaging of the sample surface, with image capture at video rates in a 512×512 pixel buffer memory. The image is generated primarily by low-energy secondary electrons produced by photoabsorption. Near-edge structure in the image photoyield as a function of photon energy is used to determine the oxidation state of microscopic regions of the surface of a single-crystal Si(111) sample. These measurements show that spectroscopic imaging with 100-nm resolution will be possible using undulator generated synchrotron radiation.

Low energy electron microscopy


Figure 1. Surface imaging methods with a cathode lens. For explanation

Ernst Bauer

Ernst Bauer is leading the charge also in making XPEEM/LEEM an essential instrument in synchrotron laboratories.
PEEM + LEEM: SPELEEM

PEEM

Magnetic separator

Spectroscopic Photoemission and Low Energy Electron Microscope

electron source

energy analyzer

magnetic separator
Microscopy aspect: Resolution

\[ \delta^2 = \delta^2_c + \delta^2_s + \delta^2_D \]

chromatic aberrations
spherical aberrations
Diffraction limit

Fig. 10. The resolution-determining factors of the homogeneous acceleration field. The solid curve is the resolution in nm as a function of the angle-limiting aperture \( r_A \) for a potential difference of 25 kV, a field length of 3 mm, a start voltage of 2.5 eV and an energy width of 0.25 eV.

LEEM Basics, Ernst Bauer
PEEM @ Synchrotron: Resolution, space-charge effects

LEEM

1 µm

2.0 \times 10^{12}

1.4 \times 10^{13}

2.5 \times 10^{13}

3.4 \times 10^{13}

ph/s

XPEEM

space-charge effects in the photoelectron cloud

energy resolution

spatial resolution

energy resolution

Locatelli et al., Ultramicroscopy 111, 1447 (2011)
XPEEM/LEEM: Intensity vs energy

XPEEM

Intensity vs energy for Carbon, with a photo-effect indicated.

LEEM

Intensity vs energy for Pt(111) and W(110), with different energy values indicated:
- Pt(111) at 13.6 eV
- W(110) at 27.2 eV

Additional references:
- X-Ray Data Booklet
- LEEM Basics, Ernst Bauer
XPEEM/LEEM: **Contrast + Information**

**LEEM:** electron diffraction morphology

- Au / W(110)
- Image size: 10 µm
- Start voltage: 7 eV
- Spatial resolution: 12 nm

**XPEEM:** XPS, XAS, XMCD chemistry, magnetism

- Au 4f XPS
  - $h\nu = 143.5$ eV
  - Analyzer slit: 0.3 eV
  - Contrast aperture: 30 µm
  - Spatial resolution: 25 nm
XPEEM/LEEM: **Contrast + Information**

**μ-LEED:** crystal structure

**μ-ARPES:** electronic structure

- **TiO2(110),** start voltage = 31 eV
  - probe area : 2 µm
  - angular res : 0.08 Å⁻¹

- **Pd(1x1)/W(110), Valence Band**
  - hv = 80 eV
  - start voltage = 75.4 eV
  - analyzer slit : 0.3 eV
  - probe area : 2 µm
  - angular res : 0.08 Å⁻¹
XMCD-PEEM: Magnetic Microscopy


elemental cobalt film

Photon energy 777 eV (Co L₃ edge)
Photoelectron kinetic energy = 1.5 eV (secondary peak)
4. Bimetallic alloys and phase separation

*Fe-Ni films on W(110)*
Fe-Ni phase diagram: miscibility gap near Invar

---

**Astronomical times:**

**Defect creation via ion bombardment:**

---

Fig. 2—Fe-Ni phase diagram proposed by Ruster et al.\(^{10}\) based on the investigation of iron meteorite structures, electron irradiated alloys, and the calculated Fe-Ni phase diagram by Chuang et al.\(^{15}\) The dotted/dashed line labeled \(M\) indicates the temperature below which martensite (\(\alpha\)) forms. The dashed lines are metastable phase boundaries below 400 °C, which emanate from the tri-critical point, and the hatched lines delineate the spinodal decomposition region within the metastable two-phase field. The dotted/dashed line labeled \(T_{\gamma}\) indicates the Curie temperature. Experimental data are shown as filled triangles from X-ray microanalysis of iron meteorites and as filled rectangles from electron irradiated alloys.

---

Fig. 4—TEM of Fe-Ni alloy aged at 400 °C (450FN15) showing intergranular precipitates. \(G\) indicates the \(\gamma\) precipitates.
Fe(70%) + Ni(30%) codeposition on W(110)

LEED @ 42 eV

1.0 ps-ML

1.22 ps-ML

2.2 ps-ML

5.4 ps-ML

14.7 ps-ML

[110]

[001]

Intensity (Arb. Units)

Time (s)

(0,0)

(1,0)

(1x8)

superstructure
Fe(70)Ni(30) / W(110): annealing, phase separation

LEEM @ 19 eV

Fe(70)Ni(30) / W(110): phase separation kinetics

Fractional fcc coverage vs time

Time evolution is nearly an exponential. **Stretched exponential** function fits better!
Fe(70)Ni(30) / W(110): fcc / bcc phase separation

DF-LEEM

Local thickness map

fcc islands are on average thicker than bcc film

LEEM I(V)

fcc islands are on average thicker than bcc film
Fe(70)Ni(30) / W(110): fcc / bcc composition: XPS

Fe 3p and Ni 3p core-levels XPS as a function of photon energy

hv = 250 eV
bcc : Fe$_{0.66}$Ni$_{0.34}$
fcc : Fe$_{0.51}$Ni$_{0.49}$

hv = 350 eV
bcc : Fe$_{0.72}$Ni$_{0.28}$
fcc : Fe$_{0.58}$Ni$_{0.42}$

hv = 650 eV
bcc : Fe$_{0.77}$Ni$_{0.23}$
fcc : Fe$_{0.62}$Ni$_{0.38}$

Figure 25. Summary plot of calculated IMFPs for the 41 elemental solids (Table 4) as a function of electron energy.
Fe(70)Ni(30) / W(110): fcc / bcc composition: XAS

- Ni moves around!
- bcc composition: $\text{Fe}_{0.77}\text{Ni}_{0.23} \pm 0.03$
- fcc composition: $\text{Fe}_{0.51}\text{Ni}_{0.49} \pm 0.05$

Fe, XAS-PEEM

Ni, XAS-PEEM

use secondaries for XAS
How to write an experimental proposal??!
Fe(70)Ni(30) / W(110): oxidation

exposure to molecular oxygen

Mössbauer

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Binding Energy (eV)

Fe₃O₄ interface

Genuzio et al., J. Mater. Chem. C 8, 5777-5785 (2020)
Fe metal-oxide coupling: reference spectra

![Graph showing Fe metal and Fe$_3$O$_4$ spectra](image)

- **Fe L$_{2,3}$ MCD**
- **X 0.5**
- **Photon Energy (eV)**
Fe(70)Ni(30) / W(110): metal-oxide coupling

Genuzio et al., J. Mater. Chem. C 8, 5777-5785 (2020)
6. Coherent Diffraction Imaging

in an XPEEM setup
Coherent X-Ray Diffraction Imaging

**REVIEW OF IMAGE FORMATION METHODS**
**WITH THE SOFT X-RAY PHOTON**

D. Sayre

IBM T. J. Watson Research Center
Yorktown Heights, New York 10598

1980

hologram. In column 6, soft x-ray diffraction patterns have been recorded from samples composed of small polystyrene latex spheres, but no construction of images appears to have been done. This will require (as in crystallography) a method of phasing the diffraction pattern. In addition, in order to be useful in biological imaging, the experiment must be modified to collect the diffraction pattern of a single biological cell or organelle. Finally, in column 7, the require-
Implementing CDI within the SPELEEM setup

Implement CDI @ Nanospectroscopy

Reflection geometry @ 16° grazing

XPEEM

MCP

CDI

X-rays

Sample

Preliminary experiments

Menteş et al., Ultramicroscopy 216, 113035 (2020)
Implementing CDI within the SPELEEM setup

Implement CDI @ Nanospectroscopy

Reflection geometry @ 16° grazing

XPEEM

Implementing CDI within the SPELEEM setup

Preliminary experiments

Simulated speckle pattern

XPEEM image at 100 eV

10 µm

Speckles at 100 eV

10 µm

Fe micro-structures
Out-of-plane magnetic stripes in a Co film

XAS-PEEM, Co L$_3$ @ 779 eV

W/Co/AuPt, collaboration with J. Vogel, S. Pizzini

XMCD-PEEM

Simulated speckles

Magnetic peak

Specular beam outside
Stripe period vs relative domain coverage

Magnetic diffraction peak across the hysteresis curve

fit function: \( p / \cos\left(\frac{\pi}{2} \left( \frac{i - i_c}{i_s} \right) \right) \)

- \( p = 238.77 \pm 0.536 \) nm
- \( i_c = 686.95 \pm 32.7 \) mA
- \( i_s = 7852 \pm 139 \) mA

- \( p = 236.94 \pm 0.409 \) nm
- \( i_c = -760.92 \pm 22.4 \) mA
- \( i_s = 7676.1 \pm 89 \) mA
Thanks for your attention.

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https://www.elettra.eu
https://www.elettra.eu/elettra-beamlines/nanospectroscopy.html