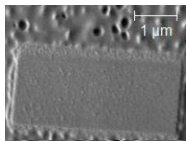
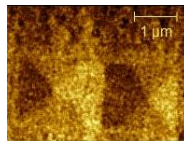


Scanning Electron Microscopy with Polarization Analysis



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European School on Magnetism

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Outline of the presentation

- 1 Scanning Electron Microscopy with Polarization Analysis
- 2 Auger electron spectroscopy
- 3 Imaging – Patterned Fe layer

Scanning Electron Microscopy with Polarization Analysis

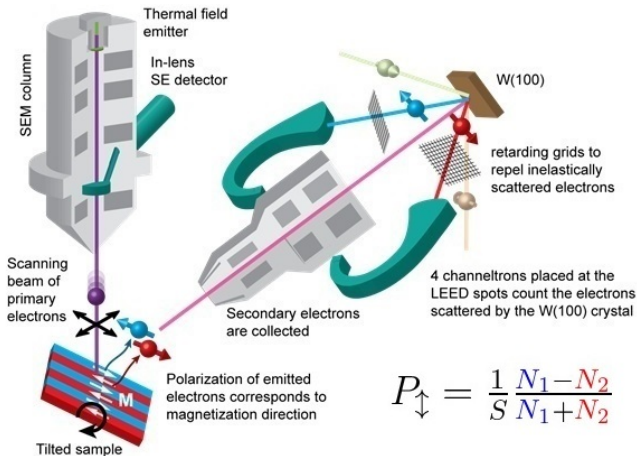


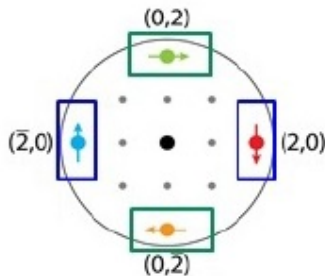
image: <https://www.klaeui-lab.physik.uni-mainz.de>

Excitation: un-polarized e-beam (common SEM)

Detection: Spin-dependent scattering of secondary electrons on W

Spin detection: Spin Polarized Low Energy Electron Diffraction (SP-LEED)

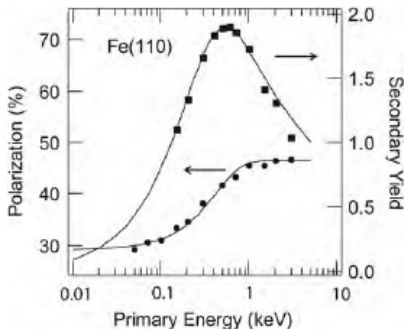
Spin-dependent spots in the LEED pattern from W(100)



<https://www.klaeui-lab.physik.uni-mainz.de>

- very poor efficiency of detection: 10^{-4} (ideal conditions)
- longer image acquisition (at least minutes)
- projection of spin onto 2 orthogonal directions
- UHV required (10^{-10} mbar; the lower the better)
- clean W crystal (flashing 2300 K daily, 1500 K each 30-60 min)

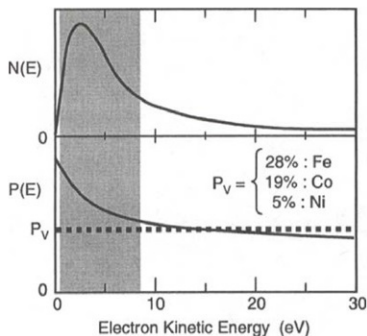
SEMPA: Primary beam energy selection



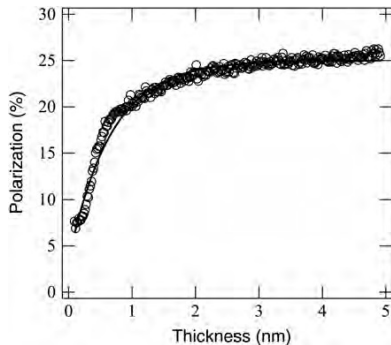
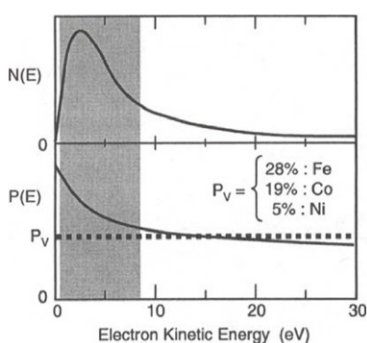
- Highest yield of secondary electrons at low primary beam energies (≈ 1 keV, material dependent)
- Polarization of secondary electrons saturates at higher energies
- Best signal: ≈ 1 keV & high beam current; **but bad spatial resolution**
Best resolution: high energy & low beam current; **but lower signal**

Koike, *Microscopy* **62**(1), 177–191 (2013)

SEMPA: Surface sensitivity (first 1 nm of your sample)



SEMPA: Surface sensitivity (first 1 nm of your sample)



N number of electrons, P polarization

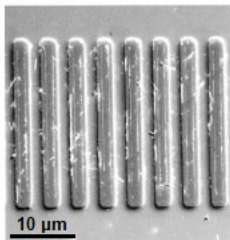
Major signal contribution: low energy secondary electrons

Unguris, *Experimental Methods in the Physical Sciences* 36, chap. 6, 167-193, (2001).

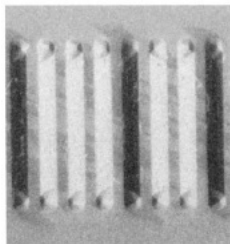
Right image (FeO) – Koike, *Microscopy* 62(1), 177–191 (2013).

Extreme surface sensitivity – How to get nice surface?

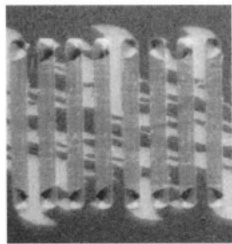
- In-situ cleaning (ion sputtering) – our case
- In-situ sample fabrication
- Decoration technique: in-situ deposition of thin Fe layer on top



Topography



⇕ P

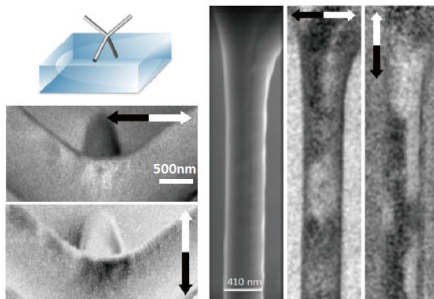


⇔ P

Oepen et al., *JVSTB* **20**, 2535 (2002)

SEMPA – Advanced

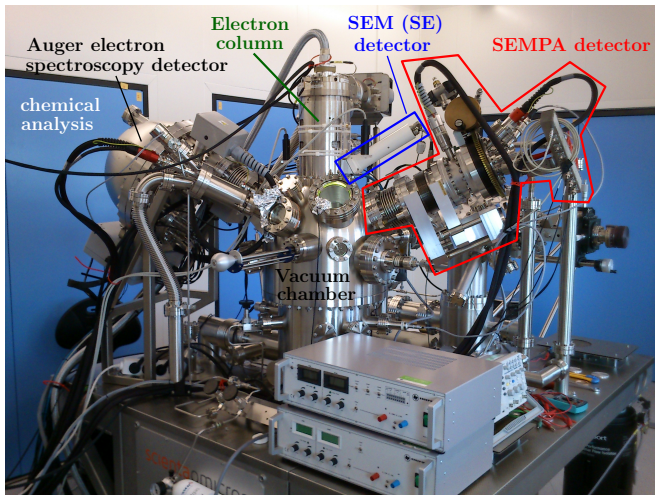
- High resolution down to 5 nm (special optics design)
Kohashi et al., J. Electron Microsc. 59(1), 43–52 (2010)
- Time-resolved (700 ps) imaging: magnetization dynamics
Frömter et al., APL 108, 142401 (2016)
- Imaging of 3D structures
Williams et al, Nano Res. 11(2), 845-854 (2018)



SEMPA: Advantages & Drawbacks

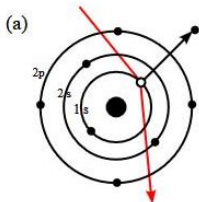
- rather expensive and complex instrument
- sample preparation – clean surface needed: UHV, in-situ cleaning (ion sputtering)
- slow acquisition (minutes, good signal/noise may require 30 min or more)
- surface sensitive
- + surface sensitive
- + high resolution (electron beam spot limited, < 10 nm ultimate)
- + probes magnetization simultaneously in 2 orthogonal directions (can be changed to get both IP and OOP)
- + high depth of focus – possibility to image surface of 3D structures

Instrumentation at CF Nano: NanoSAM+SEMPA

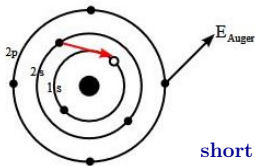
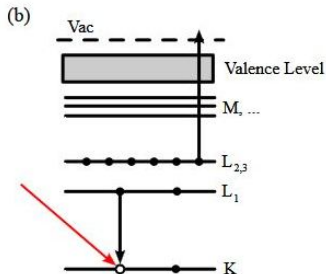


Meitner–Auger effect

Named after Pierre Auger, first discovered by [Lise Meitner](#) (1922).



Electron collision



Auger electron emission

Kinetic energy of Auger e^-

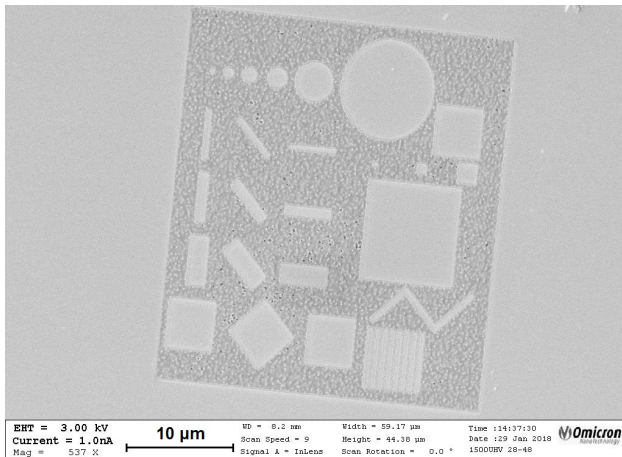
$$E_{\text{kin}} = E_{\text{core state}} - E_B - E_C$$

$$E_{\text{kin}} = K - L_1 - L_{2,3}$$

short escape length $\rightarrow$ surface sensitivity
chemical analysis, mapping

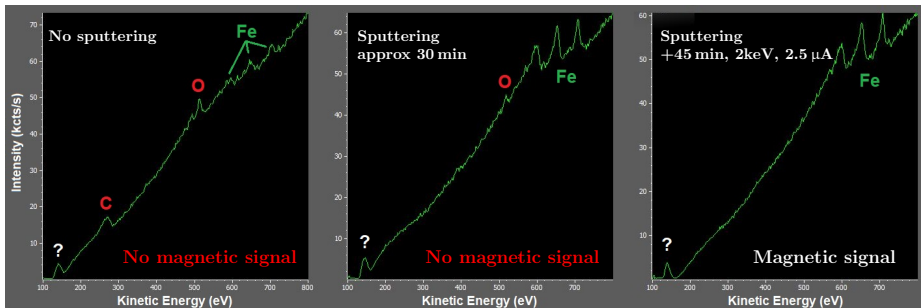
Test sample – patterned Fe layer

Fe layer (thickness 50 nm) — FIB-patterned ([Lukáš Flajšman](#))



Auger electron spectroscopy: Surface sputtering

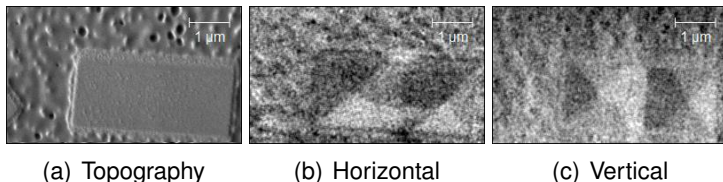
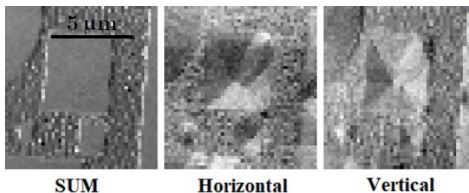
Ar sputtering: $5 \cdot 10^{-8}$ mbar Ar, 2 keV, 2.5 μ A ion beam current, defocused spot (hundreds of μ m) + raster scan



- Clean surface needed for SEMPA magnetic imaging
- Contamination (C) or oxidation (O) → no magnetic signal

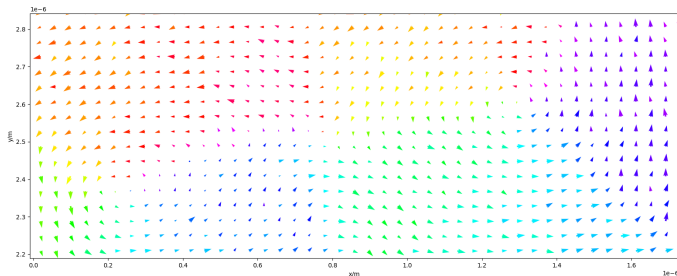
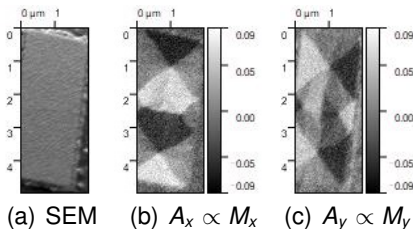
First tests – magnetic imaging (magnetic vortices)

Magnetic vortices in Fe square/rectangles – rough imaging



Acquisition time: several min to tens of min (for better signal/noise)
10 mm working distance; primary beam 2 keV, 1 nA, sample tilt 30°

SEMPA imaging during ESM practicals



(d) Processed magnetization map of center: Vortex, anti-vortex, vortex