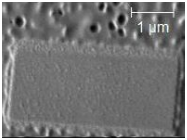
Scanning Electron Microscopy with Polarization Analysis



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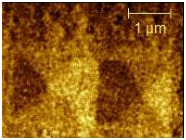

European School on Magnetism

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THE EUROPEAN SCHOOL ON MAGNETISM

CEITEC Central European Institute of Technology BRNO | CZECH REPUBLIC

BRNO UNIVERSITY OF TECHNOLOGY

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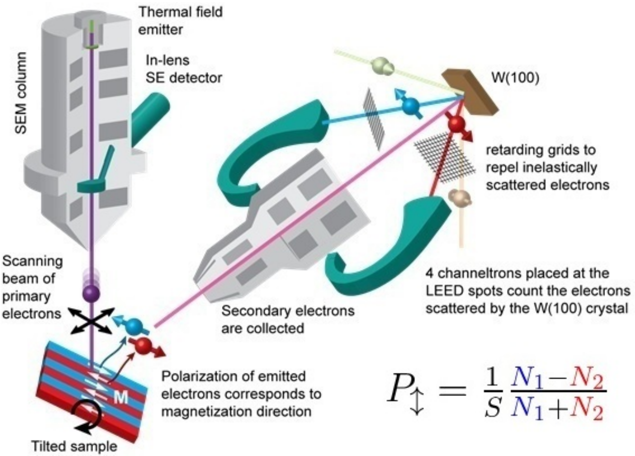
Outline of the presentation

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

Scanning Electron Microscopy with Polarization Analysis



$$P_{\updownarrow} = \frac{1}{S}\frac{N_1 - N_2}{N_1 + N_2}$$

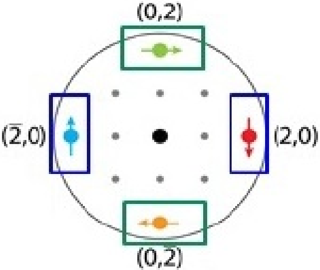
image: https://www.klaeui-lab.physik.uni-mainz.de

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

Detection: Spin-dependent scattering of secondary electrons on W

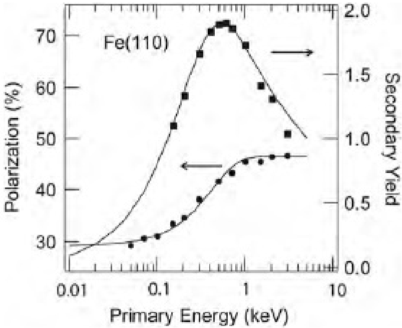
Spin detection: Spin Polarized Low Energy Electron Diffraction (SP-LEED)

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



- 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^{-11} mbar)
- clean W crystal (flashing 2300 K daily, 1500 K before each image)

SEMPA: Primary beam energy selection

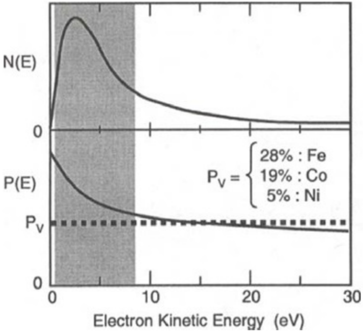


- Highest yield of secondary electrons at low primary beam energies (≈ 1 keV, material dependent)
- Polarization of secondary electrons saturates at higher energies

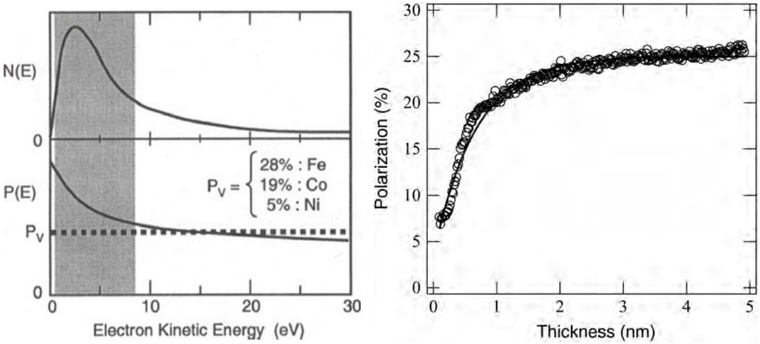
- Best signal: ≈ 1 keV & high beam current; but bad spatial resolution
  Best resolution: high energy & low beam current; but lower signal

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)



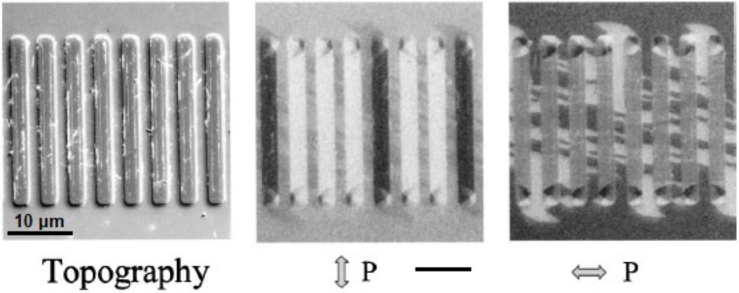
N number of electrons, P polarization

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?

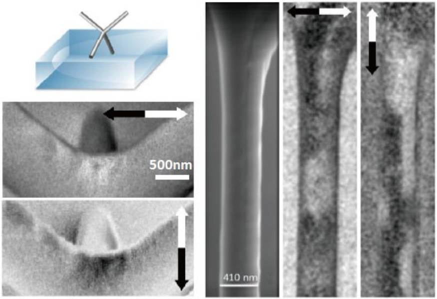
- In-situ cleaning (ion sputtering) – our case
- In-situ sample fabrication
- Decoration technique: in-situ deposition of thin Fe layer on top



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

SEMPA – Advanced

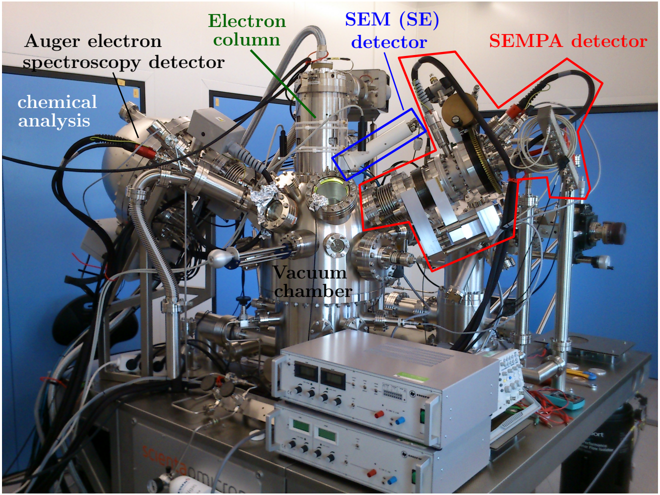
- High resolution downto 5 nm (special optics design)
  Kohashi et al., *J. Electron Microsc.* **59**(1), 43–52 (2010)
- Time-resolved (700 ps) imaging: magnetization dynamics
  Frömter et al., *APL* **108**, 142401 (2016)
- Imaging of 3D structures
  Williams et al, *Nano Res.* **11**(2), 845-854 (2018)



SEMPA: Advantages & Drawbacks

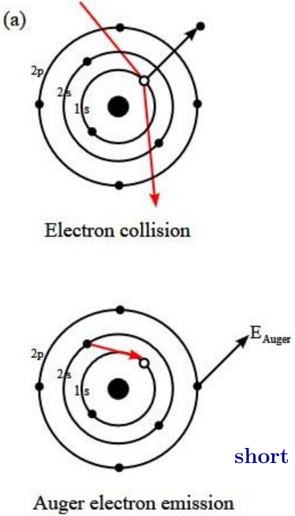
- \- rather expensive and complex instrument
- \- sample preparation – clean surface needed: UHV, in-situ cleaning (ion sputtering)
- \- slow acquisition (minutes, good signal/noise may require 30 min or more)
- \- surface sensitive
- \+ surface sensitive
- \+ high resolution (electron beam spot limited, < 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

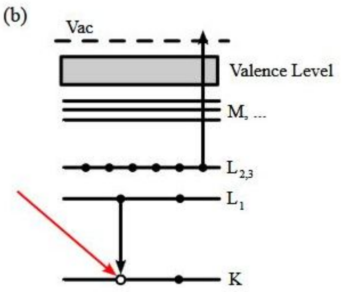
Instrumentation at CF Nano: NanoSAM+SEMPA



Auger effect

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





Kinetic energy of Auger e^-

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

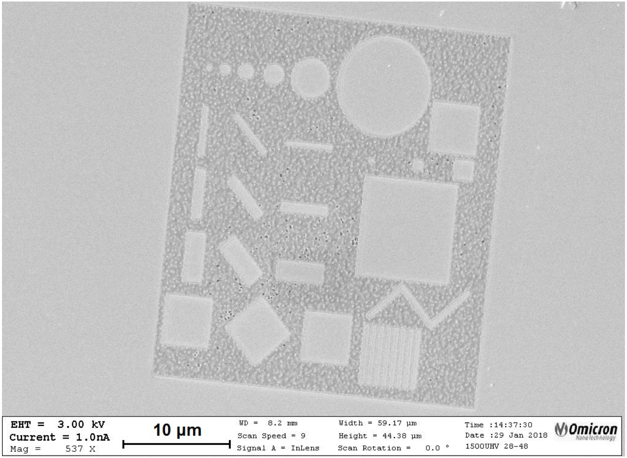
$E_{kin} = K - L_1 - L_{2,3}$

short escape length → surface sensitivity

chemical analysis, mapping

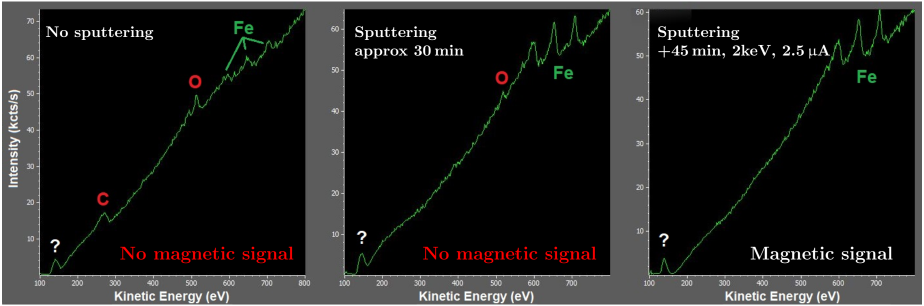
Test sample – patterned Fe layer

Fe layer (**thickness 50 nm**) — FIB-patterned (Lukáš Flajšman)



Auger electron spectroscopy: Surface sputtering

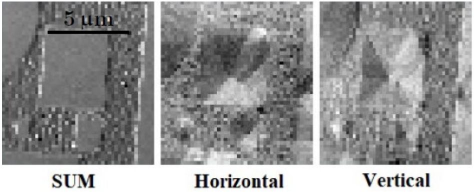
Ar sputtering: $5 \cdot 10^{-8}$ mbar Ar, 2 keV, 2.5 µA ion beam current, defocused spot (hundreds of µm) + raster scan

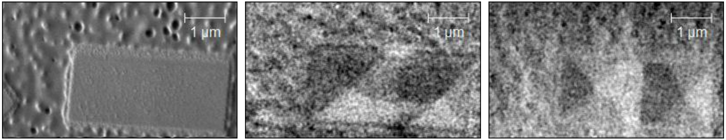


- Clean surface needed for SEMPA magnetic imaging
- Contamination (C) or oxidation (O) → no magnetic signal

First tests – magnetic imaging (magnetic vortices)

Magnetic vortices in Fe square/rectangles – rough imaging

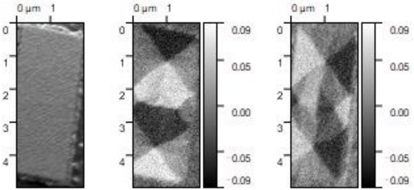




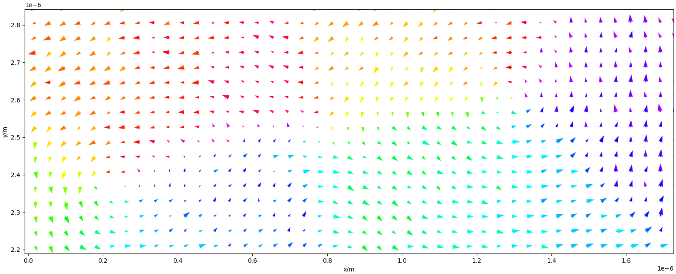
(a) Topography (b) Horizontal (c) Vertical

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



(a) SEM (b) $A_x \propto M_x$ (c) $A_y \propto M_y$



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