# Characterization techniques for nano-sized systems

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Nanomagnetism and spintronic effects arise at some characteristic length scales, so that nanosized systems are intrinsically required. The length scales may have a micromagnetic origin (anisotropy exchange length, Bloch parameter, period of spin waves etc.) or transport origin (spin mixing or spin diffusion length etc). They range from typically one to a few hundreds of nanometers, and may pertain to film thickness for stacked systems, or lateral dimensions in any system. Extrinsic effects related to the microstructure of materials are also important, for both fundamental physics and devices, involving again similar length scales in most cases. Thus, the investigation of nanomagnetism and spintronic systems raises two constraints: on the sensitivity due to the small amount of material considered, and on extracting spatially resolved information. Accordingly, in this lecture I will provide an overview of 1/ the physical effects of use in techniques for probing nanosized systems; 2/ magnetic-resolving microscopies based on these effects, highlighting their features, pros and cons.

Sensitive magnetic measurement techniques may rely on:

- The Interaction of matter with polarized light: visible to X-rays, with effects of dichroism, birefringence and scattering.
- The interaction of matter with electrons: spin polarization and related transmission, absorption or scattering, Lorentz force and vector potential.
- Probing the stray field: measuring mechanical forces, spectroscopy, magneto-resistive elements and quantum loops, inductive.

Most techniques based on the above effects can be applied globally or gathering local information to act as a microscopy, via scanning or image reconstruction. The various magnetic microscopy techniques may be examined at the light of various criteria:

- Which quantity is measured: magnetization, induction, stray field, all components or just one, is it element-selective?
- Which amount of material is measured: probing depth, surface versus volume, 2D versus 3D information, sensitivity?
- Compatibility with applied fields, and more generally with environmental conditions: temperature, strain, current.
- Suitability for time resolution.

Along the overview, I will highlight the importance of signal analysis and data reconstruction for the quantitative sake.

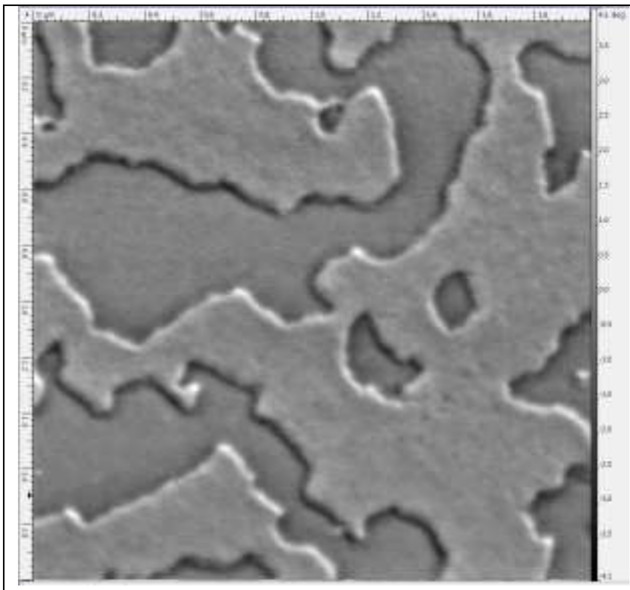

**Illustration of magnetic force microscopy (MFM).** A 2x2 µm image of up/down domains in a FePt(001)° films of thickness 4nm. Low-moment tips are used, highlighting domain walls rather than domains.

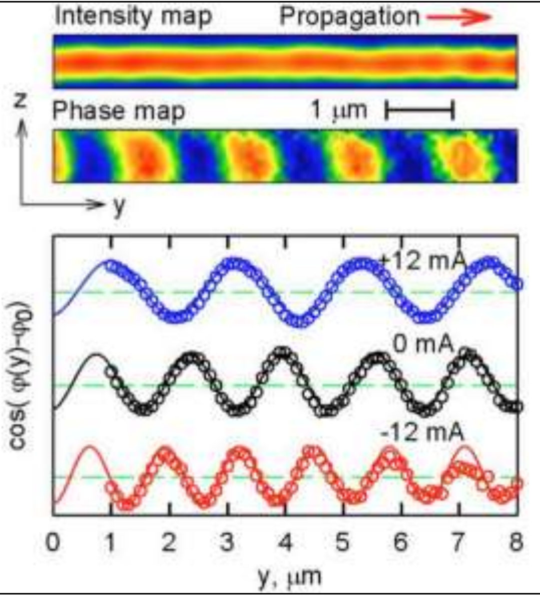


**Illustration of scanning micro-Brillouiin Light Scattering (BLS).** Intensity and phase maps of a spin wave propagation along a permalloy strip under various values of applied magnetic fields [7].

**A few references:**

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[6] R. Wiesendanger, Spin mapping at the nanoscale and atomic scale, Rev. Mod. Phys. 81, 1495 (2009): a review of spin-polarized STM.

[7] T. Sebastian, K. Schultheiss, B. Obry, B. Hillebrands & H. Schultheiss Micro-focused Brillouin light scattering: imaging spin waves at the nanoscale, Front. Phys 3, 35 (2015): illustration of scanning micro-BLS.