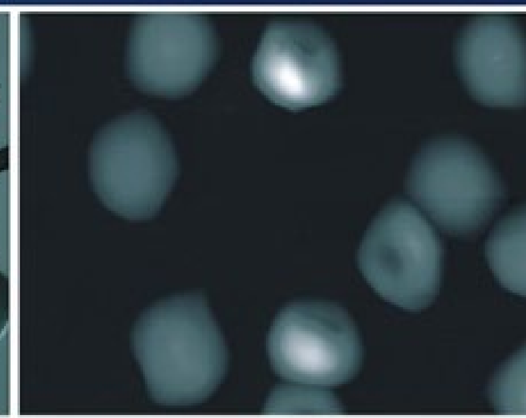
NT-MDT
Spectrum Instruments

Magnetic Force Microscopy – Basics and Application Examples

Prof. Dr. S.O. Demokritov



About Speaker

Prof. Dr. S.O. Demokritov

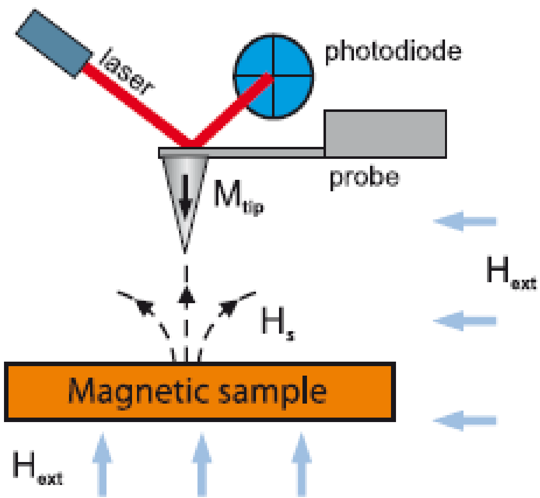
Institute for Applied Physics,
University Münster, Germany

h-index: 31

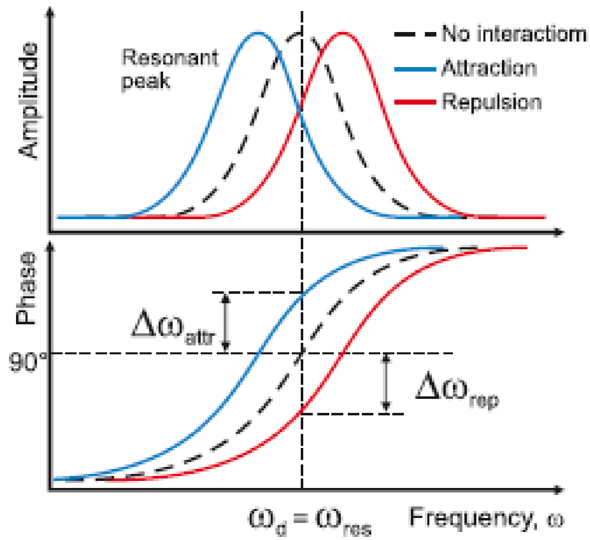
19 books, book chapters, monographs, and review articles
169 original papers in peer reviewed journals, including: Nature (2), Nature Materials (2), Phys. Rev. Lett. (22), Appl. Phys. Lett. (24)
Sum of the times cited: 3591

Magnetic Force Microscopy (MFM)

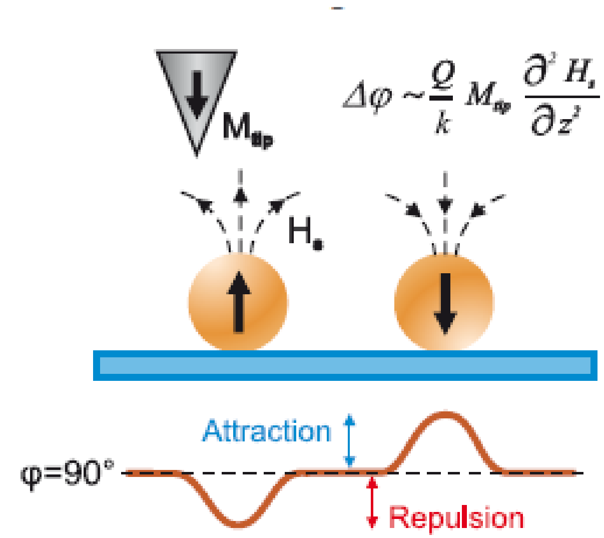
Basic MFM Principles



Scheme of MFM measurements



Principle of phase-detecting dynamic MFM



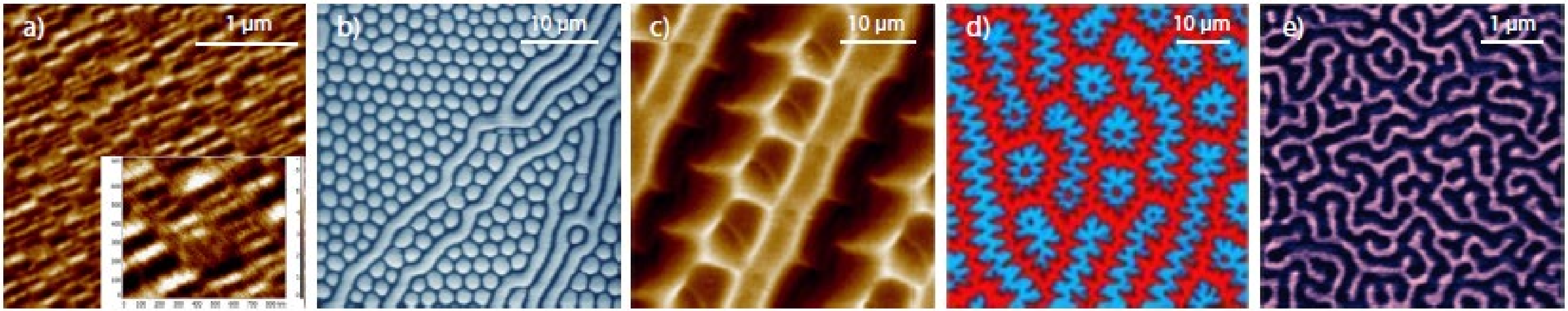
MFM image formation

Obvious difficulties/challenges:

- disturbance of the magnetic structure of the sample by the field of the probe
- remagnetization of the probe by the field of the sample
- vertical non-local imaging

MFM Applications

MFM imaging of the magnetic structures in films, nanoparticles and nanostructures



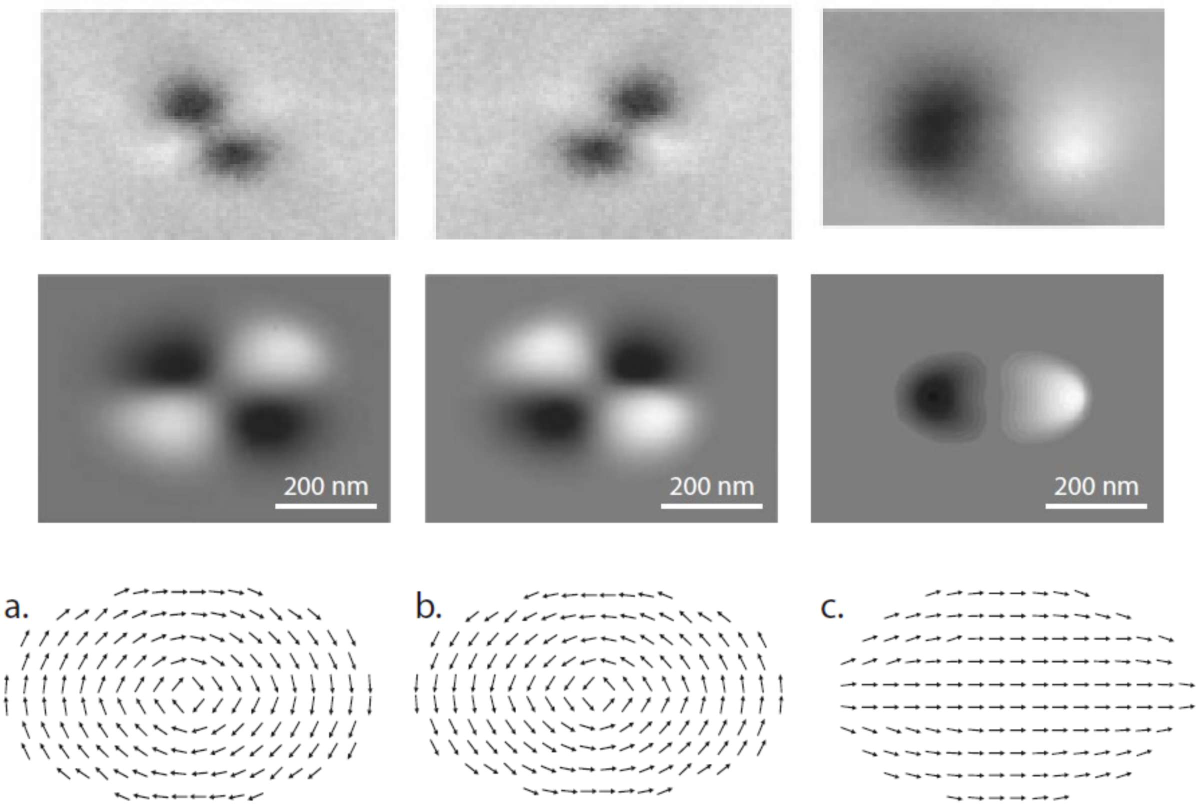
(a) a magnetic structure of a hard disk drive with bit size down to 30–40 nm, which was obtained by cobalt alloy coated probe in ambient conditions;

(b–d) domain structures of different magnetically soft garnet films. Thin magnetic coatings on the tip were utilized in order to reduce disturbance of the sample structure by the tip during measurements;

(e) the domains in Co/Au multilayered structure obtained using a probe with low magnetic moment.

MFM Applications

Elliptical FeCr particles - quantitative MFM



Measured MFM images

Simulated MFM images

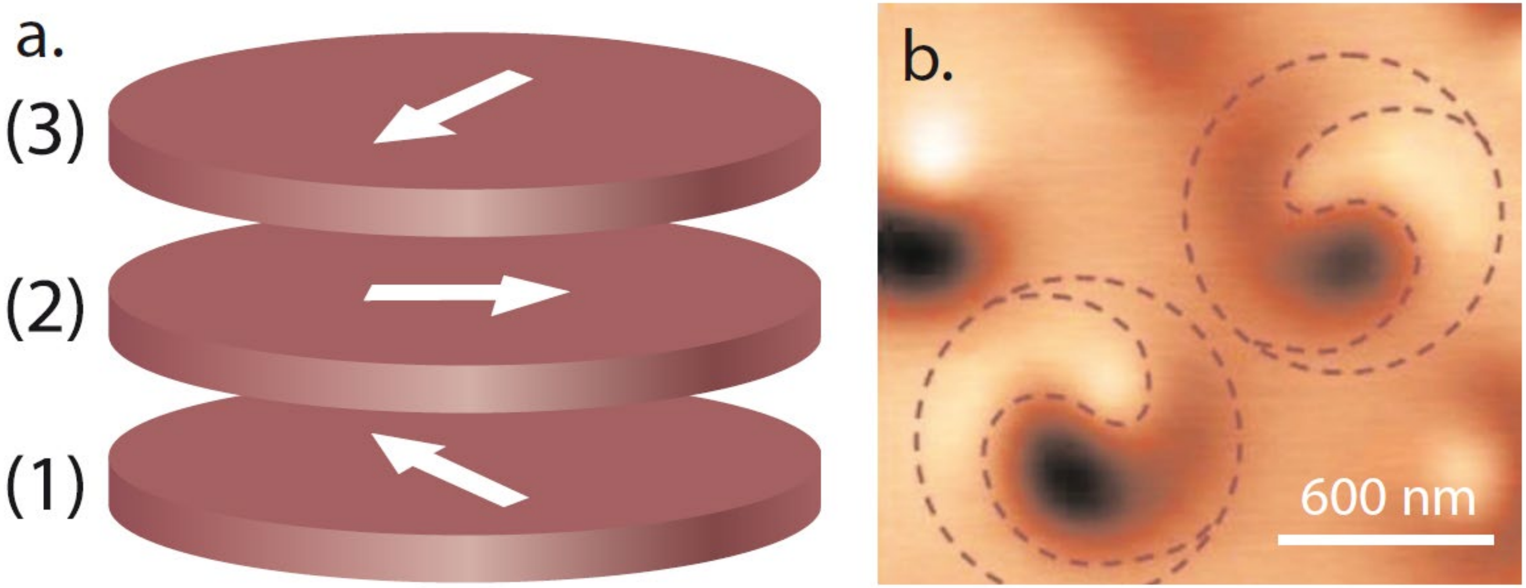
Simulated magnetization distribution

Vortexes with different chiralities (a–b) and a state with uniform magnetization (c)

J. Chang et al. J. Appl. Phys. 100, 104304, 2006.

MFM Applications

Information on the buried layers

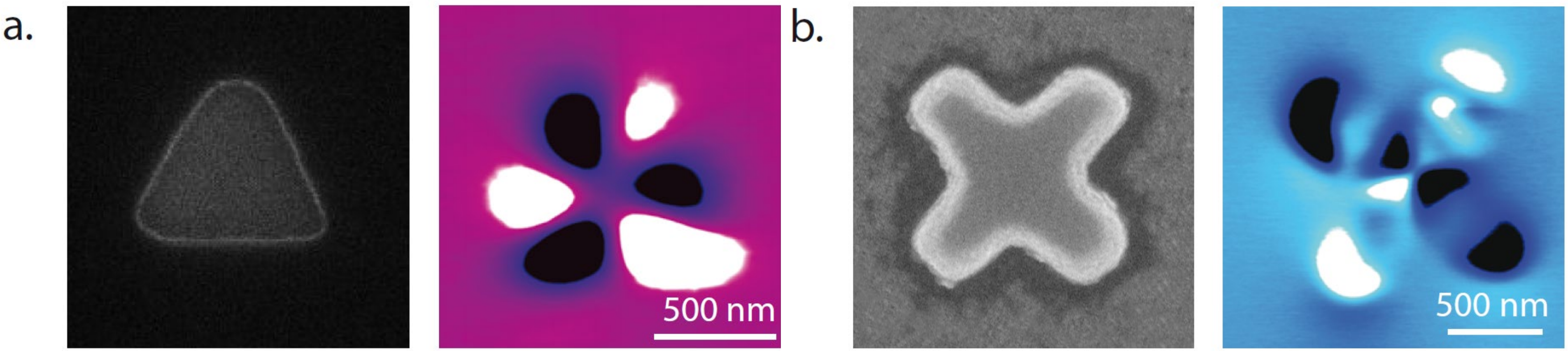


Array of stacks with three Co discs separated by Si layers
(a) scheme of single stack structure; disc diameter is 300 nm
(b) MFM image of two stacks with helical structure with different chirality.

A. A. Fraerman, et al. J. Appl. Phys. 103, 073916, 2008.

MFM Applications

"Nanoengineering" of magnetic states

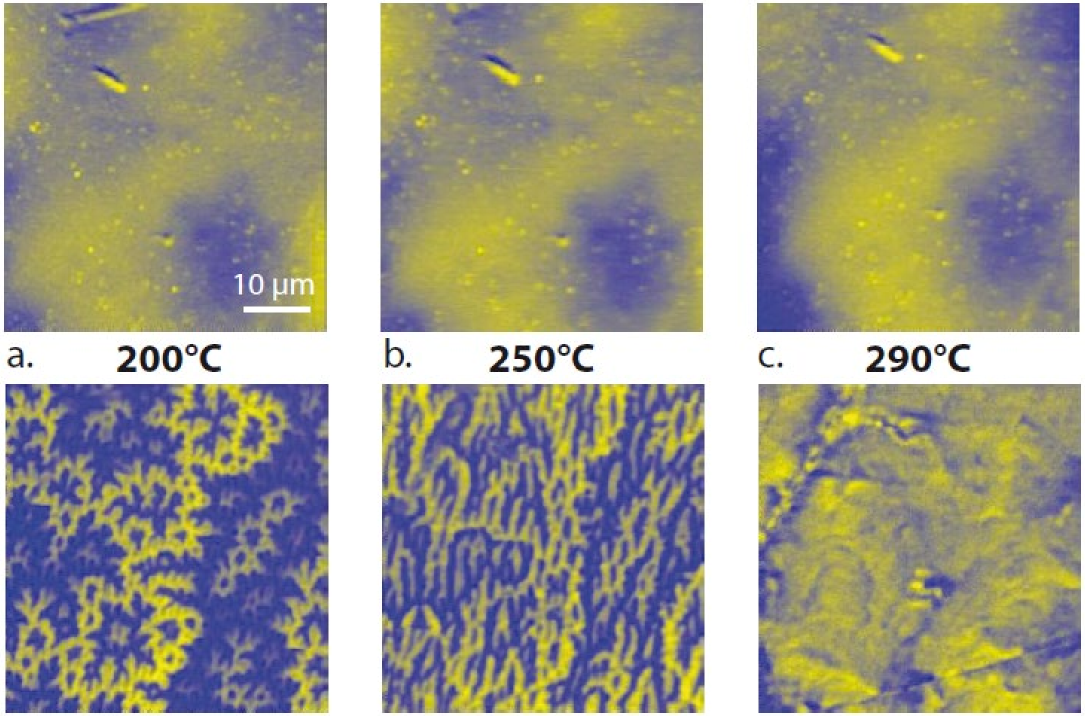


Electron microscopy images (left) and MFM images (right) of triangular and crosslike ferromagnetic Co structures. Magnetic vortex (a) and antivortex (b) are observed

V.L. Mironov et al. Phys. Rev. B . 81, 094436, 2010.
Image courtesy: B. Gribkov, V. Mironov (IPM RAS, Russia)

MFM Applications

Study of magnetic phase transitions



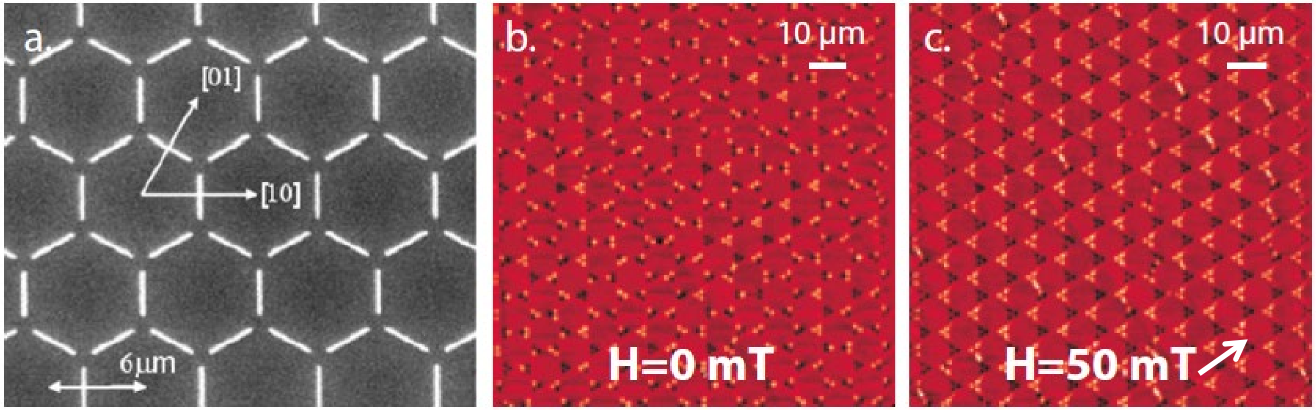
Magnetic phase transition in bulk cobalt single crystal with uniaxial anisotropy studied by in-situ sample heating. Topography (top) and corresponding MFM images (bottom)

The MFM contrast changes are caused by following changes of magnetocrytalline anisotropy under heating: uniaxial anisotropy – easy cone – easy plane.

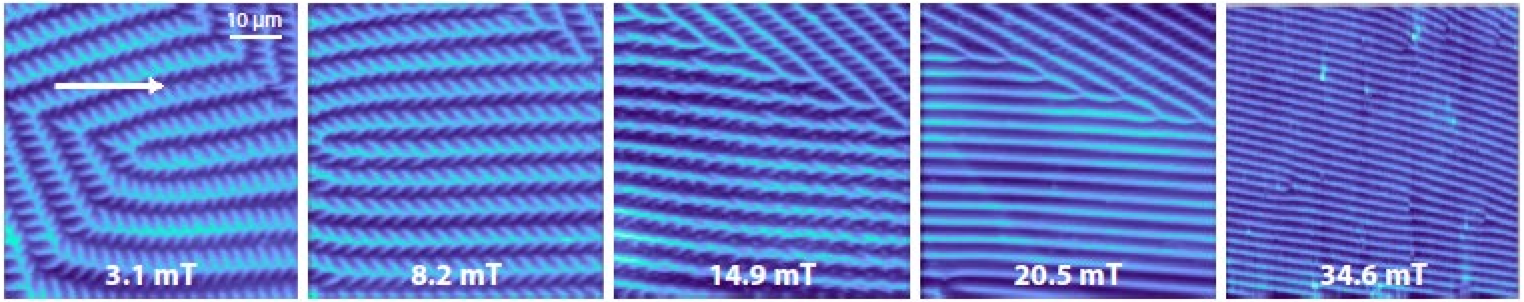
Sample courtesy: Prof. Yu. G. Pastushenkov (Tver State University, Russia).

MFM Imaging with External Magnetic Field

Horizontal external magnetic field



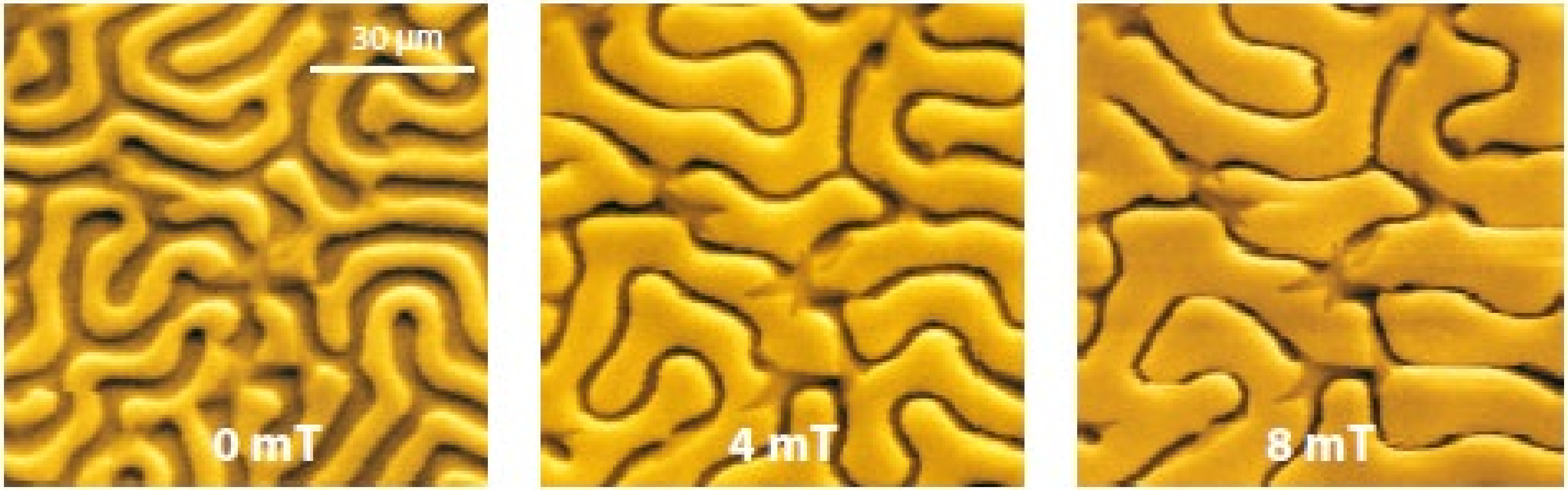
MFM images of artificial spin ice (honeycomb structure of magnetic Fe-bars with dimensions 3 µm ×300 nm ×20 nm)
A. Schumann, et al. Appl. Phys. Lett. 97, 022509 ,2010.



Reorganization of the garnet film domain structure in external horizontal magnetic field. Direction of field is indicated by arrow

MFM Imaging with External Magnetic Field

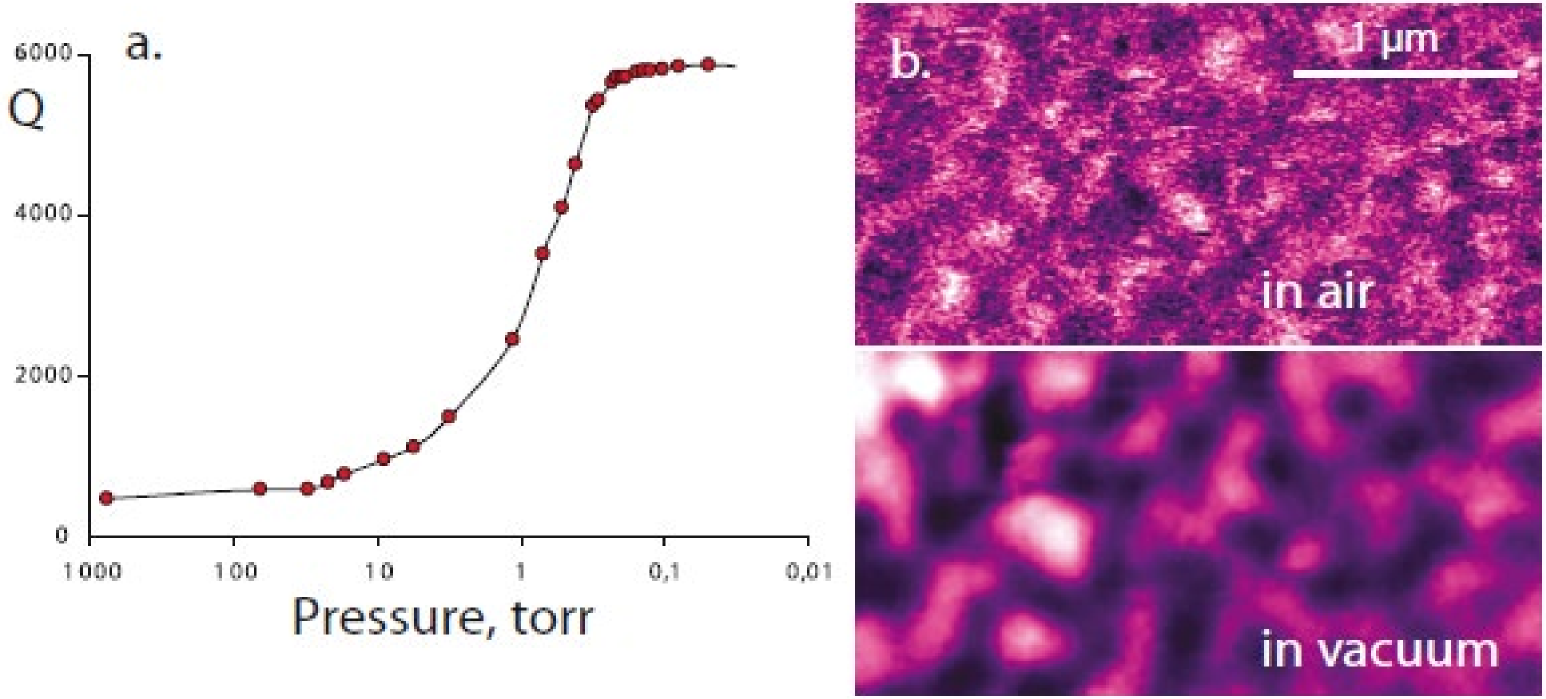
Vertical external magnetic field



MFM images of garnet film in vertical magnetic field. Extension of domains with magnetization direction coinciding with direction of the external field is clearly seen.

Sample courtesy: Prof. F.V. Lisovsky (IRE RAS, Russia).

Much better signal-to-noise ratio due to higher cantilever quality factor



(a). Saturation of cantilever quality factor Q is already achieved in low vacuum.
(b). Improvement of the contrast for MFM vacuum measurements

NTEGRA Aura – Controlled atmosphere

NTEGRA platform

Configuration for research in low vacuum up to 10^{-2} Torr

Or in controlled gaseous environment

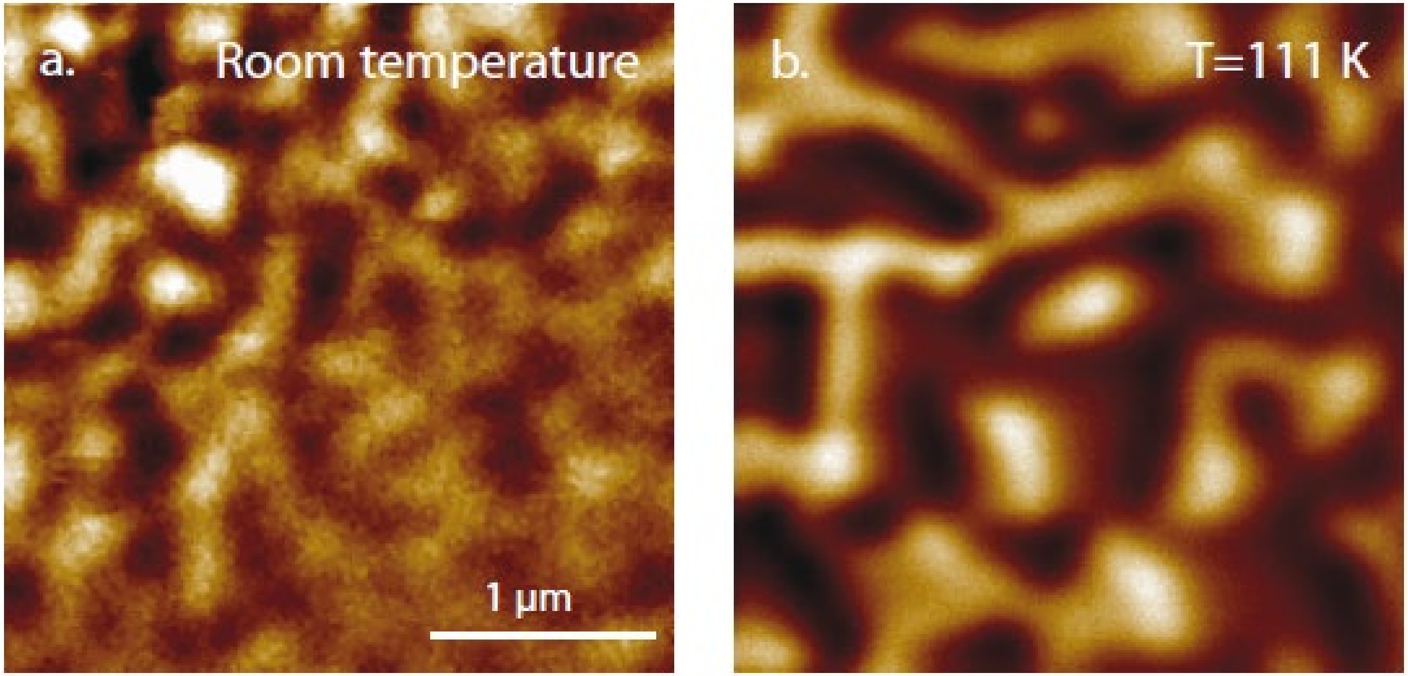
SOLVER HV-MFM

High-vacuum/low-temperature device

SOLVER platform

Research in high vacuum up to $5*10^{-8}$ Torr

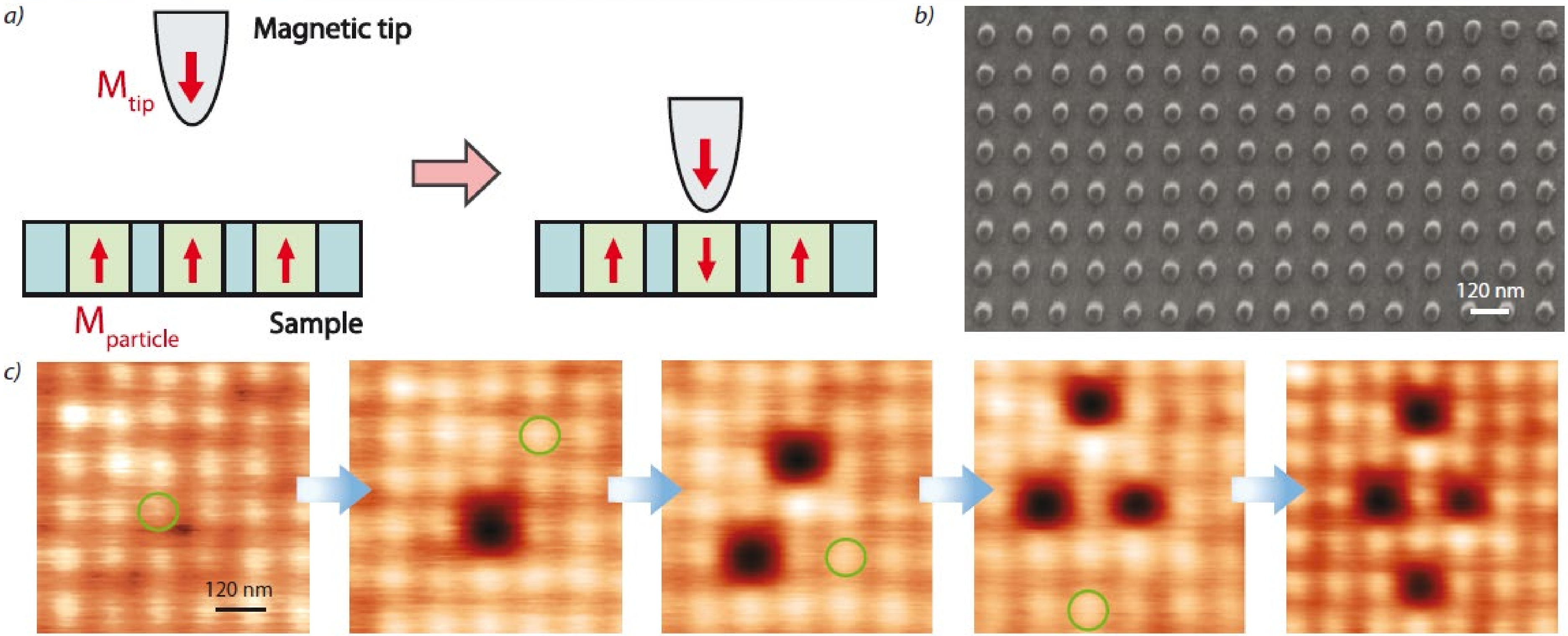
MFM in Vacuum and Low-temperature Measurements



Measurements at low temperatures require high-vacuum conditions. Different domain structures in Mo/Au/Co 1.5 nm/Au film were measured at vacuum level $5*10^{-8}$ torr.

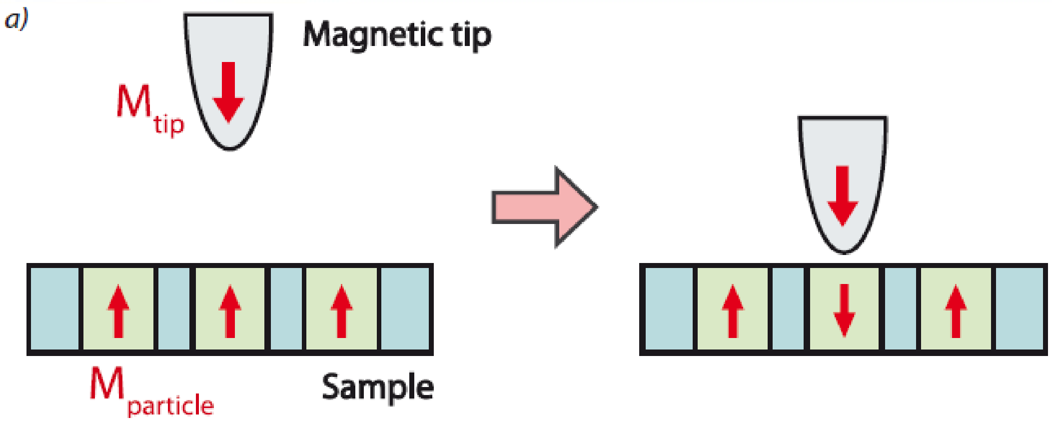
(a) MFM image at room temperature, (b) MFM image at 111 K.

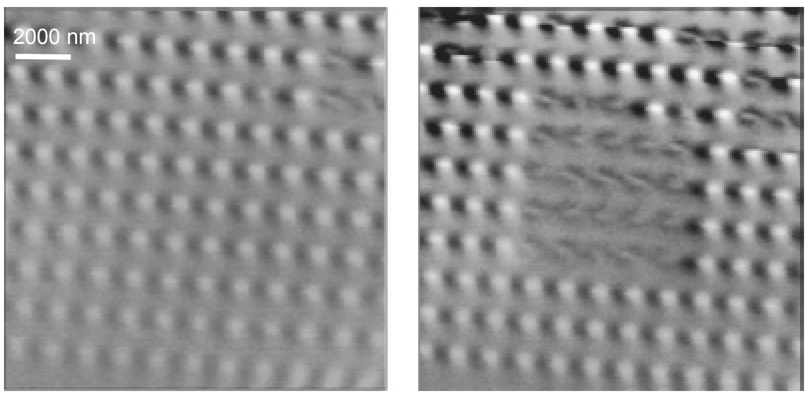
Magnetic Nanolithography

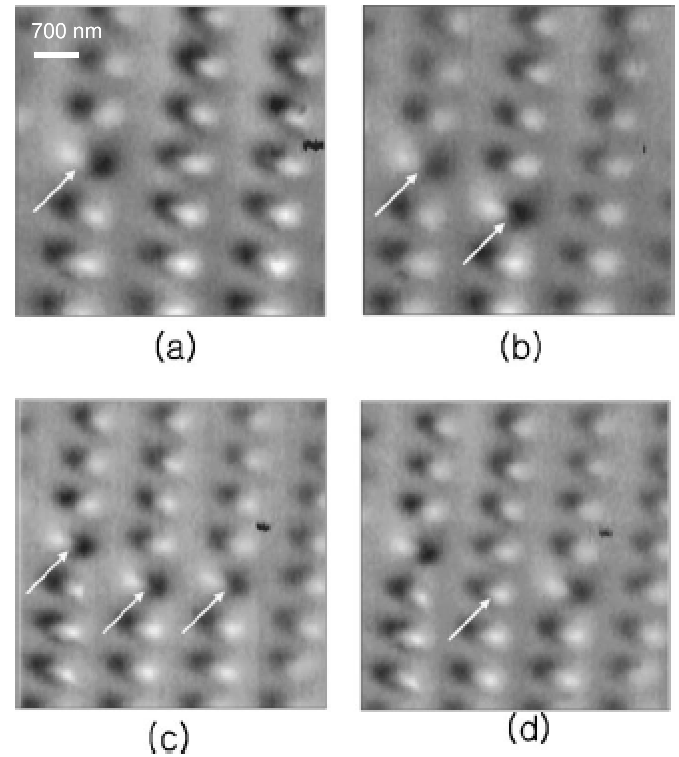


(a) Scheme of controllable magnetization reversal in selected magnetic nanoparticle: tip changes magnetization direction of the particle by approaching the sample surface; (b) The array of CoPt discs with perpendicular magnetic anisotropy is shown in electron microscopy image. Disc diameter is 35 nm, the thickness is 10 nm and the period of structure is 120 nm; (c) MFM images obtained on the same area in low vacuum conditions. Each image is obtained after magnetic reversal in one disc following scheme (a), and, finally, desired distribution of magnetic moments is achieved.

Magnetic Nanolithography



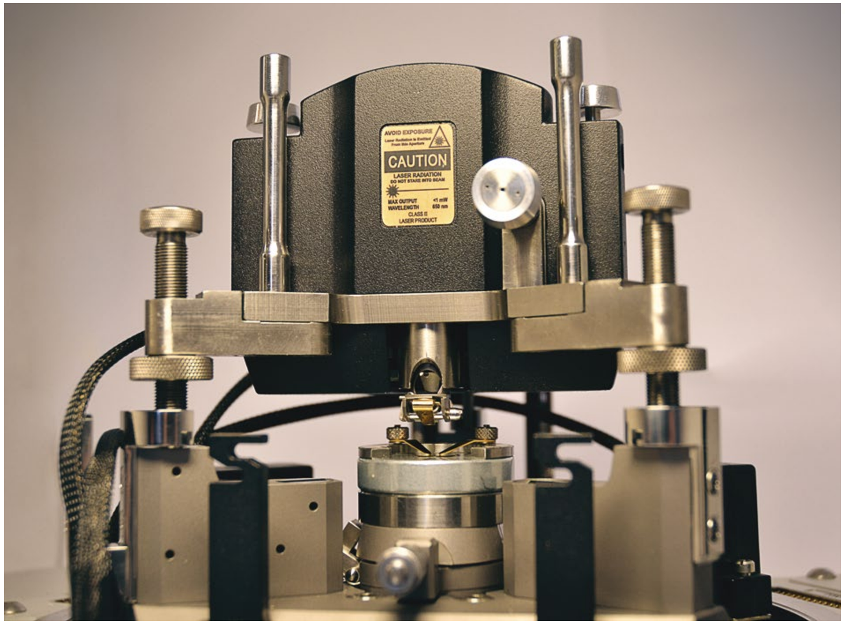




MFM images of Co dot array after magnetizing in the external field of 1 T (left) and after MFM probe induced demagnetization (right)

Subsequent control of tip induced magnetization reversal process in FeCr nanodots

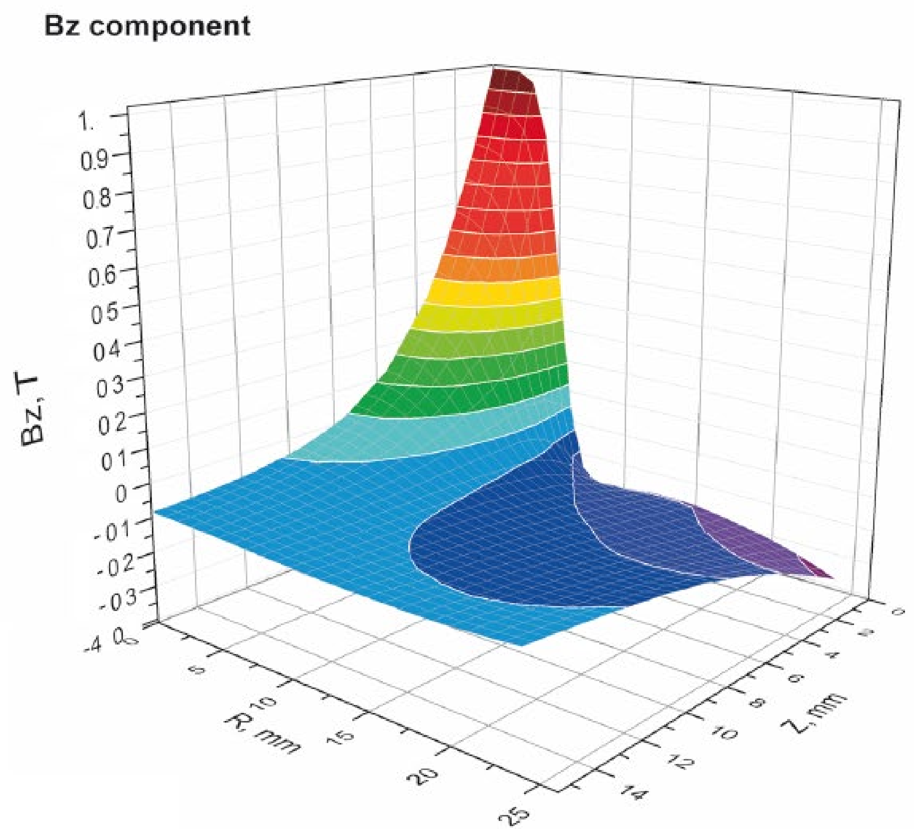
Setup for SPM with External Magnetic Field



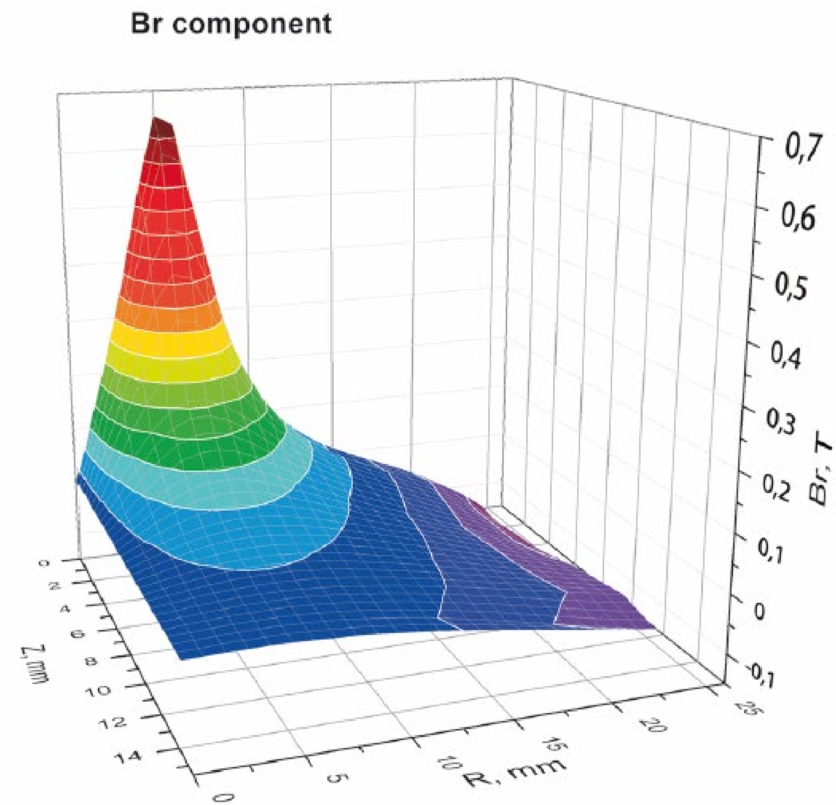
Key features of the new magnetic field module:

- Up to 0,8 Tesla (8 000 Gauss) standard, or up to 1 Tesla (10000 Gauss) by request vertical and up to 0.6 Tesla (6 000 Gauss) horizontal magnetic field with the same module
- No external cooling of the magnet required (e.g. no extra vibrations)
- No sample heating occurs
- The module is fully compatible with the existing NT-MDT NTEGRA AFM systems

Setup for SPM with External Magnetic Field



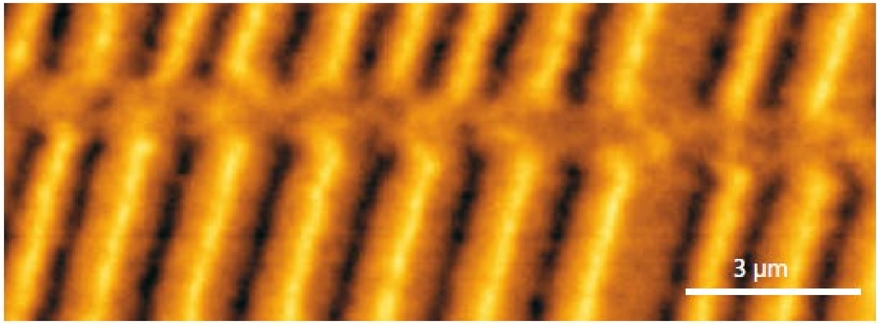
Measured vertical magnetic field component versus vertical distance (Z) from the surface and radial distance (R) from the central axis



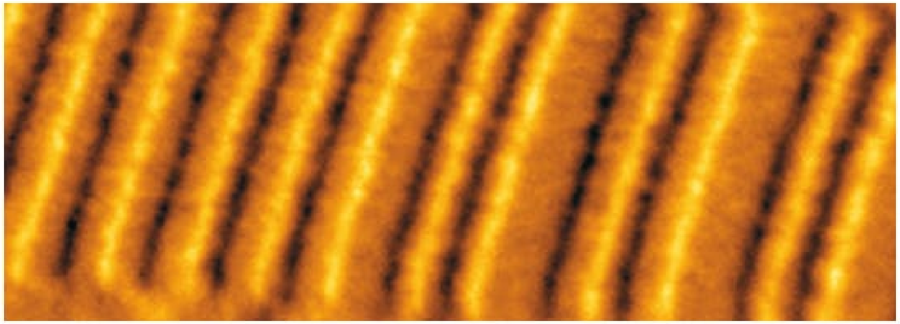
Measured horizontal magnetic field component versus vertical distance (Z) from the surface and radial distance (R) from the central axis

High Resolution Magnetic Probes

Survival test — 30 days in high humidity conditions!
(close to 100% without water condensation)



Magnetic structure of a hard disk drive, which was obtained by MFM01 probe in ambient conditions



Magnetic structure of a hard disk drive obtained by MFM01 probe which was kept in the high humidity conditions for 30 days

Cantilever series	Cantilever length, L±5 µm	Cantilever width, W±3 µm	Cantilever thickness, T±0.5 µm	Resonant frequency, kHz			Force constant, N/m		
				min	typical	max	min	typical	max
MFM01	225	32	2.5	47	70	90	1	3	5
MFM10	125	30	2.0	87	150	230	1.45	5.1	15.1

MFM is available in all NT-MDT microscopes

Flexibility - **NTEGRA AFMs**

Automation - **Solver AFMs**

NTEGRA platform: NTEGRA Spectra

NTEGRA Platform – integration with Non-AFM techniques (AFM+ e.g. confocal Raman)

SOLVER Platform – the lowest barrier for beginners; most of routine adjustments automated

Thank you!

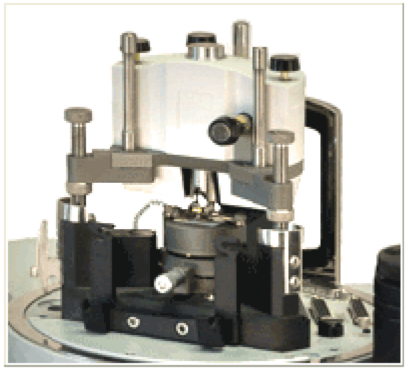
Contact Information

Any questions to Prof. Dr. S.O. Demokritov concerning the webinar you may ask:

webinars@ntmdt.com

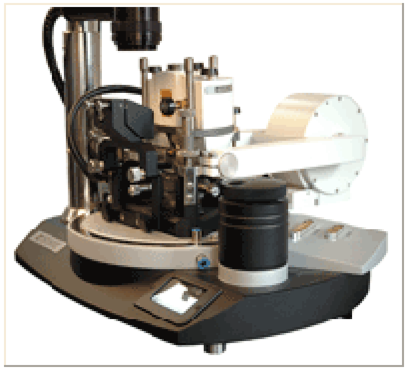
Thank you!

Measuring Head for Magnetic Research



Non magnetic measuring head for “pure” experiments and magnetic field measurements

Powerful magnet for magnetostriction research



Both out-of-plane and in-plane orientations of the magnetic field are available