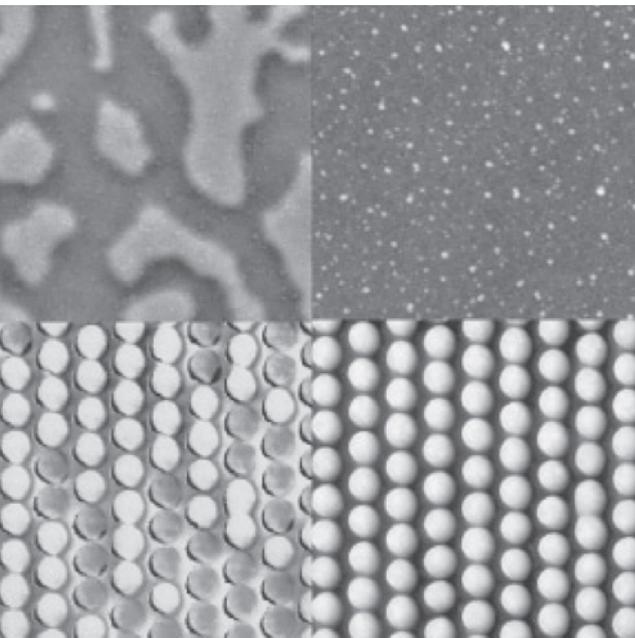




Dual-PLL Magnetic Force Microscopy



NanoScan VLS-80

Dual Phase-Locked Loop Magnetic Force Microscopy (DP-MFM) is the perfect tool to measure high-resolution MFM while simultaneously measuring topography of samples, all without touching the surface. This is a pre-requisite for maintaining the sharpness of high-aspect-ratio magnetic tips.

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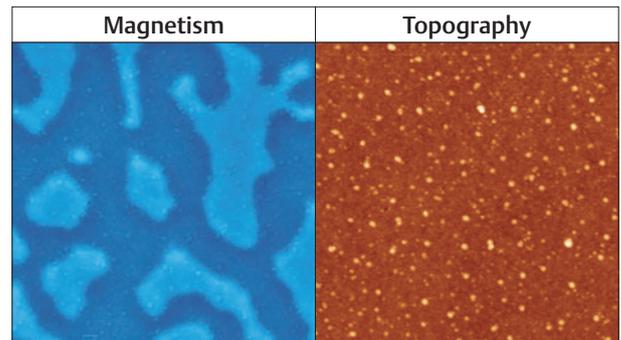
Simultaneous non-contact MFM and AFM

Top quality, high-resolution MFM requires high-aspect-ratio tips with a thin magnetic coating. These tips can easily be damaged by contact with the surface, thereby reducing the resolution. On flat surfaces, it is trivial to regulate the tip-sample distance, however, many real-world samples are not entirely flat. Here, we present measurements of two such samples and demonstrate the strength of the novel DP-MFM method¹. This mode can successfully regulate the tip-sample distance, thereby allowing the separation of topography and magnetic signal, without making contact with the surface.

DP-MFM uses the two fully independent PLLs of the NanoScan controller. It further requires high vacuum which increases the Q-factor significantly, and thus sensitivity. NanoScan MFMs operate in high vacuum.

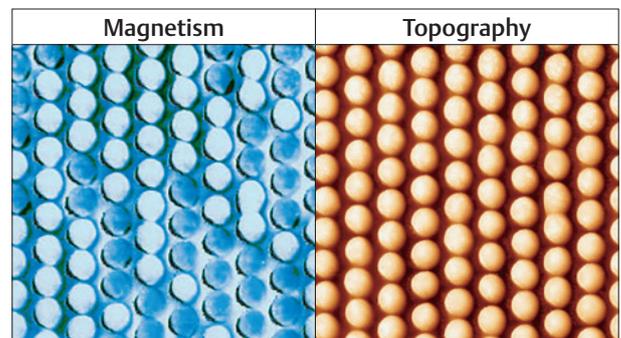
The cantilever is excited both on its soft, fundamental mode and its stiffer first overtone. One PLL demodulates the cantilever response on the first overtone, and provides the input for the Z-feedback that tracks the topography. The other PLL demodulates the cantilever response on the fundamental mode which is sensitive to the long-range magnetic stray field directly below the tip.

A CoPd multilayer and a bit-patterned media sample are presented here. Both display out-of-plane magnetic domains and both exhibit topographical features which could cause damage to the magnetic tip. Using DP-MFM, the tip is kept at a safe distance and can thus probe accurately the magnetic properties of the surface.



Dual-PLL MFM image of CoPd multilayer. Contrast is the frequency shift of cantilever fundamental resonance (10Hz dark/bright). Image size is $2 \times 2 \mu\text{m}^2$

Dual-PLL AFM image of multilayer taken simultaneously with MFM image (10 nm dark/bright). The first overtone was used as a feedback setpoint. No magnetic signal can be seen in this image. Image size is $2 \times 2 \mu\text{m}^2$



Dual-PLL MFM image of bit-patterned media (centre-to-centre spacing 200 nm). The magnetization direction of each island can be clearly distinguished as bright or dark. Contrast is the frequency shift of cantilever fundamental resonance (4 Hz dark/bright). Image size is $2 \times 2 \mu\text{m}^2$

Dual-PLL AFM image of bit-patterned media taken simultaneously with MFM image. The magnetic signal is absent from this image. (70 nm dark/bright contrast). The first overtone was used as a feedback setpoint. Image size is $2 \times 2 \mu\text{m}^2$

1. A more in-depth discussion of DP-MFM can be found in: "Non-contact bimodal magnetic force microscopy" J. Schwenk, M. Marioni, S. Romer, N.R. Joshi and H-J. Hug, Applied Physics Letters 104, 112412 (2014)

Sales Contact

ION-TOF GmbH
Heisenbergstr. 15
48157 Münster | Germany
Tel: +49 251 1622 200
Fax: +49 251 1622 199
sales@iontof.com
www.iontof.com