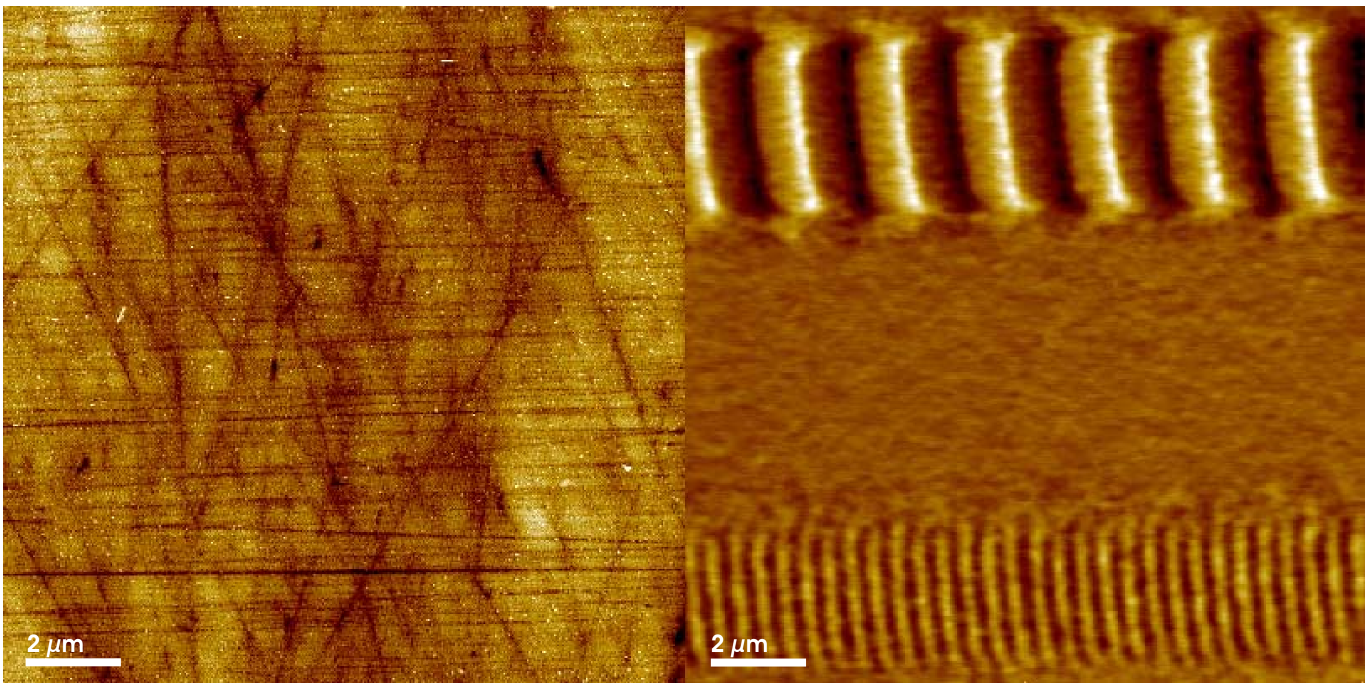
Magnetic Force Microscopy

Silicon-MFM-Probes

For visualisation of magnetic domains by Scanning Probe Microscopy different Magnetic Force Microscopy probes are offered. They are designed to match the demands of a wide range of applications defined by the variety of magnetic samples with different properties. All the different magnetic coatings of the probes have proven an excellent long-term stability.



Topography (left) and magnetic frequency shift image (right) of an experimental hard disk (courtesy of IBM) measured with a PPP-MFMR probe (z-range topography: 72nm, magnetic image scale: 22.5Hz).

In general, the measurement performance of Magnetic Force Microscopy is a compromise between sensitivity, resolution and sample disturbance. High sensitivity to magnetic signal requires a strong magnetic moment of the tip. However, this high magnetic moment may disturb the domain structure of the sample itself and usually the lateral resolution drops with increasing magnetic moment of the tip. For improvement of the lateral resolution sharp High Aspect Ratio tips and thin magnetic coatings are required. Because of the low magnetic moment of such thin magnetic films the sensitivity is decreased. An optimum trade-off between lateral resolution and sensitivity is necessary.

The magnetic domains of low coercivity samples are predominately "wiped out" by hard magnetically coated tips. This kind of sample can only be visualised by low coercivity probes which, on the other hand, may change their magnetization under the influence of a magnetic sample with higher coercivity. Therefore, in order to achieve optimum results, the MFM probe has to be chosen carefully and in accordance with the particular sample under investigation.

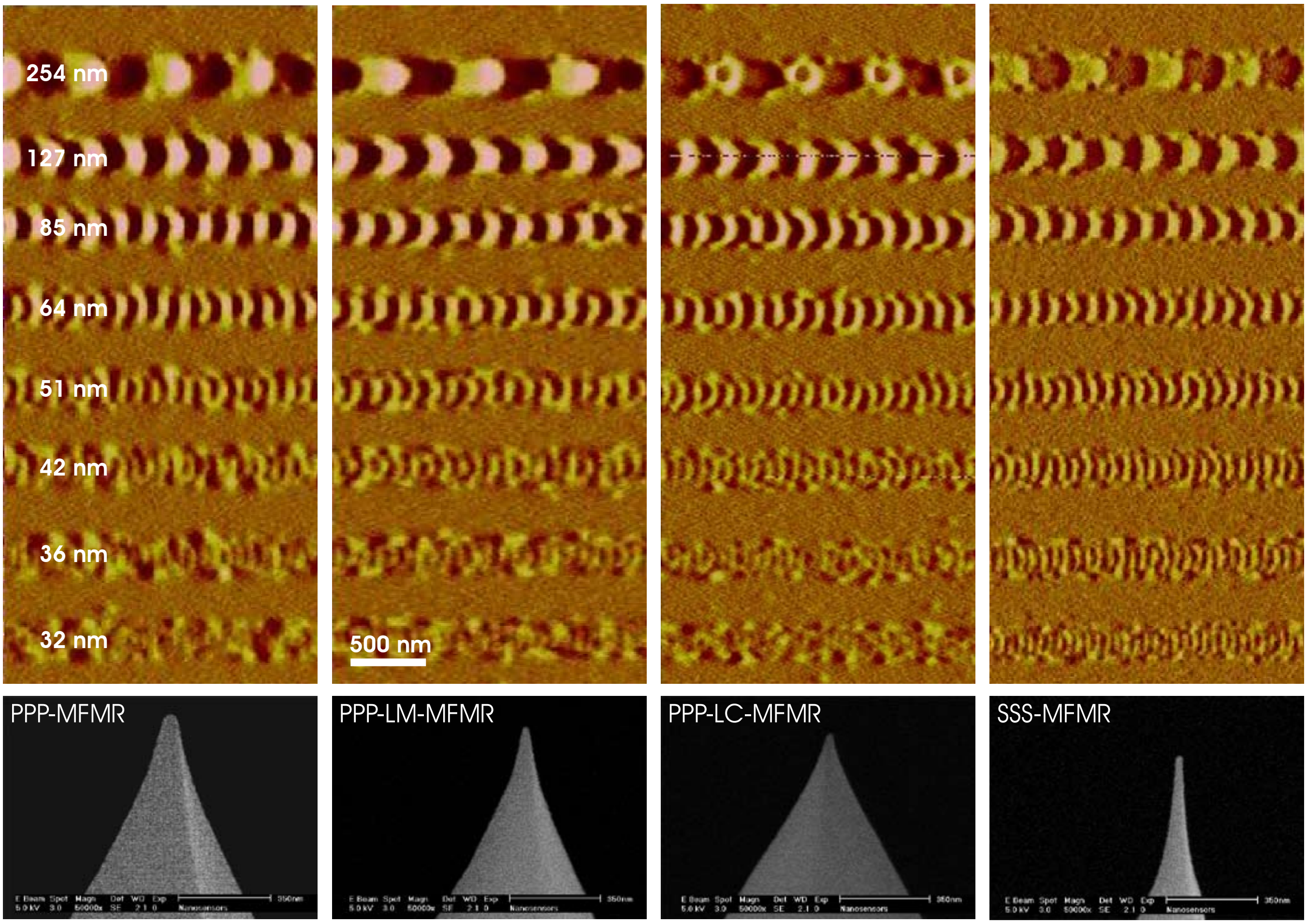
General Features

The NANOSENSORS™ Magnetic Force Microscopy probes are based on a well-established cantilever type that is specially tailored for the Magnetic Force Microscopy yielding high force sensitivity while simultaneously enabling Tapping Mode, Non-Contact and Lift Mode operation in air. In particular, the stiffness of the cantilever is a trade-off between preventing the tip snapping to the surface during Tapping Mode or Non-Contact Mode operation and sensitivity to magnetic forces during Lift Mode operation.

Technical Data (Cantilever)	Nominal Value
Thickness [µm]	3
Width [µm]	28
Length [µm]	225
Force Constant [N/m]	2.8
Resonance Frequency [kHz]	75

The detector side of the cantilever is covered with a reflex coating to enhance signal of the optical read-out and, thus, reducing the noise of the optical detection system. The reflex coating is an approximately 30 nm thick aluminum coating on the detector side of the cantilever which enhances the reflectivity of the laser beam by a factor of about 2.5.

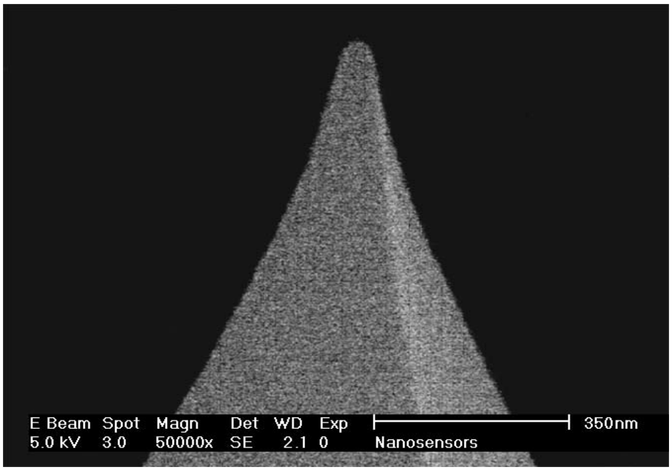
Comparison of Lateral Resolution



Magnetic images (phase shift) of an experimental hard disk with varied bit length (courtesy of Maxtor).

PointProbe® Plus Magnetic Force Microscopy Probe (PPP-MFMR)

The PPP-MFMR probe is our standard probe for Magnetic Force Microscopy providing a good sensitivity, resolution and coercivity. Stable imaging of a variety of samples such as recording media has been demonstrated.
The hardmagnetic coating on the tip is optimized for high magnetic contrast and high lateral resolution of considerably better than 50 nm. The coating is characterized by a coercivity of app. 300 Oe and a remanence magnetization of app. 300 emu/cm^3 (these values were determined on a flat surface).



SEM image of a PPP-MFMR tip (close-up).

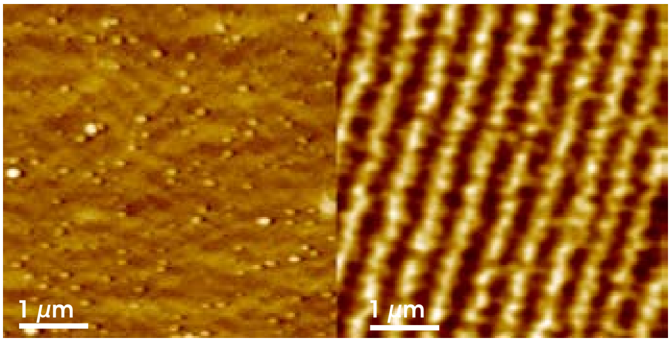
Probe Features at a Glance

- Coercivity of app. 300 Oe
- Remanence magnetization of app. 300 emu/cm^3
- Effective magnetic moment in the order of 10^{-13} emu
- Guaranteed tip radius of curvature < 50 nm
- Magnetic resolution better than 50 nm
- Reflex coating on detector side of cantilever

Application Examples

Digital Audio Tape (DAT)

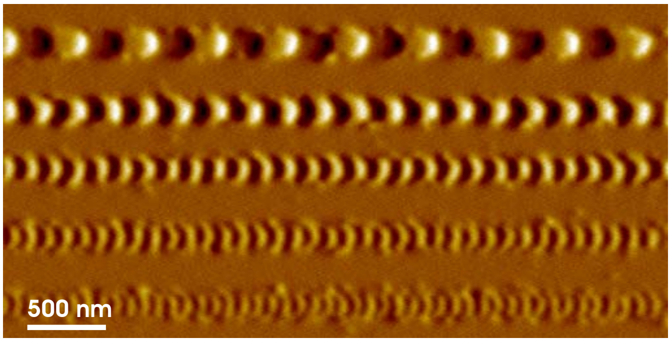
The written patterns on a digital audio tape can be visualised easily by use of the PPP-MFMR probe (right). Simultaneously, the surface topography is imaged in good quality (left).



Topography (left) and magnetic image (frequency shift) (right) of a DAT measured with a PPP-MFMR probe (z-range topography: 100 nm, magnetic image scale: 20 Hz).

Hard disk

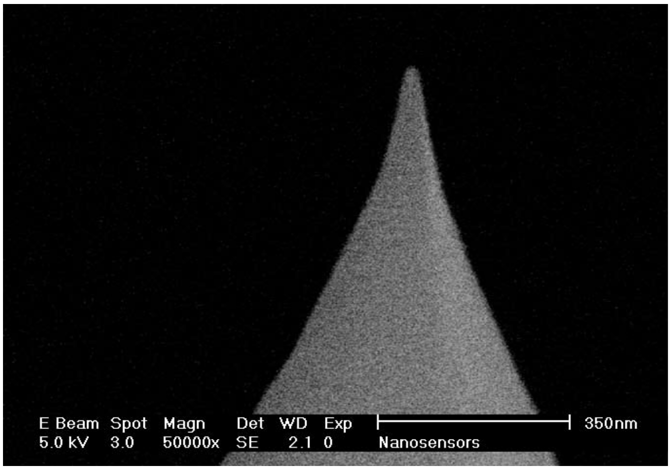
The magnetic bits written into a hard disk can be resolved down to a bit length of about 50 nm by using a PPP-MFMR probe.



Magnetic image (phase shift) of an experimental hard disk (courtesy of Maxtor) with a PPP-MFMR probe (magnetic image scale: 6°).

PointProbe® Plus Low Moment Magnetic Force Microscopy Probe (PPP-LM-MFMR)

The PPP-LM-MFMR probe is designed for reduced disturbance of the magnetic sample by the tip and enhanced lateral resolution – compared to the standard PPP-MFMR probe. These benefits however are accompanied by a reduction of the sensitivity to magnetic forces.
The hardmagnetic coating on the tip is characterized by a coercivity of app. 250 Oe and a remanence magnetization of app. 150 emu/cm³ (these values were determined on a flat surface).



SEM image of a PPP-LM-MFMR tip (close-up).

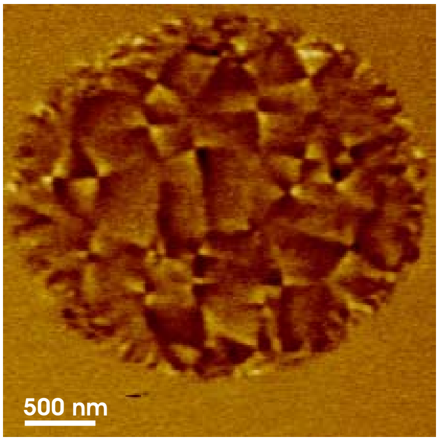
Probe Features at a Glance

- Coercivity of app. 250 Oe
- Remanence magnetization of app. 150 emu/cm³
- Effective magnetic moment 0.5x of standard PPP-MFMR probes
- Guaranteed tip radius of curvature < 30 nm
- Magnetic resolution better than 35 nm
- Reflex coating on detector side of cantilever

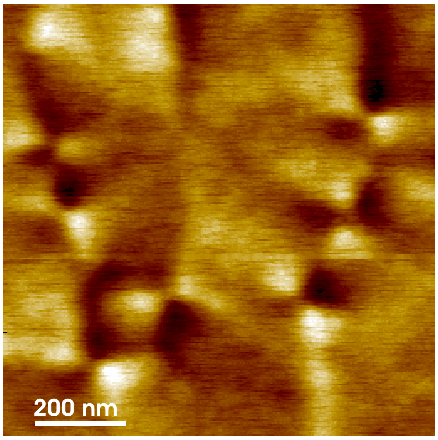
Application Example

Patterned soft magnetic thin film

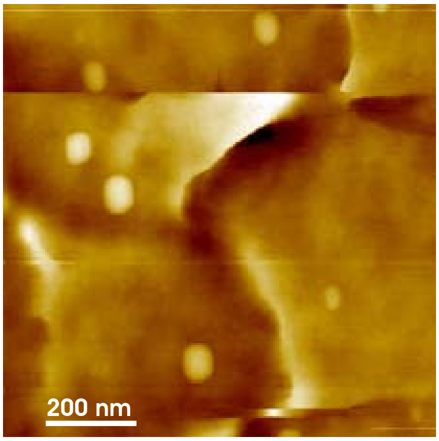
A patterned film of 20 nm thick NiCo (circular shape with a diameter of 3 μm) forms irregular, bow-tie shaped domains which can be imaged by the PPP-LM-MFMR probe. If a standard MFM probe is used, the domain structure is seriously affected by the stray field of the tip. This is shown by the comparison below.



Magnetic overview image (frequency shift) of a patterned NiCo thin film acquired with a PPP-LM-MFMR probe. (scale: 10 Hz)



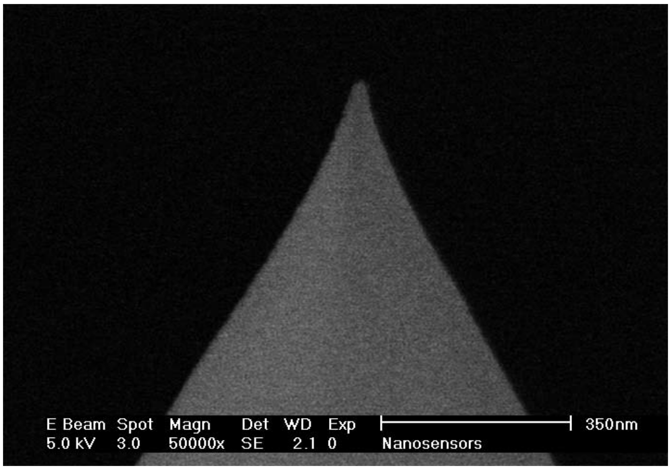
Close-up MFM image of the patterned NiCo thin film acquired with a PPP-LM-MFMR probe. (scale: 10 Hz)



Comparison measurement with a PPP-MFMR probe at the identical sample. (scale: 10 Hz)

PointProbe® Plus Low Coercivity Magnetic Force Microscopy Probe (PPP-LC-MFMR)

The PPP-LC-MFMR probe is coated with a soft magnetic thin film enabling the measurement of magnetic domains within soft magnetic samples. Due to the low coercivity of the tip coating the magnetization of the tip will easily get reoriented by hard magnetic samples.
The soft magnetic coating on the tip has a coercivity of app. 0.75 Oe and a remanence magnetization of app. 225 emu/cm^3 (these values were determined on a flat surface).



SEM image of a PPP-LC-MFMR tip (close-up).

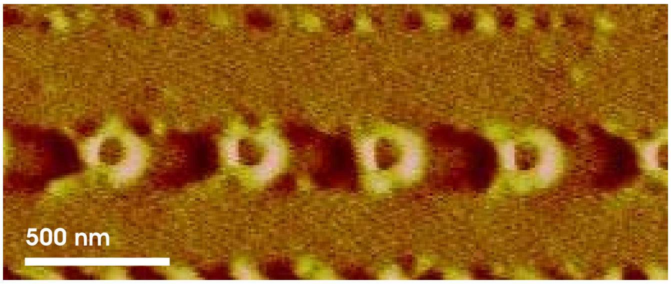
Probe Features at a Glance

- Coercivity of app. 0.75 Oe
- Remanence magnetization of app. 225 emu/cm^3
- Effective magnetic moment 0.75x of standard PPP-MFMR probes
- Guaranteed tip radius of curvature < 30 nm
- Magnetic resolution better than 35 nm
- Reflex coating on detector side of cantilever

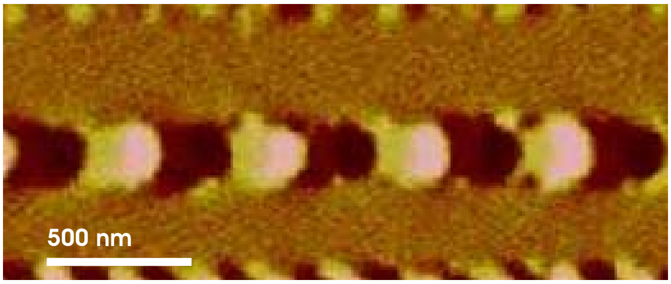
Application Example

Magnetic bits of a hard disk

The magnetization of the tip is easily reversed by the stray field of magnetic bits written into a hard disk. As a consequence attractive magnetic forces are detected at both halves of the bits. Although this effect makes the interpretation of results more difficult, it can be used to examine extremely hard magnetic samples. Instead of a random reorientation of the tip magnetization the magnetic moment of the LC-MFMR probes will always be directly opposed to the magnetization of the sample.



Magnetic image (frequency shift) of a hard disk with 254 nm long written bits (sample courtesy of Maxtor) acquired with a PPP-LC-MFMR probe.



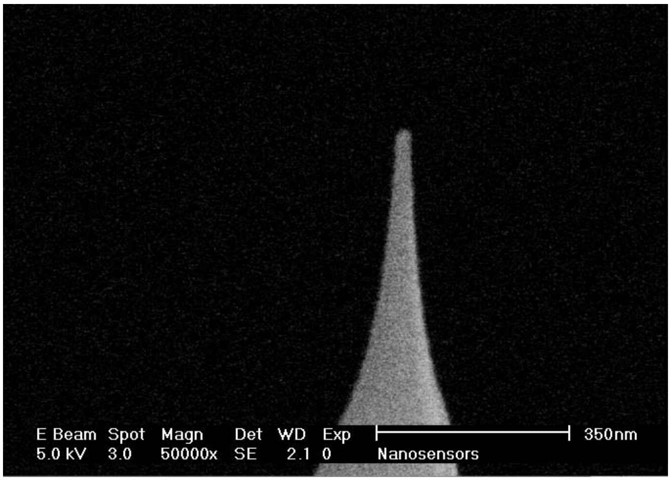
Comparison magnetic image (frequency shift) of the identical sample acquired with a standard PPP-MFMR probe.

SuperSharpSilicon™ High Resolution Magnetic Force Microscopy Probe (SSS-MFMR)

The SSS-MFMR probe is optimized for high resolution magnetic imaging. The SuperSharpSilicon™ tip basis combined with a very thin hard magnetic coating result in an extremely small radius of the coated tip and a high aspect ratio on the last few hundred nanometers of the tip apex – the essential requirements for high lateral resolution down to 20 nm in ambient conditions.

Due to the low magnetic moment of the tip the sensitivity to magnetic forces is decreased if compared to standard PPP-MFMR probes, but the disturbance of soft magnetic samples is also reduced.

The hard magnetic coating on the tip is characterized by a coercivity of app. 125 Oe and a remanence magnetization of app. 80 emu/cm³ (these values were determined on a flat surface).



SEM image of a SSS-MFMR tip (close-up).

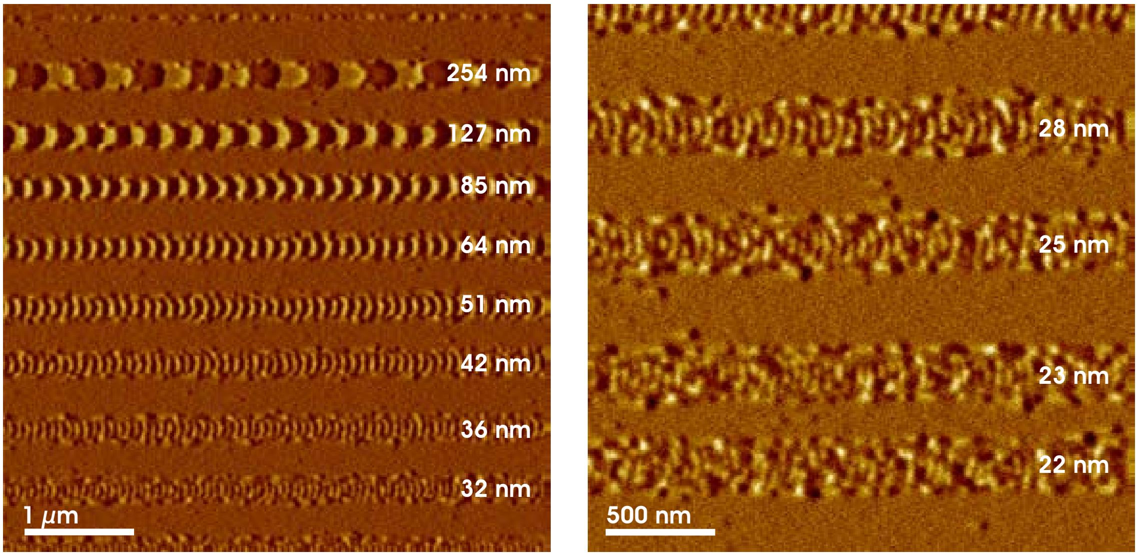
Probe Features at a Glance

- Coercivity of app. 125 Oe
- Remanence magnetization of app. 80 emu/cm³
- Effective magnetic moment 0.25x of standard PPP-MFMR probes
- Guaranteed tip radius of curvature < 15 nm
- Magnetic resolution better than 25 nm
- Reflex coating on detector side of cantilever

Application Example

High density hard disk

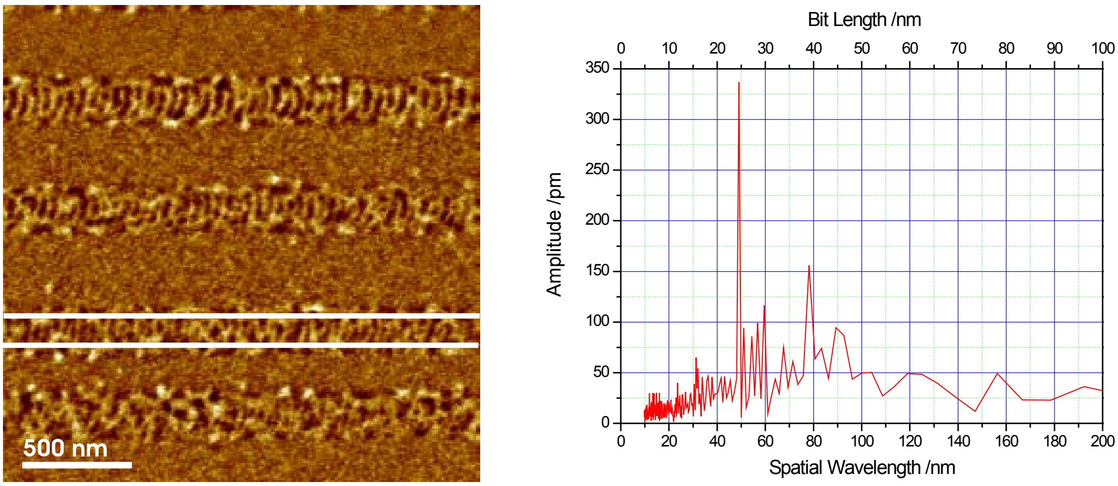
Magnetic bits on a hard disk can be characterized with the high resolution Magnetic Force Microscopy probe SSS-MFMR down to a bit length of 25 nm. This resolution capability is demonstrated by means of an experimental hard disk with varied bit length ranging from 254 nm to 22 nm.



Magnetic images (phase shift) of an experimental hard disk with varied bit length (courtesy of Maxtor) measured with a SSS-MFMR probe.

Resolution Perfomance Demonstration (SSS-MFMR)

The spatial resolution of the magnetic image can be determined by fourier analysis of measured magnetic bits at the experimental hard disk sample. In case of resolved bits the spectrum contains a clear peak corresponding to the length scale of the magnetic bits. Due to the definition of bit length as distance between opposite magnetization directions (maximum flux change) the determined spatial wavelength is exactly twice the bit length.

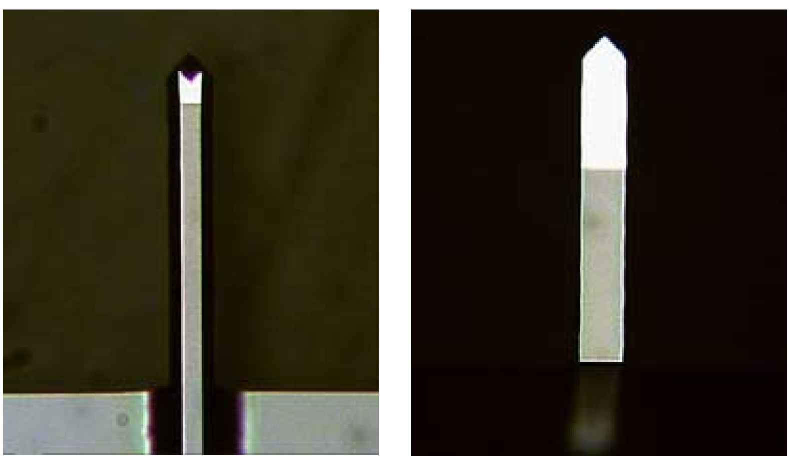


Fourier analysis of the 23 nm bit track (average profile between white lines of the left MFM image showing a significant peak at a spatial wavelength of 48 nm corrsponding to a bit length of 24 nm.

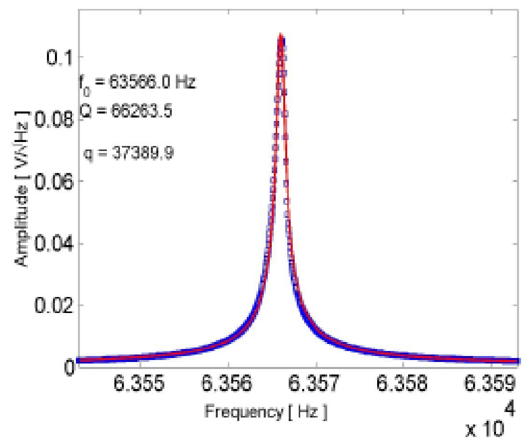
High Quality-Factor Magnetic Force Microscopy Probes (SSS-QMFMR and PPP-QLC-MFMR)

The high resolution MFM probes and the low coercitivity MFM probes are also available in a special version for applications under ultra high vacuum conditions. The SSS-QMFMR and PPP-QLC-MFMR probes are designed to achieve a Q-factor in UHV higher than 30,000.

The magnetic characteristics are identical to the properties of the SSS-MFMR and PPP-LC-MFMR probes, respectively. The typical Q-factor of over 35,000 under UHV conditions and the aluminum coating on the detector side secure excellent resolution and an enhanced signal to noise ratio.



Photographs of high quality factor MFM probes with partially coated cantilever (left: tip side, right: detector side).



Resonance curve of a typical high Q-factor MFM probe.

Probe Features

	PPP-MFMR (standard)	PPP-LM-MFMR (low momentum)	PPP-LC-MFMR (low coercivity)	SSS-MFMR (high resolution)
Force Constant (nominal)	2.8 N/m	2.8 N/m	2.8 N/m	2.8 N/m
Resonance Frequency (nominal)	75 kHz	75 kHz	75 kHz	75 kHz
Tipside Coating	Hard Magnetic	Hard Magnetic	Soft Magnetic	Hard Magnetic
Coercivity*1	300 Oe	250 Oe	0.75 Oe	125 Oe
Magnetization*1	300 emu/cm³	150 emu/cm³	225 emu/cm³	80 emu/cm³
Magnetic Tip Moment*2	$\approx 10^{-13}$ emu	x0.5	x0.75	x0.25
Guaranteed Tip Radius*3	< 50 nm	< 30 nm	< 30 nm	< 15 nm
Achievable Lateral Resolution*4	< 50 nm	< 35 nm	< 35 nm	< 25 nm
Coating on Detector Side	Reflex	Reflex	Reflex	Reflex

High Quality Factor Version			PPP-QLC-MFMR (low coercivity)	SSS-QMFMR (high resolution)
UHV Quality Factor*5			> 30 000	> 30 000

*1 coating properties measured on planar substrates
*2 estimation based on assumed effective magnetic volume at tip apex
*3 radius of curvature including magnetic coating
*4 achievable resolution at optimized measurement conditions
*5 measured under UHV conditions

For more details please refer to the product datasheet on our website
www.nanosensors.com

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