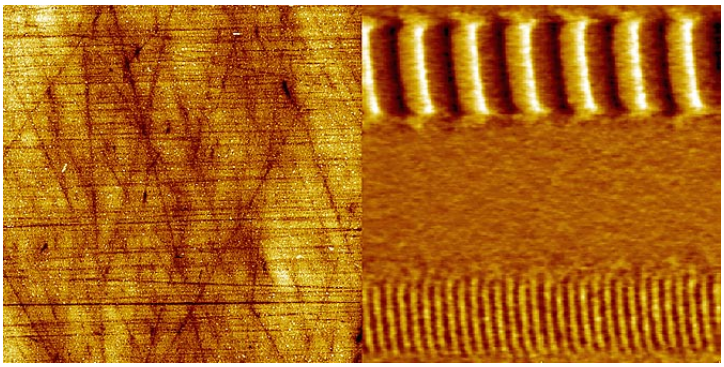
Magnetic Force Microscopy

Silicon MFM Probe Seriess

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 are showing an excellent long-term stability.

In general, the measurement performance of magnetic force microscopy is a compromise between sensitivity, resolution and sample disturbance. A strong magnetic moment of the tip leads to high sensitivity to magnetic signals. However, this high magnetic moment may disturb the domain structure of the sample.



Topography (left) and magnetic frequency shift image (right) of an experimental hard disk (courtesy of IBM) measured with a PPP-MFMR probe (image size: 14 µm x 14 µm, z-range topography: 72 nm, magnetic image scale: 22.5 Hz)

Thus, usually, the lateral resolution drops with increasing magnetic moment of the tip. In order to improve lateral resolution sharp high aspect ratio tips are required. Such tips are covered with thin magnetic coatings and show low magnetic moments that lead to poor sensitivity. 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 magnetisation under the influence of a magnetic sample with higher coercivity. Therefore, in order to achieve optimal results, the MFM probe has to be chosen carefully and in accordance with the particular sample to be analyzed.

General Features

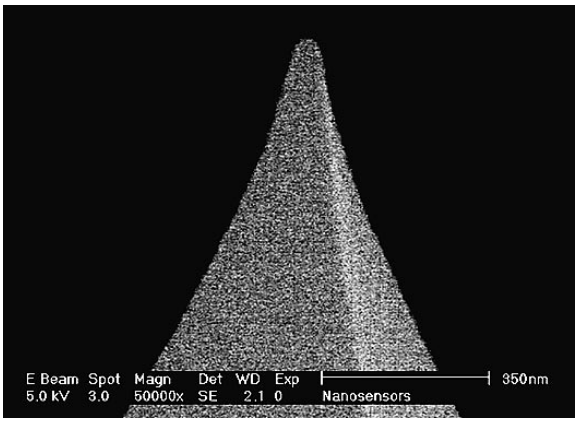
The NANOSENSORS™ MFM probes are based on a well-established cantilever type that is specially tailored for magnetic force microscopy. The probes are optimized in view of high sensitivity and enable TappingMode, Non-Contact and lift mode operation in air. In particular, the stiffness of the cantilever is a trade-off between preventing the tip snapping to the surface during TappingMode or Non-Contact mode operation and sensitivity to magnetic forces during lift mode operation.

Technical Data	Nominal Value	Specified Range
Thickness /µm	*3*	*2.0 – 4.0*
Width /µm	*28*	*20 – 35*
Length /µm	*225*	*215 – 235*
Force Constant /(N/m)	*2.8*	*0.5 – 9.5*
Resonance Frequency /kHz	*75*	*45 – 115*

The detector side of the cantilever is covered with a reflective coating to enhance the signal of the optical read-out (reflection enhancement of 2.5) and, thus, reducing the noise of the optical detection system. The reflex coating consists of an approximately 30 nm thick aluminium layer.

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 different recording media has been demonstrated.
The hard magnetic coating on the tip is optimized for high magnetic contrast and high lateral resolution considerably better than 50 nm. The coating is characterized by a coercivity of app. 300 Oe and a remanence magnetization of app. 300 emu/cm³ (these values were determined on a flat surface).



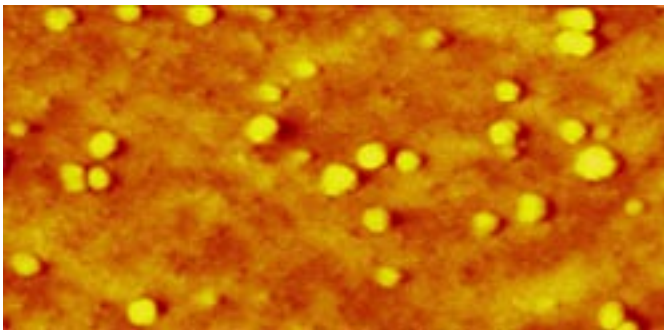
PPP-MFMR tip (close-up)

Probe features at a glance:

- Coercivity of app. 300 Oe
- Remanence magnetization of app. 300 emu/cm³
- Effective magnetic moment in the order of 10-13 emu
- Guaranteed tip radius of curvature < 50 nm
- Magnetic resolution better than 50 nm
- Al coating on detector side of cantilever

Application examples:

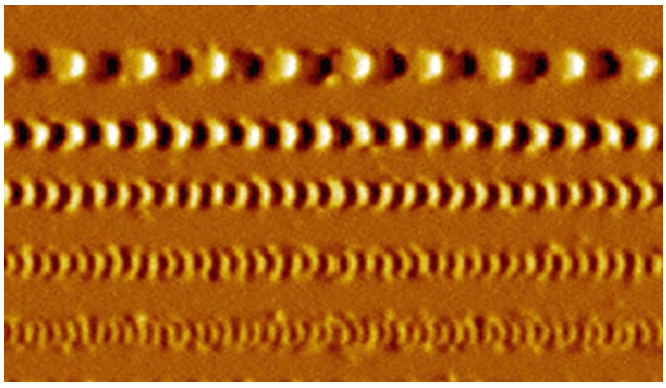
Digital Audio Tape (DAT)
The written patterns on a DAT can be visualised easily using the PPP-MFMR probe (right). Simultaneously, the surface topography is imaged in good quality (left).



Topography (left) and magnetic image (frequency shift) (right) of a DAT measured with a PPP-MFMR probe

(image size: 5 µm x 5 µm,
z-range topography: 100 nm,
magnetic image scale: 20 Hz)

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



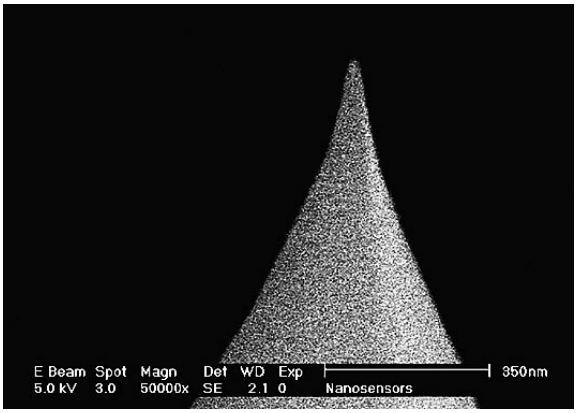
Magnetic image (phase shift) of an experimental hard disk (courtesy of Maxtor) with a PPP-MFMR probe

(image size: 2.5 µm x 1.5 µm,
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 hard magnetic 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).



PPP-LM-MFMR tip (close-up)

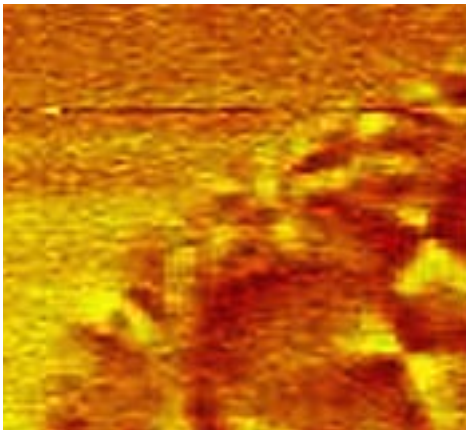
Probe features at a glance:

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

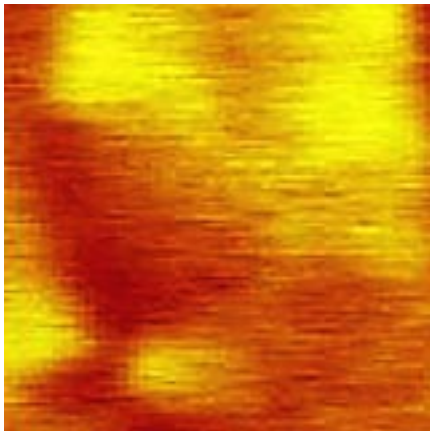
Application examples:

Patterned soft magnetic thin film
A patterned film of 20 nm thick NiCo (circular shape with a diameter of 3μm) forms irregular, bow-tie shaped domains which can be imaged with 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.

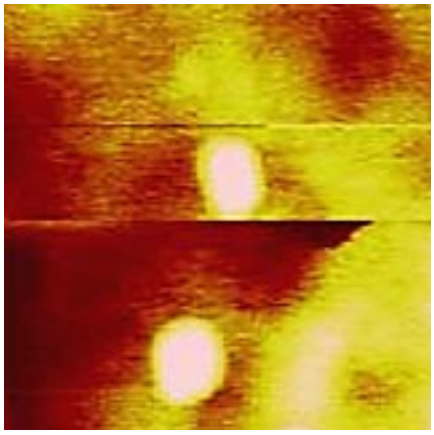
Magnetic images (frequency shift) of a patterned NiCo thin film



Large surface scan area imaged with a PPP-LM-MFMR probe (image size: 3.2 μm x 3.2 μm, scale: 10 Hz)



Close-up image of the same structure acquired with a PPP-LM-MFMR probe (image size: 1 μm x 1 μm, scale: 10 Hz)

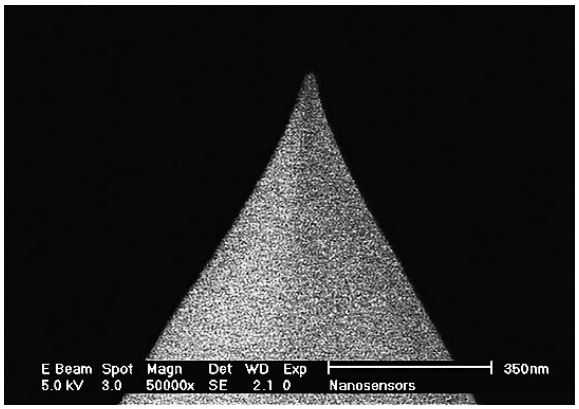


Close-up image of the same structure acquired with a PPP-MFMR probe (image size: 1 μm x 1 μm, scale: 10 Hz)

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 magnetisation of the tip will easily get reoriented by hard magnetic samples.

The soft magnetic tip coating 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).



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 probes
- Guaranteed tip radius of curvature < 30 nm
- Magnetic resolution better than 35 nm
- Al coating on detector side of cantilever

Application examples:

Magnetic bits of a hard disk
The magnetization of the tip is easily reversed by the stray field of magnetic bits written on 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 magnetisation the magnetic moment of the PPP-LC-MFMR probes will always be directly opposed to the magnetisation of the sample.

Magnetic images (frequency shift) of a hard disk with 254 nm long written bits (sample courtesy of Maxtor)

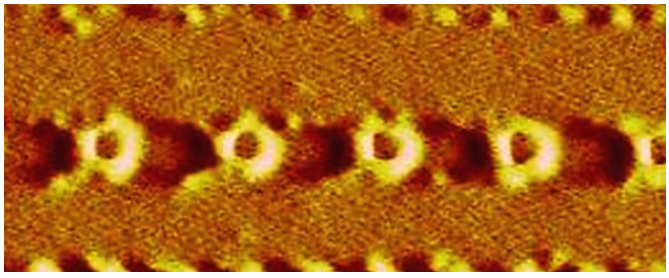


Image acquired with a PPP-LC-MFMR probe
(image size: 1.7 μm x 0.7 μm)

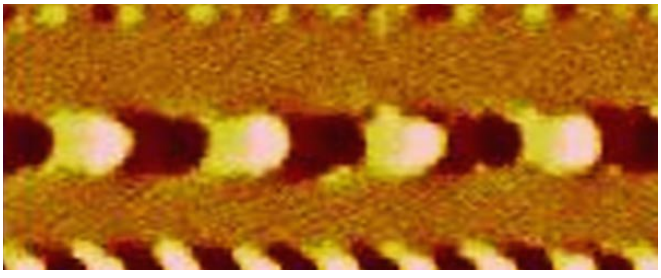
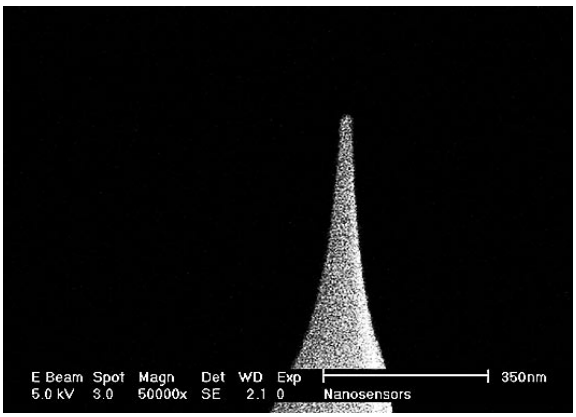


Image acquired with a PPP-MFMR probe
(image size: 1.7 μm x 0.7 μm)

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 tip radius 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 the standard MFM probe. Additionally the disturbance of soft magnetic samples is reduced.
The hard magnetic tip coating is characterized by a coercivity of app. 125 Oe and a remanence magnetization of app. 80 emu/cm^3 (these values were determined on a flat surface).



SSS-MFMR tip (close-up)

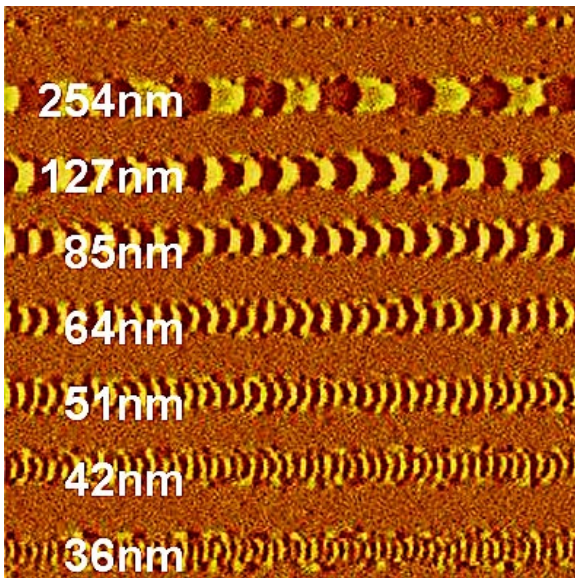
Probe features at a glance:

- Coercivity of app. 125 Oe
- Remanence magnetization of app. 80 emu/cm^3
- Effective magnetic moment 0.25x of standard probes
- Guaranteed tip radius of curvature < 15 nm
- Magnetic resolution better than 25 nm
- Al coating on detector side of cantilever

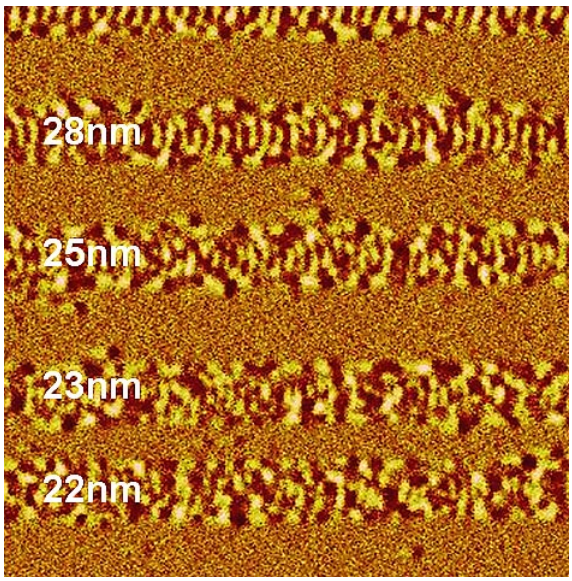
Application examples:

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 different bit lengths ranging from 254 nm to 22 nm.

Magnetic images (phase shift) of an experimental hard disk with different bit lengths (courtesy of Maxtor) acquired with SSS-MFMR



5 μm x 5 μm, magnetic image scale: 3°



2.5 μm x 2.5 μm, magnetic image scale: 2°

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. With a typical Q-factor of over 35 000 under UHV conditions and the aluminium reflective coating on the detector side to enhance the signal of the optical read-out the SSS-QMFMR and the PPP-QLC-MFMR provide excellent resolution and an enhanced signal to noise ratio.

Probe features

	PPP-MFMR	PPP-LM-MFMR	PPP-LC-MFMR	SSS-MFMR
Description	Standard	Low Momentum	Low Coercivity	High Resolution
Force constant (typical)	2.8N/m	2.8N/m	2.8N/m	2.8N/m
Resonance frequency (typical)	75kHz	75kHz	75kHz	75kHz
Tipside coating	Hard magnetic	Hard magnetic	Soft Magnetic	Hard Magnetic
Coercivity*1	300 Oe	250 Oe	0.75 Oe	125 Oe
Magnetisation*1	300 emu/cm³	150 emu/cm³	225 emu/cm³	80 emu/cm³
Magnetic tip moment*2	≈10-13 emu	x0.5	x0.75	x0.25
Guaranteed tip radius	< 50 nm	< 30 nm	< 30 nm	< 15 nm
Achievable lat. resolution*3	< 50 nm	< 35 nm	< 35 nm	< 25 nm
Coating at detector side	Reflex	Reflex	Reflex	Reflex

High Quality Factor version	PPP-QLC-MFMR	SSS-QMFMR
UHV Quality Factor*4	> 30 000	> 30 000

*1 coating properties measured on planar substrates
*2 estimation based on assumed effective magnetic volume at tip apex
*3 achievable resolution at optimized measurement parameters in air
*4 measured under UHV conditions