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Applications of High-Resolution MFM System with Low

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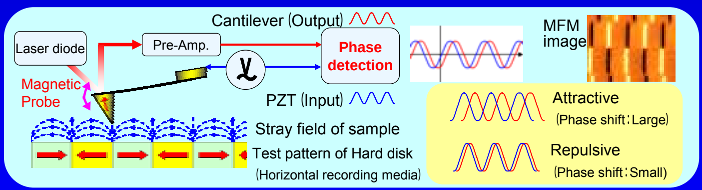
Abstract

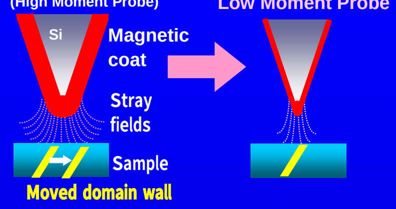
Magnetic force microscopy (MFM) is very useful for observing magnetic domain structures. However, due to stray fields from a MFM probe, observations of small magnetic domain structures are limited. We have developed a high-resolution MFM system that utilizes a low moment probe and a Q-controlled prove-driver, which allows the sensitive measurement in a vacuum without disturbing domain structures. Using this system, resolution finer than 20nm was achieved. Here, advantages of this MFM are demonstrated using a honeycomb nano-network, a semicircular loop and a cross-shaped pattern.

1. What is MFM?



Sample: Dr.Nakatani at NIMS

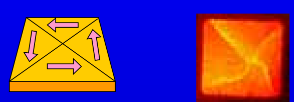
2. Unsolved Problems and Solution



Stray fields from conventional MFM probes often disturb domain structures of a sample.

Thickness of magnetic coat → Thinner

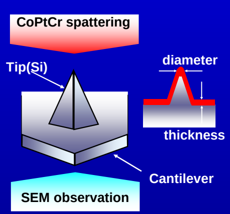
Advantages
① Non-disturb
② High-Resolution
③ Easy manufacturing

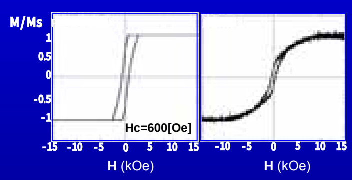


Closure domain of permalloy square film

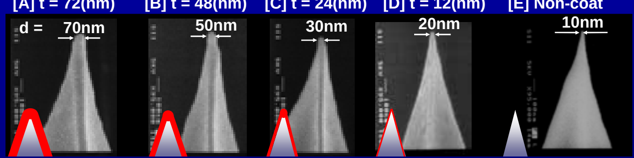
Conventional MFM image

3. Low Moment Probe[1]



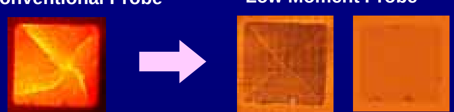


M-H curve measurement : Ishio Lab., Akita University



Conventional Probe

Low Moment Probe

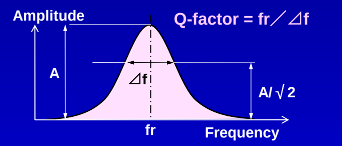


Non-disturb

Small MFM sensitivity

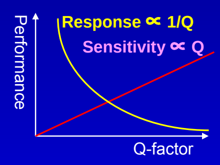
4. MFM sensitivity

What is Q-factor ?



The Q-factor indicates a resonance sharpness.

MFM sensitivity ∝ Q-factor



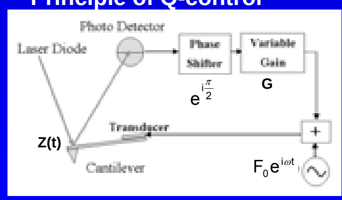
$$\Delta\phi = \frac{Q}{K}\cdot\frac{\partial F}{\partial z}$$

Δϕ: MFM signal (deg)
Q: Q-factor
K: Spring constant of cantilever (N/m)
∂F/∂z: Force gradient (N/m)

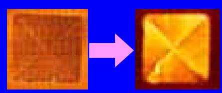
There is a range of Q-factor with the stable and sensitive.

5. What is Q-control?

Principle of Q-control



G>0 ⇒ Q_{eff}: Increase G<0 ⇒ Q_{eff}: Decrease



Q=300 Q=4000

Equation of motion

$$m\ddot{Z}(t) + \eta\dot{Z}(t) + kZ(t) = F_0 e^{i\omega t} + Ge^{i\frac{\pi}{2}}Z(t)$$

$$m\ddot{Z}(t) + \eta_{eff}\dot{Z}(t) + kZ(t) = F_0 e^{i\omega t}$$

Effective viscous coefficient

$$\eta_{eff} \equiv \eta - \frac{G}{\omega}$$

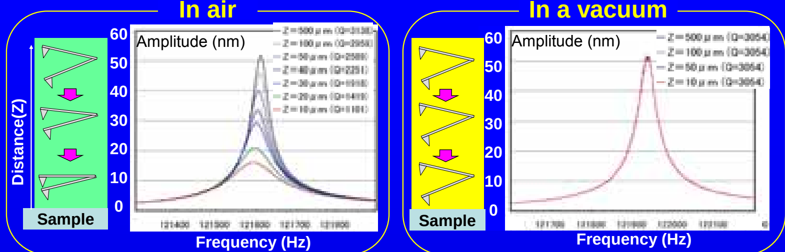
Effective Q-factor

$$Q_{eff} \equiv \frac{m\omega}{\eta_{eff}} = \frac{m\omega}{\eta - \frac{G}{\omega}}$$

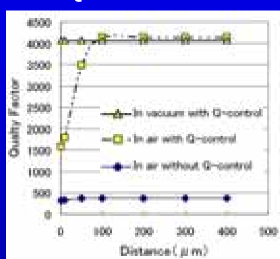
B. Anczykowski et al, Appl. Phys. A66, pp.885-889, 1998.
A.D.L. Humphris et al, Surface Science, Vol.491, No.3, pp.468-472, 2001.

6. Comparison of Q-control in Air / in a Vacuum

Changes of Q-curve when approaching the probe close to the sample



Distance dependence with Q-factor



Q-curve and Q-factor in air is influenced by the change of the viscous drag.

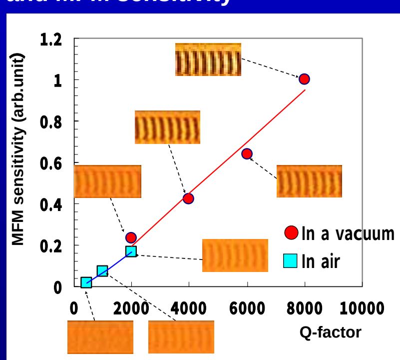
This phenomenon isn't desirable in MFM measurement.

Cantilever
Resonance frequency 250〜300kHz
Spring constant 40N/m
Low moment probe (t=24nm)

Sample
Perpendicular recording medium
200kFCI (Bit length: 127nm)

Range of stable Q
in air
200≦Q≦2000
in a vacuum
2000≦Q≦8000

Relation between Q-factor and MFM sensitivity



Q-control in a vacuum is higher sensitivity and wider range of stable Q-factor[1].

Moment Probe and Q-control in a Vacuum

(1) SII NanoTechnology Inc. 261-8507 Chiba, Japan (2) Dept. of Phys., Keio Univ. 270-2222 Yokohama, Japan

7. High-Resolution MFM System

Environment Controllable SPM

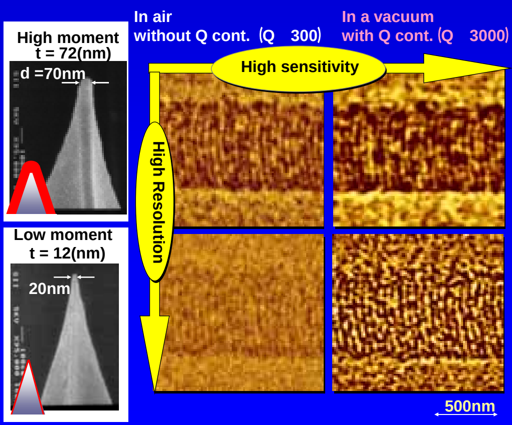
(In air, in a vacuum and in liquid)

P : 10^{-5} (Pa) by a turbo molecule pump

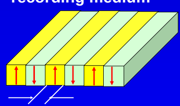
T : - 140 ～ + 800 (℃) by LN_2 and a heater

SPI4000/ E-sweep and SPA300HV, SII NanoTechnology Inc.

8. Perpendicular Recording Media[1]



Perpendicular recording medium



Bit length: 32nm

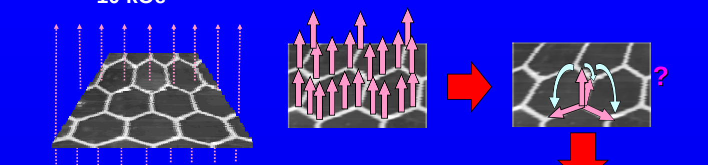
Recording density 800kFCI

Sample :

Fuji Electric Ltd.& NHK

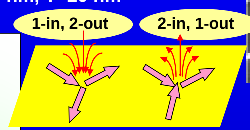
We have succeeded in the observation of 1200kFCI (bit length: 21nm) now.

9. NiFe Honeycomb Nano-Network[2]



Fabrication: Lift-off technique using electron-beam lithography

Wire size: W=50 nm, L=400 nm, T=20 nm

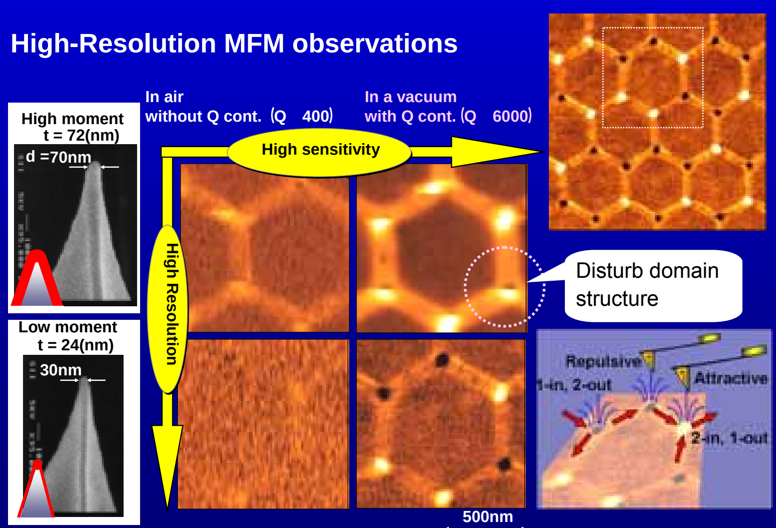


Expectation:

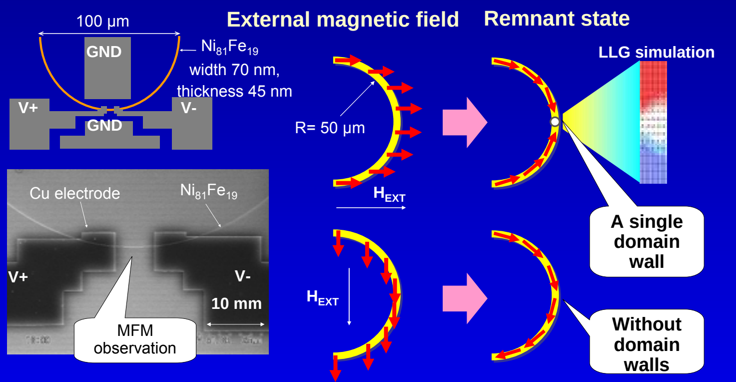
Each wire is single domain and a domain wall appears at each vertex in remnant state.

To investigate frustrated magnetic interaction in small magnets

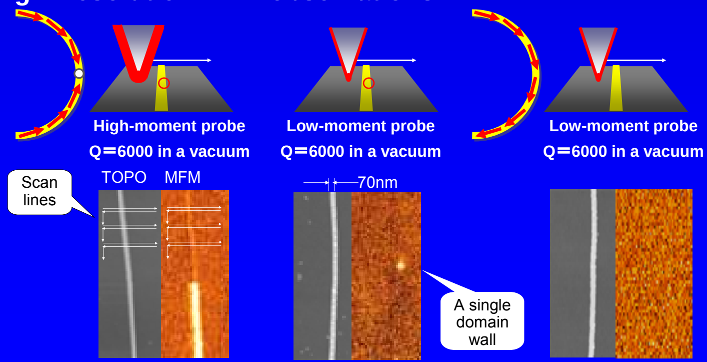
High-Resolution MFM observations



10. NiFe Semicircular Wire Loop[3]



High-Resolution MFM observations



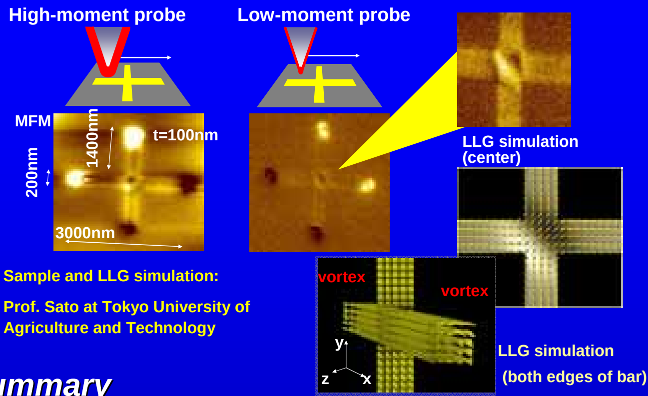
Domain wall was dragged.

The domain-wall manipulation

Nearly-free single domain wall was clearly observed.

No signal was observed.

11. NiFe Cross-Shaped Pattern



Sample and LLG simulation:

Prof. Sato at Tokyo University of Agriculture and Technology

Summary

We have demonstrated the effectiveness of the high-resolution MFM that involves the use of a low moment probe and Q-control system in a vacuum. Standard high moment probe disturbs the domain structure of the sample. In contrast, the low moment probe allows the stable and clear observation of magnetic domain. The high-resolution MFM with low-moment probe and Q-control in a vacuum should be powerful for exploring nano-scale magnetism.

Acknowledgment

The authors wish to thank Prof. Ishio at Akita University for useful discussion about the MFM technology and for M-H loop measurements

Reference

[1] T. Yamaoka, K. Watanabe, Y. Shirakawabe, and K. Chinone, “High-Sensitivity, High-Resolution Magnetic Force Microscopy System,” J. Magn. Soc. Jpn., vol.27, pp.429-433, 2003.

[2] E. Saitoh, M. Tanaka, H. Miyajima, and T. Yamaoka, “Domain-wall trapping in a ferromagnetic nano-wire network,” J. Appl. Phys., vol.93, no.10, pp.7444-7446, 2003.

[3] E. Saitoh, H. Miyajima, T. Yamaoka, and G. Tatara, “Current-induced resonance and mass determination of a single magnetic domain wall,” Nature, vol.432, pp.203-206, 2004.