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High-Resolution Magnetic Force Microscopy with Low

- Observations of a Single Magnetic Domain Wall in a Nano-Magnet -

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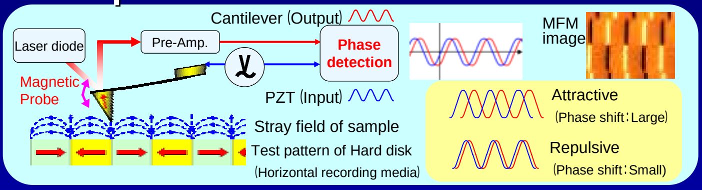
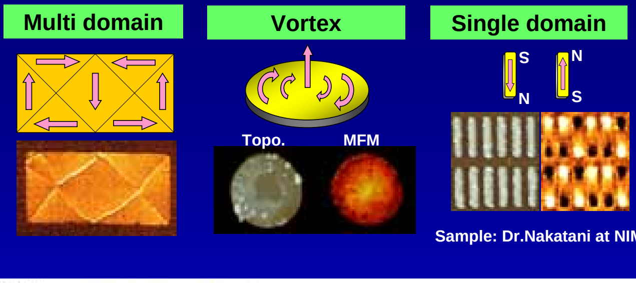
Abstract

The observation of nano-scale magnetization distribution is very important for developing ultra-high-density recording media and nano-scale magnetic patterns with the aim of creating new magnetic devices. At present, MFM has the highest resolution in general use; however, stray fields from standard MFM probes often disturb small magnetic domain structures of a sample. We have proposed a High-Resolution MFM technique that uses a low moment probe equipped in a vacuum and a Q-control system, which allows the all-round magnetic domain observation with a resolution finer than 20 nm. This technique enables sensitive observations without disturbing a magnetic domain structure of a sample. [1,2,4] The High-Resolution MFM has been applied to a permalloy semicircular wire loop with a single magnetic domain wall (DW). [3,4] We have successfully observed the nearly-free single DW in such a nano-magnet, which is easy to move even by weak magnetic fields. In the case of the MFM measurement with a high moment probe, the effects of probe's stray field cause "DW manipulation", and the MFM signal becomes maximum just above the wire. When using the low moment probe; the MFM signal becomes maximum at the side of the wire, which is agreeable with a result of the micromagnetic simulation.

High-Resolution Magnetic Force Microscopy [1],[4]

Principle of MFM

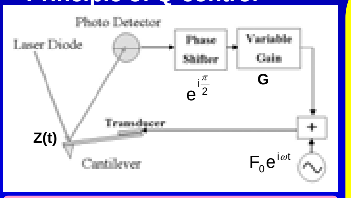




Sample: Dr.Nakatani at NIMS

Q-control

Principle of Q-control



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

Equation of motion

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

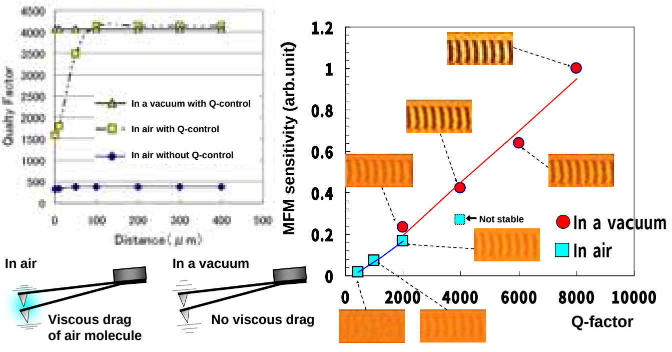
$$m\ddot{Z}(t) + \eta_{eff}\dot{Z}(t) + kZ(t) = F_0 e^{i\omega t}$$

Effective viscous coefficient

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

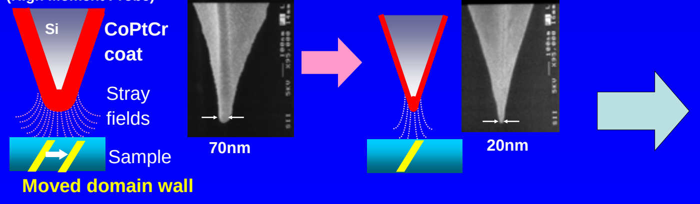
Effective Quality factor

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



The MFM measurement with Q-control in a vacuum is more desirable because no viscous drag is in a vacuum.

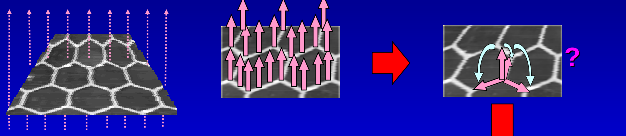
Low Moment Probe



High-resolution (< 20 nm)

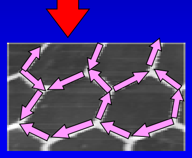
Non-disturb a magnetic domain structure of a sample

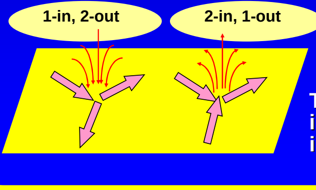
NiFe Honeycomb Nano-Network [2],[4]



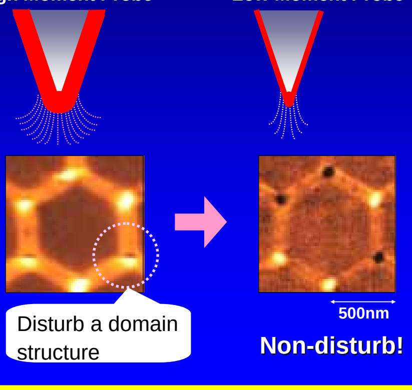
Fabrication: Lift-off technique using EB lithography

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



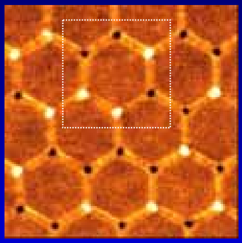


This sample has been made to investigate frustrated magnetic interaction in small magnets.



Disturb a domain structure

Non-disturb!



Moment Probe and Q-control in a Vacuum

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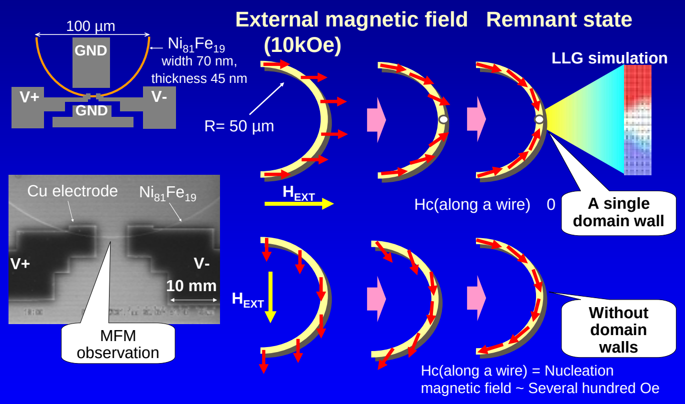
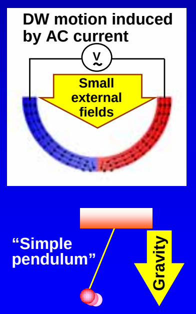
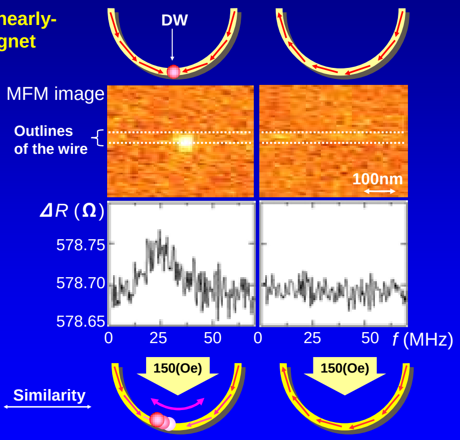
Observation of a single DW with High-Resolution MFM and mass determination by resonance-amplified spectroscopy [3]



The single DW is easy to move even by weak magnetic fields. Thus the conventional MFM observations are difficult to detect such a nearly-free DW stably.

We successfully observed a nearly-free single DW in a nano- magnet by High-Resolution MFM.

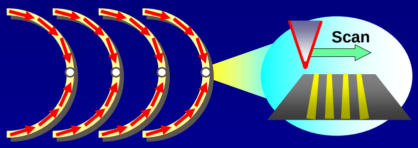




The DW mass (6.6×10^{-23} kg) as a virtual particle was determined from the resonance data and DW width ~70 nm which is obtained from High-Resolution MFM.

Effects of MFM probe's stray field in observations of the single DWs

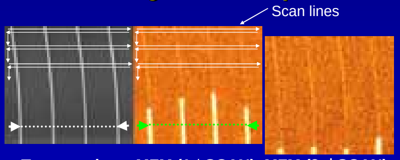
MFM observations of single DWs in multistep wires



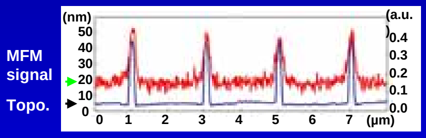
Comparison between high moment probe and low moment probe

Confirmation by repeat scan

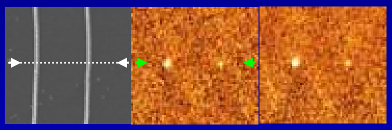
In case of high moment probe



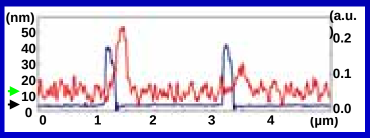
Topography MFM (1st SCAN) MFM (2nd SCAN)



In case of low moment probe



Topography MFM (1st SCAN) MFM (2nd SCAN)

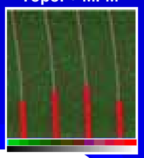


"The DW manipulation"

All DWs moved to the end point of the 1st scan.

MFM signals became maximum right above all wires.

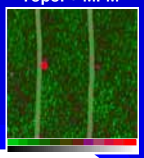
Topo. + MFM

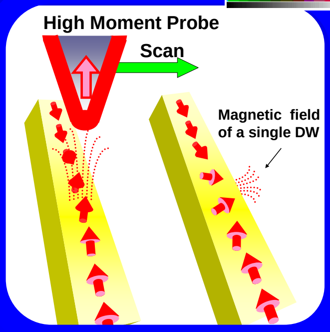


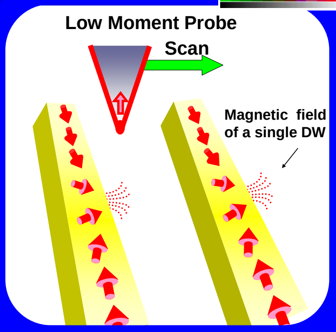
Clearly DW's signals at the same place in both the 1st scan and the 2nd scan

MFM signals became maximum in the side of wires.

Topo. + MFM







The stray field from the high moment probe changes compulsorily the magnetization structure of the sample.

The result of the micromagnetic simulation

MFM images are agreeable with the result of the micromagnetic simulation.

Conclusions

In the case of the high moment probe, the effects of probe's stray field causes the DW manipulation, and the MFM signal becomes maximum just above the wire. Because the stray field from the high moment probe changes compulsorily the magnetization structure of the sample. In the case of the low moment probe, we have successfully observed a nearly-free single DW in the stable and sensitive; MFM signal becomes maximum at the side of the wire, which is agreeable with the result of the micromagnetic simulation. The high-resolution MFM using the low moment probe and Q-control in a vacuum are powerful for exploring nano-scale magnetism. And it will become possible to understand more deeply the magnetic domain structures of the nano-scale magnet with the comparison and analysis of the MFM measurement results by both of the high moment probe and the low moment probe.

Acknowledgment

The authors wish to thank Prof. Ishio at Akita University and Dr. Takahoshi at Yamagata Fujitsu for useful discussion about the MFM technology and estimation of the stray field of MFM probe.

Reference

[1] T. Yamaoka, K. Watanabe, Y. Shirakawabe, and K. Chinone, J. Magn. Soc. Jpn., 27 (2003) 429
[2] E. Saitoh, M. Tanaka, H. Miyajima, and T. Yamaoka, J. Appl. Phys., 93 (2003) 7444
[3] E. Saitoh, H. Miyajima, T. Yamaoka, and G. Tatara, Nature, 432 (2004) 203
[4] T. Yamaoka, K. Watanabe, Y. Shirakawabe, K. Chinone, E. Saitoh, M. Tanaka, and H. Miyajima, IEEE Trans. Magn. (In press).