Magnetic force microscopy(MFM) & Magnetic exchange force microscopy(MExFM)

June 10th, 2015

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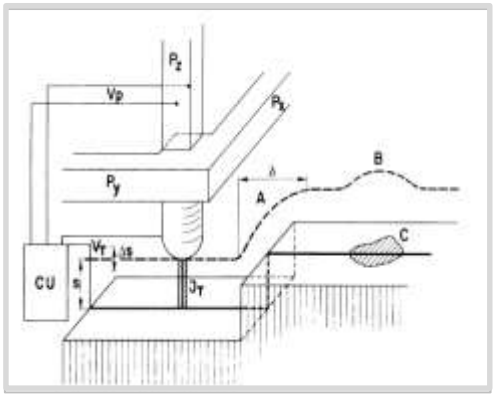
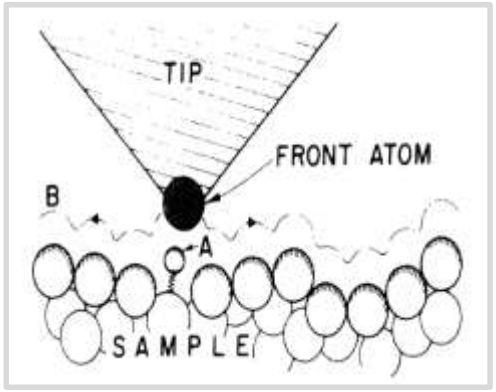
- History of MFM & Applications
- Principle of MFM
- Improvements of MFM
- MExFM

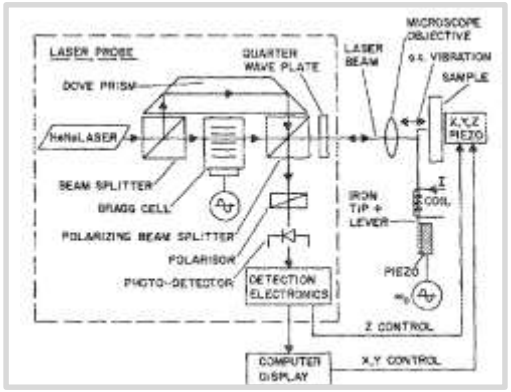
Histroy of MFM & Applications



G. Binning et al., *Appl. Phys. Lett*. **40**, 178 (1981)



G. Binning et al., *Phys. Rev. Lett.* **56**, 930 (1986)



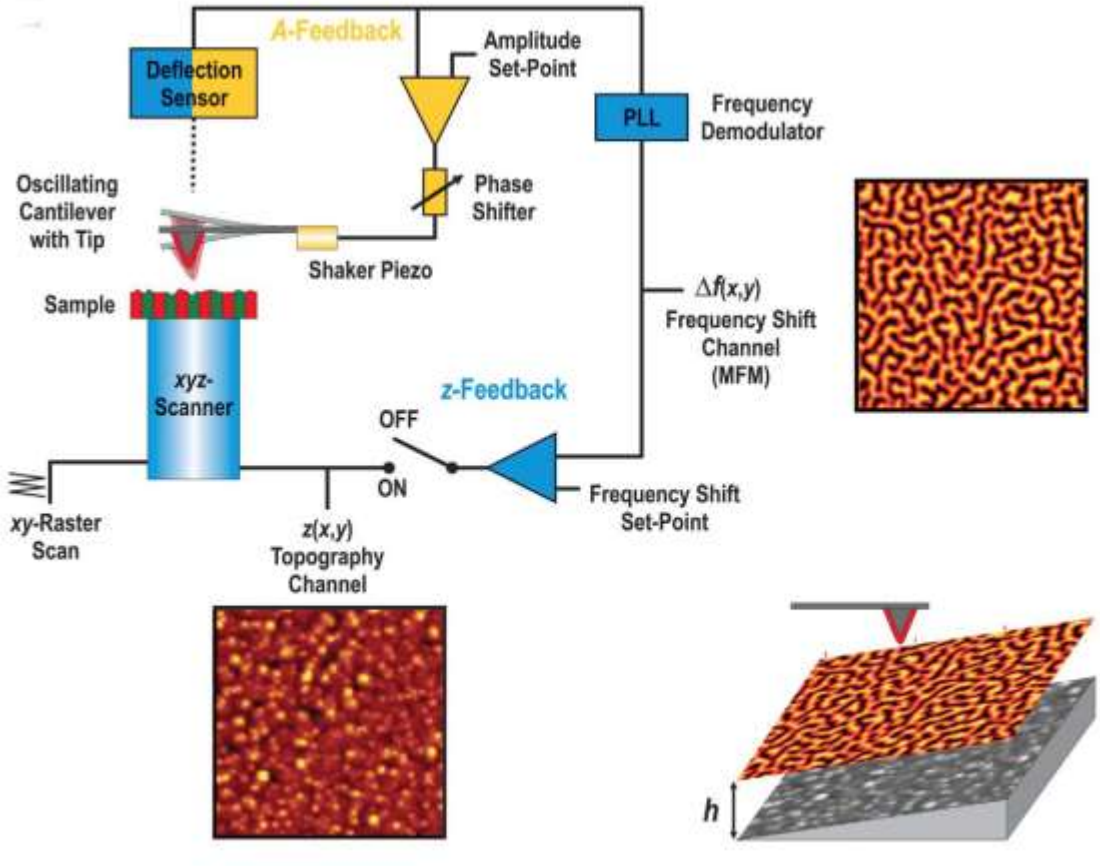
Y. Martin et al., *Appl. Phys. Lett.* **50**, 1455 (1987)

Scanning Tunneling Microscope(STM)

Atomic Force Microscope(AFM)

Magnetic Force Microscope(MFM)

Histroy of MFM & Applications



- Magnetic data storage industry
- Sensor technologies
- Fundamentals of magnetic phenomena
  a. Domain patterns
  b. Domain walls
  c. Flux lines in superconductors

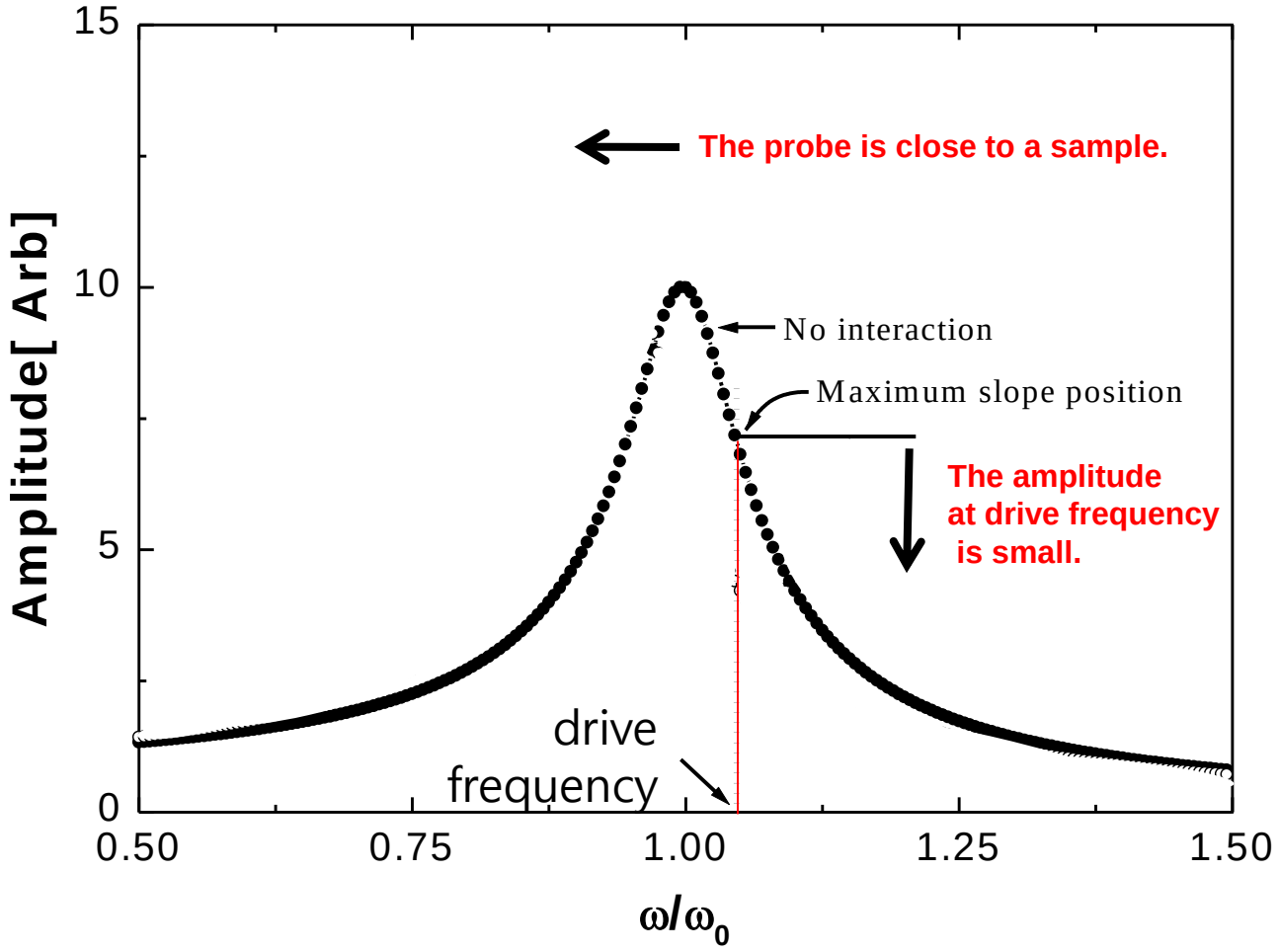
Schwartz A. et al., *Nano Today* **3**, 28(2008)

Non contact mode AFM

$$f = \frac{1}{2\pi}\sqrt{\frac{k_{ef}}{m}}$$

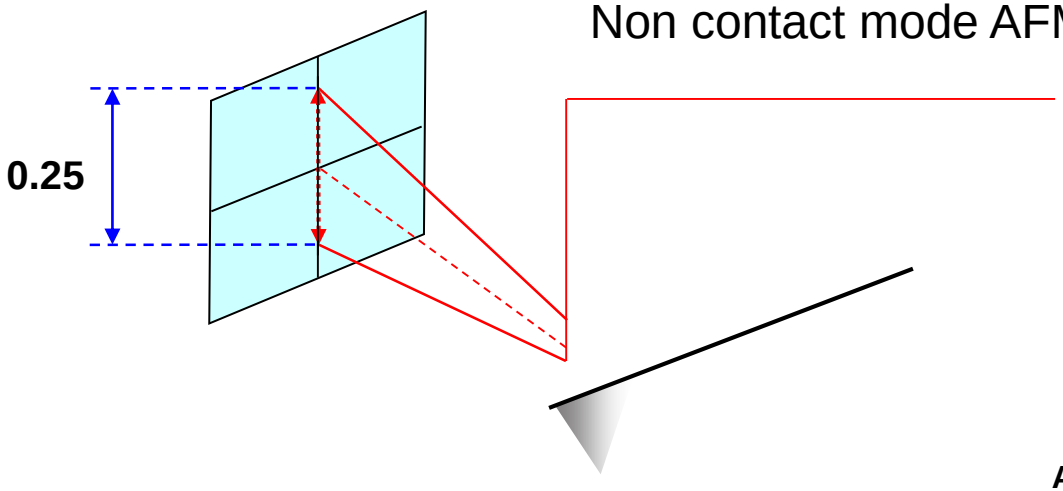
$$k_{ef} = k - \frac{\partial F}{\partial z}$$

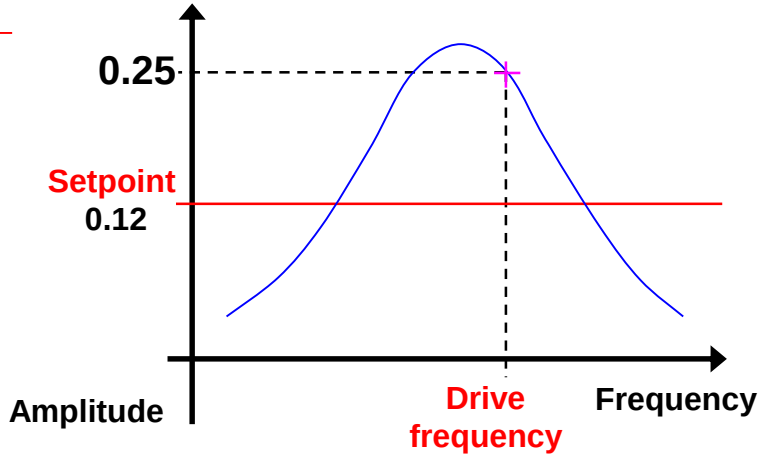
$$f = f_0\sqrt{1 - \frac{\frac{\partial F}{\partial z}}{k}}$$

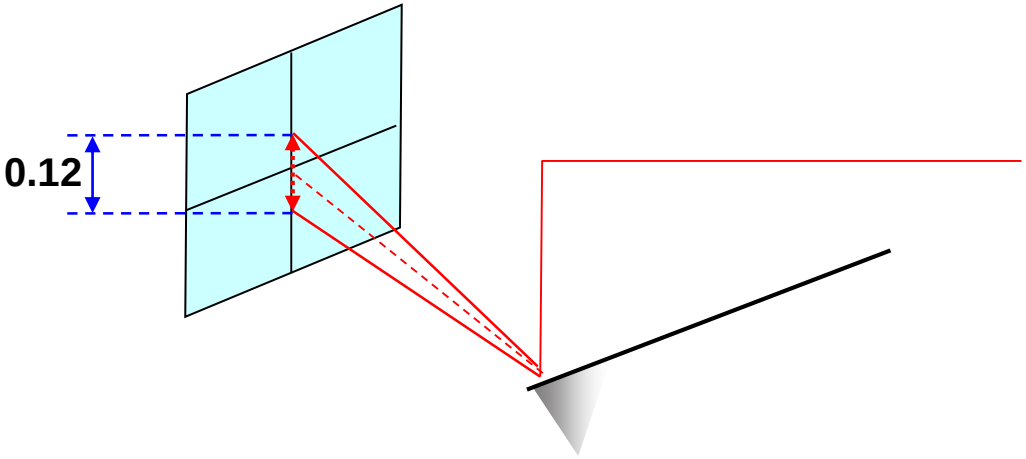


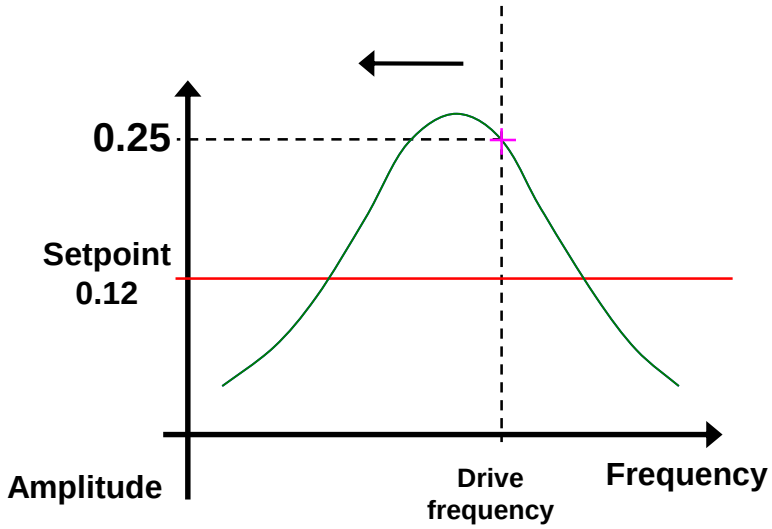
Principle of MFM

Non contact mode AFM





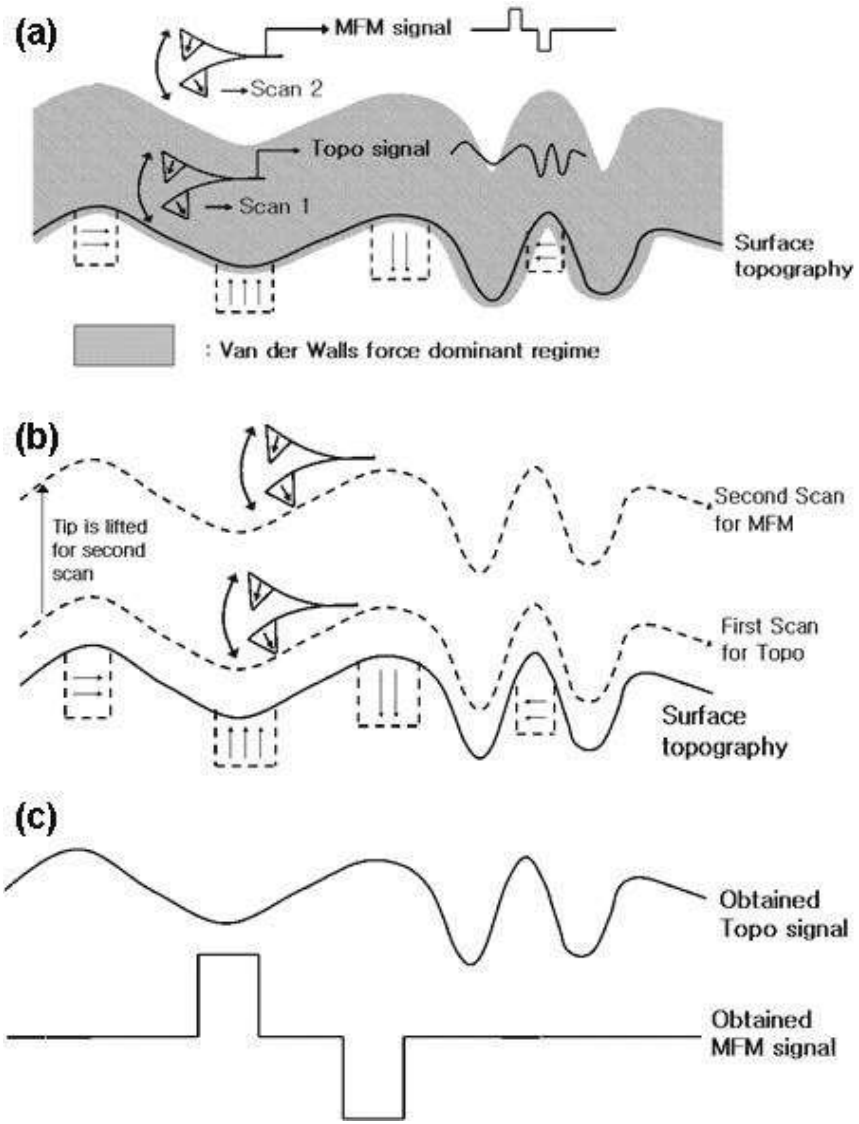




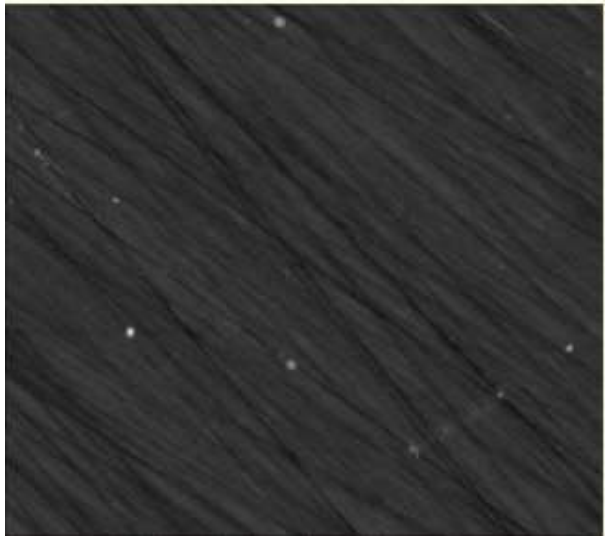
Sample

“Approach”

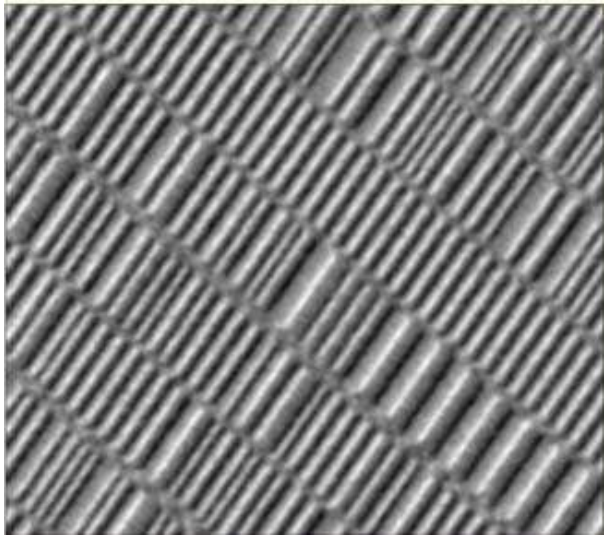
Principle of MFM



Hendrych, A. et al. , *Modern Research and Educational Topics in Microscopy* ,805(2007)

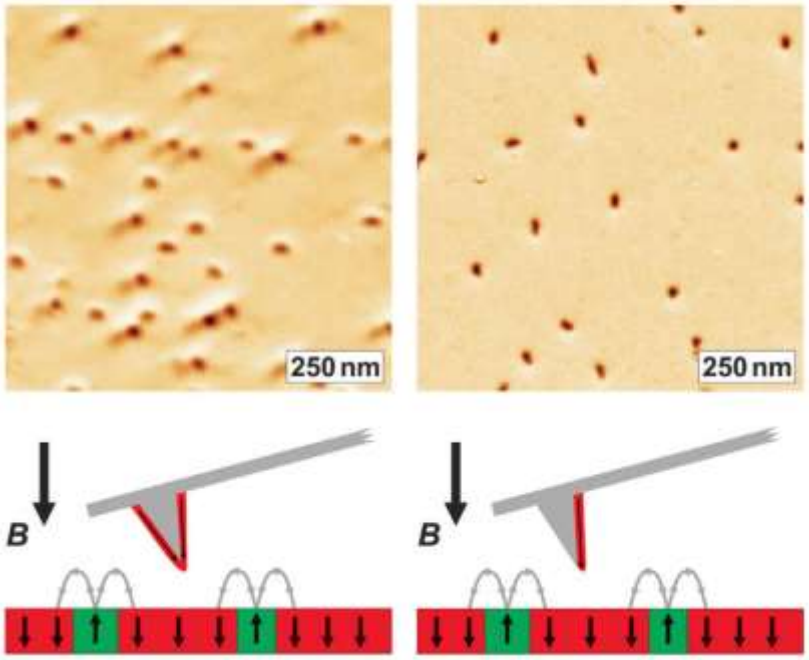


Topography image



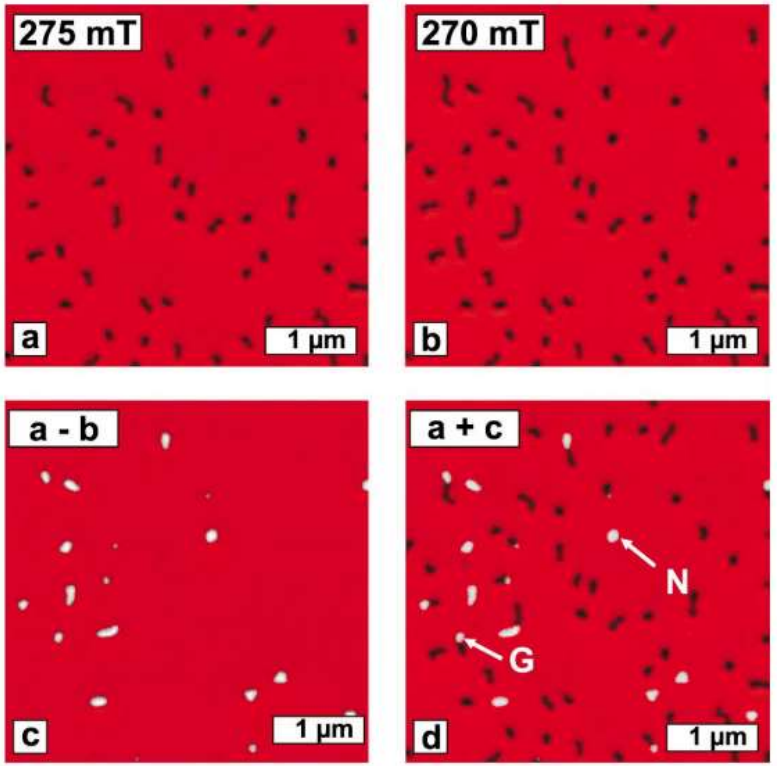
Magnetic contrast image

Improvements of MFM



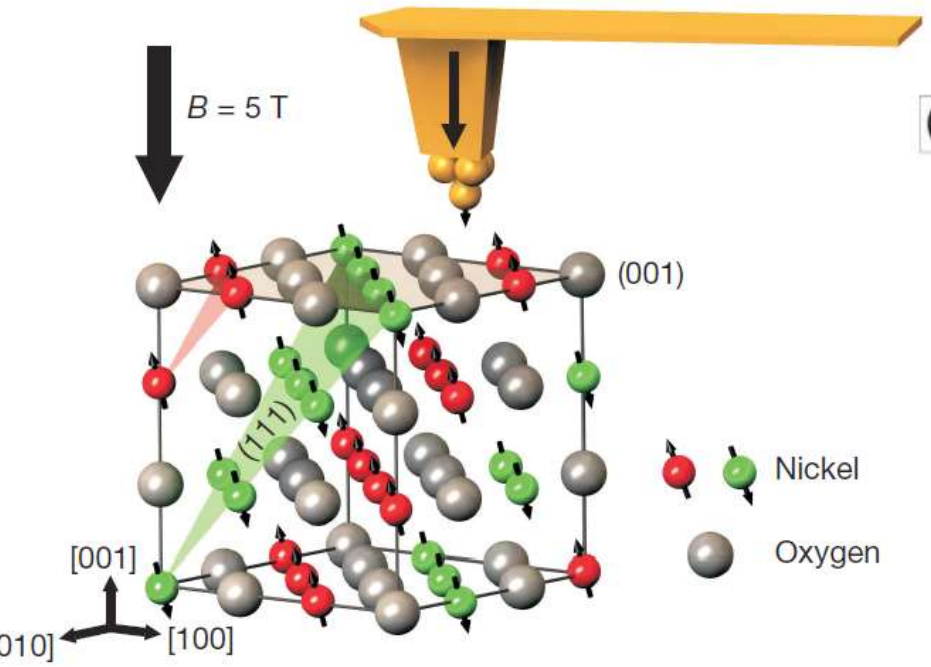
M. Liebmann et al., *Phys. Rev*. B **71(10)**, 104431(2005)

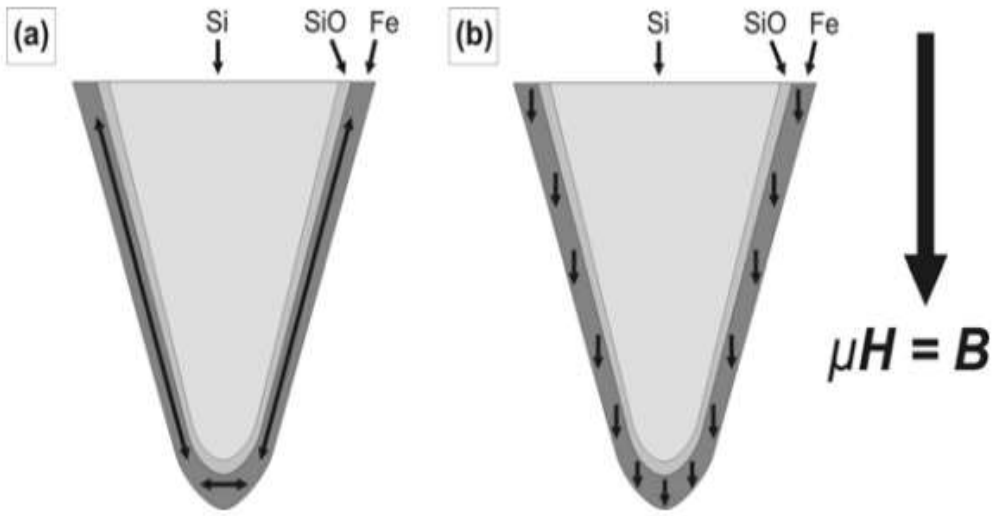
- Magnetic structure is dominated by shape anisotropy
- Easy axis → plane of the film
- Complex domain structure



Schwarz A., *et al.*, *Phys. Rev. Lett.* **92**, 077206(2004)

- External flux change
- Reversal of magnetization direction
- Resolution of 10nm





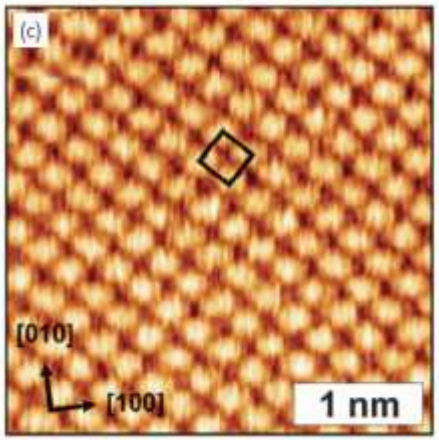
Kaiser et al., *Nature* **446**, 522(2007)

Heisenberg model

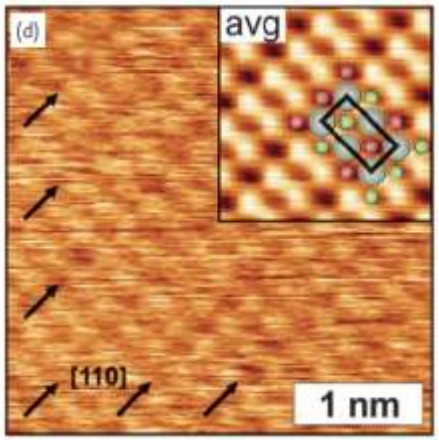
$$H_{ij} = -\sum_{ij} J_{ij} \cdot \vec{S_i} \cdot \vec{S_j}$$

- Atomic resolution → tip-sample distance<0.5nm
- Separation of chemical interaction & magnetic exchange interaction
- Foremost atom should carry a stable magnetic moment

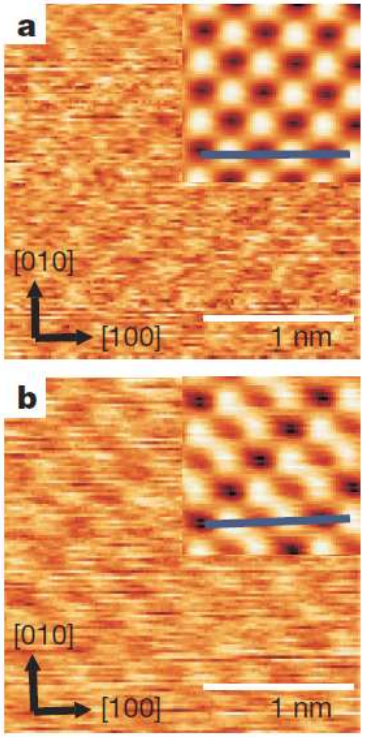
MExFM

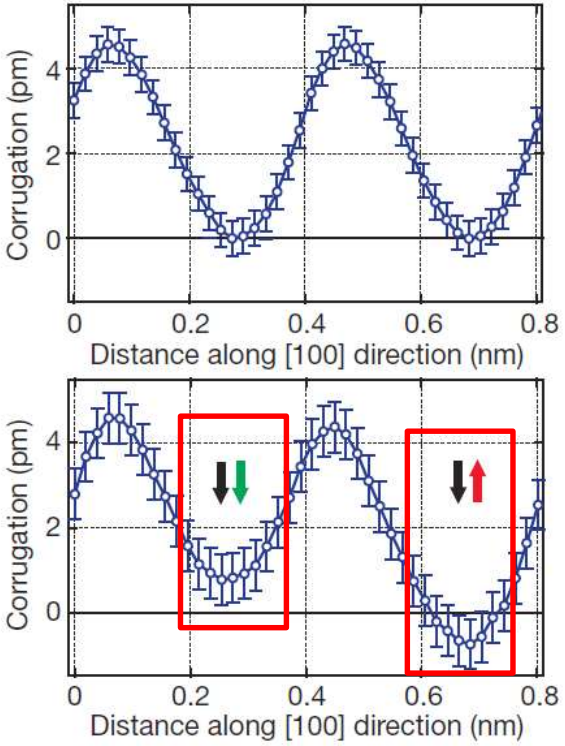


Atomic resolution with chemical contrast



MExFM image





Kaiser et al., *Nature* **446**, 522(2007)

- NiO(001): antiferromagnetic insulator
- Protrusions and depressions indicate interaction strength
- Magnetic properties of NiO are determined by the d-electrons of Ni

Thank You