Magnetic Force Microscopy

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Systems and Materials for Information storage

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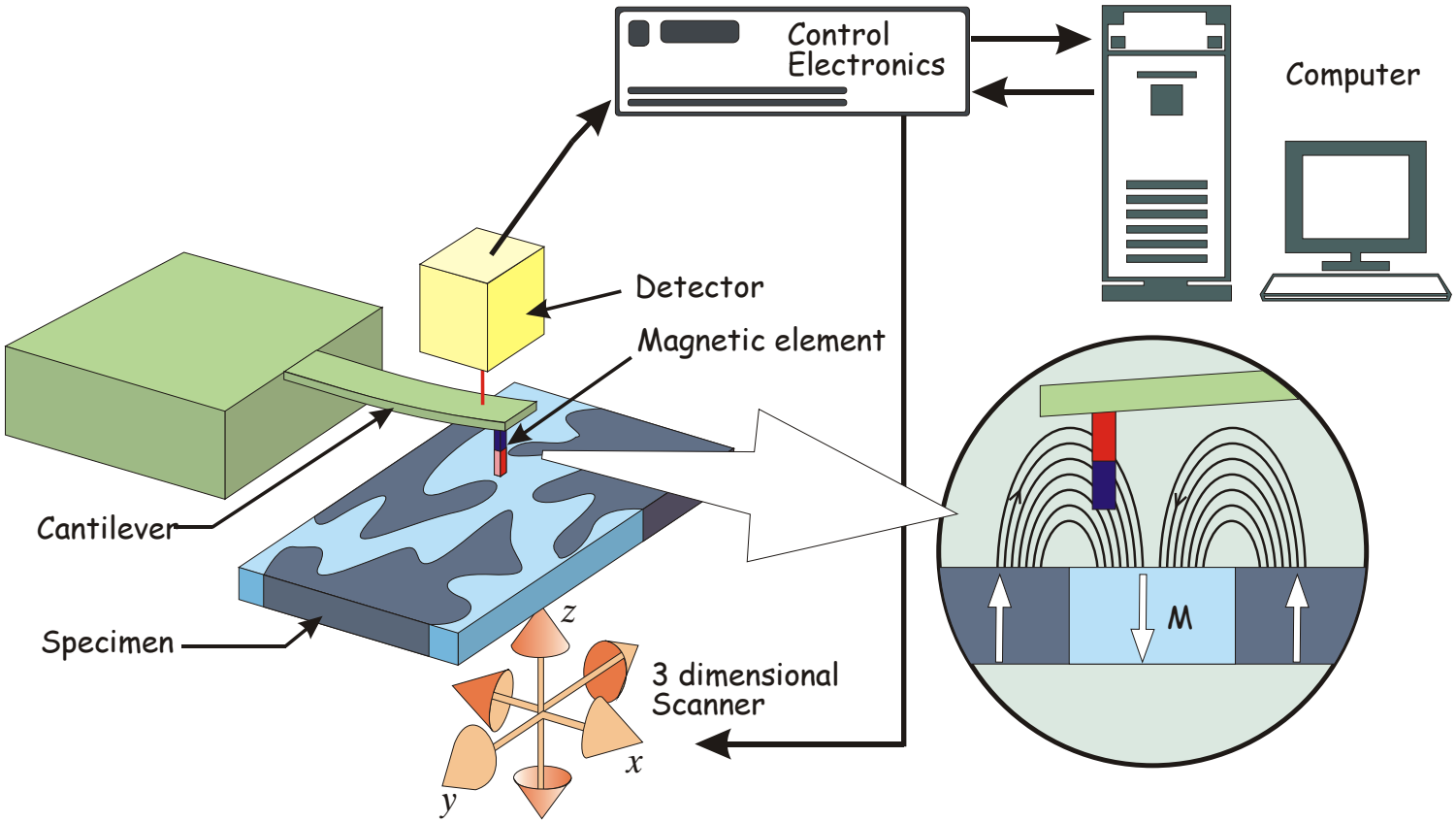
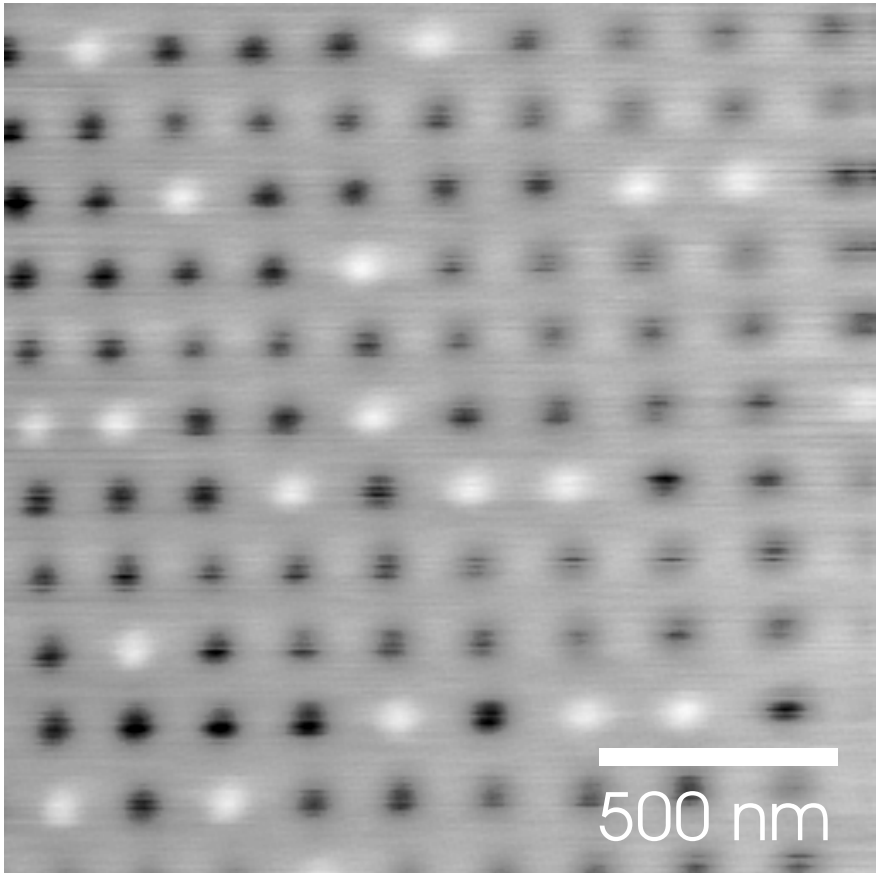
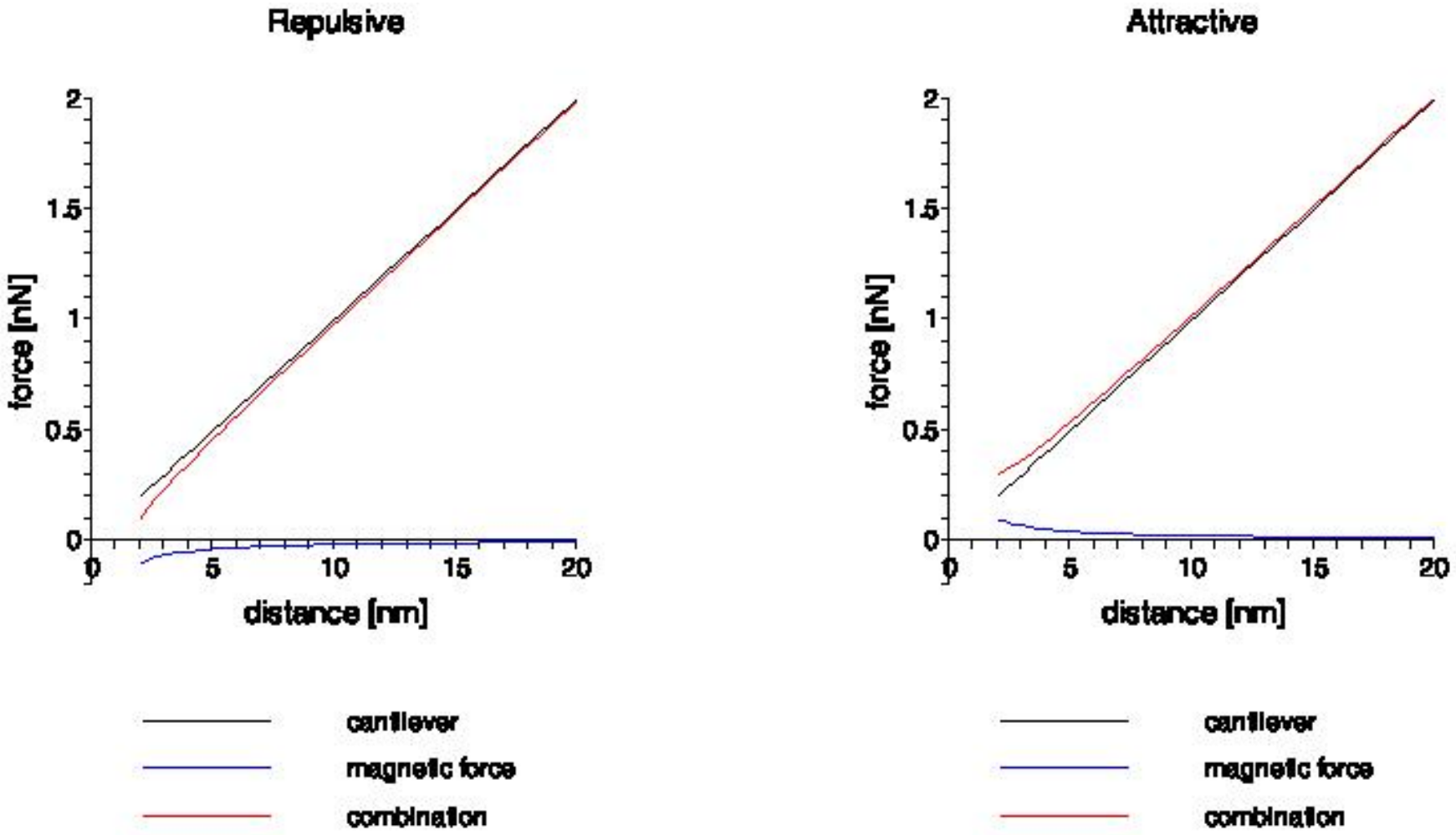
Principle of MFM



Magnetic Force Microscopy



Change in resonance



Amplitude, Phase, Frequency

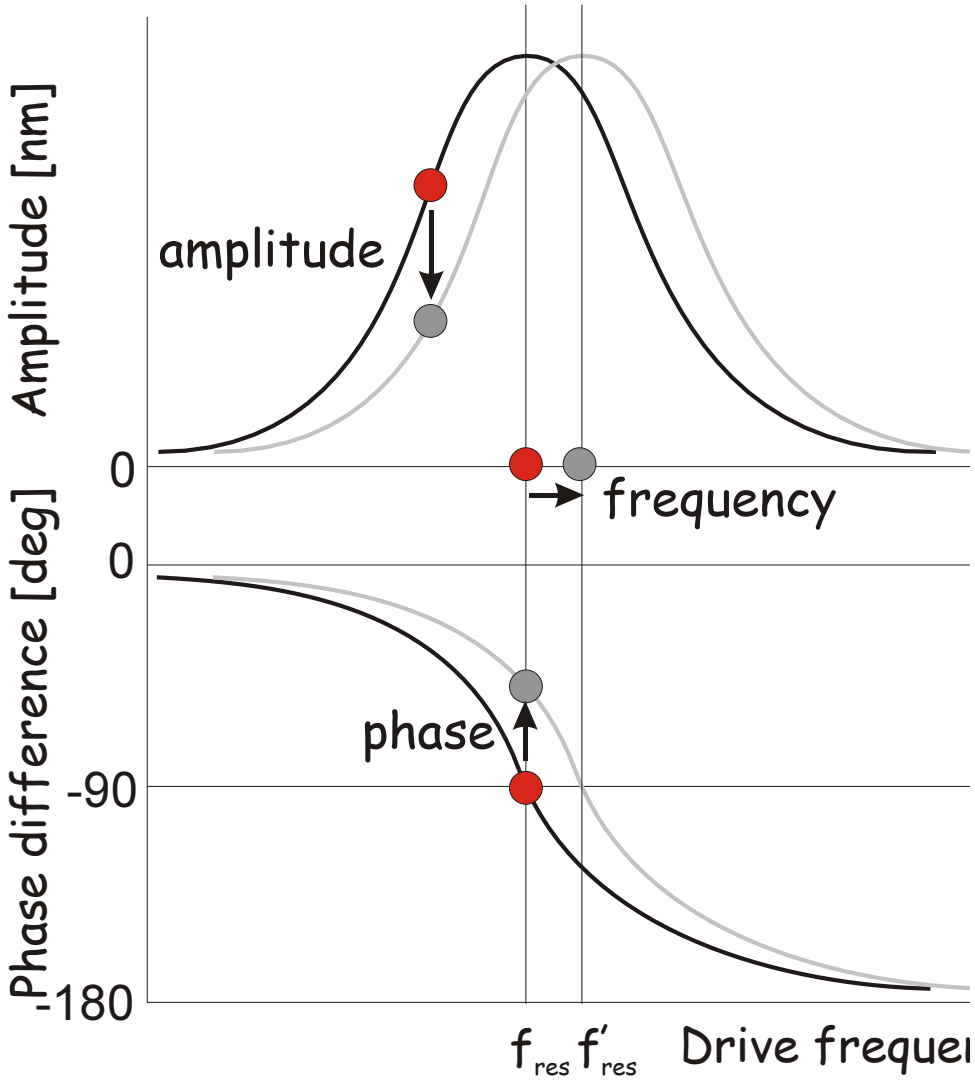


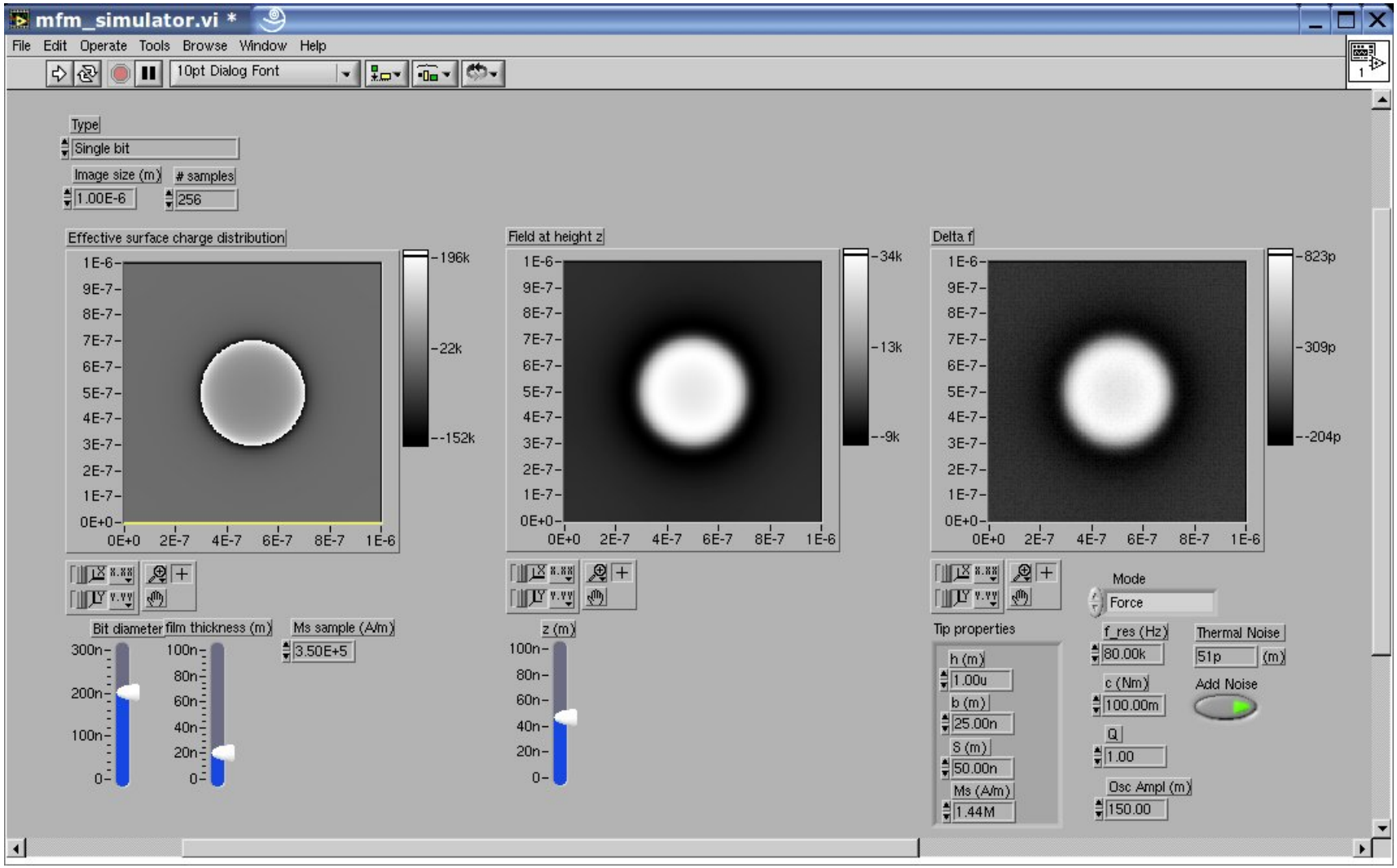
Image formation

Transform stray field to Fourier space:

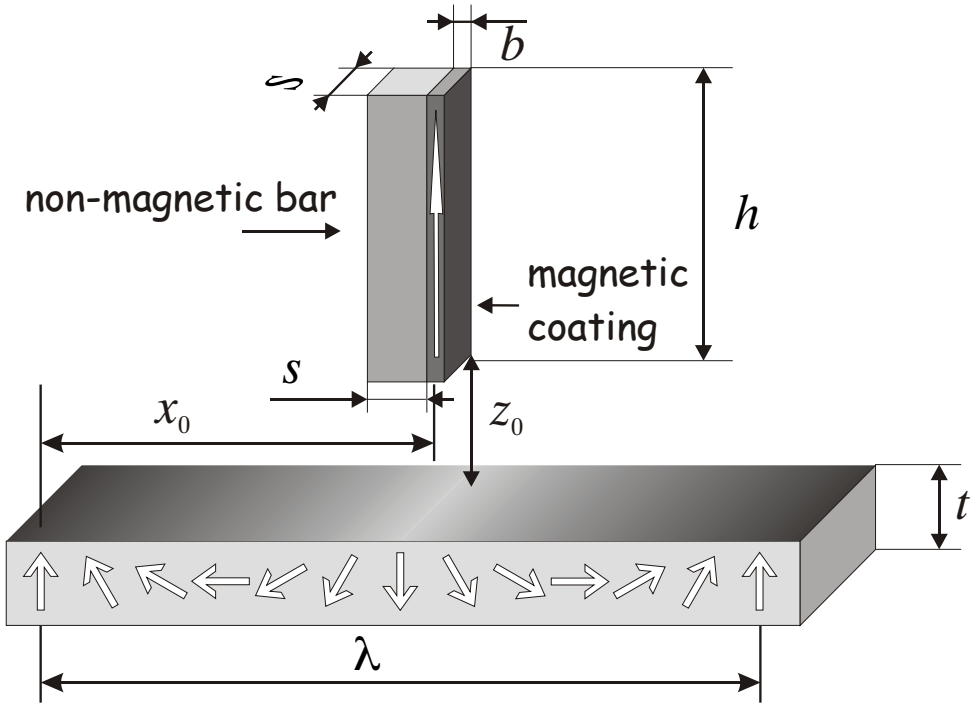
$$\widehat{\boldsymbol{H}}(k_x, k_y, z) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \boldsymbol{H}(x, y, z) e^{-i(xk_x + yk_y)} dx dy$$

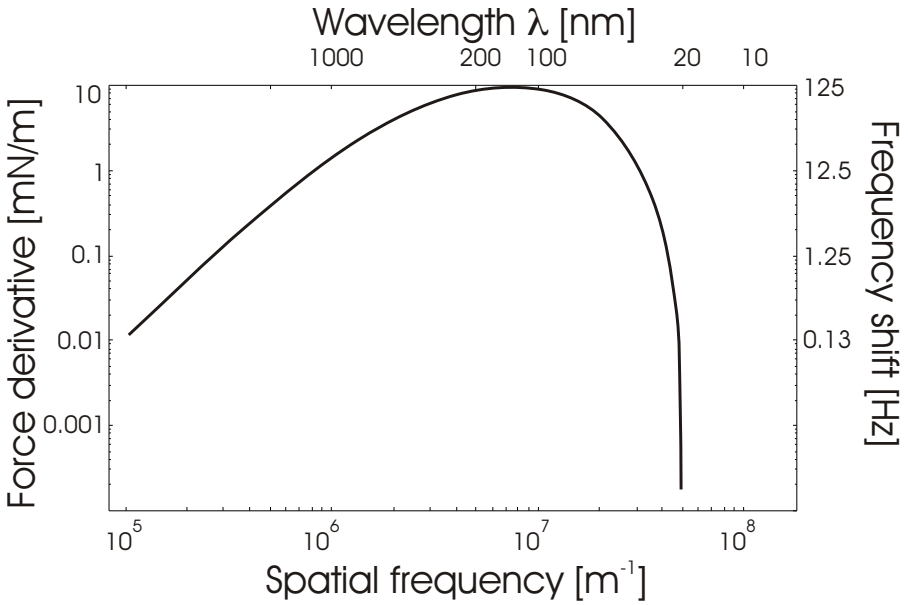
$$\widehat{\boldsymbol{H}}(k_x, k_y, z) = \exp(-|\boldsymbol{k}|z) \cdot \widehat{\boldsymbol{H}}(k_x, k_y, 0)$$

MFM Demonstrator



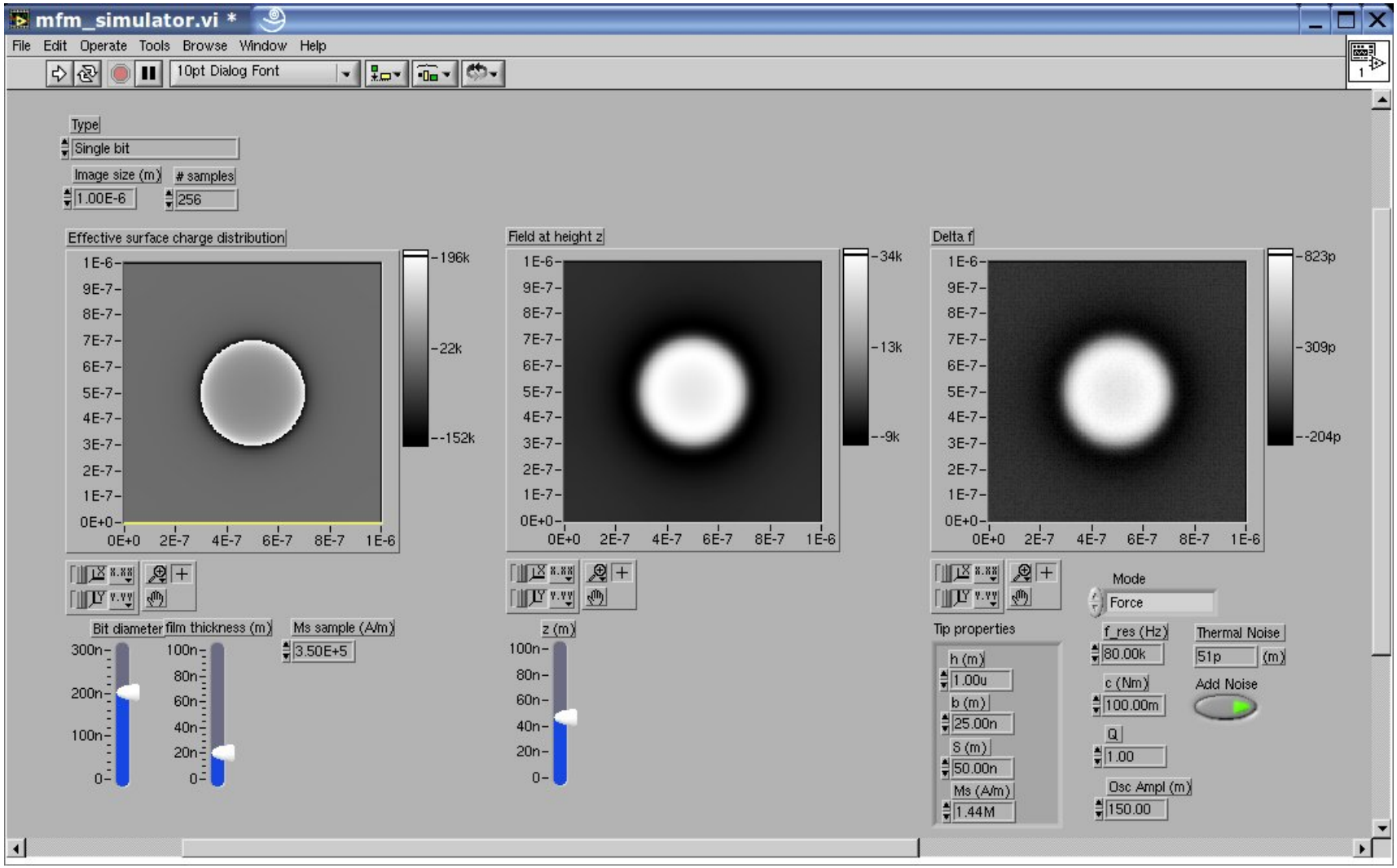
Tip transfer function



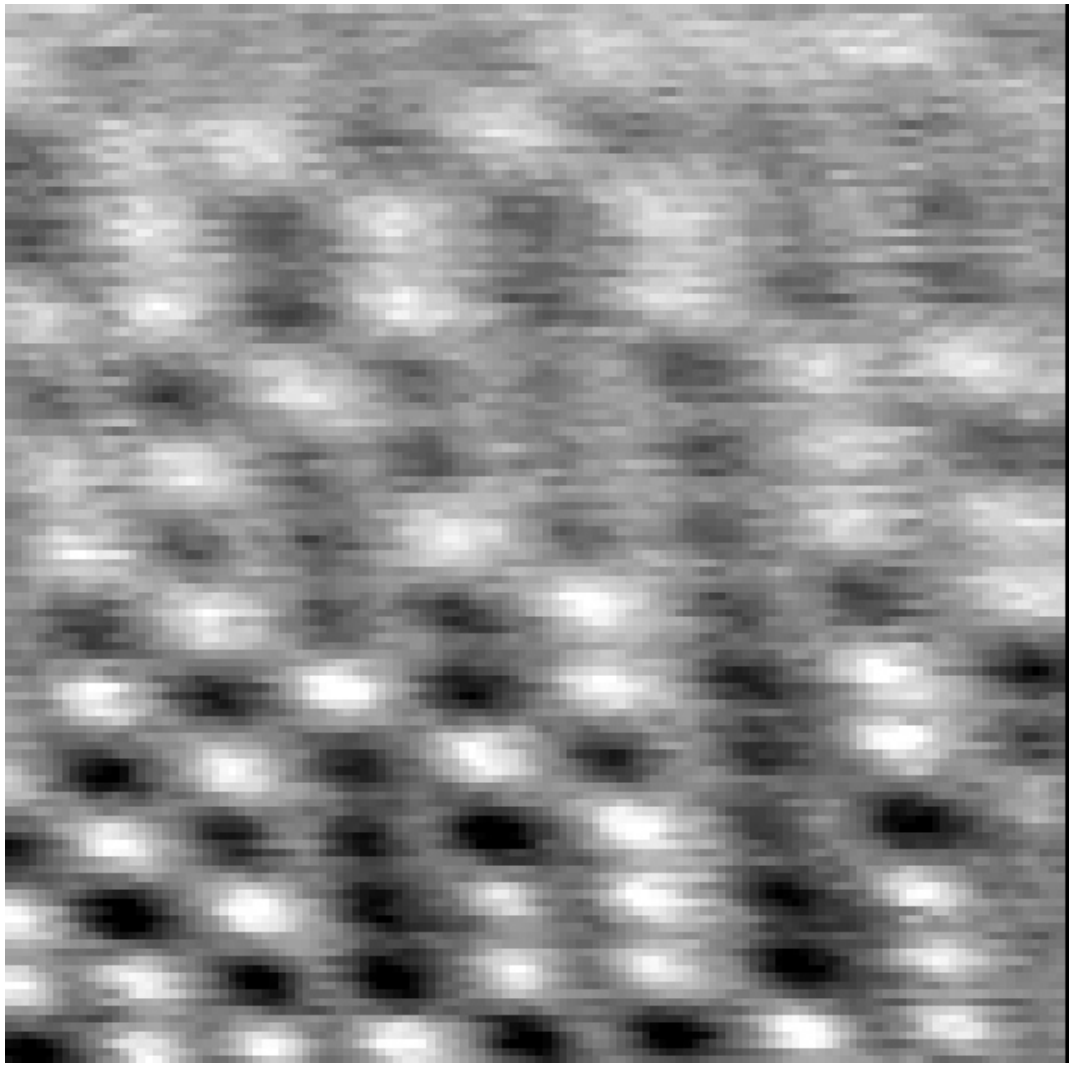


$$\widehat{F}_z(\boldsymbol{k}, z) = -\mu_0 M_t \cdot b \; sinc(\frac{k_x b}{2}) \cdot S \; sinc(\frac{k_y S}{2}) \cdot \widehat{\boldsymbol{H}}(\boldsymbol{k}, z)$$

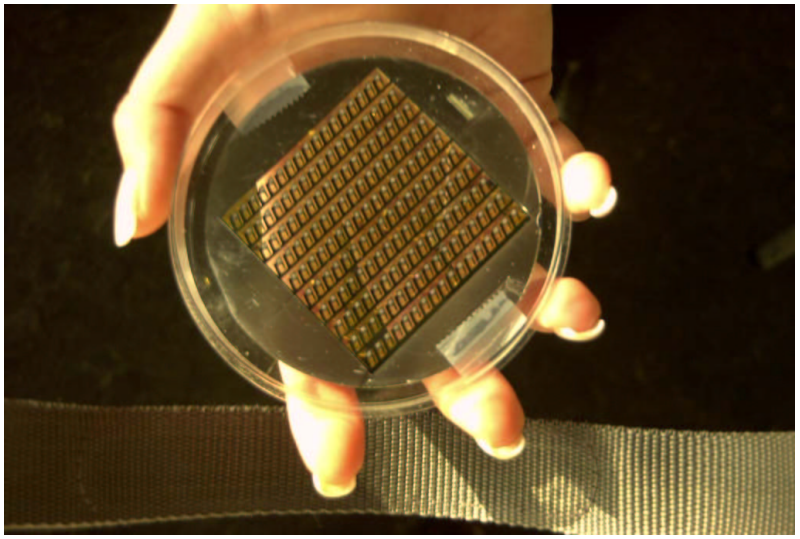
MFM Demonstrator 2

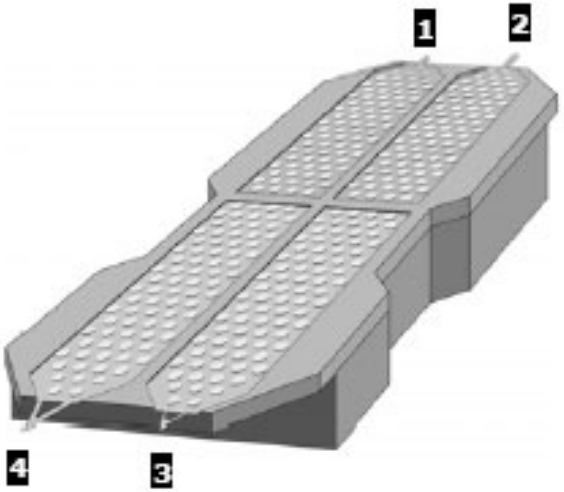


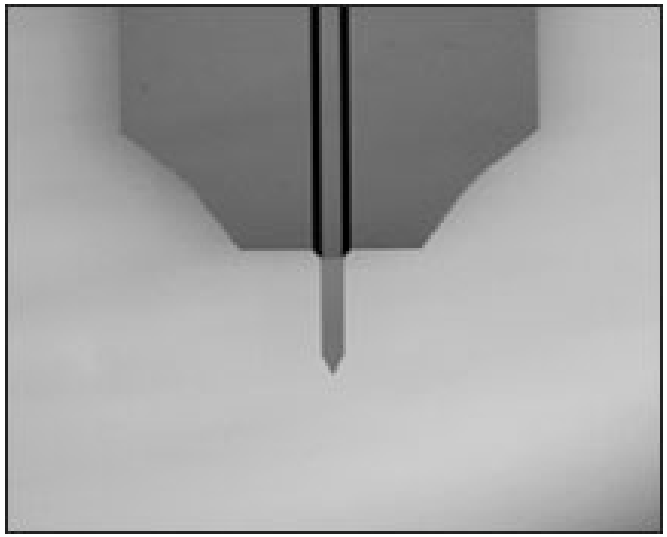
Resolution versus distance

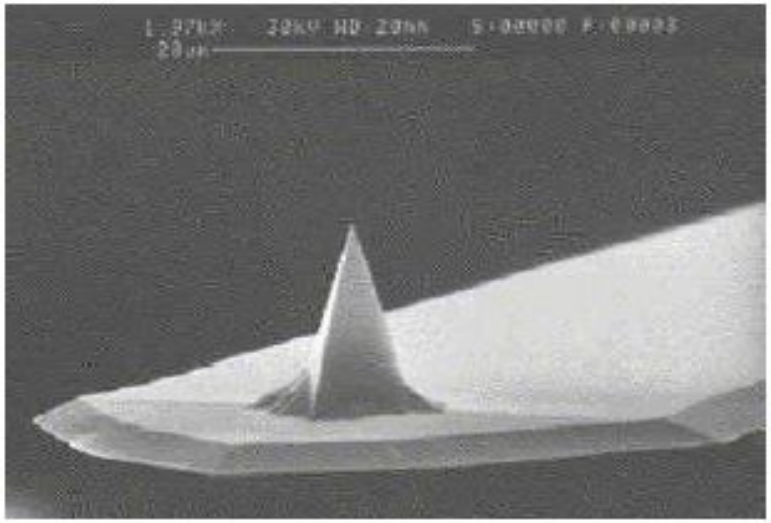


Probes

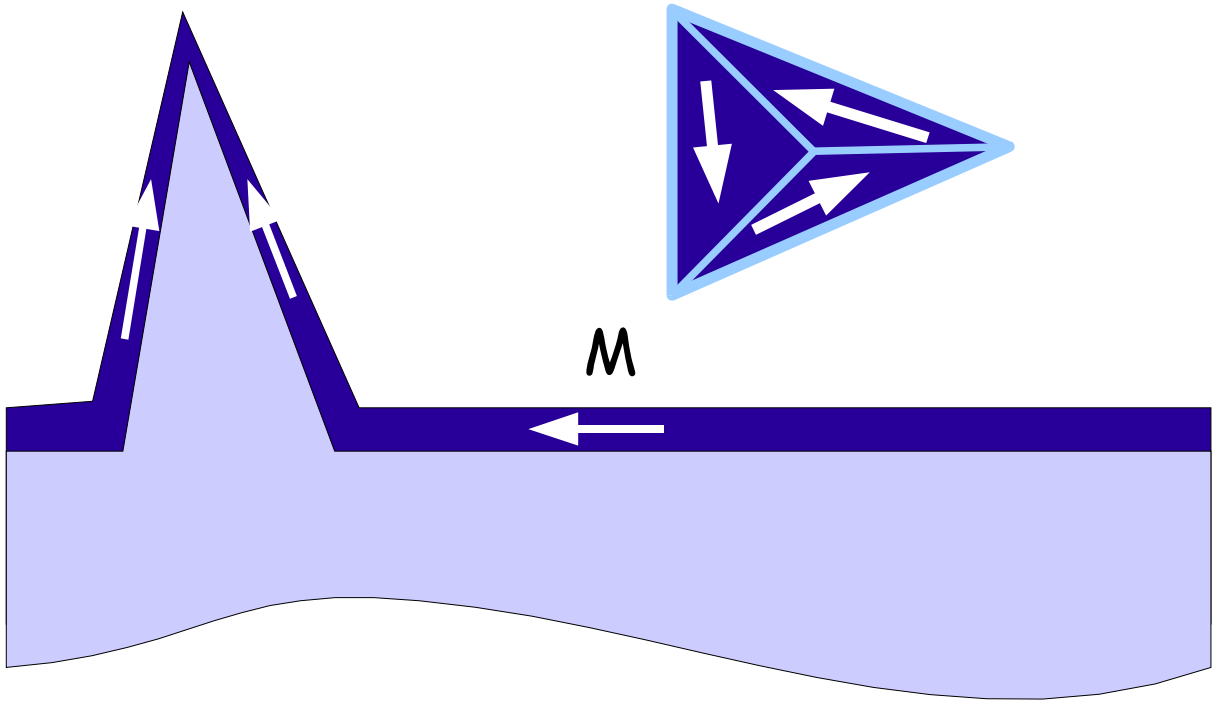






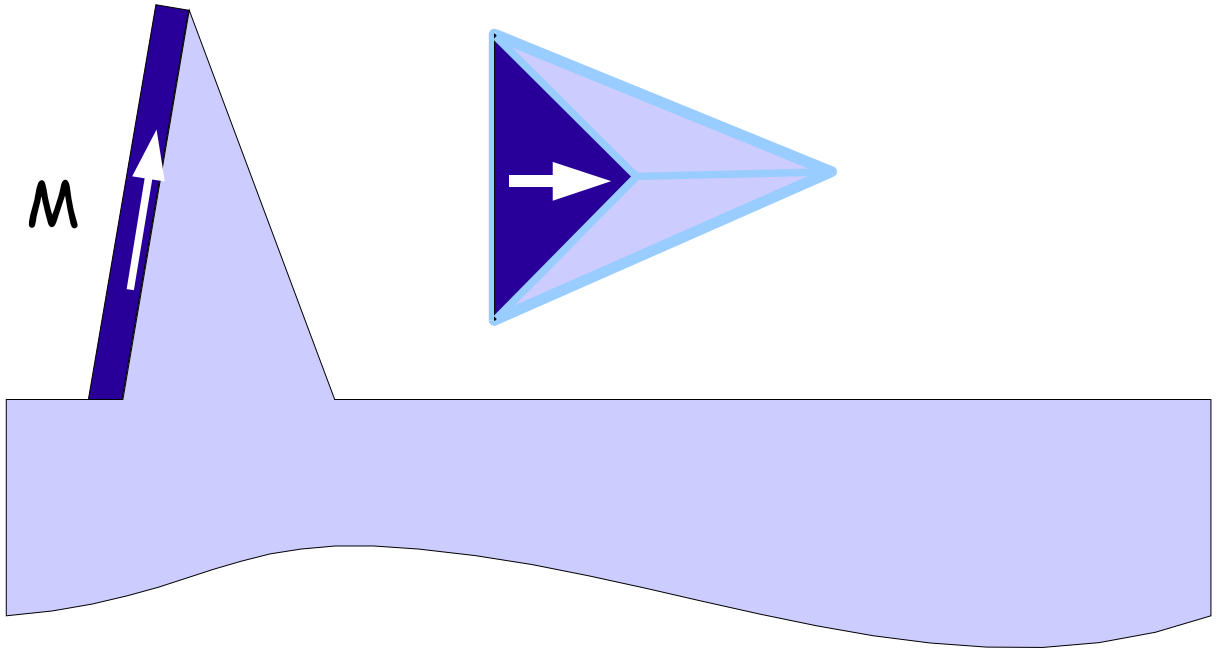


AFM sputtered



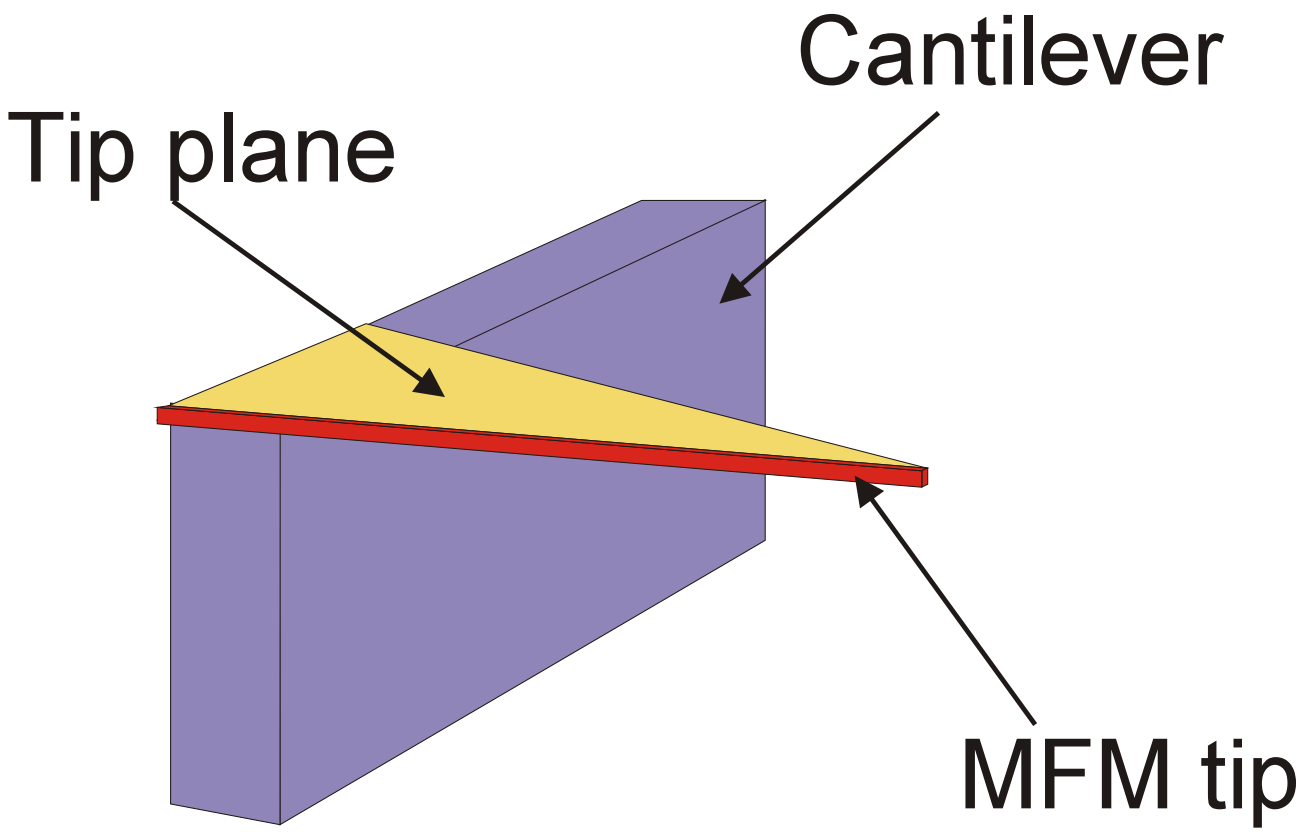
- Sputtered CoCr(X) hard disk materials
- Low/high moment: layer thickness
- Fe, NiFe for low coercivity tips

AFM side coated



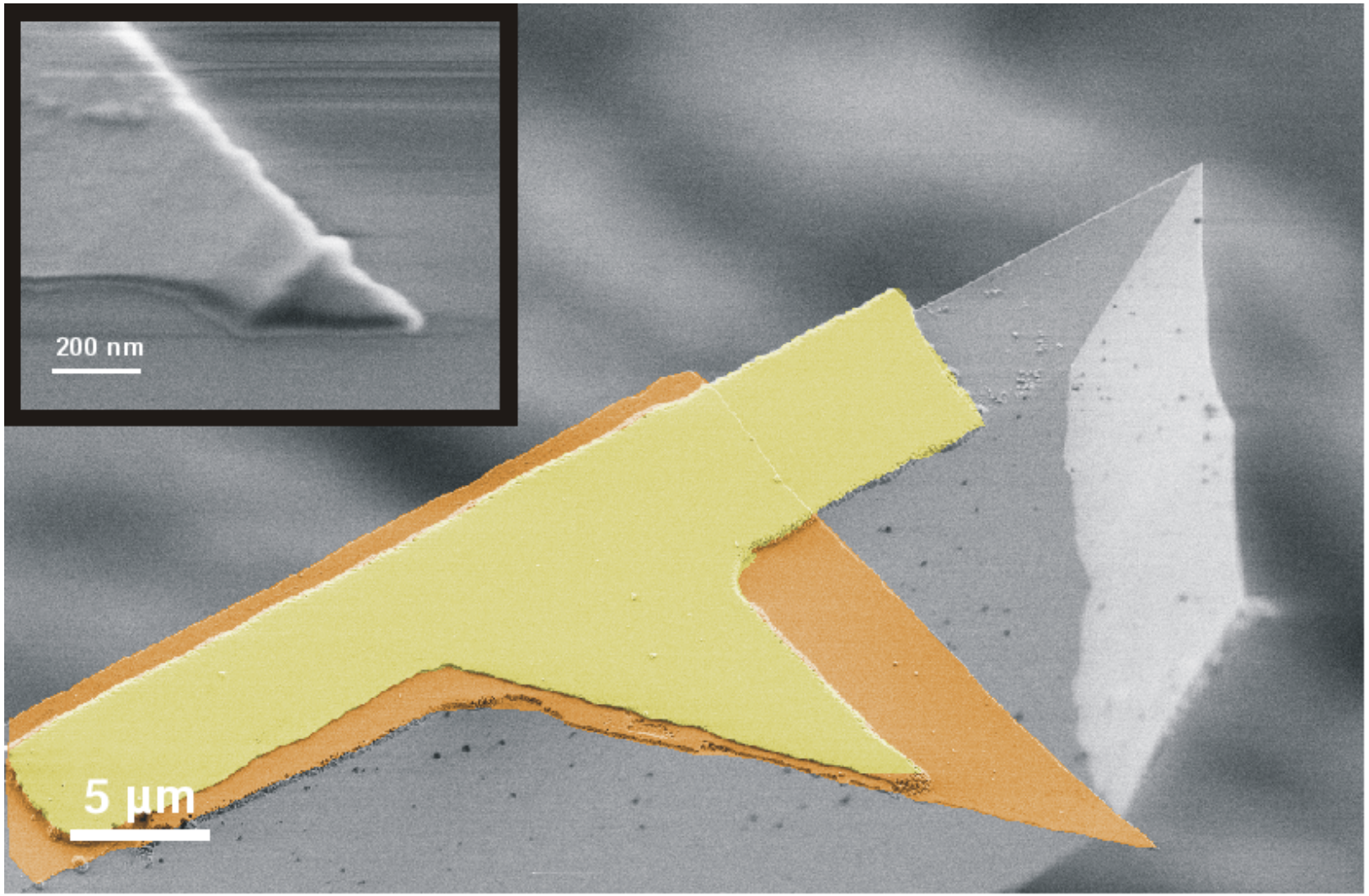
- Co, NiFe evaporated
- Shape anisotropy
- Stable domain structure

CantiClever

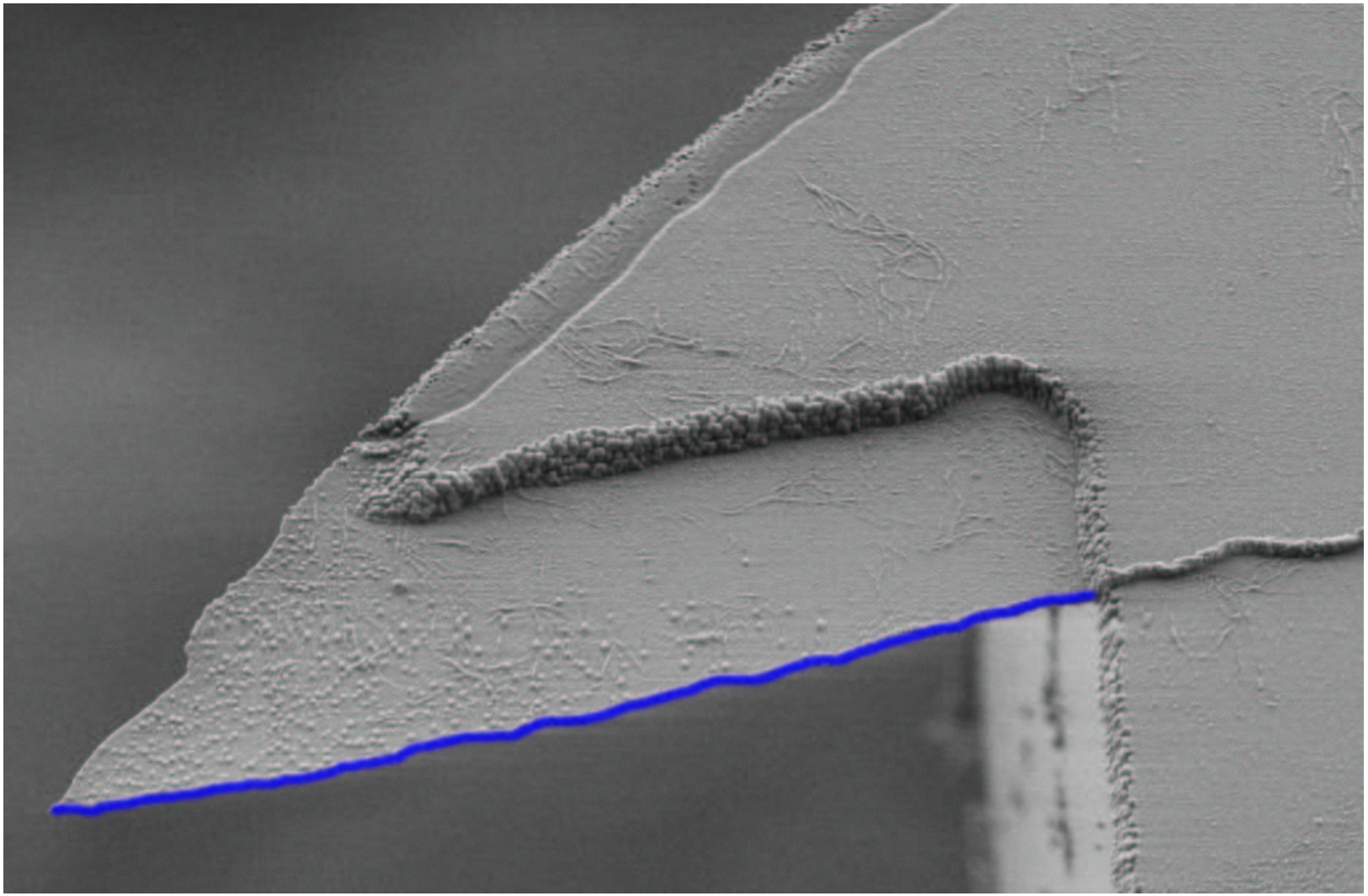


Cross-section determined by layer thicknesses

SEM Images cantilever

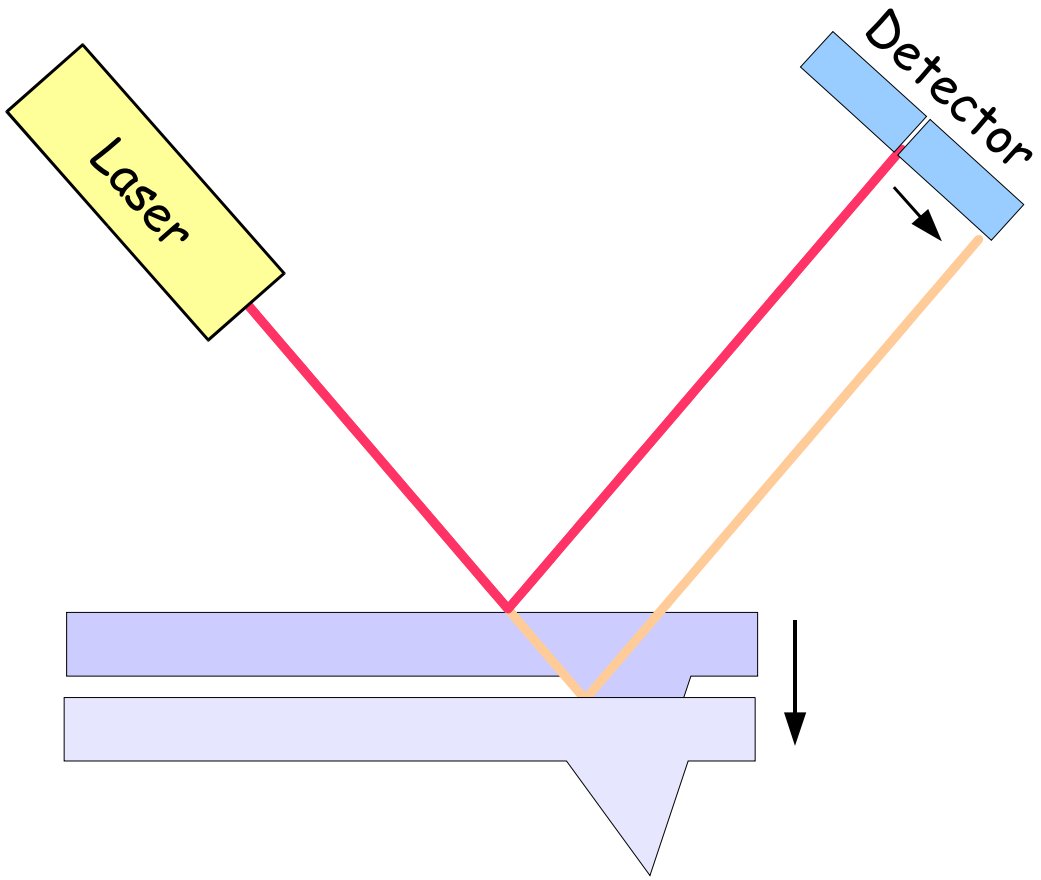


SEM Images tip



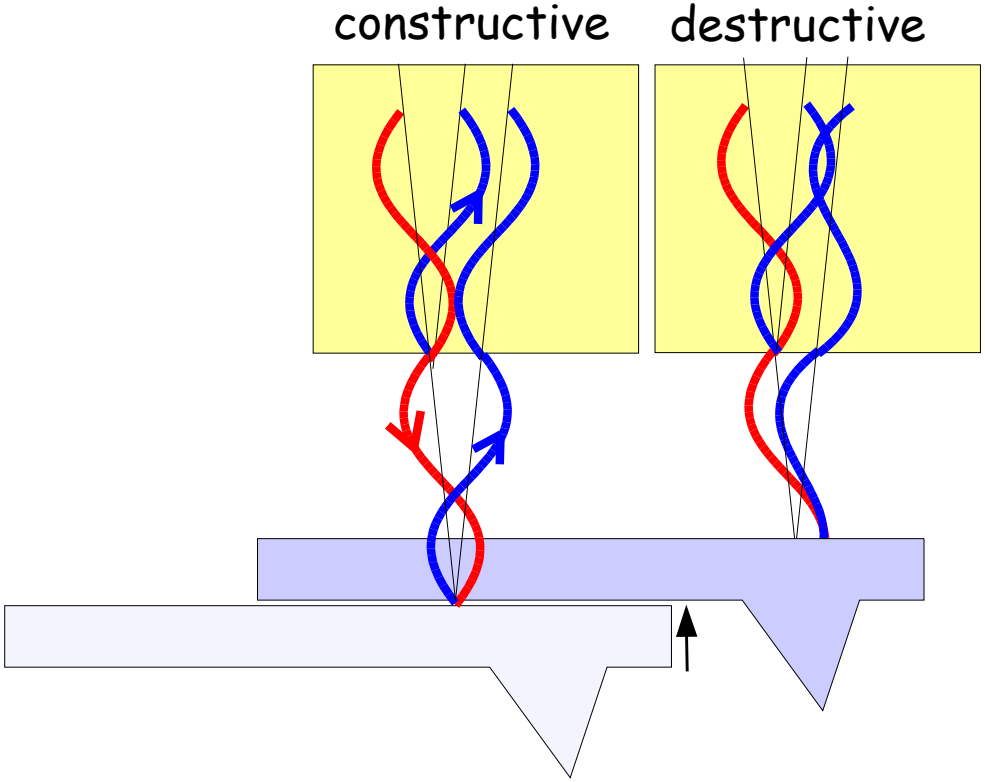
Break

Beam Deflection



- Laser
- LED

Interferometer

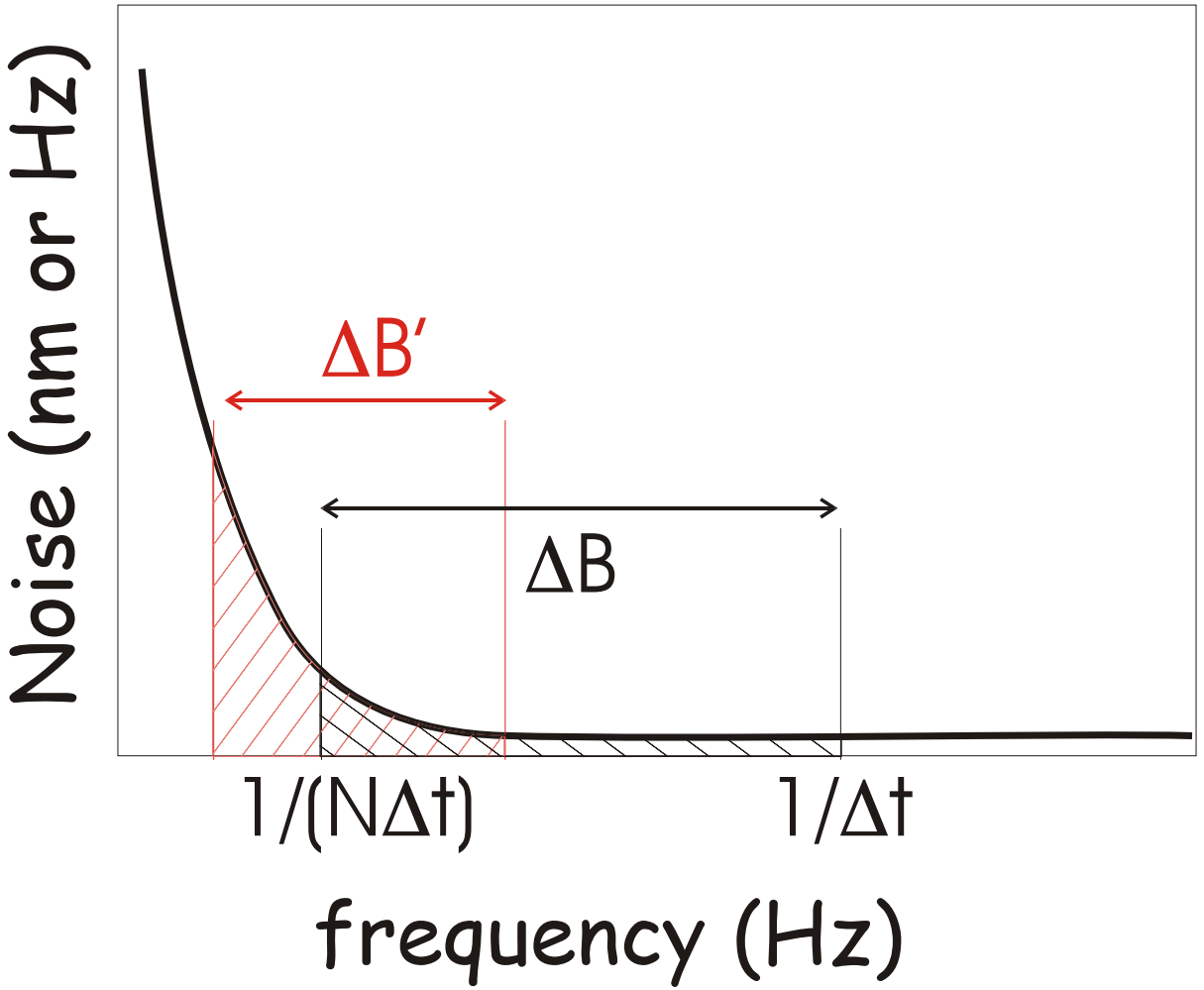


- factor 10 better sensitivity
- difficult to align
- better reflection coatings

Thermal Noise

$$\left(\Delta\left(\frac{\partial F}{\partial z}\right)_{th}\right)_{rms} = \sqrt{\frac{4kTc\Delta B}{\omega_n Q\langle z_{osc}^2\rangle}}$$

Drift



Vacuum

- Reduce damping, improves Q-factor by 10^5
- Sound isolation
- Remove most of water film (meniscus)

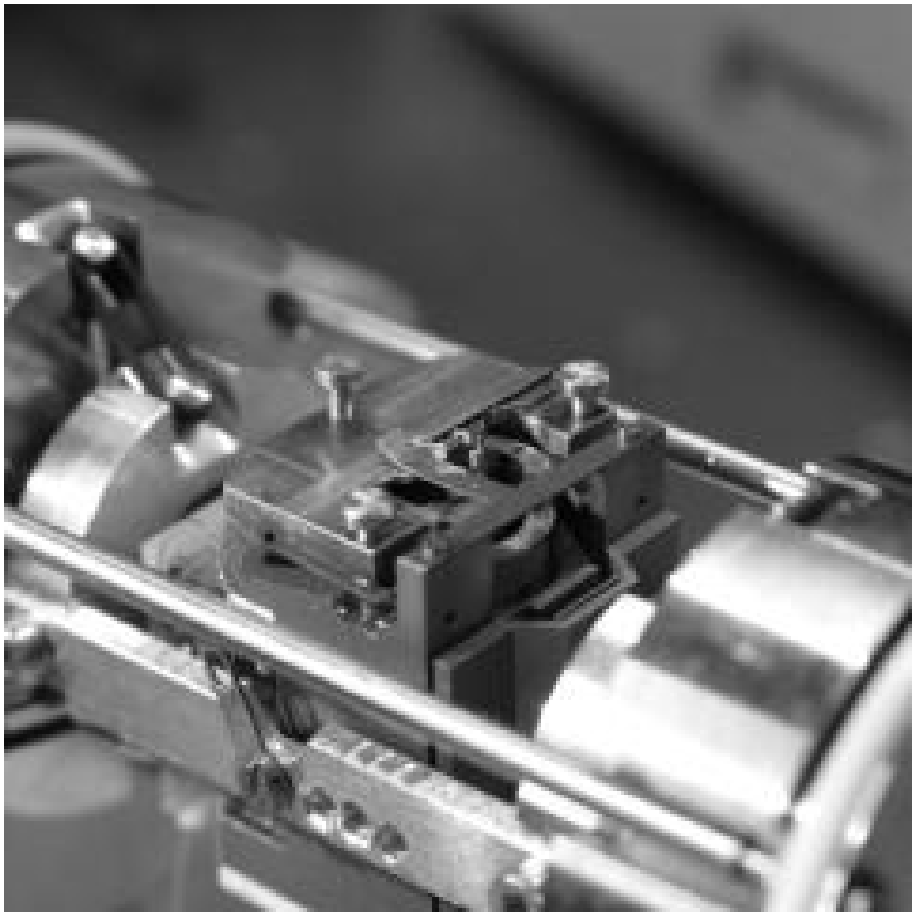
  Be careful with break-down (Paschen curve)

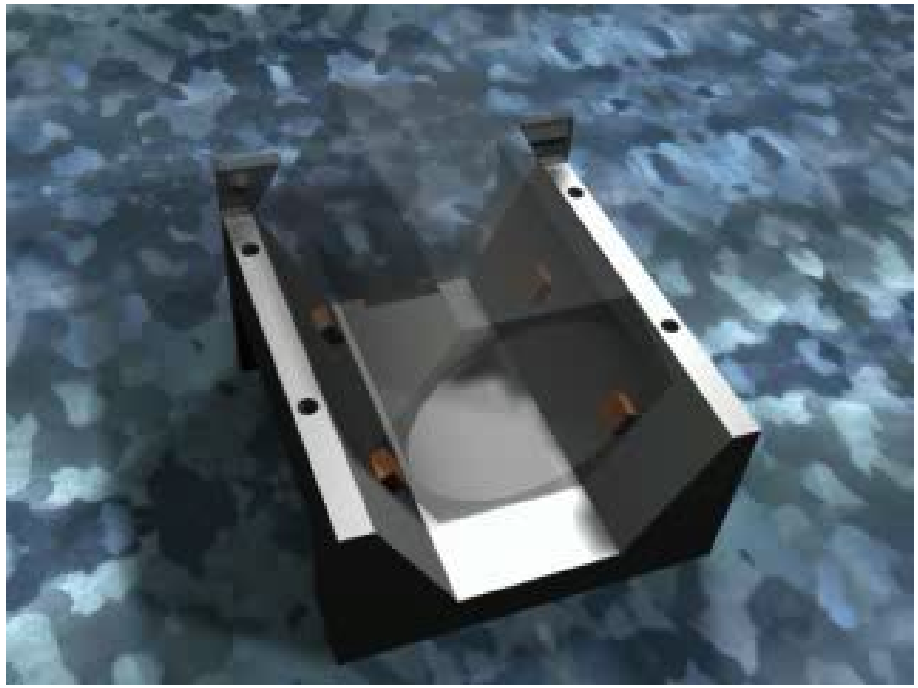
Magnetic Field

Application of magnetic fields

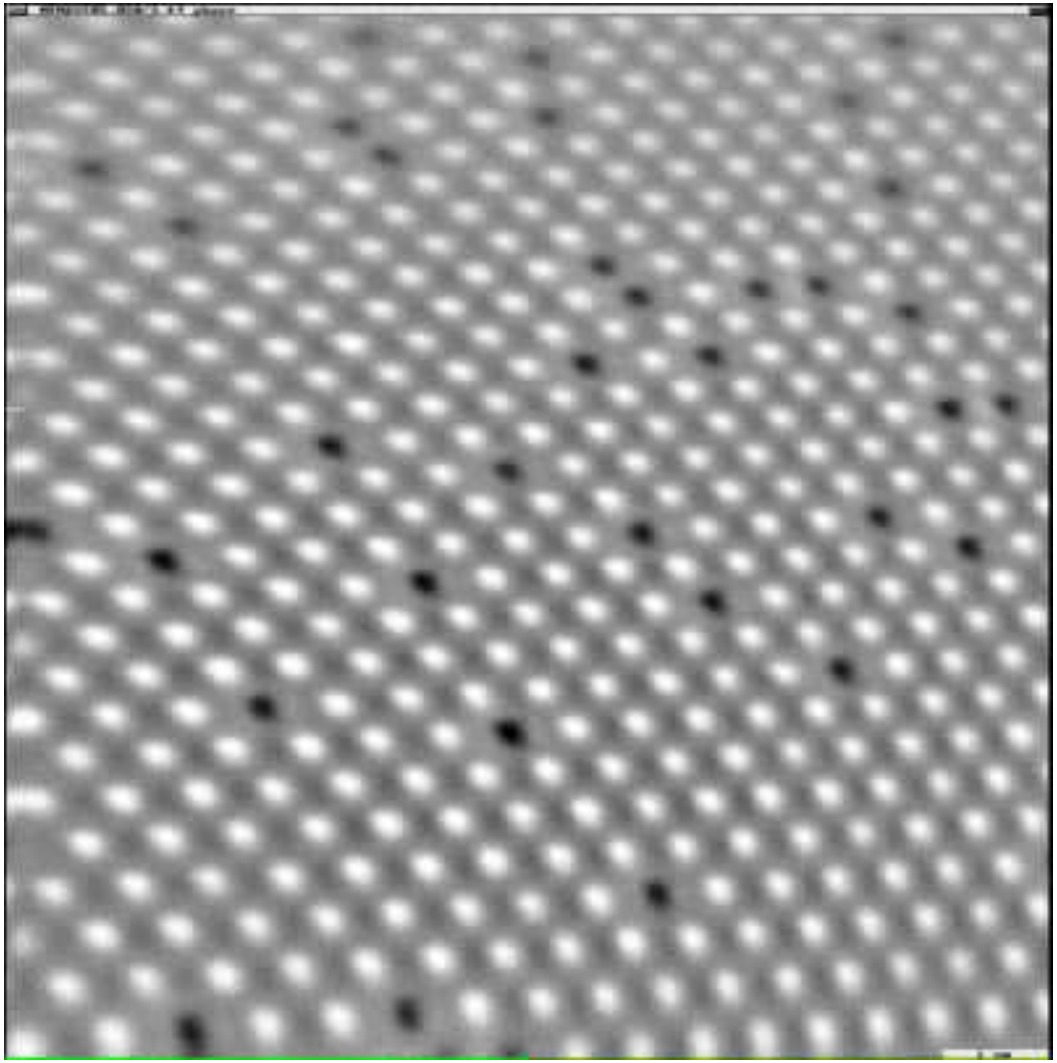
- On sample
  - Simple
  - Only in-plane
  - Low field
  - Heating
- On microscope
  - Requires very small microscope

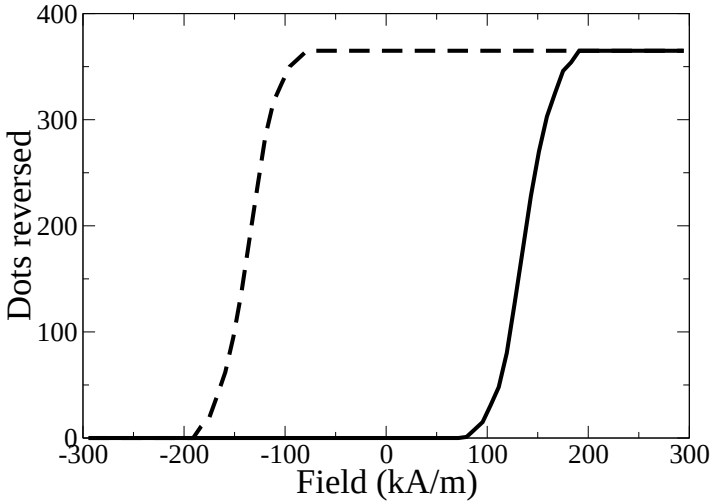
Instrumentation



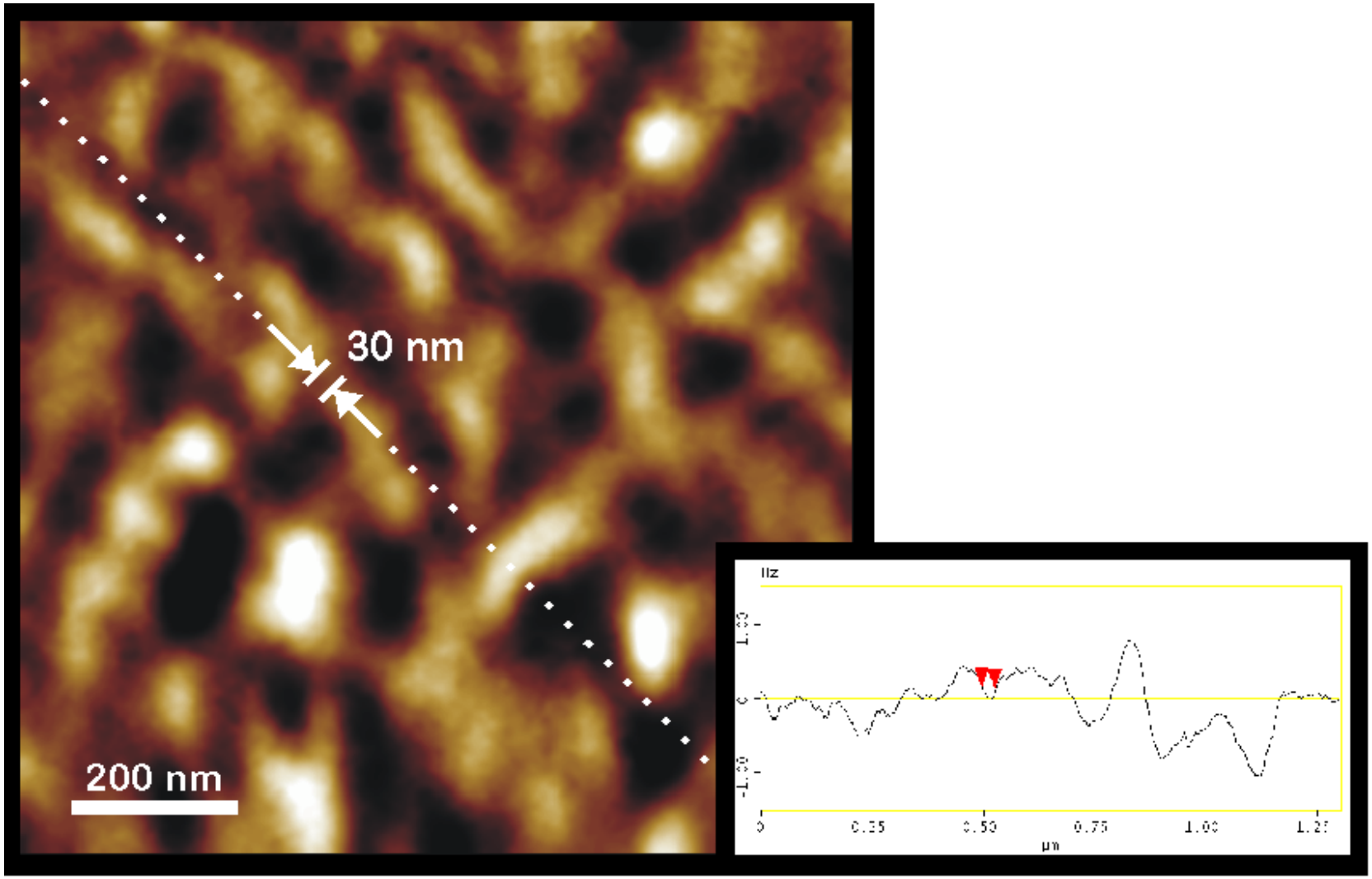


Switching Field Distribution

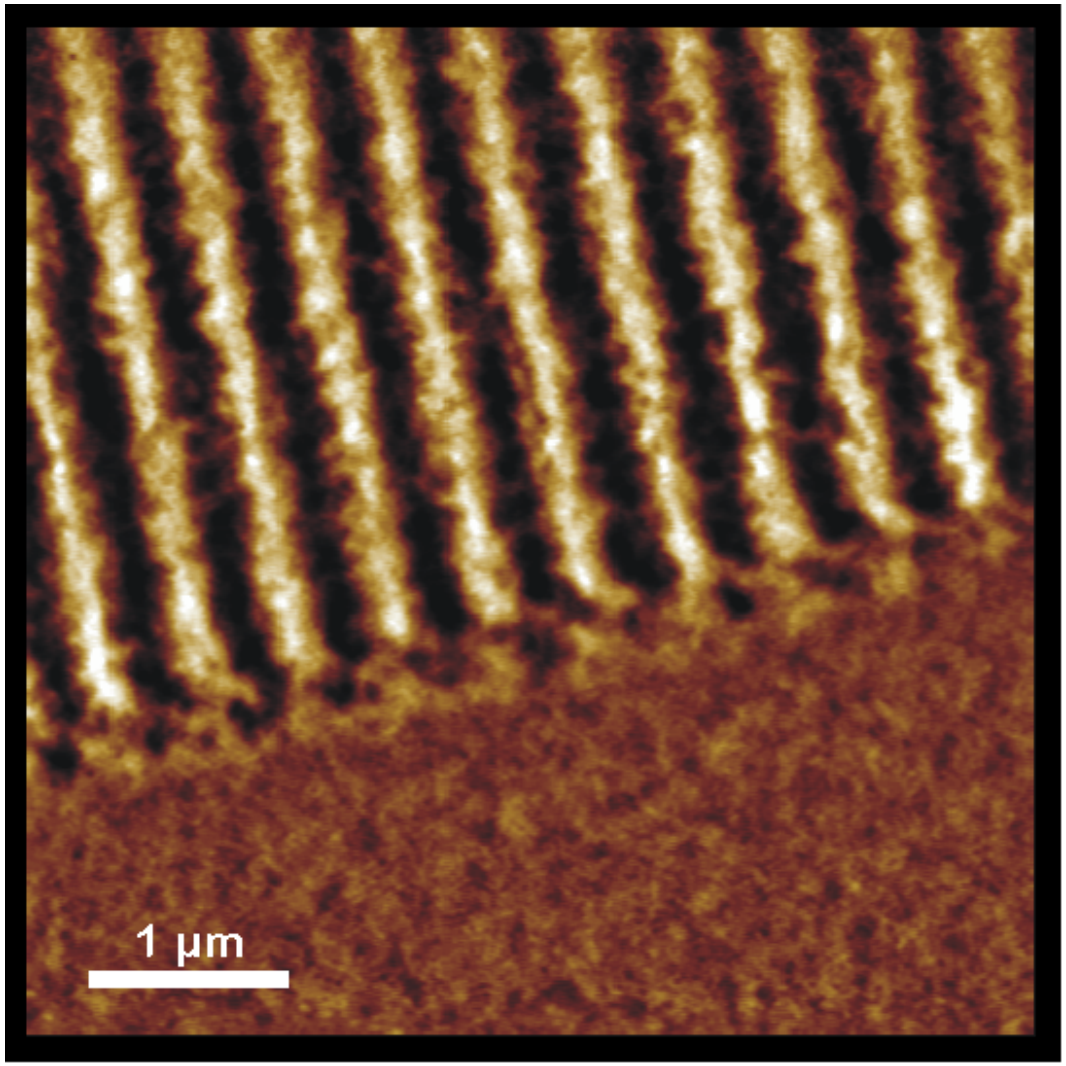




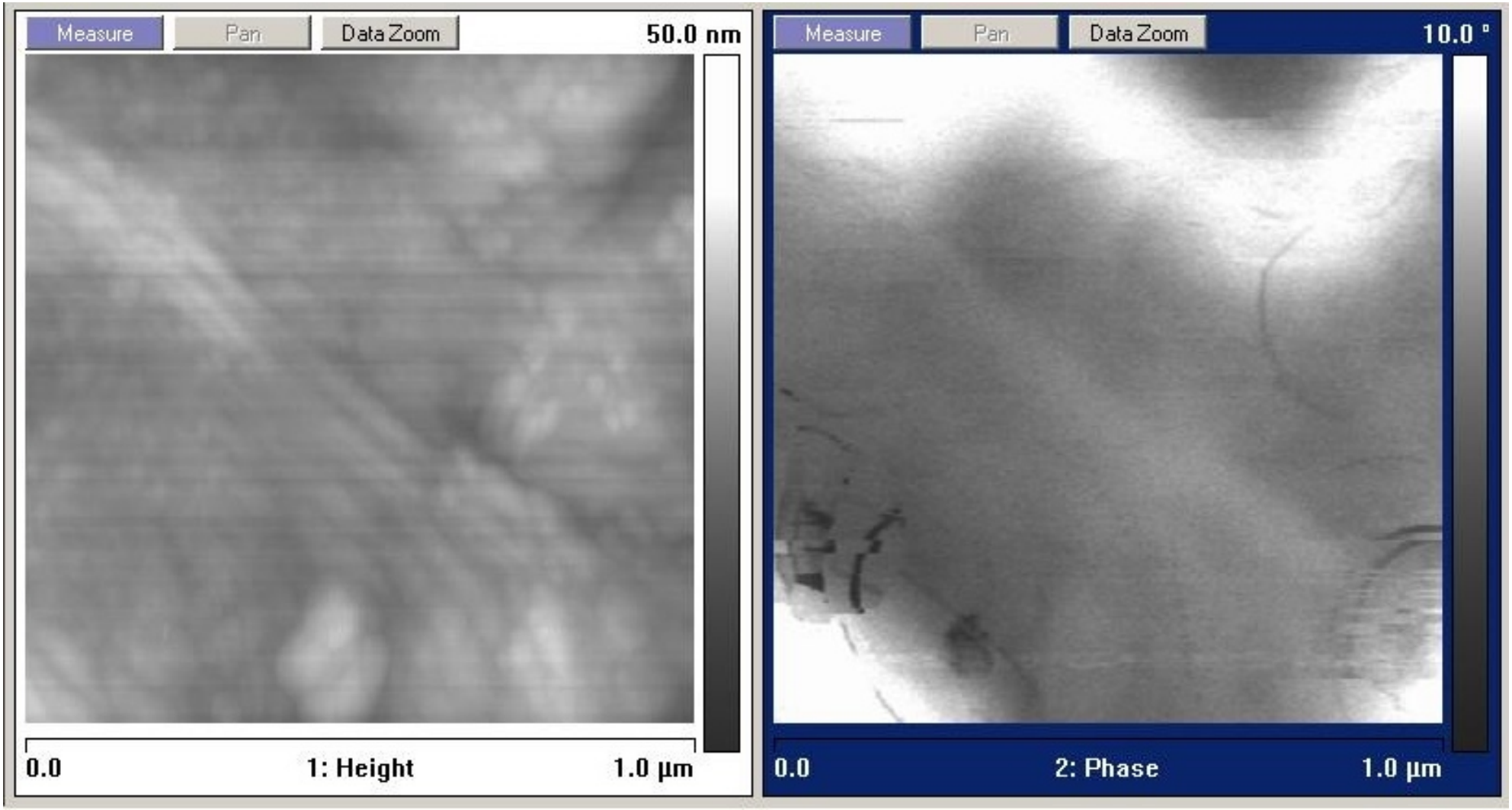
Correct domain image



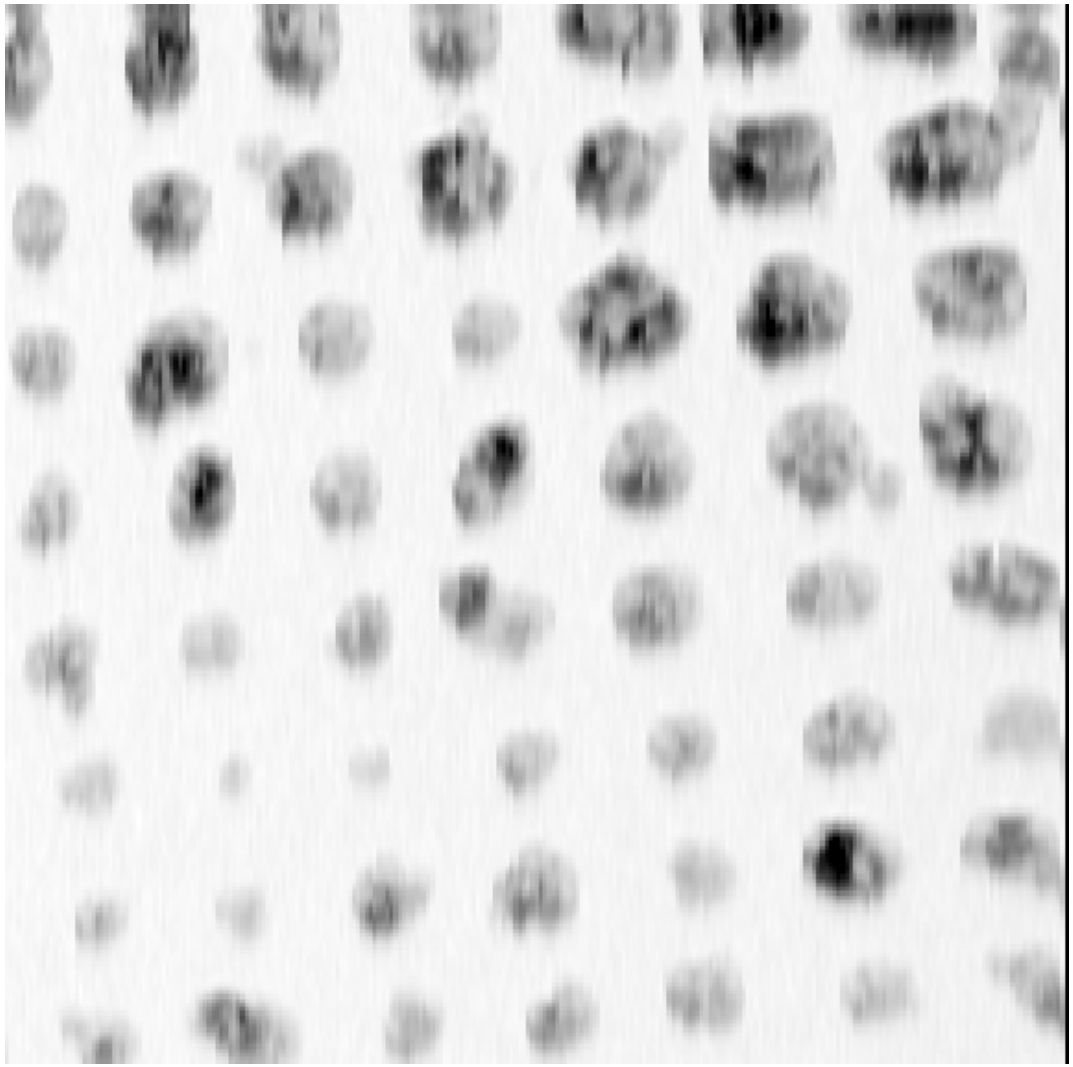
Correct bit pattern



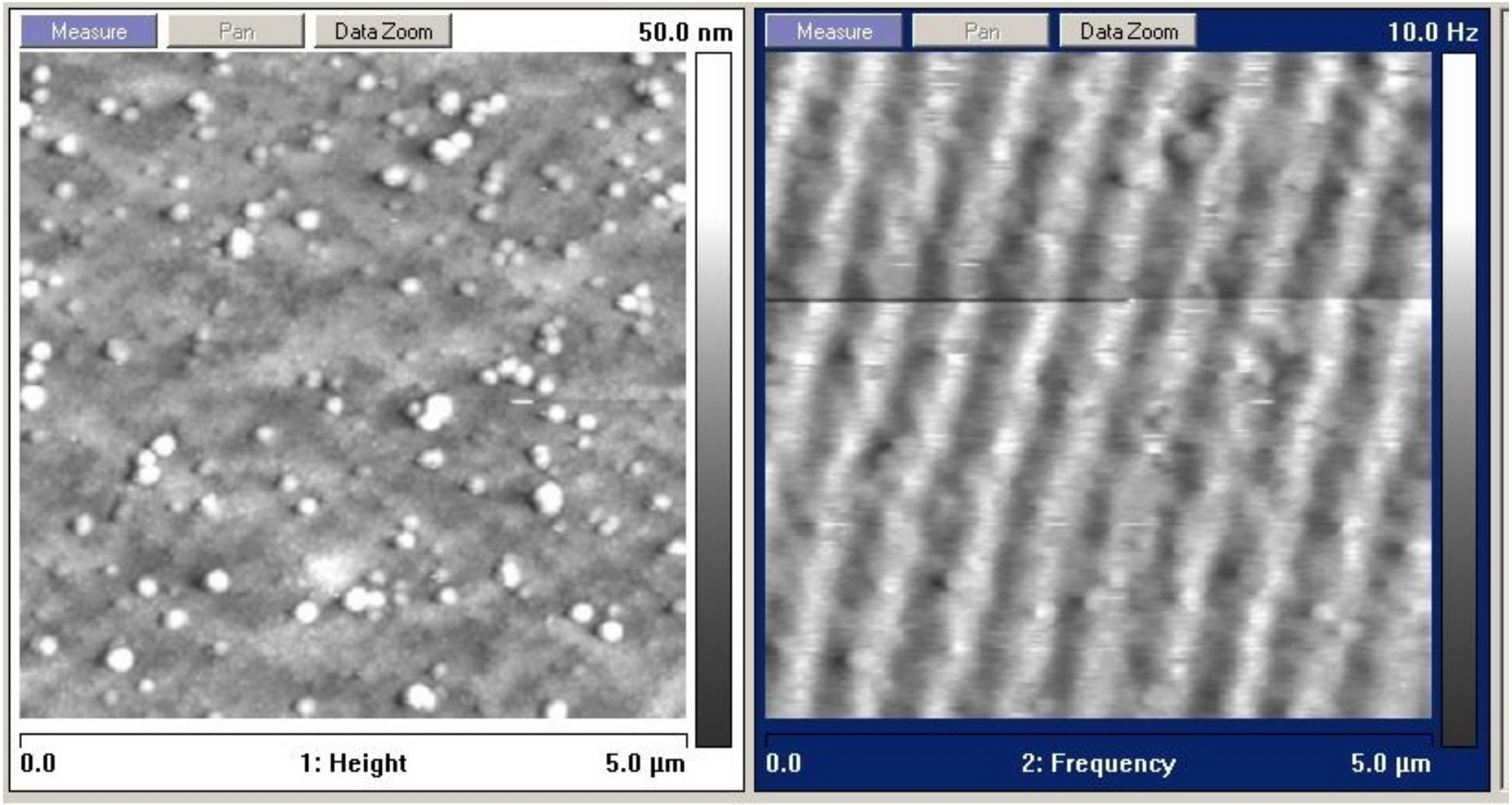
Interference stripes



Topographic contrast



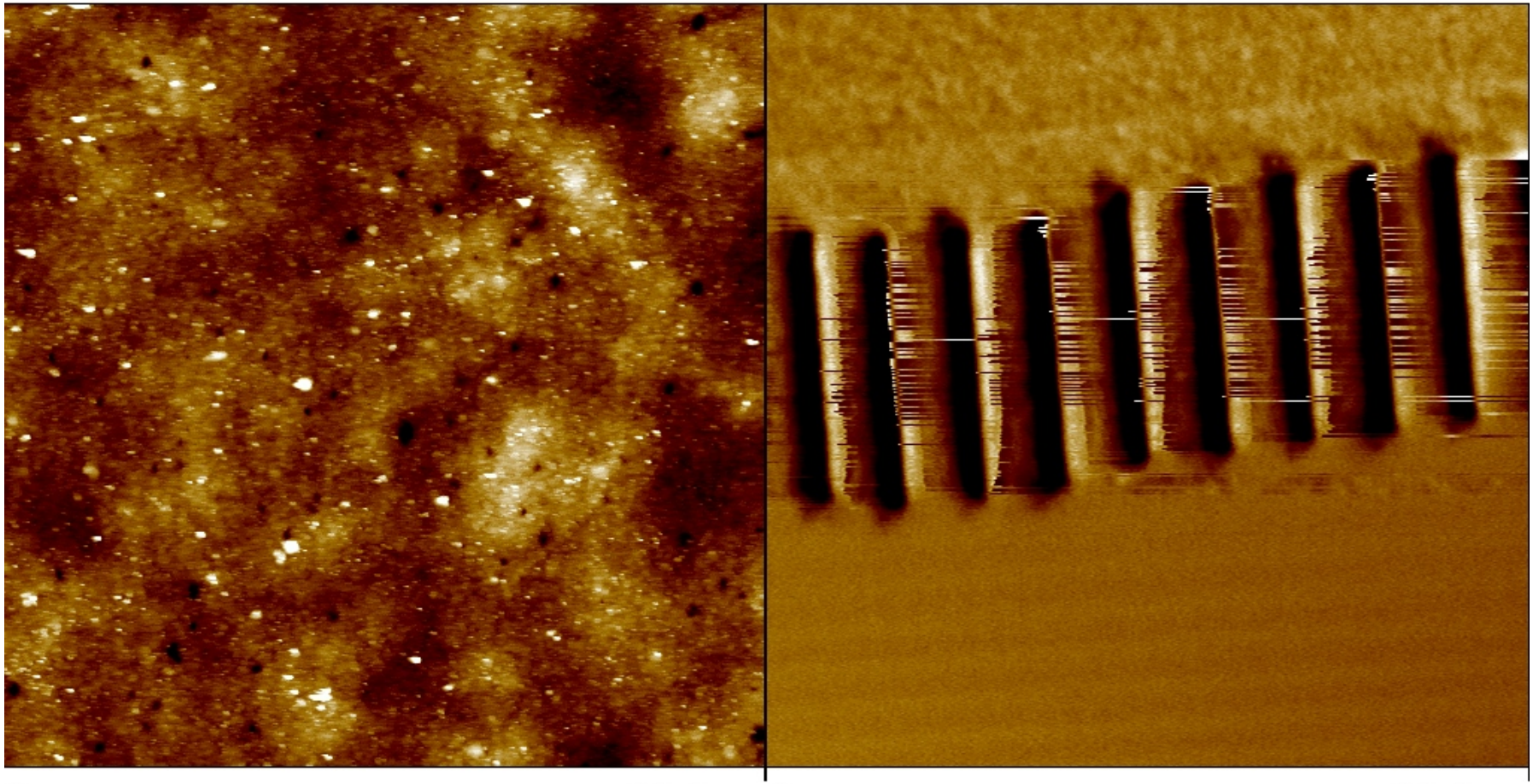
Topographic contrast 2



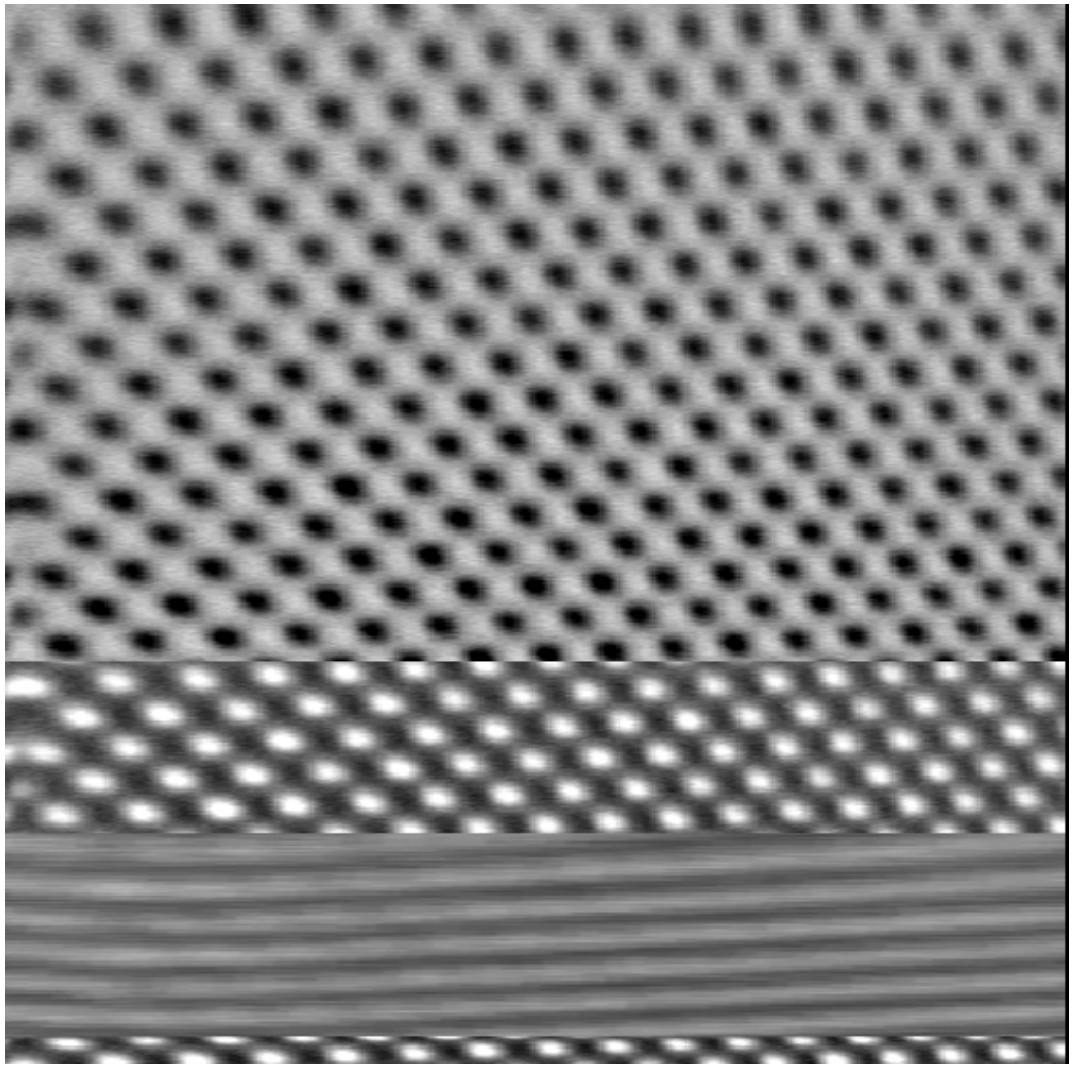
Interaction

- Sample disturbs tip
- Tip disturbs sample
- Reversible/Irreversible

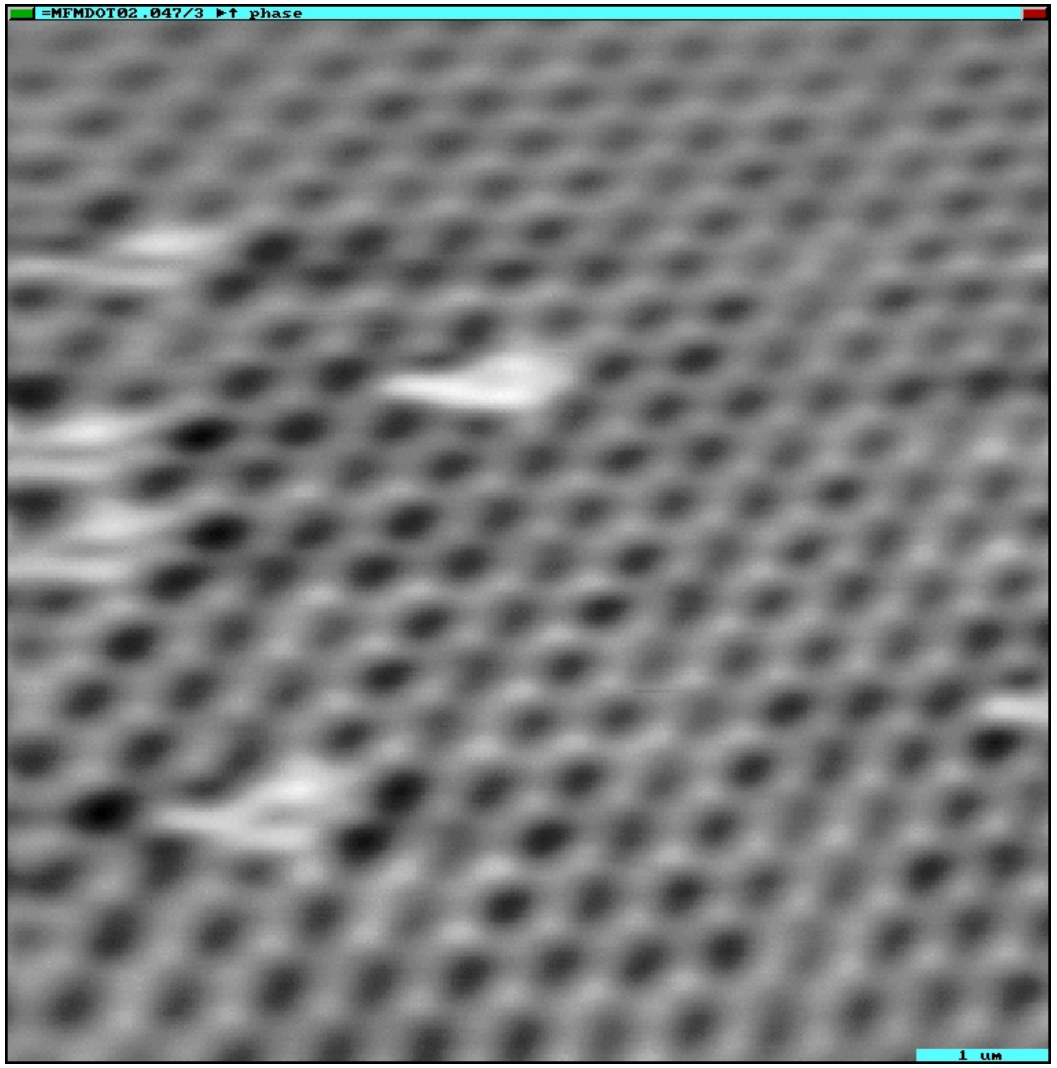
Tip reversal on strong sample



Tip reversal in external field



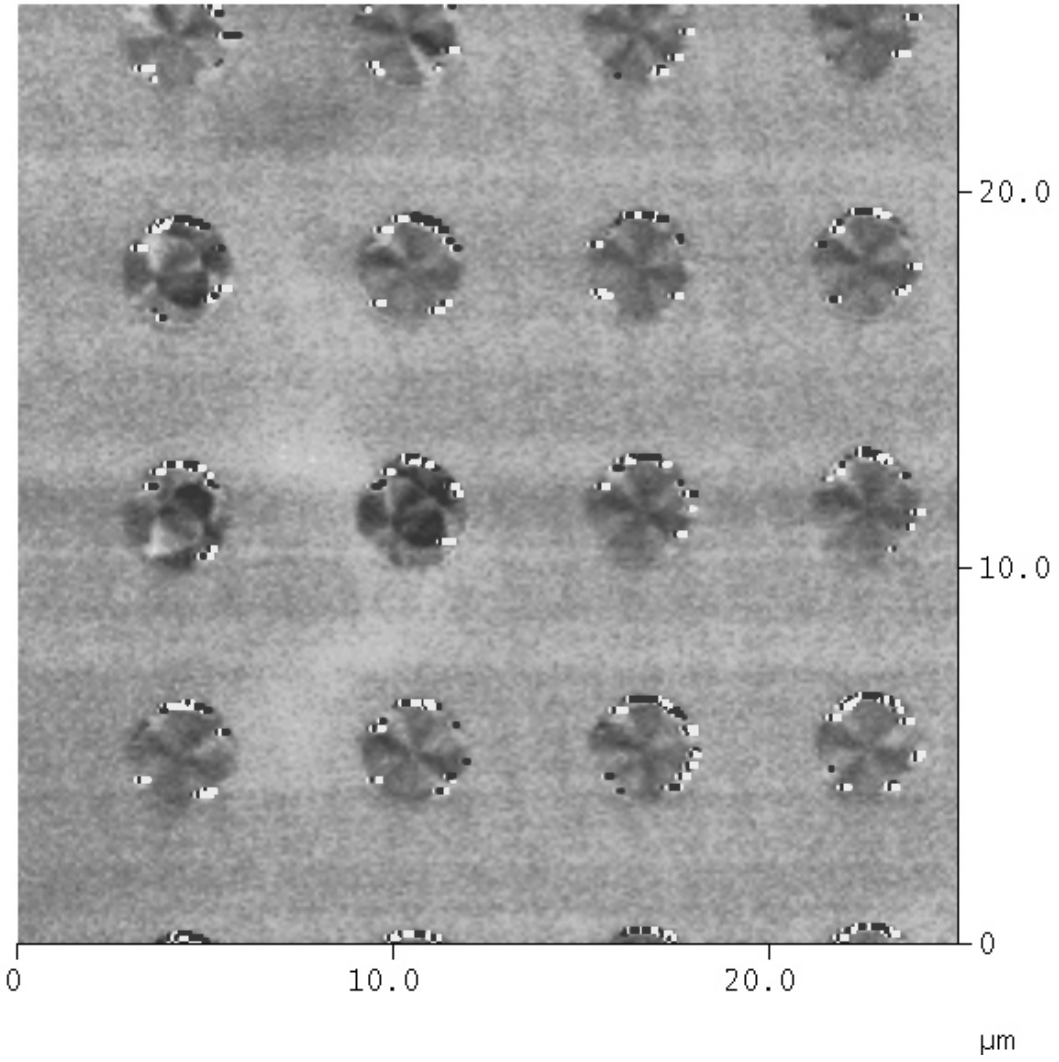
Domain in tip



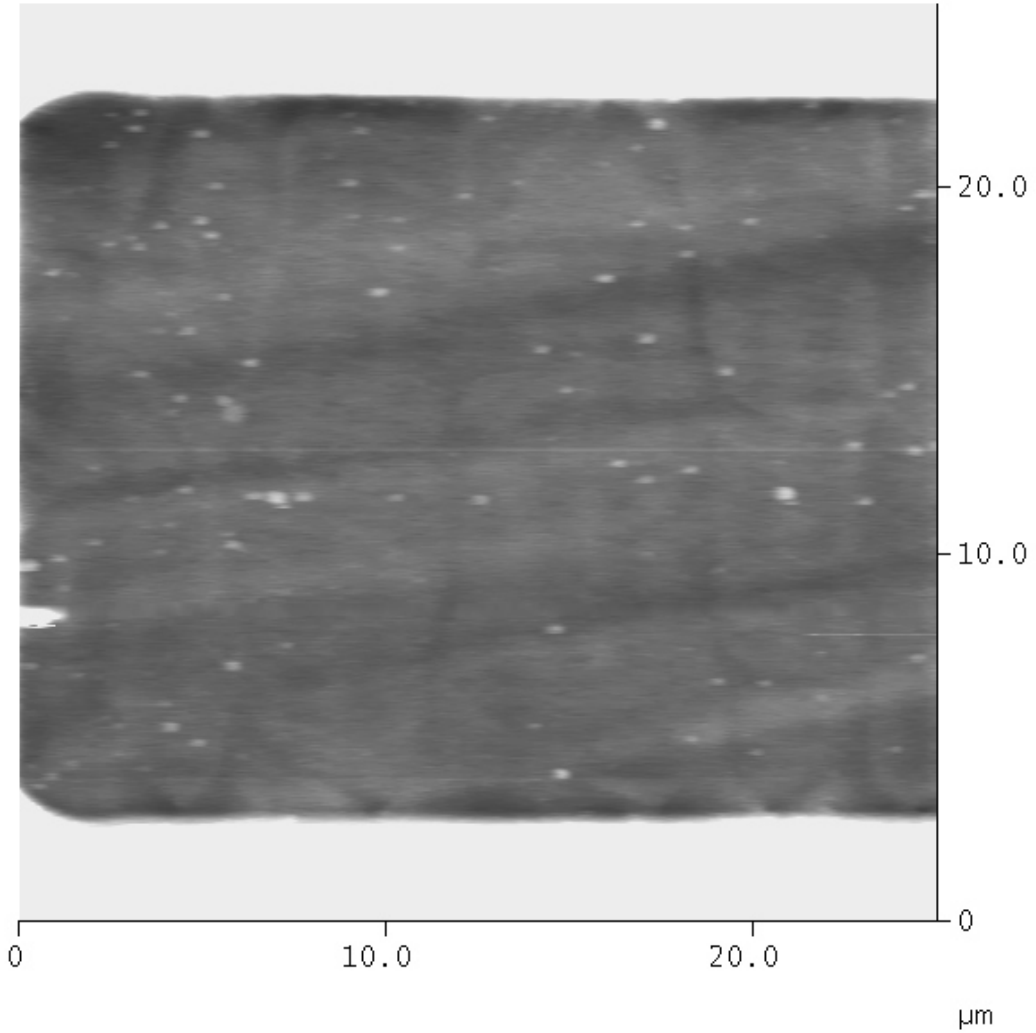
Sample disturbance

- Reversible (susceptibility contrast)
- Irreversible

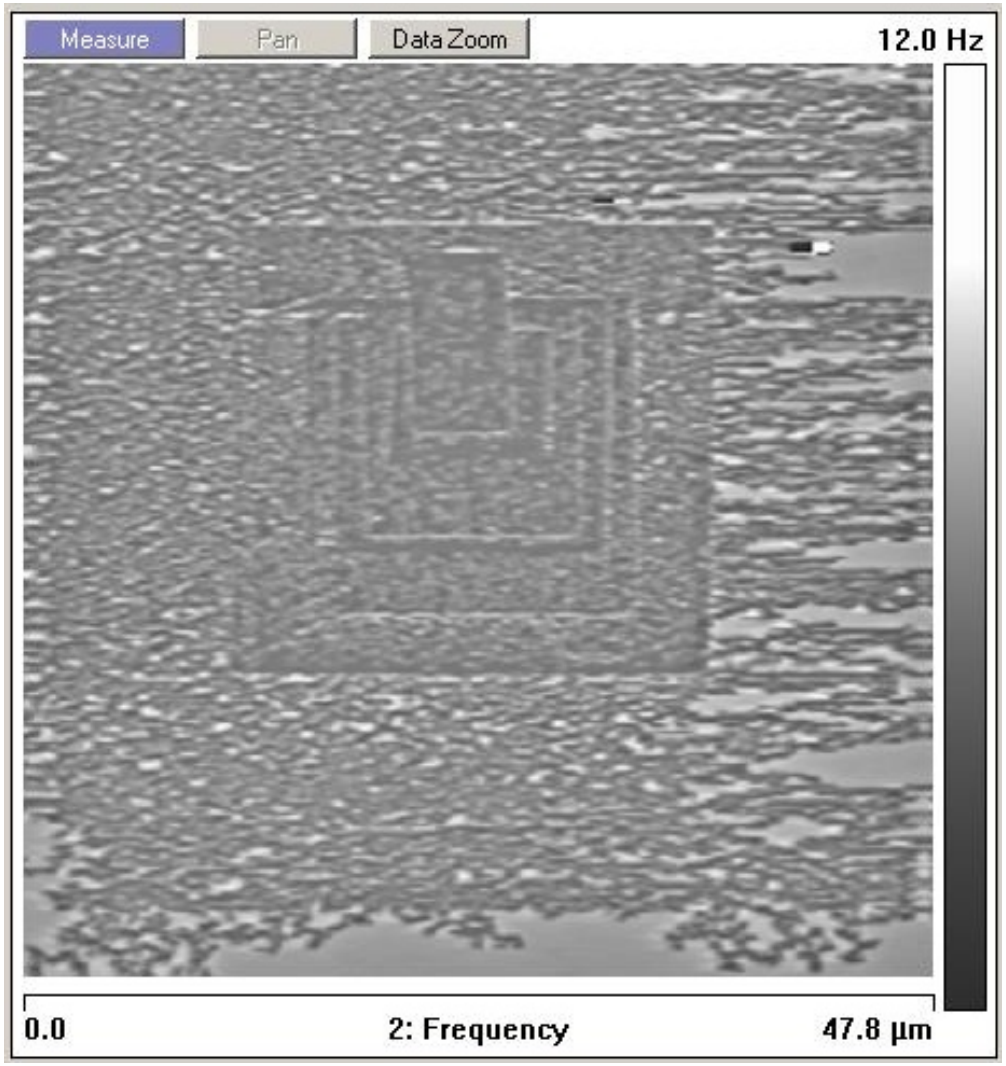
Susceptibility contrast



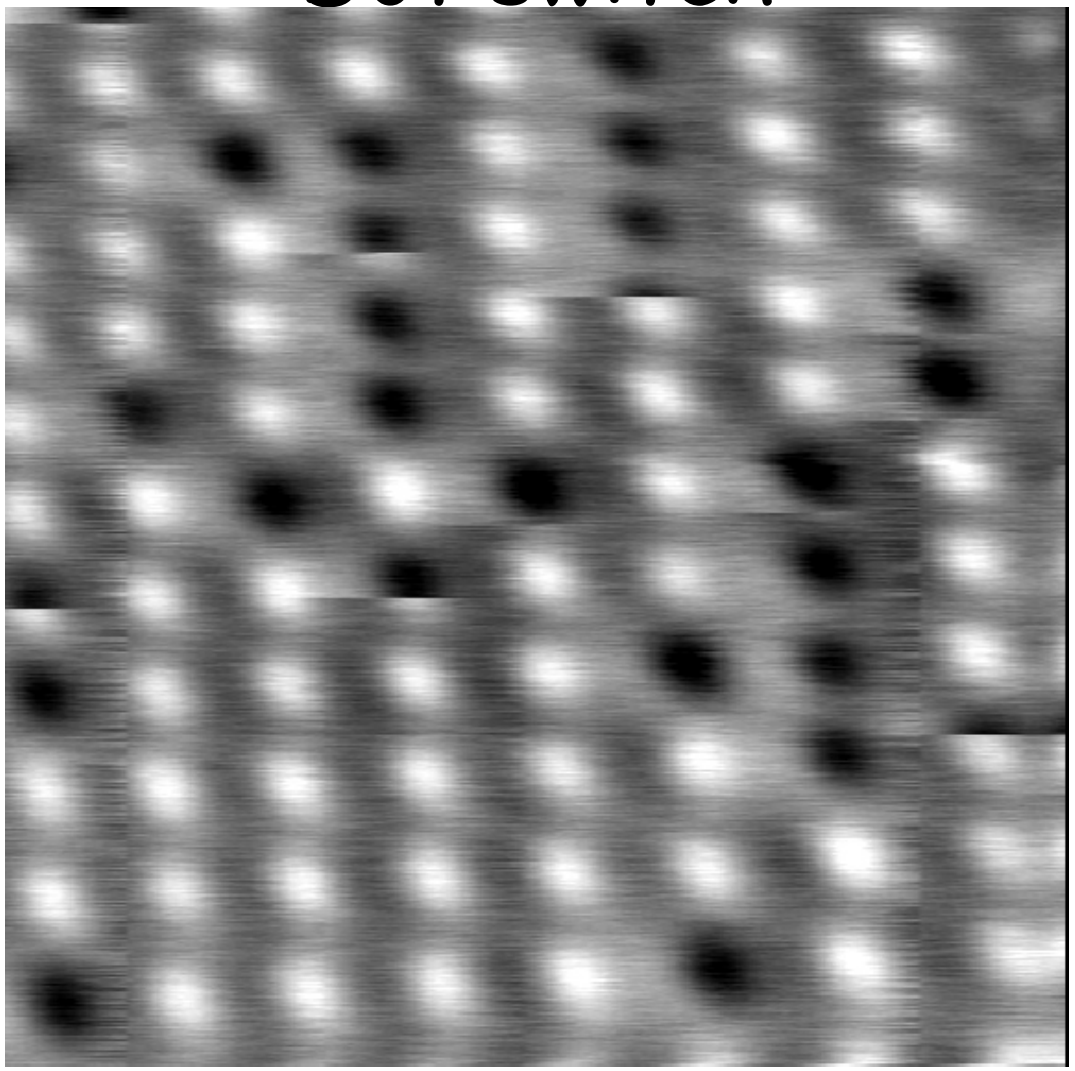
Move domain walls



Disturb sample



Dot switch



Data Storage

Conclusions

- Imaging principle (deflection, phase, frequency)
- Fourier transform for image formation
- Side coated tips
- Noise, bandwidth
- Artefacts (interference, topography)
- Tip/sample interaction