

Magnetic Force Microscopy

Leon Abelmann and Martin Siekman Systems and Materials for Information storage MESA⁺ Research Institute University of Twente

Systems and Materials for Information storage



Contents

• Before break: MFM Operation

- Principle of MFM
- MFM tips
- After break:
 - Instrumentation
 - Artefacts

Principle of MFM





Change in resonance



Amplitude, Phase, Frequency



Image formation

Transform stray field to Fourier space:

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

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

Principle of MFM

MFM Demonstrator

🖪 mfm_simulator.vi * 🥘			X
File Edit Operate Tools Browse Window Help			
수 🐼 🛑 💵 10pt Dialog Font 🛛 🗸 🚛 🗸 🦚 🗸			1
Type Single bit	-		
Image size (m) # samples			
Effective surface charge distribution	Field at height z	Delta f	
1E-6- 9E-7-	1E-6- 9E-7-	1E-6- 9E-7-	
8E-7-	8E-7-	8E-7-	
7E-7-	7E-7-	7E-7-	
6E-7-	6E-7-	6E-7-	
5E-7-	5E-7-	5E-7-	
4E-7-	4E-7-	4E-7-	
3E-7-	3E-7-	3E-7-	
2E-7-	2E-7-	2E-7-	
1E-7-	1E-7-	1E-7-	
0E+0- 0E+0 2E-7 4E-7 6E-7 8E-7 1E-6	0E+0- 0E+0 2E-7 4E-7 6E-7 8E-7 1E-6	0E+0- 0E+0 2E-7 4E-7 6E-7 8E-7 1E-6	
		Image: Weight of the second	
Bit diameter film thickness (m) Ms sample (A/m)	<u>z (m)</u>	Tip properties f_res (Hz) Thermal Noise	
300n-100n-33.50E+5	100n-	h (m)	
80n -	80n-	C (Nm) Add Noise	
200n-1 60n-1	60n-	b (m) #100.00m	
100n-40n-	40n-	₹ <u>125.00n</u>	
20n-	20n-	<u>5 (m)</u> ≜50.00p	
0- 📕 0- 📕	0-	Ms (A/m) Osc Ampl (m)	
		₹ 1.44M	
			• •

Principle of MFM

31,3(3)

Tip transfer function



$$\widehat{F}_{z}(\boldsymbol{k},z) = -\mu_{0}M_{t} \cdot b \operatorname{sinc}(\frac{k_{x}b}{2}) \cdot S \operatorname{sinc}(\frac{k_{y}S}{2}) \cdot \widehat{\boldsymbol{H}}(\boldsymbol{k},z)$$

MFM Demonstrator 2



Resolution versus distance



53,12(2)

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

59,18(2)





Cross-section determined by layer thicknesses

SEM Images cantilever



SEM Images tip



Break





- Laser
- LED



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

7,7(3)

Thermal Noise



10,10(3)

Drift



Vacuum

- Reduce damping, improves Q-factor by 10⁵
- 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



20,20(2)

Switching Field Distribution



22,22(2)

Correct domain image



24,24(2)

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





Data Storage

Conclusions

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