

Deconvolution of Atomic Force Measurements in Special Modes – Methodology and Application



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Teilprojekt C2 „Sensornaher Messdatenerfassung und Verarbeitung“

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FG Nanotechnologie / TU Ilmenau
SFB 622 „Nanopositionier- und Nanomessmaschinen“
Teilprojekt A8 „Multifunktionale Nanoanalytik“

Contents

- SFB 622
- Measurement System / Atomic Force Microscope
- Imaging Model of Kelvin Force Microscopy (KFM)
 - Noise in KFM Data
 - Analytical PSF Estimation
- Model Limitations
- Deconvolution Algorithm
- Deconvolution Results
- Conclusion & Outlook

Goal: Nanopositioning and Nanomeasuring Machine

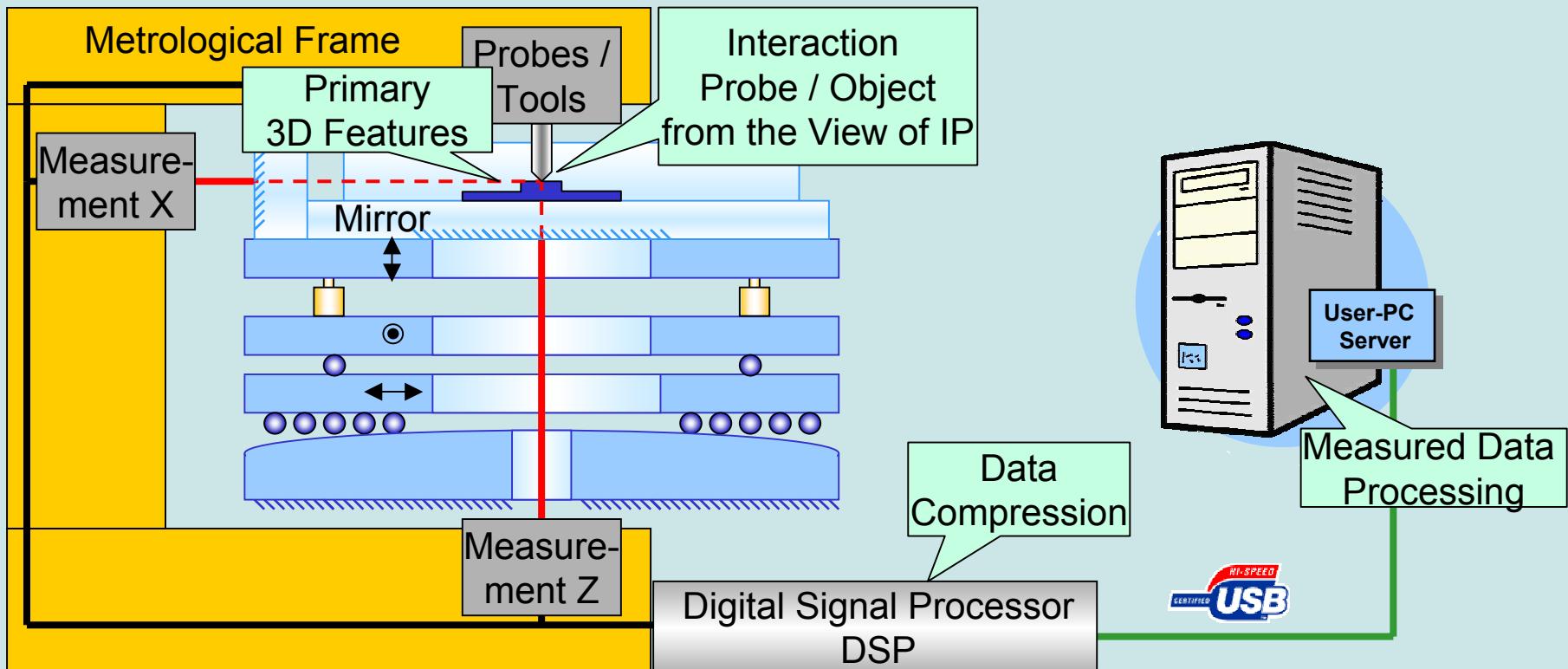
Positioning volume: 350 mm x 350 mm x 5 - 50 mm

Measurement system: exchangeable 2.5D, 3D

Resolution: 0.05 nm

Reproducibility: < 1 nm

Role of subproject C2



Measurement System / Atomic Force Microscope

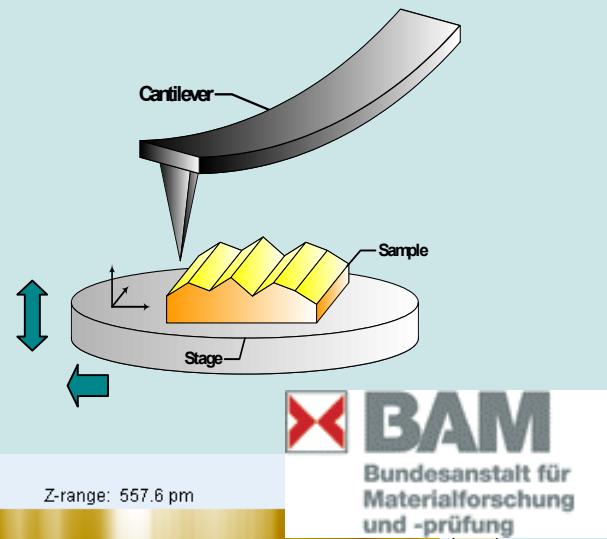


Lateral Resolution:

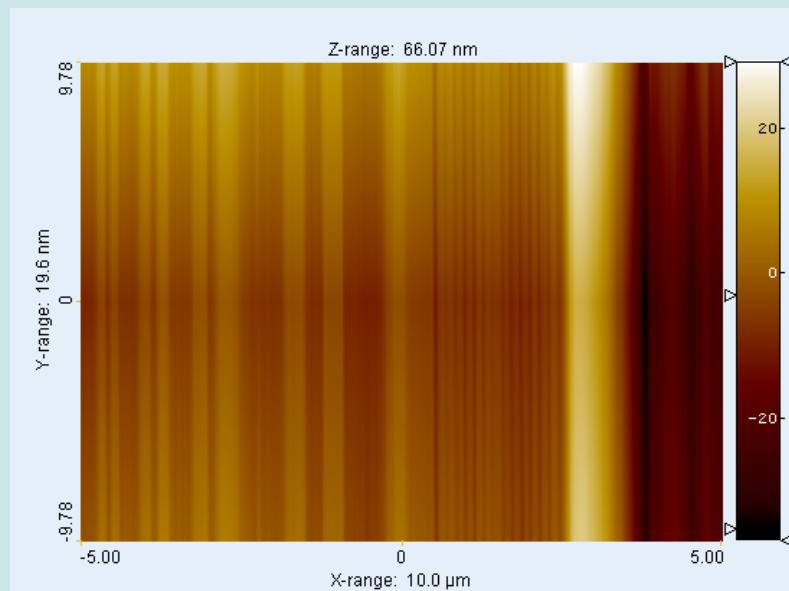
AFM topography mode: approx. 2 nm

AFM special mode: approx. 50 – 100 nm

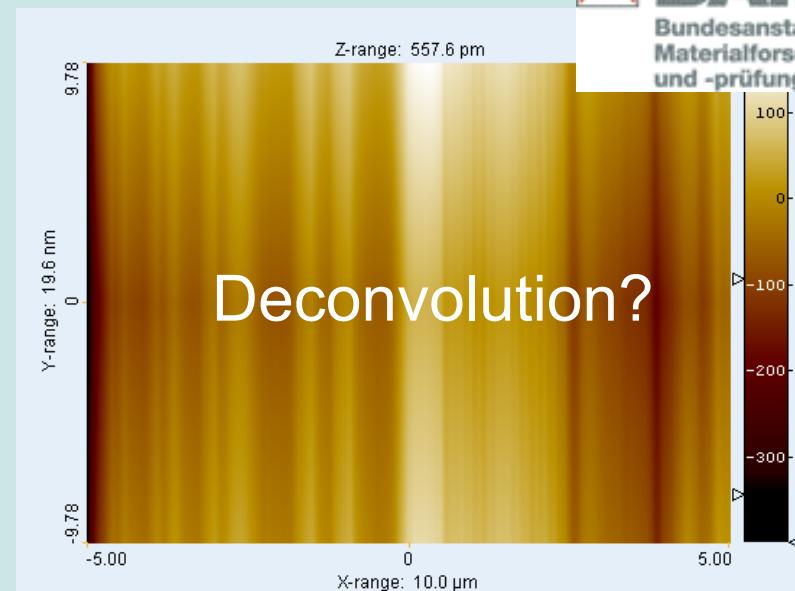
potential measurement (EFM, KFM),
magnetic force measurement (MFM), ...



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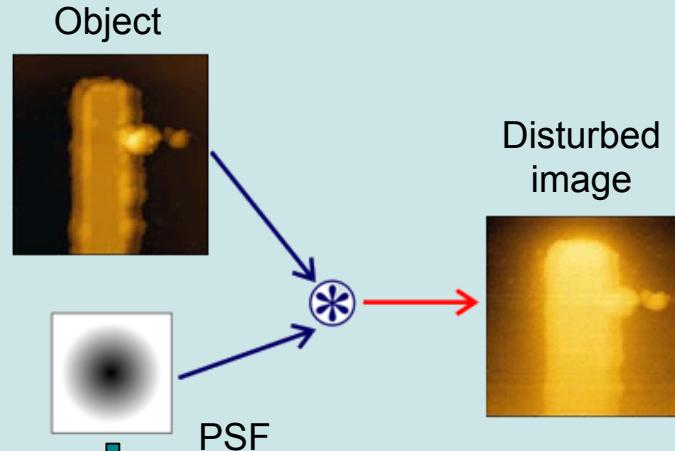
Topography measured by AFM



Deconvolution?

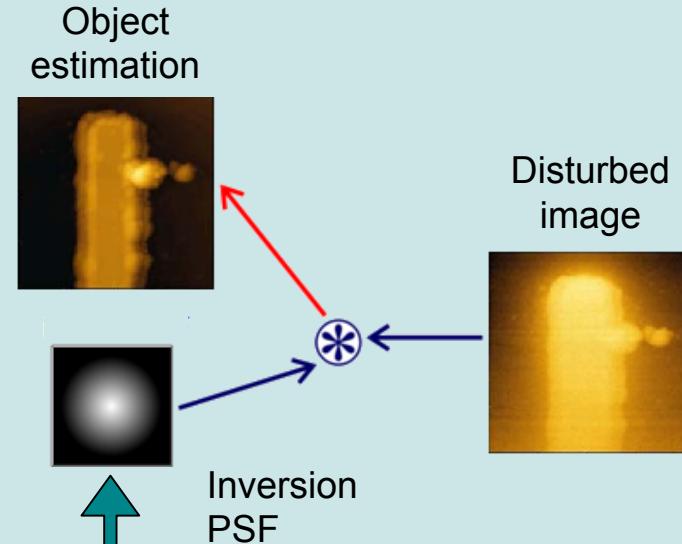
Deconvolution of AFM Measurement in Special Mode

Imaging process



- PSF determination
- Noise suppression

Deconvolution process

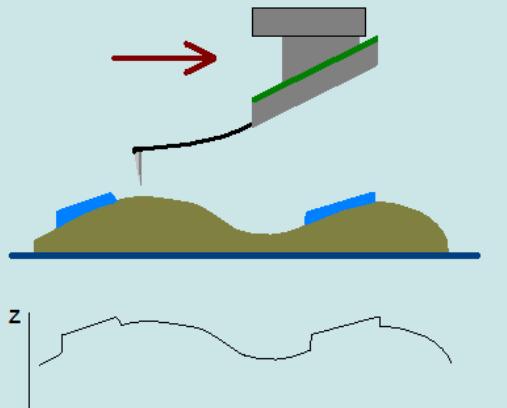


Kelvin Force Microscopy - KFM

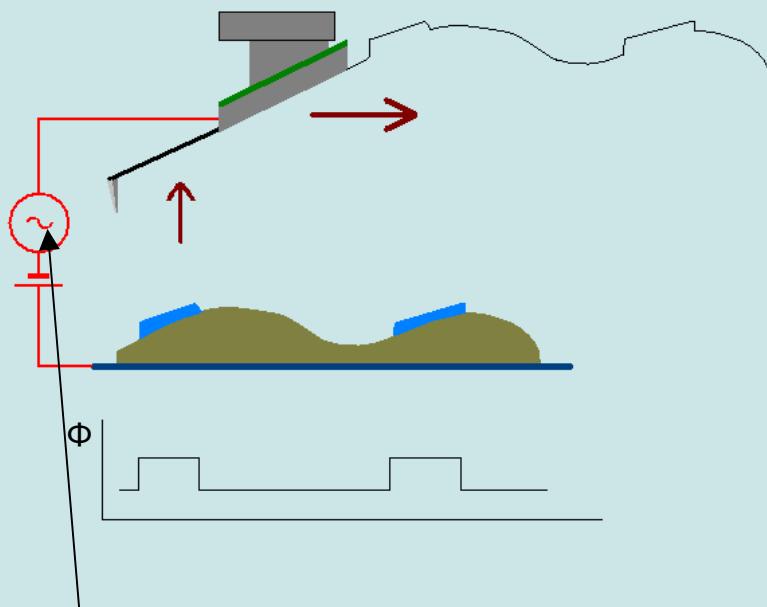


Principle: Indirect determination of surface potential by means of an electrostatic force acting on the measuring system

1st pass
Topography determination

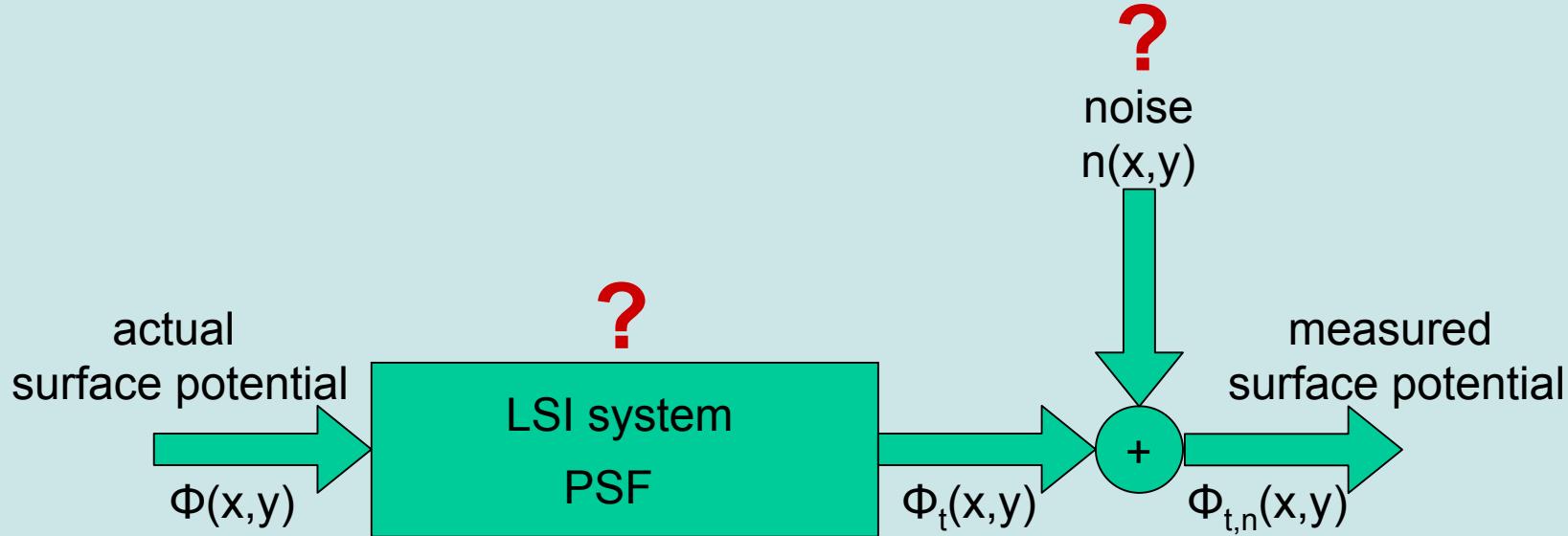


2nd pass
Surface potential measurement

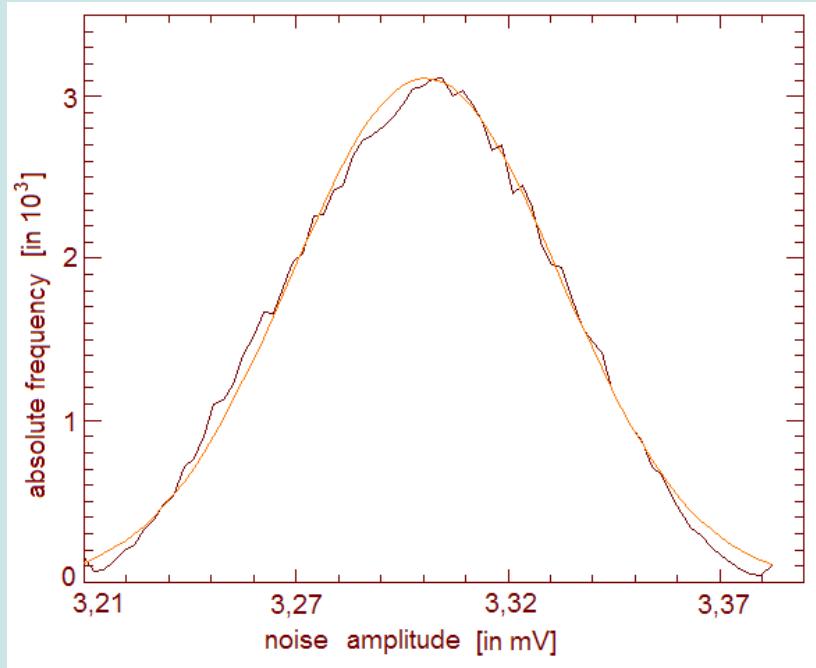


$$F_{c,\omega}(x, y) = \iint_{x,y} C'(x, y) \cdot (\Phi(x, y) - \Phi_t) \cdot U_{ac} \cdot \sin(\omega t) dx dy$$

Imaging Model of KFM



- LSI system: linear shift-invariant system
with a point spread function (PSF) as the convolution kernel
- additive noise at the channel output

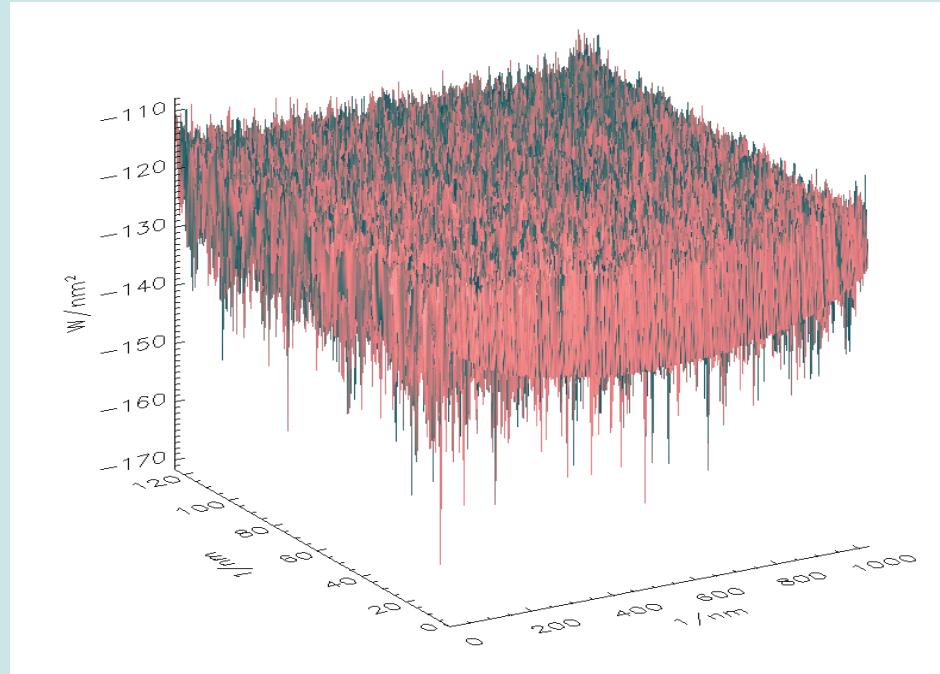


Amplitude distribution:

Histogram counting of noise amplitude

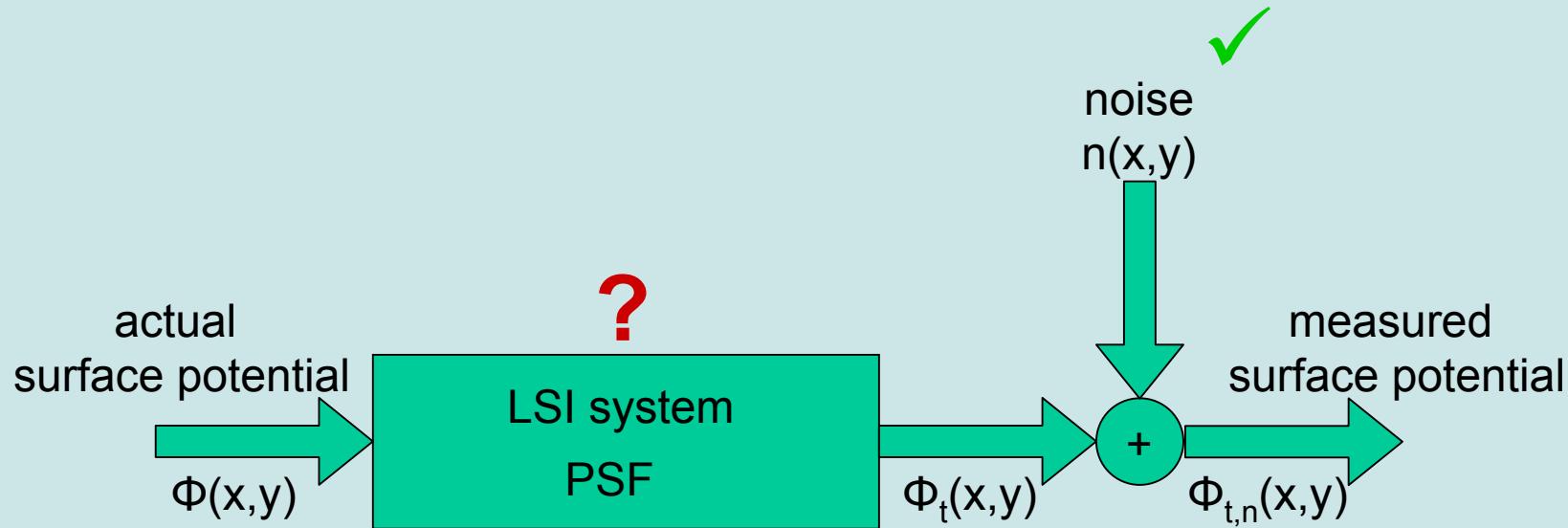
⇒ Gaussian distribution

Imaging Model of KFM – Noise Analysis



Frequency distribution:
Fourier-transformed KFM image
equally distributed \Rightarrow **white noise**

Imaging Model of KFM

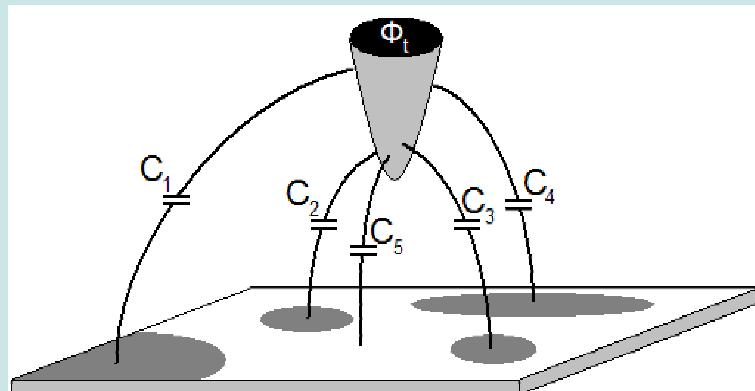
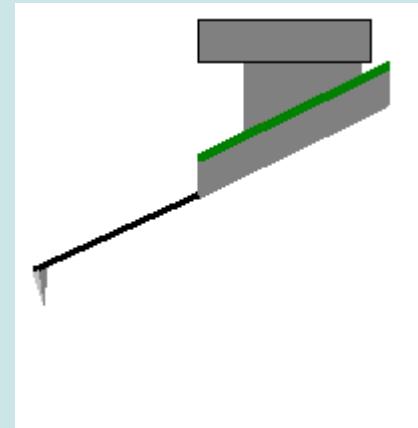


- Additive white Gaussian noise

Image interrelation at KFM

$$F_{c,\omega}(x, y) = \iint_{x,y} C'(x, y) \cdot (\Phi(x, y) - \underbrace{\Phi_t}_{\text{control unit}}) \cdot U_{ac} \cdot \sin(\omega t) dx dy$$

$$F_{c,\omega}(x, y) = 0 \quad , \text{for } \Phi(x, y) = \Phi_t(x, y)$$



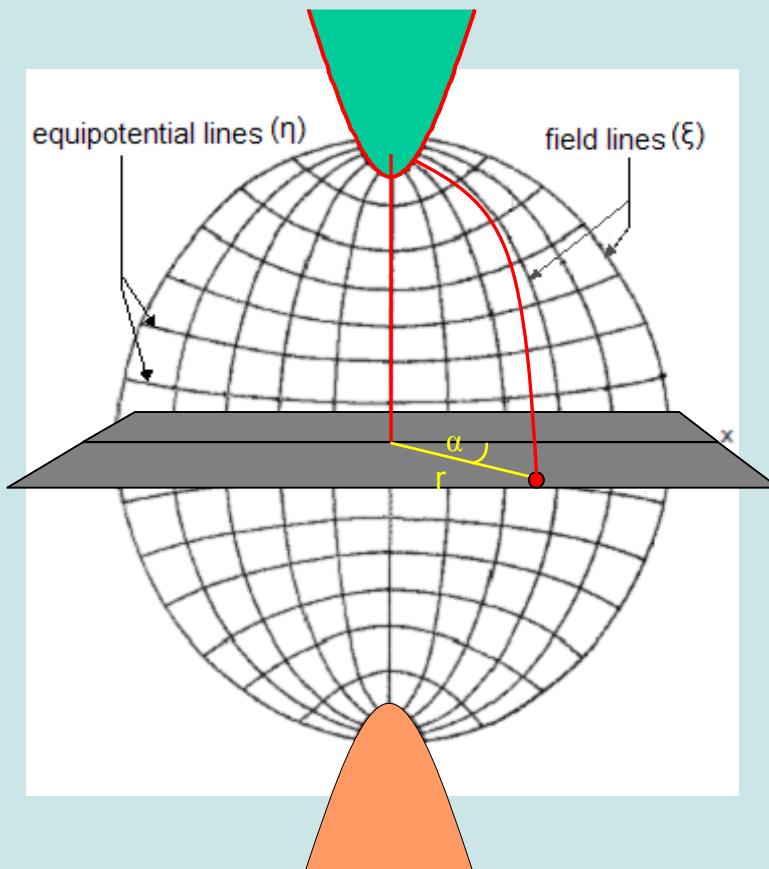
$$\Phi_t(x, y) = \iint_{i,j} \frac{C'_{ij}(x - x_i, y - y_j)}{C'(x, y)} \cdot \Phi(x_i, y_j) di dj$$

convolution kernel

Imaging Model of KFM – PSF Calculation

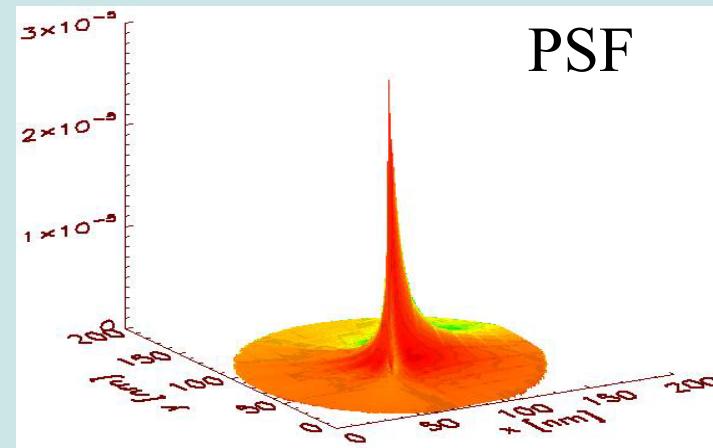


Transform KFM tip geometry
to polar coordinates

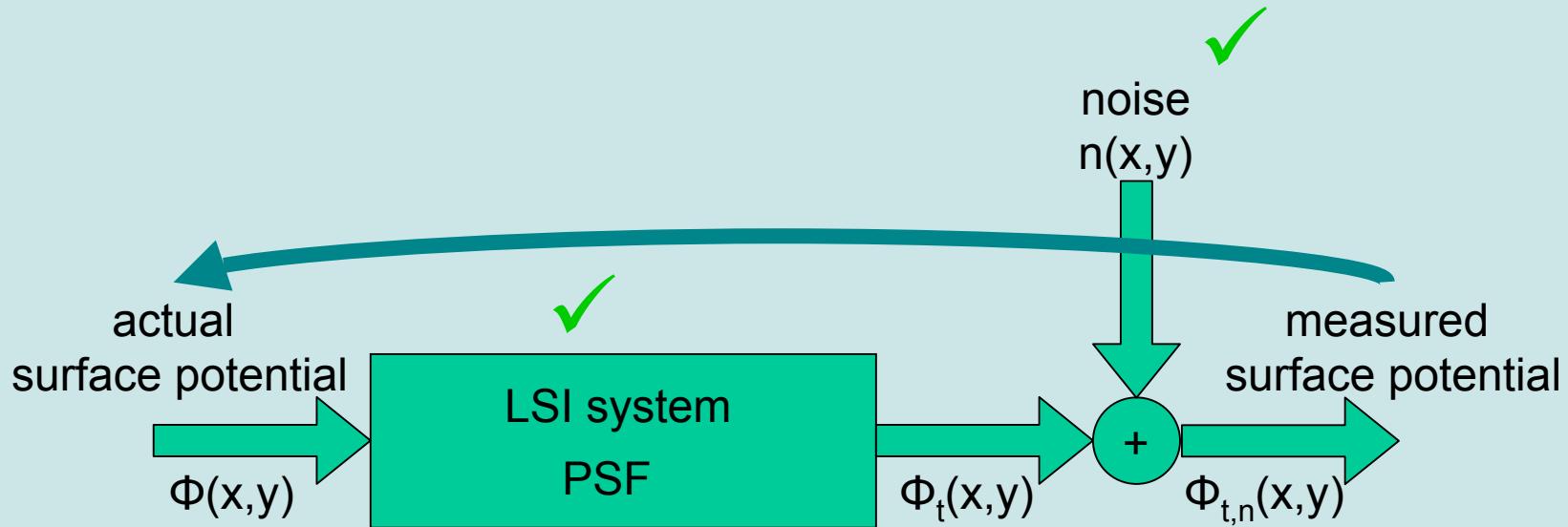


Fit a hyperbola $r^2 = C_1 z + C_2 z^2$ to each angle α

Calculate the electric field distribution at $\eta=0$ and ξ by means of heights C_1 and C_2



Imaging Model of KFM



- Additive white Gaussian noise
- LSI system: Linear and shift-invariant convolution kernel

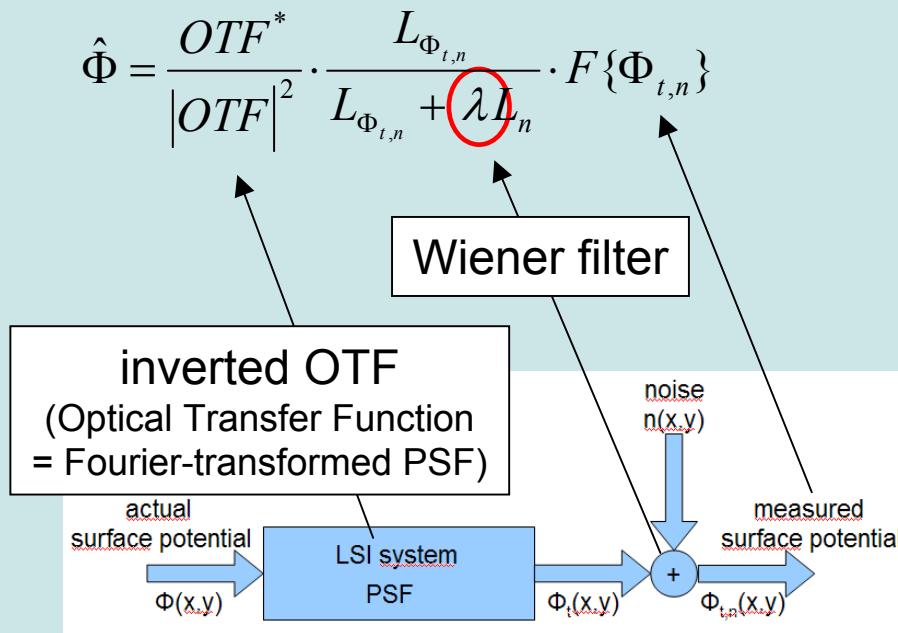
Assumptions:

- Sample topography must be negligible
- Only the electrostatic force is acting on the detection system

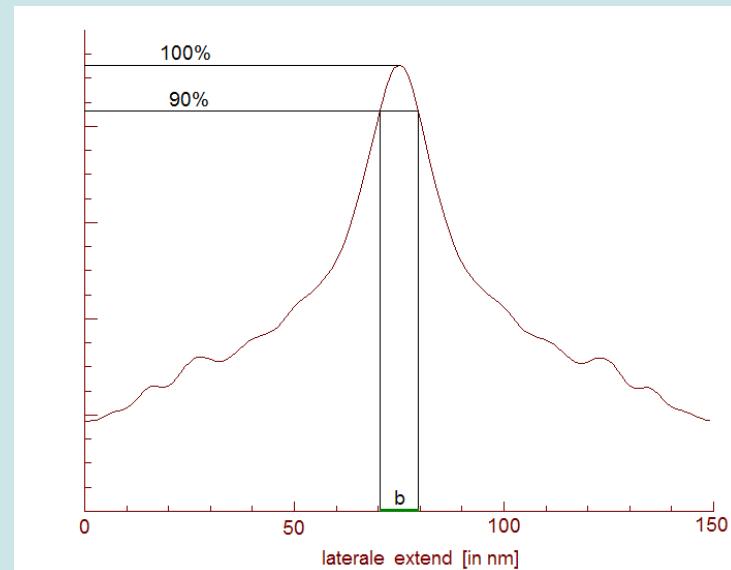
Solution:

- Measurement at sufficiently large tip-to-sample distance

Inversion of the PSF with Wiener noise suppression



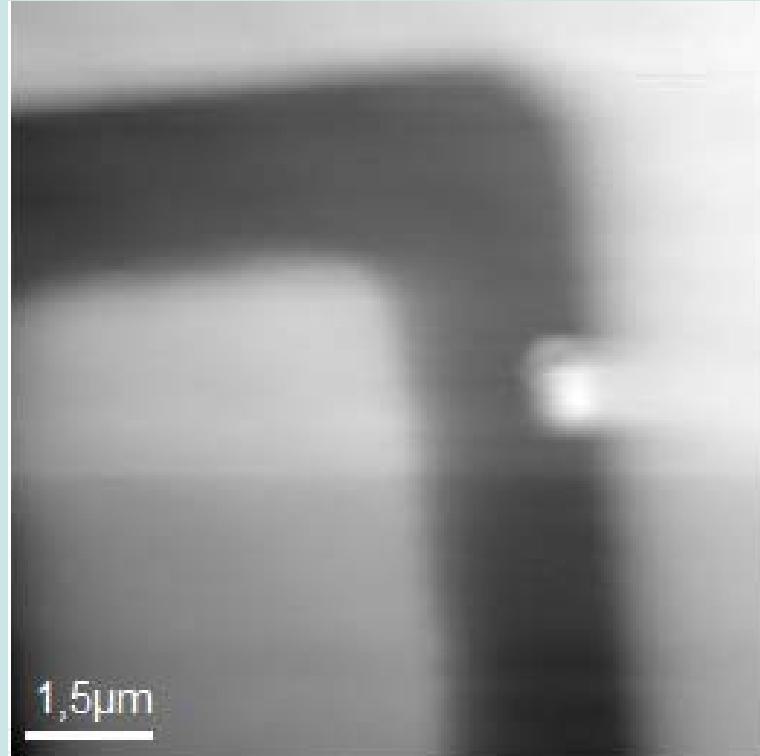
Filter adjustment by resolution boundary



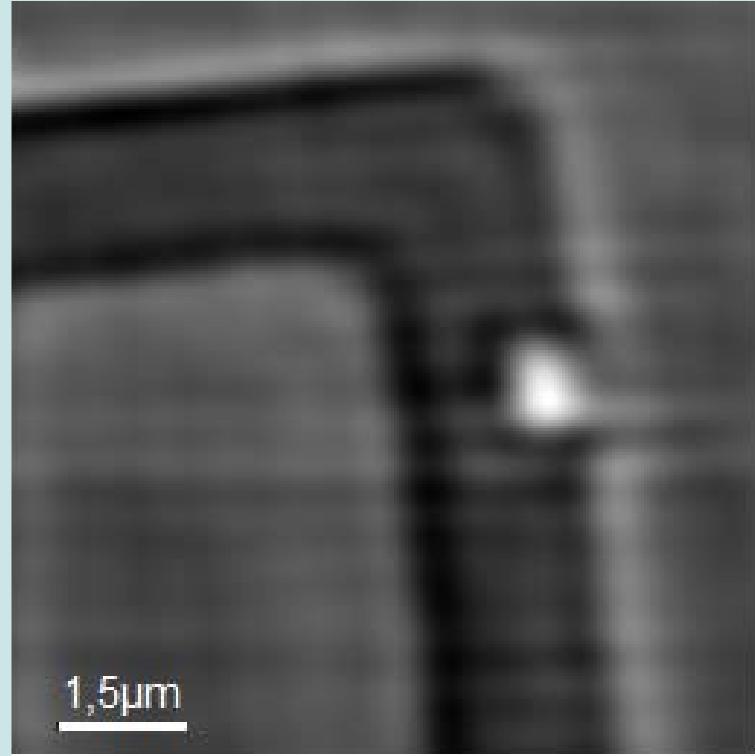
Imaging Model of KFM - Deconvolution



measured KFM data



deconvolved data



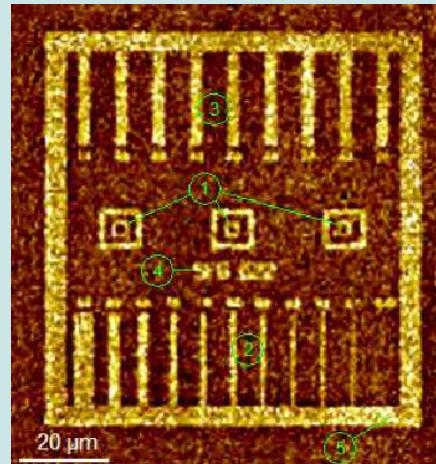
- KFM measurement data have bad lateral resolution
- The imaging process can be described as an LSI model
- An analytical method was presented to determine the PSF
- Deconvolution was demonstrated using inversion of the PSF and Wiener noise suppression

Outlook

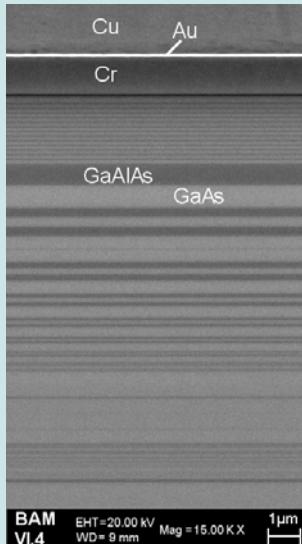


- Using a measured method to determine the PSF

Sample to determine the PSF
(Developed by ZMN Ilmenau,
SFB 622 TP A8)



- Expansion of the deconvolution method (e.g. pixon method)



- Forder practical analysis



BAM-L200

Nanoscale stripe pattern for testing of lateral resolution
and calibration of length scale

Thanks for your attention!

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