UNIVERSITÄT DUISBURG ESSEN

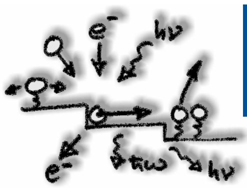
SFB 616 C6

Eddy Current Microscopy (ECM) of Nanostructures

Sonderforschungsbereich 616

„Energy dissipation at surfaces“

Project C6: **Electronic energy dissipation in thin metal films**



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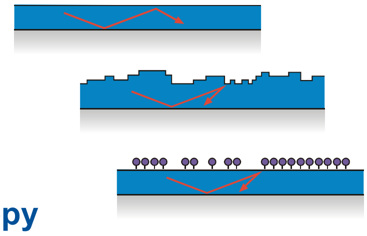
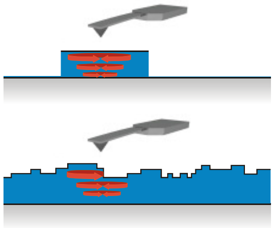
Goals

- characterisation of electronic energy dissipation for various systems
- investigation of the local mobility of conduction electrons in metallic structures
- influence of film thickness and defects, roughness, adsorbates and quantum size effects on local conductivity



Eddy Current Microscopy

- non-contact atomic force microscopy (NC-AFM)
- magnetic stray fields of magnetic domains induce eddy currents within a conducting probe
- time-dependent magnetic field of an oscillating magnetic probe induces eddy currents within conducting materials
- oscillation is damped according to Lenz´s rule
- no contacts are necessary
- energy dissipation varies with local conductivity



Induced currents lead to an electrodynamic interaction between probe and sample:

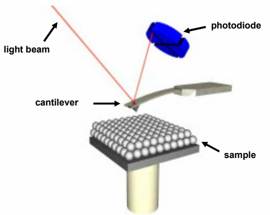
$$\frac{\partial H}{\partial t} = -\frac{1}{\mu\sigma}\nabla \times j$$

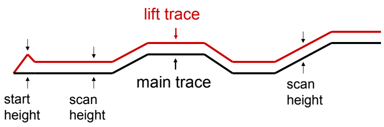
→ eddy currents within conducting materials [1]

LiftMode™

- LiftMode™ allows the imaging of relatively weak but long-range interactions while minimizing the influence of the topography.
- Measurements are taken in two passes across each scan line; each pass consists of one trace and one retrace.

The motion of the tip during the trace and retrace is demonstrated below:





1. Cantilever traces / retraces surface topography on first trace / retrace
2. Cantilever ascends to lift scan height
3. Lifted Cantilever profiles / reprofiles topography while detecting the magnetic interaction on second trace / retrace

- The influence of force is measured using the principle of force gradient detection during the second pass.
- In LiftMode™, the feedback is turned off, and the tip lifted off the surface and scanned at a user-selected height.
- Topography data recorded during the main pass is used to keep the tip a constant distance from the surface during the interleave trace and retrace.

Simulation

Using the oscillator equation

$$\frac{\partial^2 d}{\partial t^2} + \frac{\omega_c}{Q_c}\frac{\partial d}{\partial t} + \omega_c^2 (d - d_0) + \frac{F_z(d, \partial d/\partial t)}{m_c} = A_0 \omega_c^2 \cos(\omega t)$$

Including this force:

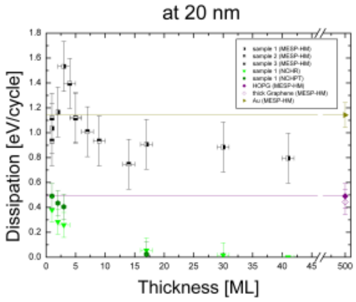
$$\vec{F} = -\frac{\sigma \mu^2 m^2}{64\pi d^3}\frac{\partial d}{\partial t}\vec{e}_z$$

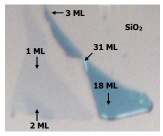
(dipol approximation)

and typical experimental parameters $Q_c = 170$, $\omega_c = 65$ kHz, $A_0 = 30$ nm

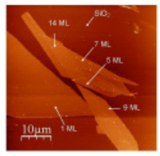
Experiment Graphene

The observed phase shift depends on the thickness of the graphene in eddy current microscopy





sample 1: different numbers of monolayers on 300 nm SiO_2, acquired with an optical microscope

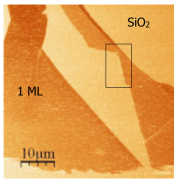


sample 2: acquired with a conventional AFM

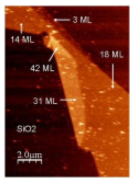
The observed phase shift corresponds to an energy dissipation in eV/cycle [2]

$$P_{tip} = \frac{1}{2}\frac{k\omega_c A_0^2}{Q_c}[\sin\varphi - 1]$$

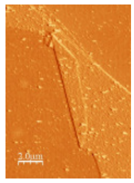
To be able to compare the values in different experiments we have defined the value measured at the SiO_2 surface to be equal to zero.
It can be seen that the energy dissipation is largest at 3-4 ML.



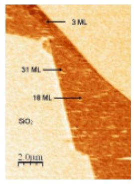
phase at 20 nm acquired with a magnetic tip



topography with numbers of monolayers

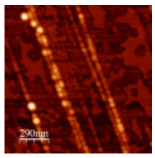


phase at 0 nm acquired with a non magnetic tip

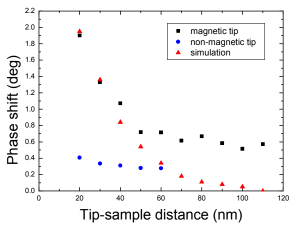


phase at 20 nm acquired with a magnetic tip

Experiment CaF_2

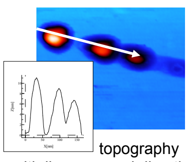


The tip-sample distance dependence of the phase signal in eddy current microscopy [3].
The amount of the calculated phase shift and the range are consistent with experimental data
The measured CaF_2 sample was irradiated with swift heavy ions under grazing incidence [4].

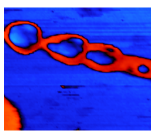


- the first curve (■) was measured with a magnetic tip, a phase shift is observable up to 110 nm
- the second curve (●) was measured with a non-magnetic tip, a phase shift is observable up to 60 nm
- the third curve (▲) is simulated, a phase shift is observable up to 100 nm

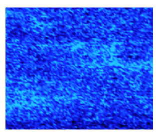
Topography and phase images of CaF_2, Image size: 180 nm x 180 nm, false color images, flattened



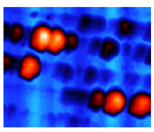
topography with linescan and direction of the incoming ion



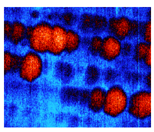
phase at 0 nm acquired with a non magnetic tip



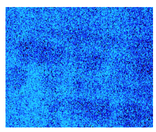
phase at 60 nm acquired with a non magnetic tip



topography



phase at 60 nm acquired with a magnetic tip



phase at 100 nm acquired with a magnetic tip

References:
1) B. Hoffmann, R. Houbertz, U. Hartmann; Appl. Phys. A 66, S409–S413 (1998)
2) B.Anczykowski, B. Gotsmann, H. Fuchs, J.P. Cleveland, V.B. Elings; Appl. Surf. Sci., 104, 376 (1999)
3) T. Roll, M. Meier, U. Fischer, M. Schleberger; Thin Solid Films (in press)
4) N. Khalfaoui, M. Görlich, C. Müller, M. Schleberger, H. Lebius; NIMB 245, 246 (2006), E. Akcöltekin, T. Peters, R. Meyer, A. Duvenbeck, M. Klusmann, I. Monnet, H. Lebius, M. Schleberger; Nature Nanotechnology 2, 290-294 (2007)