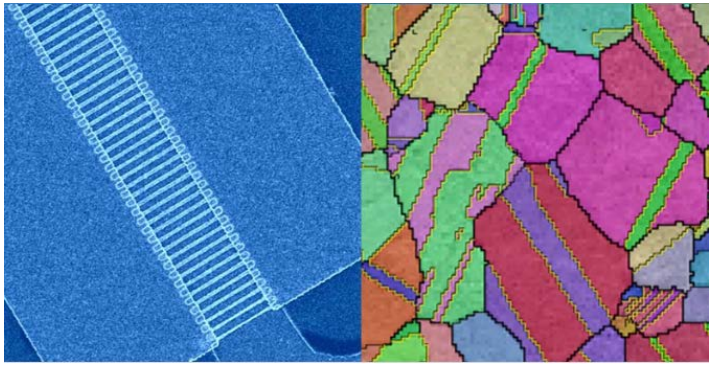
NT-MDT Spectrum Instruments

Touching the Nanoworld.

Various Ways for Surface Characterization at Nanoscale by means of AFM

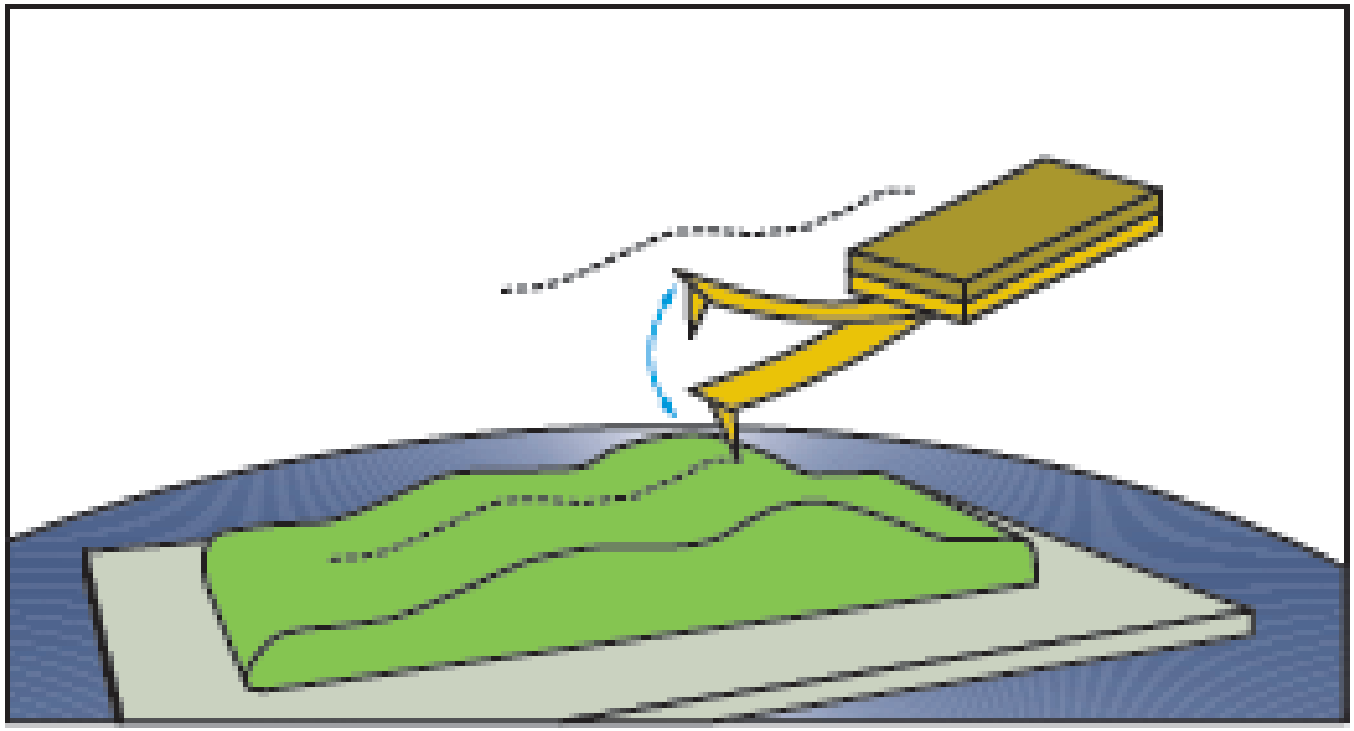
Workshop on Nanomaterials Characterization.
Purdue University, Discovery Park. March, 22nd 2018

Dr. Stanislav Leesment, Senior Application Scientist
NT-MDT Spectrum Instruments

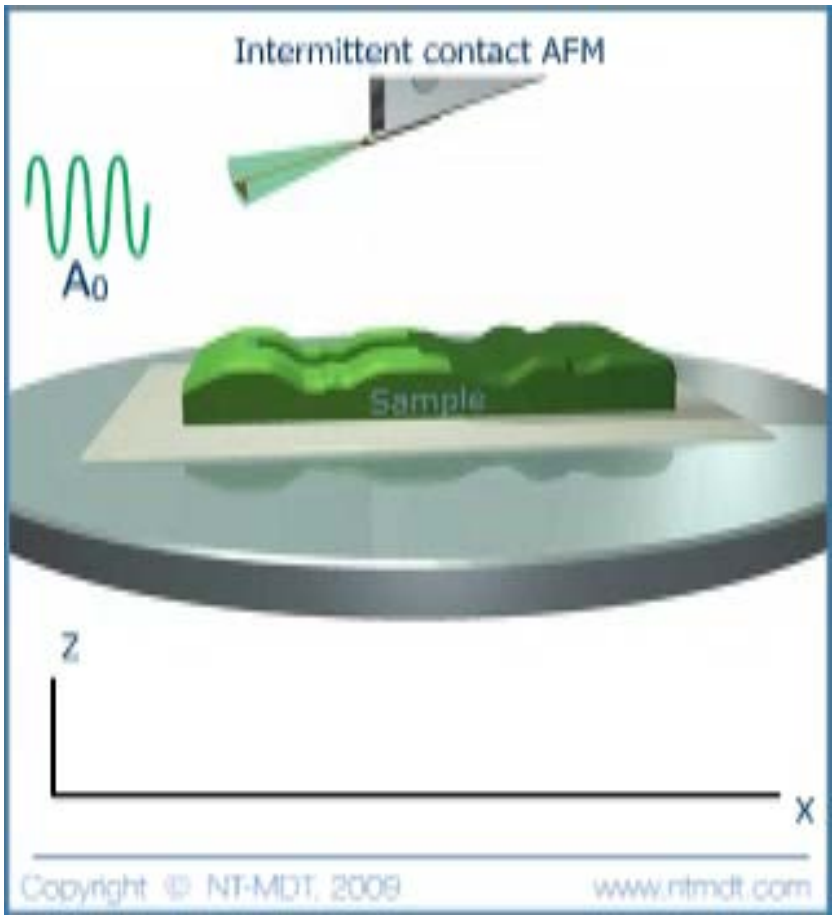


NT-MDT
Spectrum Instruments

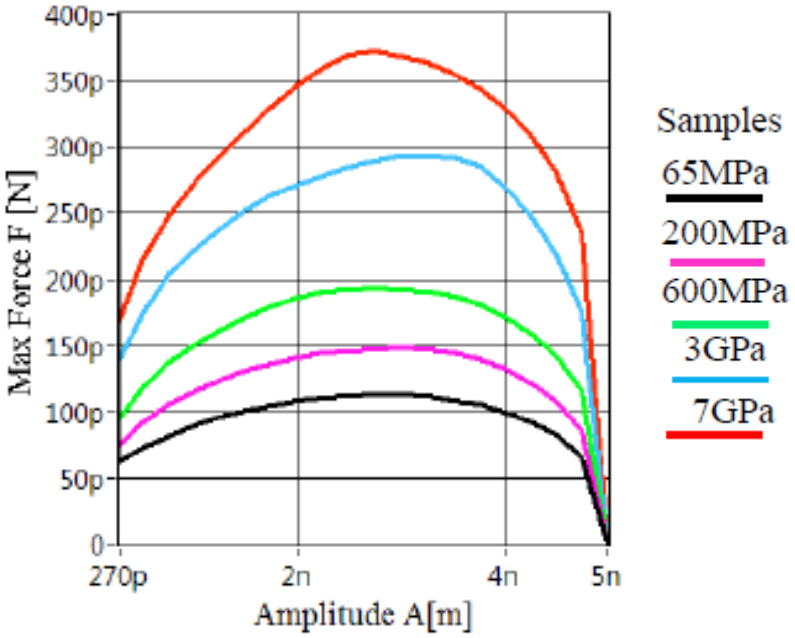
Resonant AFM



Tapping (Semicontact, Non-contact, AM-AFM) Mode



AFM probe, w=50 kHz, k = 0.5 N/m,
Q = 80, Rt =10 nm, A0 = 5 nm

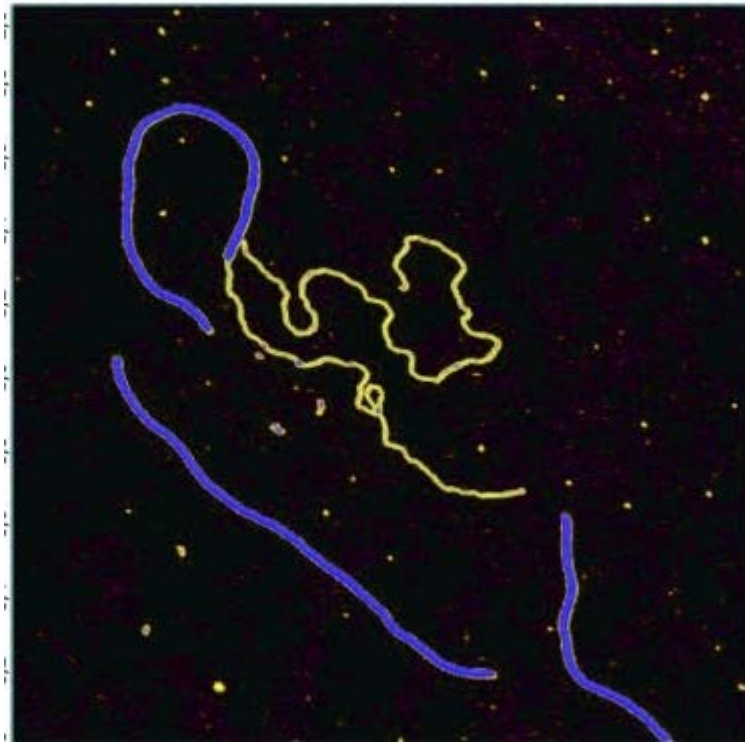


$$\begin{cases} \sin\theta = A_{sp} / A_0 \\ \cos\theta = -\dfrac{2Q}{\pi k A_0}\displaystyle\int_0^{\pi} F_z\left(Z_c + A_{sp}\cos y\right)\cos y\,dy \end{cases}$$

S. Belikov et al *Fall 2012 MRS Proceedings*, ***2013***

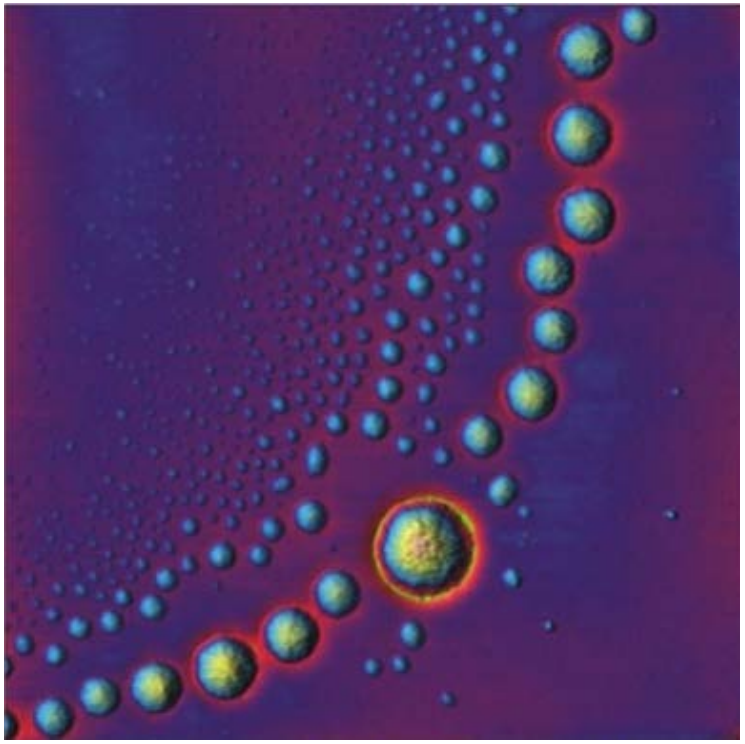
Amplitude Modulation Mode Examples

Bacteriophages & DNA



Scan Size: 2 2 µm
Image Courtesy: Prof. Alexandr Kotlyar. Professor of the dept. of Biochemistry and Molecular Biology at Tel Aviv University

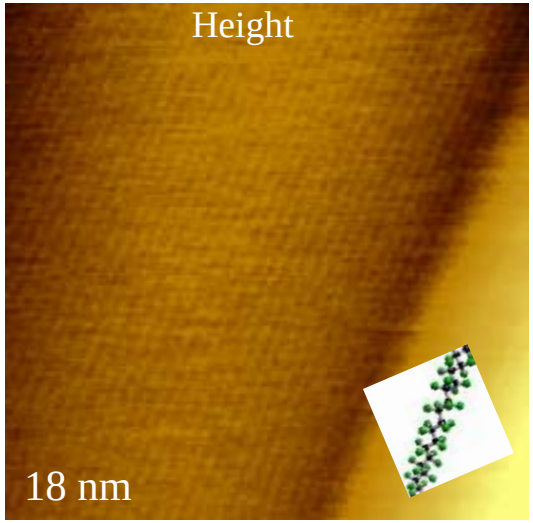
PS-LDPE Blend



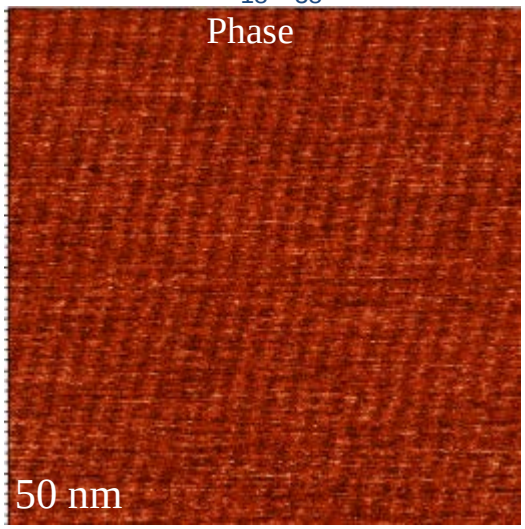
Scan Size: 9 9 µm
Image Courtesy: Dr. Sergey Magonov NT-MDT Development Co.

High-Resolution Imaging in AM-AFM in Air

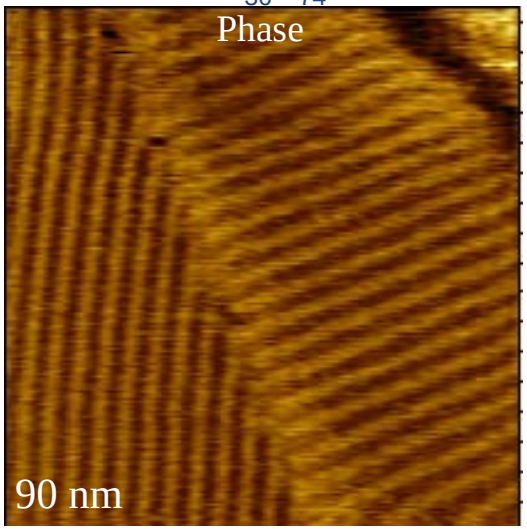
PTFE
Height



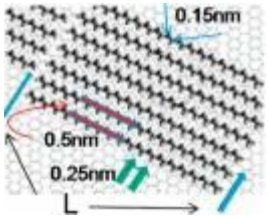
$C_{18}H_{38}$
Phase



$C_{36}H_{74}$
Phase

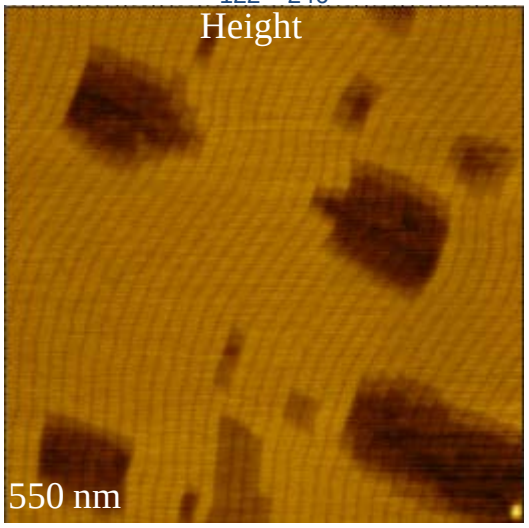


C_nH_{2n+2}

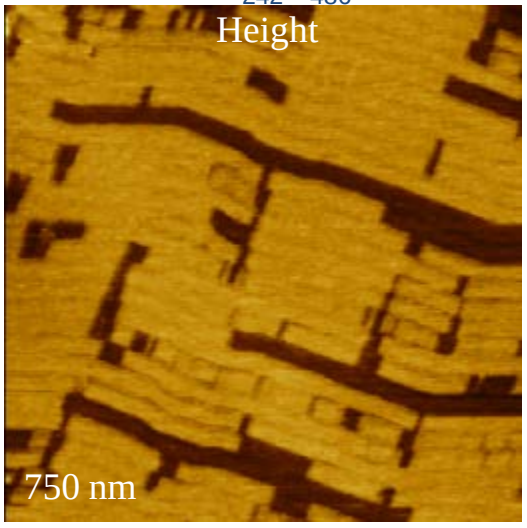


$C_{18}H_{38}$	2.8 nm
$C_{22}H_{46}$	3.0 nm
$C_{36}H_{74}$	4.5 nm
$C_{60}H_{122}$	7.5 nm
$C_{122}H_{246}$	15.0 nm
$C_{242}H_{486}$	29.0 nm
$C_{390}H_{782}$	49.0 nm

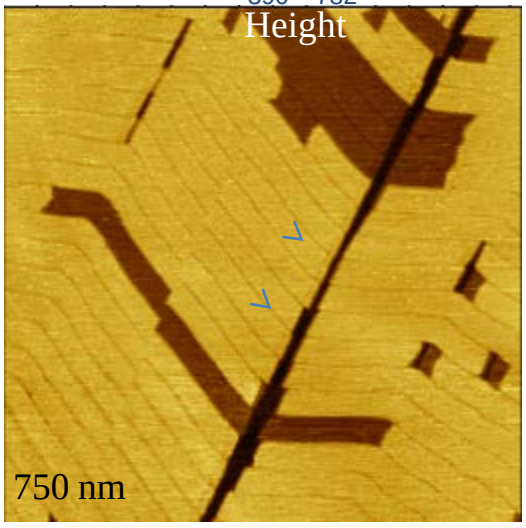
$C_{122}H_{246}$
Height



$C_{242}H_{486}$
Height



$C_{390}H_{782}$
Height



$C_{122}H_{246}$
Height

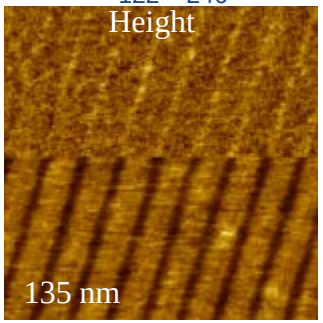
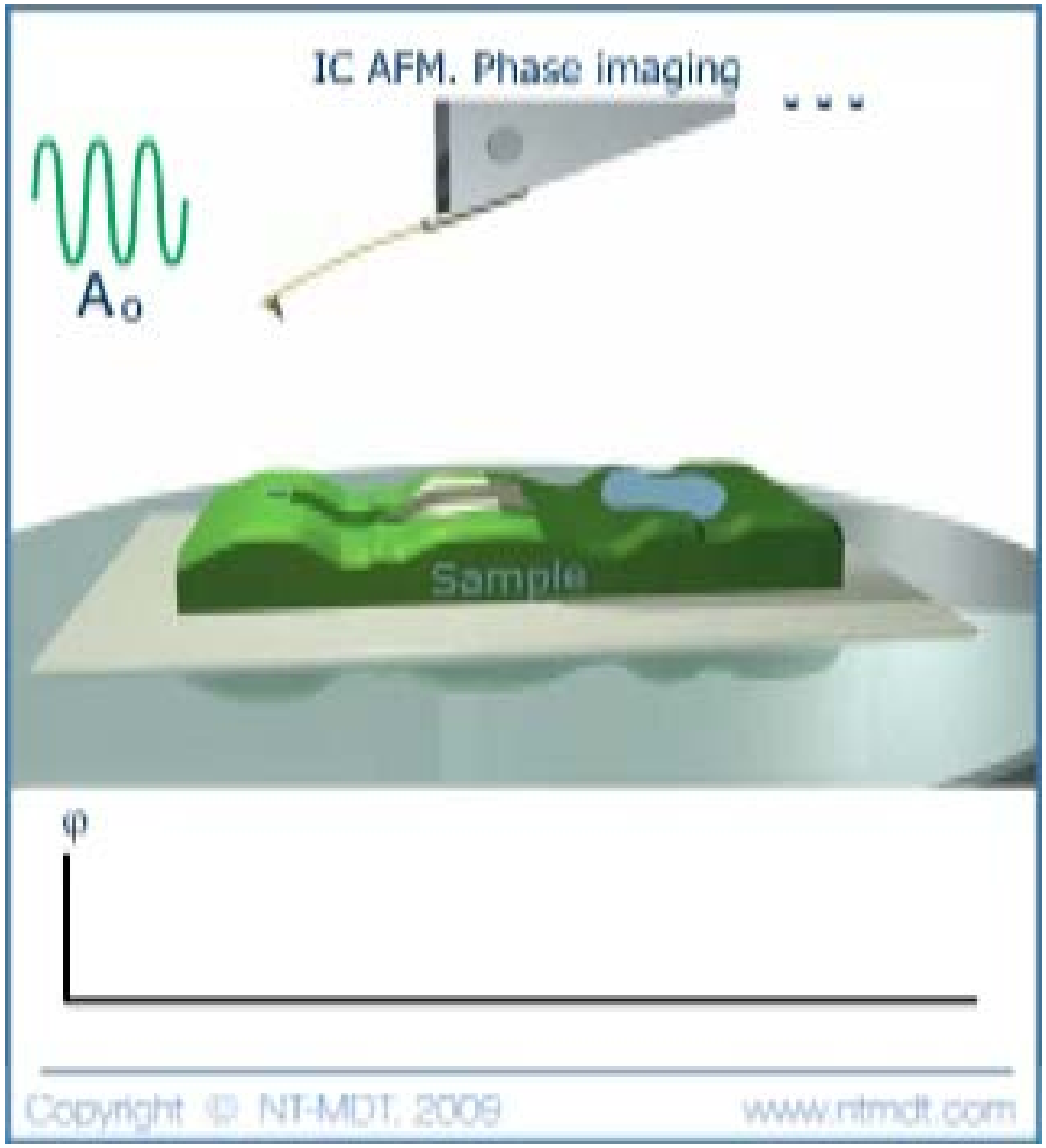


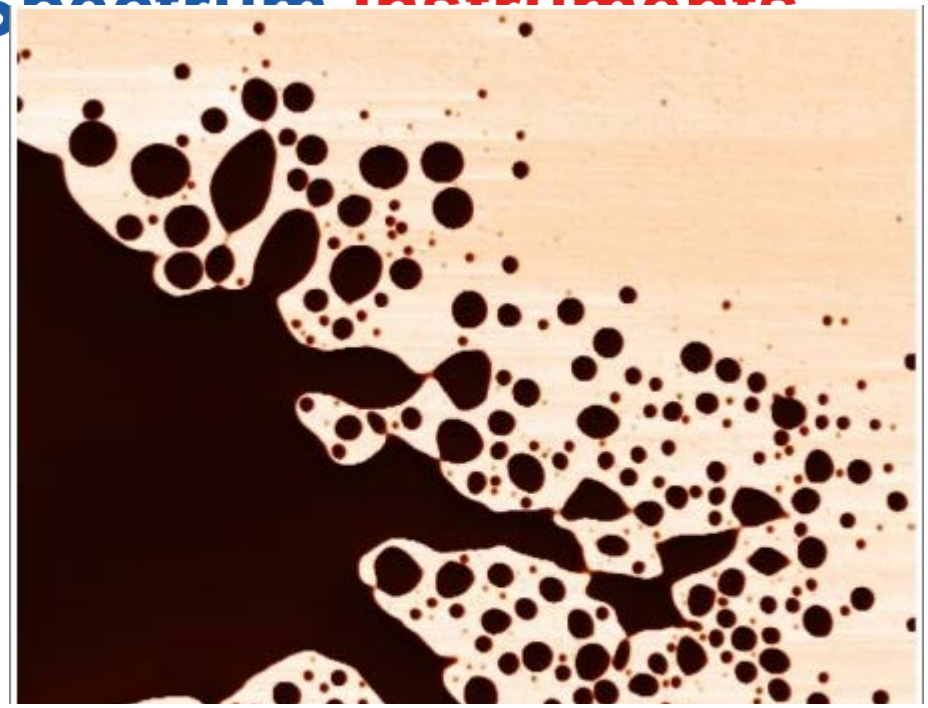
Image Courtesy:
Dr. S. Magonov,
NT-MDT
Development Co.

NT-MDT
Spectrum Instruments

Phase Imaging



Phase Imaging. Scan Examples.

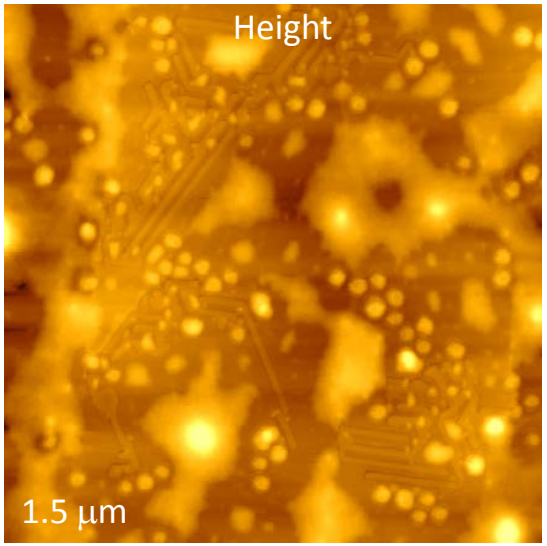


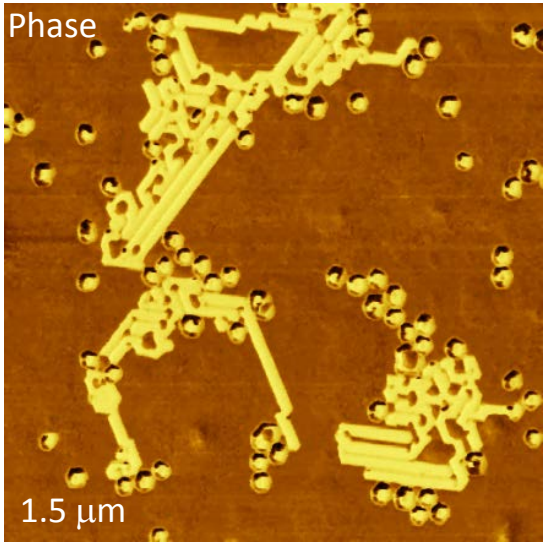
Name: Water on Mica
Environment: Air
Tip: NSG10
Size: 10x10 um
Sample and Image Courtesy: Reinier Oropesa-Nuñez, CEAC, Cienfuegos, Cuba

Amplitude Modulation with Frequency Imaging

Semi-fluorinated alkanes F14H20 on HOPG

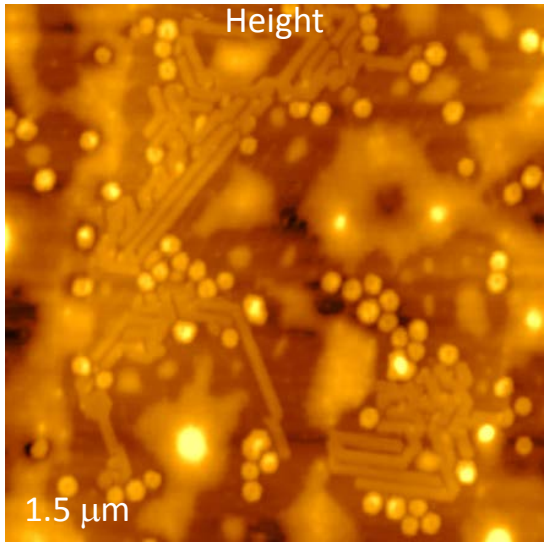
AM-PI

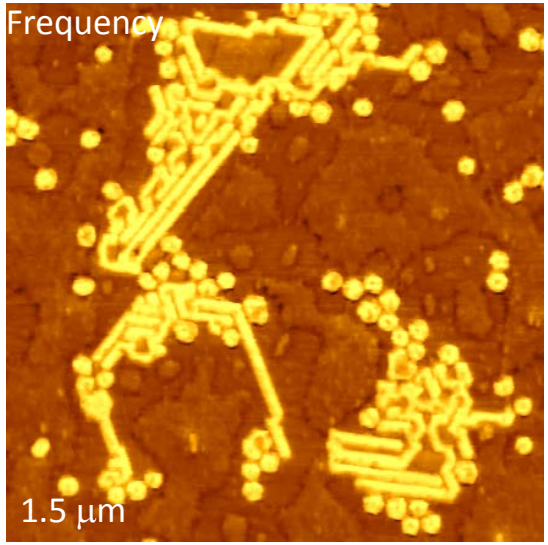


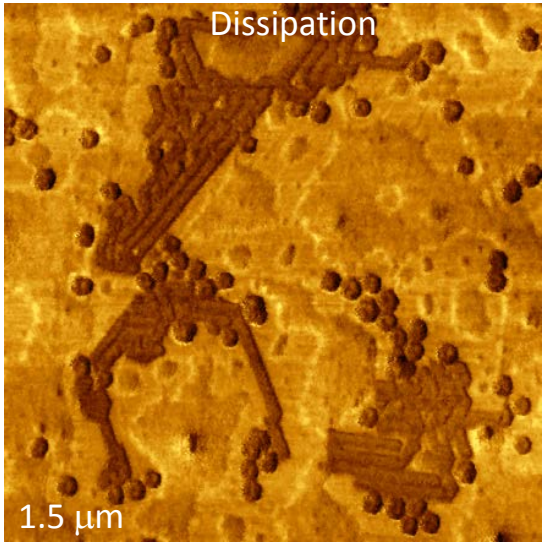


Sample – courtesy Prof. M. Moeller (Aachen)

AM-FI



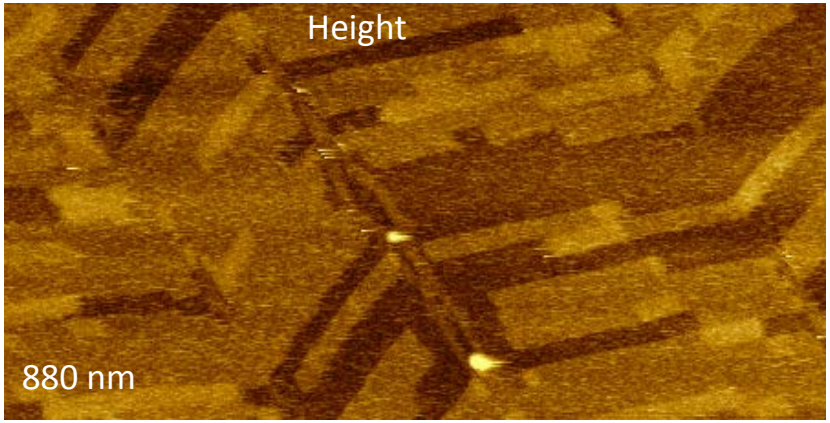




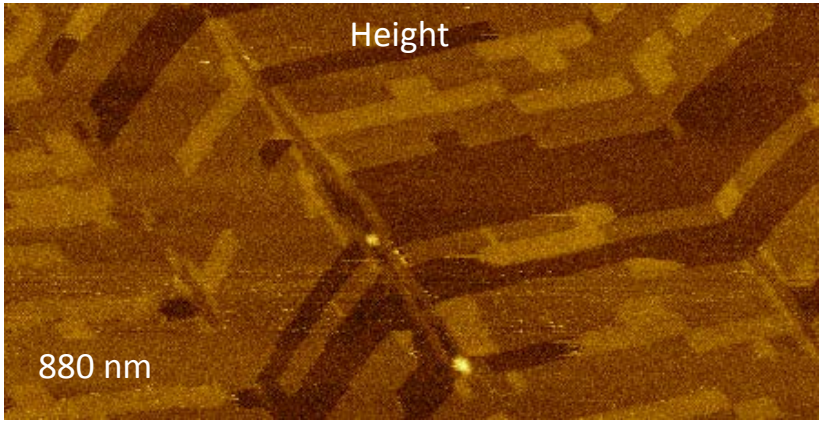
Frequency Modulation Mode

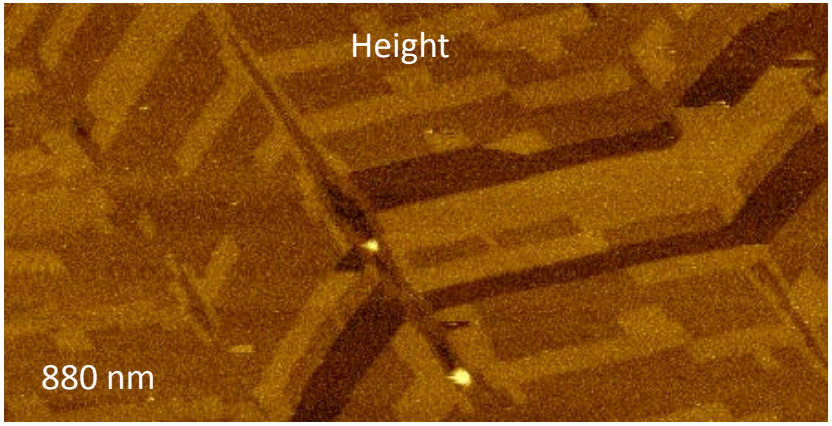
Lamellar layers of $C_{242}H_{486}$ on HOPG

AM-PI



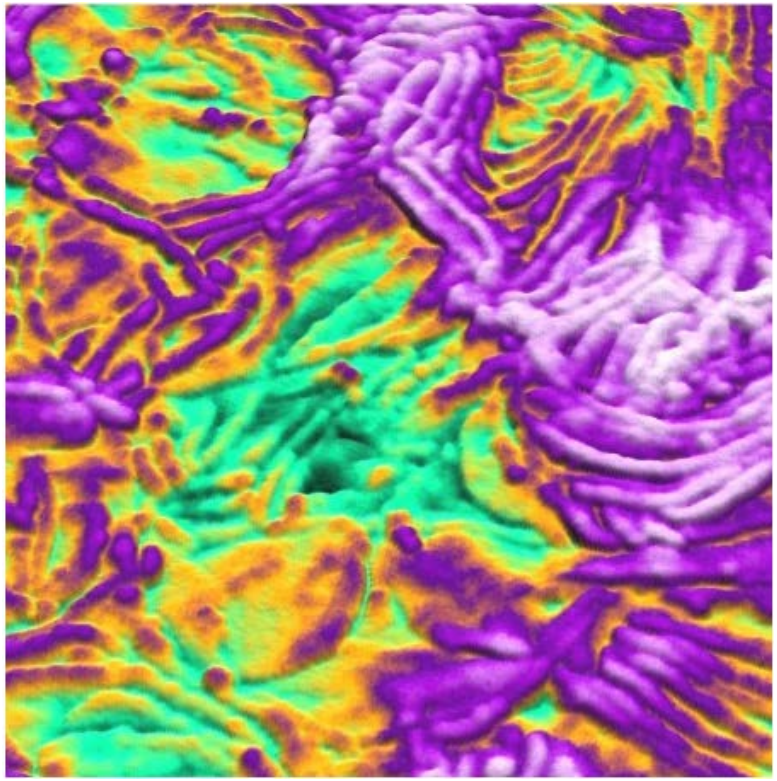
FM





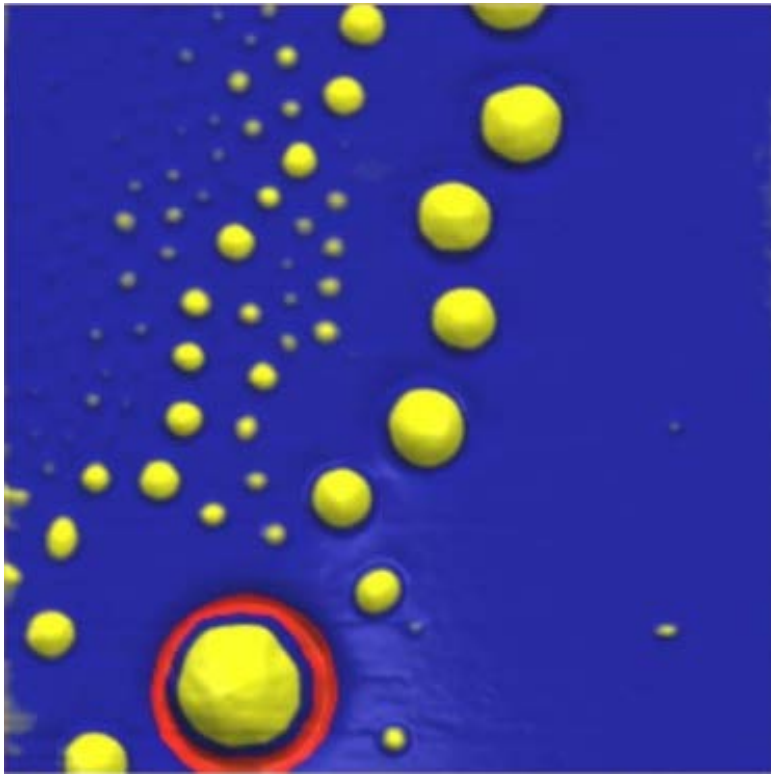
Amplitude Modulation Mode Examples

HDPE



Scan Size: 1 1 µm

PS-LDPE Blend



Scan Size: 6 6 µm

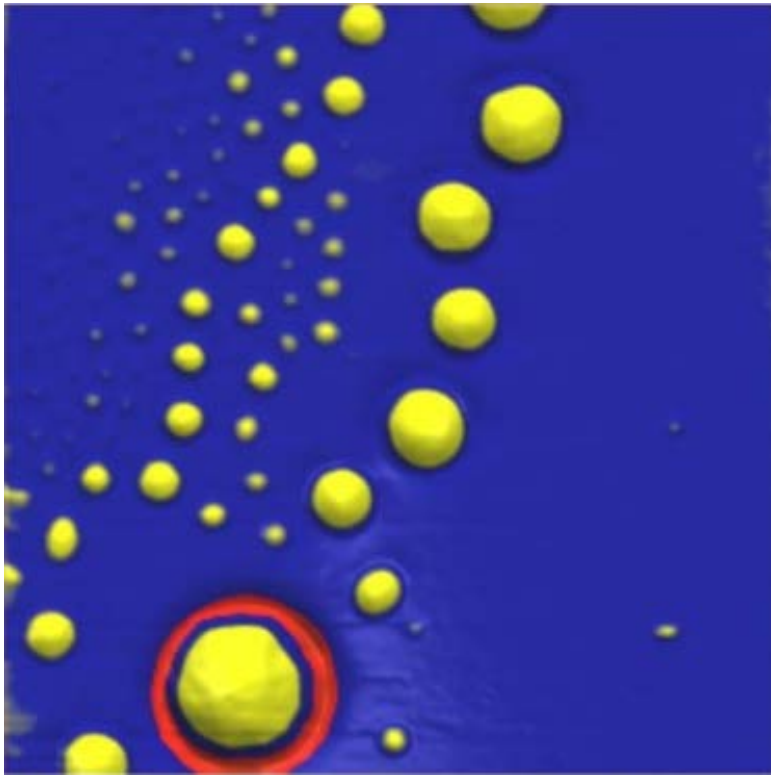
Image Courtesy: Dr. Sergey Magonov
NT-MDT Development Co.

AFM vs. Astronomy

Full Lunar Eclipse September 28 2015

Image Size: 14 000 14 000 km

PS-LDPE Blend



Scan Size: 6 6 µm

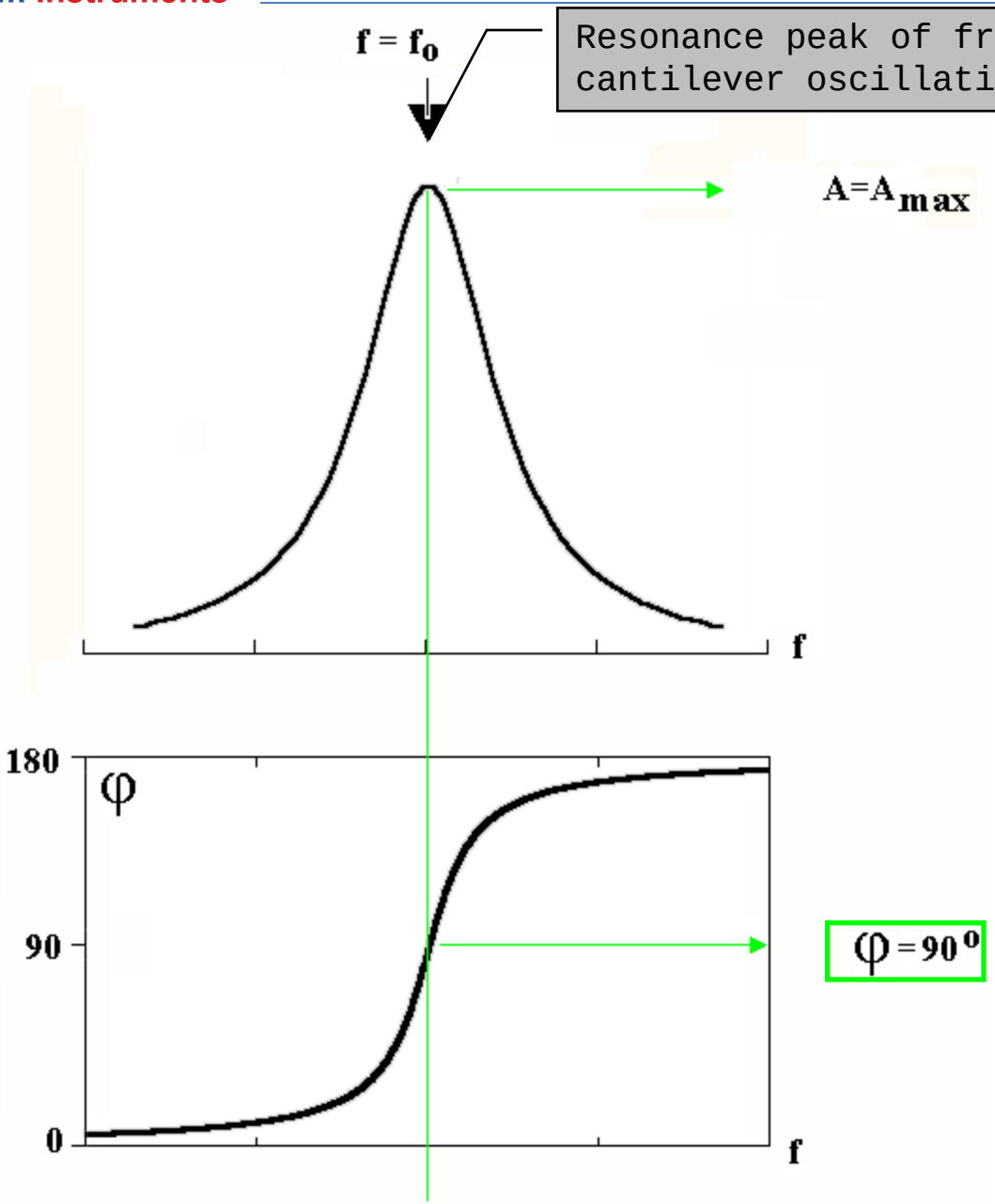
~2,3 Billion times scale difference

NT-MDT
Spectrum Instruments

Easy Way of Getting a Good Images in Tapping Mode

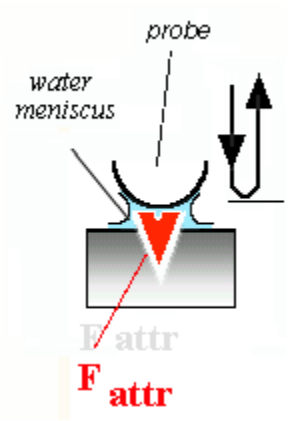
(Attraction and Repulsion Regime)

Simple Harmonic Oscillator

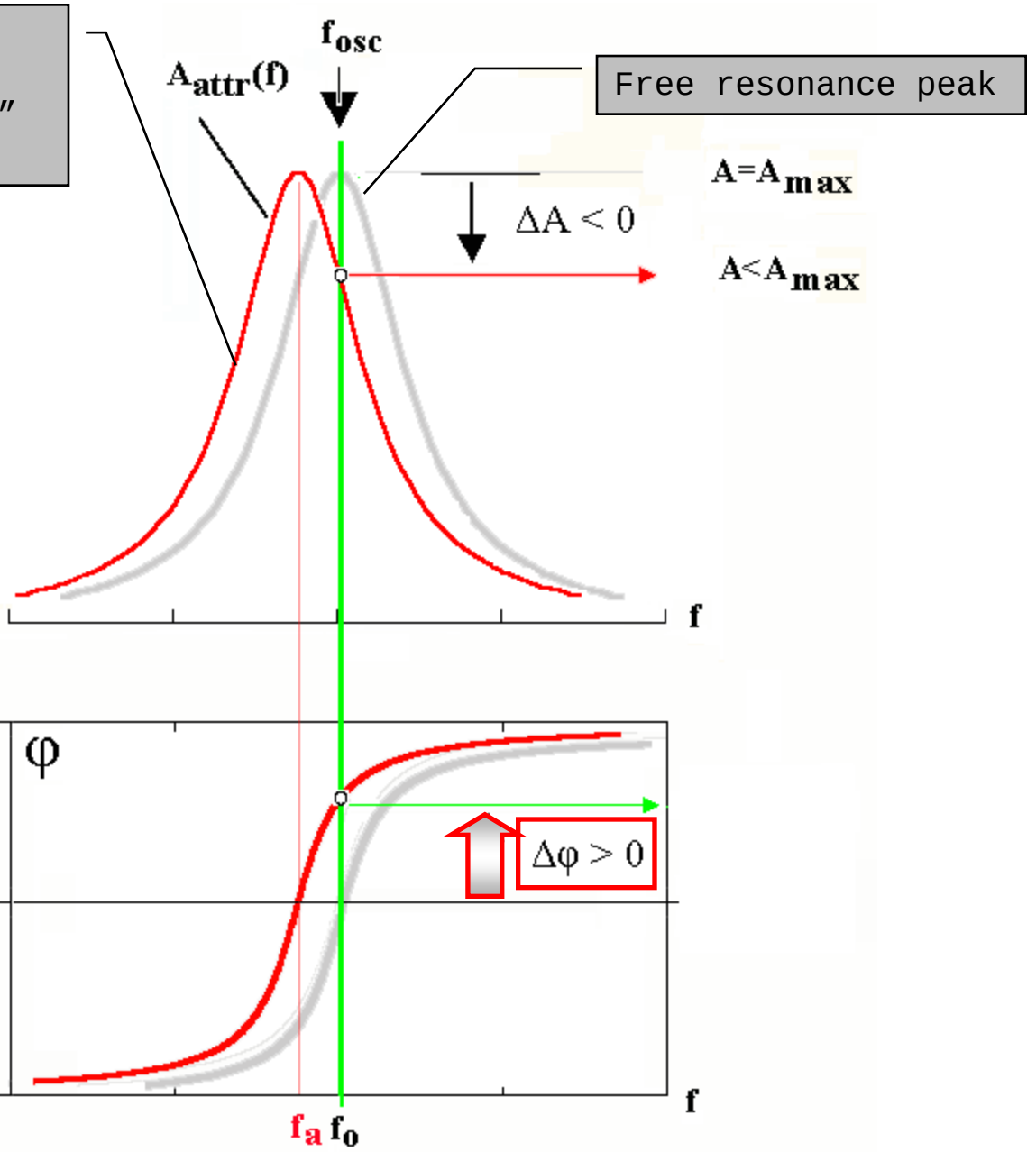


It is known that the phase shift between free and clamped sides of cantilever is 90° at resonance

Attraction Regime



Resonance peak in "attraction" regime



$k^* = k + \langle dF_{attr}/dz \rangle$,

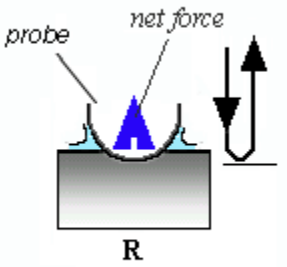
$k^* < k$, $f_{attr} < f_0$

Resonance peak shifts to left

Amplitude decreases,

Phase Increases.

Repulsion Regime



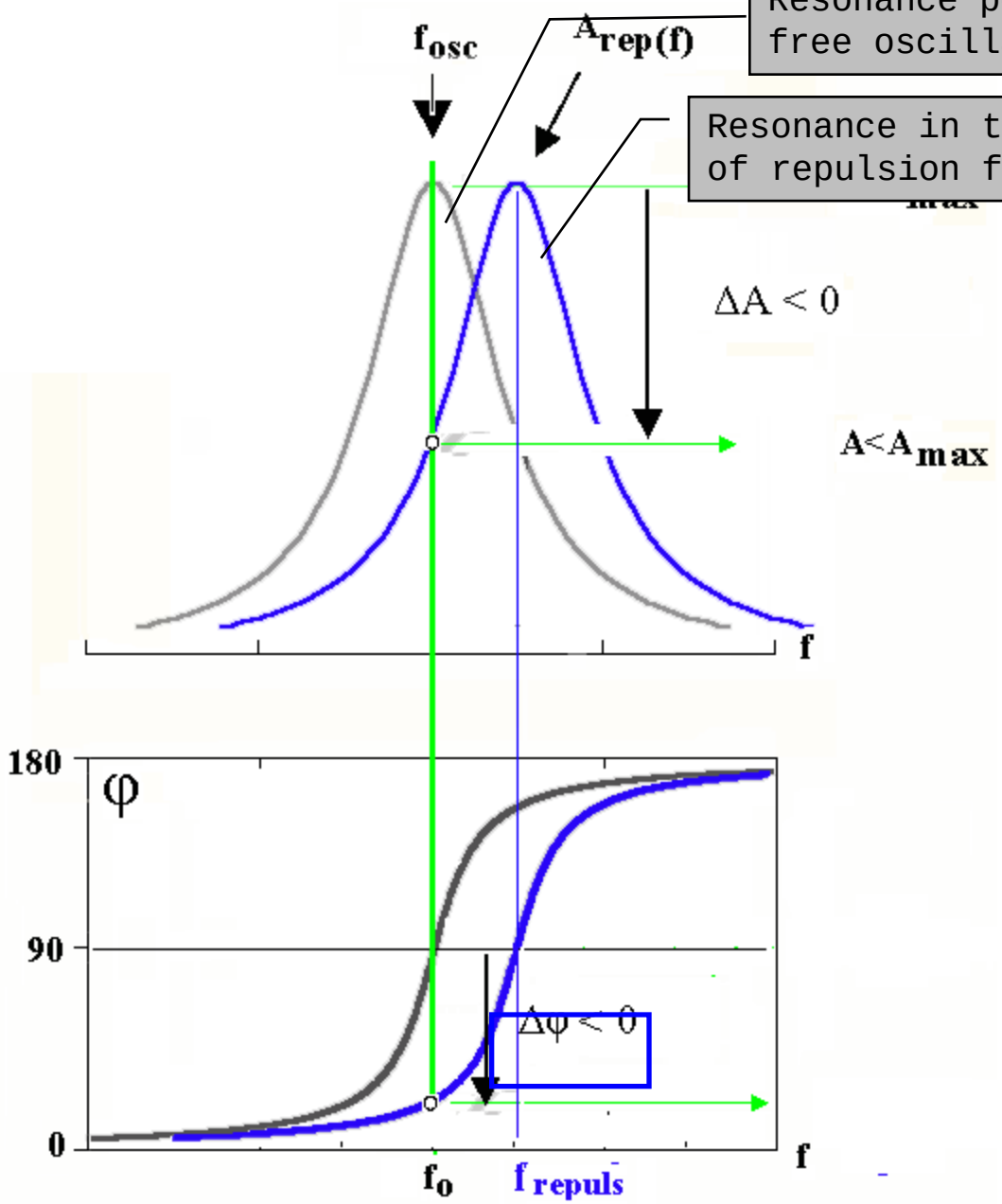
$k^* = k + \langle dF_{attr}/dz \rangle$,

$k^* > k$, $f_{rep} > f_0$

Resonance frequency shifts to the right

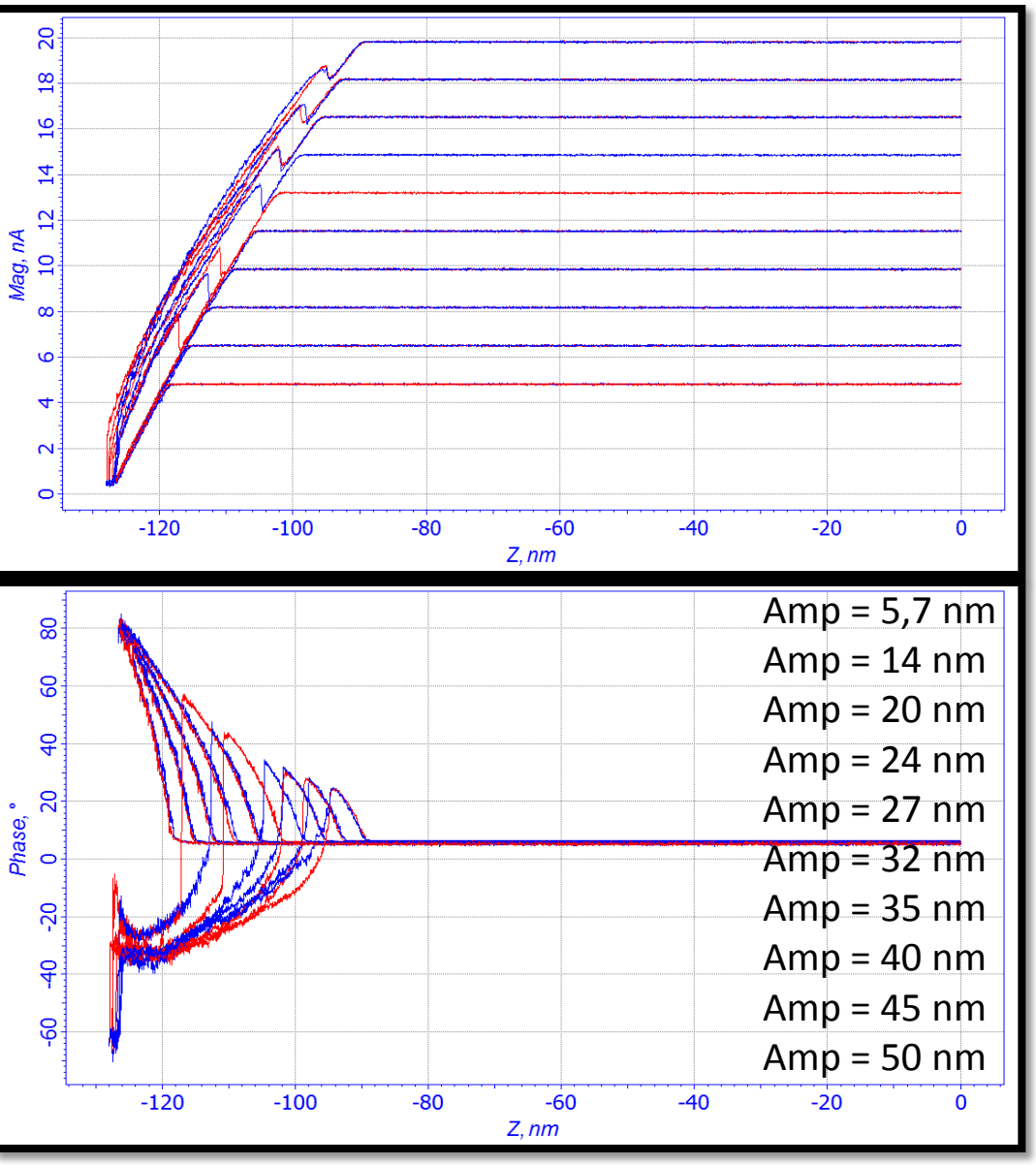
Amplitude decreases,

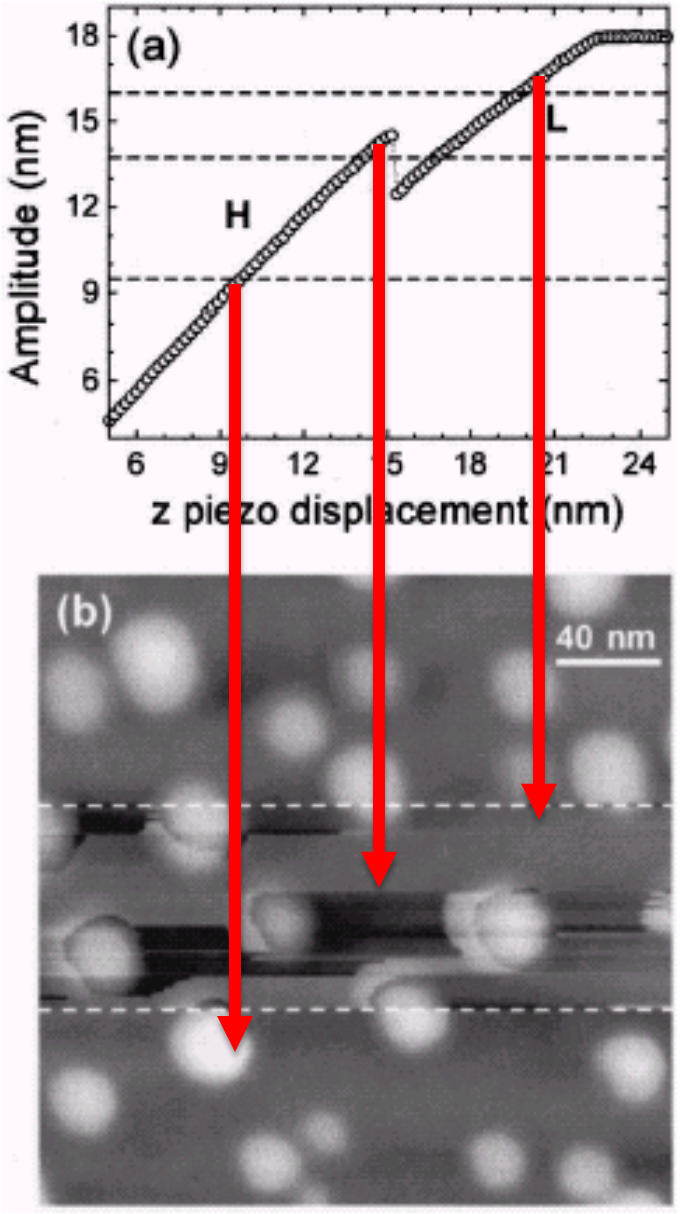
Phase decreases.



NT-MDT Spectrum Instruments

Switching Between the Regimes



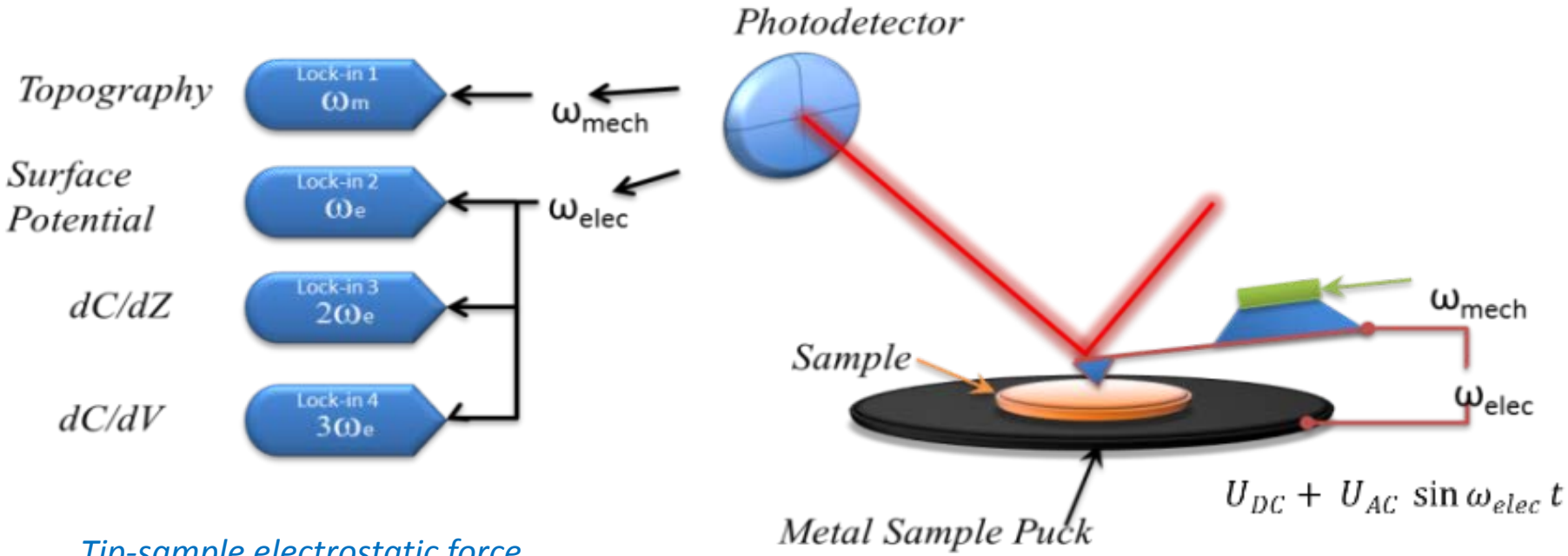


NT-MDT
Spectrum Instruments

Examination of Local Electrostatic Properties

Examination of Local Electric Properties

Single-Pass Local Electric Studies



Tip-sample electrostatic force

$$F_{\omega_{elec}}(Z) = -\frac{\partial C}{\partial Z}\left[(\varphi - U_{DC})\, U_{AC} \sin(\omega_{elec} t)\right]$$

$$F_{2\omega_{elec}}(Z) = -\frac{1}{4}\frac{\partial C}{\partial Z} U_{AC}^2 \cos(2\omega t)$$

Parallel LIA Setting — ***Amplitude Modulation (AM)***

In Series LIA Setting — ***Phase Modulation (PM)***

dC/dZ → *Dielectric response*

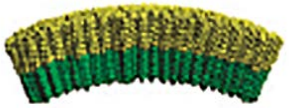
Kelvin Force Microscopy

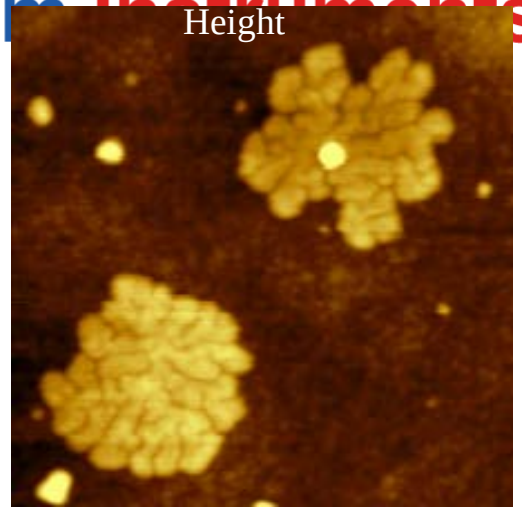
Examination of Local Electric Properties

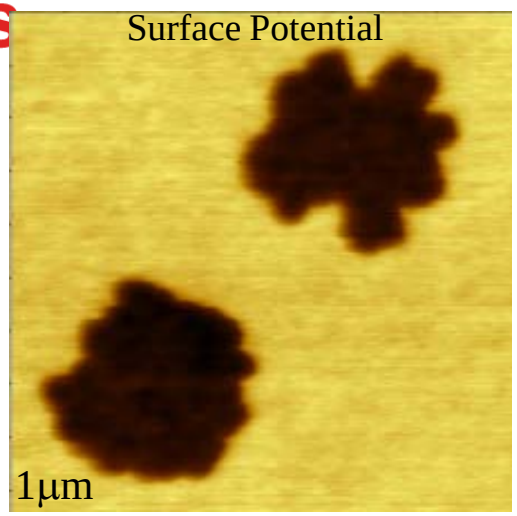
Single-Pass Kelvin Force Microscopy of Self-Assemblies of F14H20 on Si

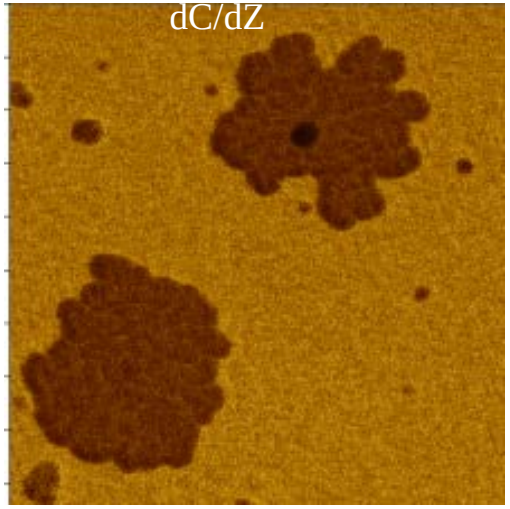
$CF_3(CF_2)_{14}(CH_2)_{20}CH_3$

F14H20







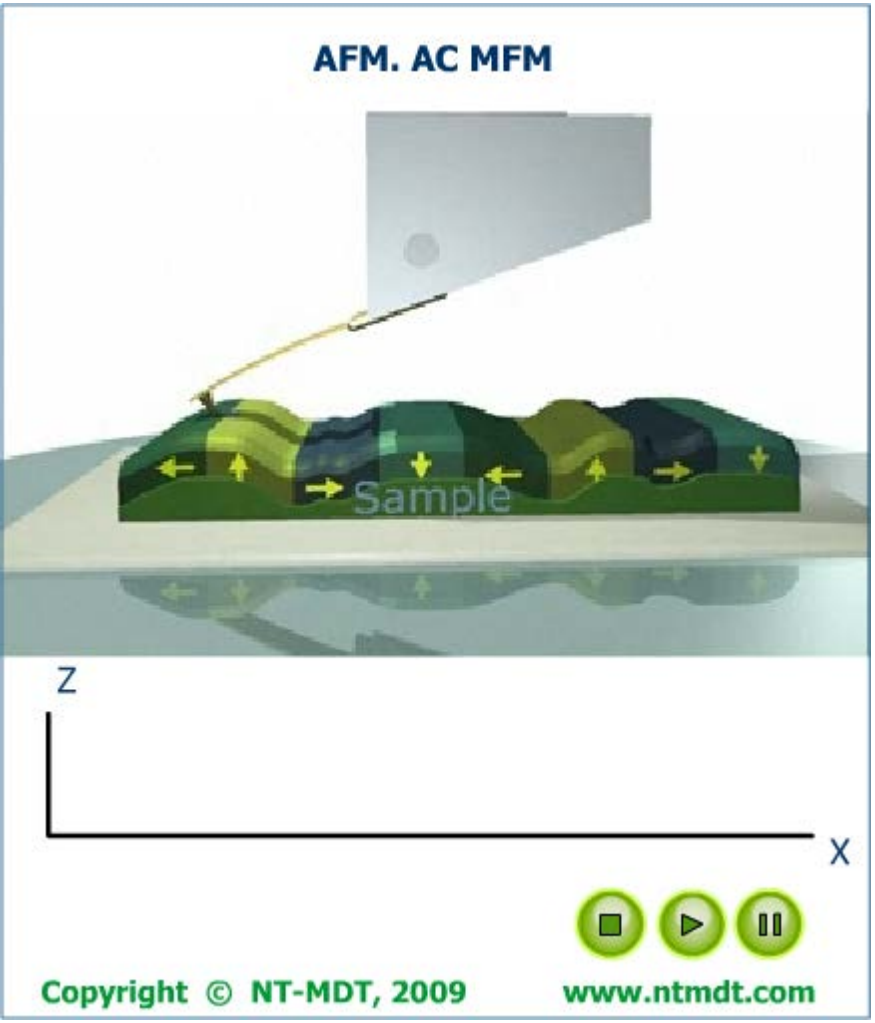


PS – PS/Poly(vinyl acetate) –PVAC Blend

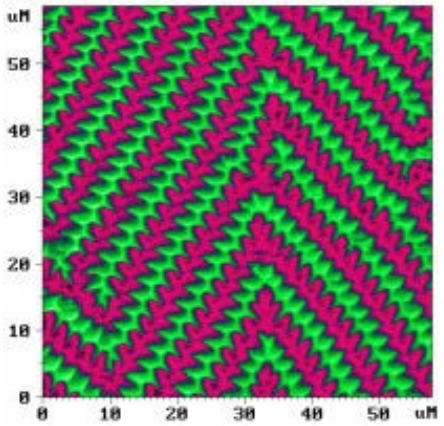
NT-MDT
Spectrum Instruments

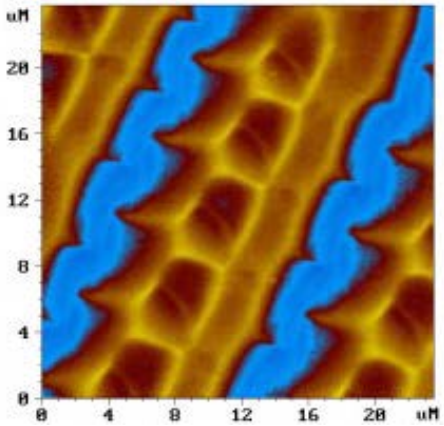
Magnetic Force Microscopy (MFM)

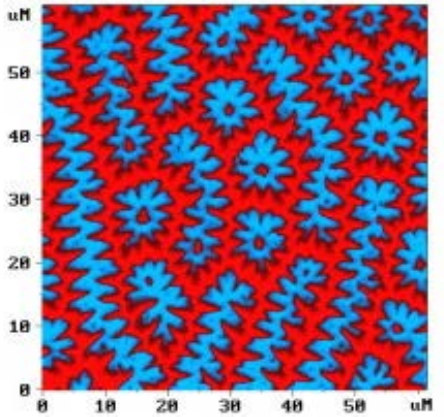
MFM Principle



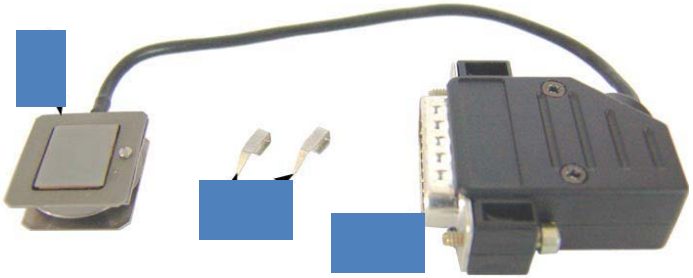
Different magnetic domain structures of nonhomogenious Yttrium Iron Garnet (YIG) films. YIG film has substantial variation of anisotropy field along the film thickness



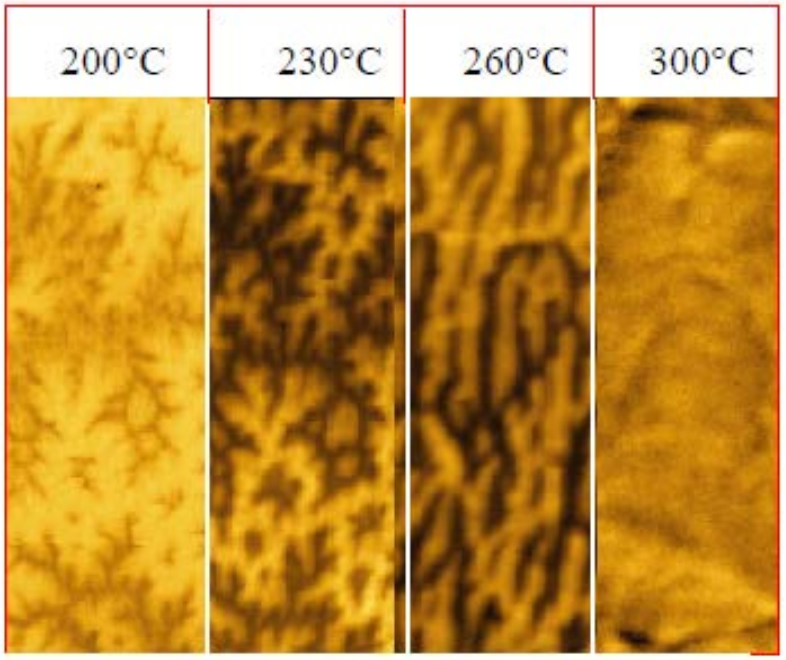




Temperature Dependency



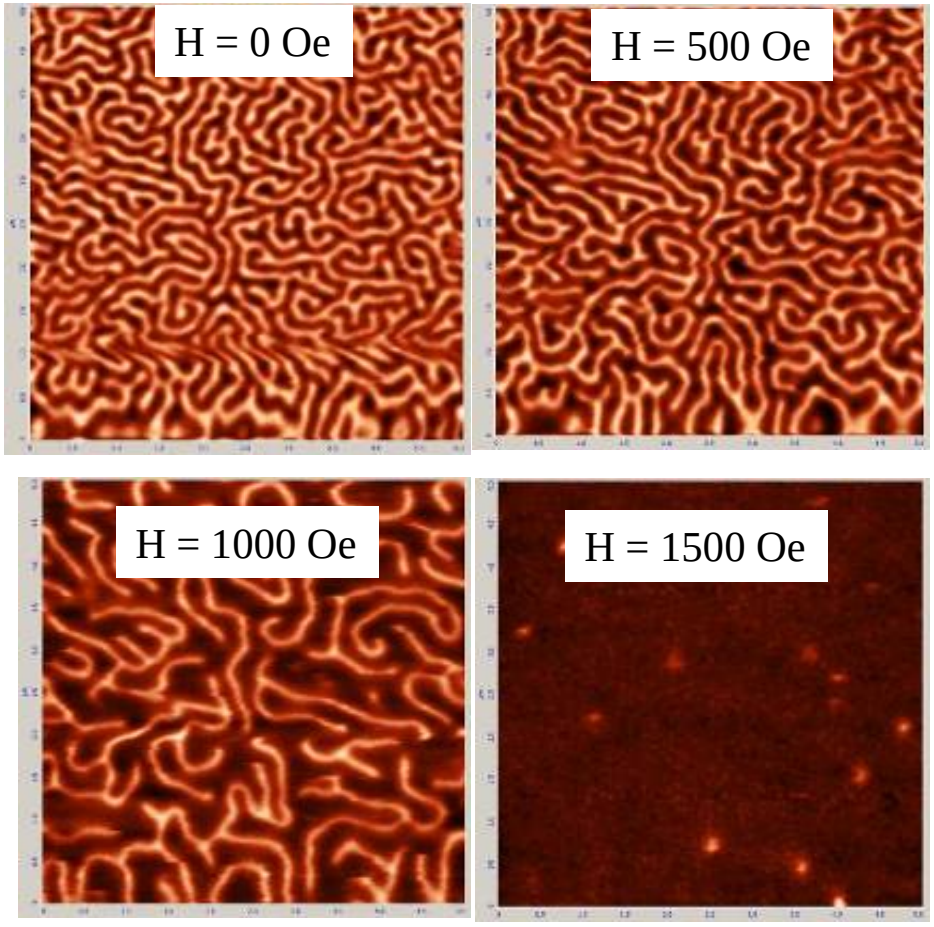
Temperature control: -28...+300 C



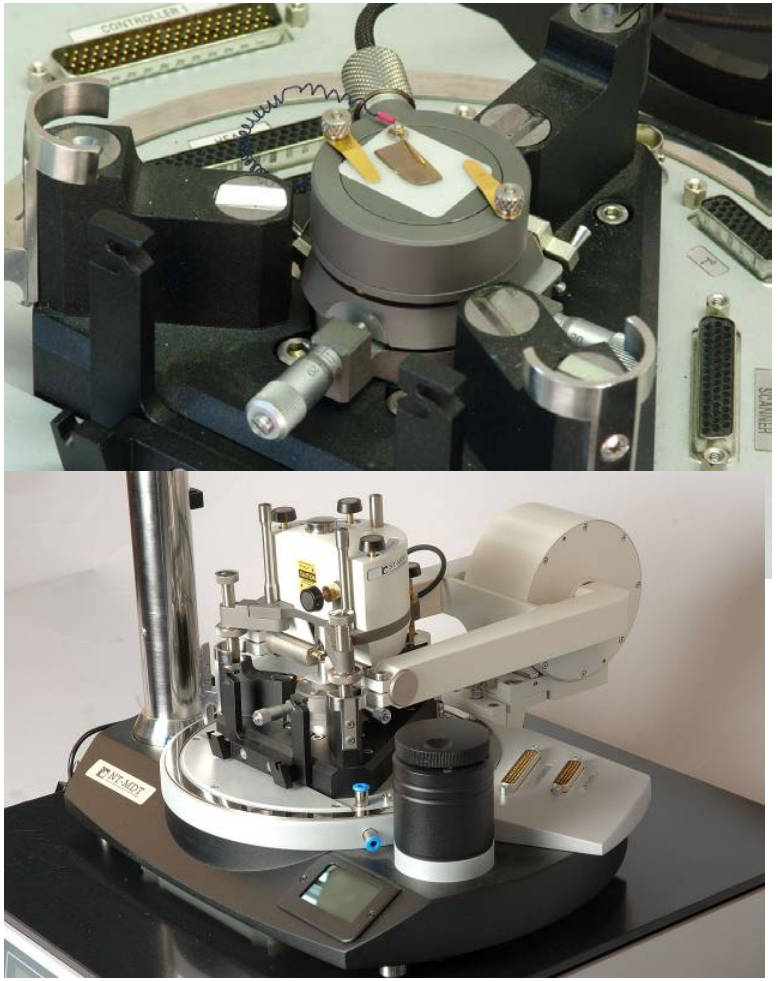
MFM images of the cobalt monocrystal with uniaxial anisotropy. Phase transition occurs when temperature increases.
Images obtained from the same area, 14x40 μm. Sample courtesy of Prof. A.G. Pastushenkov, Tver University, Russia.

Domain Structure Transformation in External Magnetic Field

Changes of the domain structure of Au/Co/Au ...Co/Au sandwich structure.



In-Plain External Magnet



Out-of-Plain External Magnet