

Invited Presentation at AVS Thin Film Division Meeting, July 17, 2002, Sunnyvale

Scanning Probe Microscopy An Ultimate Tool for Nanoscience and Nanotech

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Vecco Basic Components Diagram of an SPM





What SPM Can Do in NanoWorld?

- Visualize atoms, molecules and nanostructures
- Manipulate materials down to atom by atom
- Probe other sample characteristics at nanoscale





Observing Atoms with STM

Metrology Group

Si(111)7x7 in UHV



Au(111) reconstruction in air





Vecco Visualization of Single Macromolecules with AFM







Problems with SPM Imaging

Slow scan speed

One of the Solutions

Tapping Mode Fast Scanning Scan Speed improved by factor of 10

•NSIV Controller •Micro-actuated Probe



Vecco Problems with Speeding up TappingMode™

Metrology Group



- Slow, asymmetric error growth rate
- Fast scan increases amp. error
- High setpoint → not tracking
- Low setpoint \rightarrow possible contact mode
- Low bandwidth of tube Z
- Resonant F 0.7 kHz ~ 5 kHz
- Low gains \rightarrow high amp. error
- High gains \rightarrow oscillation

OPTIMIZE SYSTEM → MINIMIZE ERROR



Metrology Group Improvements in the NSIV Controller



- Large cantilever with ZnO actuator.
- Resonant frequency ~ 50 kHz
- Actuator provides both oscillation and fast deflection in Z
- Z-range about 700 nm

Standard Silicon Probe









TappingMode+ Fast Scanning

Fe nanoparticles on GaAs. Individual nanoparticles and atomic terraces typical of epitaxial growth, along with other surface detail, are visible in both images.

> 5 minutes



< 30 seconds TappingMode+



2µm









High Speed with Accuracy



SLZ only @ 1 Hz Depth=115.8 nm

FSZ only @ 11 Hz Depth=113.4 nm

Depth=115.0 https://www.section.org/lineary-sections/continued/se



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leeco Manipulating A&M with STM Fe on Cu(111)



Lutz & Eigler

Kanji characters for "atom."

CO on Pt(111)



P. Zeppenfeld & D. Eigler







Problems with SPM Manipulations •Piezo problem in open loop scanners •Control of actuate positioning

One of the Solutions

NanoMan Platform for Nano-scale Manipulation and Lithography

•Hardware: Dimension Closed Loop Head •Software: NanoMan Interface







- Most advanced scanning and nanoscale positioning
- Closed loop with lateral noise < 2 nm RMS, 6 nm p-p
- <1% nonlinearity with Max. scan size 100 μm







CCCO Dimension "CL" SPM Performance Low-noise

~8nm wide parallel polymer lamellae. XY closed-loop feedback active. •



Topography



Phase





Interface for direct control of nanopositioning, scripting, and lithography



Nudging the Nanotubes





Manipulation of Single Macromolecules

Metrology Group

Manipulation of jacketed polystyrene molecules on HOPG;
500 nm scan
Imaging Mode:
Imaping
Manipulation Mode:
constant height
Dotted lines indicate
the tip motion





Pushing Au Particles on Mica









"no job too small"

~15 nm line widths





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Magnetic Force Microscopy (MFM)
Electric Force Microscopy (EFM)
Current Measurements in Contact AFM
TUNA
Conductive AFM
Scanning Capacitance Microscopy (SCM)
Scanning Thermal Microscopy



Veeco MFM Phase Images of Garnet Metrology Group $40 \ ^{\circ}C$ 26 °C $60 \ ^{\circ}C$



 $(60 \,\mu\text{m}, \text{Z-scale} = 2 \,\text{de})$



Height

3µm scan

EFM Phase







Application Modules



- Scanning Capacitance
- Scanning Spreading Resistance
- Tunneling AFM
- Conductive AFM
- Scanning Thermal





Scanning Capacitance Microscopy

- Measures capacitance variations between a conductive probe and semiconductor sample while scanning in contact mode
- Produces a 2D image of near surface variations in carrier concentration with a sensitivity range of 10¹⁵-10²⁰ carriers/cm³ and a lateral resolution of 10 to 20 nm







Vecco Operation of Scanning Capacitance System





Courtesy: R. Klienman





Capacitance of unexpected 8V avalanche breakdown















Scan size: $1x1 \ \mu m^2$



Courtesy: S Madhukar













Thermosensitive Probe



Standard Si₃N₄ tip/cantilever assembly

Metal film conductors on either side of the tip

High thermal coefficient of resistivity film along the side of tip.

TCR of the sensor ~ $2.3 \times 10^{-3/\circ}$ C









Sensitivity Calibration

Metrology Group



Invar puck on heater with controlled ramping rate: 10 K/minute from 35°C to 45°C



Vecco Temperature Profile of Laser Diode



Metrology Group Topography and Thermal Images





Measurement with 5 Probes

