Recent Advances in AFM

- Unifying Theme -

taking advantage of cantilever modes
Force vs. **Distance** provides material properties

**Force vs. Distance at one point**

From cantilever deflection infer loading force

![Diagram showing the transition between repulsive and attractive forces](image-url)
Force vs. Time in dAFM

With feedback, measure topography at each point.

Repeated $f_o$ times in one second at EVERY pixel.
Photodiode Voltage \[ \rightarrow \]

Waveform

\[
S(t) = \sum_{n=0}^{N} A_n \sin(2\pi n f_o t + \phi_n)
\]

Fourier Transform of Waveform

- **Amplitude**
- **Phase**

http://www.falstad.com/fourier/
How does a cantilever respond to the harmonics?

(Acoustic excitation: Lecture 11)

Transfer function - acoustic driven cantilever
Typical Cantilever Driven Vibration Spectrum
“Vibration Fingerprint”

Bending Modes:
- $f_1 = 21.2$ kHz
- $f_2 = 146.3$ kHz
- $f_3 = 386.0$ kHz

Why not just pure bending modes?

Beware: peak heights NOT proportional to vibration amplitudes

Question

Can you design a cantilever/tip system that has flat response over broad frequency range?
Torsion cantilever

Veeco website

1st torsion mode
(~816 kHz)

1st bending mode
(51 kHz)

2nd bending mode
(321 kHz)

~15 μm
General Operation

Use first bending mode as usual to monitor topography

Measure harmonic spectrum using torsional mode and reconstruct tip-substrate forces while scanning
Results

Bending response

Polystyrene Substrate

Graphite Substrate

Torsional response

50 nm thick film: PMMA in PS matrix

Increasing Temperature

85° C

Boundaries disappear: mixing of two phases

Small contrast: comparable stiffness

Contrast increases: glass transition temperature

215° C

Concerns

Requires reliable cantilever fabrication

Is the harmonic vibrational spectrum accurately measured: non-linear coupling?

Small errors in higher harmonic estimation (either phase or amplitude) produces disastrous effects.