Intentionally Nonlinear Design of Multi-Frequency AFM for Enhanced Material Characterization

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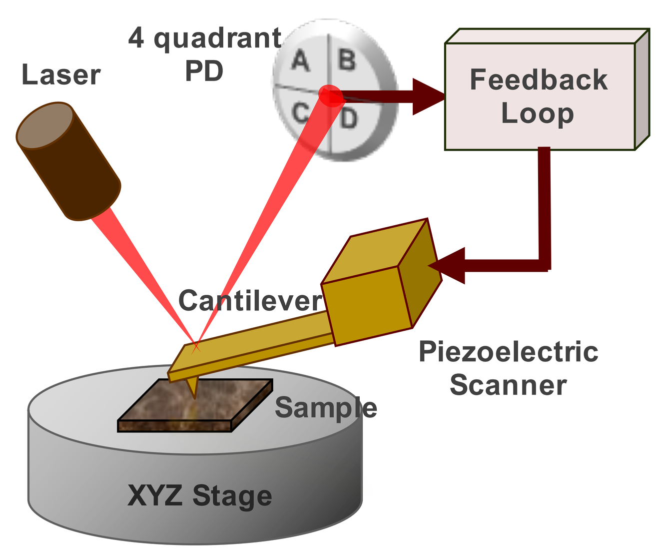
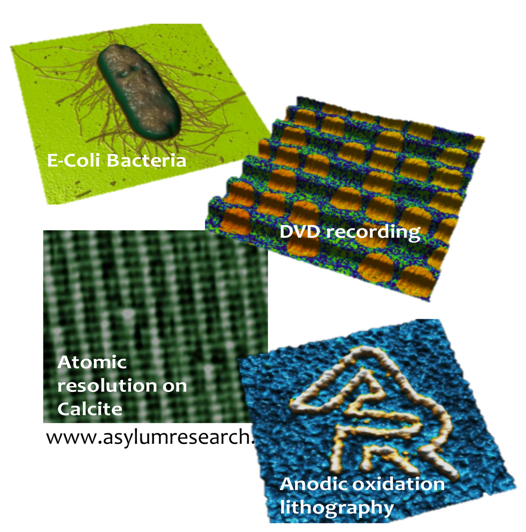
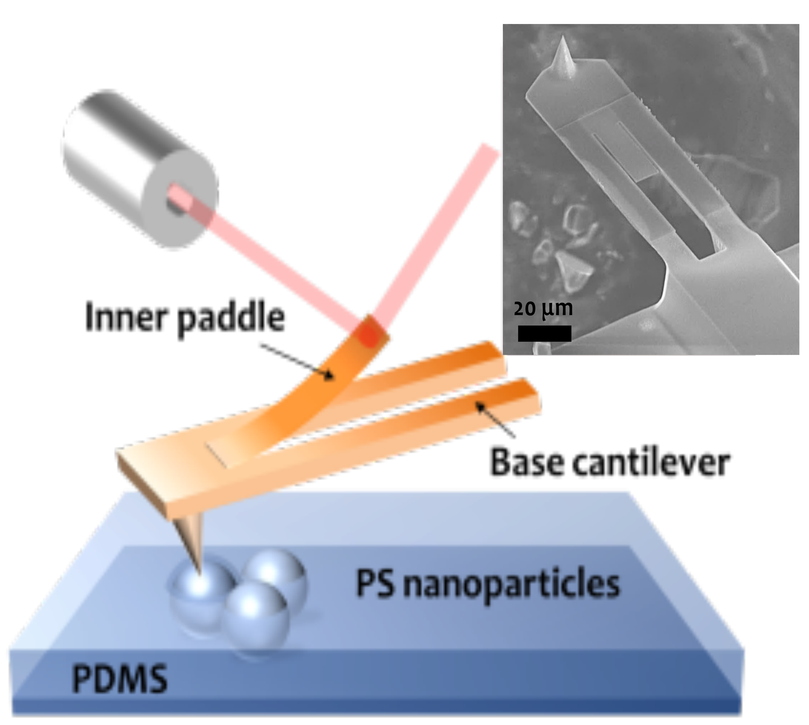
Atomic Force Microscopy (AFM)





Since its development in the mid-1980s, AFM has been one of the most useful tools in the fields of nano- and bioscience. AFM is capable of imaging and characterizing various materials with nanometer-scale spatial resolution under any environmental conditions, in both air and liquid. By introducing an AFM cantilever with a nanometer-scale tip, extremely small changes in tip-sample interaction forces can be sensed, instead of relying on electron or phonon measurements.

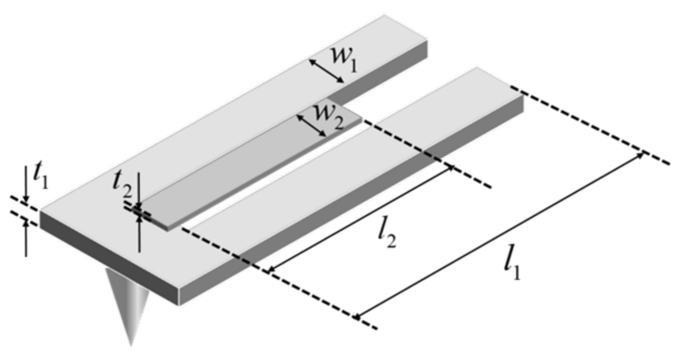
Advance the State-of-the-art AFM Via a New AFM Cantilever Design

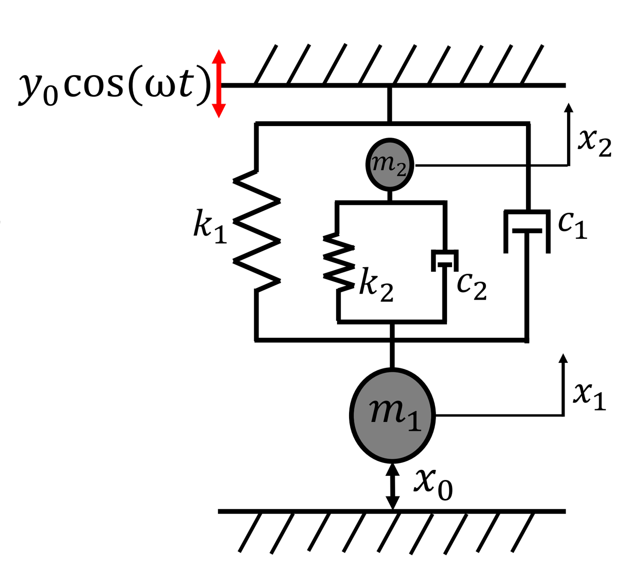


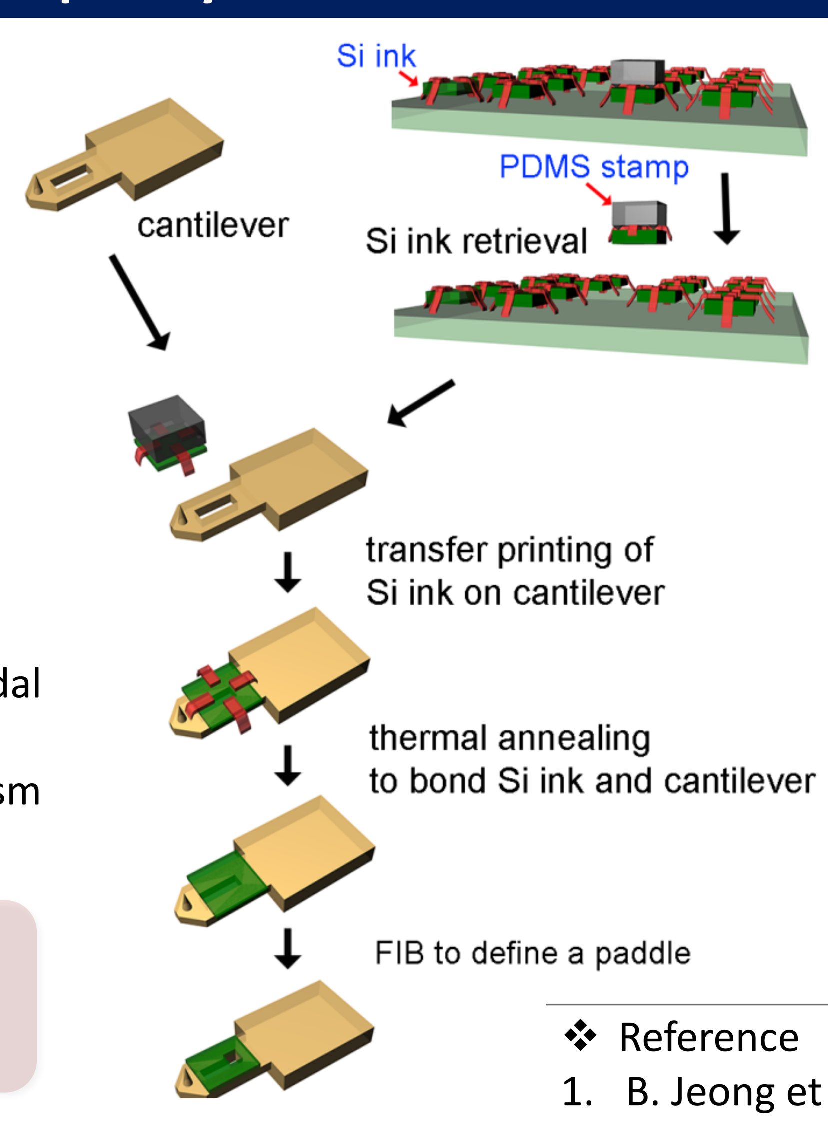
During dynamic atomic force microscopy (AFM), the deflection of a scanning cantilever generates multiple frequency terms due to the nonlinear nature of AFM tip-sample interactions. Even though each frequency term is reasonably expected to encode information about the sample, only the fundamental frequency term is typically decoded to provide topographic mapping of the measured surface. One of main reasons of discarding higher harmonic signals is their low signal to noise ratio.

We introduce a new design concept for multi-harmonic atomic force microscopy, exploiting intentional nonlinear internal resonance for enhancement of higher harmonics. The nonlinear internal resonance, triggered by the non-smooth tip-sample dynamic interactions, results in nonlinear energy transfers from the directly-excited fundamental bending mode to the higher-frequency mode and, hence, enhancement of the higher harmonic of the measured response.

New Cantilever System for Multi-Frequency AFM







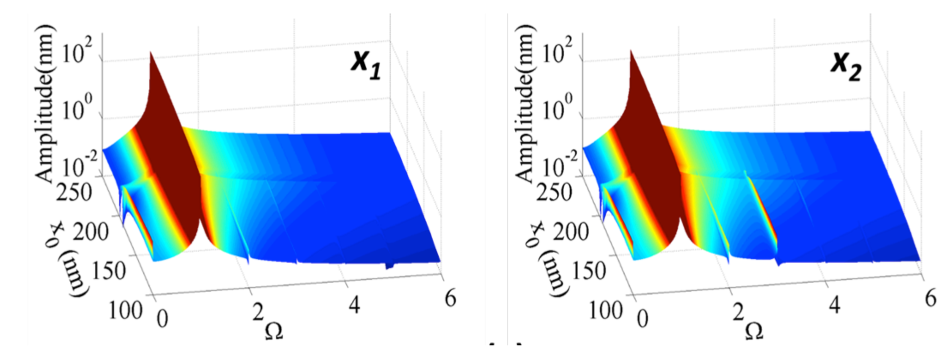
- Conventional AFM cantilever is modified to have an inner paddle.
- Intentionally designed to match in-phase and out-of-phase bending modal frequencies to 1:n ratio.
- Tip-sample interaction triggers the higher harmonic through the mechanism of internal resonance.

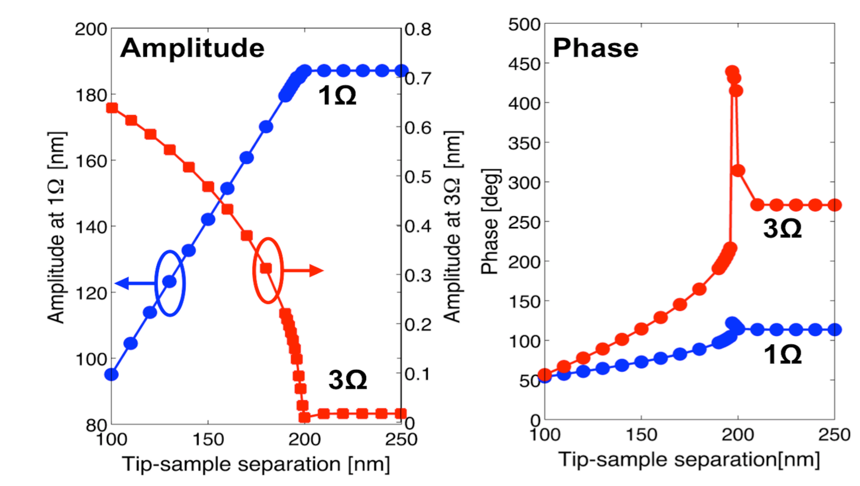
$$m_1\ddot{x}_1 + c_1\dot{x}_1 + k_1x_1 + k_2(x_1 - x_2) + c_2(\dot{x}_1 - \dot{x}_2) = k_1y_0\cos\omega_d t + F_{ts}(x_1)$$

$$m_2\ddot{x}_2 + k_2(x_2 - x_1) + c_2(\dot{x}_2 - \dot{x}_1) = 0$$

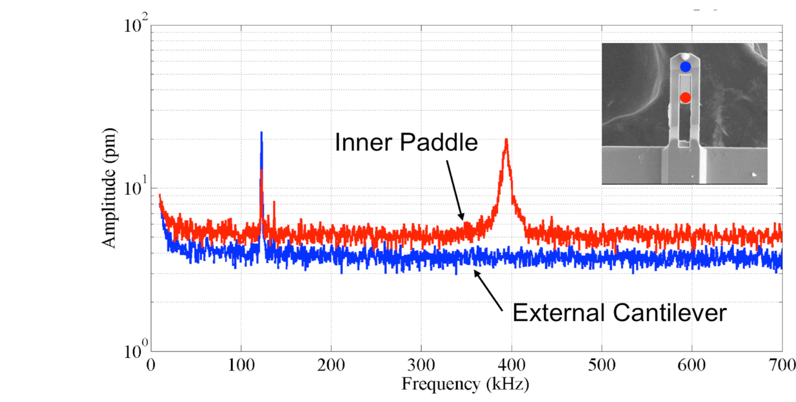
Nonlinear Dynamics of New Cantilever System

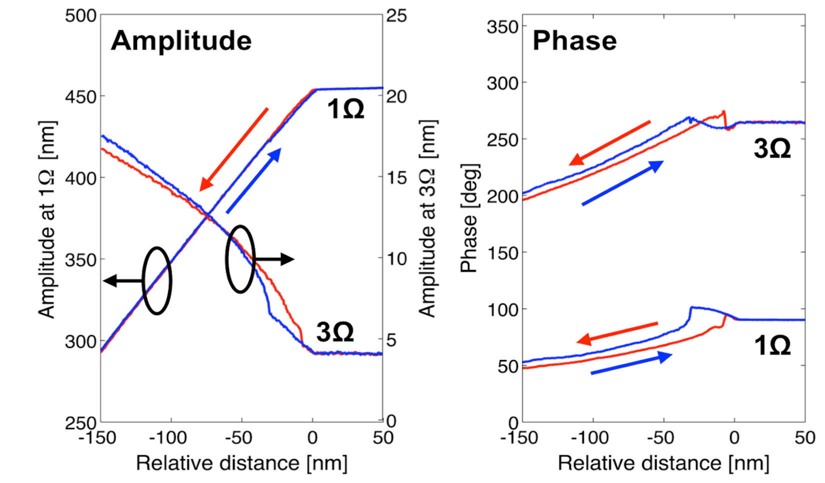
Numerical simulation results





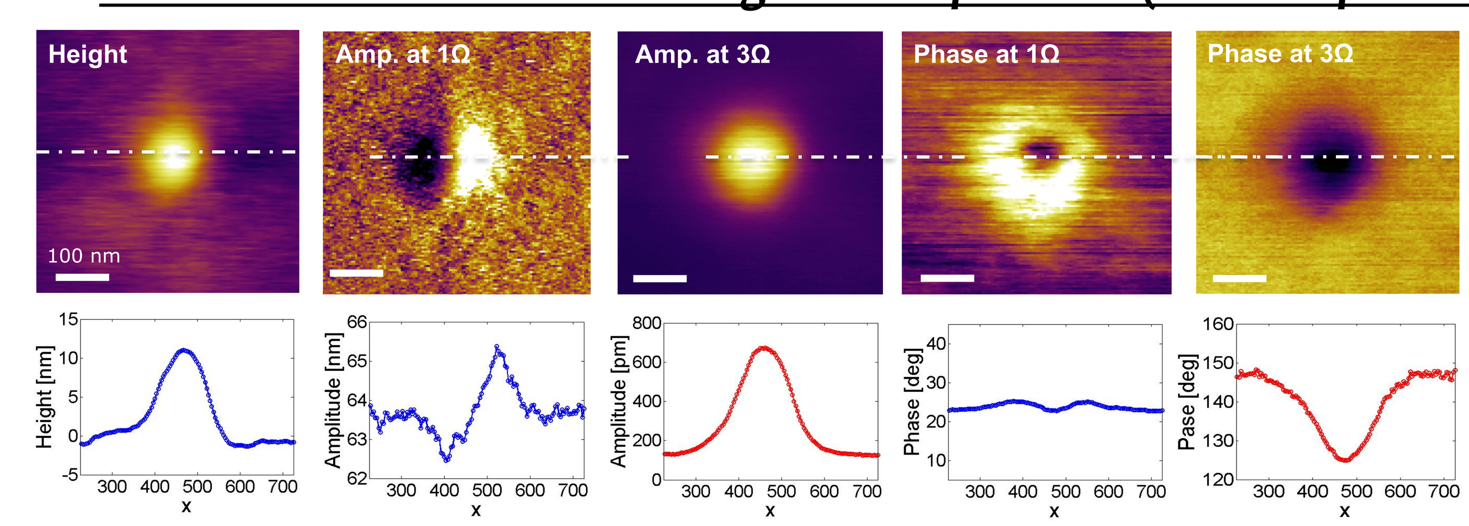
Experimental results



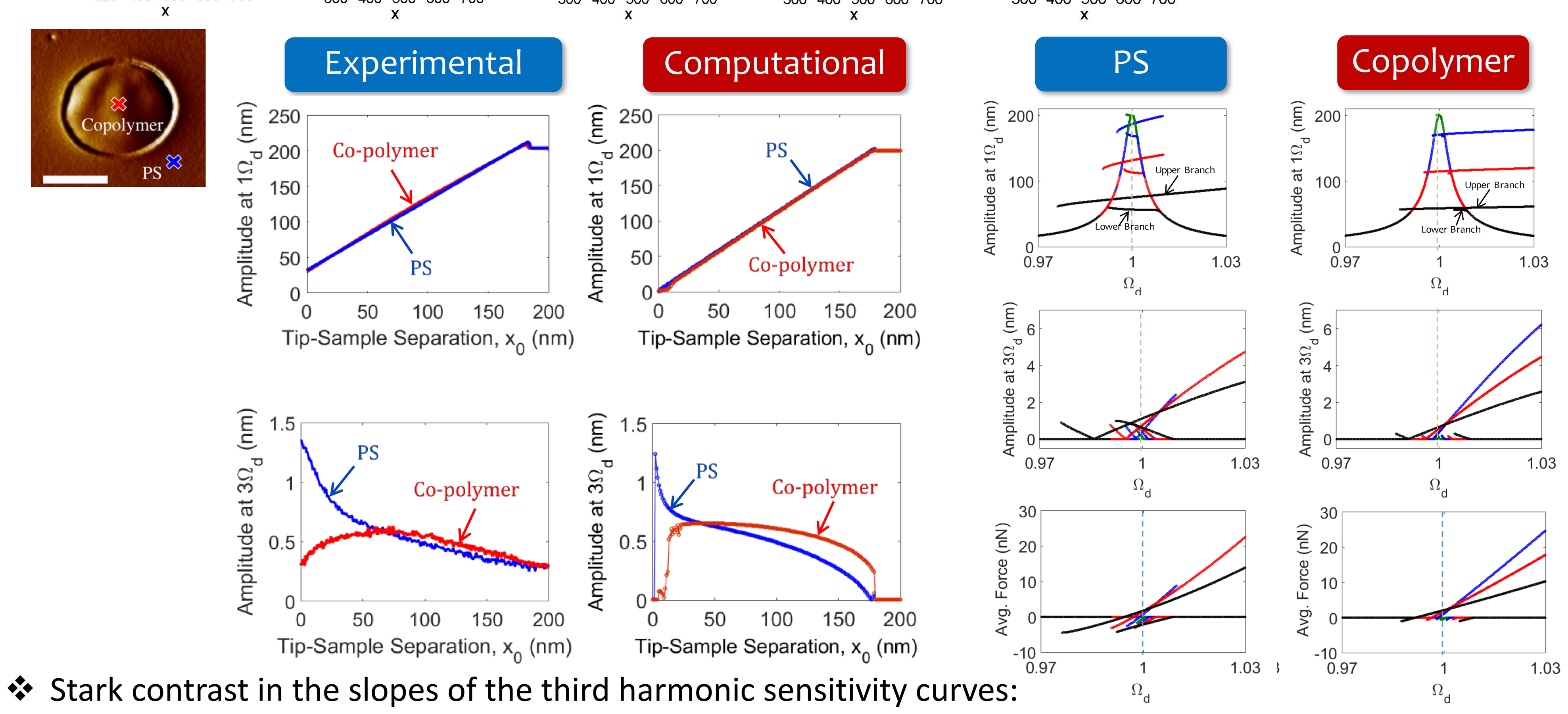


AFM Measurement Results

AFM measurement on inhomogeneous specimen (PS Nanoparticles in PDMS Film)



- *Third harmonic amplitude can clearly recognize the nanoparticle.*
- *Sensitivity of phase is improved by almost 10-fold at the third harmonic.*
- *No crosstalk between the amplitude and phase.*



- Stark contrast in the slopes of the third harmonic sensitivity curves:
  - The 'stiff' PS region leads to dynamics that are attracted by a stable upper branch, repulsive interaction regime.
  - The 'soft' Co-polymer leads to dynamics attracted by a lower branch, attractive interaction regime.
- A strong linear correspondence between the average tip-sample force per cycle and the amplitude of the third harmonic was observed.

Reference

1. B. Jeong et al., "Utilizing Intentional Internal Resonance to Achieve Multi-Harmonic AFM," Nanotechnology **27** 125501 (2016).
2. R. Potekin et al., "Cantilever Dynamics in Higher-Harmonic AFM for Enhanced Material Characterization," Int. J. Solids Strut. (in press).