

Photothermal Cantilever Excitation: Unlocking New Methods in Atomic Force Microscopy

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Atomic force microscopy (AFM) has become a widely used technique in many different research disciplines from physics, through materials science to life sciences. Advances in instrumentation and new measurement methods have allowed for imaging surface structures as well as acquiring secondary information such as mechanical and electrical properties of samples at high spatial resolution. An important advance in AFM instrumentation has been the development of photothermal cantilever excitation. Photothermal excitation directly excites the cantilever by locally heating it at its base, and thus allows stable and clean excitation in nearly any environment [1].

The ability to effectively drive cantilevers with photothermal excitation well below their resonance frequency allows off-resonance imaging modes to be operated at higher actuation frequencies compared to traditional piezo-based methods. If the oscillation of the cantilever is generated by modulating the AFM's Z-scanner, the speed-limited factor is the resonance of the Z-scanner. AFM cantilevers, on the other hand, can be directly actuated at significantly higher resonances and with photothermal excitation, the actuation is free of parasitic coupling with the environment. Off-resonance imaging modes have been shown to have exquisite force-control allowing for a more controlled probe-sample interaction force. Along with a high-frequency oscillation and high measurement bandwidth, dynamic processes of soft materials can be measured [2].

The clean and unambiguous photothermal excitation of the cantilever coupled with its textbook-like response, especially in liquids, allow for novel, non-imaging measurements. For example, the frequency of a cantilever with spring constant k and effective mass m^* is $f = (2\pi)^2 \sqrt{k/m^*}$. When a mass is added to the cantilever, such as eukaryotic cells, changes in the resonance frequency of the cantilever, can be used to determine the mass of that cell. By using photothermal excitation to drive the cantilever at sub-nanometer amplitudes, we can dynamically monitor changes in the mass compared to measuring the resonance through thermal excitation. Thus, we have developed a cantilever-based mass sensor that is measuring masses with picogram resolution on millisecond timescales [3]. This technique has been used to take time-resolved mass measurements of living eukaryotic cells in physiological conditions. In addition, by combining several frequency measurements at different cantilever eigen-modes, we can determine the position of the mass along the cantilever, which is especially useful for measurements involving living and motile organisms.

Cantilever-based micro-rheology relies on sample actuation and the mass of the sample can affect the available range in the frequency response of the sample. Using photothermal excitation, the measurement bandwidth is no longer limited by the sample mass nor by the resonance of the Z-scanner, but by the fundamental resonance of the cantilever. This allows for a much wider range of frequencies to be measured. We have developed a micro-rheology technique that probes the nanomechanical properties of viscoelastic systems over a wide range of frequencies where both the active and passive mechanical response is monitored, enabling time-lapse rheology and spatially resolved rheological mapping [4].

Here, we will show the technical difficulties and concepts implemented to include photothermal excitation in our newly developed DriveAFM. Our AFM features a fully-motorized, tip-scanning design that allows for integration with optical microscopy, flexibility regarding sample size and weight, and the possibility for automated system operation from laser adjustment to sample translation. In addition, we will present measurement data that shows some of the new and interesting measurements made possible by this implementation.

References:

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