Abstract:
We designed and fabricated a novel AFM probe that significantly improves the signal-to-noise ratio and frequency response over current commercial probes. Our probe is a 20 x 30 µm composite (Si/Si₃N₄/SiO₂) torsion lever with an integrated reflective pad and tip. It has been designed for mass production and can be used in conventional atomic force microscopes without specialized optics. The symmetrical structure reduces warping.

In liquids, our probes have significantly less viscous drag and mass coupling than commercial levers. This results in an improved Q factor, smaller frequency shift and lower noise. The noise baseline for our prototype levers is as low as 1pN in a 1kHz band. We believe that this new lever design will have significant impact on liquid AFM imaging and force spectroscopy applications where higher resolution, greater sensitivity and lower noise are critical factors.

The Atomic Force Microscope (AFM):
The AFM was developed as an extension of other scanning probe microscopies [1]. The idea, illustrated in Figure 1, is beautifully simple – a small soft probe can softly touch a surface, and as the sample pushes back, the movement of the probe can be recorded. The probe evolved into a microfabricated cantilever, and the recorder into a focused laser spot, reflected off the back of the cantilever onto a position sensitive photodetector (PSPD). The angular deflection of the cantilever results in a movement of the optical beam on the PSPD. Therefore, shorter cantilevers have higher optical gains.

Liquid AFM, A Sticky Situation:
For cantilevers operated in water, the Reynolds number, which is an estimate of the significance of inertial and viscous forces, is around 1. At this low Reynolds number, the effects of both the inertia and viscous drag need to be considered. As a cantilever is submerged into a sticky environment, such as water (viscosity 1Cp), there are two effects. First, the lever’s dynamic response is retarded by viscous drag, proportional to the probe’s moving area. Second, the mass of the cantilever increases, because of a thin water layer that becomes directly associated with the lever, thus increasing the lever’s apparent mass. Both of these effects can be minimized if the cantilever size is decreased [2]. Small cantilevers have shown an astonishing decrease in baseline noise, because they have small moving areas and higher angular gain.

In our design, a small silicon pad twists on thin and compliant hinges, and is held extended from the silicon die by a beam (Figure 2). The extension beam allows the integration of this lever into a standard AFM setup and provides optical clearance for probe positioning. These support beams are ~5 µm thick and stiff, kbeam ~ 300 N/m. The pad has the same thickness as the support beam, and torsionally oscillates on the silicon nitride hinges. This arrangement of the torsion hinges is significant for two reasons: 1) minimal hinge movement minimizes drag, and 2) no stress or thermal warping. Since liquid AFM allows us to work in a biologically friendly environment, such as saline, and biological samples tend to be soft, we are interested to make the hinges of the torsion levers soft. For torsion, hinge stiffness varies with the cubed of thickness, so hinges must be thin, SiN (~100 nm). At CNF we are able to grow these films reproducibly and defect-free.

As expected, torsion levers show improved performance in fluids. In water, the resonant frequencies for torsion levers are several times higher than the conventionally available cantilevers. This allows lower noise recording in larger band-widths (Figure 3).

References:
Figure 1, top right: The Atomic Force Microscope (AFM). Cantilever deflection is sensed by the optical lever and feedback may be used for closed-loop operation.

Figure 2, below left: Microfabricated torsion lever with an integrated high-aspect tip.

Figure 3, below right: Very soft torsion levers can be used to measure pico-Newton forces.