Highly Compliant Gimbaled AFM Probes

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Atomic Force Microscopy:

The operating principle of the AFM [1] is simple: a soft probe interacts with the sample, and its deflection is measured by reflecting a laser from the back of a microfabricated cantilever onto a 4 segment position sensitive photodetector (PSPD)-an arrangement termed the “optical lever” [2]. The difference between the sum signal of the top and bottom (T-B) segments of the PSPD is directly related to the probe’s displacement in z. Left-right (L-R) signal has been used to monitor the cantilever’s twisting and these measurements are often related to friction [3]. It has been shown that the sensitivity of the AFM probe (cantilever) is the limiting factor in mechanical resolution of the AFM [4]. The cantilever’s disabilities are especially pronounced when the AFM is operated in fluid. As viscosity of the environment around the cantilever increases, viscous drag becomes significant and additional fluid coupling to the cantilever increases mass. Both viscous drag and mass increase decrease sensitivity and dynamic response of the cantilever [5].

Soft Gimbaled AFM Probes:

We have recently developed torsion AFM levers that have minimal moving areas and lower noise. The fabrication process was developed and optimized at CNF; it requires four contact photolithography layers and allows us to produce a highly compliant and ultra-small (20 x 20 µm) torsion probe [6]. These levers allow more sensitive operation in liquid and better thermal stability than commercially available levers. In addition, our fabrication process allows for design flexibility in three dimensions and we have utilized this fact to produce dual-axis gimbaled levers. These levers have two sets of orthogonally-arranged soft SiN hinges onto which we mount a pad and a gimbaled mount (Figure A). These AFM probes will be useful in a wide range of applications, due to the fact that we can uncouple movement in two directions using a single optical lever (Figure B). The entire structure moves in the z direction and shows up as a 26 kHz resonant peak in the B-T signal (Figure B, left). The inner pad rotates on an orthogonal axis and it has a 95 kHz resonant peak on the L-R channel (Figure B, right).

Dual-beam AFM operation has been shown to eliminate instrumental drift and minimized noise to allow pN force resolution [7]. However, this setup requires a dual optical lever, which is currently not available on commercial AFMs. Our dual axis lever accomplishes the same task with a single optical lever. A single laser beam illuminates both axes, but the two axes of the PSPD (B-T, & L-R) now become useful independent data channels. External z-noise sources can be removed by taking the difference of the two signals (after appropriate scaling for differences in optical gain of the two axes). This cancellation will be effective at least up to the lower of the two resonant frequencies. Noise of the laser system can also be suppressed since both axes are illuminated by the same laser.

Presently, we are optimizing such probes as combined friction/topography AFM probes (Figure A), gimbaled AFM probes that will minimize noise by differential cancellation (Figure A), drift-free/noise-free AFM probes that will measure sample position and noise against substrate position/noise (Figures C & D).

The probe’s specific design can be modified according to the desired application. Our process allows a simultaneous production of soft hinges for the measurement levers and production of either soft SiN hinges (Figure C) or stiff Si hinges for the reference hinges (Figure D). Soft reference hinges maximize force sensitivity while stiff hinges allow stable reference contact and maximum noise reduction.

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References:

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Figure A, top: Typical gimbaled AFM lever. Orthogonally-oriented hinges are sensitive in 2-D. This particular lever may be used as a sensitive probe for friction measurements. One can use $\delta(B-T)$ for scanning topology, while simultaneously recording $\delta(L-R)$ as friction at high sensitivity.

Figure B, middle: Resonance peaks for the outer gimbal (left) and inner pad (right) of Figure A. Distinct resonance peaks imply ability to sensitively monitor two movement axes. The typical spring constants for the pad are ~ 0.01 N/m.

Figures C & D, bottom: Alternative geometric configurations and additional tips allow production of AFM referencing levers. These levers will use the referencing tip (on the outer gimbal) to monitor position of the substrate, while the measurement tip (on the pad) will record on the orthogonal data channel.