A Nano-Cheese-Cutter to Measure Interfacial Adhesion of Freestanding Nano-fibers

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Introduction

Freestanding structures such as beams and diaphragms, are indispensable in N/MEMS. Performance and reliability of these micro-devices rely critically upon the adhesion in the presence of water moisture, intrinsic intersurface forces, external electric field etc. In this paper, a novel fixture is designed and fabricated to characterize freestanding nano-fibers for their elastic modulus and adhesion, which can be adapted for other 1-dimensional nano-structures such as carbon nano-tubes.

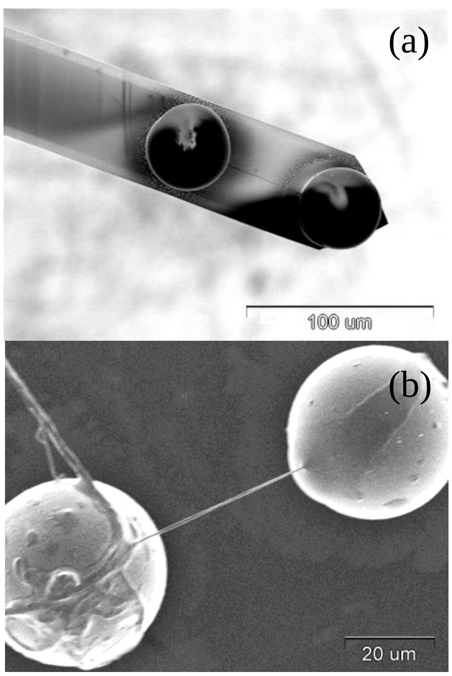

Figure 1. SEM pictures of (a) nano-cheese-cutter on AFM cantilever; (b) fiber on mica substrate.

Experimental

Nylon 6 nano-fibers are made by electrospinning. Using a high resolution micro-manipulator combined with a stereomicroscope, two identical glass microspheres (30-50 μm in diameter) are attached to an AFM cantilever using epoxy with a designated separation (~50-120μm). A freestanding electrospun fiber is picked up with microcapillary needles. The two ends are glued to the spheres to form a freestanding fiber aligned with the cantilever axis (Fig.1a). Another freestanding fiber is similarly made on mica surface (Fig.1b). The cantilever is precisely positioned such that the midpoint of nanofiber on AFM is immediately above that on mica at right angle. Force-displacement, $F(w_0)$, is measured while the nano-cheese-cutter is lowered onto the other fiber (Fig.2).

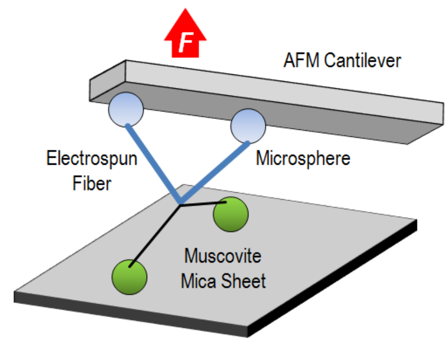

Figure 2. Under an external tension, the two fibers deform into V and inverted-V shape.

Results and Discussion

The length and diameter of fiber are measured by SEM. Figure 3 shows $F(w_0)$ for fiber-fiber interaction. Along AB, the fibers are too far apart to be interacting with each other, as long-range intersurface attraction is negligibly small here. At B, the fibers adhere and both become taut. Further compression along BC stretches the top fiber into an inverted V-shape and the lower fiber into a complementary V-shape. From the measured $F(w_0)$, elastic modulus of the fibers is found to be E = 14.70 ± 0.75GPa. The designated maximum vertical displacement is reached at C. Upon unloading, the cantilever retracts along CD, which does not coincide with BC, presumably due to fiber viscoelasticity. Plastic deformation is ruled out. Along DG, the external load vanishes, indicating fiber sagging. The fibers become taut again at G, and the applied load turns tensile. At H, an instability or "pull-off" occurs, when the fibers spontaneously separate from each other at F^*. The external load then drops to zero at J.

The experiment is repeated for another pair of nano-fibers. Cyclic loading-unloading is performed. Force measurements show reversible adhesion-detachment for the first 5 cycles with roughly the same pull-off forces. Subsequent cycles shows deterioration as reflected in the pull-off force and displacement.

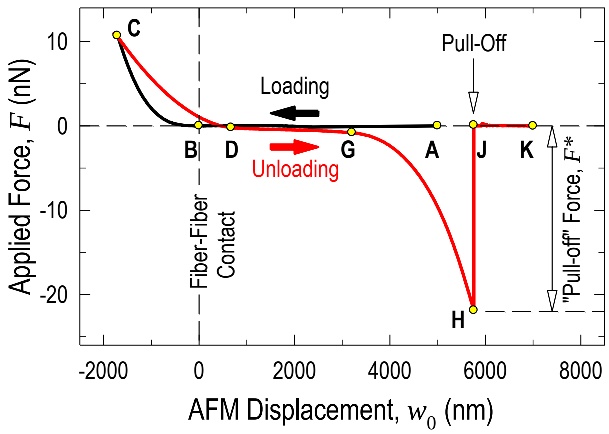

Figure 3. Typical force-displacement measurement showing paths of loading (ABC) and unloading (CDGHJK). Here d_1 = 109 ± 16 nm and l_1 = 91 ± 4.8μm of nano-cheese-cutter on AFM cantilever, and d_2 = 580 ± 20 nm and l_2 = 97 ± 5 μm of freestanding nanofiber on mica.

Conclusions

We have demonstrated for the first time direct adhesion measurement of two freestanding polymer nano-fibers at right angle. The new AFM tip design resembling a nano-cheese-cutter allows many unique features. The commercially available AFM probes and nano-indenters are limited to essentially a point load on sample surface, yet the current configuration makes a line load possible. Other advantages include both elastic modulus and adhesion strength can be measured in a single setup; the fixture is not confined to fibers of the same materials but allows dissimilar fibers of a different geometry, chemical nature, and even coating; and experiments can be conducted in an aqueous environment with desirable ionic strength at a specific temperature. The nano-cheese-cutter is believed to be the sharpest knife known.

Acknowledgements

KTW and XW are supported by the International Research and Education Exploration program of the US National Science Foundation (CMS # 0547094).

References

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