Electronic Supplementary Material (ESI) for Soft Matter

Supplementary Information

Hierarchical Gecko-Inspired Nanohairs with a High Aspect Ratio Induced by Nanoyielding

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Energy dissipation As seen in Figure 4a, pull-off forces were observed to increase with AR from 2 to 5. Elastic dissipation may be responsible for the adhesion increase with fiber length as discussed elsewhere.[1] Assuming the elastic energy by fiber elongation during the pull-off process is fully dissipated and added to adhesion energy, effective work of adhesion (W_{eff}) can be expressed as

$$W_{eff} = W + \frac{\sigma^2 Lf}{2E} \tag{1}$$

where σ is the interfacial strength (typically ~ 10^8 Pa for stiff material),[2] f is the areal density of fibers (=0.227 for SL structures), and W is the work of adhesion and approximated to be $2(\gamma_{silica}\gamma_{ps})^{0.5}$ ~ 0.11 J/m^2. Then, W_{eff} for SL 2 and 5 are calculated to be 0.29 and 0.56 J/m^2 respectively (~2 fold increase). Since the pull-off force (P_c) is linear with the adhesion energy for spherical shape, pull-off forces are expected to be proportional to change in W_{eff}. In Figure 4a, ~1.7 fold-increase in pull-off forces is observed from SL 2 to 5, which is qualitatively coincident with prediction from Equation 1.

Further increasing AR (SL 12) results in smaller pull-off forces than SL 5, even though these nanohairs should have increased amount of energy dissipation. This can be explained by the collapsed structure of SL 12 (Figure 4c), where the contact area is much decreased by the engagement of several nanohairs into bundles that are not as compliant as individual nanohairs.

For elongated hierarchical nanohairs, dissipated energies are calculated to be 1.08 and 0.04 J/m^2 for base and terminal hairs respectively, considering ~ 3 terminal hairs are typically longer than the other hairs on a single base hair, and assuming only these elongated terminal hairs have significant effect on adhesion/friction. This yields W_{eff} of 1.22 J/m^2, ~ 4.2 fold-increase compared to SL 2, which is also similar with experimantal observation, ~ 4 fold-increase in Figure 4a. As calculated above, base hairs have main contribution to the energy dissipation, thus, substantial increase in adhesion through large energy dissipation is achieved only for elongated hierarchical nanohairs with the merit of avoiding fiber collapse, which were not possible for SL 12.

Reference

1 C. Greiner, A. del Campo and E. Arzt, *Langmuir*, 2007, **23**, 3495.

2 A. Jagota and S. J. Bennison, *Integr. Comp. Biol.*, 2002, **42**, 1140.

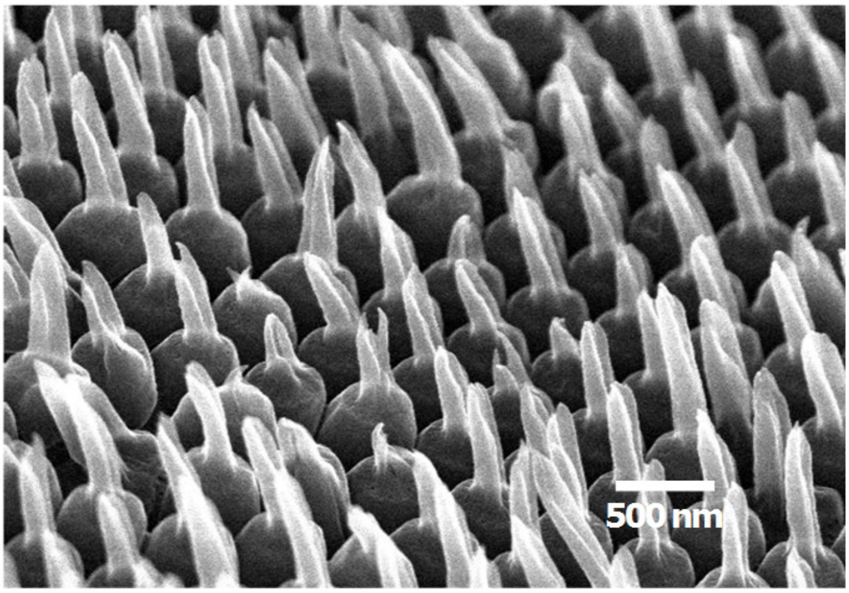

Figure S1. SEM image of PS nanohairs peeled off from an untreated multi-branched AAO template with multi-branching.

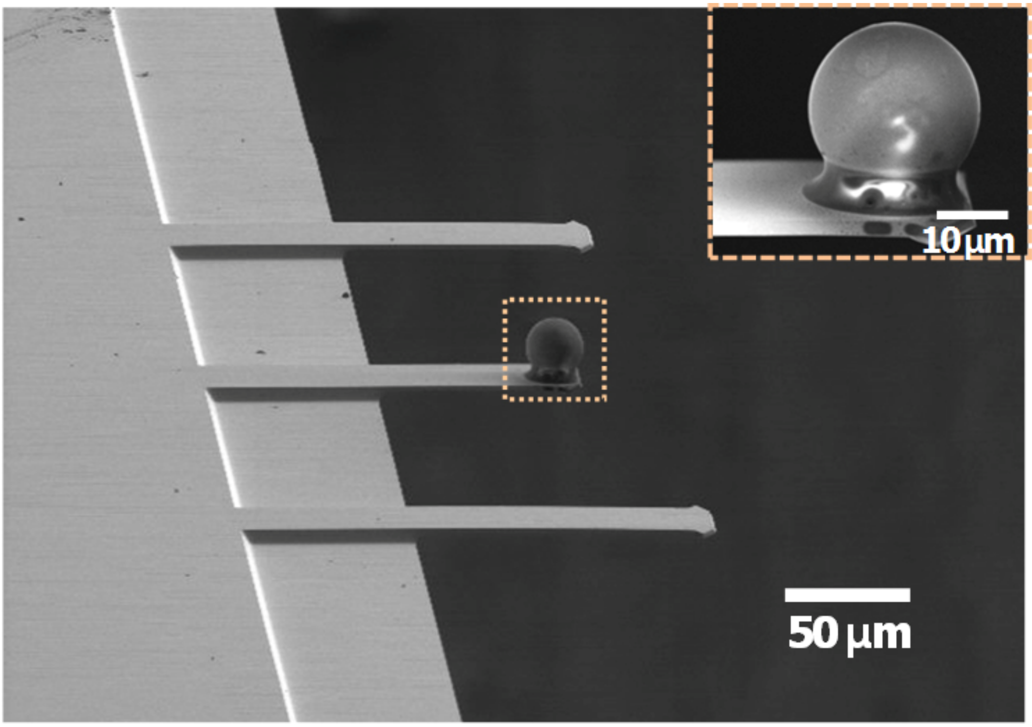

Figure S2. SEM image of the cantilever tip modified with a silica ball (24 µm in diameter).