Ethylene Vinyl Acetate Copolymer-Based High-Adhesion, Low-Cost and Superlyophobic Dry Adhesives

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Gecko's remarkable ability to attach and climb has attracted significant attentions for centuries. However, the nature of its fantastic climb ability ascribed to the intermolecular Van der Waals force is revealed only in recent years [1, 2]. A variety of biomimetic dry adhesives based on various materials have been fabricated via different methods. To achieve high adhesion, vertically aligned carbon nanotube-based dry adhesives have shown superior adhesion strength (~100 N/cm^2) but their fabrication processes are typically expensive and cannot be easily controlled [3]. On contrary, polymer-based dry adhesives can be fabricated in a simple and low-cost, yet their adhesion strength is significantly lower. The best one reported for polymer dry adhesive was less than 40 N/cm^2 in our survey so far [4]. Herein, we propose a new strategy to achieve high-performance dry adhesive with high adhesion, high durability and low-cost based on polymer such as ethylene-vinyl acetate (EVA) and poly(dimethyl siloxane) (PDMS) with mushroom-shaped structures.

Figure 1 shows the EVA-based dry adhesive fabrication process obtained by soft replication. As shown in part I, mushroom-shaped Si template were obtained using deep reactive ion etching (DRIE) after patterning SiO_2 cap on Si. The fabrication complexity and cost of the initial master template can be further reduced by replacing the Si master with the dual-layer resist master, where inverse mushroom-shaped micro-cavities were fabricated in two resist layers, as shown in part II. Part III shows the fabrication of mushroom-shaped EVA dry adhesives by soft replication process. PDMS was dispensed on the as-fabricated master and cured in an oven. Afterward, the vinyl acetate ethylene emulsion was spin-coated on the PDMS mold and cured to form the EVA film. Then the film was grafted in the vapor phase to achieve hydrophobicity. Figure 2 shows typical mushroom-shaped microstructures of Si and dual-layer resist templates by a scanning electron microscope (SEM). The SiO_2 cap of the Si templates were 400 nm thick with undercut varied from 2 μm to 3 μm while the cap thickness of the dual-layer resist templates is 1.5 μm with undercut varied from 500 nm to 5 μm.

A low-force mechanical testing system was used to measure the pull-off forces of EVA and PDMS samples, illustrated in Figure 3. After applying a preload to samples to ensure full contact with the glass slide, we lifted the motorized stage with speed of 0.03 nm/s and the recorded the maximum pull-off force, which indicates the adhesion force of dry adhesive. As shown in Figure 4, the adhesion force for all samples is quite small without applied preload, while the adhesion forces of both patterned and flat dry adhesives significantly increase with applied preload, due to the increment of effective contact area. We noticed that the adhesion forces of EVA patterned samples are 10 times higher than those PDMS counterpart, and its maximum adhesion force reached up to ~ 25.0 N (~ 70.0 N/cm2) with mushroom-shaped microstructure， which is the best record for polymer dry adhesives by far, and can be further increased by optimizing geometric designs. Following our previous work on superlyophobic surfaces [5-7], mushroom-shaped EVA dry adhesives present excellent superlyophobic performances as well, as seen in Figure 5, which is suitable for self-cleaning and durable uses. In addition, their superior flexible, stretchable characteristics and low-cost, facile fabrication process shed new lights for the practical applications.

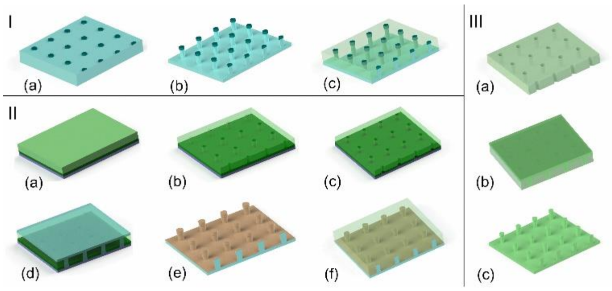

Figure 1: Fabrication process of polymer dry adhesives

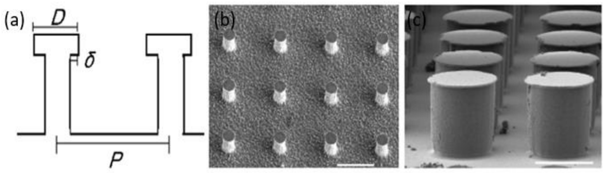

Figure 2: SEM images of mushroom-shaped master templates (a) Micro-structure parameters (b) Si template (3) Resist Template

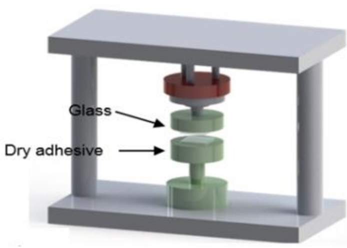

Figure 3: Schematic of pull-off force measurement

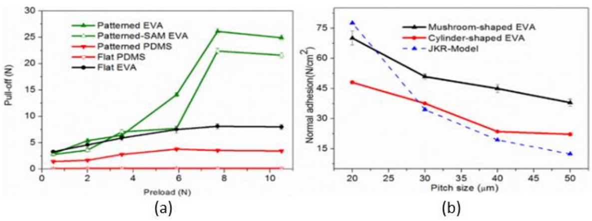

Figure 4: (a) Pull-off force comparison of patterned and flat samples under different preloads. $D = 10\ \mu m$, $\rho = 40\ \mu m$, $\delta = 3 \mu m$. (b) Comparison of the normalized adhesion forces for patterned dry adhesives with and without undercuts. $D = 10\ \mu m$, $\rho = 20\ \mu m$, $\delta = 3\mu m$, preload = 8.0 N.

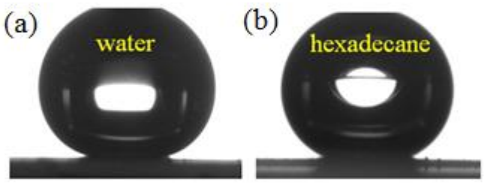

Figure 5: Excellent superlyophobic performance of the as-prepared EVA film

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