Hierarchical and Re-entrant Micro/Nano-structures for Superhydrophobic Surfaces with Extremely Low Hysteresis

Vikhram V. Swaminathan, Huan Hu, Mahmoud Reza Zamani Farahani, Glennys Mensing, Junghoon Yeom, Mark A. Shannon, Likun Zhu

We report a low-cost, scalable way of fabricating hierarchical micro/nano structures with re-entrant shapes for superhydrophobic surfaces with extremely low hysteresis. Superhydrophobic surfaces have numerous applications in self-cleaning [1, 2], anti-fouling [3], anti-freezing [4] and heat transfer enhancement [5]. Surface nanofeatures reduce the actual contact area between a solid surface and liquid droplet—thus contact angle increases and sliding angle decreases [6]. In contrast to most hierarchical geometries with simple micropillar structures that do not prevent water from falling into gaps, re-entrant structures minimize the droplet contact area by repelling water from contacting the micropillar sidewalls [7]. We combined the hierarchical micro/nanostructuring with re-entrant profiles for the micropillars (Fig. 1a-d) to draw advantage of both effects. Re-entrant microstructures were produced using conventional silicon microfabrication, and silicon nanopillars (SiNPs) were patterned over these microstructures by metal-assisted-chemical etching (MACEtch) [8]. We have developed a unique method of treating rough sidewall profiles resulting from a DRIE process that enables complete coverage of SiNPs on patterned microstructures. Our results (figure 1e) indicate that tuning the re-entrant geometry (area fraction) drives hydrophobicity, which is further strengthened by the SiNPs that prevent hysteresis by reducing the sliding angle well below the 2° criterion for superhydrophobicity. We have demonstrated water contact angle of 170° and minimum hysteresis with a sliding angle as low as 0.5°.

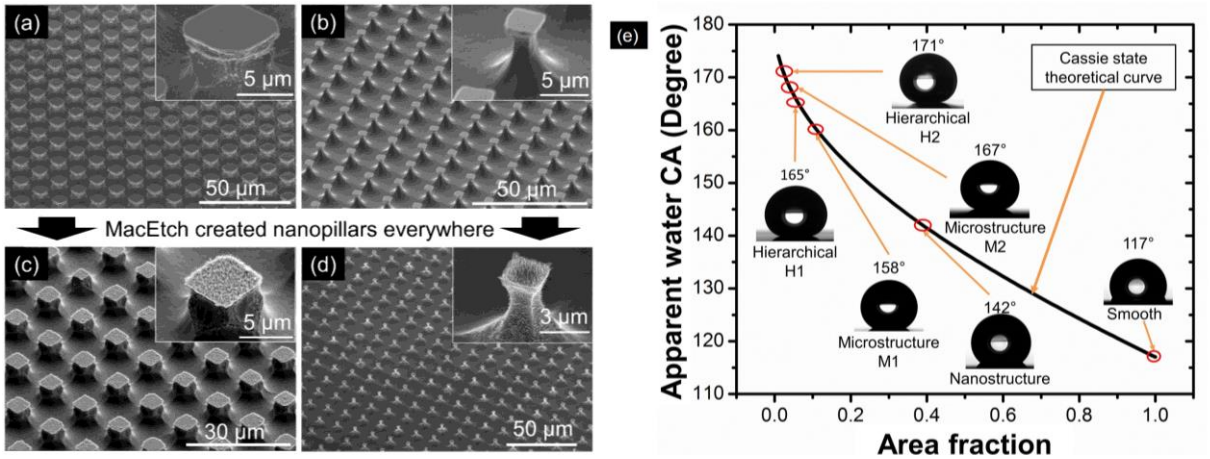

Figure 1. SEM images of (a & b) microfabricated re-entrant microstructures and (c & d) corresponding hierarchical micro/nano structures created by MACEtch. (e) Apparent water contact angle meaurements from wetting studies

References

[1] Furstner, R., *et al.* Wetting and self-cleaning properties of artificial superhydrophobic surfaces. *Langmuir*, **2005**, *21*, 956-961.
[2] Blossey, R. Self-cleaning surfaces—virtual realities. *Nat. Mater.*, **2003**, *2*, 301-306.
[3] Scardino, J., *et al.* The role of nano-roughness in antifouling. *Biofouling*, **2009**, *25*, 757-767.
[4] Mishchenko, *et al.* Design of Ice-free Nanostructured Surfaces Based on Repulsion of Impacting Water Droplets. *ACS Nano*, **2010**, *4*, 7699-7707.
[5] Miljkovic, N., *et al.* Jumping-Droplet-Enhanced Condensation on Scalable Superhydrophobic Nanostructured Surfaces. *Nano Lett.*, **2013**, *13*, 179-187.
[6] Lee, *et al.* Maximizing the Giant Liquid Slip on Superhydrophobic Microstructures by Nanostructuring Their Sidewalls. *Langmuir*, **2009**, *25*, 12812-12818.
[7] Tuteja, *et al.* Designing Superoleophobic Surfaces. *Science*, **2007**, *318*, 1618-1622.
[8] Z. Huang, *et al.* Metal-Assisted Chemical Etching of Silicon: A Review. *Adv. Mater.*, **2011**, *23*, 285-308.