Supporting Information for

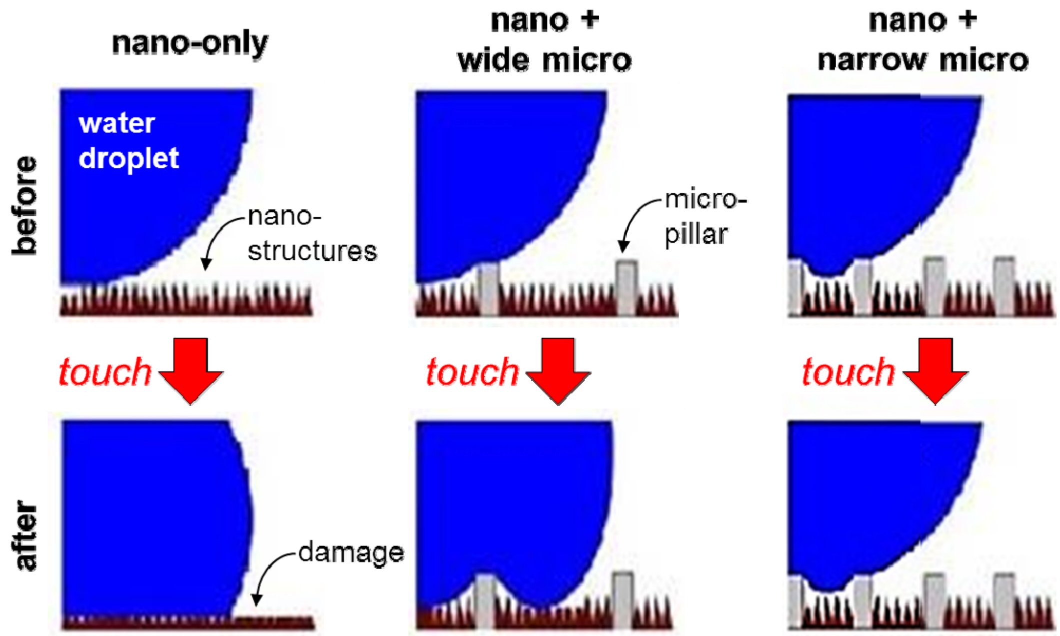
Microbumpers maintain superhydrophobicity of nanostructured surfaces upon touch

By

I. D. Jung, M. C. Lee, H. Lim, E. Smela, J S Ko

1 Concept for Maintenance of Superhydrophobicity

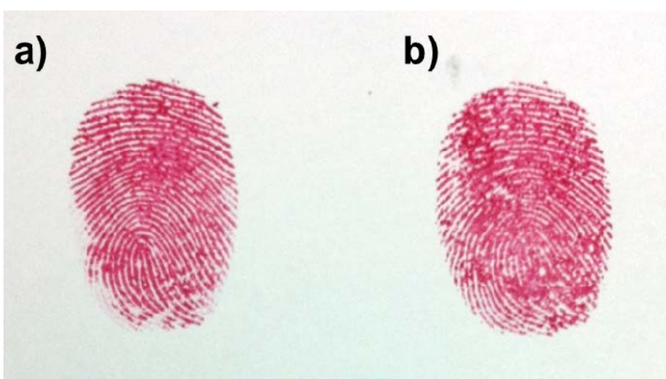
SI Fig. 1 shows the concept for maintaining the superhydrophobic nature of a nanostructured surface upon touch using microbumpers. If there are only nanostructures on the surface (SI Fig. 1, left), they can be easily damaged upon touch, causing a loss of superhydrophobicity. However, if there are microbumpers on the surface with a proper pitch (right), they can protect the nanostructures upon touch, so superhydrophobicity is maintained. If the pitch of the microbumpers is too great (center), they cannot protect the nanostructures sufficiently.



SI Fig. 1. Cartoon representations of droplet wetting before (upper row) and after (lower row) touching (not shown) of the surface. (left) No microbumpers and loss of superhydrophobicity due to serious damage to the nanostructures upon touch. (center) Larger pitch, on which the contact angle is lowered due to slight damage upon touch. (right) Small micro-pillar pitch, which maintains surface superhydrophobicity by protecting the nanostructures from mechanical damage during touch.

2 Prints from Human and Model Fingers

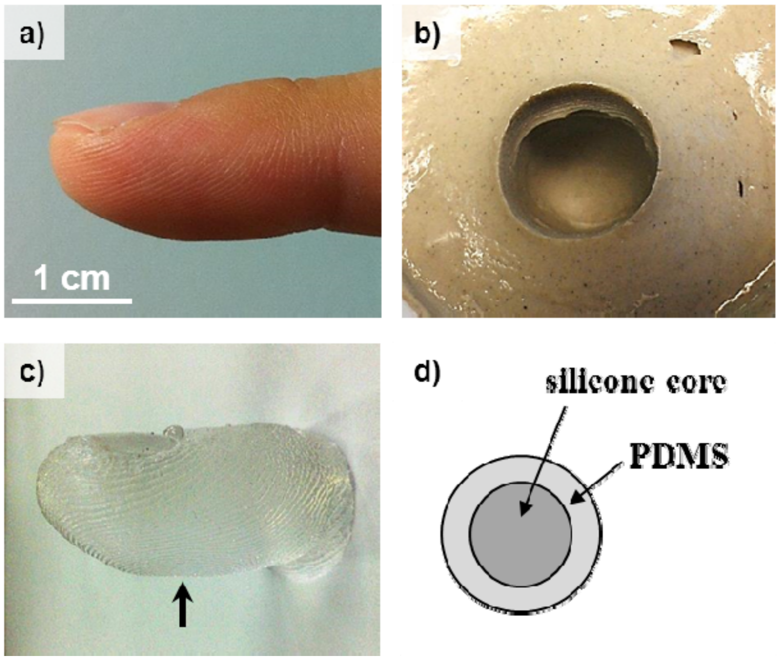
SI Fig. 2 shows fingerprints produced by inking and stamping the human finger and the model finger. Both prints were made at 100 gf. (See section 2.1 of the main text for a description of the procedure.)



SI Fig. 2. Fingerprints produced at 100 gf by (a) a human finger and (b) the finger model.

3 Fabrication of the Finger Replica

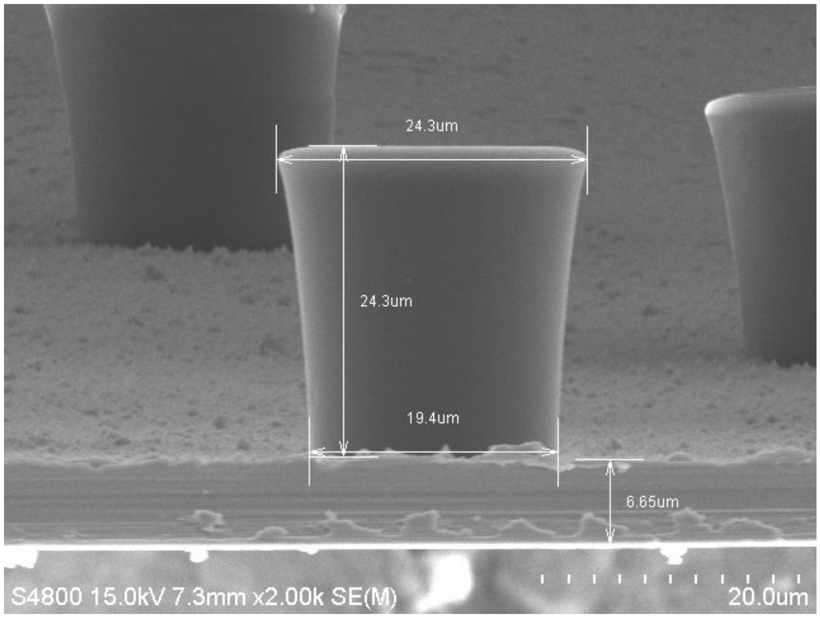
SI Fig. 3 illustrates the stages of the fabrication process for producing the finger replica as described in section 2.1.



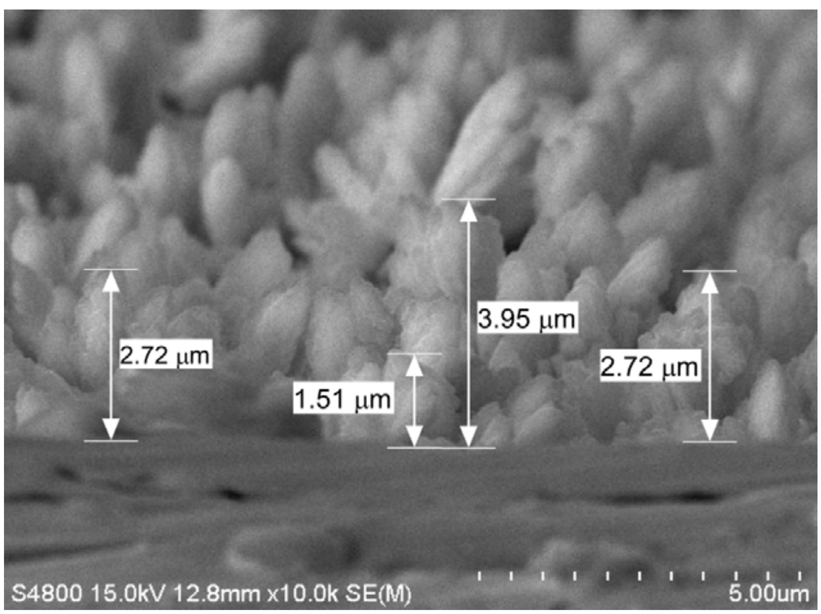
SI Fig. 3. Fabrication of the finger replica. (a) Side view of the human finger that served as the master for the replica. (b) The cast that was formed by alginate that served as the mold for casting the finger replica. (c) Side view of the finger replica. The arrow indicates the part of the finger that touched the samples. (d) A schematic cross-sectional view of the finger replica.

4 Size of the Microbumpers and Nanostructures

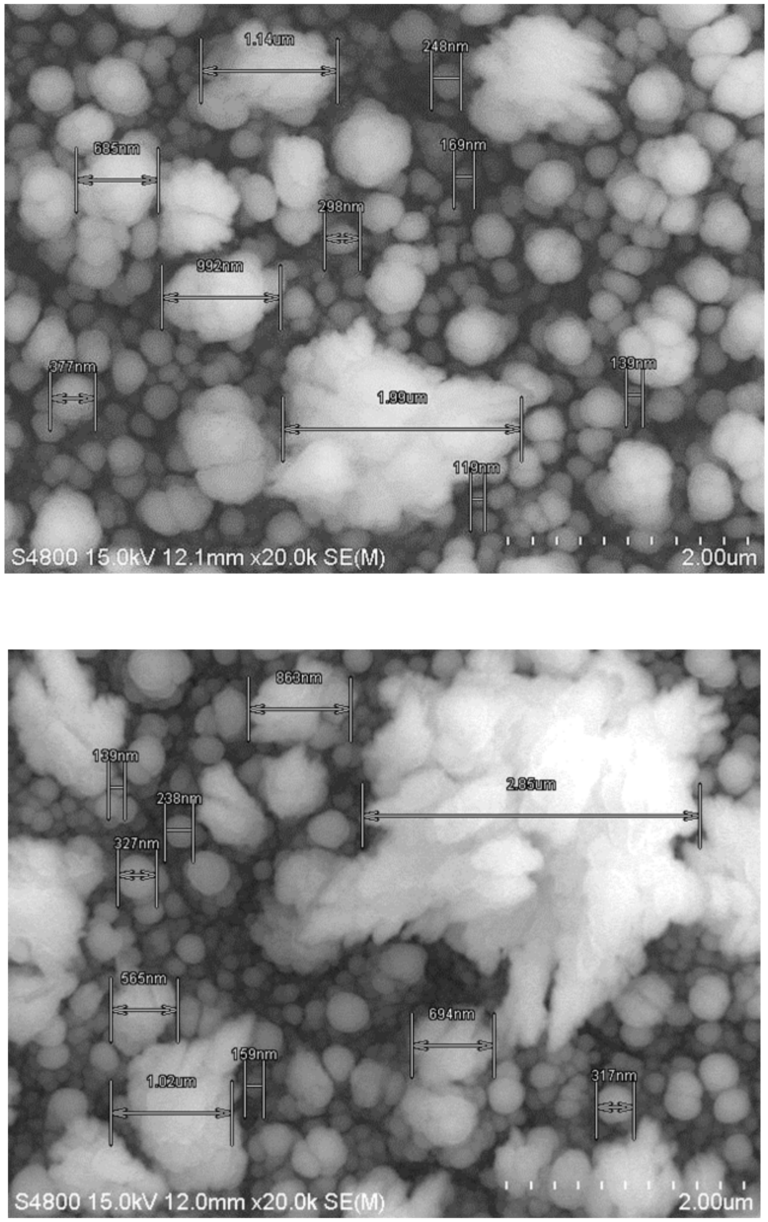
SI Fig. 6 shows a close-up SEM image of a microbumper. Its height is 24.3µm; the diameter at the top is 24.3 µm, and the diameter at the bottom is 19.4 µm. The thickness of the nickel layer is 6.65 µm. SI Fig. 6 shows an SEM of the nanostructures, which are up to several micrometers high.



SI Fig. 4. SEM image of a microbumper with dimensions. The pillars are slightly wider at the top than at the base.



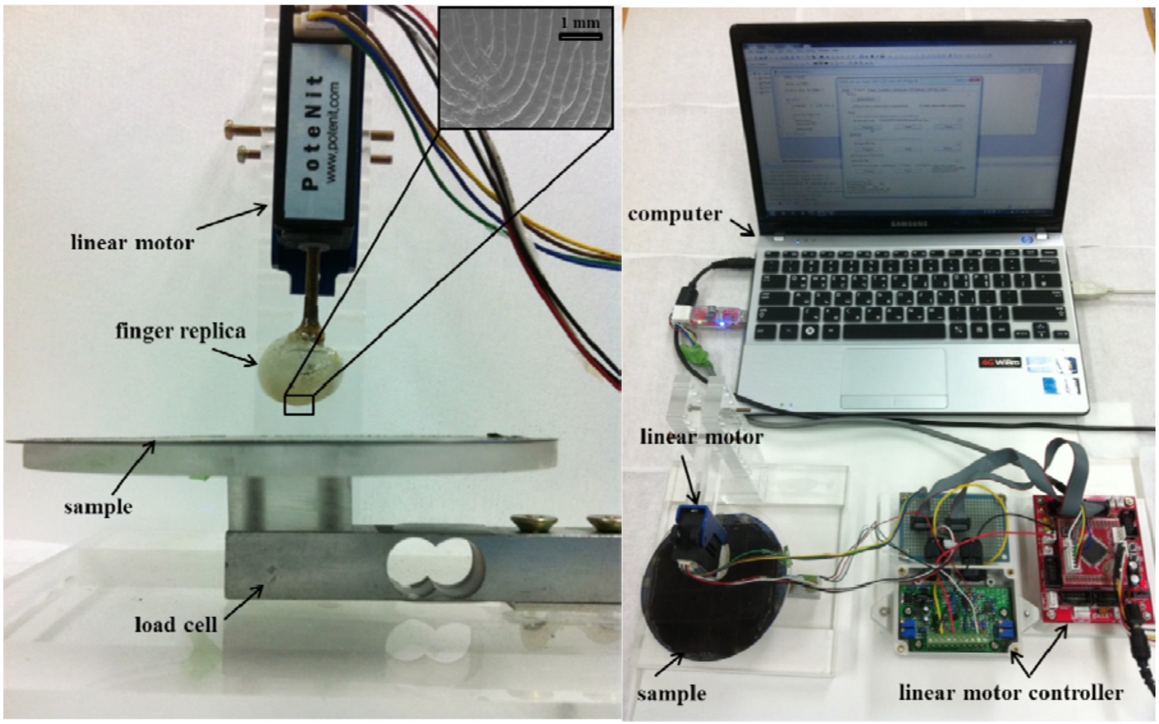
SI Fig. 5. Side-view SEM image of the nanostructures, with dimensions.



SI Fig. 6. Overhead SEM images of the nanostructures on two areas, with dimensions.

5 Touch Test System

Photographs of the touch test system, described in section 2.2, are shown in SI Fig. 7.

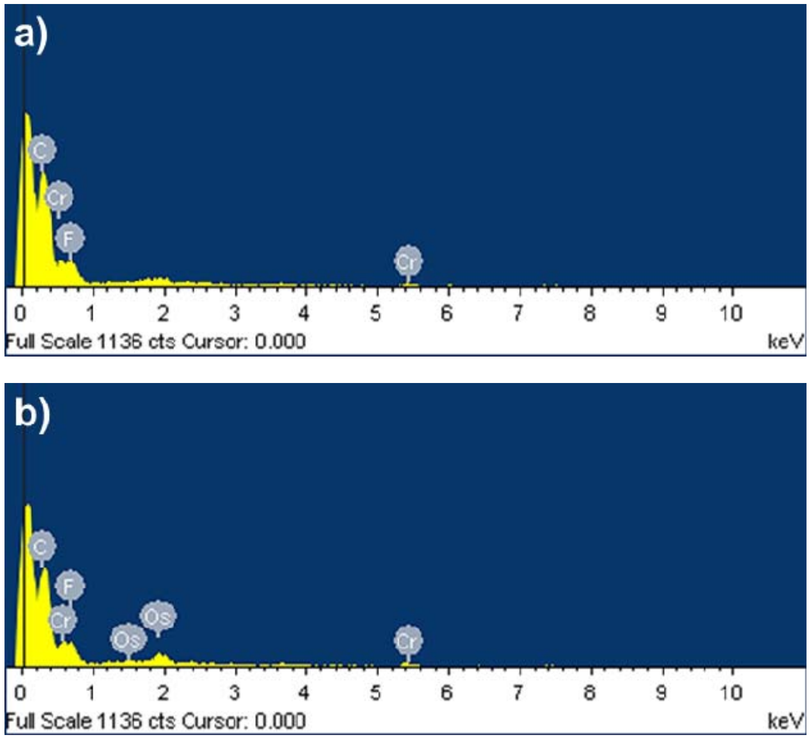


SI Fig. 7. Touch test system in side and overhead views.

6 Elemental Analysis: Effect of Touch

The contact angle was shown to be sensitive to changes in the surface, brought about by touch, that were apparently not structural. Elemental analysis was therefore performed to determine whether there had been a chemical change, such as a deposition of a PDMS residue or partial removal of the PPFC coating. An area scan was conducted on two samples having100 μm pitch, one without touch testing and one after 100 cycles at 100 gf.

As shown in SI Fig. 8, the element fluorine (F) in the PPFC coating was detected on both samples in essentially equal amounts, 13.73% before and 13.26% after touch testing. These numbers are averages over a 10 ×10 μm2 area on the top surface of a microbumper. This result indicates that the PPFC was not removed over large areas. (If the PPFC had been removed, the amount of fluorine would have been reduced.) In addition, C and Cr were detected, and their amounts were also the same. Finally, the Os coating was seen on both samples (although it is only labeled in (b).)



SI Fig. 8. Elemental analysis on the top of a microbumper in the touched region of a 120 μm pitch sample (a) before touch and (b) after 100 cycles touch at 100 gf.

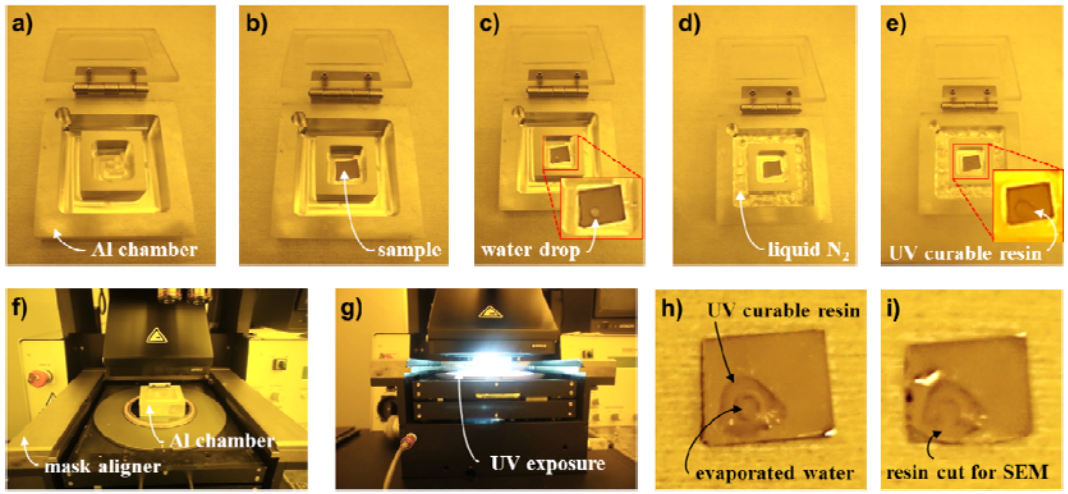
7 Measured Touch Force

We measured the force applied by people pretending to touch a cell phone to establish a standard touch force for this paper (section 4.1). Ten men and 10 women (graduate students and staff at Pusan National University) each touched the table of the touch test system, which measured the forces. They were asked to treat the system as if it were a cell phone. The results are shown in SI Table 1.

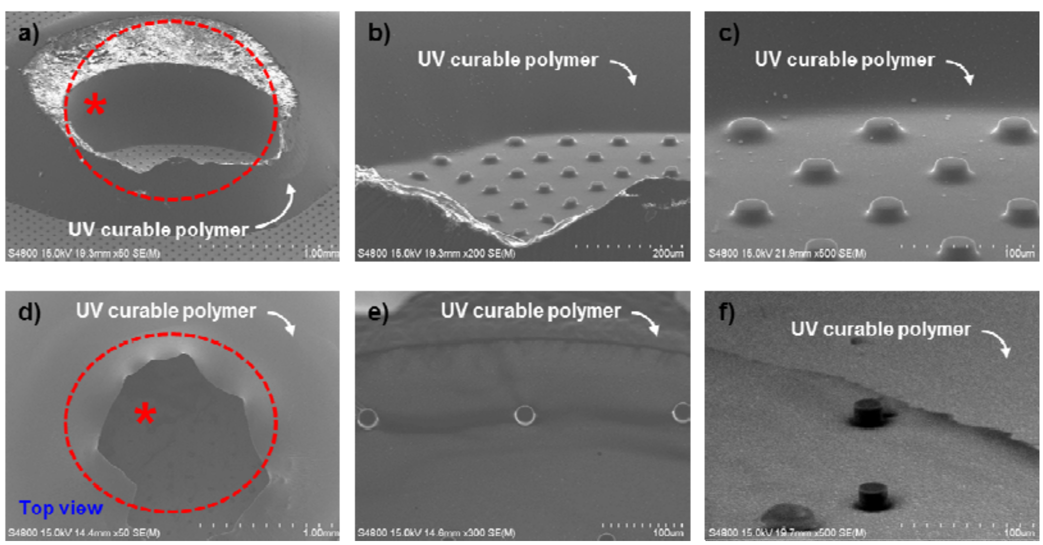
SI Table 1. Average force exerted upon a force table "cell phone" upon touching with one index finger for 10 men and 10 women.

Subject	Touch Force, Male (gf)	Touch Force, Female (gf)
1	96±11	90±8
2	98±9	90±10
3	101±3	85±9
4	126±10	98±12
5	119±14	85±11
6	98±10	90±8
7	134±5	94±8
8	108±9	79±9
9	101±11	88±9
10	119±7	93±7
Average	**110**	**89.2**

8 Freeze-Fixing, Resin-Embedding (FFRE) Procedure and Results



SI Fig. 9. FFRE procedure, explained in the text.

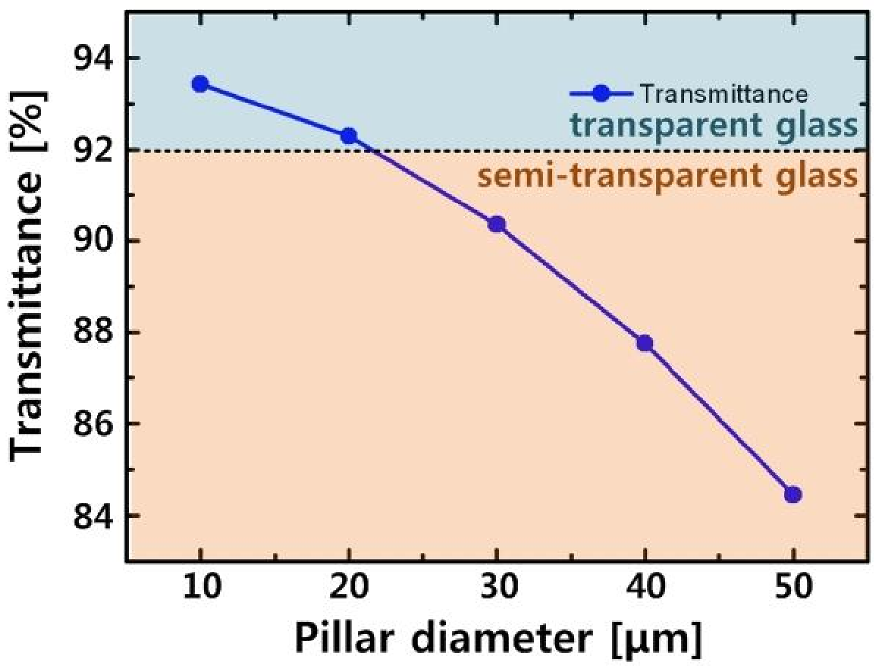


SI Fig. 10. FFRE results for nano-micro-structured surfaces with pitches of 120 µm (a, b, c) and 160 µm (d, e, f). *The space where the frozen droplet was placed (red circle).

The FFRE procedure is shown in SI Fig. 9. (a-b) A sample was loaded into an Al chamber with a transparent acrylic lid. (c) A water droplet was placed onto the sample surface using a syringe. (d) Liquid nitrogen (LN2) was poured into the surrounding well, avoiding getting any LN2 into the sample chamber. The lid was then closed, and the water droplet froze solid in approximately 1 minute. (e) UV curable resin was applied to the surface, close to the frozen water drop. (f-g) A mask aligner was used to expose the resin on the sample, through the transparent lid. (h) The LN2 was removed and the water drop allowed to evaporate. (i) One edge of the resin was removed using razor to allow cross-sectional SEM imaging. SI Fig. 10. shows SEM images of resin in boundary of the wafer drop was placed.

9 Microbumper Transparency

SI Fig. 11 shows transmittance as a function of micro-pillar size1. The substrate was quartz and the micro-pillars were formed from the negative photoresist THB-151N (JSR Micro Inc., USA). The pitch and height of the pillars were 100 and 15μm, respectively. For pillar diameters smaller than 20 μm, the transmittance is greater than 92%.



SI Fig. 11. Visible light transmittance as a function of micro-pillar diameter [1].

References

[1] J.H. Song, Micro bumpers for nano structure protection M.S. Thesis, Pusan National University (2013)