Oriented Bouncing of Droplets with A Small Weber Number on Inclined One-dimensional Nanoforests

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SEM images of NFA with inclined angles of 30°, 45° and 50° are shown in Figure S1. Titled NFAs treated with 35 minutes of oxygen plasma and 50 minutes of argon plasma are shown in (a), (c) and (e), and those treated with additional 30 minutes of argon plasma are shown in (b), (d) and (f). Apparently, inclined NFAs treated with longer argon plasma have greater diameter, spacing and smaller height.

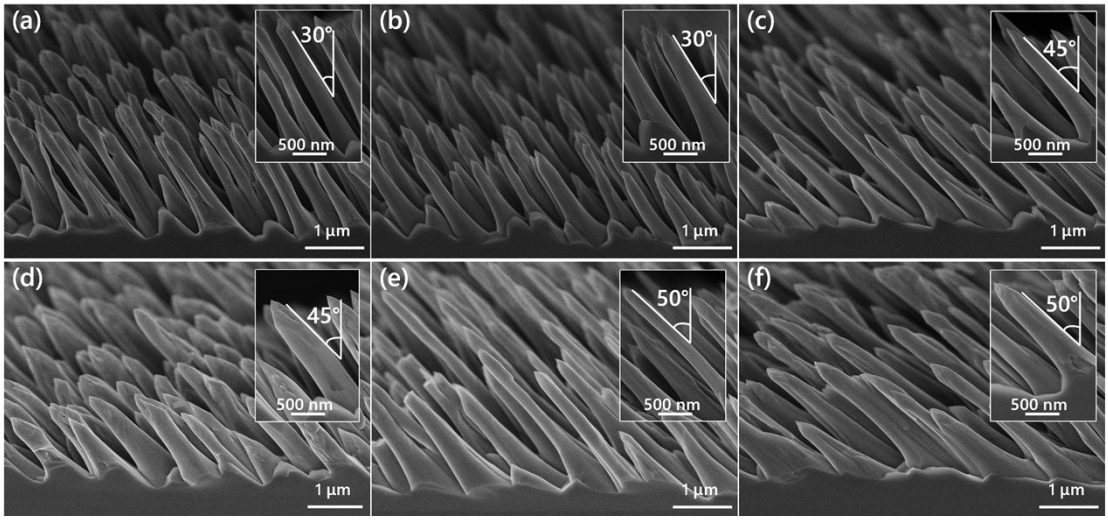

Figure S1 Inclined NFAs with different angles and different plasma treatment durations.

Chemical bonds related to carbon have been analyzed and shown in the XPS results in Figure S2. C-C and C-H bonds occupy the entire carbon content in NFO, and small account of C-O bonds appear in NFAs. This phenomenon demonstrates the grafting ability of the argon plasma.

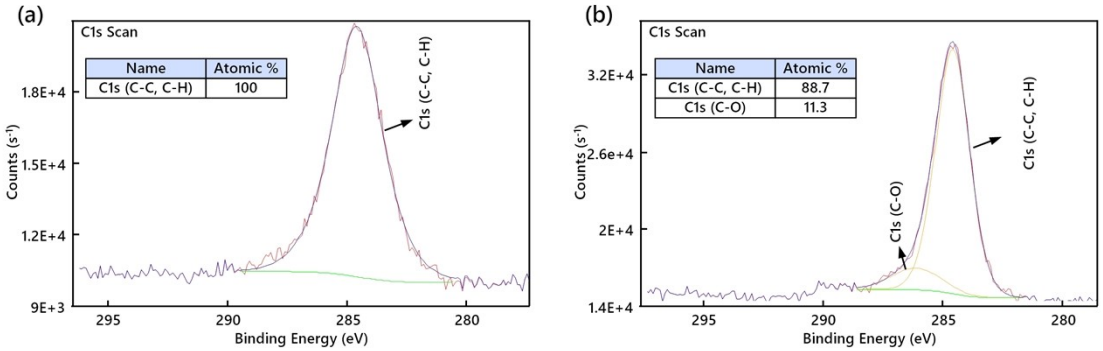

Figure S2 Composition and content of chemical bonds related to carbon on surface of (a) the NFOs and (b) the NFAs.

Contact angle of a droplet on the surface of NFOs decorated with FAS-17 molecules is shown in Figure S3. The contact angle is around 153°, demonstrating the superhydrophobicity of the NFOs after reducing the surface energy by using FAS-17.

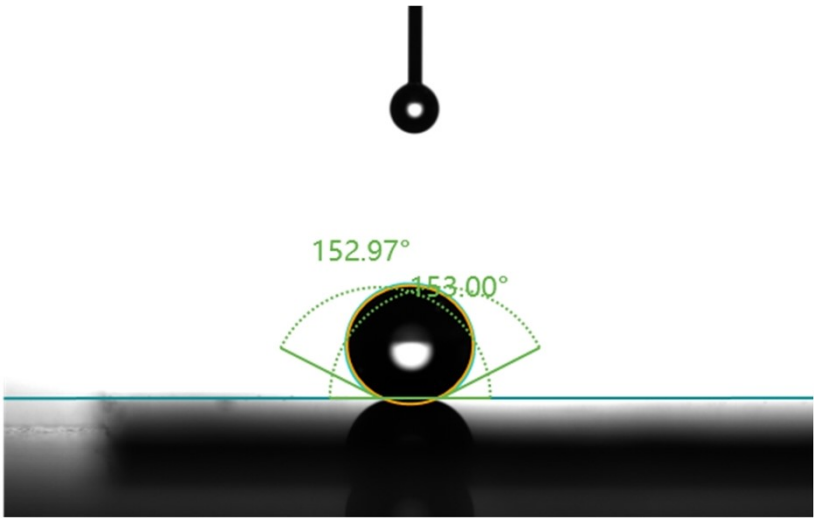

Figure S3 Contact angle of a droplet on surface of the NFOs.

Table S1 Structural parameters and bouncing distances of samples A1, A2, B1, B2, C1 and C2.

Sample	A1	A2	B1	B2	C1	C2
Diameter	230 nm	300 nm	230 nm	400 nm	250 nm	400 nm
Angle	30°	30°	45°	45°	50°	50°
Compression1	0 μm	0 μm	0 μm	0 μm	0 μm	0 μm
Compression2	190 μm	210 μm	210 μm	270 μm	250 μm	320 μm
Compression3	390 μm	430 μm	430 μm	570 μm	470 μm	560 μm
Compression4	600 μm	710 μm	730 μm	920 μm	800 μm	880 μm

Tables S2 Parameters of samples A1s, B1s, and B2s used in the simulation.

Sample	A1s	B1s	B2s
Diameter	250 nm	250 nm	400 nm
Angle	30°	45°	45°
Length	2 μm	2 μm	2 μm
Distance	500 nm	500 nm	500 nm

L/*R* ratio and horizontal velocity of droplets are used to characterize the differences of droplet morphologies between A1s, B1s, and B2s in simulation. *L*/*R* ratio when the droplet reaches its maximum spreading increases with the increments of tilt angles and diameters, as shown in Figure S4 (a). The *L*/*R* ratios are 1.09, 1.16, and 1.21 for A1s, B1s, and B2s, respectively. Similarly, as the tilt angles and diameters increase, horizontal velocity increases when the droplet bounces off the surface and floats in the air, as shown in Figure S4 (b). The horizontal velocities are 3.26, 5.02, and 6.55 cm/s for A1s, B1s, and B2s, respectively.

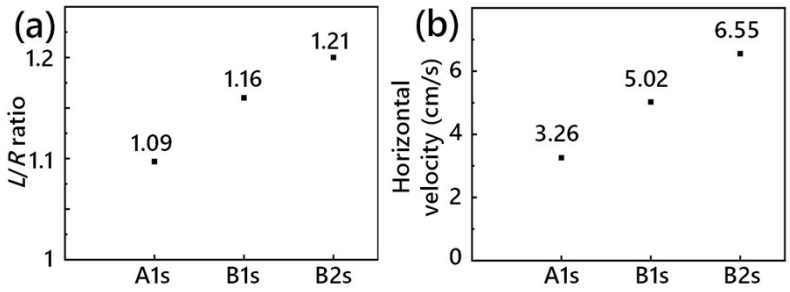

Figure S4 *L*/*R* ratios and horizontal velocities of A1s, B1s, and B2s.

Simulation

Coupled Level Set and VOF approaches are used to simulate the bouncing process of a droplet impact on a nanoforest structure. The VOF methodology is controlled by defining a volume function F, then denoting the volume share within each computational grid cell by F, whose governing equations are:

$$\frac{\partial F}{\partial t} + \nabla \cdot (UF) = 0$$

where U is the velocity vector. By defining ϕ, the Level Set method employs the idea of segmented linear interface reconstruction and moves the interface in the normal direction to make the area ratio of the unit liquid region match the value of the F. The vertical distance from the center of the unit to the phase interface is obtained by iteratively solving for the cut line. The governing equation for ϕ is:

$$\frac{\partial \phi}{\partial t} + \nabla \cdot (U\Phi) = 0$$

the interface normal vector n is calculated as:

$$n = \frac{\nabla \phi}{|\nabla \phi|}$$

the interface curvature κ is calculated as:

$$\kappa = \nabla \cdot \frac{\nabla \phi}{|\nabla \phi|}$$

the continuity and momentum equations for two-phase flow are:

$$\nabla \cdot U = 0,$$

$$\rho(\phi)(\frac{\partial U}{\partial t} + U \cdot \nabla U) = -\nabla p - F_s + \nabla \cdot \mu(\phi)[\nabla U + (\nabla U)^T]$$

where ρ is the density, p is the pressure, μ is the viscosity, and F_s is the source term,

respectively.

The continuum surface force (CSF) model is used to solve the surface tension:

$F_s = \sigma\kappa\nabla H(\phi)$

where σ is the surface tension coefficient and $H(\phi)$ is the Heaviside function with the expression:

$$H(\phi) = \begin{cases} 0, & \phi \le h \\ 0.5 + \frac{\phi}{3h} + \frac{1}{2\pi}\sin(\frac{2\pi\phi}{3h}), & |\phi| \ge h \\ 1, & \phi \ge + h \end{cases}$$

where h is the grid size. The ρ and μ for different regions can be calculated by the Heaviside function:

$$\rho(\phi) = \rho_l[1 - H(\phi)] + \rho_g H(\phi)$$

$$\mu(\phi) = \mu_l[1 - H(\phi)] + \mu_g H(\phi)$$

where the subscripts g and l denote the gas and liquid phases, respectively.

Wall adhesion is also considered in the model and the wettability of the wall is defined by setting the contact angle (CA) of the contacting wall. The CA is defined to be θ, which is used to adjust the normal vector of the cell surface in the vicinity of the wall when the droplet is spreading on the solid surface.

The governing equations are discretized using the finite volume method. The pressure-velocity coupling is done by the Coupled method. The pressure solution is done by the PRESTO! method. The Level Set equation and convective terms are solved by the QUICK algorithm. The diffusion terms are interpolated by the cell-based least-squares method. the discretization of the energy equations is done in the second-order windward format.

During the simulation, the density and viscosity of water are set at 998.2 kg/m^3 and 0.001003 kg/(m·s), respectively. The surface tension is set at 0.073 N/m and the contact angle of the surface is 153°. The initial velocity of the droplet is set at 0.4427 m/s.