Electronic Supplementary Material (ESI) for Nanoscale.

Supplementary Information

Scalable Alignment and Transfer of Nanowires in a Spinning Langmuir Film

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S1 - Removal of surfactant

In order to study the surfactant removal with 95°C baking, we have measured the surface roughness of silicon substrates with Atomic Force Microscope. In Fig. S1, (a) is from the surface of a clean silicon substrate, (b) is from the silicon contaminated with the surfactant, and (c) is from the contaminated silicon baked at 95°C for 15 min. The surfactant formed some microstructures on the silicon in Fig. S1(b), which disappeared in Fig. S1(c) after the baking. For each kind of sample, we have scanned 5 different points, and the average surface roughness (R_a) is 402 pm, 930 pm, and 403 pm, respectively, indicating that the 95°C baking had restored the original surface of the silicon substrate.

The surface scan shows that at least most part of the surfactant could be removed by the baking. However, it is possible that on the surface of silicon substrates or the nanostructures, there are surfactant molecules covalently to the surface. Those bonds may be stronger than the hydrogen bonds among surfactant molecules, and therefore could not be broken under the 95°C baking. In that case, short exposure to the oxygen plasma is recommended to clean the surface.

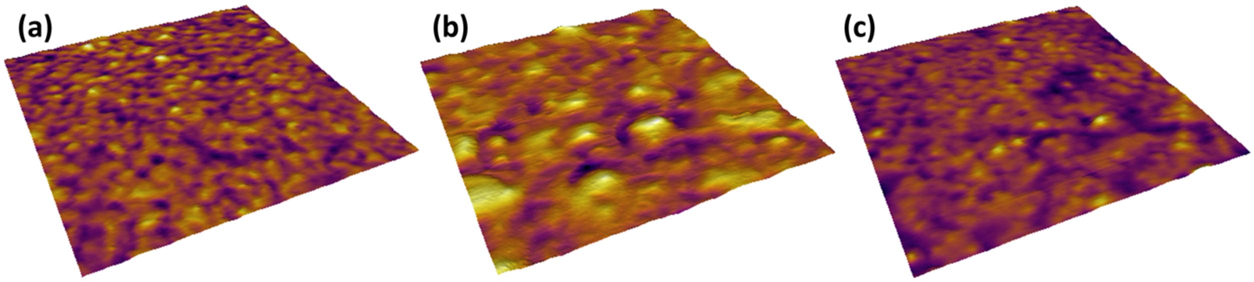

Fig. S1. Atomic Force Microscope images of the silicon surface. (a) The surface of a clean silicon substrate. (b) The surface of a silicon substrate contaminated with the surfactant. (c) The surface of a contaminated silicon substrate that was baked at 95°C for 15 min. The scan area is a 500 nm by 500 nm square.

S2 - Alignment distribution on the water surface

In a typical nanowire alignment experiment, the PTFE rod is concentric with the PTFE funnel and the width of the water surface for nanowire alignment is 10 mm. The rectangular silicon substrate (8 mm by 10 mm) is brought to the water surface such that its long edge is tangent to the circular water edge. The schematic diagram is shown in Fig. S2(a).

To characterize the alignment distribution on the water surface, we collected three samples at different locations. On the silicon substrate, the transferred nanotubes form three zones. The area close to the PTFE rod and the area close to the PTFE funnel have sparse or no nanotubes, while the middle area of the substrate contains aligned nanotubes along the shear direction with the best uniformity.

Fig. S2(b)-(g) show the alignment at three different points (Pt1, Pt2, and Pt3) on one substrate. The nanotubes are aligned in the tangential direction along the ring. Fig. S2(d) and (f) also show how the nanotubes become sparse near the PTFE rod. The other two silicon substrates have a similar distribution of nanotubes. Therefore, except for the area close to the PTFE rod and the

PTFE funnel where there are little nanotubes, the nanotubes are aligned along the shear direction over the entire water surface.

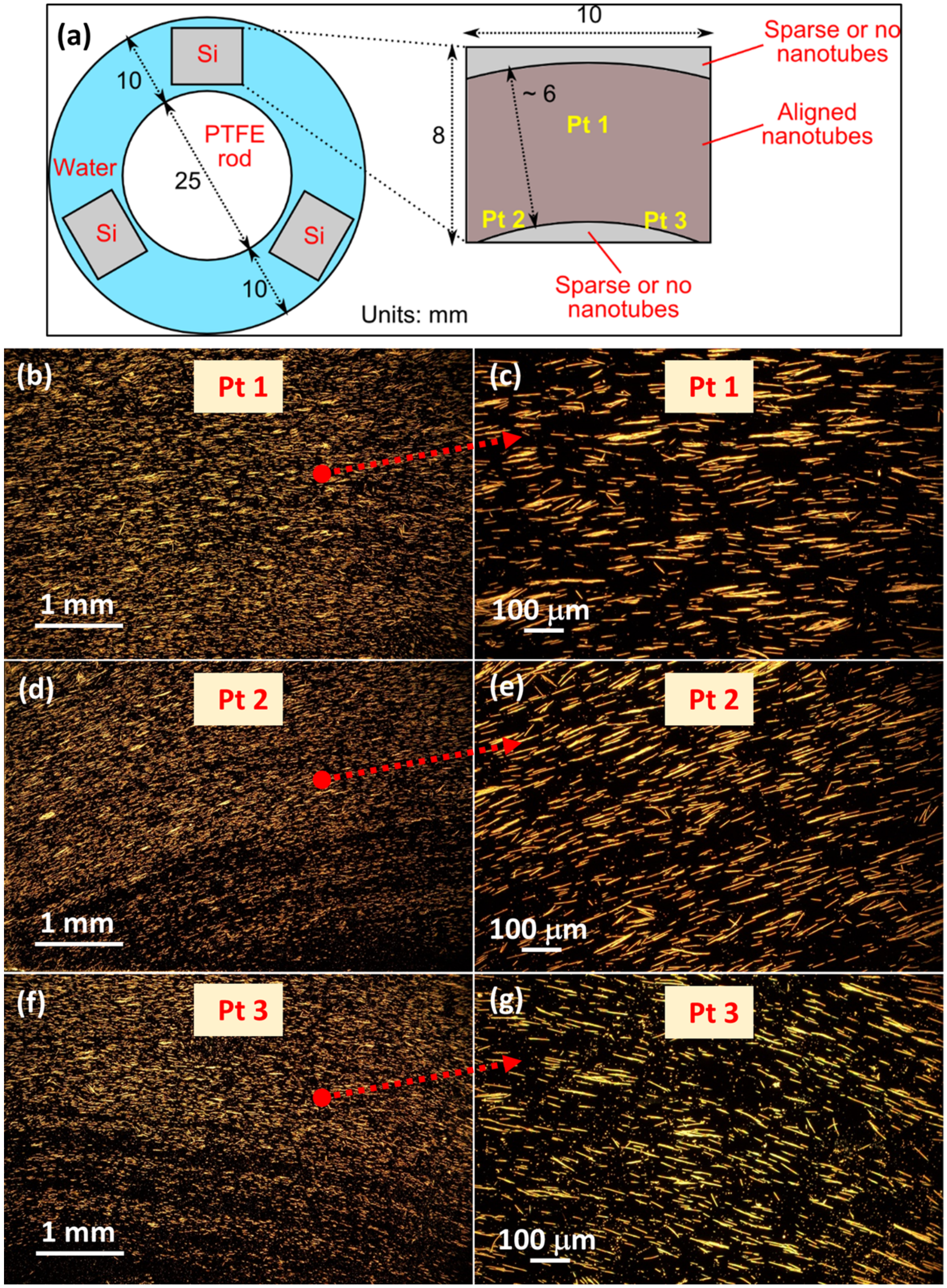

Fig. S2. The alignment of nanotubes on the water surface. (a) Schematic drawing showing the water surface and the receiving silicon substrates. The optical images of the aligned nanotubes at points Pt1, Pt2, and Pt3 are provided at lower magnifications in (b), (d), and (f), and higher magnifications in (c), (e), and (g), respectively. Note that (e) and (g) are from the dense area in (d) and (f).

S3 - Two methods for density control

The areal density of aligned nanowires can be controlled by either changing the water surface area, or adding different amounts of nanowires onto a fixed water surface area. Two methods are proven to be equivalent for arrays with relatively low or medium density, and both methods can provide uniformly aligned nanowire arrays. When very dense nanowire arrays are desired, surface compression through draining water is the preferred method, because water compression reduces the probability of nanowire overlap. Fig. S3 compared the two methods for dense nanotube arrays, and the dense array from water surface compression has much fewer overlapped nanotubes.

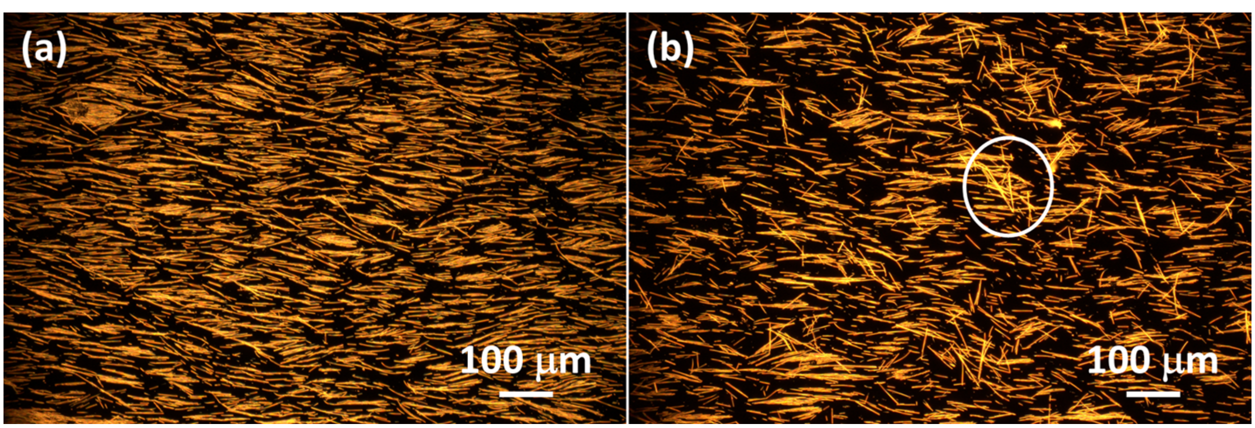

Fig. S3. Relatively high-density arrays obtained by two different methods. (a) Dense nanotube array compressed from a larger water surface area A_1 to a smaller area A_2 (A_1/A_2=1.7). (b) Dense nanotube array obtained by adding the same amount of nanotubes directly onto the smaller area A_2; the circle indicates a typical area with overlapped nanotubes.

S4 - Effect of spinning time

With the PTFE rod rotating at a low speed of 61 rpm, we were able to observe the development of the alignment over time. As shown in Fig. S4(a), without any spinning, the nanotubes were randomly oriented on the water surface. After only 10 sec of spinning, the nanotubes were aligned over the whole water surface (Fig. S4(b)). As the spinning time was reduced to 1 sec, only those nanotubes near the PTFE rod were aligned and most nanotubes were randomly oriented (Fig. S4(c)). When the spinning time was 2 sec, the area of aligned nanotubes increased (Fig. S4(e)). Therefore, the alignment starts from the area adjacent to the rotating rod and moves toward the steady funnel wall with a speed of a few millimeters per second.

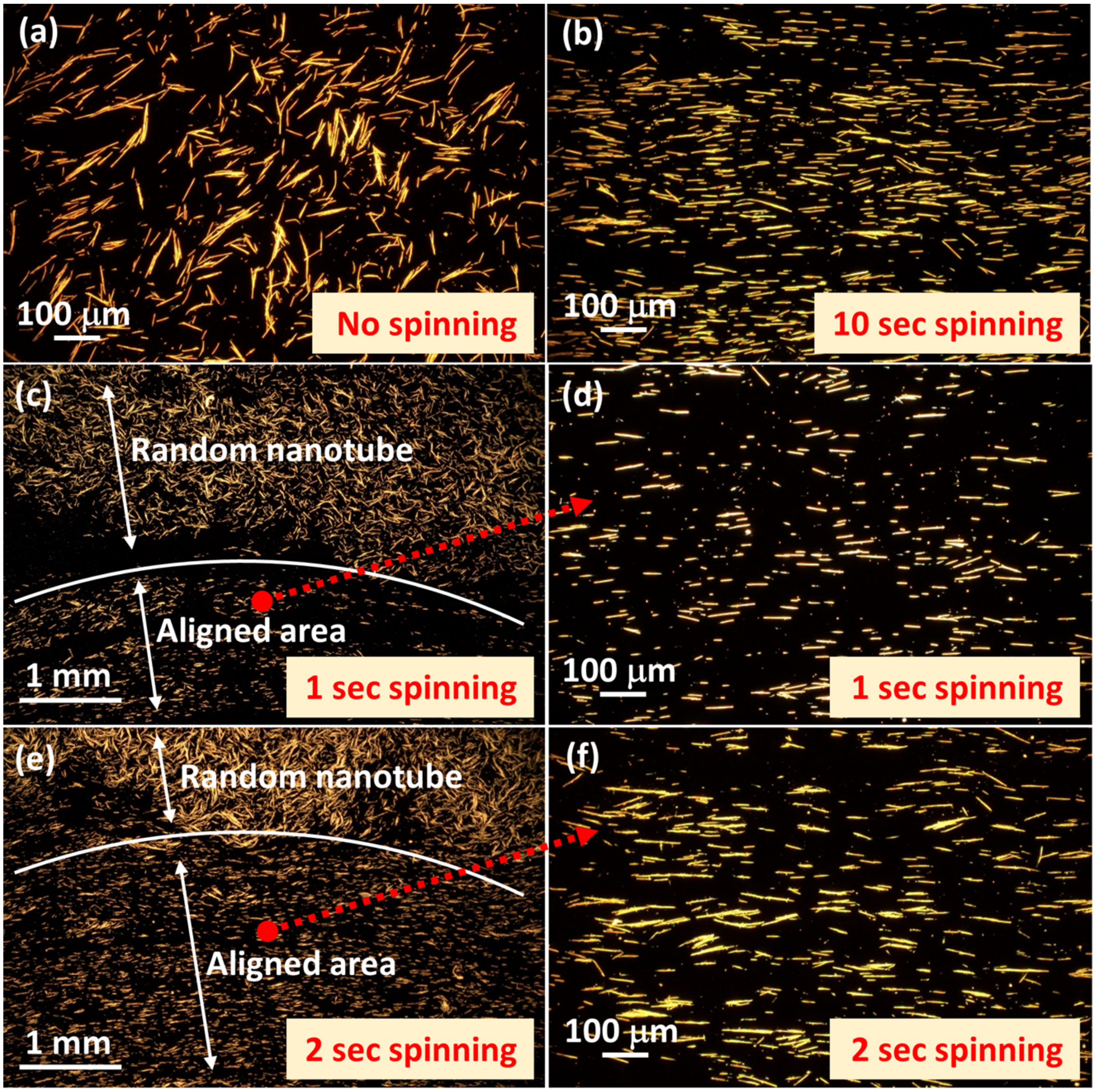

Fig. S4. Nanotube array after different durations of spinning. (a) Random nanotubes before spinning alignment. (b) Nanotubes after 10 sec of spinning; nanotubes were aligned over the whole water surface. (c) Partially aligned nanotubes after 1 sec spinning; the boundary between aligned area and unaligned area is indicated by a curved line. (d) The aligned area in (c) at a higher magnification. (e) Partially aligned nanotubes after 2 sec spinning; the aligned area has grown. (f) The aligned area in (e) at a higher magnification.