Reusable-template-assisted fabrication of rolled-up 3D hierarchical structures

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Recently, rolled-up nanotechnology has been proved to be efficient, economic and versatile to fabricate high-performance micro-/nano-structures such as self-propelled microjets, cell scaffolds, field effect transistors, and fluidic sensors and actuators, etc.[1-3] In this work, a feasible and robust method has been demonstrated to fabricate well-defined three-dimensional (3D) hierarchical structures by rolling up the multilayered nanomembranes containing dot arrays replicated from a reusable silicon template in a reversal manner.

Fig. 1 schematically illustrates the fabrication process of the dot-structured microtubes by both dry releasing[4] and wet etching. A-200-nm-thick PMMA sacrificial layer was spin-coated onto a Si template patterned with high-density dot arrays, followed by sequential depositions of 15 nm SiO, 15 nm SiO_2 and 10 nm Au. After the sacrificial layer dry-removed by thermal annealing at 500℃ for 40s, the dot-structured thin films, which are dressed with nanoparticles re-solidificated from continuous Au film, rolled up into a fine textured microtube for potential applications in surface plasmon resonance (SPR) biosensors. Fig. 2 shows the SEM images of microtubes decorated with dot structures of various geometry (i.e., shape and period (λ)) transferred from the Si templates. Fig. 3a presents optical image of parallel arrayed dot-structured microtubes fabricated by a pre-covered shadow mask with square openings during deposition, suggesting good controllability. On the other hand, by misaligning a shadow mask with rectangular openings to the preference rolling direction introduced during the glanced angle deposition,[3] porous microsprings (shown in Fig. 4) took shape after wet-etching the sacrificial layer due to the higher depth and larger diameter of dots. In summary, dot-structured microtubes and porous microsprings have been fabricated by the reusable-template-assisted approach, which may provide an effective way for controllable and high-yield synthesis of highly functionalized 3D structures for promising applications in bioengineering, lab-on-a-tube microfluidics, environmental sensors, and metamaterials, etc.

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[1] G. S. Huang and Y. F. Mei, Adv. Mater. **24**, 2517 (2012).
[2] D. Grimm et al., Nano Lett. **13**, 213 (2012).
[3] W. M. Li, et al., Lab Chip **12**, 2322 (2012).
[4] J. X. Li, et al., Adv. Mater. **25**, 3715 (2013).

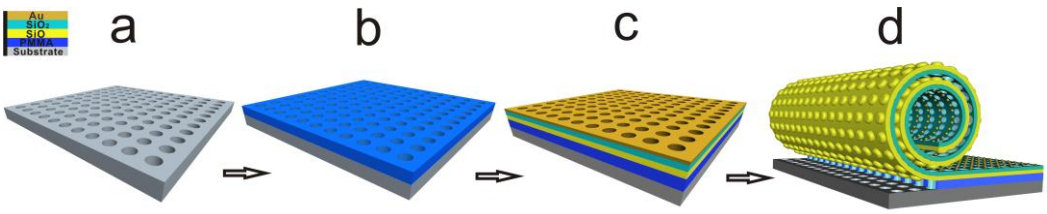

Fig. 1: Schematic drawing illuminates the reusable template assisted fabrication of dot-structured microtubes by both dry releasing and wet etching.

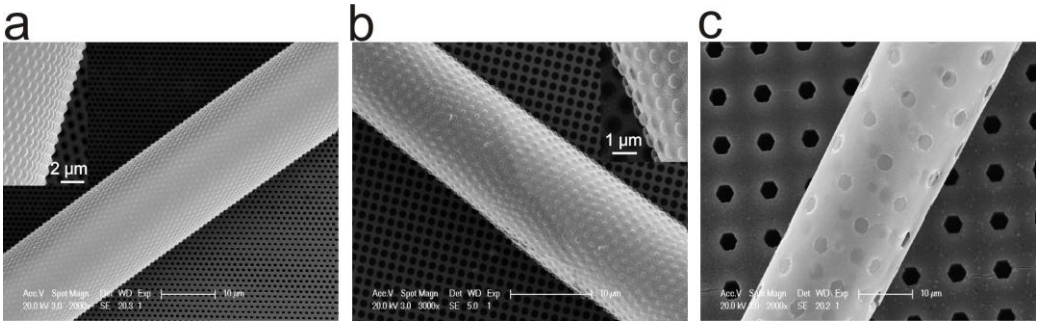

Fig. 2: SEM images of the dot-structured microtubes rolled up from different dots template: (a) ellipses, λ=~1um; (b) circles, λ=~1um; (c) hexagons, λ=~8um.

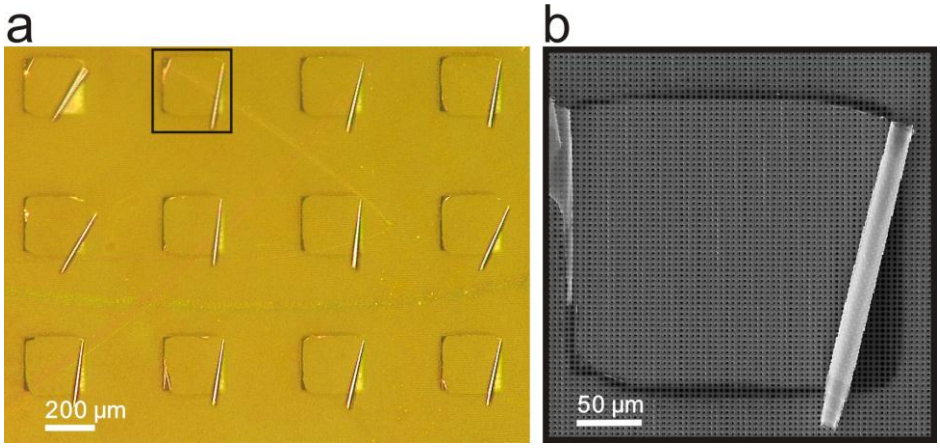

Fig. 3: (a) Optical image of an array of dot-structured microtubes. (b) SEM image of a single unit from (a).

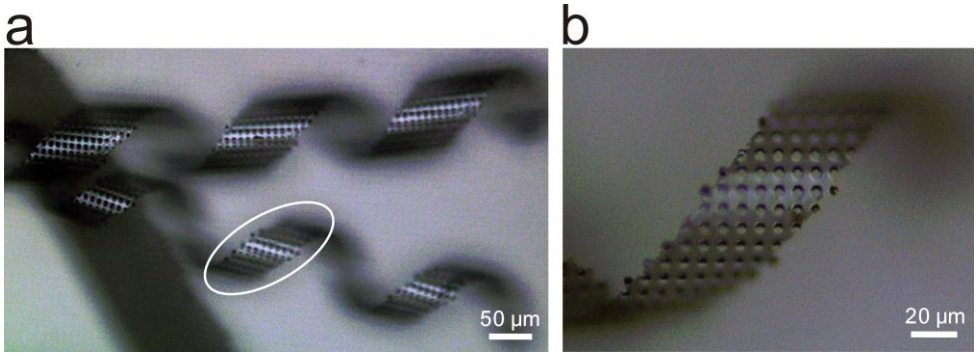

Fig. 4: (a) Optical image of porous microsprings with a helical angle of ~40°. (b) The close-up optical image presents one turn of the porous microspring.