ADVANCED MATERIALS

Supporting Information

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Dry-Released Nanotubes and Nanoengines by Particle-Assisted Rolling

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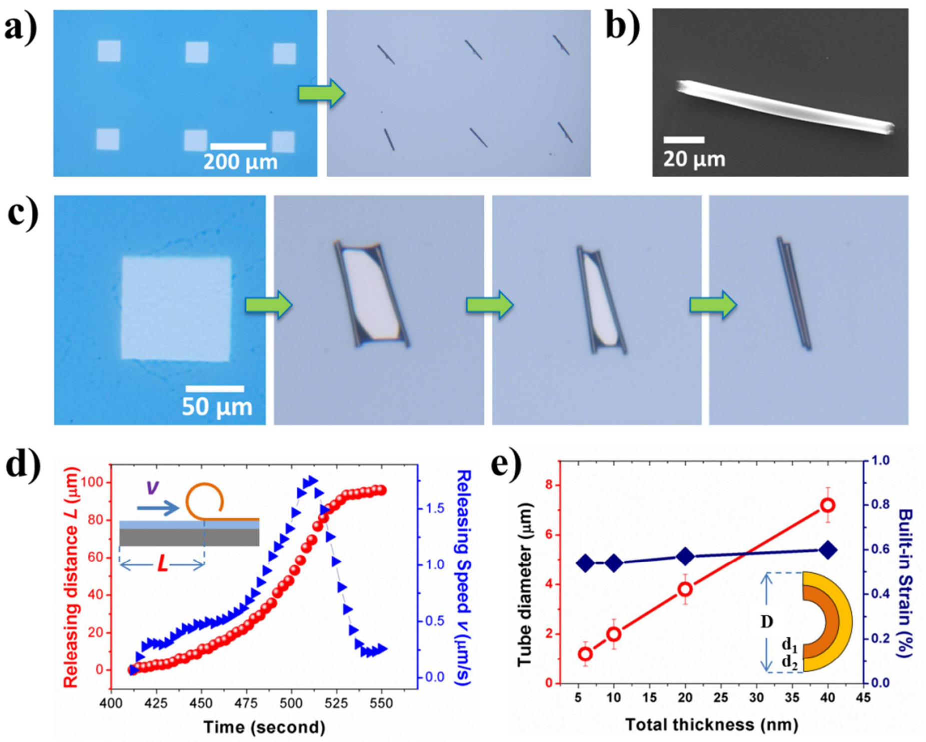
Supporting Information

1. Strain-engineered microtubes

Strain-engineered microtubes were prepared by thermally induced delamination. SI Figures 1 shows an example of the controlled assembly of microtube arrays from nanomembranes by delamination. Here we choose SiO and Cr because these two materials can build largest strain gradient in our previous experiments. After materials deposition with a shadow mask, pattered SiO/Cr (thickness 20/20 nm) nanomembranes having size of 100×100 μm^2 are left on the PMMA layer. The flat nanomembranes are release from the polymer support and self-assembled into microtubes after thermal treatment. It is easy to find that the rolled-up microtubes are roughly parallel to each other. The self-arrangement is resulted from the elastic anisotropy of the nanomembrane evolved during the material deposition process.[1] In this case, the nanomembrane is energetically preferred to only roll along the elastically most compliant direction. The highly ordered microtube array formed after thermal treatment confirms that assembly can be intentionally and orderly triggered as desired. Enlarged SEM image of the rolled microtube is displayed in SI Figure 1b. The tube diameter is measured to be ~11.3μm with ~3 rotations. In SI Figure 1c one can see that during the soft baking process how the nanomembrane rolls from both sides to form tubes moving towards each other and finally forming a twin-tube configuration. The single tube diameter is measure to be ~5 μm with ~2 rotations respectively. A completely detailed rolling process for a twin-tube array formation is recorded by microscopy video (Supplementary Movie 2) and is analyzed by the software ImageJ. The quantitative measurements of releasing distance and speed as a function of heating time are presented in SI Figure 1d. SI Figure 1e shows results of the scalability of the tube diameter as a function of the total thickness varying from 6 to 40 nm and the corresponding calculated built-in strain ε. A high biaxial strain up to 0.6% is obtained. Each data point represents the average of the diameters for ten rolled-up microtubes.



SI Figure 1. Strain-engineered microtubes. (a) Patterned SiO/Cr (20/20 nm) nanomembranes delaminated from PMMA support and self-assembled in to a microtube array after thermal treatment. (b) SEM image of a rolled-up SiO/Cr microtube. (c) Optical images of square SiO/Cr (10/10 nm) nanomembrane rolls from its both sides to form tubes moving towards each other and finally forming a twin-tube configuration upon thermal treatment. (d) Releasing distance and speed as a function of heating time during the SiO/Cr (10/10nm) nanomembrane releasing. (e) Scalability of the rolled-up SiO/Cr tube diameter as a function of the total thickness varying from 6 to 40 nm and the corresponding calculated built-in strain between the bilayer.

2. Supporting video I.

Real-time video of a fast-moving (~195 body lengths/s) nanoengine coated with Pt nanoparticles in a 10% H_2O_2 aqueous solution.

3. Supporting video II.

Real-time video of a strain-engineered twin-tube array formation based on thermal delamination.

Reference:

1. W. M. Li, G. S. Huang, J. Wang, Y. Yu, X. J. Wu, X. G. Cui, Y. F. Mei "Superelastic metal microsprings as fluidic sensors and actuators" Lab On A Chip 12, 2322-2328 (2012).