Magnetically Responsive Polymer Nanopillars with Nickel Cap

***Zhiren Luo*[*1]*, Xu Zhang*[2]*, and Chih-Hao Chang*[1]**

[1] Department of Mechanical Engineering, University of Texas at Austin, Austin, Texas 78712
[2]Department of Mechanical and Aerospace Engineering, North Carolina State University, Raleigh, NC 27695

Magnetically responsive microstructures have attracted research attention due to their advantages such as low energy consumption, non-contact manipulation, and quick response time [1]. One common method to implement these responsive microstructures is to embed magnetic particles into compliant polymeric matrices [2-3]. However, the balance between mechanical compliance and magnetic susceptibility cannot be decoupled and the particles are limited by the pillar feature size, which can limit the actuation performance [4]. Here we demonstrate a new type of magnetically responsive nanostructure consisting of a polydimethylsiloxane (PDMS) nanopillar array with deposited nickel caps, that has successfully achieved such decoupling with multiple cap-geometry designs for a better actuation control.

The fabrication process for the proposed responsive PDMS pillars with nickel caps is illustrated in Figure 1. First, anti-reflection coating and photoresist SU-8 are spincoated on silicon substrates. Then the photoresist is exposed by two orthogonally exposures using Lloyd's mirror interference lithography with 325 nm laser [5], resulting in two-dimensional periodic holes array with 540 nm period. The photoresist mold is then treated by oxygen plasma and trichloro(octyl)silane to decrease surface energy. PDMS with 1:10 mixing ratio is applied into the photoresist mold, cured, and demolded using soft lithography, resulting in a pillar array. Then nickel is deposited onto the PDMS pillars using electron-beam evaporation. During the deposition, the pillar array is tilted at a small angle, resulting in 200 nm nickel cap on the pillar top and thin nickel coating (~ 11 nm) on the sidewall. The SEM images of the fabricated nanopillars are shown in Figure 2 and have 1.3 μm height and 410 nm diameter. These nanopillars are then actuated by a permanent magnet and recorded by optical microscope, as shown in Figure 3. The actuation is then analyzed using image processing method, leading to a maximum displacement of 180 nm with a ratio of 13.9% with respect to the pillar height.

This structure demonstrates a feasible strategy for magnetic actuation at the sub-micrometer scale with freedom to design magnetic cap and polymeric pillar separately. It demonstrates that magnetic torque induced by cap sidewall plays a critical role in actuation. This structure can be utilized in multiple applications such as tunable optical elements, dynamic droplet manipulation, and responsive particle manipulation. More details will be reported including the fabrication process and actuation results, as well as the challenge and limitations.

*zhiren.luo@utexas.edu

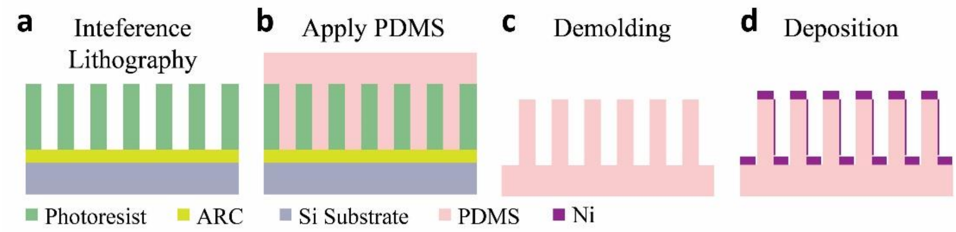

Figure 1. Fabrication processes of nickel-capped PDMS pillars. (a) The two-dimensional pattern is generated in photoresist using interference lithography. (b) PDMS is applied into the photoresist mold. (c) PDMS pillars is demolded. (d) The nickel is deposited with a small tilted angle onto the pillars.

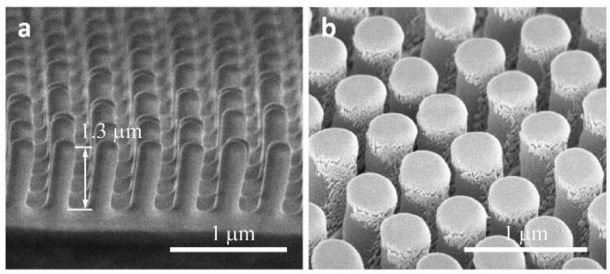

Figure 2. SEM images of nickel-capped PDMS pillar array. (a) The nanopillar array before nickel deposition. (c) The nanopillar array after nickel deposition.

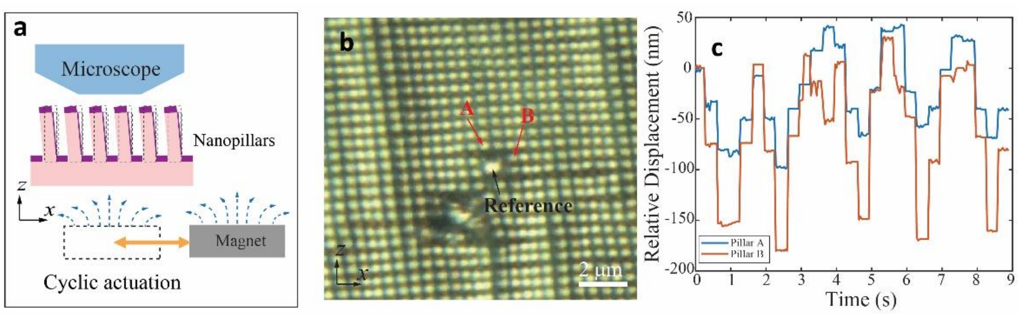

Figure 6. The experimental results of Type II pillars. (a) The schematic of actuation setup. (b) The top-view microscope image. (c) The relative displacements of nanopillars.

Reference

[1] Zhang, X., Sun, L., Yu, Y. & Zhao, Y. Flexible Ferrofluids: Design and Applications. *Adv. Mater.* **31**, 1903497 (2019).

[2] Drotlef, D.-M., Blümler, P. & Campo, A. del. Magnetically Actuated Patterns for Bioinspired Reversible Adhesion (Dry and Wet). *Adv. Mater.* **26**, 775–779 (2013).

[3] Luo, Z., Zhang, X. A., Evans, B. A. & Chang, C.-H. Active Periodic Magnetic Nanostructures with High Aspect Ratio and Ultrahigh Pillar Density. *ACS Appl. Mater. Interfaces* **12**, 11135–11143 (2020).

[4] Evans, B. A. *et al.* A highly tunable silicone-based magnetic elastomer with nanoscale homogeneity. *J. Magn. Magn. Mater.* **324**, 501–507 (2012).

[5] Smith, H. I. Low cost nanolithography with nanoaccuracy. *Phys. E Low-Dimens. Syst. Nanostructures* **11**, 104–109 (2001).