

Two-Step Photolithography for Fabrication of High Aspect Ratio SU-8 Rings

2016 CNF REU Intern: Ryan James Branch,
 Chemical Engineering, University of Michigan – Ann Arbor

CNF REU Principal Investigator: Dr. Abraham Duncan Stroock,
 Robert Frederick Smith School of Chemical and Biomolecular Engineering, Cornell University
 CNF REU Mentor: Neeraj Nitin Sinai Borker, Sibley School of Mechanical and Aerospace Engineering, Cornell University
 Primary Sources of Research Funding: National Science Foundation under Grants No. ECCS-1542081 and No. 1435013
 Contact: rjbrjb@umich.edu, abe.stroock@cornell.edu, ns762@cornell.edu

Abstract:

When suspended in a linear, low Reynolds number flow, most axisymmetric particles will rotate in periodic orbits. However, there exist certain shapes that are predicted in theory to resist this tumbling motion, and instead reach an equilibrium orientation, coming to a halt. If these theoretical predictions can be confirmed, particles of such shapes would be very valuable in applications where suspensions with a high degree of anisotropy are desired, such as fiber reinforced composites. We investigated the fabrication of one such shape, a ring with an “L”-shaped cross section, depicted in the top of Figure 1. Photolithographic techniques offer the benefit of simultaneous production of different sized particles, in large enough quantities for rheological experiments. We characterized and optimized a process to fabricate these shapes out of the negative photoresist SU-8, due to its ability to form strong, well defined, and chemically resilient structures. With aspect ratios ranging from 12 to 100, the rings created through this process were of the appropriate dimensions and surface regularity, possessing both rigidity and structural stability when released into solution.

Summary of Research:

The goal was to create ring particles with an “L”-shaped cross section (shown in the top of Figure 1) having a base height of 5 μm , and a total height of 17 μm . By varying the diameter of the particles, we provided a basis for experimental confirmation of the predicted fluid mechanical properties of these rings; their tumbling behavior can be calculated based on their aspect ratio. Masks were created to facilitate the

fabrication of rings with outer diameters between 200 and 1700 μm .

We developed a procedure to reliably fabricate rings of this shape out of SU-8, an epoxy based negative photoresist, which has been previously used to create well-defined nonspherical particles [1]. An outline of the photolithographic steps is shown in Figure 2.

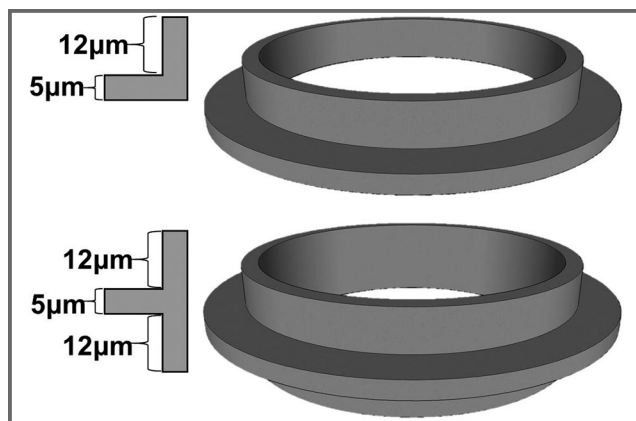
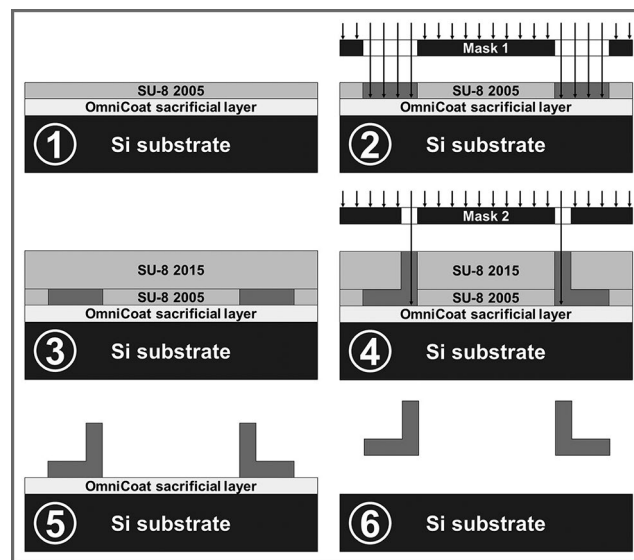


Figure 1, above: Comparison of cross section and overall shape for “L”-shaped ring vs. ring with fore-aft symmetry. Figure 2, right: Outline of photolithography process used to fabricate ring particles with “L”-shaped cross sections.



The process can be summarized as follows: First, on the surface of a 4-inch silicon wafer, a sacrificial layer of OmniCoat™ (which is later dissolved to facilitate particle release) was spin-coated. Then, a 5 μm thick layer of SU-8 2005 was spun and exposed, using the ABM contact aligner, to form the base layer of the ring. A post-exposure bake step was carried

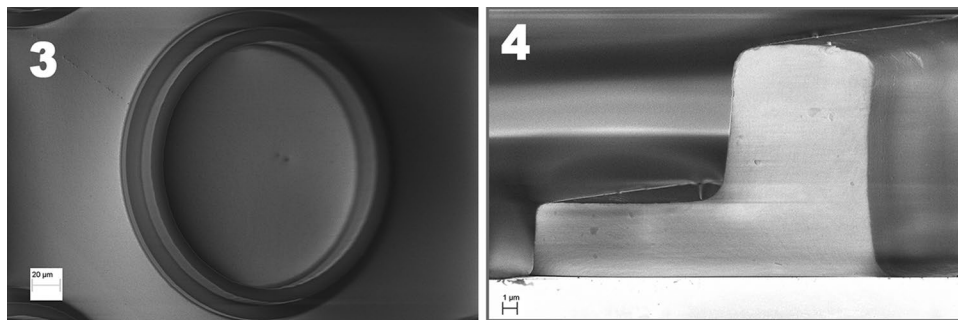


Figure 3, left: SEM of completed SU-8 ring particle, viewed with a tilt of 35 degrees.

Figure 4, right: SEM of cross section of ring, achieved by scoring and breaking wafer.

out in order to preserve the cross linked structure in this first layer, which would otherwise be destroyed through diffusion of solvent from the following layer [2]. Next, a 12 μm thick layer of SU-8 2015 was spun and exposed to form the upper portion of the ring. The wafer was then cut into 14.25 mm squares using a dicing saw, such that each piece contained rings of a given aspect ratio. These pieces were developed using SU-8 developer, then hard baked in order to anneal any cracks in the rings, and strengthen the SU-8 epoxy material. From there, Remover PG was used to dissolve the OmniCoat layer, in combination with a sonicator to release the particles into solution.

Preceding the release step, the dimensions of the rings were characterized with the P10 profilometer. To understand other characteristics of the shape, such as surface defects and sidewall profile, scanning electron microscopy (SEM) was employed, as shown in Figures 3 and 4. By scoring and breaking a piece of a wafer which contained rings on the surface, we could view the cross sectional profile to further confirm that the shape produced fit our desired parameters.

Beyond the “L”-shaped rings, we explored various methods for fabricating a modified ring shape that possesses fore-aft symmetry. Figure 1 shows the differences in cross section and overall ring shape. While more difficult to fabricate due to the overhanging portion of the structure, such a shape would resist the tumbling motion at a much lower aspect ratio, and resist drifting transverse to the direction of flow. Our most promising results in this regard came from the creation of ring shaped “trenches” out of a positive photoresist, which were then filled with SU-8. However, difficulty filling trenches past a depth of 5 to 9 μm, as well as solvent diffusion at areas of contact with different resist, prevented us from successfully creating this more complicated particle. Down the line, the incorporation of a metal layer to stop diffusion or even act as an in-line mask could potentially address these issues.

Results and Conclusions:

A process was defined such that particles of the appropriate height dimensions can reliably be manufactured on a large enough scale for fluidic experiments to be carried out. For the entire range of diameters produced, the particles were observed to remain rigid and structurally stable when released into solution. Work on fore-aft symmetric particles provides information for future attempts to create ring shapes with overhang features.

Future Work:

The fabricated particles can be suspended in a viscous solution and flow visualization experiments performed in order to confirm the theoretical properties such shapes are predicted to exhibit. Using insights from our preliminary explorations, more could be done to achieve the fore-aft symmetric SU-8 ring particles.

CNF Tools Used:

ABM contact aligner, DISCO dicing saw; P10 profilometer; Zeiss Supra SEM.

Acknowledgments:

Dr. Abraham D. Stroock, Neeraj Nitin Sinai Borker, Dr. Donald L. Koch, CNF REU Program Coordinators and CNF Staff. This work was performed in part at the Cornell NanoScale Facility, a member of the NNCI, which is supported by the NSF (Grant ECCS-1542081). This project is supported by NSF Award No. 1435013.

References:

- [1] Badaire, Stéphane, et al. “Experimental investigation of selective colloidal interactions controlled by shape, surface roughness, and steric layers.” *Langmuir* 24.20 (2008): 11451-11463.
- [2] Bohl, Benjamin, et al. “Multi-layer SU-8 lift-off technology for microfluidic devices.” *Journal of Micromechanics and Microengineering* 15.6 (2005): 1125.