

Fabrication and Stabilization of Non-Spherical Colloids for Self-Assembly

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Abstract:

Currently, there are no general purpose methods of selectively assembling non-spherical colloidal particles into large ordered structures. One proposed solution to this dilemma is the depletion interaction, an entropy driven ordering effect, which can be manipulated through the shape of the particles.

The challenge is two-fold: the fabrication of non-spherical objects at the limit of micron-scale technology, and manipulating specific interactions to force the ordered assembly of said objects. Our work focused on this first challenge, to experimentally produce these non-spherical particles. We utilized photolithography techniques to fabricate releasable cylindrical particles on a silicon wafer. We employed an interferometer to test the average height of the particles; the variation across a wafer was $1.2 \mu\text{m} \pm 3\%$. Examination under SEM showed that the cylindrical particles were approximately $1 \mu\text{m}$ in diameter and mono-dispersed in both shape and size. The particles displayed Brownian motion when suspended in an aqueous solution.

Our work also studied the possibility of fabricating particles that could compliment each other, introducing structures comprised of particles with different shapes. For this, we produced mono-dispersed particles with a negative curvature of radius $\sim 1 \mu\text{m}$; these particles are predicted to assemble specifically with the cylinders.

Introduction:

The science of colloids, Brownian particles in solution, has been greatly advanced during the last century. Through the study of colloidal materials and the interactions between them, scientists will be able to develop novel applications to solve the problems currently facing the world. However, previous studies have mostly focused on spherical colloid particles [1]. But to truly understand the phenomena, we need to study the interactions between increasingly complex colloidal structures.

It is for this reason that we look towards the depletion interaction to serve as an assembling force for colloidal particles and to understand the interactions of non-spherical colloidal objects. Dispersed colloidal particles exclude a small volume outside their actual size, preventing other non-adsorbing polymers from entering the excluded region. The entropy of this system is maximized through the assembly of the colloidal particles. The shape dependency of the

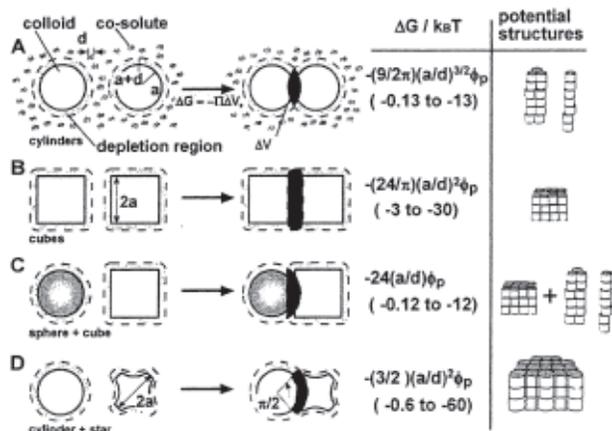


Figure 1: Shape dependency of the depletion interaction.

interaction, illustrated in Figure 1, suggests that a complementary surface would induce a stronger interaction than a non-complimentary surface, such as a sphere [1]. Therefore, developing methods of fabricating non-spherical particles at this level becomes critically necessary to understanding the depletion interaction.

Procedure:

Our experiment had three main goals; (1) fabrication, (2) stabilization, and (3) assembly. The process developed to create our particles is directed nanofabrication. This method involved spinning a layer of SU-8 negative photoresist (MicroChem) on top of a sacrificial layer of OmniCoat (MicroChem), which is spun on a silicon wafer. The SU-8 was spun at speeds of 6000 RPM to produce a layer as thin as possible.

The mask used for the photolithography step was comprised of an array of 2000×2000 circles, $1 \mu\text{m}$ in diameter with a $2 \mu\text{m}$ pitch which, once processed, would become cylinders. Alternate masks were used as well to test more complex shapes than cylinders. The GCA Autostep allowed us to repeat this array 450+ times across the wafer, fitting approximately 1.5 billion circles on a single wafer. SU-8 polymerizes during the photolithography process, making it possible for us to use the resist as our colloidal particle. Figure 2 illustrates each step of the process.

Once fabricated, the layer of OmniCoat is dissolved by submerging the processed wafer in RemoverPG

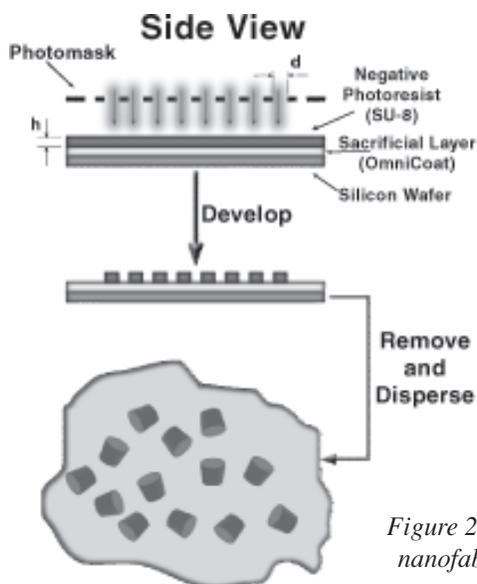


Figure 2: Directed nanofabrication.

(MicroChem) for 30 minutes. Afterwards, we sonicated the wafer in a minimal solution of isopropyl alcohol to facilitate the removal from the silicon wafer.

The next step was to suspend and stabilize our particles in a surfactant solution. We centrifuged the particle/IPA solution at 13,000 RPM in a microcentrifuge and then redispersed the particles in a Water/Triton X-100/NaCl solution. The concentrations of Triton and sodium chloride were 0.15 mM and 5 mM respectively. Once stabilized, a solution of varying molecular weight poly(ethylene oxide) (PEO, Fisher) was added to initiate the depletion interaction.

Results:

The directed nanofabrication process proved to be successful in fabricating and assembling colloidal cylinders. Interferometer testing showed that the average thickness of SU-8 on the wafers was $1.2 \mu\text{m} \pm 3\%$, a relatively small deviation considering most manufactured colloids have much higher deviation in size. Also, from run to run, we were able to produce a high yield of cylinders with little to no defects. We believe that using highly automated equipment such as the GCA Autostep will reduce the amount of error introduced during the photolithography step.

During the release process, we determined that given enough time and amount of IPA, 99% of the cylinders were released into solution. However, because of the volume limitations of a microcentrifuge tube, our average yield per wafer was 85-90%. Figure 3a is an SEM picture of released cylinders on aluminum foil. When PEO was added to the solution, we found small columnar phases forming, shown in Figure 3b. However, at most these columns were comprised of 8-10 cylinders, which we compared to a zero PEO solution, where we found no columnar phases.

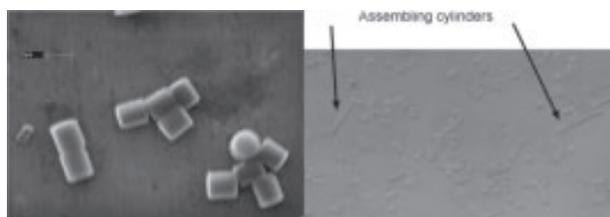


Figure 3: (a) Released particles on aluminum foil. (b) Initial assembly of colloidal cylinders.

We also investigated irregular particles, structures based upon groupings of smaller “cylinders”, and given enough exposure time, we are able to create unique shapes that have the potential of assembling complementarily with the cylinders. Figure 4 shows the structure of one of these complimentary structures.

Future Work:

Future work in this area will involve further investigation of the relation between the aspect ratio of our cylinders versus their ability to form columnar phases. Also, we will explore more thoroughly colloids made from other materials, and of different shapes and sizes.

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References:

- [1] Ilett S M, Orrock A, Poon C K, Pusey P N. Phase behavior of a model colloid-polymer mixture. *Phys. Rev. E*, Volume 51, No 2, 1995, pp. 1344-1352.

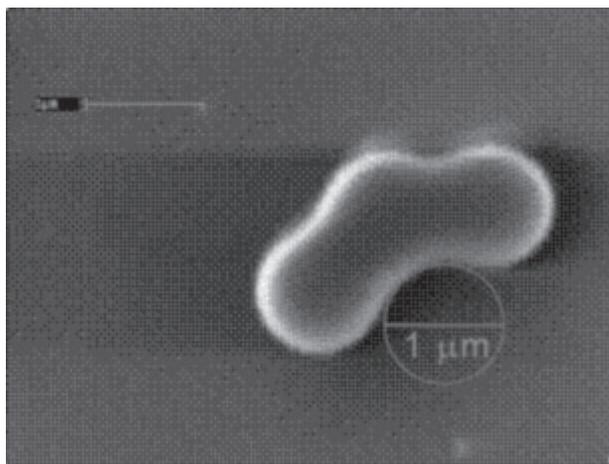


Figure 4: Complimentary shapes.