Self-Assembly of Nanofabricated Colloids

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Abstract:

Colloidal dispersions are made of solid particles with sizing between 10 nm and 1 μm in solution. These particles can self-assemble into crystals with lattice spacing on the order of the wavelength of visible light, and thus are useful in the field of optics. Currently, most scientists are working with spherical colloid particles, but we believe that cylindrical particles will also form intriguing crystals.

We use photolithography to define cylindrical objects on the order of 1 μm out of silicon dioxide, and then release them from the substrate, forming a colloidal dispersion. Within the dispersion, the cylindrical particles will interact by shape-specific depletion interactions, forming structures that will be studied, and hopefully used in photonics applications.

In this study, we fabricated cylindrical colloid particles from silicon dioxide. We chose silicon dioxide for its well-known properties. We first used photolithography techniques to create cylinders of positive photoresist, which we used as a mask to plasma etch through a layer of silicon dioxide on a sacrificial substrate. In order to study the cylinders as freely dispersed colloidal particles, we released them from the substrate using phosphoric acid. We will study these particles in capillaries under various conditions to determine the structures formed.

Introduction:

As the field of optics advances, engineers look for new crystals that will help them better control light. Self-assembled colloidal crystals are likely to be of use, and scientists are currently working with spherical particles to create these crystals. Spherical particles assemble into useful crystals, but particles of other shapes may also assemble into valuable structures.

Spherical particles are also widely available to laboratories who wish to use them, but other shapes are not available, and it is necessary to fabricate them. In this project, we fabricated cylindrical colloidal particles from silicon dioxide. We chose silicon dioxide because it is a well-studied substance and thus structures assembled from the particles could be easily compared to structures assembled from the spherical shape. We chose to use photolithography to create the particles in order to control the size and shape, and to end with a monodisperse dispersion.

Experimental Procedure:

The following process used photolithography and etching techniques to create silicon dioxide cylinders in the colloidal size range. We started with silicon wafers coated with 250 nm silicon nitride and 1 μm silicon dioxide.

We first fabricated photoresist cylinders to be used as a mask in the etching process. We tried three different photoresists; SPR955-CM-2.1 and SPR220-3.0, positive photoresists, and SU8, a negative photoresist. Of these, only SPR220-3.0 held up well during etching. Before spinning the resist, we spun a 150 nm layer of XHRiC-16 antireflective coating and baked at 175°C for 60 sec. We then spun a 2.0 μm layer of SPR220-3.0 positive photoresist, and baked at 110°C for 120 sec.

We exposed using the GCA Autostep and a mask with 1 μm circles that were 2 μm from center to center, and did a post exposure bake at 115°C for 90 sec. We developed in 300 MIF for 60 sec. The photoresist cylinders can be seen in Figure 1.

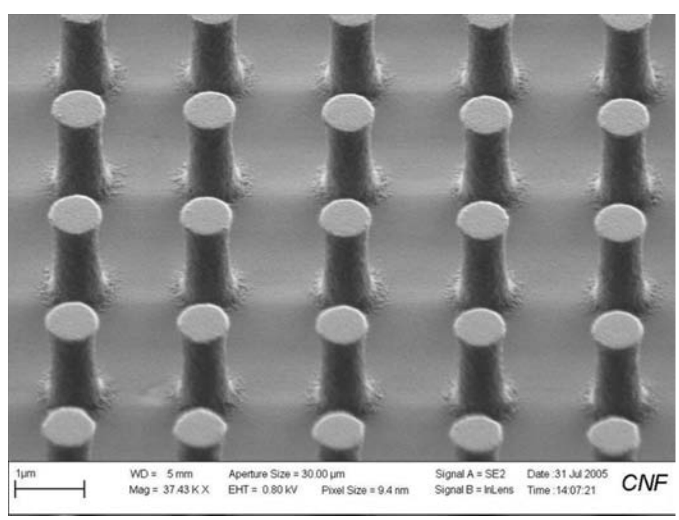

Figure 1: Photoresist cylinders, about 600 nm diameter.

Following the fabrication of the photoresist cylinders, we etched the silicon dioxide using the Oxford 80 plasma etcher. We first hardbaked the resist for 2-3 hours at 90°C. We then did a 60 sec oxygen plasma clean to straighten out the walls of the resist cylinders. The final etching process used a 50% CHF_3 and 2% O_2 gas combination for one hour to etch through the silicon dioxide. The etching process is anisotropic, and the etched cylinders can be seen in Figure 2.

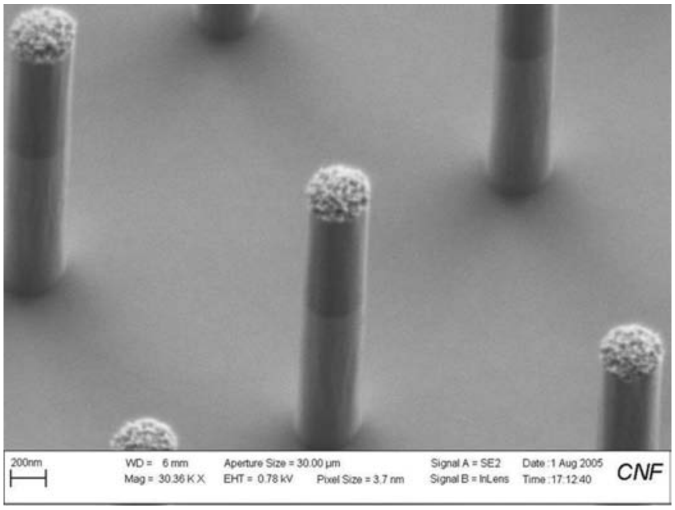

Figure 2: Etched cylinders with resist layer on top, about 300 nm diameter.

Results:

The process developed to fabricate the SPR220-3.0 photoresist cylinders produced cylinders approximately 600 nm in diameter with smooth sidewalls. The cylinders should have been 1 μm in diameter, but because such a large area was exposed, they were smaller. The cylinders also had a small foot of resist on the bottom and a small lip on the top, making the sidewalls not completely straight. This was fixed using an oxygen plasma etch before the final etch.

The silicon dioxide cylinders created through the photolithography and etching process had smooth side-walls, but were only about 300 nm in diameter. This is probably due to the oxygen plasma etch used to straighten the resist cylinders, which may have etched too far into the resist sides, but 300 nm is still in the colloidal size range, so is useful for further studies.

Future Work:

Before the cylindrical particles can be self-assembled, they must be removed from the silicon substrate. Initially we wanted to use silicon nitride as a sacrificial layer and etch it using hot phosphoric acid, releasing the cylinders, but this process may be too harsh for the cylinders to survive. So we will try an aluminum or chrome sacrificial layer and use a gentler etching process to release the cylinders.

Once the cylinders have been released, we would like to use the colloidal dispersion to perform self-assembly experiments to create crystals. We will use surfactants and their depletion interactions to self-assemble crystals that may take the shape seen in Figure 3. In studying the self-assembly, we will create a phase diagram of structures formed using the cylindrical colloid particles.

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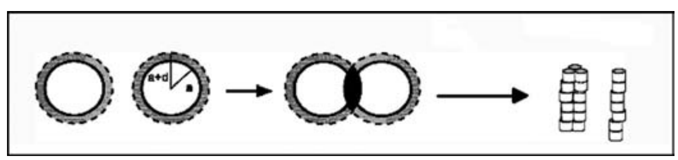

Figure 3: Possible assembly of cylindrical particles.