Self-Assembly of Sub-Micron Channels for Nanofluidic Applications using Interferometric Lithography and Spin-Coating

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Abstract:

Nanoscale channels offer an experimental apparatus for validating theoretical predictions of fluid flow in the nanometer regime, as well as practical applications in biology, chemistry, and engineering. In nanochannels, the electrical double layer becomes large compared to the dimensions of the channel, and flow is strongly dependent on the electrical properties of the channel and the fluid. The focus of this project is to fabricate nanochannels using a faster, cheaper method.

Interferometric lithography is used to create a template in Shipley 510A photoresist and a wet-i ARC layer, on which silica beads self-assemble during spin-coating. The sample is then calcinated, burning off the photoresist and wet-i ARC template and leaving the beads. Nanochannels as narrow as 300 nm have been fabricated. These devices will provide a good basis for further investigation of nanofluidic flow.

Introduction:

Currently, microfluidic technology offers intriguing possibilities for biological, chemical, and engineering applications. Microfluidics allow heatsinks to be integrated into microchips, make possible on-chip gene sequencing, and enable advanced propulsion technologies. Future applications will include automated chemical and biological synthesis at the nanoliter scale.

Nanofluidic technology, although further into the future, offers even more exotic promise. Nanochannels are on the length scale of large molecules and so can shape them somewhat directly. They allow assays to be performed on picoliter and smaller samples. As channels narrow, electrical effects from the walls spread into the bulk of the fluid. This allows efficient electrical manipulation of fluid flow and other properties.

Nanochannels are the pipes of a nanofluidic plumbing system. No more than voids in some material, they are the simplest nanofluidic device. Valves, joints, basins, reactors, and all other devices require more complex design; as such, nanochannels are the obvious first thing to try to design.

Procedure:

Our fabrication process begins with a 6 inch diameter silicon wafer. Before it can be processed, it must be clean of all organic residues. This is accomplished by dipping it first into a hot solution of 3/4 sulfuric acid (70% aqueous H_2SO_4) and 1/4 hydrogen peroxide (30% aqueous H_2O_2). This caustic mixture, called pirahna, cleans away all organic traces from the wafer, but leaves it with a coating of hydrophilic silica. Hydrofluoric acid (50% aqueous HF) is then used to remove this layer of silica, leaving a clean and hydrophobic surface.

The clean wafer is spin-coated with two chemicals. Spin-coating, similar to the spin-art process beloved by children, involves applying a few drops of chemical to a quickly spinning (~3k rpm) silicon wafer. The chemical forms a thin, even layer across the surface and quickly dries.

The two chemicals here are a wet-i back antireflective coating, which prevents reflections off the shiny wafer from interfering with the exposure, and Shipley 510A photoresist, the light-sensitive

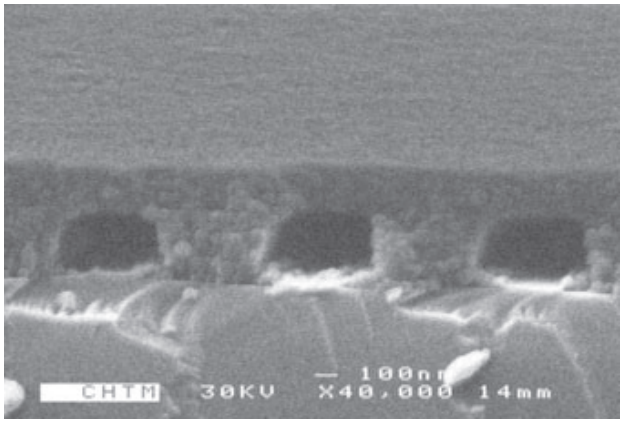

Figure 1: Nanochannels of silica nanospheres on a silicon substrate.

chemical that can be developed into our template.

The wafer is exposed to laser light in the desired pattern, gently baked, and developed. Areas exposed to light either etch away or are retained, depending on whether a positive or negative photoresist was chosen. We exposed a series of regular vertical bars, seen in Figure 1 end-on. Typical channel widths are in the low hundreds of nanometers.

The developed wafer is spin-coated with a 5% by weight solution of approximately 60 nm silica spheres. This concentration was chosen so that a single spin-coating would yield roughly a single layer of spheres. The spheres fill the grooves in the photoresist first.

After 3 or 4 coatings, the grooves are filled. The silica spheres are not hydrophobic, so one can see from the behavior of the aqueous sphere solution that the grooves have been filled.

Having filled the grooves, one may now calcine (bake) the sample for 2 hours in an 800°C oven. This will form hard, open grooves of silica spheres. Hydrolytic bonding is believe to occur between the spheres; longer bakes yield little difference. Higher temperatures cause cracking as the spheres deform too much; lower temperatures do not allow the spheres to bond.

Irregular and even arbitrary patterns of nanochannels can be easily fabricated; the simplicity of this pattern results from limitations in our interferometric lithography setup, and not the general process.

Results and Conclusions:

Nanochannels have been successfully fabricated using self-assembly and interferometric lithography. Representative nanochannels are shown in the two electron micrographs. The methods presented here are fast, comparatively environmentally friendly, and require less equipment than many others. The nanochannels we fabricated are useful; they offer an experimental system in which to verify currently-untested theoretical predictions of molecular dynamics and electrokinetic flow. They could be an important component in biological or chemical sensing or synthesis systems.

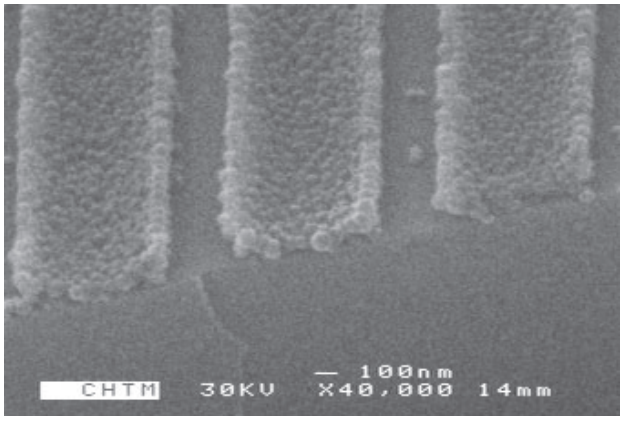

Figure 2: A single layer of silica nanospheres on a silicon substrate.

Future Work:

Future work includes further characterization of this process and analysis of fluid flow within the channels. Long-term future work includes fabrication of arbitrary patterns of nanochannels, nanochannels with different surface properties, and nanofluidic devices.

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