Template-Directed Epitaxial Growth of Colloidal Crystals

CNF Project # 1361-05
Principal Investigator(s): Itai Cohen
User(s): Sharon Gerbode, Mark Buckley, Rajesh Ganapathy

Affiliation(s): LASSP, Physics Department, Cornell University
Primary Research Funding: NSF Grant DMR0606040
Contact: ic64@cornell.edu, sjg53@cornell.edu, mrb45@cornell.edu, rg362@cornell.edu
Web Site: http://cohengroup.ccmr.cornell.edu/

Abstract:
Microfabricated polymethylmethacrylate surfaces on glass substrates prepared using photolithography and reactive ion etching techniques are used to structure colloidal suspensions of micron-sized particles. A single patterned substrate is used as a template for epitaxial growth of colloidal crystals.

Summary:
Microfabricated templates have been successfully used [1] to structure sedimented colloidal particles. This technique allows for accelerated colloidal crystallization, which has been exploited to study the effects of various boundary conditions, including stretched templates [2] and surfaces with embedded grain boundaries [3].

In our current research project, we fabricate polymethylmethacrylate (PMMA) templates on silica glass substrates. A suspension of 1 µm diameter silica colloidal particles is sedimented onto the patterned surface, whose 1 µm diameter holes trap a monolayer of particles, forcing them to assume the prescribed structure. The growth of subsequent layers atop the trapped layer is then studied using an inverted microscope. The dynamics of crystallization of the colloidal particles can then be directly observed, providing intuition for similar atomic systems.

The fabrication process involves both photolithography and reactive ion etching. Photoresist layered on PMMA is exposed using a custom-designed mask and is then developed. The remaining photoresist is then used as a mask for the PMMA, which is etched away using oxygen plasma reactive ion etching. The photoresist is finally flood exposed and developed away, leaving the desired pattern in the PMMA film.

Two kinds of templates are used to probe different behaviour in dense colloidal suspensions. A square lattice of micron-sized holes (Figure 1) may be used to grow an face-centered cubic FCC crystal along the (100) axis—by tuning the lattice constant of the array, we can probe both commensurate and incommensurate lattice matches. Alternatively, we pattern triangular lattices of micron-sized holes (Figure 2), which allow the formation of a random close-packed crystal. In either system, we are able to observe the dynamics of island growth while varying the ratio D/F of diffusion rate on the surface to the deposition flux. Initial experimental results suggest that these dynamics are consistent with nucleation theory for atomic systems [4], as well as experimental results observed for Ag/Pt(111) epitaxial growth [5] (Figure 3).

Our work on epitaxial growth of colloidal crystals is supported by NSF grant DMR0606040.

References:
Figure 1: (a) Colloidal particles (shown as black circles) occupy square lattice sites as directed by the PMMA template. (b) Square islands nucleate and grow on top of the colloidal monolayer shown in (a).

Figure 2: (a) Colloidal particles (shown as black circles) occupy triangular lattice sites as directed by the PMMA template.

Figure 3: Saturation island density ($n_c$) plotted against $D/F$. The upper light grey circles are from our colloidal sedimentation experiments on a square lattice and the lower black circles are from simulation results for atomic systems. The line has a power-law slope $-1/3$ (predicted by classical nucleation theory) and is a guide to the eye. The plateau in the saturation island density at low $D/F$ values is due to growth and nucleation post-deposition [5].