Shearing Confined Colloidal Suspensions Using Microfabricated Templates

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Principal Investigator: Itai Cohen
Users: Sharon Gerbode, Mark Buckley

Affiliations: LASSP, Physics Department, Cornell University
Primary Funding: NSF Grant DMR0606040
Contact: ic64@cornell.edu, sjg53@cornell.edu, mrb45@cornell.edu
Web Site: http://cohengroup.ccmr.cornell.edu/

Abstract

Microfabricated poly(methyl methacrylate) (PMMA) templates prepared using photolithography and reactive ion etching techniques are used to structure surfaces that shear colloidal suspensions of micron-sized particles. Two parallel patterned plates confine the suspension while the structure and dynamics of the constituent particles are monitored in real-time using confocal microscopy. By applying oscillatory force to one plate while holding the other fixed, the effects of shearing on the confined suspension are probed.

Summary

Recently, 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 PMMA templates on both silicon wafers and silica glass substrates. A suspension of 1 µm diameter PMMA colloidal particles is then sandwiched in a 1 to 50 µm gap between the glass and silicon templates. By using index-matched PMMA on glass, we enable confocal microscopy of the colloidal suspension through one of the patterned plates. This technique allows direct 3D imaging of the particle positions and dynamics of the confined suspension.

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 behavior in dense colloidal suspensions. A square lattice of micron-sized holes is used to grow an FCC crystal along the (100) axis; the colloidal crystal is then slowly sheared between the patterned plates and shear-induced structural rearrangements are imaged. Alternatively, we pattern templates of randomly positioned micron-sized holes, which are used to prevent crystallization between the plates. This enables the investigation of glassy and super-cooled confined colloidal suspensions. The effects of shear on glassy suspensions is monitored in real-time on the particle scale using confocal microscopy.

One defining characteristic of glassy systems is the observation of non-exponential correlation functions using relaxation techniques. There are two dominant models for this behaviour. In the first, the system is spatially heterogeneous with respect to relaxation times, but does not evolve in time. The second model describes a system in which one region is first characterized by a particular relaxation time, then by another at a later time. These models have been explored in polymeric glasses using such techniques as multidimensional NMR [4], but the issue remains unresolved. Our direct visualization experiments on confined colloidal glasses allow us to address this active question in glassy physics. We watch a single region of the system and monitor its characteristic relaxation time as the glass ages. The patterned templates we fabricate at CNF are essential to this technique, since they grant us the unique ability to confine our colloidal suspensions while simultaneously jamming them and preventing crystallization.

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References


Figure 1: A square lattice of 1 µm diameter circular holes etched into PMMA.

Figure 2: One layer of an FCC colloidal crystal of 1 µm diameter particles.

Figure 3: A random distribution of 1 µm diameter circular holes etched into PMMA.