Confinement Assisted Self-Organization of Photonic Templates

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Abstract:

Photonic templates of self-assembled spherical colloidal particles have generated interest for their applications in integrated optical devices. However, stronger light-matter interactions have been predicted for colloids with complex geometries. Although simulations have shown that large and robust photonic band gaps may be achieved by lowering crystal symmetry using asymmetric scattering units [1], empirically verifying the bandgap properties of nonspherical two-dimensional (2D) monolayer and quasi-2D transition colloidal crystals has been limited by the lack of large area samples.

This project used colloidal self-assembly via gravitational sedimentation in height-confined cells to grow large photonic templates with controllable phase. Wedge-geometry cells [2] constructed using photoresist promoted the growth of colloidal crystals from mushroom cap-shaped particle building blocks (Figure 1) that measured an order of magnitude greater than previously achieved. The hexagonal and unconventional rotator and buckled phases were observed by confocal microscope and characterized using positional and orientational correlation functions as well as order parameters. A parallel plate-geometry cell [3] is being developed as the next cell refinement to produce larger crystals.

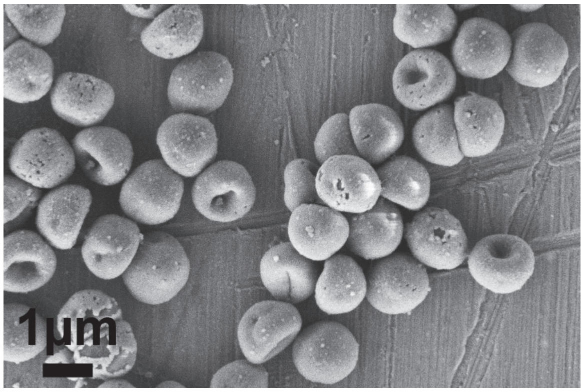

Figure 1: SEM image of mushroom cap particles at 25000X magnification.

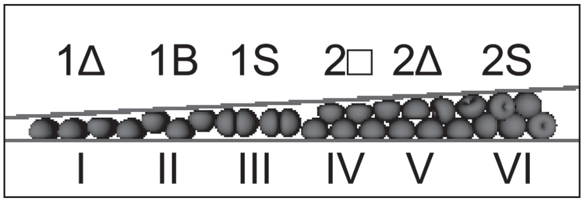

Figure 2: Schematic of wedge cell highlights phases as a function of height.

Approach:

By creating a wedge cell with a smaller spacer, and thus lower minimum angle, a significantly larger cell area restricted to two or less particle diameter height encouraged the growth of monolayers and bilayers (Figure 2). The next design iteration employed parallel plate geometry with a fixed height and a filter at the bottom edge of the cell to increase colloidal concentration. The controllable height ranged from 900 nm to 1.6 μm. During the course of this project, we completed and tested the wedge cell, and began fabrication of the parallel plate cell.

Methods:

Patterning the Wedge Cell Coverslip. Glass microscope coverslips were scrubbed sequentially with acetone, isopropyl alcohol, and deionized (DI) water. Primer (P-20) and photoresist (Shipley 1800 series S1827) were spun onto the coverslips and baked after each spin step to obtain a target height of ~ 2.7 μm. Due to their unconventional rectangular shape, coverslips were exposed using the ABM contact aligner and hand developed in 726MIF developer.

Assembling the Wedge Cell. Wedge cell construction consisted of two coverslips and a 1 × 3-inch support glass slide. A blank microscope coverslip and the unpatterned portion of a developed coverslip were washed in a NaOH, ethanol and DI water solution of pH 14 to remove contaminants. The blank coverslip was bonded to the support slide using UV adhesive. The patterned coverslip was placed on the blank coverslip with the photoresist between the glass surfaces. Pressure applied by hand to the top coverslip created a zero-height region at the base of the cell. The sides and bottom of the cell were sealed with adhesive. To reduce colloid absorption to the cell walls, the cell was filled with 15 μL of polyvinylpyrrolidone (PVP) and DI water solution via pipette through the unsealed edge, and placed in a low pressure chamber to boil off excess. The cell was filled with approximately 15 μL of the colloid suspension in PVP, sealed, and tilted at ~ 80º to promote gravitational sedimentation of the particles into the monolayer and bilayer regions.

Patterning the Parallel Plate Cell Wafer. Fused silica wafers were coated with ~ 200 nm of polycrystalline silicon (polysilicon). ARC AR3 primer and UV210 photoresist were consecutively spun and baked onto the wafers for a total height of ~ 900 nm of resist. The wafers were exposed using the ASML 300C DUV stepper. Plasma etching was required to achieve the target maximum height of 1.6 μm. The Oxford 80 etcher was used to remove the primer, and additional etching with the Oxford 100 etcher relied on the polysilicon as a mask to encourage increased fused silica etching.

Results:

Wedge Cell Results. Confocal data was collected using a Zeiss LSM 5 LIVE confocal microscope. The refined wedge cell produced an unconventional rotator phase colloidal crystal monolayer (Figure 3), an order of magnitude greater than achieved by the previous wedge cell — specifically 7.4 mm by 300-500 μm compared to former crystals of a couple hundred micrometers. The asymmetric properties of the rotator phase suggest interesting optical properties. Additionally, square bilayer phase crystals had begun to form at larger confinement heights (Figure 4); this phase has been shown in simulations to have multiple bandgaps.

Crystal Analysis. Representative confocal micrographs of the rotator monolayer and square bilayer phases were characterized using a Fast Fourier Transform (FFT) and a radial distribution function to determine rotational and translational order, respectively. A Voronoi diagram was generated to identify crystal defects and grain boundaries. However, these sedimentation samples required additional time to organize high-quality crystals prompting the analysis of more mature crystals in previously fabricated wedge cells to better illustrate the phases observed.

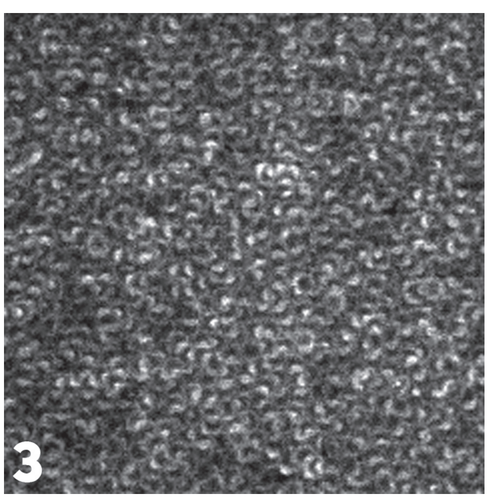

Figure 3: Confocal image of rotator phase in refined wedge cell.

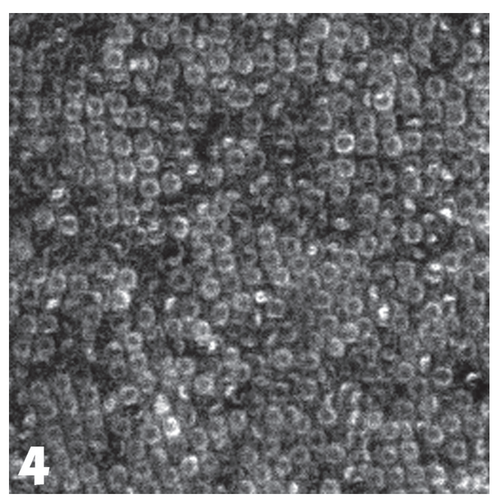

Figure 4: Confocal image of square bilayer phase in refined wedge cell.

Conclusions and Future Work:

The refined wedge cell enhanced the growth of single phase monolayers by an order of magnitude. The parallel plate cell is expected to increase the crystal size to centimeters enabling an empirical verification of photonic bandgaps via transmission and reflection spectra.

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References:

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[2] Riley E and Liddell C; "Confinement-controlled self assembly of colloids with simultaneous isotropic and anisotropic cross-section"; Langmuir 2010, 26, 11648-11656.

[3] Park S, Qin D, and Xia Y; "Crystallization of mesoscale particles over large areas"; Advanced Materials 1998, 10, 1028-1032.