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Feedback Controlled Colloidal Assembly at Fluid Interfaces

MICHAEL BEVAN, Johns Hopkins University

The autonomous and reversible assembly of colloidal nano- and micro- scale components into ordered configurations is often suggested as a scalable process capable of manufacturing meta-materials with exotic electromagnetic properties. As a result, there is strong interest in understanding how thermal motion, particle interactions, patterned surfaces, and external fields can be optimally coupled to robustly control the assembly of colloidal components into hierarchically structured functional meta-materials. We approach this problem by directly relating equilibrium and dynamic colloidal microstructures to kT-scale energy landscapes mediated by colloidal forces, physically and chemically patterned surfaces, multiphase fluid interfaces, and electromagnetic fields. 3D colloidal trajectories are measured in real-space and real-time with nanometer resolution using an integrated suite of evanescent wave, video, and confocal microscopy methods. Equilibrium structures are connected to energy landscapes via statistical mechanical models. The dynamic evolution of initially disordered colloidal fluid configurations into colloidal crystals in the presence of tunable interactions (electromagnetic field mediated interactions, particle-interface interactions) is modeled using a novel approach based on fitting the Fokker-Planck equation to experimental microscopy and computer simulated assembly trajectories. This approach is based on the use of reaction coordinates that capture important microstructural features of crystallization processes and quantify both statistical mechanical (free energy) and fluid mechanical (hydrodynamic) contributions. Ultimately, we demonstrate real-time control of assembly, disassembly, and repair of colloidal crystals using both open loop and closed loop control to produce perfectly ordered colloidal microstructures. This approach is demonstrated for close packed colloidal crystals of spherical particles at fluid-solid interfaces and is being extended to anisotropic particles and multiphase fluid interfaces.