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Project Title:	Structure and Dynamics of Monodisperse Liquid Crystal Domains created on Suspended, Molecularly-Thin Smectic Films using Sub-Femtoliter Inkjet Technology		
Division Name:	Physical Sciences		
Program/Discipline:			
Program/Discipline--Element/Subdiscipline:	COMPLEX FLUIDS/SOFT MATTER--Complex Fluids		
Joint Agency Name:		**TechPort:**	No
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Zip Code:	44242-0001	**Congressional District:**	13
Comments:			
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Flight Program:	ISS		
Flight Assignment:	Liquid Crystal Facility		
Key Personnel Changes/Previous PI:	November 2017 report: Dr. Padetha Tin is no longer CoInvestigator on this project.		
COI Name (Institution):	Emelyanenko, Alexander Ph.D. (Co-PI/ Lomonosov Moscow State University) Tabe, Yuka Ph.D. (Co-PI/ Waseda University, Japan)		
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Task Description:

Small domains or islands of liquid crystal embedded in a few molecular layer-thick smectic liquid-crystal ultrathin films offer an ideal system to study two-dimensional colloidal phenomena. The smectic film has fluidity and orientational order of molecular axis that, in combination, result in complex island-island interactions which do not exist in ordinary colloidal systems. Liquid crystal molecules also possess a symmetry property such as chirality and polarity that macroscopically manifest in structural symmetries, and in elastic and hydrodynamic properties. The molecular chirality further gives rise to a unique non-equilibrium molecular dynamics, arguably referred to as molecular motors, which are known to play a significant role in the biological energy transduction. Although the elasticity and flow induced island-island interactions are expected to open a novel route to self-assembled ordered structures, the meniscus or capillary forces, convective flows, and sedimentation caused by gravitational field make it difficult to explore the anticipated possibility with sufficient clarity as to be compared with theoretical predictions. The proposed project investigates the static and dynamic 2D structures in smectic film-based 2D colloid, by the use of advanced inkjet technique to dispense small liquid crystal islands of fixed size (<20micron) on the smectic film in a prescribed pattern at the right point at the right time. The structural evolution of the 2D island system thus created will be observed and compared with theoretical simulations to elucidate the underlying island-island forces and their molecular origins. For this flight experiment, we develop a compact sub-femtoliter droplet dispenser compatible with flight experiments, using the super inkjet which has a capability to deliver sub-femtoliter droplets, and study the 2D self-organization of domains and nonequilibrium behaviors such as domain coalescence, Oswald ripening, Lehmann rotations and collective orientational excitations and 2D flow. We develop an integrated inkjet chip that is capable of depositing fine droplets of liquid crystals in prescribed pattern. The structural evolution of a certain pattern of islands in 2D allows a rigorous theoretical treatment, thereby enabling us to study the colloidal behaviors in an unprecedented detail. Specifically, we study Oswald ripening and spontaneous reconfiguration of islands.
Of particular fundamental significance in the liquid crystal molecular science is the coupling between molecular rotation and flow vortex. This is a multiscale phenomenon, covering the length scale from a single molecule to macroscopic flow. The microgravity environment, combined with a highly accurate theoretical modelling, is expected to address this subtle, yet fundamental issue in liquid crystal science that has evaded full understanding for decades due to the experimental difficulty in the ground-based studies.

Although liquid crystal is a macroscopic state of matter, the local interaction inside and between the molecules is decisive in determining the critical material parameters such as the rotational viscosity. The outcomes of the proposed microgravity study will shed new light on the rational design of high performance liquid crystals with regard to the underexploited yet attractive features of liquid crystals.

Rationale for HRP Directed Research:

Research Impact/Earth Benefits:

The principal scientific objective of this flight experiment is to explore the hidden phenomena in free standing smectic liquid crystal films in the microgravity environment in which the capillarity-induced forces disappear. Generally, interactions of microscopic particles and islands freely-suspended in two-dimensional liquid films are of central significance in a wide range of industrial fields ranging from oil and mineral recovery, food processing, pharmaceuticals, coating and wet processes, as well as in basic sciences dealing with protein-protein interactions in cell membranes. In Earth's gravitational field, intricate molecular interactions are often overwhelmed by capillarity forces and are hardly accessible in direct physical experimentations. Microgravity in space enables us to approach these phenomena such as Ostwald ripening, molecularly mediated island-island interactions, and the Lehman rotation in liquid crystalline islands and films driven by the transmembrane molecular flow through the observation of configurational evolution of liquid crystalline islands on the smectic thin film. To prepare the required initial arrangement of islands, we develop and employ the sub-femtoliter inkjet deposition technology. Crucial for the liquid crystal science and technology is the understanding of intermolecular interactions responsible for the formation of liquid crystal phases. This space research aims to provide novel information that is hardly acquired from ground-based experiments.

Task Progress:

Proposed Flight Experiments: In the projected flight experiments, free standing films of typical smectic liquid crystals are prepared either in the flat film form as illustrated or as an inflated bubble. The thickness of the film is self-regulated through the chemical potential of the liquid crystal molecules, which is controlled by electric field and/or pressure applied to the liquid crystal. On the smectic film will be deposited islands of distinct liquid crystalline material in a prescribed configuration by means of the electrostatic sub-femtoliter inkjet deposition device. Optical microscopy observation of the translational and rotational movement islands and the variation of island sizes is conducted and the results are compared with theoretical predictions based on a particular type of intermolecular interactions.
Research Activities and Outcomes

As the first year of the project, we focused on the development of sub-femtolitter inkjet device for use with viscous liquid crystals. The rest of the research hinges on the availability of this device, and this will be the integral component of the flight experiment hardware. Currently commercially available are two types of technologies for dispensing small volume of liquid below 1nl: Inkjet printers of various types and the electrospinning or electrospray technology. The inkjet printers for office use and for 3D printing is based on a fine nozzle connected to a source of impulsive pressure generated by piezo actuators or bubbling. This type of device is sensitive to the viscosity of ink and is easily vulnerable to clogging. There also exists a finer inkjet technology based on electrostatic driving; this still uses even finer nozzles to deposit femtoliter droplets, which shares the common problem of clogged nozzle. Our approach here is to combine the electrospray, which is free from clogging issue, with the electrostatic inkjet to facilitate a clog-free sub-femtoliter inkjet.

The key feature of the present design is the open construction without a fine aperture nozzle. In the electrospray, which uses the same open construction, the application of high voltage to the ink results in the formation of the Taylor cone that generates a continuous flow of liquid. In order to achieve the drop-on-demand action with the capability of dispensing sub-femtoliter drops, a fine metal wire is inserted in such a way that the edge of the wire is slightly out of the surface of the liquid. By applying a high enough pulse voltage between the wire and the target, a small droplet is forced to detach from the edge of the wire. The most significant factors determining the droplet size are the thickness of the wetting liquid layer at the wire edge and the magnitude and width of the voltage pulse. Unlike the electrospray, the supply of the liquid is severely limited by the presence of the wetting liquid layer covering the metal wire extended out of the meniscus. We have carried out a preliminary yet substantial characterization of the inkjet performances under various operation conditions. We used a room temperature smectic liquid crystal, octyl-cyanobiphenyl (8CB). Its viscosity is in the range of 30-40 mPa.s, while the viscosity of commercial inkjet inks is formulated to be around 2 mPa.s, which is roughly twice as large as that of water. Despite the high viscosity, our device could deposit 8CB micrometer sized droplets in the drop-on-demand mode, provided the proper operation conditions are set. The driving scheme has been proven to be decisive to facilitate the drop-on-demand operation in the desired range of droplet size. The bias DC voltage (400V-1.5KV) is necessary to charge up the liquid crystal to a certain level and to attract the liquid crystal near the edge of the wire based on the focused electric field at the edge. The pulse voltage (400V-1KV) is to propel a charged droplet to be detached from the wetting layer. The width of the pulse, which turned out to be in the range of 2-13 ms, must be adjusted to make an isolated droplet rather than a continuous flow of liquid as in the electrospray. The target must be within the range 30-100 micrometer from the wire edge. The size of the droplet can be controlled from below 1 mm diameter to several tens of micrometer by adjusting the applied voltages. For a constant deposition condition, the size remains highly uniform.

The fundamental design of the sub-femtoliter inkjet device has been made and the performance characterization proved its potential utility in the projected space experiments. A crucial remaining task is to integrate an extraction gate electrode that replaces the target substrate used in the present experiment. It is also necessary to add a charge neutralizing chamber before the deposition of the droplets on the smectic liquid crystal film.

Bibliography Type:	Description: (Last Updated: 12/04/2023)