Nematic Colloidal Crystals, Microresonators and 3D Microlasers for Soft Matter Photonics

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We shall discuss general properties of nematic colloids, which are dispersions of microparticles in a nematic liquid crystal. A nematic liquid crystal is an orientationally ordered fluid, which interacts with the surfaces of inclusions. This interaction generates topological defects, which are responsible for structural forces between dispersed microparticles [1]. The structural forces in liquid crystals are extremely strong, anisotropic and long-range, and are responsible for self-assembly of a broad variety of colloidal superstructures in liquid crystals: 2D colloidal crystals [2], colloidal wires, assembled by entangled topological defects [3], superstructures in the mixtures of large and small colloidal particles [4] a broad variety of 2D nematic colloidal crystals [5] and colloidal knots and links [6]. In all cases, the colloidal binding energy is of the order of several 1000 k_BT. It is therefore several orders of magnitude higher compared to water based colloids and could provide assembly of nanometer-sized colloidal particles [7].

It has recently been demonstrated, that several classes of tunable and active microphotonic devices could be realized in water or polymer-based dispersions of liquid crystals. When a nematic liquid crystal is dispersed in an insoluble isotropic media, like water or a polymer, nematic microdroplets are created that are excellent and highly tunable optical microresonators [8]. Light can be trapped in a microdroplet due to the total internal reflection and the resonant eigenmodes can be tuned by a relatively small external electric field over a tuning range of more than 20 nm. This could be a basic tunable optical resonant element for future soft matter photonic devices. It has been demonstrated in 2010 [9], that Bragg-onion optical microresonators could be created by simply dispersing a chiral nematic liquid crystal in water or polymer. 3D laser emission has been demonstrated from micrometer-sized chiral nematic droplets, where the wavelength tuning could be obtained over more than 200 nm range by changing the temperature of the material. Strategies for creating soft matter microphotonic devices and systems are discussed.

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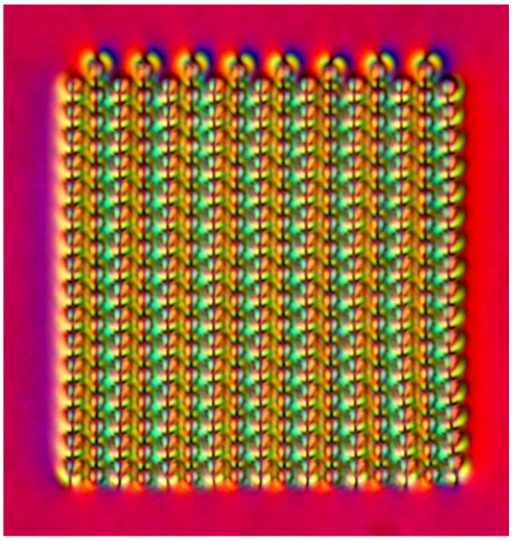
Figures

Fig. 1. 2D nematic colloidal crystal, assembled from 2.3 μm silica microspheres in a nematic liquid crystal 5CB. The microspheres are bound together by an array of topological defects. Topological defects are responsible for a fascinating variety of colloidal assemblies in liquid crystals.



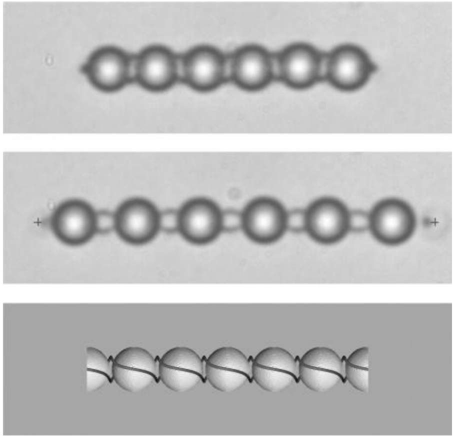


Fig. 2. Nematic colloidal wire, assembled from 2.3 μm silica microspheres in a nematic liquid crystal 5CB. The microspheres are bound together by entangled defect lines, which are wrapped around the microspheres. The bottom image shows the results of Landau-de Gennes simulations.

Fig. 3. A single droplet of a nematic liquid crystal 5CB, which is embedded into a low refractive index polymer matrix, is an optical microresonator. Light is circulating inside the droplet due to total internal reflection at the interface. The resonant frequencies of these Whispering Gallery Modes can be tuned by an external electric field, which modifies the index of refraction of a liquid crystal. The range of tuning is nearly two orders larger compared to solid state devices.

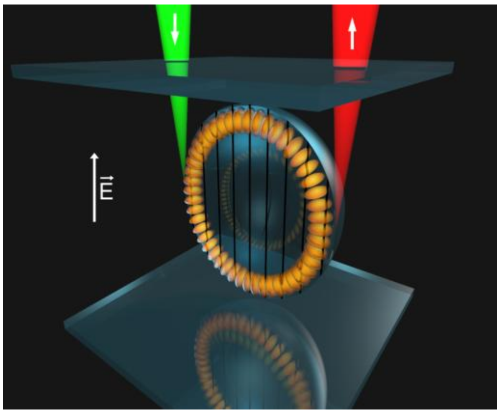


Fig.4 A single droplet of a cholesteric liquid crystal doped with a fluorescent dye and immersed in water or other immiscible liquid is a 3D microlaser. Because of chirality, the LC molecules form a helical birefringent structure, originating at the center and spiraling to the surface. Optically, this is a spherical, onion-Bragg microresonator. When pumped with external light, the 3D microlaser starts emitting coherent light in 3D.