Invited Paper

Non-contact optical control of multiple particles and defects using holographic optical trapping with phase-only liquid crystal spatial light modulator

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ABSTRACT

In this work, three-dimensional manipulation of multiple defects and structures is performed in the framework of holographic optical trapping approach using a spatial light modulator. A holographic optical tweezers system is constructed using a liquid crystal spatial light modulator to generate multiple optical traps. We optimize the tweezers setup to perform polarization-sensitive holographic optical trapping and then explore properties of optical trapping in thermotropic liquid crystals and compare them to the case of isotropic fluids. One of the major challenges complicating the quantitative measurements in these fluids is the anisotropic nature of the liquid crystal medium, which makes the tight focusing of the laser beam difficult and considerably weakens optical trapping forces. Using liquid crystals with low birefringence allows us to mitigate these artefacts. Optical trapping forces and the trap stiffness are first calibrated for different laser powers using viscous drag forces. This is then used to probe inter-particle and defect-particle interaction forces as well as to characterize tension of line defects in the bulk of liquid crystals.

Keywords: Optical tweezers, micro-manipulation, multiple traps, liquid crystals, spatial light modulator (SLM), CGH (computer generated holograms), holography, disclination

1. INTRODUCTION

Non-contact optical control is of great interest for many areas of science and technology as it can allow one to manipulate objects spanning from single atoms to microscopic particles. Soon after the demonstration of a single beam optical technique for trapping micrometer-sized transparent dielectric particles suspended in a fluid medium [1], the so-called optical tweezers permeated research in the biological and condensed matter physical sciences. In biology, the

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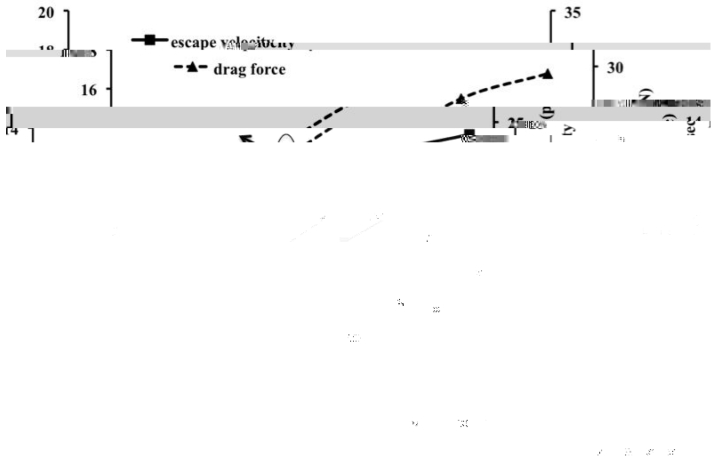
In order to achieve this, two telescopes are included in the optical train of the HOT setup, one before, and the other after the SLM. The first 2.5:1 telescope arrangement is used to expand the laser beam from 5.0 mm to 12.0mm in order to overfill the active area of the SLM. It consists of two solution at the edge of the cover slide of this cell next to the channel; the cell is then self-filled due to the action of capillary forces. The typical concentration of polystyrene spheres in the deionized water is kept below 0.01wt%. The LC cells are assembled from glass plates coated with polyvinyl alcohol (obtained from Alfa Aesar) alignment layers buffed to set the uniform in-plane far-field director $\hat{n}$. The thickness of the LC cell is set at 30-60μm using UV-curable adhesive with the dispersed appropriately sized glass spacers. The samples are prepared using low-birefringence (n~0.04) nematic LC ZLI-2806 having the average refractive index of ~1.49 (n_o= 1.48 and n_e= 1.52 are ordinary and extraordinary refractive indices, respectively). To obtain the cholesteric LC, ZLI-2806 is doped with a chiral additive CB15 (obtained from Merck). For the FCPM studies, the LCs are doped with ~0.01wt% of the fluorescent dye N, N'-Bis(2,5-di-tert-butylphenyl)-3,4,9,10-per

3.2 In-plane spatial calibration

3.4 Trapping depth calibration

A cell filled with deionized water containing 2 m polystyrene spheres is used for the trapping depth calibration. A single trap is created using the software. When a polystyrene sphere is brought close to the trap, it experiences the influence of optical forces, eventually hops towards the trap and becomes spatially-localized, i.e., its Brownian motion is ceased. If the sphere is trapped in the beam but appears out of focus,



maximum laser trapping force for a given laser power (for such estimates, one can assume that $\eta_{eff} \approx \alpha_4 = 57cP$, i.e., equal to the average viscosity of ZLI 2806 at 20°C). The escape velocity measurements were performed along two mutually orthogonal paths, one parallel and the other perpendicular to the rubbing direction of the alignment layer. We observe directional anisotropy of the viscous drag forces, Fig. 7, which is related to the anisotropy of $_{eff}$

In general, the optical trapping forces in the LCs (e.g. ZLI-2806) are somewhat weaker as compared to the forces acting on the particles of the same size dispersed in water (partially due to the fact that the difference between the refractive index of the particle and the surrounding medium is larger in the case of water) but still sufficiently strong to enable robust laser manipulation. Fig. 10 illustrates the holographic optical trapping and manipulation of 4 m MR particles in the bulk of the cholesteric LC of pitch about 5 microns using the SLM-based HOT setup.

4.2. Three-dimensional trapping of multiple colloids

Figure 11 shows the movement of multiple 2 m polystyrene spheres in water along the optical axis. The sequence of images shown therein demonstrates that the spheres can be programmed to move in different groups while being trapped at different depths in the vertical direction, along the microscope's optical axis. All the six spheres trapped in the outer ring of Fig 11(a) are co

17e). Thus, manipulation of defect lines with trapped colloidal particles allows one to test topological stability of LC defect lines.

We have constructed the holographic laser trapping system integrated with a fluorescence confocal microscope that is optimized for polarization-sensitive 3D trapping and imaging of director structures, defects, and colloidal particles in the LC media and other anisotropic fluids. We have provided examples of the simultaneous multiple-particle manipulation at different depths of the LC and isotropic fluid samples. We also show feasibility of 3D manipulation of defects and testing of their topological stability using the holographic optical trapping approach. The combined 3D imaging and trapping in LCs and LC colloidal suspensions further expands the manipulation and imaging capabilities available for the study of these intriguing anisotropic media.

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