Towards total photonic control of complex-shaped colloids by vortex beams

Clayton P. Lapointe,[1,2] Thomas G. Mason,[2,4] and Ivan I. Smalyukh[1,3,5]

[1]Department of Physics and Liquid Crystals Materials Research Center, University of Colorado at Boulder, Boulder, CO 30309, USA
[2]Department of Physics and Astronomy, Department of Chemistry and Biochemistry, and California NanoSystems Institute, University of California at Los Angeles, Los Angeles, CA 90095, USA
[3]Renewable and Sustainable Energy Institute, University of Colorado and National Renewable Energy Laboratory, Boulder, CO 30309, USA
[4]mason@physics.ucla.edu
[5]1_0 6.41605 Tm [(1_0 6.41605 T-4(3)7(09.41608i(si)st)9(i)-6(-4(U)4(S)-8(A)13(-8(n)7(d)-si)st)9(i)90

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single fixed orientation of the particle relative to the laser propagation direction, and in some

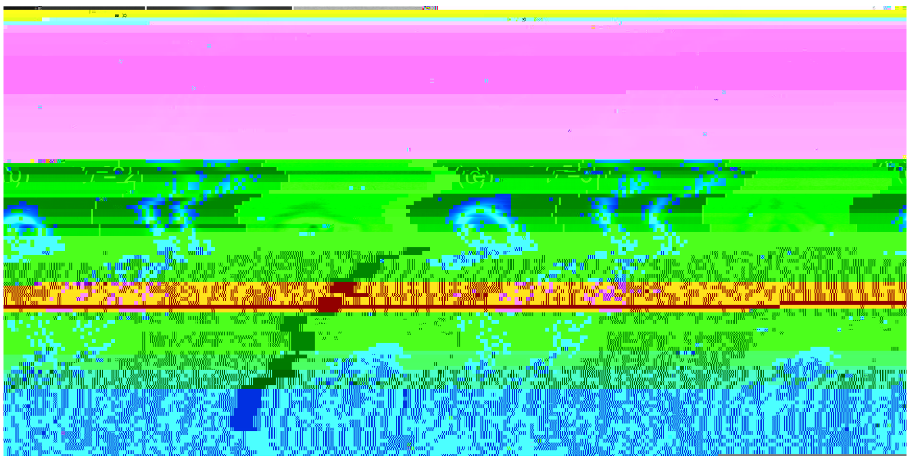
Fig. 1. Schematic of dynamic holographic optical tweezers. The output beam (red) from a ytterbium-doped fiber laser is expanded with a telescope (L_1 and L_2) to overfill the pixel array of a reflective spatial light modulator (SLM). The reflected beam size is reduced with a second telescope (L_3 and L_4) to fill the back aperture of a microscope objective (MO). A rotatable halfwave plate (HWP) controls the linear polarization state of the beam and the dichroic mirror (DM) is used to direct the beam into MO while allowing visible light (yellow) transmitted through the sample to travel to the CCD camera. A polarizer (P) located before the condenser (CD) and an analyzer (A) mounted below the sample allow for observations under crossed polarizers such as the images of a square colloid (top) and a triangular colloid (bottom) in 5CB shown on the left (scale bar: 5 μm). The SLM is capable of generating Laguerre-Gaussian optical vortices as shown in the images of the intensity(g)7(e)1-6(y(g3(r)4(i)-6(z)10(e)10(r)4)-169(5)-8( )]TJ 5B)9( )]TbJ 5B ni0(

4. Results and discussion

Whether the particles are trapped upright with an $l = 0$ Gaussian trap or in-plane with a l 0 optical vortex, they can be translated either by steering the trap within the field of view using computer-controlled holography or translating the sample using a stage. At the laser powers used in these studies (20 mW), the maximum velocities achievable before viscous drag forces pull the particle out of the trap are limited to 1-2 m/s, because of the high shear viscosity of 5CB (~100 cP). Using a drag coefficient 2x10 ^{6} kg/s determined in previous experiments [18] for similar square shaped colloids in 5CB, we estimate a maximum optical force without viscous drag pulling the particle out is 1-2 pN. Rotating the polarization of the beam parallel to n_0 results in the colloid being pushed out of the trap for all shapes and any l, similar to the case of spherical colloids having refractive index intermediate between the ordinary and extraordinary indices of the LC which can be repelled or attracted to the laser trap by controlling beam’s polarization [22]. Furthermore, in isotropic solvents, we cannot stably trap similar colloidal particles while keeping their long axes parallel to the focal plane

$$
\begin{aligned}
E_p^l \quad & \exp \frac{ikr^2 z}{2 \; z_r^2 \quad z^2} \; \exp \frac{r^2}{\;^2} \\
& \exp \; i \; 2p \; l \; 1 \; \arctan z \; z_r \quad \exp \; il \qquad (1) \\
& 1^{\,p} \; \frac{r\sqrt{2}}{\;}^{\,l} \; L_p^l \; \frac{2r^2}{\;^2}
\end{aligned}
$$

where l and p are mode indices, $k = 2 \; n/ \quad 8 \; 10^{3} \mathrm{nm}^{1}$ is the wave number using a refractive index $n \quad 1.5$ and vacuum wavelength $= 1064$ nm, $(z) = {}_0[1 + (z/z_R)^2]^{1/2}$ is the beam waist at a distance z away from the focus along the optical axis, $z_r = \; n \; {}_0^2/$ is the Rayleigh length and $L^l_p(x)$ is a Laguerre-Gaussian polynomial [29].



LTo /Td nTo /Td To /Td_]T0 79lu0 79m0 0( )1xu94O 1J -3 53l[w8005i(To /Td)-74To /T4.566eJ 36ltd n 9tJ 8OuT3804f -5(r)-5(61J 78 -2253l 23c[TJ u --5(r)-5((/J / 48=)]TJ /148T61.56.3]TJ /148Tn1(]T0 79(m) 48[(itJ / 48l 168J / 48l)-7(l.59Tq156 0 0l)-7(l.537 1-56-3)-34T 48[T-517]h0 0u0 0 13(3)-34T 48[td)-7( )]TJ /148T(itJ / 48[3.246n0 0g/(m0l.537 J / 48(hu)3.3.246n0 0J / 48[b1.56( )]T T)4OeJ161J8334O 1J -3 53l[hu)3.T0

that these strategies can be extended to other types and shapes of colloids as well as other anisotropic complex fluids such as surfactant or macromolecular based lyotropic liquid crystals, wormlike micellar fluids, and polymer solutions. Furthermore, employing other types