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Quenching nematicon fluctuations via photo-stabilization

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Abstract—Light localization into optical spatial solitons can be achieved by launching optical beams in nonlocal nonlinear nematic liquid crystals. Such solitons often undergo undesired fluctuations of their trajectories. We demonstrate that partial polymerization in monoacrylate-doped nematic liquid crystals is effective in quenching such fluctuations in transverse space.

Spatial nonlocality in the optical response of dielectrics entails a number of benefits when dealing with nonlinear optics for signal processing and switching. It was recognized in the early days of nonlinear integrated optics that a diffusive hence nonlocal response, such as in thermo-optic materials, could lead to longitudinal optical feedback even in the absence of resonances, with consequent hysteresis versus input beam excitation [1-4]. More recently, a nonlocal nonlinear response was found fit to stabilize beam self-confinement into two-dimensional (2D) spatial solitons which, in local Kerr media with an intensity-dependent refractive index, are otherwise unstable and prone to filamentation and catastrophic collapse [5-10]. In the highly nonlocal limit in space, spatial optical solitons tend to mutually attract and exhibit long-range interactions, [11-12] as well as reduced modulational instability [13-14], incoherent character [15-16], and breathing oscillations [17-18]. The synergy of local and nonlocal effects in time was indicated as a route towards spatiotemporal light bullets [19].

Nematic liquid crystals (NLC) are molecular liquids with a substantial degree of orientational order, so much so that they exhibit a macroscopically (positive) uniaxial response, a reorientational nonlinearity, a large electro-optic effect as well as high nonlocality [20-21]. When an intense light beam with electric field \mathbf{E} wave propagates through NLC, the induced microscopic dipoles tend to rotate under the action of torque:

$$\Gamma = \varepsilon_0 (n_e^2 - n_o^2) (\mathbf{n} \cdot \mathbf{E}) (\mathbf{n} \times \mathbf{E}) \quad (1)$$

with ε_0 the dielectric susceptibility of vacuum, n_e and n_o the refractive index eigenvalues for electric fields parallel and orthogonal to the optic axis \mathbf{n} , respectively. The resulting increase of the orientation angle θ between the

wavevector $\mathbf{k}||z$ and \mathbf{n} yields self-focusing through an increase in the extraordinary (e)-refractive index ruled by

$$n_e(\theta) = \frac{n_o n_e}{\sqrt{(n_o^2 - n_e^2) \sin^2 \theta + n_e^2}}. \quad (2)$$

When self-focusing compensates for diffraction, a stable spatial soliton (a nematicon) is formed, with an associated graded-index waveguide wider than the beam generating it [5, 22]. All-optical reorientation enables nematicon generation even at sub-mW power levels [23-24], but such self-trapped beams are usually subject to dynamic instabilities due to the interplay between optical torque, thermal agitation, fluid convection [25], anisotropy [26], and anchoring conditions at the boundaries.

Transverse light localization through all-optical reorientation, in fact, is understood to locally increase the order parameter of this soft matter; this local field (all-optical) effect combines/competes with the bulk reorientation of the optic axis (molecular director) due to elastic interactions of the molecules (i.e., nonlocality) and their anchoring at the boundaries of the cell containing the liquid dielectric [21, 27]. As a narrow self-guided solitary beam is established in the nonlocal medium, the boundary conditions tend to restore the uniform distribution of a molecular director in the bulk, trying to relax light-induced orientation distortion and thus pulling/pushing sideways the nematicon from its straight trajectory. The latter results in transverse fluctuations of the nonlinear beam versus time, particularly for propagation distances large enough to witness an appreciable reduction of its power through scattering losses.

Since nematicons are associated with light-induced waveguides potentially useful for guided-wave signal processing [28-29], a few strategies have been undertaken to reduce such transverse fluctuations in planar cells, e.g., by introducing external low-frequency electric fields along the direction of propagation [30-31], by varying the sample temperature [31], or by applying external magnetic fields [32]. Here, we report our first results on reducing/quenching nematicon transverse fluctuations through photo-induced stabilization in suitably doped

materials, i.e., slightly altering the material itself as in Refs. [33-35].

We employed planar cells comprising two parallel glass slides separated by 100 μm and with the inner interfaces coated with rubbed polyimide layers to anchor the molecular director at $\pi/4$ with respect to z in the plane yz . The liquid crystals we used were the standard nematic mixture 5CB doped with 10mol% monoacrylate (6-(4-cyano-biphenyl-4'-yloxy) hexyl acrylate). The addition of monoacrylate into 5CB has been previously shown to increase reorientational nonlinearity compared to pure 5CB [34-35]. The unexposed NLC mixture exhibits the same optical properties as pure 5CB, with $n_o=1.54$ and $n_e=1.70$.

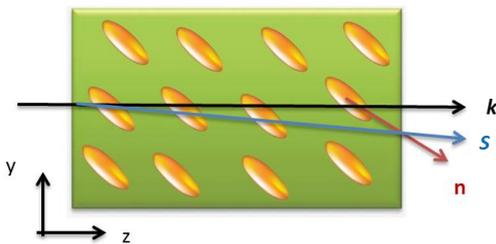


Fig. 1. Planar NLC cell for the study of nematicons. A y -polarized input beam can reorient nematic liquid crystals and produce self-focusing into a spatial soliton S propagating in the plane yz at a walk-off angle δ with respect to the wave vector k/z . The director \mathbf{n} was set at an initial orientation $\theta=\pi/4$.

Nematicons were generated by launching a 3mW y -polarized continuous-wave Gaussian laser beam of wavelength $\lambda=1.064\mu\text{m}$ into a 3mm long cell, monitoring the beam evolution in yz with an optical microscope and a charge-coupled device camera able to image the out-of-plane scattered light.

Figure 2(a) shows a typical spatial soliton with a wavevector along z but Poynting vector S at the walk-off angle δ , due to the birefringence of the positive uniaxial [36]. Figure 2(b) graphs various realizations of nematicon trajectories for a fixed excitation within a time interval Δt of about 4.5s: due to transverse fluctuations, the solitary paths are distributed within a cone (seemingly distinct origins are just an artefact of the image fits).

Then, we illuminated the NLC sample with an ultraviolet (incoherent) continuous-wave light source (LED lamp) at $\lambda=365\text{nm}$, with the power density $5\text{mW}/\text{cm}^2$, and monitored the soliton trajectories in fixed intervals of 4.5s versus the UV exposure time. Noteworthy, since the dopant is a monomer and no photo-initiator was introduced in the mixture, no polymerization was expected as such. However, as shown in Fig. 3(a-b), the fluctuations were progressively quenched upon prolonged UV exposures. We attribute this behavior to weak partial polymerization of the acrylate groups.

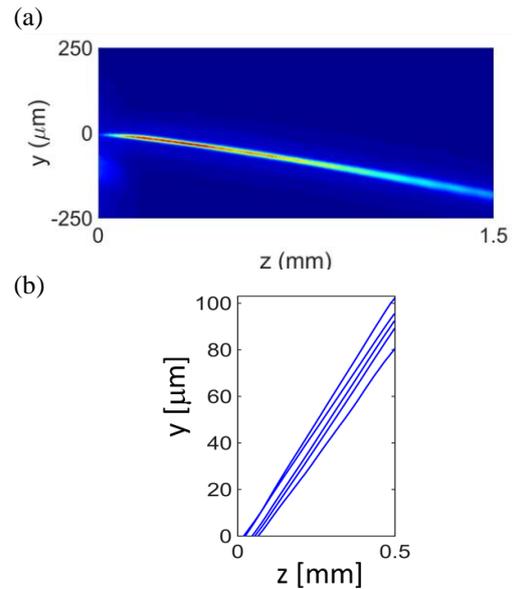


Fig. 2. (a) Color-coded photograph of a typical self-trapped spatial soliton excited by a 3mW near-infrared beam. (b) Soliton trajectories of several nematicons randomly acquired within a time interval of about 4.5s.

From the graphs, a substantial decrease in the angular span of (3mW) nematicon fluctuations with increasing UV exposure is apparent, with a path-cone of aperture nearly halved after 2 hours, as compared to the case before the exposure (Fig. 2(b)). Despite the extended UV illumination and reduced fluctuations, transverse light confinement was not appreciably affected, i.e. the nonlinear (reorientational) response of the sample did not undergo any degradation.

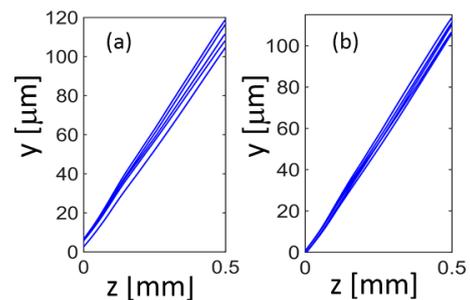


Fig. 3. Various realizations of nematicon trajectories in the plane yz within a time interval $\Delta t=4.5\text{s}$, after UV exposure times of (a) 1.5h and (b) 2h, respectively.

In conclusion, the tested new doped-NLC system exhibits lower transverse instabilities without penalty on all-optical reorientation. Such an improved response, consistent with the previous reports in polymer stabilized liquid crystals [33-35], can be attributed to modified

viscosity or elasticity through partial polymerization, even though neither cross-linkers nor photo-initiators were present. These results are promising towards the all-optical generation of robust and temporally stationary guided-wave structures for optical signal processing.

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