Light induced waveguides in nematic liquid crystals

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Abstract—Spatial optical solitary waves in media with nonlinear refractive index are self-localized beams as well as waveguides induced by light. We review their guiding features in reorientation-birefringent soft matter, namely nematic liquid crystals, for which a highly “nonlocal” response enhances the confinement, stabilization and robustness of the generated optical solitary waves, termed “nematicons.” The waveguiding properties of spatial solitons in nematic liquid crystals are illustrated through the confinement of low power signals and other solitary waves, as well as optical vortices.

Index Terms—Solitons, Liquid crystals, Nonlinear optics, Optical solitons, Optical vortices

I. INTRODUCTION

Nematic liquid crystals can be considered an ideal medium for exploring nonlinear optical effects and light manipulation [1], [2]. This is due to their “huge” nonlinearity and negligible absorption, so that nonlinear optical effects occur at power levels of the order of milliwatts and over millimeter distances. Nematic liquid crystals (NLC) belong to a broad class of materials termed soft matter, in that they form an elastic medium which can flow while maintaining a finite order, hence their name [3]. In standard forms, they consist of elongated organic molecules which, in the nematic phase, possess a large degree of orientational order, but negligible positional order. NLC molecules contain benzine rings, so that their electrons exhibit a high non-localization and can easily move in the presence of an electric field, giving rise to dipoles which can be rotate, opposing the intermolecular links (elastic forces) in order to align to the field vector and so reduce the interaction energy. Such a “reorientational” response manifests itself both as an electro-optic effect and as an all-optical nonlinearity. For the latter, since “reoriented” dipoles correspond to a “rotated” optic axis (or molecular director) in the macroscopic uniaxial dielectric, the refractive index increases in a nonlinear manner under the action of light in the extraordinary polarization, i.e. with electric field coplanar with the wavevector and optic axis [3]. Therefore, beams of light with polarized electric field non-orthogonal to the molecular director can undergo self-focusing through all-optical reorientation, eventually balancing diffraction and supporting the generation of self-confined transversely invariant spatial solitary waves, or simply solitons. The term “nematicon” refers to such self-trapped beams and the corresponding refractive index potentials or waveguides in nematic liquid crystals [1], [2], [4].

Optical solitary waves in nematic liquid crystals, nematicons, have been proposed as the basis for all-optical circuits [4], [5], [6], with several functionalities relying on their use as reconfigurable/readaddressable waveguides. Here we will review some of the configurations proposed for nematicon waveguide applications. Nematicon waveguides can be controlled through external electric fields [1], [7] or by interaction with other optical beams [1], [8], [9], [10], [11], [12], [13]. Since nematicons are nonlinear optical beams, they can alter their uniaxial environment and so change their own path [14]. Furthermore, since NLC are nonlocal in that the response to an optical beam extends far beyond its waist [1], [2], [15], nematicons can act on each other at a distance through the medium [16], [17], [18]. Finally, a nematicon waveguide can stabilize beams which tend to become unstable upon interacting with, for example, refractive index perturbations [19], [20], [21]. In the following we shall address these features and properties of nematicon waveguides.

II. GOVERNING EQUATIONS

Let us consider the propagation of a linearly polarized beam of light through a planar cell filled with undoped nematic liquid crystals. Let the propagation direction of the beam be \( z \) and the direction perpendicular to the confining interfaces be \( x \), with \( y \) completing the coordinate triad. The complex valued envelope of the electric field of the beam will be denoted by \( u \).

To overcome the optical Freedericksz threshold [3] occurring when field and director are orthogonal, the nematic molecules are pre-tilted at an angle \( \theta_0 \) to the propagation direction. This is achieved by either applying a low frequency electric field (bias voltage) across the cell thickness in the \( (x,z) \) plane or by “rubbing” the planar interfaces of the cell, so that the director is aligned to the rubbing direction in the \( (y,z) \) plane, with this alignment spread into the bulk via the intermolecular links. The angle \( \theta \) will then denote the extra nonlinear rotation given to the molecules (director) by the light beam, so that the total angle the director makes to the \( z \) direction is \( \theta_0 + \theta \). The non-dimensional equations governing the propagation of light in the paraxial, slowly varying envelope approximation are [1], [2], [15], [22], [23]

\[
i \frac{\partial u}{\partial z} + \frac{1}{2} \nabla^2 u + 2\theta u = 0, \tag{1}
\]

\[
\nu \nabla^2 \theta - 2q \theta = -2|u|^2. \tag{2}
\]

Equation (1) governs the evolution of the electric field of the light beam, with equation (2) giving the resulting NLC

G. Assanto is with NooEL—Nonlinear Optics and Optoelectronics Lab University of Rome “Roma Tre”, 00146 Rome, Italy and Optics Lab, Tampere University of Technology, FI-33101 Tampere, Finland email: as-santo@uniroma3.it

N.F. Smyth is with School of Mathematics, University of Edinburgh, Edinburgh EH9 3FD, Scotland, U.K. email: N.Smyth@ed.ac.uk
response in terms of the reorientation angle. These equations form a coupled system. The Laplacian in these equations is in the transverse \((x, y)\) plane. The parameter \(\nu\) measures the strength of the elastic forces (nonlocality) in the NLC and is \(O(100)\) in most experimental regimes [1], [24], [25]. The parameter \(q\) is proportional to the square of the pre-tilting electric field across \(x\) or related to the rest angle in the case of “rubbing” in \(yz\) [15], [26]. As inherent to the propagation of extraordinarily polarized light in uniaxials, the Poynting vector (power flow direction) for the extraordinary beam is at a “walkoff” angle to the input direction of its wavevector, around a maximum value of \(7^\circ\) in NLC with the usual birefringence of about 0.2 [1], [2]. The walkoff, associated with nonlinear beams as well [1], [2], has been factored out of the electric field equation (1) by a phase transformation [18], [27]. A typical cell thickness is \(75\mu m\) and a typical input beam width is \(4\mu m\) for visible/near infrared wavelengths [28]. As the electric field \(u\) and the director angle perturbation \(\theta\) decay exponentially away from the beam profile, the effect of the cell interfaces can be neglected for beams launched along \(z\) around the middle of the cell across \(x\). We shall therefore take the NLC sample to be infinite when deriving solutions of the nematic equations (1) and (2).

While the system of equations (1) and (2) has been derived for optical beam propagation in nematic liquid crystals, it is more general and holds for nonlinear beam propagation in media whose response is governed by some type of diffusive phenomenon [29]. For example, the system of equations (1) and (2) governs light beam propagation in thermo-optic media [30], such as lead glasses [31], [32], [33], and in photorefractive crystals [34], [35]. The same system also arises in \(\alpha\) models of fluid turbulence [36], [37] and in the Schrödinger-Newton model of quantum gravity [38], [39].

The nematic equations (1) and (2) possess a solitary wave solution, termed a nematicon [1], [2], [4], [26]. Numerical methods can be used to find this nematicon solution [40], [41], [42], but there is no known general analytical nematic solution, just specific ones for fixed parameter values of \(\nu\) and \(q\) [43]. A nematicon is formed by a balance of the nonlinear self-focusing in the NLC with linear diffractive spreading [1], [2]. The corresponding refractive index distortion is a graded-index waveguide, able to confine other optical signals [26], with or without angular momentum. A nematicon waveguide can also stabilize, or enhance the stability of, a co-propagating optical beam.

For the numerical solutions of the nematic equations presented in this work, the electric field equation (1) and its extensions dealt with below were solved using the pseudospectral method of Fornberg and Whitham [44]. The elliptic director equation (2) and its extensions were solved using a Fourier method outlined in [45].

III. NEMATICON WAVEGUIDES

The waveguiding capabilities of a nematicon were detailed in the early work in which a nematicon was experimentally demonstrated by exploiting the reorientational response of undoped NLC [26]. The guidance of a longer wavelength signal (632.8 nm) by a fundamental order solitary wave launched at 514 nm was supported by the large numerical aperture associated with the nonlocal response of the NLC [26], a property responsible for the formation of nematicons, even with spatially incoherent light [24], [43], [46]. The formation of a nematicon waveguide from a 1064 nm Nd:YAG laser of power 2.0 mW and the confinement of a co-propagating weak, 30 \(\mu\)W copolarized probe from a Helium-Neon laser of wavelength 632.8 nm is illustrated by photographs in Figure 1 for the case of a cell with optic axis planarly aligned at 45° with respect to \(z\). Figure 1(a) shows the evolution of a low power (i.e. linear) beam which diffracts, since it does not carry enough power to form a nematicon, and propagates with walkoff (about \(7^\circ\)) with respect to its wavevector along \(z\). A red low power probe beam, colaligned and copolarized with input electric field oscillating along \(y\), also diffracts and spreads in the transverse \((x, y)\) plane, as seen in Figure 1(b) after propagating over 1 mm. For an input nonlinear beam of sufficient power, a defractionless nematicon is formed, as in Figure 1(c). This nematicon is also a waveguide for the weak probe, which gets confined, as shown in Figure 1(d). The red light does not diffract and remains confined and bell shaped in \((x, y)\) at the cell output.

This guiding of a low power signal by a nematicon was extended in a recent numerical and theoretical study of the interaction between two such beams [47]. This study included a detailed investigation of how the trajectory of the nematicon could be controlled by the low power beam, with trajectory deviation resulting from momentum exchange between the beams.

Reorientational nematic liquid crystals are a self-focusing medium, so that regions of higher beam intensity tend to exhibit higher refractive index. However, a light-induced reduction in the order parameter through the introduction of dopants, such as azo-dyes, can turn the NLC into a self-defocusing medium, so that dark solitary waves can be excited [48]. For a defocusing NLC, the electric field equation (1) becomes

\[
\frac{\partial u}{\partial z} + \frac{1}{2} \frac{\partial^2 u}{\partial x^2} - 2\theta u = 0
\]
for one-dimensional dark solitons [49]. The self-defocusing nematic equations (2) and (3) support dark nematicons, solitary waves which are dips in a background carrier wave, rather than the intensity hump of the “bright” nematicons of the focusing equations (1) and (2).

Dark nematicon solutions on a constant background are of the form

\[ u = f(x - Uz)e^{-2iuqz^2/q}, \]  

(4)

for a (complex) function \( f \) which gives the dark nematicon profile [50]. A typical dark nematicon solution is shown in Figure 2 and differs from the dark soliton solution of the nonlinear Schrödinger equation [49]. This can be seen in Figure 2 as two humps in the electric field at the tails of the dark nematicons. These humps are due to a linear wave mode trapped in the tail of the dark nematicon owing to the nonlocal response of the NLC [50] which extends well beyond the beam. A mathematical dark nematicon (4) differs from an experimental dark nematicon: the former has a carrier wave which extends to \( x = \pm \infty \), whereas in the latter the carrier wave has a finite extent, often Gaussian. Nevertheless, in both limits dark nematicons are associated with a coaxial graded-index waveguide supporting the guided co-propagation of a (bright) linear signal. This property was exploited to experimentally guide a longer wavelength copolarized probe in a dark nematicon [48].

Figure 3 shows simulated and experimental results obtained in an azo-doped NLC cell with resonant absorption around 475nm. In Figure 3(a) the simulated diffraction of a linear (bell shaped) beam with a central dip (top) is compared with the simulated evolution of a dark nematicon (bottom). As expected, the low power beam diffracts (the notch gets wider), whereas the high power nematicon remains self-confined. The corresponding experimental results for extraordinary polarized light in Figure 3(b) show a low power (0.1mW) dark beam at 532nm diffracting along \( z \) (top), whereas at high power (4mW) it gives rise to a self-confined dark nematicon. The propagation of a weak (0.1mW) copolarized bell-shaped probe at 1064nm is illustrated in Figure 3(c). When colaunched in the low power dark beam, the probe diffracts as expected (top), whereas when the dark nematicon is formed, the near-infrared signal is trapped by the dark nematicon waveguide (bottom) [48].

IV. MUTUALLY GUIDING NEMATICONS

Being nonlinear waveguides, nematicons can produce confining effects not only on weaker probes, but also on other nonlinear beams and nematicons. Let us first consider the incoherent interaction of two nematicons of different wavelengths (colors), as discussed in [18], [17]. The extension of the (non-dimensional) nematic equations (1) and (2) to this two color case is [51]

\[ i\frac{\partial u}{\partial z} + \frac{1}{2}D_u\nabla^2 u + 2A_u\theta u = 0, \]  

(5)

\[ i\frac{\partial v}{\partial z} + \frac{1}{2}D_v\nabla^2 v + 2A_v\theta v = 0, \]  

(6)

\[ \nu\nabla^2 \theta - 2q\theta = -2A_u|u|^2 - 2A_v|v|^2. \]  

(7)

Here \( u \) and \( v \) are the complex valued envelopes of the electric fields of the two beams. As the two beams have different wavelengths, they have different diffraction coefficients \( D_u \) and \( D_v \), and interaction strengths \( A_u \) and \( A_v \) with the NLC. For instance, for the experiments of Alberucci et al [51] the diffraction coefficients were 0.805 for red and 0.823 for near-infrared light, respectively. The initial beams in the modes \( u \) and \( v \) can be taken to be

\[ u = a_u\text{sech}\frac{\nu}{w_u}e^{i\psi_u}, \quad v = a_v\text{sech}\frac{\nu}{w_v}e^{i\psi_v}, \]  

(8)
and so reduces the amplitude of their oscillations about each other until they share the same trajectory [18]. Due to the large nonlocality \(\nu\), this occurs over a very long \(z\) distance as the loss to radiation scales as \(1/\sqrt{\nu}\) [52].

V. NEMATICONS GUIDING OPTICAL VORTICES

Let us now consider the guidance of an optical vortex by a co-propagating nematicon, as studied in [19], [20], [21]. As expected on the basis of the highly nonlocal medium response, the nematicon acts as a waveguide even for a vortex: while an isolated vortex could not survive interaction with an index perturbation or interface and undergo stable refraction, in the presence of a coaxial nematicon it gets stabilized by the nonlinear index potential and can be deviated/refracted [19], [20], [21]. We consider a nematicon and a vortex to be generated from polarized beams of the same wavelength, so that we can take \(D_u = D_v = 1\) and \(A_u = A_v = 1\) in terms of the two color nematic equations (5)–(7). The NLC can have an imposed refractive index potential generated, for instance, by voltages applied across its thickness [11], [12], [13], by finite light beams travelling through the cell [8], [9], [10] or nonuniform anchoring. If this index potential has the general form \(F(x, z)\), the non-dimensional equations governing the guiding of the optical vortex by the nematicon are [2], [51], [53]

\[
\frac{du}{dz} + \frac{1}{2}\nabla^2 u + 2F(x, z)u + 2\theta u = 0, \tag{12}
\]

\[
\frac{dv}{dz} + \frac{1}{2}\nabla^2 v + 2F(x, z)v + 2\theta v = 0, \tag{13}
\]

\[
\nu\nabla^2 \theta - 2q\theta = -2|u|^2 - 2|v|^2. \tag{14}
\]

The initial beams are taken to be

\[
u = a_v e^{-r^2/w_v^2} \frac{e^{i\sigma_u+iU_v(x-\xi_u)}}{w_v} \tag{15}
\]

\[
\frac{d\xi_u}{dz} = D_u U_u, \quad \frac{d\xi_v}{dz} = D_v U_v. \tag{11}
\]

As the initial “velocities” \(U_u\) and \(U_v\) for the trajectories in Figure 4 are not equal and opposite, the mean trajectory of the nematicon pair has a non-zero transverse “velocity”. In addition, the unequal diffraction coefficients \(D_u\) and \(D_v\) contribute to produce different trajectories. As the two solitary waves oscillate about each other, they shed diffractive radiation, which takes away momentum from the nematicons and so reduces the amplitude of their oscillations about each other until they share the same trajectory [18]. Due to the large nonlocality \(\nu\), this occurs over a very long \(z\) distance as the loss to radiation scales as \(1/\sqrt{\nu}\) [52].

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The sample. Therefore, these light induced guides can be other optical beams or by the application of voltages across the presence of other optical waves, nematicons, can be formed in a manner similar to other forms of optical waveguides. There are, however, a number of advantages of nematicons as optical waveguides. Nematicon trajectories can be changed by the presence of other optical beams or by the application of voltages across the sample. Therefore, these light induced guides can be redirected and so form readdressable “circuits” to guide other signals. Nematicons can also form waveguides for high power, nonlinear optical beams, such as other nematicons. They have the further advantage of stabilizing beams, such as vortices, which can otherwise become unstable when their trajectory is changed by, for instance, regions of varying refractive index. Furthermore, since nematicons are nonlinear optical beams, the nonlinear interaction between a nematicon and another beam can be used to change the trajectories of either, or both, so that the waveguide layout becomes power dependent, with potential applications to signal control and routing. Such beam-on-beam control can be achieved in a number of different ways, with fine all-optical control by adjusting beam width and power.

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REFERENCES

E.A. Kuznetsov and A.M. Rubenchik, “Soliton stabilization in plasmas”.


A. Alberucci, A. Fratalocchi, M. Peccianti and G. Assanto, “Steering of optical solitary waves by coplanar low power beams in reorientational media.”

M. Peccianti and G. Assanto, “Incoherent Spatial Solitary Waves in Nematic Liquid Crystals.”


M. Peccianti and G. Assanto, “Spatial solitons in quadratic and soft media, Ge-on-Si detectors.”


W. Bao and Q. Du, “Computing the ground state solution of Bose-Einstein condensates by a normalized gradient flow.”

G. J. Lord, D. P. Hof, B. Sandstede and A. Scheel, “Numerical computation of solitary waves in infinite cylindrical domains.”

J. Yang “Newton-conjugate-gradient methods for solitary wave computations.”


M. Peccianti and G. Assanto, “Nonlinear versus Kerr dark and grey solitary waves using modulation theory.”


Gaetano Assanto obtained an M.Sc. degree with honours from the University of Palermo, Italy in 1981 and a Ph.D. in optics from the University of Arizona, Tucson, Arizona in 1987.

He was a research associate at the Optical Sciences Center at the University of Arizona from 1988 to 1990 and a senior research scientist with CREOL, University of Central Florida from 1990 to 1992. He is currently Professor of Optoelectronics with the University of Rome “Roma Tre” and head of NooEL, the Nonlinear Optics and OptoElectronics Lab. His interests include parametric effects for all-optical processing, spatial solitons in quadratud and soft media, Ge-on-Si detectors for the near infrared, nonlinear optics in liquid crystals.

Dr. Assanto is a Fellow of the IEEE (Photonics Society), a Fellow of OSA and topical editor of various journals, including Optics Letters, Nature Scientific Reports and IOP Journal of Optics.

Noel F. Smyth was born in Brisbane, Queensland, Australia in 1958. He received his B.Sc. (honours) in mathematics from the University of Queensland, Brisbane, Queensland in 1980 and his Ph.D. in applied mathematics from the California Institute of Technology, Pasadena, California in 1984.

Between 1984 and 1987 he was a post-doctoral fellow at the California Institute of Technology, the University of
Melbourne and the University of New South Wales. He was a lecturer in the Department of Mathematics and Applied Statistics at the University of Wollongong between 1987 and 1990. Since 1990 he has been in the School of Mathematics at the University of Edinburgh, first as a lecturer (1990–1999), senior lecturer (1999–2004), reader (2004–2009) and finally professor of nonlinear waves (2009–present). He is the author of 4 book chapters and 122 articles. His research interests are in the general area of linear and nonlinear waves and nonlinear optics, including solitons, water waves, bores and waves in oceanography and meteorology.

Professor Smyth is a member of the American Physical Society, the Optical Society of America, the Society for Industrial and Applied Mathematics and the Australian Mathematical Society. He is a Senior Member of the Optical Society of America.