Signal processing by opto-optical interactions between self-localized and free propagating beams in liquid crystals

Alessia Pasquazi, Alessandro Alberucci, Marco Peccianti and Gaetano Assanto
NooEL - Nonlinear Optics and OptoElectronics Laboratory Department of Electronic Engineering and National Institute for the Physics of Matter - INFM-CNISM University “Roma Tre”, Via della Vasca Navale 8i, 00146 Rome - Italy
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The reorientational nonlinearity of nematic liquid crystals enables a self-localized spatial soliton and its waveguide to be deflected or destroyed by a control beam propagating across the cell. We demonstrate a simple all-optical readressing scheme by exploiting the lens-like perturbation induced by an external beam on both a nematicon and a co-polarized guided signal of different wavelength. Angular steering as large as 2.2 degrees was obtained for control powers as low as 32mW in the near infrared.

Optical spatial solitons, i.e. self-localized light beams in nonlinear media, are excellent building blocks for all-optical signal processing. In Kerr-like media with a self-focusing response, spatial solitons can also confine a signal which propagates un-diffracted in the corresponding waveguide. Owing to their “particle-like behavior”, spatial solitons have been exploited in several configurations and materials for optical signal readressing, logic gating and switching. In most configurations, however, spatial solitons were required to interact with other solitons or beams over propagation lengths of magnitude larger than their transverse size. Recently, the highly non local and non-resonant molecular response of undoped nematic liquid crystals (NLC) has enabled the demonstration of stable (2+1)-dimensional spatial solitons (or nematicons) and their interactions at mW power levels. In this Letter, based on the large molecular nonlinearity of NLC (several orders of magnitude higher than in CS$_2$), we demonstrate all-optical readressing of spatial solitons via the lens-like perturbation induced by an external beam propagating across the medium.

NLC consist of anisotropic rod-like molecules which tend to be aligned in a specific direction owing to intermolecular forces, anchoring at the interfaces, an electrostatic (or in general low-frequency) or magneto-static bias. Fig. 1(a) shows a typical cell arrangement in the presence of an external voltage to pre-tilt the molecules and facilitate their all-optical response. An external polarization-lit beam can reorient the molecules towards the field vector due to (induced) dipolar reaction. Such reorientation results in a self-focusing (an extraordinary index increase) because of the medium birefringence; this response is also non local because of the elastic forces binding the molecules to one another. When diffraction is balanced by nonlinearity, a nematicon is obtained: its own graded-index waveguide also able to guide a co-polarized (weak) signal even at a different wavelength (see Fig. 1(b)).

An external z-polarized (control) beam propagating through the NLC cell can also induce an index perturbation owing to reorientation (see sketch in Fig. 1 (a) and (c)). Such perturbation can overlap the refractive distribution due to the voltage bias and the nematicon when launched. Defining $\theta$ the angle between the light wave vector and the molecular major axis (or director), the perturbation can be evaluated by considering both the low-frequency bias and the control beam of electric field amplitudes $E_{RF}$ and $E_c$, respectively:

$$K\nabla^2\theta + \epsilon_0\left(\frac{1}{2}\Delta\epsilon_{RF}|E_{RF}|^2 - \frac{1}{4}\epsilon_a|E_c|^2\right)\sin(2\theta) = 0 \quad (1)$$

as well as the propagation of the external beam across the non-homogeneous sample:

$$2ik\frac{\partial E_c}{\partial x} + \nabla_{yz}^2 E_c + k_0^2(n(\theta)^2 - \bar{n}^2)E_c = 0 \quad (2)$$

being $\Delta\epsilon_{RF}$ and $\epsilon_a$ the dielectric anisotropies at low and optical frequencies, respectively, $K$ the NLC elastic constant (averaged over all molecular distortions), $k=2\pi\bar{n}/\lambda=\kappa\bar{n}$ the wave number with $\lambda$ the wavelength, $\bar{n}$ and $n(\theta)$ a reference and the extraordinary refractive indices, respectively. Coupled equations (1) and (2) were numerically integrated with reference to a cell of thickness $h=75\mu$m, the liquid crystal E7 ($K=1.9\times10^{-11}$N,
two beams after the Y-stem were self-localized or diffracted.

Noteworthy, compared to previous soliton steering, the...
FIG. 4: Nematicon trajectories in the $yz$ plane for various $P_c$. The control beam had a waist of 8 µm and was centered in $\Delta y = 9$ µm.

demonstrated scheme requires a very short interaction region. Thereby repeated all-optical deflections and more complex logic and routing schemes could be per-

FIG. 5: Steering angle $\alpha$ versus control power $P_c$. Parameters are as in Fig. 4.

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