Properties of nematicons in low-birefringence nematic liquid crystals

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Abstract—We investigate a nonlinear self-focusing and nematicon generation in low birefringence nematic liquid crystals (NLCs), where $\Delta n \approx 0.04$. Nematicons are obtained for larger optical powers but they are more stable than in NLCs with standard birefringence, of the order of $\Delta n \approx 0.2$. Moreover, in low-birefringent NLCs, polarization components exchange energy in a nonlinear regime. Such behaviour is not observed in typical NLCs, where ordinary and extraordinary waves tend to propagate independently due to large walk off. The results of our experimental test are also compared with numerical simulations, using a fully vectorial BPM. Calculations and experimental results are in good qualitative and quantitative agreement.

Optical spatial solitons in nematic liquid crystals (NLCs), commonly referred to as nematicons, result from balancing diffraction with self-focusing due to reorientational nonlinearity [1]-[2]. This type of nonlinearity derives from changes in the refractive index in a liquid crystalline medium caused by the intensity of light. With the increase of light intensity the optic axis of NLCs changes its direction and a gradient profile of the refractive index is formed. Therefore, an optically induced nonlinear waveguide is formed and it supports light guiding. Such a trapped light beam propagates without spreading over distances up to several millimeters. Nematicons have been demonstrated and investigated in several NLCs geometries, including planar [3], homeotropic [4], twisted and chiral [5-6]. A large electro-optic response of liquid crystals combined with highly nonlocality allows for precisely controlling the trajectory of nematicons by using either external electric fields or completely optical methods, through interaction with the intensity of additional beam(s) [2].

The excitation of nematicons in planarly oriented NLCs samples is associated with the Freedericksz threshold [7], which can be avoided by pre-tilting molecules by external electric fields or by rubbing the inner sides of the cell to provide proper alignment. When the director **n** is not perpendicular to the electric field vector, reorientation occurs continuously [8]. Since the mutual orientation of molecular director and electric field of EM wave vectors affects the NLCs nonlinearity, the polarization and optical intensities required for nematicon generations vary together with the beam launch conditions.

This work addresses nematicon propagation in a low-birefringence planarly oriented sample of NLCs. By launching a light beam in the *yz* plane (Fig. 1), at arbitrary angles α relative to the director, the optimal conditions for self-trapping can be defined. A good agreement between experimental results and fully vectorial simulations of beam propagation was achieved [9]. The propagation properties of nematicons were checked for two NLCs mixtures which possess low- and standard value of birefringence, respectively.

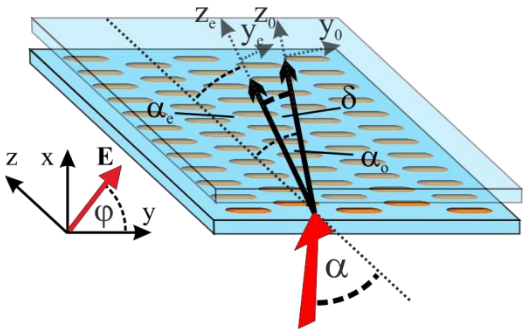

Fig. 1. Configuration of NLCs sample and beam excitation.

The planar liquid crystal sample, with a separation d=50μm between the glass slides, is shown in Fig. 1. The cell was filled with a low birefringence NLCs (1110 mixture synthesized at the Military University of Technology), with ordinary and extraordinary refractive indices equal to n_0=1.45 and n_e=1.49, respectively. The linearly polarized light source was a Nd:YAG laser operating at λ=1064nm, with a combination of a polarizer and a half wave plate to control the input power and polarization. The beam was focused at the entrance of a cell by a 20x microscope objective, which results in a beam waist w_0=3.8μm. For a fixed orientation (described by the angle α in a range of 0°÷45°) self-focusing was analysed for various light polarizations, including the

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cases $\boldsymbol{E}||x$ (φ=90°), $\boldsymbol{E}||y$ (φ=0°), as well as the intermediate states. For clarity, the images of light propagation acquired by a high resolution CCD camera are presented in a y_0z_0 reference frame, where z_0 is along the wave vector of an ordinary input wave.

In low birefringence liquid crystals the minimum optical power required for self-trapping is higher (about 2-3 times) than in LCs with typical values of Δn, both nematics [10] and cholesterics [5]. A low birefringence implies also a smaller walk-off, the angular separation between ordinary and extraordinary waves (Poynting vectors). Its maximum calculated value for 1110 is δ=1.6°, at variance with δ=7° in 6CHBT (4-trans-4'-n-hexyl-cyclohexyl-isothiocyanatobenzene) [11], for which refractive indices are n_o=1.51 and n_e=1.67 in the near infrared.

Figure 2 presents results on numerical propagation of light beams polarized at φ=45° with respect to the propagation plane in the two NLCs mixtures. All simulations were performed in geometry with an input wave vector parallel to z_0 and director initially oriented at $-\alpha_e$ with respect to z_0. This assumption significantly simplifies the calculations, while it is consistent with the experimental conditions.

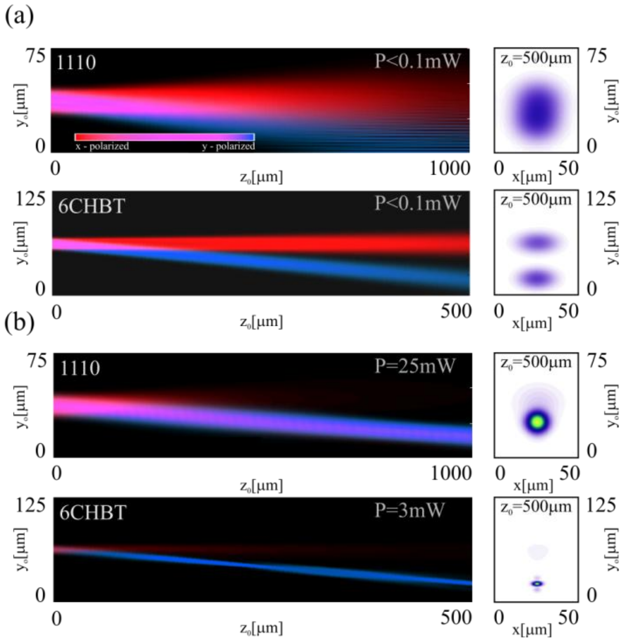

Fig. 2. Numerically simulated beam evolution in y_0z_0 for α=45° and φ=45°. Propagation results are presented in linear (a) and nonlinear cases (b) for two NLCs mixtures with different Δn. The initial width of the beam was w_0=7.65μm.

In the linear case (Fig. 2a) both waves (ordinary and extraordinary) undergo diffraction and propagate independently along their own paths. At the end of the cell, in the xy_0 plane, the beams are clearly separated. When the input optical power is high enough to induce nonlinear changes in refractive index distribution, the extraordinary beam starts to self-collimate and, for P=25mW (1110) or P=3mW (6CHBT) a nematicon is formed (Fig. 2b). Self-trapped beams induced by two polarization components exhibit a diffractive background, caused by energy exchange between ordinary and extraordinary components. These results are confirmed experimentally.

Figure 3 shows the beam evolution for three input polarizations, whereas the launching direction and optical power remained constant. Firstly, the ordinarily polarized light (φ=90°) diffracts for optical powers up to about 100mW. Temporally unstable nematicons are formed when thermo-optic instabilities entail convective molecular motion above the Freedericksz threshold. For an extraordinarily polarized beam (φ=0°) molecular alignment in the same plane of the wave vector is the best in terms of energy needed for their spatial redistribution in the y_0z_0 plane. In this case the optical power required for nematicon generation is the lowest, about P=15mW. Mixed polarization light beams with the same optical power are also capable of inducing nematicons but, due to power coupling between polarization components, the extraordinary part of the beam is less confined and a blurred diffractive background is observed. However, by increasing the input power above 20mW, an increased self-focusing takes place. As the optical power rises, more and more energy in the x–polarized beam is trapped, which results in reducing the background in the proximity of nematicons.

On the other hand, keeping the polarization of the beam fixed but changing the input angle α from the optimum value of 45° to 0°, self-confinement takes place for higher and higher powers. In the case of normal incidence (α=0°) x–polarized light undergoes a threshold effect with unstable propagation in the nonlinear limit. Conversely, for y–polarized beams no reorientation takes place and light diffracts independently from the excitation power.

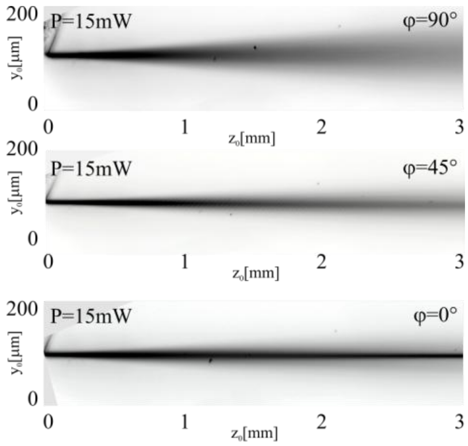

Fig. 3. Experimental results on evolution of a beam launched at α=45°, P=15mW for three different polarizations φ=(0°, 45°, 90°) in the y_0z_0 reference plane.

In addition to the extended propagation distances of nematicons, another very important factor is their stability. Considering the best case, when the reorientation of molecules occurs in the y_0z_0 plane and the minimum optical power is needed for the formation of nematicons, the stability of a self-guided wave can be studied as the time dependent location of a nematicon at the end of the system. Such analysis is presented in Fig. 4 and reports the output positions of two beams after a propagation distance z_0=4mm. Both beams are launched at α=45° and polarized at φ=(0°, 45°). In both cases the maximum trajectory deviation from the mean value is less than 5 microns. The separation between nematicons generated by differently polarized beams and measured in the observation plane (xy_0) is about 23µm. Noticeably, the fluctuations of beam position are smaller when polarized at φ=0° due to the absence of an ordinary component.

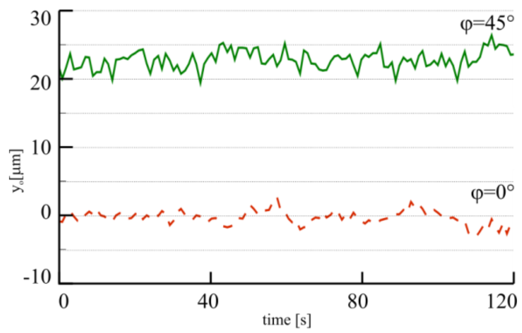

Fig. 4. Output position of nematicons in z_0=4mm, in the case of extraordinary wave excitation (φ=0°, P=15mW, dashed line) and mixed-polarized input beam (φ=45°, P=20mW, solid line).

Concluding, low birefringence nematic liquid crystals support stable nematicon propagation over distances of 4mm but require larger optical powers as compared with NLCs with typical birefringence. Optimum self-focusing is achieved when the wave vector **k** and the molecular director **n** form an angle α=45° and propagation concerns an extraordinarily polarized beam (φ=0°). Contrary to the evolution of light beams in high birefringence NLCs, in the present case nonlinear propagation leads to a coupling between ordinary and extraordinary wave components.

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