Mol. Cryst. Liq. Cryst., Vol. 527: pp. 92/[248]–97/[253], 2010

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2010.486630

Nematicons Interaction in Chiral Nematic Liquid Crystals

URSZULA A. LAUDYN, MICHAL KWASNY, AND MIROSLAW A. KARPIERZ

Faculty of Physics, Warsaw University of Technology, Warsaw, Poland

Recently, it has been shown experimentally that due to the reorientational nonlinearity in nematic liquid crystals (NLCs) it is possible to generate self-trapped non-diffractive light beams for relatively low power. Such spatial solitary waves in NLCs are called nematicons. Very interesting and promising properties have nematicons in chiral nematic liquid crystals (ChNLCs), where the incident light propagates perpendicular to the helical axis.

In this work we report on the experimental studies of the existence of nematicons in such ChNLCs cells. We show that it is possible to utilize multi-layers for propagation of independent and interacting nematicons.

Keywords Nematicons; reorientational nonlinearity; spatial solitons

Nematic liquid crystals are very attractive medium in optoelectronics. This is caused by the fact that liquid crystals have very large birefringence and external fields can easily reorient the birefringent axis. This reorientation can be induced by external electric fields and also by the electric field of light waves [1–3]. The latter is the basic of the reorientational optical nonlinearity in liquid crystals. Due to the reorientational nonlinearity it is possible to generate self-trapped non-diffractive light beams (spatial solitons) for relatively low power, called nematicons [4]. They are light beams that do not spread because of the balance between diffraction and self-focusing, i.e., their size is unchanged during propagation. They can be applied in all-optical switching and routing systems. It has been demonstrated that spatial solitons can be effectively generated in nematic liquid crystals at propagation distance of few millimeters [5,6]. Very interesting and promising properties have nematicons in chiral nematic liquid crystals (ChNLCs), where the incident light propagates perpendicular to the helical axis [7]. Soliton interaction have been studied extensively in all types of materials [8], including nematic liquid crystals [9,10]. Depending on the initial geometry and the strength of the nonlinearity, the two beams interaction can have different outputs, i.e., solitons can propagate parallel to each other, drag each other, pass through each other or merge in a single self-confined beam. In this

Address correspondence to Miroslaw A. Karpierz, Optics and Photonics Division, Faculty of Physics, Warsaw University of Technology, Koszykowa 75, Warsaw 00-681, Poland. Tel.: 48 222347277; Fax: 48 226282171; E-mail: karpierz@if.pw.edu.pl

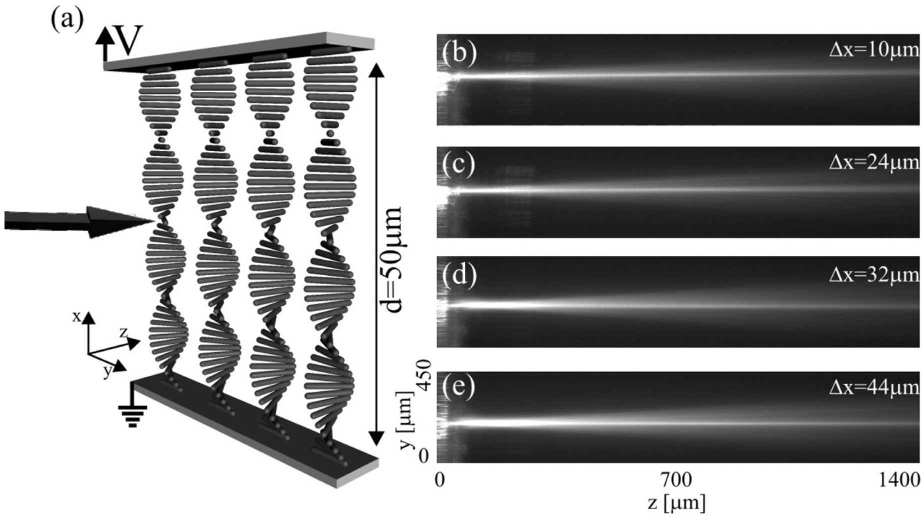

Figure 1. (a) Configuration of the analyzed nematic liquid crystal cell; (b–e) Experimental results of creation spatial solitons in different layers across the ChNLC cell for different input vertical positions marked on photos as Δx.

paper the interactions of solitons in chiral nematic liquid crystals is considered and future perspectives are shown.

Analyzed sample is sketched in Figure 1a. To form ChNLCs a nematic material 6CHBT (4-trans-4′-n-hexyl-cyclohexyl-isothiocyanatobenzene) [11,12] was mixed with a chiral dopant. The mixture has the following properties: pitch $p = 25\,\mu\text{m}$, dielectric anisotropy $\Delta\varepsilon = 8$, Frank elastic constants $K_{11} = 8.8\,\text{pN}$; $K_{22} = 3.7\,\text{pN}$; $K_{33} = 9.5\,\text{pN}$. The ChNLCs sample of thickness $d = 50\,\mu\text{m}$ was confined between a pair of glass plates with transparent indium tin oxide (ITO) electrodes to enable application of the electric field and was initially in the planar texture configuration with the helical axis perpendicular to the cell's surface (Fig. 1a). The y axis is perpendicular to the helix axis and the molecules are twisted in the yz plane, where z is the propagation axis.

The orientation of ChNLC is determined by the anchoring conditions at the boundaries where the interaction with the cell walls (glass plates) introduces boundary orientation. The orientation angle between molecules direction and y axis is initially equal to: $\theta(x) = (2\pi m/d)x$, where m is an integer. Consequently the electric permittivity tensor in such medium has the form:

$$\varepsilon = \begin{pmatrix} \varepsilon_\perp & 0 & 0 \\ 0 & \varepsilon_\perp + \Delta\varepsilon \cos^2\theta & \Delta\varepsilon \sin\theta\cos\theta \\ 0 & \Delta\varepsilon \sin\theta\cos\theta & \varepsilon_\perp + \Delta\varepsilon \sin^2\theta \end{pmatrix} \quad (1)$$

where: $\Delta\varepsilon = \varepsilon_\parallel - \varepsilon_\perp$ represents an optical anisotropy, $\varepsilon_\perp = n_o^2$ is an ordinary and $\varepsilon_\parallel = n_e^2$ is an extraordinary electric permittivity and θ is the angle of orientation between molecules direction and y axis. The x polarized field, connected with E_x component is assumed to be much weaker than the y field connected with E_y

component and the E_x component has a $\pi/2$ phase shift versus the E_y [13]. The y polarized light beam propagates in the vicinity of the region, where the molecules are parallel to the electric field (where the refractive index is the largest). With increase of light intensity, the width of the region with $\theta = 0$ increases and it also increases the effective refractive index. Additionally, increasing of light power modifies the twisting angle what results in the self-focusing of the light beam in y-direction and finally the nematicon creation.

The width of the cell (about 50 μm) and the pitch of the ChNLC (25 μm) resulted in four layers where molecules orientation is the same and hence soliton propagation was allowed in each independent layers. Figures 1b–e show such soliton propgation obtained in each layer. Position $\Delta x = 0$ means, that the light beam propagates at the verge of glass plate and liquid crystals. The nematicon formed in the first layer marked as $\Delta x = 10\,\mu m$ (Fig. 1b) and is repeatable in each next layer about 10–12 μm away from each other (what corresponds to half of the pitch) (Fig. 1c–e).

When a nematicon was generated in one of the layer it induces the channel waveguide which indicates confinement along the y axis. The corresponding guided mode has a dominant E_y component and the largest refractive index change occurs where the liquid crystal molecules orientation is parallel to the y axes. Two beams of equal initial width, equal power forming two identical solitons, induce two identical channel waveguides. When two self-guided beams propagate close to each other, the correspondingly widened refractive index distribution can attract them and drag the solitons toward each other. An attractive force between them can bend their individual trajectories and cause two initially parallel-propagating solitons (or diverging) to connect and then finally collapse into one, third soliton. Additionally time dependence can be observe as the sequence of linear diffraction of the two beams, two identical soliton formation, attraction each other, pass through each other and eventually fusing into one beam.

The experimental setup devoted to soliton – soliton interaction is illustrated in Figure 2. The laser beam from an infrared Ti:Sapphire laser is split into two beams using beam-splitters, then they are combined together with a small separation through other beam-splitter and launched into the cell by a 15× microscope objective. The beam width at the focus $w_0 = 2\,\mu m$, the separation distance and relative angle between the two beams was estimated by measuring the divergence of the

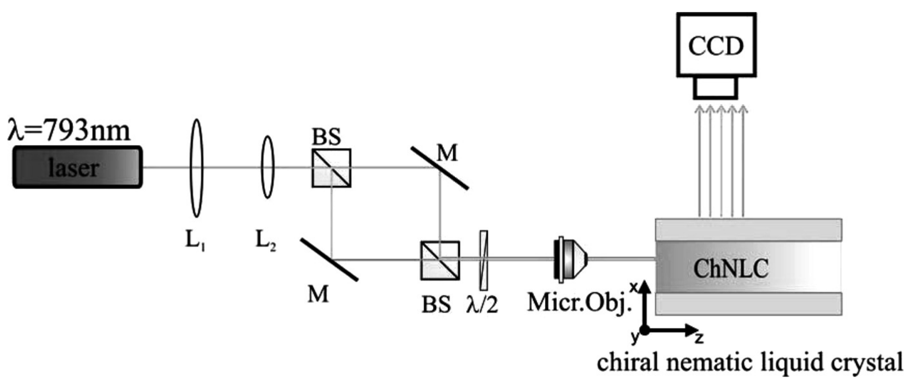

Figure 2. Schematic drawing of the experimental setup to investigated soliton-soliton propagation and interaction.

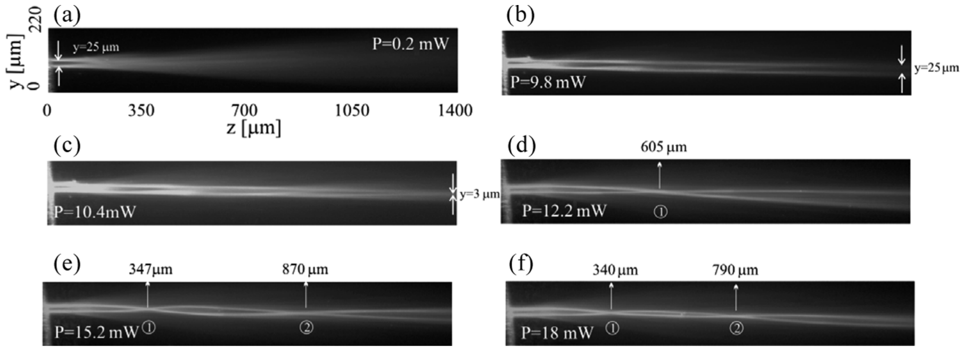

Figure 3. Experimental results showing soliton-soliton interaction (a) linear diffraction of two identical input beams injected into the cell with separation 25 μm; (b) two identical soliton each 9.8 mW launch power propagating parallel two each other with separation 25 μm; (c) soliton-soliton attraction for powers 10.4 mW; (d) same as (c) but for powers 12.2 mW, first crossing point visible marked on photo; (e) soliton-soliton interaction for powers 15.2 mW with crossing points marked on photo; (f) soliton-soliton interaction for powers 18 mW with crossing points marked on photos.

beams during linear propagation in the liquid crystal film. Figure 3 shows a typical examples of two input beams with equal powers injected inside the ChNLC cell nearly parallel to each other and the distance between them was estimated to be 25 μm. At low power both beams diffracts (Fig. 3a). Increasing the optical power leads to a focusing of the beams. For a certain optical power, about 10 mW, both beams propagate soliton-like along the z direction parallel to each other with separation equal to initial separation (Fig. 3b). At power slightly more than 10 mW the separation decreases to 3 μm (Fig. 3c) and finally at power about 11 mW (not shown) the soliton cross each other. Further increasing the power leads to move the crossing point into the beginning of the cell (Fig. 3d) and at power about 15 mW the second crossing point occurs (Fig. 3e). The position of the crossing points depend on input light power (Fig. 3f).

Finally, Figure 4 displays an example of time evolution of a soliton-soliton interaction. Two beams at the power level 10 mW propagate in the y-z plane with initial separation 25 μm. Due to the slow NLC time response, after the illumination no nonlinear behavior is visible and the diffraction is observed with the overlap of

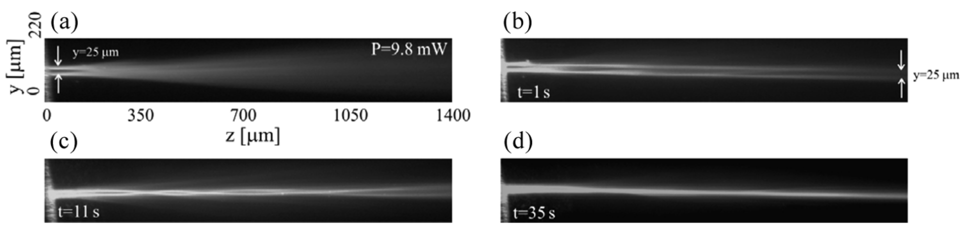

Figure 4. Time evolution of soliton-soliton interaction for powers 9.8 mW each (a) linear diffraction of two input beams witch separation 25 μm; (b) soliton formation after 1 s with separation equal to initial separation; (c) solitons attraction and crossing after 11 s; (d) soliton fusion into one beam after 35 s.

the two waves as they propagate (Fig. 4a). After 1s two soliton are formed and propagate maintaining their initial separation (Fig. 4b). In a few seconds the soliton start to attract each other (Fig. 4c). Eventually, due to the nonlocality of the NLC, after 35 s collapsing into one beam (Fig. 4d). It is worth noting that the described interaction is phase-independent, the interaction owing to the nonlocality is mainly incoherent.

Those results were obtained in one layer of the chiral nematic liquid crystal cell. However interaction of soliton propagating in different layers is also possible. Owing to the fact that the refractive index distribution changes along x direction, i.e., perpendicular to the glass plates analyzed cell can be treated as a matrix of waveguide structure with periodically modified refraction index. In proposed geometry, it is possible to obtain conditions in witch conventional continuous diffraction is substitute by discrete one in the sense of discrete coupling between waveguides aside. The magnitude of discrete diffraction can be easily modified by changing geometrical dimensions of analyzed structure.

Presented results are a good introduction for investigation light propagation in different layers of the analyzed structure and to investigate the discrete light propagation in x direction. However, for geometrical parameters of the structure described in previous section no light coupling between layers was observed. It was caused by relatively high value of the pitch, i.e., the distance between two neighboring layers is too high for light coupling, and also by high birefringence of used ChNLC, i.e., high amplitude of modulation of refractive index. To obtain light coupling to the neighboring layers certain conditions need to be fulfill, i.e., a proper pitch of the cell, birefringence and also the length of the cell to enable experimental observation of light propagation. Numerical simulation were done and it was obtained that for smaller pitch of the ChNLC (about 10 μm), the cell thickness about 50 μm and lower birefringence of ChNLCs such a behavior occurs.

Acknowledgments

The work of U. A. Laudyn has been supported by the European Union in the framework of European Social Fund through the Warsaw University of Technology Development Programme.

References

[1] Simoni, F. (1997). *Nonlinear Optical Properties of Liquid Crystals*, World Scientific Publ.: London.
[2] Khoo, I. C. (2007). *Liquid Crystals* 2nd Edition, John Wiley Sons Inc.: New York.
[3] Karpierz, M. A. (2001). In: *Soliton Driven Photonics*, Boardman, A. D. & Sukhorukov, A. P. (Eds.), Kluwer Academic Publishers: Dordrecht, 41.
[4] Assanto, G., Peccianti, M., & Conti, C. (2003). *Opt. Photon. News*, *14*, 44.
[5] Karpierz, M. A. (2002). *Phys. Rev. E*, *66*, 036603.
[6] Peccianti, M., Assanto, G., De Luca, A., Umeton, C., & Khoo, I. C. (2000). *Appl. Phys. Lett.*, *77*, 7.
[7] Laudyn, U. A., Kwasny, M., & Karpierz, M. A. (2009). *Appl. Phys. Lett.*, *94*, 091110.
[8] Stegeman, G., & Segev, M. (1999). *Science*, *286*, 1518.

[9] Peccianti, M., Brzdąkiewicz, K. A., & Assanto, G. (2002). *Opt. Lett.*, *27*, 1460.
[10] Rasmussen, P. D., Bang, O., & Królikowski, W. (2005). *Phys. Rev. E*, *72*, 066611.
[11] Baran, J., Raszewski, Z., Dabrowski, R., Kedzierski, J., & Rutkowska, J. (1985). *Mol. Cryst. Liq. Cryst.*, *123*, 237.
[12] Dabrowski, R., Dziaduszek, J., & Szczucinski, T. (1985). *Mol. Cryst. Liq. Crys.*, *124*, 241.
[13] Karpierz, M. A. (2001). *Acta Physica Polonica A*, *99*, 161.