Nematicons in chiral nematic liquid crystals

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We report on the experimental studies of the existence of spatial solitons called nematicons in chiral nematic liquid crystal cells. The low absorption allows us to observe soliton propagation at a distance of over a few millimeters in range. The results of our experiment also show that it is possible to create independent nematicons in different layers formed by a helical structure of the liquid crystals. © *2009 American Institute of Physics*. [DOI: 10.1063/1.3093498]

In recent years nematic liquid crystals (NLCs) have attracted a lot of attention due to their nonlinear optical behavior arising from molecular reorientation and/or thermal effects. Reorientational nonlinearity in NLCs is a source of various phenomena,[1] including the creation of spatial solitons, called nematicons.[2,3] Spatial optical solitons are self-confined beams that propagate without diffraction. They can occur when the material has a nonlinear optical response similar to self-focusing or self-lensing: Self-focusing exactly balances the diffraction and the beam propagates laterally in the cell without changes. Their applications are potentially attractive: among others, all optical switching, light guided by light, and parallel signal processing. Recently, different configurations of NLCs were proposed, including homeotropic,[4,5] planar,[6–8] and twisted textures,[9,10] as a compelling way to implement spatial solitons.

This work contains experimental studies of soliton propagation in chiral nematic liquid crystals (ChNLCs).[11,12] In principle, the light beam propagation and nematicons creation in ChNLCs are similar to those in twisted nematic (TN) layers.[9] However, the configuration with ChNLCs offers some additional opportunities in comparison with TNs. This is connected with the fact that the width of the guiding layer is determined not only by the thickness of the sample (like in TNs) but also by the chirality pitch. As a result, in ChNLCs it is much easier to choose the proper width of the guiding layer and, as a consequence, the proper nonlinearity strength than in TNs. It is also possible to utilize multilayers for propagation of independent or interacting nematicons. In this letter we present the experimental results on the nematicon propagation in different layers and the possibility to create as many solitons as layers in the structure.

The sample used in the experiment consisted of two glass plates glued together, with a gap between the plates which was controlled by a spacer. An alignment layer was deposited on top of this to control the alignment of the liquid crystal molecules. The cell was filled through a capillary effect with 4-trans-4′-*n*-hexyl-cyclohexyl-isothiocyanatobenzene (6CHBT) doped with a chiral material. 6CHBT possesses low absorption and high nonlinear response,[13,14] with the refractive indices $n_o = 1.51$ and $n_e = 1.67$ in the near infrared range. The chiral liquid crystals consist of molecules, in which the direction of alignment twists across the cell. This results in a helical structure of a definite pitch described as the distance along the helical axis after which the direction of molecule orientation has turned through an angle of 360°.[15] The width of the analyzed cell was 50 μm and the pitch of the ChNLC was about 25 μm. In the analyzed configuration (presented in Fig. 1), a light beam propagates in the z direction parallel to the glass plates. ChNLCs scatter light due to the fluctuations in molecule orientation. Thanks to this, the beam propagation in the cell was observed by a 16× microscope objective lens connected to a charge coupled device (CCD) camera mounted in an (x,y,z) stage. Acquisition and analysis were made by a computer system.

The light is polarized along the y direction, which means that the refractive index varies across the sample from n_o in planes where molecules are perpendicular to the electric field to n_e in planes where molecules are parallel. Therefore, the light beam is guided in the xz plane; however, in the yz plane the light beam diffracts, as the refractive index distribution is constant.

In a nonlinear regime, for higher light intensities, the liquid crystal molecules are forced to reorient parallel to the electric field. This increases the refractive index, which leads to the self-focusing effect and, consequently, the nematicon creation. Because the reorientation is slow in comparison to the electromagnetic wave period, molecules tend to lay parallel to the mean direction of the electric field.

Experimental results obtained for a Ti: sapphire laser ($\lambda = 793$ nm) are presented in Fig. 2. Increasing the input beam power leads to self-focusing and, finally, for the average optical power $P \geqslant 8.6$ mW, the spatial soliton was formed. The initial input beam waist was estimated to be about 2 μm by measuring the divergence of the beam during the linear propagation in the liquid crystal film. The solitary beam has a transverse intensity distribution, which was un-

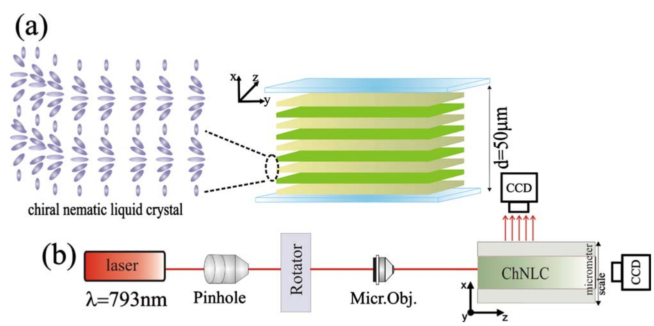

FIG. 1. (Color online) (a) Configuration of the analyzed NLC cell. (b) Schematic drawing of the experimental setup.

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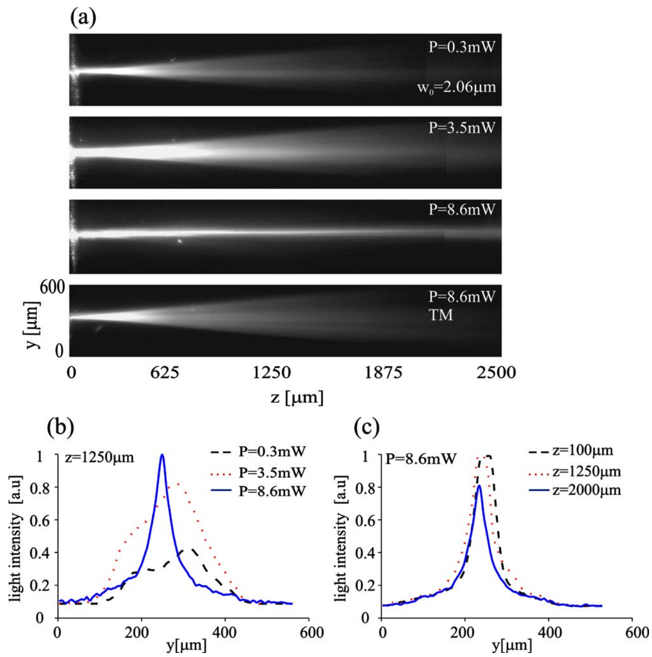

FIG. 2. (Color online) Experimental results of spatial solitons creation in ChNLCs layer for a Ti:sapphire laser: (a) light beam propagation for different inputs of light power (marked on photos) and centrally launching light beam, the last picture was taken for TM polarization. (b) and (c) Light intensity profiles for low and high power, respectively, and for different values of propagation distance.

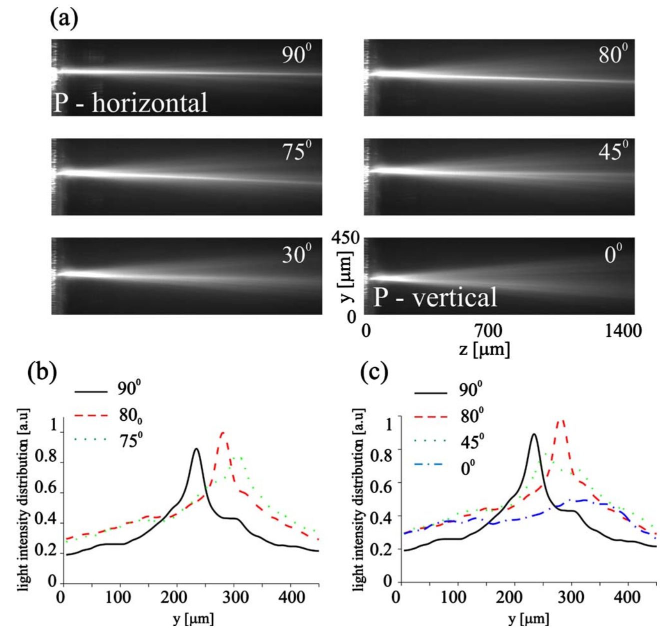

FIG. 3. (Color online) (a) Experimental results showing the beam walk-off effect by changing the polarization of input light beam. (b) Normalized light intensity profile distribution for three different polarizations for which the soliton changed its direction. (c) Normalized light intensity profiles for different polarizations crossing from TE to TM-like.

changed at a propagation distance of about 2 mm (that is, over 80 times the Rayleigh length). We also considered the impact of initial waist to soliton generation. By increasing the input beam waist, the intensity of light needed to create the nematicon decreases. Due to the finite thickness of each layer in a chiral structure, there is only a certain range of the values of input waists for which the nematicon can be formed.

There were also observed changes in the nematicon direction while changing the polarization of the input beam. Indeed, as is shown in Fig. 3, crossing from the TE-like to the TM-like polarization causes the nematicon to propagate to a different direction. However, for the TM-like polarization (for which the nematicon does not exist), the light beam again propagates parallel to the z axis. Please note that all direction changes are in the yz plane. The beam walk-off effect is caused by the structural anisotropy connected with chiral orientation. It should be noted that the beam walk-off effect was already observed in asymmetrical twisted NLC cells.[10]

Light beam propagates in the region where the ChNLC molecules are parallel to the electric field. The width of the cell (about 50 μm) and the pitch of the ChNLC (25 μm) indicate that there are four layers where molecules are oriented in the same way. Results show that there are four layers with the thickness of about 12 μm, in which nematicons can be created independently. We show the possibility of obtaining as many solitons as layers in the structure by changing the vertical position along the cell. In this part, the vertical position of the ChNLC cell was controlled by means of a microscope slide with micrometer patterns fixed to the (x,y,z) stage and a second CCD camera mounted at the back of the cell.

The vertical position of the ChNLC cell changes for a defined TE-like polarization and light power high enough (about 10 mW) to form nematicons. Results are presented in Fig. 4 with input positions marked on photos. Position $\Delta x = 0$ means that the light beam propagates at the verge of the glass plate and liquid crystals. The nematicon is formed in the first layer marked $\Delta x = 10$ μm [Fig. 4(a)] and is repeatable in each succeeding layer. Indeed, four nematicons were formed in different layers about 10–12 μm away from each other. Please note that positions were estimated using the second CCD camera with the accuracy of ~ 2 μm.

In conclusion, we have demonstrated the most important experimental results on the existence of spatial optical

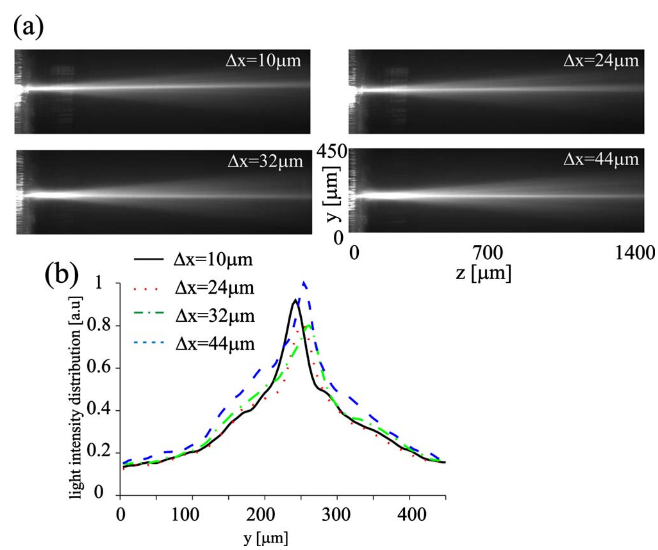

FIG. 4. (Color online) (a) Experimental results of creating spatial solitons in different layers across the ChNLC cell for different input vertical positions marked on photos as Δx. (b) Normalized intensity distribution profiles for each position and for the propagation distance $\Delta z = 1000$ μm.

solitons in ChNLCs for tens of milliWatt input powers propagating over a few millimeters. In particular, we proved that the investigated geometry takes advantage of the unique properties of ChNLCs and enables one to utilize multilayers for propagation of independent nematicons. This effect can also have potential application in the exploration of a discrete structure of waveguide matrices. The large variety of proposed configurations and types of solitons allow one to build-different elements with properties necessary for a given application.

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