Spatial Solitons in Twisted Nematic Layer

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In this work we investigate light beam propagation in twisted nematic liquid crystalline film. Due to the optical reorientational nonlinearity light beam is self-focusing and finally the spatial solitary wave is created. With increasing the nonlinear effect the direction of light beam propagation is also changing. The samples were filled with 6CHBT nematic liquid crystal and the propagation of light beam at the distance of few millimeters was measured. Nonlinear self-focusing was obtained for a light power of few tenths of milliwats.

Keywords: spatial solitons, reorientational nonlinearity in nematics

Reorientational nonlinearity in nematics is a source of various phenomena [1,2], including the creation of spatial solitons, called as nematicons [3]. Nematicons were observed in different geometries and configurations of nematic medium [4-8]. It was proved, that light beams with the power of order of few milliwats can form nematicons at the distance of few millimeters. Due to the high birefringence of liquid crystals, walk-off of nematicons has been reported and discussed [9-11]. The existence of discrete nematicons in liquid crystalline array of waveguides was also demonstrated [12].

Usually, homeotropic or planar orientations of liquid crystals layers were investigated as media for nematicons generation. In this paper we demonstrate existence of nematicons in twisted nematics (TN). Due to the optical anisotropy of liquid crystalline molecules and anisotropy of their orientation, light beam in TN layer walks-off from origin direction of incident path. Nematicon formation in this media is caused by the light induced local reorientation of birefringence axis. The spatial soliton formation in twisted nematic liquid crystal was theoretically predicted in previously published works [13-14]. In this paper we show the experimental results.

The configuration of our TN sample is schematically presented in Figure 1a. The orientation of LC molecules is parallel to the surrounding glass plates and twisted in the layer, in the way that molecules at both boundaries make an angle of $\pi/2$. Consequently, the light beam is launched to the sample in the direction, which is parallel to the molecules at the bottom bounding surface and perpendicular to the molecules at the top. Birefringence axis of nematics is connected with the molecular orientation. Therefore for the light beams linearly polarized in y direction the effective refractive index is varying across the layer (see Figure 1b).

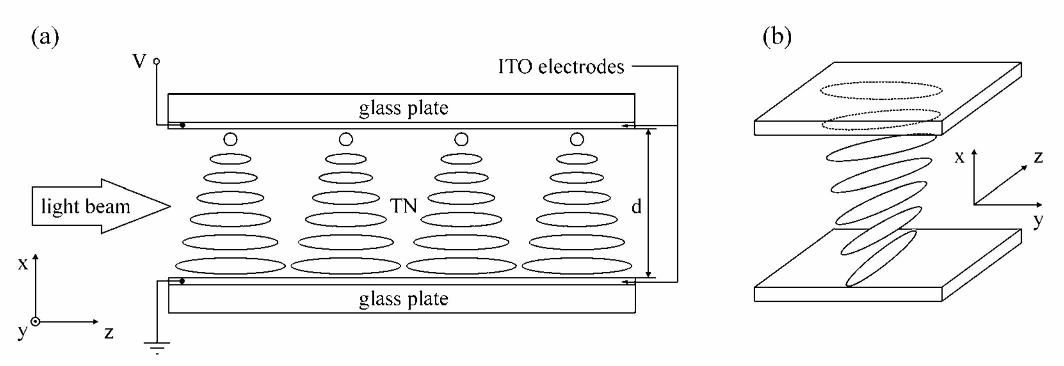

Fig. 1. Schematic drawing of the sample (a) created with twisted nematic film (b).

In the nonlinear regime the dominant E_y component of the electric field in the polarized light beam causes the reorientation of the molecules in the yz plane. The reorientation in liquid crystal changes the birefringence axis orientation and changes the propagation of the light beam.

The behavior of the light beam propagating in TN layer can be simply described using the following approximated model, which assumes that beam profile in x direction is unchanged during the propagation. This assumption is correct at some distances from the input plane, where the guided mode is formed. Because the E_z component is much weaker than the E_y component, it is possible to assume that the fields are in the following form:

$$E_y = A(y,z)\varphi(x)\exp(i\omega t - i\beta z), \tag{1}$$

$$E_z = A(y,z)\phi(x)\exp(i\omega t - i\beta z), \tag{2}$$

where: $\varphi \exp(i\omega t - i\beta z)$ and $\phi \exp(i\omega t - i\beta z)$ are components of the planar waveguide mode, and A is a complex amplitude of the electric field slowly varying in z direction. Following this approximation the complex amplitude A fulfills the equation [11]:

$$2i\beta \frac{\partial}{\partial z} A = \frac{\partial^2}{\partial y^2} A - i\beta \frac{\partial}{\partial y} \kappa_2 A + \beta^2 \kappa_3 A, \tag{3}$$

where coefficients κ_2 and κ_3 depend on orientation angle of liquid crystalline molecules and as a consequence of the reorientation nonlinearity they depend on the light intensity. The coefficient κ_2 is connected with the walk-off of the light beam. For small light intensity κ_2 is the highest but when the light intensity increases κ_2 becomes smaller and then the walk off effect is weaker. It means that change of the light intensity affects the direction of beam propagation. The coefficient κ_3 is purely nonlinear and it is responsible for self-focusing of the light beam and creation of the spatial soliton. As a consequence, from simplified equation (3) it can be predicted that light beam is self-trapped and changes its walk-off with increasing the light intensity.

Light beam propagation in TN film was investigated experimentally by measuring the scattered light from the sample by using the CCD camera. The argon laser (λ = 514nm) with pinhole, polarization controller and optics focusing of the input beam to the spot of few micrometers were used. The sample layer with the thickness d = 40µm was filled with 4-trans-4'-n-hexyl-cyclohexyl-isothiocyanatobenzene (6CHBT) nematic liquid crystal.

Typical pictures taken by the CCD camera are presented in Figure 2. For the linear case when the light power is too low to induce reorientation the beam diffraction is observed (Fig. 2a). For higher power the light is self-focused and finally the light beam creates solitary wave (Fig. 2b). The light power was measured at the front of the cell and it includes also the light losses during the coupling into the layer. To compare pictures taken for different light power, the intensity profiles at the distance z = 1.6 mm are presented in Figure 3. Note, that for light power P > 10 mW the light is confining at the beam edge. This self-focusing effect can be recognized as a creation of non-diffractive solitary wave.

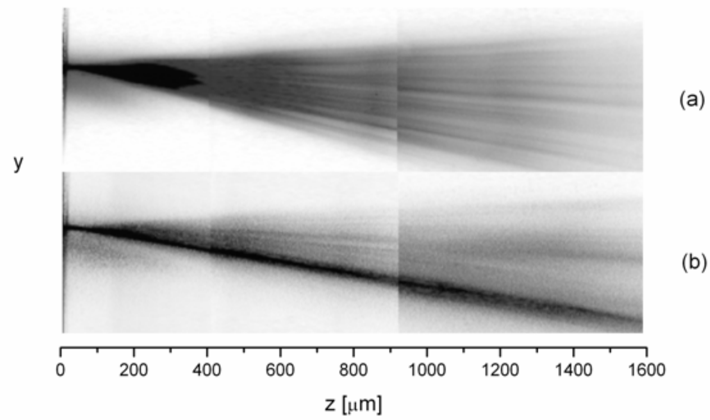

Fig. 2. Light beam propagation in twisted nematic film for low power (a) and light power P = 55 mW (b).

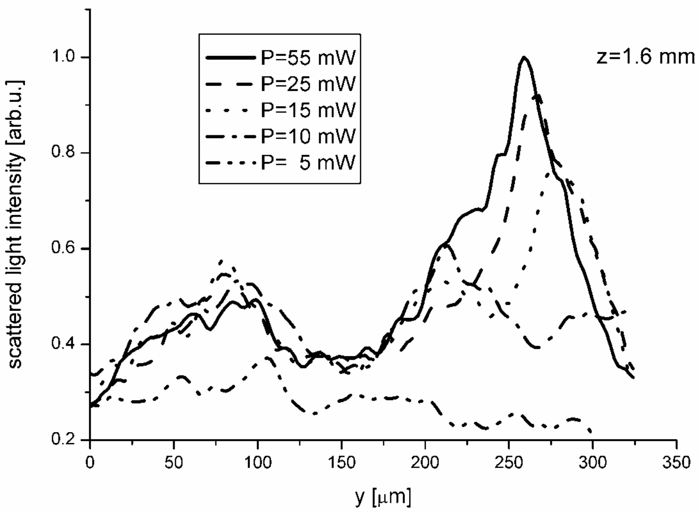

Fig. 3. Light intensity profiles at the distance z = 1.6mm for different values of the light power.

Comparison of the size and shape of such nematicon at different distances is presented in Figure 4. The scattered light intensity cross-section profiles in this figure were normalized to their maximum values and shifted in y-direction to have the maxima in the same position. Although the noise in the background is strong, the peak with the constant shape and width is well visible. The size and shape of obtained nematicons do not change significantly with increasing of the light power. This is caused by the saturating character of the reorientational nonlinearity. However, the increasing of light power can modify the walk-off strength. This is presented in Figure 5, where the intensity profiles of nematicons for different power at different distances are compared. The changes of the beam direction with increasing the light power are weak but measurable. Effectively at the distance of 1 millimeter the beam can change position of approximately 20 micrometers by increasing the power from 20 to 50 milliwats.

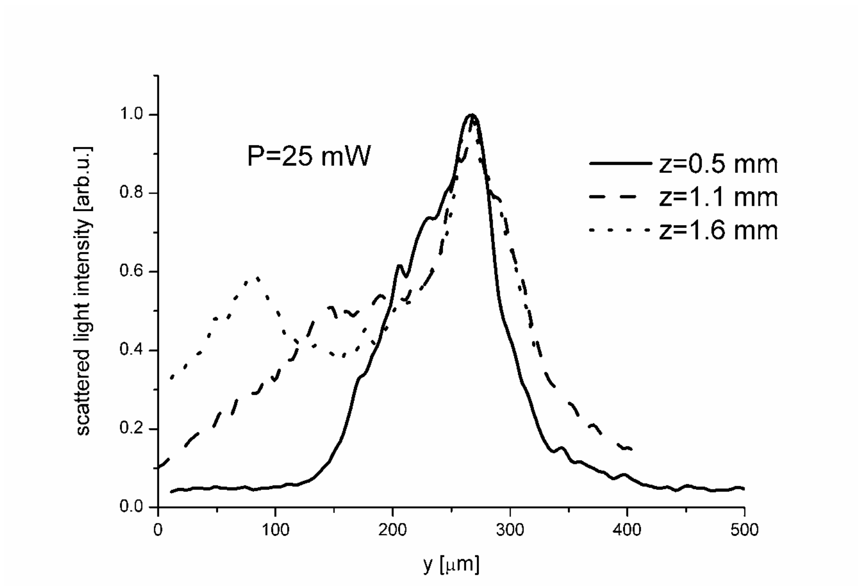

Fig. 4. Comparison of the beam peaks at different distances for the light power P = 25 mW. The light intensity profiles are normalized and shifted to have their maxima in the same position.

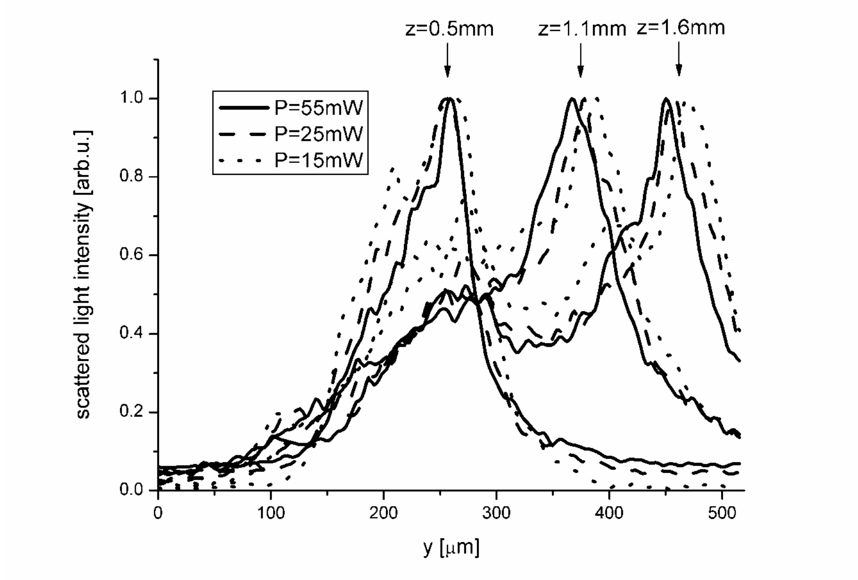

Fig. 5. Comparison of the beam peak shapes and positions at different distances for three values of the light power. The intensity profiles are normalized to their maximum values.

In conclusions, we have shown that nonlinear self-focusing of light beam at the power level of few tenths of milliwats can be observed in twisted nematics. Experimental results show also changing the direction of propagation with increasing the light power. Additionally, the observed effects are dependent on light polarization and they are destroyed by the externally applied low-frequency electric field. Such experimentally measured behavior is qualitatively agreed with the theoretical predicted properties of nematicons in TN. It is worth to note, that the proposed configuration can be applied in switching of the light beam in low-power all optical systems.

REFERENCES

1. Khoo, I.C., Wu, S.T. *Optics and Nonlinear Optics of Liquid Crystals*. World Scientific Publ., Singapore, (1997).
2. Simoni, F. *Nonlinear Optical Properties of Liquid Crystals*. World Scientific Publ., London, (1997).
3. Assanto, G., Peccianti, M., Conti, C. *Optics & Photonic News*, 14, 44, (2003).
4. Karpierz, M.A. *Soliton Driven Photonics*, A. D. Boardman, A. P. Sukhorukov (Eds.), Kluwer Academic Publishers, Dordrecht, (2001).
5. Peccianti, M., Assanto, G., De Luca, A., Umeton, C., Khoo, I.C. *Appl. Phys. Lett*. 77, 7, (2000).
6. Peccianti, M., Brzdąkiewicz, K.A., Assanto, G. *Opt. Lett.* 27, 1460 (2002).
7. Assanto, G., Peccianti, M. *IEEE J. Quantum Electron*. 39, 13, (2003).
8. Henninot, J. F., Debailleul, M., Derrien, F., Abbate, G., Warenghem, M. *Synth. Met.* 1-5, 8915, (2001).
9. Peccianti, M., Conti, C., Assanto, G., De Luca, A., Umeton C. *Nature* 432, 733, (2004).
10. Peccianti, M., Fratalocchi, A., Assanto, G. *Opt. Expr.* 12, 6524, (2004).
11. Peccianti, M., Conti, C., Assanto, G. *Opt. Lett.* 30, 415, (2005).
12. Fratalocchi, A., Assanto, G., Brzdąkiewicz, K. A., Karpierz, M. A. *Opt. Expr.* 13, 1808, (2005).
13. Karpierz, M. A., Sierakowski, M., Woliński, T. *Mol. Cryst. Liq. Cryst.* 375, 313, (2002).
14. Karpierz, M.A., Brzdakiewicz K.A., Nguyen, Q.V. *Acta Phys. Polonica A*, 103, 169, (2003).