Nematicons in twisted liquid crystals

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Abstract— In this work we demonstrate the properties of spatial solitary waves (nematicons) in a twisted nematic liquid crystalline film. Such self-trapped beams were created due to optical reorientation nonlinearity for a light power of a few tenths of milliwats at the distances of a few millimeters. Additionally, it was demonstrated that a weak signal beam can be guided in a channel formed by a nematicon.

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 [1-3]. Reorientational nonlinearity in nematic liquid crystals is a source of various phenomena [1], including the creation of spatial solitons [2,3]. In 2003 G. Assanto et al. [3] proposed a new name for these spatial solitons in nematic liquid crystal cells, namely *nematicons*. It was demonstrated that a light beam with a power in the order of a few milliwats can form nematicons at a distance of a few millimeters. For low optical power (in the linear case), the beam broadens due to diffraction. At a power high enough, due to reorientational nonlinearity in liquid crystals, self-focusing starts to become significant and at a certain value a solitary wave is formed. Nematicons have already been observed in different configurations and geometries [4-8]. Their applications are potentially attractive: all optical switching, light guided by light, parallel signal processing etc. The spatial soliton formation was already predicted theoretically and observed experimentally in twisted nematics (TNs) where the NLC molecules at the two planar surrounding interfaces were oriented parallel to the beam wavevector on both sides, or parallel on one and perpendicular on the other, respectively [9-10].

In this work we briefly summarize the study of soliton propagation in a TN liquid crystalline waveguide at a green argon laser wavelength (λ = 514 nm). Moreover we demonstrate the possibility to guide a weak signal beam (at λ = 633 nm) in the light-induced waveguide created by the nematicon.

The configuration of our TN samples is schematically presented in Figure 1. Light beam propagation was investigated experimentally by measurement of the scattered light from the sample by using a CCD camera (Fig. 1c). There were used an argon laser ($\lambda = 514nm$) with a pinhole, polarization controller and optics focusing of the input beam to the spot of few micrometers. The sample layer with the thickness of 40μm was filled with 4–trans-4'–n–hexyl – cyclohexyl - isothiocyanatobenzene (6CHBT) nematic liquid crystals. Moreover, the samples had ITO (Indium Tin Oxide) electrodes.

The 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: from n_o in planes where molecules are perpendicular to the electric field, to n_e - in planes where molecules are parallel. As a consequence, the light beam is guided in a thin layer where the orientation of molecules is close to the direction of the y axis.

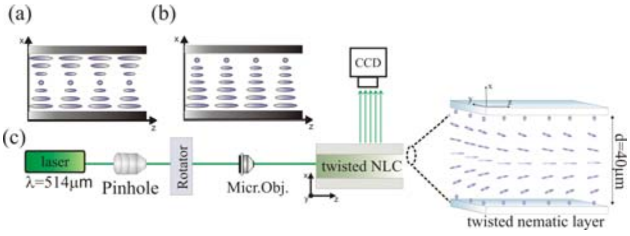

Fig.1.Configuration of analyzed twisted nematic liquid crystal cells: (a) symmetrical, (b) asymmetrical, and (c) schematic drawing of the experimental setup.

In the linear case, when the light power is low, the beam spreads due to its diffraction in the yz plane. In a nonlinear regime, for higher light intensity, liquid crystal molecules are forced to reorient to be parallel to the electric field. This results in an effective refractive index

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increase and beam focusing. As a consequence, a self-trapped beam, i.e. nematicon, is forming.

The propagation of a light beam in a twisted nematic waveguide and the possibility of creating solitons were tested by injecting a Gaussian beam with the initial waist of a few micrometers. The results obtained in the first step of the experiment, for symmetrical geometries, are depicted in Fig. 2. In the linear case (signed as P~0mW), the diffractive broadening beam propagates in the *yz* plane parallel to the *z* axis. Increasing the light power leads to reorientational nonlinear effects and, finally, causes self-focusing of the beam. For the optical power P~100mW the diffraction is compensated by the nonlinearity and soliton-like beam propagating at the direction parallel to the z axis (see Fig.2c). The solitary beam has a transverse intensity distribution which is unchanged with a propagation distance of about 4mm (which is over 50 times the Rayleigh length).

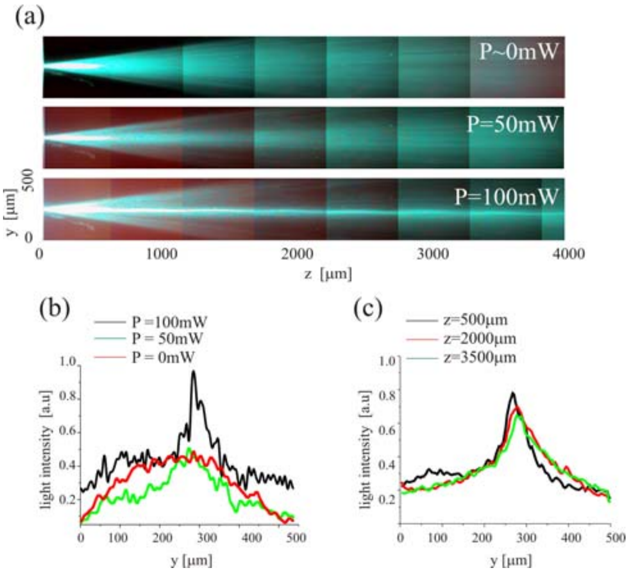

Fig. 2. Experimental results of creating nematicons in symmetrical TN cell: (a) light beam propagation for different inputs of light power (marked on photos) and centrally launched light beam, (b) light intensity profiles for low and high power respectively, and (c) light intensity profiles of nematicon (*P* = 100mW) at different distances.

For the asymmetrical twisted geometry, where the molecules at one glass plate are perpendicular and at the second one are parallel to the direction of light beam propagation (Fig.1b), the beam is guided close to the NLC/glass boundary. As a consequence, the effective direction of a birefringence axis is not perpendicular to the initial direction of a light beam. Therefore the walk-off effect of a light beam is present. Firstly, light propagation in a homogenous medium was investigated to check whether the beam is launched parallel to the y axis or not (Fig. 3a). It was obtained by applying an external field, since an applied external field causes the medium to become homogenous for E_y polarization. Next, without any external electric field, the direction of beam propagation was changed, showing the walk-off effect. In the linear case when the light power was too low to induce reorientation (P~0mW) diffraction was observed. Increasing the light power modifies the twisting angle and increases the effective refractive index. The light starts changing the direction of its propagation and, finally, due to self-focusing a solitary wave is formed for the light power P~20mW (Fig. 3). To compare the pictures from Fig.3a, profiles were made for different light power for three distances: 500µm, 1100µm, 1600µm. The scattered light intensity cross-section profiles in this figure were normalized to their maximum values.

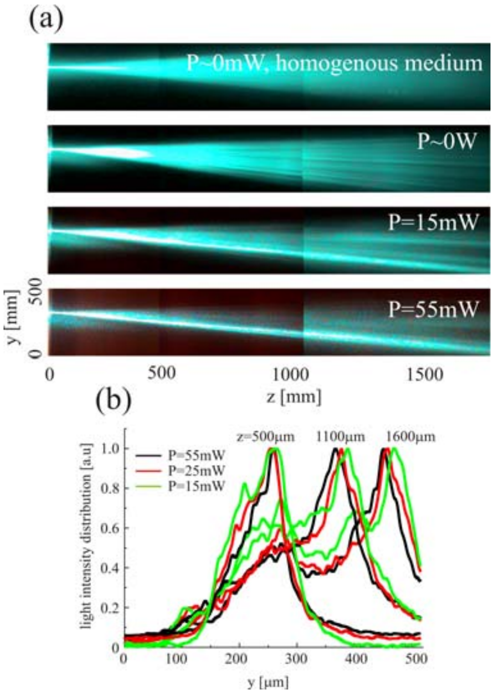

Fig.3. Experimental results of creating nematicons in asymmetrical TN cells: (a) light beam propagation for different inputs of light power (marked on photos), (b) light intensity profiles for different light power and different distances.

The second experimental setup included two light sources: an argon laser (pump beam) and a helium-neon laser (probe beam). Trough a pinhole two co-propagating and co-polarized beams were coupled into a TN cell using a microscope objective. The light propagation in the yz plane was analyzed by collecting scattered light through a red filter to let only the probe beam light through, whenever required.

Spatial soliton formation in the liquid crystal cell corresponds to the guided-wave eigensolution. It introduces changes in the refractive index distribution and leads to the formation of an optical waveguide. This was verified by injecting a second co-polarized low-power probe beam. When the pump beam diffracts, the probe beam diffracts also (Fig. 4a). The widths of these two co-propagating beams were almost the same (the waist of the input beams was measured to be nearly 2μm). When the high power TE-polarized beam from an argon laser forms a spatial soliton in a symmetrical cell, the co-propagating low power probe beam is also confined. Moreover the probe beam follows exactly the direction of the soliton formed by the pump light beam. Increasing the power of the pump causes the lensing effect that focuses the beam, and the probe becomes increasingly confined too. When the light power of the pump is high enough to create a spatial soliton, the width of the probe beam also stays almost constant over the propagation distance (Fig 4b).

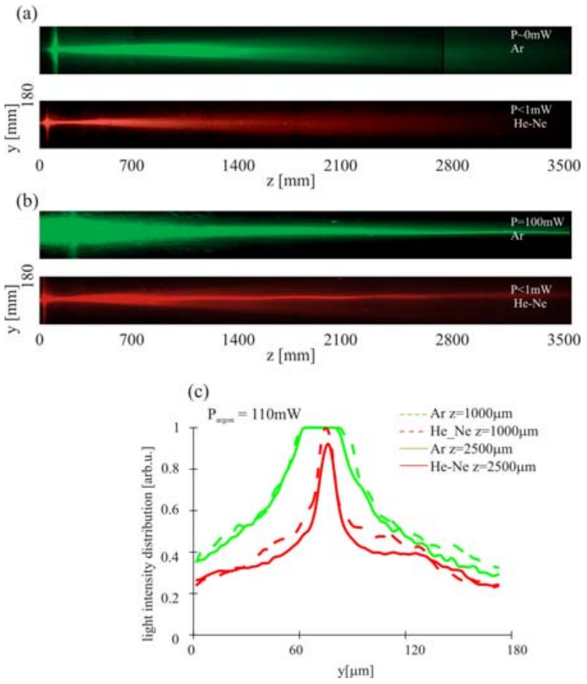

Fig.4. Spatial soliton and optically induced waveguide in twisted nematic liquid crystal cells, (a) linearly diffracted pump beam (from Ar laser) and corresponding propagation of a low power probe beam (from He-Ne laser); (b) nematicon propagation for a high power pump beam and the corresponding probe beam; (c) normalized light intensity profiles for different values of propagation distance and for a high power pump beam and the corresponding low power probe beam, respectively.

Concluding, in this paper it has been proved that twisted nematic liquid crystals can support spatial solitons at distances of a few millimeters for the light power that is a few tenths of a milliwatt. The experimental results also show a changing direction of propagation with increased light power in the asymmetrical case. The observed effects depend on the polarization state of an input beam. Additionally, the changes of NLC induced by nematicons can guide other signal beams. It is worth noticing that the proposed configuration can be applied in the switching of a light beam in all low-power optical systems. All these properties cause the nematicons to be very promising in application to all-optical steering and switching elements that require low-power and low losses for switching, instead of fast switching.

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