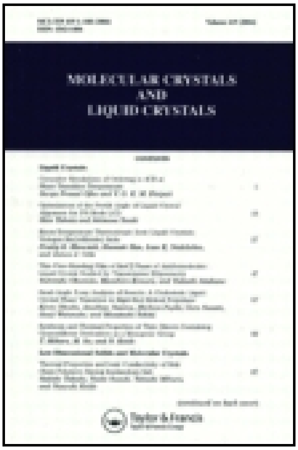

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Discrete Optical Solitons in Nematic Liquid Crystals

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DISCRETE OPTICAL SOLITONS IN NEMATIC LIQUID CRYSTALS

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In the paper we propose the realization of liquid crystals waveguide arrays, and introduce the concept of a periodic photonic structure with refractive index changes controlled by an electric field. Such a voltage-tunable geometry, in conjunction with a reorientational nonlinearity, offers a wealth of possibilities for the study of discrete optical phenomena. Theoretical and experimental results show the presence of discrete solitons in proposed configuration.

Keywords: discrete spatial solitons; reorientational nonlinearity

Recently, linear and nonlinear effects in discrete systems like photonic structures with periodic modulation of refractive index (such as waveguide arrays) became the subject of intensive investigations and this growing interest is motivated also by potential possibilities of discrete solitons generation [1,2]. Similarly to continuous systems, also in discrete arrays stable spatial solitons can be formed when self focusing mechanism is strong enough to balance discrete diffraction. Properties of discrete optical solitons have been firstly described by Christodoulides *et al.* [3] and after studied theoretically in various nonlinear materials. Recently they have been verified also experimentally [4] in AlGaAs, in arrays of silica waveguides, in photorefractive SBN-crystals and also in structures based on parametric response of Lithium Niobate. Moreover, it has been shown that discrete solitons are very promising in novel generations of all-optical switching circuits and optical networks [1,5].

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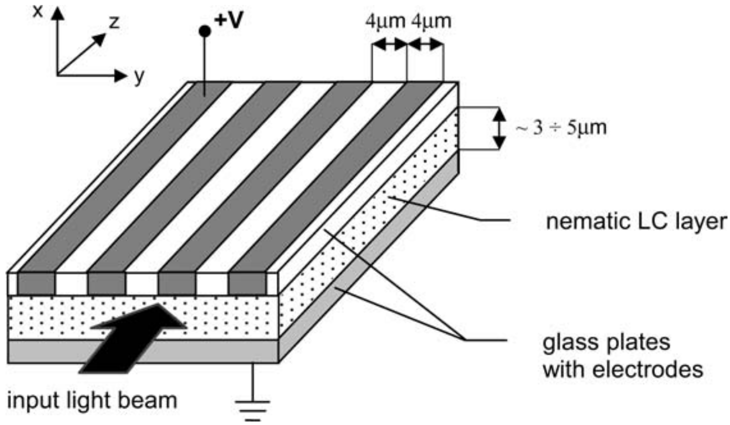

FIGURE 1 Sketch of the liquid crystal waveguide array.

Simultaneously, it has been demonstrated that spatial solitons can be effectively generated in nematic liquid crystals (LCs) at propagation distances of few millimeters (what is much greater than the Rayleigh range). In such media soliton creation can take its origin from large non- resonant, saturable and non-local nonlinearity arising from molecular reorientation. Huge birefringence with addition to giant nonlinear response leads to statement that nematic liquid crystals are very prospective materials for nonlinear optics applications. It has been shown that at variance with other types of nonlinear mechanisms, reorientational nonlinearity in nematic liquid crystals allows generation of spatial solitons in both waveguide and bulk geometry, requiring only a few milliwats of light power [6–11].

Combining two mentioned subjects of intensive investigations in nonlinear optics i.e., specific properties of discrete systems and unique

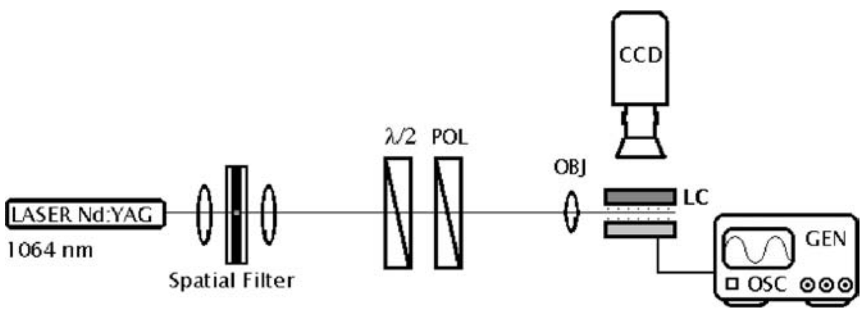

FIGURE 2 Experimental setup: $\lambda/2$ – half-wave plate, POL – polarizer; OBJ – objective/lens; LC – liquid crystal cell; CCD camera; GEN – generator; OSC – oscilloscope.

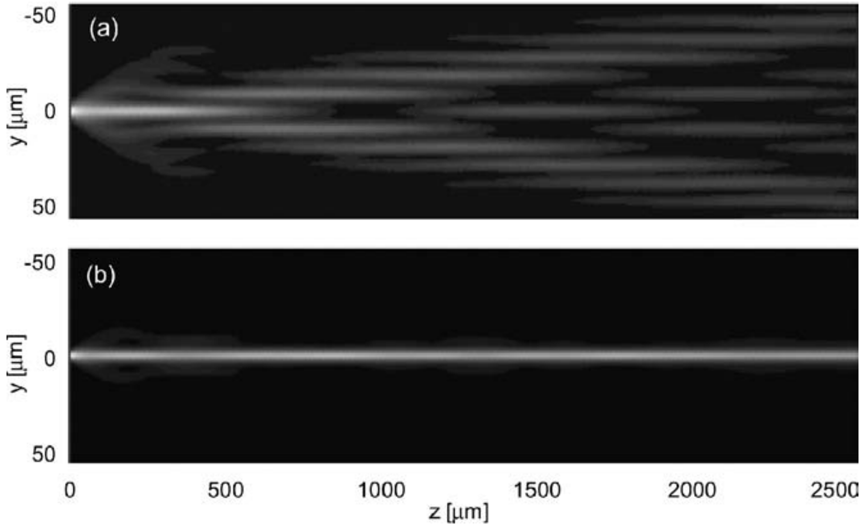

FIGURE 3 (a) Discrete linear diffraction for the $w_0 = 2\,\mu m$ Gaussian beam ($\lambda = 1064\,nm$) launched into the one of the guides, thickness of $5\,\mu m$, electrode width and spacing of $4\,\mu m$ and applied voltage of 1.4 V; (b) Generation of discrete spatial soliton when the input light power is increased to 4.5 mW.

nonlinear response of nematic liquid crystals, we propose construction of waveguide arrays in such medium. Sketch of projected device is presented in Figure 1. Glass cell is filled with the 5CB nematic liquid crystal, forming planar waveguide. Anchoring conditions at both top and bottom surfaces determinate planar alignment of the molecules. To introduce refractive index modulation inside of LC layer and to obtain voltage-adjustable nonlinear response, set of periodic electrodes on the top surface is used to apply a reorientational bias across the cell.

In proposed system geometry, it is possible to obtain conditions in which conventional continuous diffraction is substituted 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 or applied voltage level. This fact brings important consequences not only to linear but also to nonlinear properties of such discrete system, so efficiency of nonlinear processes can be greatly enhanced in properly designed and realized device.

Propagation of light beam in nematic liquid crystal layer was investigated using Beam Propagation Method with TM polarized Gaussian beam as the input signal. Refractive index changes were calculated basing on solutions of Euler-Lagrange equation describing reorientation of liquid

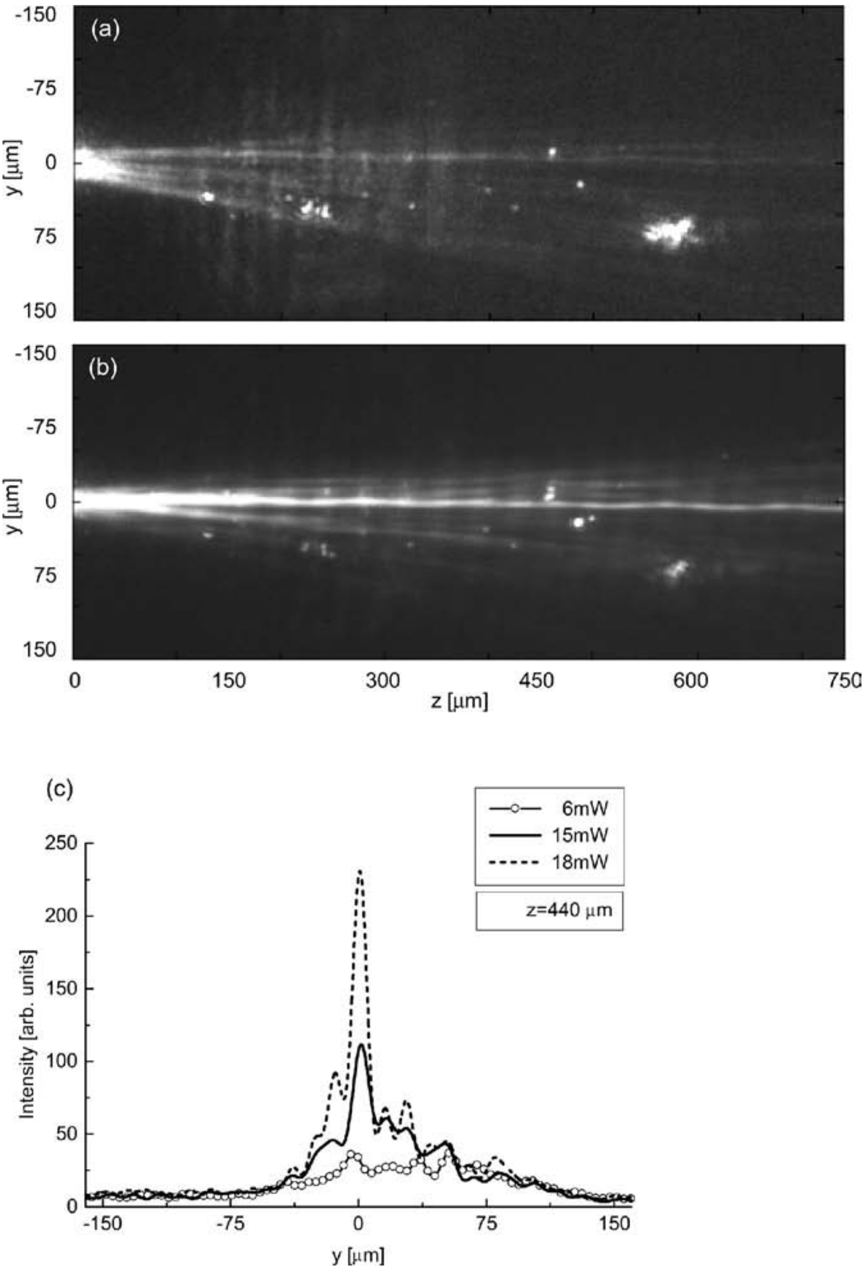

FIGURE 4 Experimental illustration of the discrete spatial soliton creation. Photographs show light beams propagating inside the LC cell, coming from Nd:YAG laser with a power of 6 mW (a) and 15 mW (b). The graph (c) presents the corresponding transverse profiles after propagation distance z = 440 μm. Voltage applied to the sample was 0.8 V (RMS).

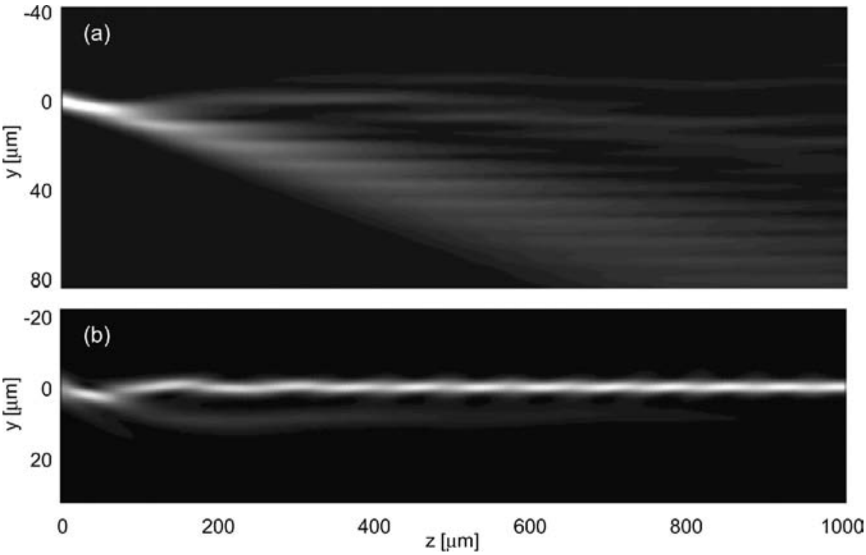

FIGURE 5 Results of numerical simulations for the Gaussian beam initially tilted of 7deg. In figure (a) linear case ($P \ll 1$) is shown, while (b) presents situation in which with increasing light power ($P = 16\,mW$) beam is changing its initial direction of propagation and spatial soliton is created.

crystal molecules due to the influence of the bias and the electric field of the electromagnetic wave. Results of numerical simulations were obtained for parameters characteristic for 5CB nematic liquid crystal i.e., refractive indices: $n_o = 1.52$, $n_e = 1.69$ and for wavelength of 1064 nm.

Experimental setup is presented in Figure 2. Light propagation in the LC cell is observed through the CCD camera detecting scattered light. As a light source the Nd:YAG laser oscillating at wavelength $\lambda = 1064\,nm$ were used and the light beam were focused to the spot of approximately $4\,\mu m$ in diameter.

When intensity of incident beam is low, light is coupling and spreading into increasing number of channels as it propagates, broadening its own spatial distribution. This process, shown in Figure 3a, is analogous to diffraction in continuous media but in discrete systems the effective diffraction can be reduced and even can be negative. It happens because main consequence of discrete diffraction is redistribution of energy among guiding channels.

Passing from linear to nonlinear regime, when intensity is increased, refractive index of excited waveguides is modified by nonlinearity, which tends to compensate effect of discrete diffraction. In particular conditions,

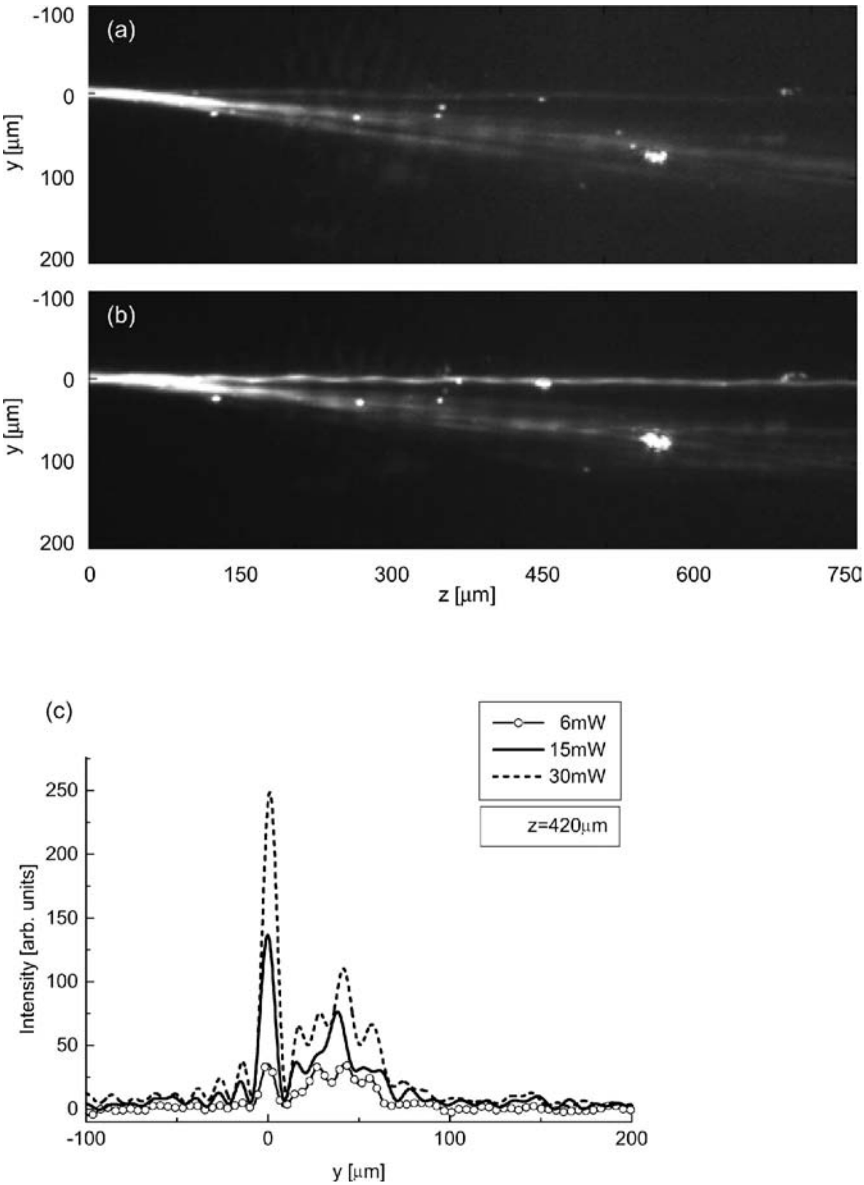

FIGURE 6

beam of proper power can propagate along medium keeping its spatial profile unchanged. In this case optical field is localized and can be regarded as a formation of discrete soliton, which is presented in Figure 3b.

Figure 4 shows the experimental evolution of the light beam propagation from discrete diffraction to discrete self-focussing. Figure 4a is an example of linear propagation while in Figure 4b the beam tends to reduce its overall discrete divergence limiting the number of channels where light is propagating. The applied voltage (0.8 V) was lower than required to create well-defined waveguides.

While the creation of discrete solitons propagating along waveguides is similar to the conventional ones, the propagation tilted to the waveguides gives quite new behavior. Waveguides array is in principle anisotropic structure and therefore the linear diffraction looks like in Figure 5a. In the nonlinear regime, light beam is trapped in the single waveguide area, which is shown in Figure 5b. Such behavior can be applied in power-adjustable and controlled steering of the light beams.

To conclude, we presented the novel conception of nonlinear array of waveguides, which can be obtained thanks to reorientational nonlinearity that is characteristic for LCs. Combination of discrete diffraction and giant nonlinear response in such structure allows us to observe discrete solitons at mW power levels, which propagate along the waveguide structures. It is worth to underline that proposed configuration offers considerable flexibility in the sense of changing of coupling strength (in linear regime) and properties of discrete solitons (in nonlinear regime) by tuning of adjustable structure geometrical parameters or by varying the value of pplied voltage. Preliminary experimental results are quite encouraging, their trend being in agreement with the theoretical predictions.

REFERENCES

[1] Lederer, F., Darmanyan, S., & Kobyakov, A. (2002). In: *Spatial Solitons*, Trillo, S. & Torruelllas, W. (Eds.), Wiley: New York.
[2] Sukhorukov, A. A., Kivshar, Y. S., Eisenberg, H. S., & Silberberg, Y. (2003). *IEEE J. Quantum Electronics*, *39*, 31.
[3] Christodoulides, D. N. & Joseph, R. I. (1988). *Opt. Lett.*, *13*, 794.
[4] Eisenberg, H. S., Silberberg, Y., Morandotti, R., Boyd, A. R., & Aitchison, J. S. (1998). *Phys. Rev. Lett.*, *81*, 3383.
[5] Efremidis, N. K., Sears, S., Christodoulides, D. N., Fleischer, J. W., & Segev, M. (2002). *Phys. Rev. E*, *66*, 046602.
[6] Braun, E., Faucheux, L. P., & Libchaber, A. (1993). Strong self-focusing in nematic liquid crystals. *Phys. Rev. A*, *48*, 611–622.
[7] Warenghem, M., Henninot, J. F., & Abbate, G. (1998). Bulk optical Frederiks effect: nonlinear optics of nematic liquid crystals in capillaries. *Mol. Cryst. Liq. Cryst.*, *320*, 207–230.
[8] Karpierz, M. A., Sierakowski, M., Świłło, M., & Woliński, T. R. (1998). Self focusing in liquid crystalline waveguides. *Mol. Cryst. Liq. Cryst.*, *320*, 157–164.

[9] Peccianti, M., Assanto, G., de Luca, A., Umeton, C., & Khoo, I. C. (2000). *Appl. Phys. Lett.*, *77*, 7.
[10] Peccianti, M. & Assanto, G. (2002). *Phys. Rev. E*, *65*, 035603.
[11] Karpierz, M. (2002). *Phys. Rev. E*, *66*, 036603.