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Spatial solitons in photorefractive lattices

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We present a summary of the recent results of our studies of nonlinear localization effects in optically-induced periodic index structures in photorefractive crystals. We demonstrate the generation of spatial bright solitons, controllable excitation of gap solitons and their anomalous steering properties.

Keywords: periodic structures, gap solitons, nonlinear optics.

1. Introduction

There has been growing interest in propagation of optical beams and pulses in media with periodically varying refractive index [1–4]. Such periodic structures or optical lattices lead to appearance of a band gaps in the transmission spectrum of waves [5]. As a result, diffractional properties of optical beams can be drastically modified by the presence of a lattice. For instance, depending on the wave number, the sign of diffraction may change from normal to anomalous. Lattice-induced propagation effects become even more dramatic in the presence of the nonlinearity of the medium leading among others to the formation of discrete and gap solitons. Typical experimental approach to studies of light propagation in periodic structures involves optical beams propagating through permanent structures created by, for instance, etching or diffusion in the optical materials such as semiconductors or polymers. In fact, such waveguide structures have been successfully employed recently to investigate both linear and nonlinear light propagation [6–8]. Recently, dynamically created periodic structures in photorefractive crystals have been demonstrated [9,10]. By interfering two or more plane waves in the crystal and utilizing the photorefractive effect, one- and two-dimensional periodic lattices of various symmetries have been obtained. Propagation of an optical beam in such structure lead to self-trapping of the beam in form of nonlinear localized modes.

In this paper we present a summary of results of our recent theoretical and experimental studies of nonlinear propagation of optical beams in optically induced lattices. In particular, we will discuss formation of discrete and gap solitons and their properties.

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2. Theory

We begin with the theoretical analysis of spatial beam propagation in an optically-induced photonic lattice using the normalized paraxial equation for the beam electric field envelope $E(x, z)$ [11,12]

$$i\frac{\partial E}{\partial z} + D\frac{\partial^2 E}{\partial x^2} + \mathcal{F}(x|E|^2)E = 0, \quad (1)$$

where x and z are the transverse and propagation coordinates, normalized to the characteristic values x_0 and z_0, respectively, $D = z_0\lambda/(4\pi n_0 x_0^2)$ is the beamdiffraction coefficient, n_0 is the average medium refractive index, and λ is the vacuum wavelength. Our experiments are performed using a dynamically induced lattice in a biased photorefractive crystal [10–13], where the optically induced change of the refractive index is

$$\mathcal{F}(x,|E|^2) = -\gamma[I_0 + I_g \cos^2(\pi x/d) + |E|^2]^{-1},$$

I_b is the constant dark irradiance, I_g is the peak intensity of the two-beam interference pattern which induces the lattice with a period d, and γ is a nonlinear coefficient. In order to match our experimental conditions, we use below the following parameters for the theory and numerical calculations: λ = 0.532 µm, n_0 = 2.4, x_0 = 1 µm, z_0 = 1 mm, d = 22.2, I_0 = 1, I_g = 1, γ = 5.31, and the crystal length L = 15 mm. We note that the model Eq. (1) is very general and appears in other areas of physics. It can describe, in particular, the BEC dynamics in optical lattices where the matter-wave solitons are expected to have similar properties to their optical counterparts.

Existence of solitons is closely linked to the structure of the linear wave spectrum. In periodic lattices, the spectrum is composed of bands corresponding to the propagating Floquet-Bloch modes, which are separated by gaps where the wave propagation is forbidden. The Floquet-Bloch modes are solutions of linearized Eq. (1) of the form

$$E_{\kappa,n}(x,z) = \psi_{\kappa,n}(x)\exp(i\kappa x/d + i\beta_{\kappa,n}z),$$

where $\beta_{\kappa,n}$ and κ are the Bloch-wave propagation constant and wavenumber, respectively, the index $n = 1,2, ...$ marks the order of the transmission band, and $\psi_{\kappa,n}(x)$ has the periodicity of the lattice.

In Fig. 1(a), we plot the dispersion relation $\beta_{\kappa,n}$. In this plot, we indicate two types of band gaps: the top one exists due to total internal reflection and extends to $\beta \to +\infty$, whereas lower gaps have a finite width and appear due to Bragg scattering from the periodic structure.

Bright spatial solitons are self-trapped localized beams, which transverse profiles do not change during propagation due to a balance between diffraction and nonlinearity. The corresponding solutions of the model Eq. (1) have the form $E_{\kappa,n}(x,z) = u(x)\exp(i\beta z)$, where $u(x,\beta)$ is the soliton profile, and β is the propagation constant. Solitons can exist when β belongs to a spectral gap. In particular, for self-focusing nonlinearity ($\gamma > 0$), the simplest localized modes, are found in the semi-infinite gap. These solitons resemble conventional bright solitons modulated by the lattice. In the so called tight-binding approximation, i.e. when the total electric field can be decomposed into a sum of weakly coupled fundamental modes excited in each waveguide of the periodic structure, these solitons can be adequately described by a discrete nonlinear Schrödinger (NLS) equation [1,3,4,14], that has stationary, spatially localized solutions in the form of discrete optical solitons. These solitons have been extensively explored in a number of theoretical papers (see, e.g., Refs. 1 and 3), and also observed experimentally [7,15].

In the self-defocusing medium (g < 0), solitons do not exist in the total internal reflection gap. Instead, staggered solitons appear near the lower edge of the first band and they resemble discrete solitons in self-focusing media being associated with coupling between the guided modes confined at refractive index maxima [3,10].

Almost two decades ago, it was suggested that the systems with periodically modulated parameters can support a novel type of solitons – gap solitons [16,17], which exist in band gaps of the linear spectrain various structures including fiber Bragg gratings [18], photonic crystals [19], and Bose-Einstein condensates loaded onto optical lattices [20]. Gap solitons are composed of the forward and backward propagating waves which are coupled nonlinearly and both

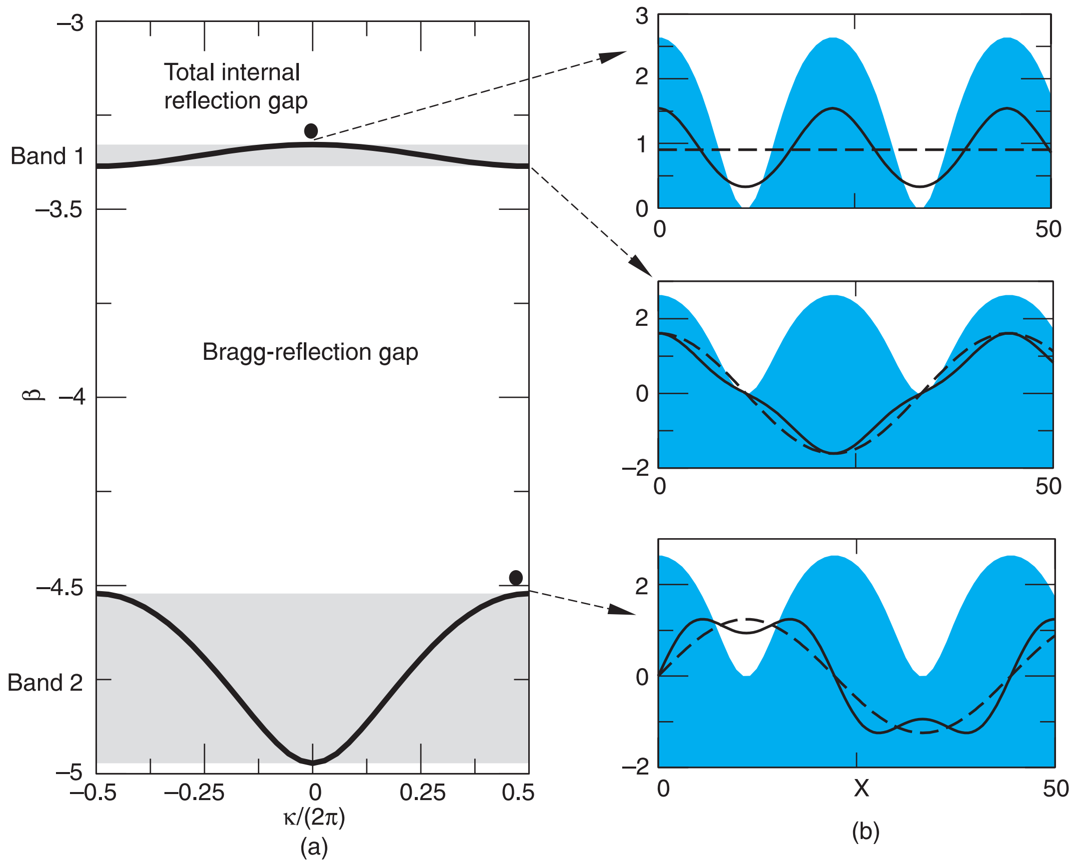

Fig. 1. Dispersion of Bloch waves in an optically-induced lattice; the spectrum bands are shaded (a). Bloch-wave profiles (solid) and leading-order Fourier components (dashed) superimposed on top of the normalized refracted index profile of the periodic lattice (shown with shading) for different gap edges indicated by the arrows (b). Bullets indicate possible location of soliton states.

experience Bragg scattering from the periodic structure. The strongest coupling occurs when the wave amplitudes are balanced, corresponding to the formation of slow or immobile gap solitons. In this regime, the specific dispersion [18] and stability [21] of gap solitons become most evident.

In case of focusing nonlinearity the simplest gap solitons can form near the edge of the second transmission band [12,22]. In Fig. 2 we present a direct comparison of fundamental properties of discrete and gap solitons. The plots are presented for the solitons centered at maxima ("odd" solitons) and minima ("even" solitons) of the lattice. At high powers, discrete solitons become localized at one or two neighbouring lattice maxima, and this defines their minimum widths. In contrast, the power of gap solitons is bounded from above because the Bragg-reflection gap is of finite width, and the spectrum of the maximum soliton localization should be narrower and lay inside the gap [18,23]. All even solitons are unstable and tend to transform into their odd counterparts, however the instability growth rate for gap solitons is much smaller than that for discrete solitons due to a limited difference in soliton powers and widths in the gap. On the other hand, gap solitons can become unstable due to inter-band coupling, whereas discrete solitons do not exhibit such in stabilities [24].

Gap solitons in periodic systems have profiles closely resembling modulated Bloch waves near the corresponding band-edges [24]. Therefore, controlled experimental excitation of spatial gap solitons can be realized if the modulated Bloch-wave profile is properly matched at the input. Since the Bloch waves are periodic, they can be decomposed into the Fourier series. In Fig. 1(b) we show the characteristic profiles of the Bloch waves, and also plot the contribution from the leading-order Fourier components (dashed lines). Therefore it appears that lattice solitons in the semi-infinite total internal reflection gap. i.e. discrete solitons, can be generated by a single incident beam, as was realized in earlier experiments for arrays of weakly coupled optical waveguides [2]. On the contrary, the Bloch waves in the Bragg-reflection gap are composed of counter-propagating waves. Therefore, spatial gap solitons can be generated by using two Gaussian beams which are tuned to the Bragg resonanceand have opposite inclination angles, as was originally suggested in Ref. 25.

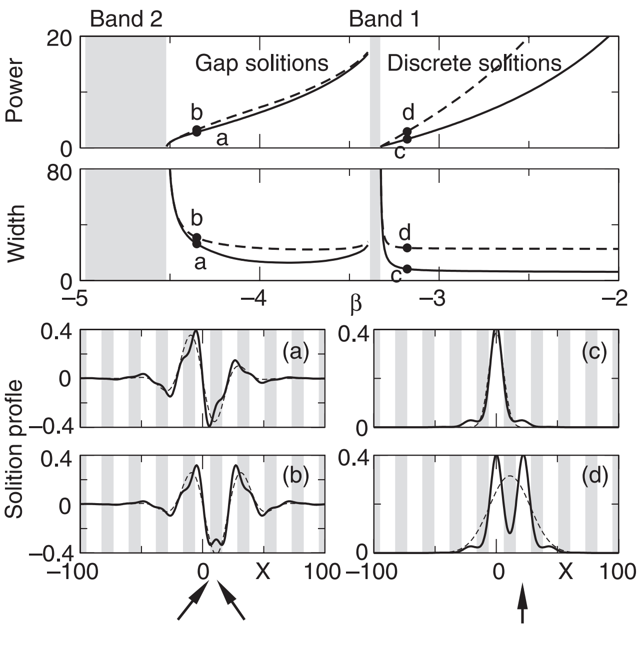

Fig. 2. Numerical results for soliton families: power (top) and width (middle) vs. the propagation constant. Bottom: soliton profiles (solid) corresponding to the marked points (a–d) in the upper plots; shadings mark the lattice minima. Arrows illustrate the direction of the input beams, which pattern (dashed) approximates the soliton profile.

3. Experiment and results

The experimental setup is shown in Fig. 3. The light of a solid state laser at 532 nm is split into two parts.The transmitted (extra-ordinary polarized) beam serves as a probe beam to induce either discrete or gap solitons in the 15 mm long SBN:60 photorefractive crystal. The second, ordinary-polarized beam is used to form the optical lattice. It passes through a Mach-Zehnder interferometer aligned such that its two output beams intersect at a small angle, thus producing interference fringes inside the 15 mm long SBN:60 photorefractive crystal crystal. The difference in the optical paths of the interferometer could be locked by use of a piezo-controlled mirror, in order to stabilize the interference pattern. When electric field is applied to the crystal, the interference pattern induced a periodic modulation of the optical refractive index via the photorefractive effect. The input and output faces of the crystal could be imaged by a microscope objective onto the two CCD cameras. Additional white-light illumination is used to vary the dark irradiance of the crystal and subsequently control degree of saturation of the nonlinearity.

Similar to the localized modes of discrete nonlinear lattices, spatial solitons in optically-induced gratings can be "even", i.e. centered between two induced waveguides

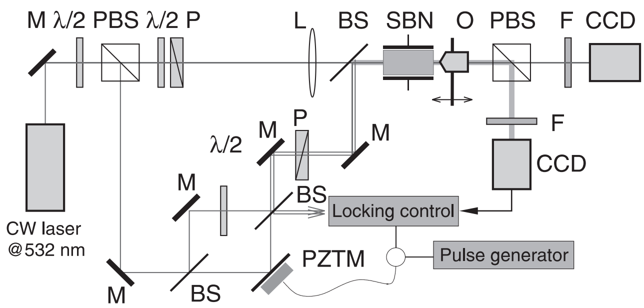

Fig. 3. Experimental setup: M – mirrors; PZTM – piezo translational mirror; PBS – polarizing beam splitters; BS – plane beam splitters; P – polarizer; SBN – photorefractive crystal; O – microscope objective; $\lambda/2$ – half-wave plate; L – AR-coated lens; F – filters; CCD – cameras.

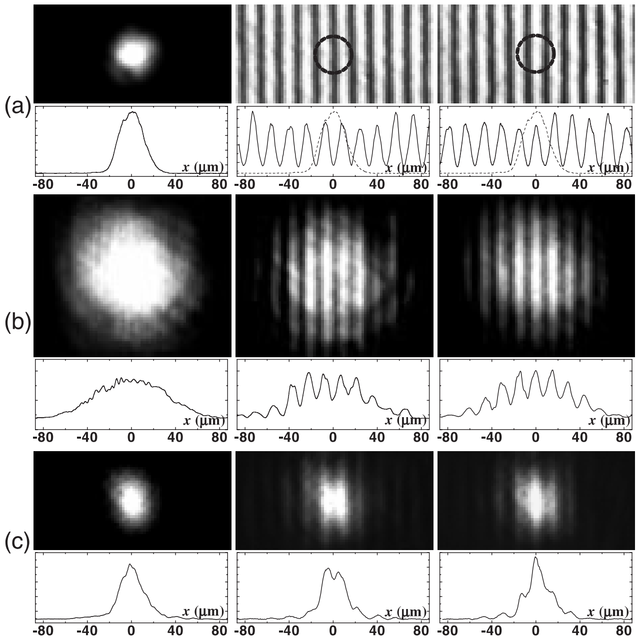

Fig. 4. Experimental demonstration of odd and even spatial-solitons. Input beam and optical lattice (power 23 μW) (a); the output probe beam at low power (2×10^{-3} μW) (b); localized states (87×10^{-3} μW) (c). Left column – no lattice (vibrating PZTM), middle – even excitation, right – odd excitation. Electric field is 3600 V/cm.

(minimum of the grating intensity), or "odd", i.e. centered on the waveguide (maximum of the grating intensity). We observed both types of the localized modes. To this end, the extra-ordinary probe beam was focused by a 6-cm (or 5-cm) focal-length lens on the input face of a crystal.

At low intensities of the probe beam ($|E|^2 = 0.02$) we observed diffraction resembling the formation of Bloch waves of the periodic potential (Fig. 4). Diffraction pattern is almost independent of the initial position of the probe beam relative to the grating [Fig. 4(b)]. However, when the intensity of the probe beam is increased ($|E|^2 = 0.83$) two distinct states form [Fig. 4(c)]. When the maximum of the probe beam is centered between the maxima of the grating, an even state is generated [Fig. 4(c) – middle column]. However, when the probe beam is centered on a maximum, an odd state forms [Fig. 4(c) – right column]. The even mode was observed to be unstable, and transforms into a non-symmetric structure due to small perturbations of the beam position. The qualitative picture described above does not change if a smaller input beam is used (focusing with a 5-cm lens), such that only a single waveguide is initially excited. If the grating is erased by introducing a frequency detuning between both grating writing beams (by driving PZTM with a high frequency AC signal), a standard single soliton state is observed [Fig. 4(c) – left column].

The simplest "twisted" mode is similar to a pair of two out-of-phase solitons; it can also be odd or even. The twisted modes are generated by introducing a tilted glass plate in half of the input beam. The tilt is set such that both

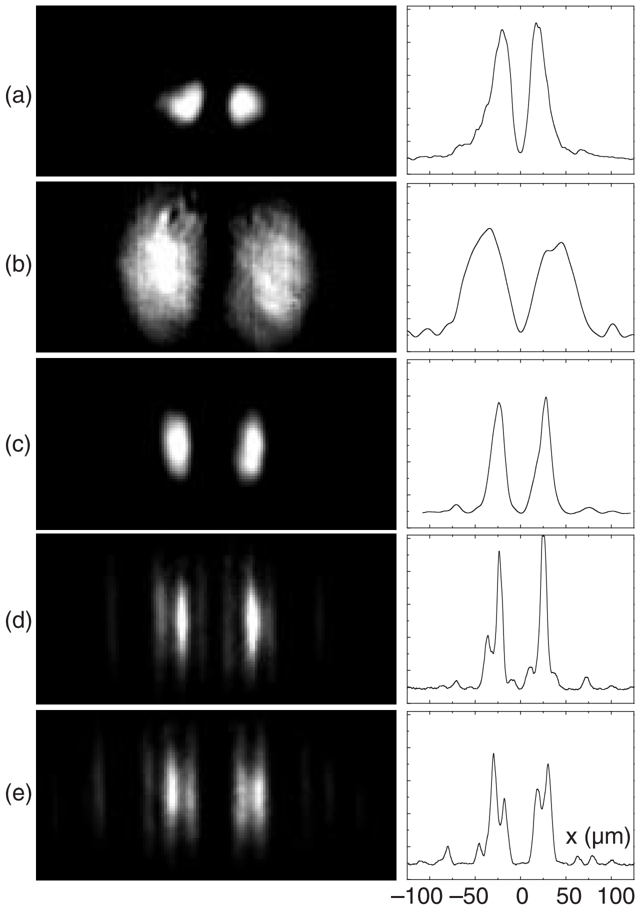

Fig. 5. Experimental demonstration of the soliton bound states--twisted modes: input (a); outputs (b-e): linear diffraction (b); dipole beam (c); even symmetry twisted mode (d); odd symmetry twisted mode (e). Powers: grating – 23 μW, dipole beam – 0.12 μW. Intensity ratio ($|E|^2$) is 0.077, electric field is 3600 V/cm.

parts of the beam are π-phase shifted, Fig. 5. The input beam [Fig. 5(a)] can be centered in between two maxima or on a maximum of the optical lattice. Without a DC field, the dipole beam diffracts [Fig. 5(b)]. When a voltage is applied and the PZT mirror is set to vibrate, a pair of two repelling bright solitons is observed [Fig. 5(c)]. When the optical lattice is formed, a pair of out-of-phase "odd" states is created [Fig. 5(d)]. If the beam is centered on a maximum of the optical lattice, a pair of "even"states is observed with a central waveguide not being excited at all [Fig. 5(e)].

In order to excite gap solitons, the probe beam was split into two parts which were focused by cylindrical lens and made to overlap at the input face of the crystal [12]. The angle between these two beams was set to twice the Bragg angle, such that the periodicity of the interference pattern was equal to that of the lattice (22 μm). In our case, such value of the periodicity allows for a relatively wide gap in the transmission spectrum, as shown in Fig. 1(a). The relative phase between the probe beams was tuned such that a symmetric interference pattern (with a peak intensity I_0) is obtained, as shown in Fig. 6 (top). The relative position be-

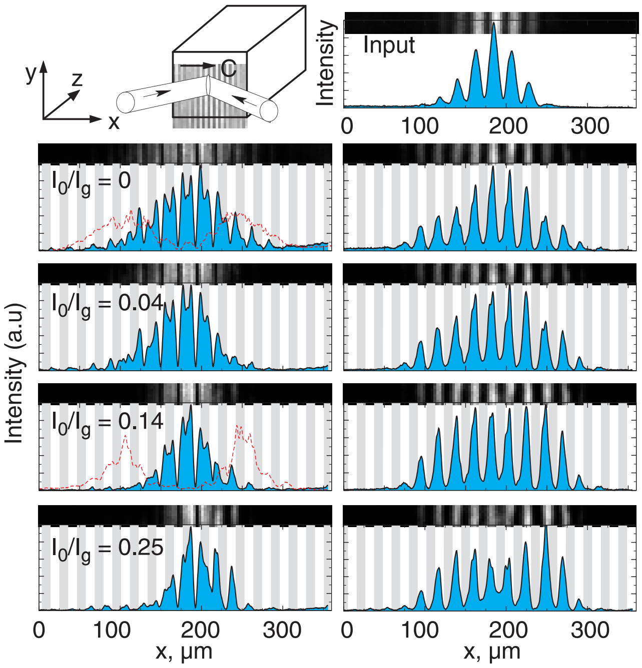

Fig. 6. Experimental results for two-beam interaction (after Ref. 12). Top: excitation scheme (left) and the input intensity profile (right). Below: output for varying beam power: Left: mutual focusing and gap soliton formation when interference maxima are aligned with the lattice minima; Right: self-defocusing when interference maxima are at the lattice maxima. Dashed curves represent the beam profiles at the indicated beam intensity when the grating is erased.

tween this pattern and the lattice could also be controlled, by changing the relative phase between the two lattice forming beams. The input width of the overlapping probe beams is w = 55 μm (65 μm FWHM). For a zero bias field, when the lattice is absent, the beams become fully separated at the crystal output. When electric field of 5000 V/cm is applied to the crystal, the interference pattern induced a periodic modulation of the optical refractive index and the probe beams excite Bloch waves at the edge of the Brillouin zone corresponding to the first or the second band, depending on the relative lattice position. We positioned the beams to excite the even gap soliton, corresponding to $x_e = d/2$.

The experimental results are shown in Fig. 6. First, we align the interference maxima of the input beams with the minima of the induced lattice at the input face of the crystal and record the beam profiles at back face for several input powers [see Fig. 6 (left column)]. The output intensity is exactly zero at the maxima of the index grating. The intensity maxima are out-of-phase, as confirmed with interferometric measurements, and posses a double peak structure located at the minima of the grating. At low powers, the output intensity pattern is broad and corresponds to the Bloch waves at the lower gap edge.The beam is exactly centered between two unperturbed output beams [dashed curve in Fig. 6 (left column)] measured for zero voltage. At higher intensity (I_0/I_g = 0.04), we observe mutual focusing of the beams. For intensities I_0/I_g = 0.14 the output beam is self trapped to a state with a width equal to that of the input [see Fig. 6 (left column)], indicating the formation of a spatial gap soliton.

This gap soliton has zero transverse velocity, and is centered between the two output beams which separate when the grating is erased (dashed curve). As predicted theoretically, the effect of the mutual focusing is limited and at higher intensities (I_0/I_g = 0.25) the beam disintegrates [see Fig. 6 (left column, bottom plot)] while its profile becomes asymmetric due to the diffusion contribution to the photorefractive nonlinearity. On the other hand, when we align the interference maxima of the input beams at the lattice maxima, the excited Bloch wave corresponds to the upper gap edge [see Fig. 1] and they experience anomalous diffraction [26] leading to self-defocusing as the power is increased [Fig. 6 (right)]. Our experimental results are in very good accord with theory. Fig. 7 shows result of numerical simulation of dynamics of finite-size Bloch wave represented by the following function

$$E_0(x) = \sqrt{I_0} e^{-(x-x_e)^2/w^2} \cos[p(x-x_s)/d],$$

where the exponential term approximates the gap soliton envelope, w being the width of the input beams. The interference term approximates the Bloch-wave profile, with the shift x_s depending on the relative phase difference between the two beams. When the interference maxima are at the minima of the refractive index profile, the Bloch mode is excited at the lower edge of the Bragg-reflection gap, and the input pattern can well match the gap-soliton profile, as shown in Figs. 2(a,b).The beams diffract at a low input power [Fig. 7(a)], whereas an immobile gap soliton forms when the input power is increased [Fig. 7(b)]. The required power depends on the input beam width, as follows from Fig. 2, and the minimum soliton width defines the fundamental limit on the degree of two-beam mutual focusing. Indeed, as the power is increased, a soliton break-up occurs through a resonant excitation of the first band, and subsequent formation of a quasi-periodic breather [Fig. 7(c)]. These are generic effects which may occur in lattices with various geometries [23], and breathing states were recently observed in waveguide arrays [6].

Finally, we studied mobility of spatial gap solitons and a possibility to vary their transverse velocity. Experimentally, the soliton steering is induced by tilting the lattice by 20% of the Bragg angle thus introducing a lateral shift of the induced waveguides by 16 μm at the output [the lattice is shifted to the right as illustrated in Fig. 8(a)].

Results of the experimental observations and the numerical simulations are presented side-by-side in Fig. 8(b,c) show that the generated gap solitons move to the left whereas the grating is tiled to the right. In the experimentally obtained intensity profile, on the right-hand side of the gap soliton (positive x), a small radiation from the gap soliton can be seen (contribution from the first

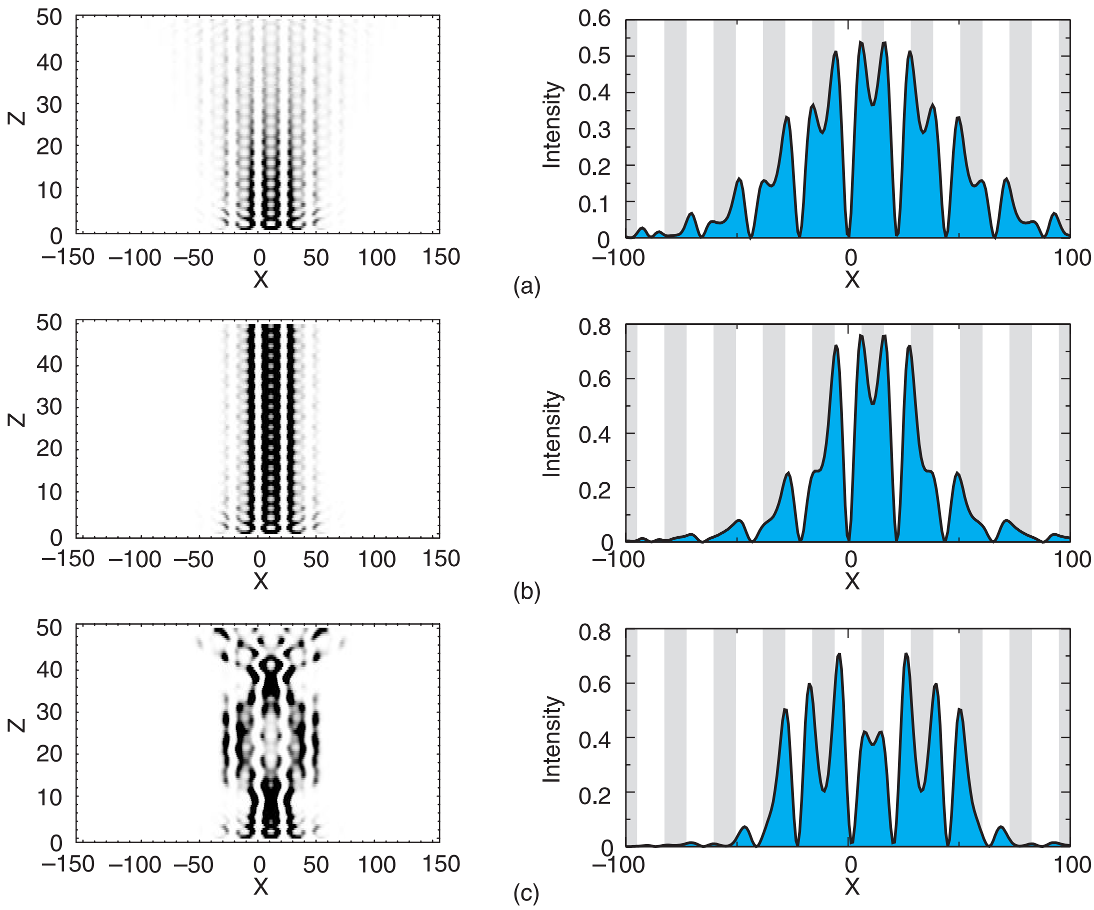

Fig. 7. Numerical results. Dynamics of the Bloch waves excited through two-beam interference: linear diffraction at low power ($I_0 \cong 0$) (a), excitation of a gap soliton in the nonlinear regime ($I_0 = 0.048$) (b), beam breakup and the formation of a quasi-periodic breathing state at higher powers ($I_0 = 0.29$)(c). Left: variation of intensity along the propagation direction; Right: beam profiles at the crystal output ($z = 15$ mm) normalized to I_0.

band), which appears due to asymmetry of the initial excitation profile and due to the in homogeneities of the lattice. The anomalous steering behavior occurs because the spatial group-velocity dispersion (GVD) for gap solitons associated with the second band is almost three times larger compared to a homogeneous crystal under our experimental conditions. This is an analogy in the spatial domain to the superprism effect in photonic crystals. By changing the lattice period and modulation depth, it is possible to increase or decrease the GVD of gap solitons. In contrast, the discrete solitons associated with the first band always experience reduced spatial GVD, and therefore tend to propagate along the lattice [8].

4. Conclusions

We have demonstrated the generation of spatial optical solitons in an optically-induced lattice in a photorefractive crystal. In particular, we have observed discrete solitons and their bound states (twisted modes). We also realized a fully controlled excitation of spatial gap solitons and observed novel effects such as anomalous steering of gap solitons and the limitation of the two-beam mutual focusing through inter-band coupling. We believe our results can also be useful for the study of nonlinear effects in photonic crystals and nonlinear dynamics of the Bose-Einstein condensates in optical lattices.

Acknowledgements

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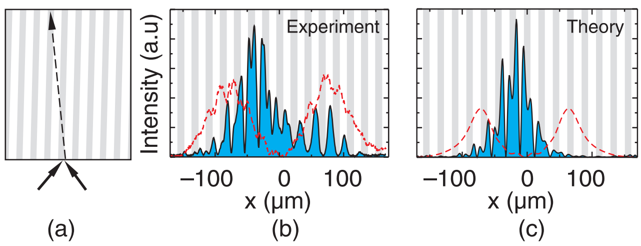

Fig. 8. Schematic demonstration of anomalous gap-soliton steering induced by a tilt of the lattice; dashed line shows the propagation direction of a gap soliton; arrows indicate the directions of the input beams (a). Output soliton profile for a lattice tilt in the direction of larger x by 20% of the Bragg angle with respect to normal; dashed lines show the beam profiles when the lattice is absent (b,c).

References

1. F. Lederer, S. Darmanyan, and A. Kobyakov, in: *Spatial Solitons*, p. 269, edited by S. Trillo and W.E. Torruellas, Springer Verlag, Berlin, 2001.
2. D.N. Christodoulides, F. Lederer and Y. Silberberg, *Nature*, **424**, 817 (2003).
3. Yu.S. Kivshar, *Opt. Lett.* **18**, 1147 (1993); W. Krolikowski and Yu.S. Kivshar, *J. Opt. Soc. Am.* **B13**, 876 (1996).
4. A.B. Aceves, C. De Angelis, T. Peschel, R. Muschall, F. Lederer, S. Trillo, and S. Wabnitz, *Phys. Rev.* **E53**, 1172 (1996).
5. P.St.J. Russell, *Appl. Phys.* **B39**, 231–246 (1986).
6. D. Mandelik, *Phys. Rev. Lett.* **90** 253902 (2003).
7. H.S. Eisenberg, *Phys. Rev. Lett.* **81**, 3383 (1998).
8. R. Morandotti, *Phys. Rev. Lett.* **83**, 2726 (1999).
9. N.K. Efremidis, S. Sears, D.N. Christodoulides, J. Fleischer, and M. Segev, *Phys. Rev.* **E66**, 046601 (2002).
10. J.W. Fleischer, T. Carmon, M. Segev, N.K. Efremidis, and D.N. Christodoulides, *Phys. Rev. Lett.* **90**, 023902 (2002).
11. A.A. Sukhorukov, D. Neshev, W. Krolikowski, and Y.S. Kivshar, *Phys. Rev. Lett.* **92**, 093901 (2004).
12. D. Neshev, A.A. Sukhorukov, B. Hanna, W. Krolikowski, and Y.S. Kivshar *Phys. Rev. Lett.* **93**, 083905 (2004).
13. D. Neshev, E. Ostrovskaya, Y. Kivshar, W. Krolikowski, *Opt. Lett.* **28**, 710 (2003).
14. D.N. Christodoulides and R.I. Joseph, *Opt. Lett.* **13**, 794 (1988).
15. Y. Silberberg and G.I. Stegeman, in: *Spatial Solitons*, p. 37, edited by S. Trillo and W.E. Torruellas, Springer-Verlag, Berlin, 2001.
16. Yu. I. Voloshchenko, *Zh. Tekh. Fiz.* **51**, 902 (1981) (in Russian) [Tech. Phys. **26**, 541 (1981)].
17. W. Chen and D.L. Mills, *Phys. Rev. Lett.* **58**, 160 (1987).
18. C.M. De Sterke and J.E. Sipe, "Gap solitons" in *Progress in Optics*, Vol.XXXIII, pp. 203–260 edited by E. Wolf, North Holland, Amsterdam 1994).
19. N. Akozbek and S. John, *Phys. Rev.* **E57**, 2287 (1998).
20. O. Zobay, *Phys. Rev.* **A59**, 643 (1999).
21. I.V. Barashenkov, *Phys. Rev. Lett.* **80**, 5117 (1998).
22. D. Mandelik, *Phys. Rev. Lett.* **92**, 93904 (2004).
23. A. Sukhorukov and Y. Kivshar, *Opt. Lett.* **28**, 2345 (2003)
24. D.E. Pelinovsky, A.A. Sukhorukov, and Yu.S. Kivshar, *Phys. Rev.* **E70**, 036618 (2004).
25. J. Feng, *Opt. Lett.* **18**, 1302 (1993).
26. R. Morandotti, *Phys. Rev. Lett.* **86**, 3296 (2001).
27. A.A. Sukhorukov and Yu.S. Kivshar, *Phys. Rev.* **E65**, 036609 (2002).
28. P.Y. Louis, E.A. Ostrovskaya, C.M. Savage, and Yu.S. Kivshar, *Phys. Rev.* **A67**, 013602 (2003).


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