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Formation of waveguide channels by dark spatial solitons in a planar waveguide optically induced in a lithium niobate crystal

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***Abstract*. The formation of optical waveguide channels is experimentally demonstrated upon the photorefractive self-action of a phased light beam in a planar waveguide optically induced in an iron-doped lithium niobate crystal. Planar and channel waveguides were produced by using a 633-nm He – Ne laser with output powers 1 mW and ~ 10 μW, respectively.**

Keywords: *dark solitons, planar waveguide, interaction of radiation with matter.*

Spatial optical solitons – regions of a light field with almost diffraction-free behaviour in an optically nonlinear medium attract considerable recent interest [1 – 3]. In the simplest case, this is a bright spatial soliton, i.e., a light beam whose diffraction spread is compensated by self-focusing [1, 2]. In a defocusing medium, dark solitons can exist, i.e., non-illuminated diffraction-free regions in the light field [3]. Photorefractive spatial solitons were observed at micro- and milliwatt powers of light in crystals of bismuth titanate [4] and strontium – barium niobate [5] and some other electro-optical crystals in an external electric field. One-dimensional dark photovoltaic solitons were obtained in bulk lithium niobate samples ($LiNbO_3$) [6]. In [7 – 9], bright and dark photorefractive solitons were observed in planar waveguides formed by ion implantation on the surface of strontium – barium niobate samples [7] and by thermal diffusion of Fe and Ti on the $LiNbO_3$ surface [8, 9]. A dark soliton induces a waveguide channel in a nonilluminated region similarly to a bright soliton inducing such a channel in an illuminated region.

In this paper, we demonstrate for the first time the formation of waveguide channels by the filed of dark photovoltaic solitons in planar waveguides optically induced in an iron-doped lithium niobate crystal ($Fe:LiNbO_3$).

Planar waveguides were produced by the double-beam writing of one-dimensional photorefractive gratings by ordinarily polarised radiation from a 633-nm He – Ne laser in a $Fe:LiNbO_3$ crystal of size 9 mm × 6 mm × 8 mm along the x, y, and z axes, respectively. The grating vector was oriented along the crystal optical axis (the z axis). The total power of the writing radiation beams was ~ 1 mW and their aperture was varied from 2 to 3 mm. The refractive index in the grating region changes in the linear approximation as $n(z) = n_s + \Delta n \cos^2(\pi z/\Lambda)$, where n_s and Δn are its unperturbed value and maximum variation, and Λ is the spatial period of the grating. In the general case, such gratings are the systems of coupled planar waveguides [10, 11].

The coupling coefficient between adjacent elements depends on the period Λ and Δn. Under certain conditions the waveguide layers prove to be virtually isolated. Figure 1 shows the distributions of the light intensity in the output plane in the systems of coupled and isolated planar waveguides induced in a given sample upon their excitation by an extraordinarily polarised Gaussian beam. The light field was studied with a video camera. One can see that a light beam undergoes usual diffraction in the waveguide plane, while diffraction along the grating vector is restricted or determined by waveguide properties.

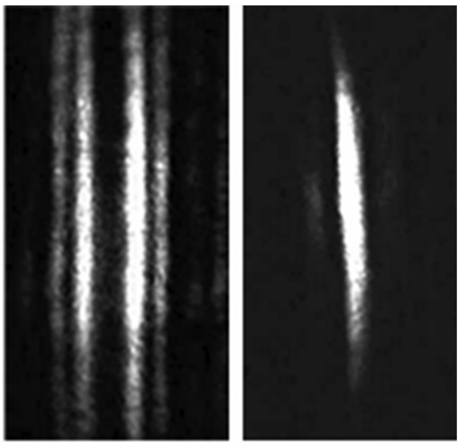
a b

Figure 1. Intensity distributions in the output plane upon excitation of one waveguide layer in the systems of coupled ($\Delta n = 10^{-4}$ and $\Lambda = 15$ μm) (a) and isolated ($\Delta n = 10^{-4}$ and $\Lambda = 20$ μm) (b) planar waveguides.

Waveguide channels were induced in a planar waveguide by using light beams with the amplitude profile close to that required to produce dark spatial solitons. A thin glass plate was introduced into the input light beam to block half its aperture, providing the phase shift of the light field equal to

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$(2m+1)\pi$, where m is an integer. The light beam was focused on the input plane of the waveguide layer with the help of spherical lenses with the focal distance from 2 to 5 cm. The plate was periodically removed from the forming beam, which allowed us to observe the variation in the readout beam intensity profile in the output plane and the formation of a waveguide channel. Figure 2 shows the diffraction of the readout light beam over the crystal length in a homogeneous region and the intensity distributions in the output plane of the waveguide for the forming and readout beams in the grating with $\Lambda = 20$ μm and $\Delta n = 10^{-4}$. The forming phased light beam with the waist of size 15 μm had a power of 10 μW on the input plane of the waveguide.

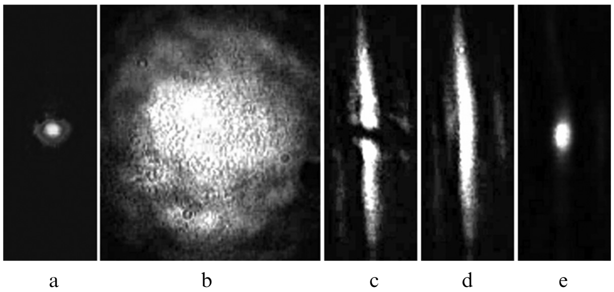

Figure 2. Intensity distributions in the input (a) and output (b) planes of a homogeneous crystal for a Gaussian beam with the 15-μm waist and in the output plane for the forming beam for $t = 0$ (c) and the readout beam for $t = 0$ (d) and 180 min (e).

Already for the exposure time $t < 30$ min, a noticeable localisation of the light field of the readout beam was observed in the region of the minimum intensity of the forming beam. For $t = 180$ min, the diffraction-limited divergence of the readout beam in the waveguide plane was almost completely compensated (Fig. 2e). This suggests that a dark photorefractive spatial soliton was formed in the planar waveguide, which induces a channel waveguide in the nonilluminated region. The evolution of the intensity distribution of the readout beam in the output plane of the waveguide is illustrated by the dependence of the ratio of its transverse sizes w_z/w_y on the exposure time during the production of the channel waveguide by the forming beam (Fig. 3). Here, w_z and w_y are the FWHM of the beam along the normal to the waveguide plane and in the given plane,

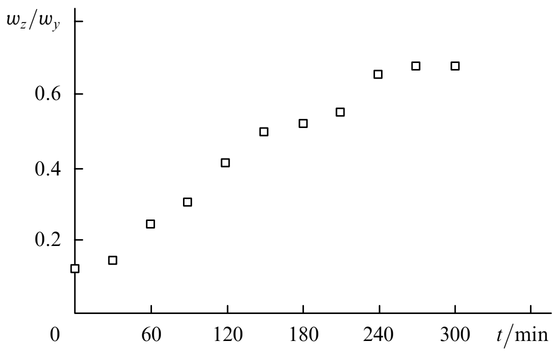

Figure 3. Time dependence of the ratio w_z/w_y of the FWHM beam sizes in the output plane of the crystal.

respectively. The cross section of the readout beam remains slightly elliptic even for exposures $t = 5 - 6$ h because a change in the refractive index in the waveguide plane can be equal to that along the normal to this plane only when the waveguide layer in the illuminated region completely disappears.

Thus, we have demonstrated the generation of isolated two-dimensional waveguide channels in a $Fe : LiNbO_3$ crystal. Our results show that more complicated channel waveguide structures can be formed in the systems of coupled and isolated planar optical waveguides optically induced in $Fe : LiNbO_3$ crystals.

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