Reconfigurable waveguides for soliton-driven photonics

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ABSTRACT

We review the propagation and interaction behaviour of spatial screening solitons generated in a photorefractive SBN crystal in order to exploit them for new perspectives in soliton-driven photonics. We report on the successful experimental generation of an array of 5 x 5 spatial screening solitons. The waveguide properties of each channel are probed by a beam of different wavelength, and each channel is found to guide the probe beam independently. By combining the interaction and waveguide properties, we achieved channel combination and separation, thereby realizing complex waveguide couplers and dividers. Furthermore we show that image processing is possible using parallel propagating photorefractive solitons, allowing to create new features in the frame of the concept of "light is guiding light".

1. INTRODUCTION

One of the most fascinating manifestations of optical nonlinearities, associated with an intensity-dependant refractive index modulation, is the spontaneous self-focusing of an optical beam. For the case when the strength of the focusing effect exactly balances the diffraction that occurs during propagation of the optical beam, a bright spatial soliton forms. Experimentally, two-dimensional spatial solitons can be realized in nonlinear optical materials that exhibit a saturable nonlinearity. Among them, photorefractive materials are ideally-suited, because they allow to create spatial solitons at very low laser power, using a biasing DC electric field and a background illumination in order to create a refractive index modulation proportional to the light intensity distribution. Since their discovery in 1992 [see e.g. 1], photorefractive spatial solitons have become an own, rapidly growing field of nonlinear optics. One of the major features of photorefractive solitons is their nonlocal potential, which results in an anisotropic modulation of the refractive index.

In this contribution, we will review several of the most exciting features of complex photorefractive solitons. We will show that interacting photorefractive solitons lead to a complex propagation behaviour, including anomalous interaction due to the anisotropic refractive index modulation, spiraling and energy as well as momentum exchange of the solitons [2]. More complex beam structures as those carrying angular momentum normally decay into a number of self-trapped bright solitons. We will show that it is possible to stabilize these structures by the superposition with a fundamental solitary beam, allowing the generation of complex vector solitons or molecules of light [3]. Moreover, we show that the waveguide characteristics of photorefractive solitons [4] lead to the formation of waveguide couplers and dividers [5] as well as to the formation of complex waveguide arrays. This shows the potential of an all-optical control of the single channels in a photorefractive soliton array. In the following sections, several examples of waveguiding scenarios are shown, demonstrating the potential of soliton-driven photonics.

2. REALIZATION OF A SOLITON ARRAY

To create an array of 5 x 5 solitons in a photorefractive crystal, the beam of a frequency-doubled Nd:YAG-laser (λ = 532 nm) illuminates a spatial light modulator (SLM), on which the image of the beam array is imprinted. The SLM in turn is imaged onto the front face of a photorefractive SBN60:Ce crystal, which is biased by an external electric field in order to ensure soliton beam formation. The back face of the crystal is monitored with a CCD-camera, showing the soliton array (fig. 1). Once this array is written, it is possible to use the beam of a HeNe-laser with an intensity of a few mW/cm^2 to test the waveguide properties of the single channels of the array.

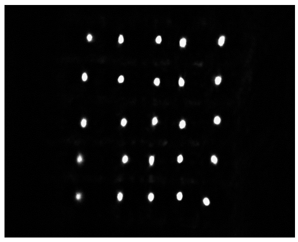

Fig. 1: A 5 x 5 soliton array.

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Since the photorefractive material is less sensitive to light in the red wavelength region, the induced refractive index modulation can be scanned without a nonlinear interaction. Positioning the red probe beam one after another to the positions of a 3 x 3 soliton array on the crystals front face, we found the probe beam to be guided in each of the nine channels solely (fig. 2). Because of the anisotropic character of the photorefractive refractive index modulation the distances in the direction perpendicular to the applied electric field have to be larger than in the direction of the applied field to obtain parallel propagation of the solitons. Looking at the back face of the crystal (figure 2a) one clearly can distinguish 9 single channels of the array, each with a diameter of about 12 µm. The guiding features of the array are shown in fig. 2b and 2c. Even though no fixing procedure was applied, every single channel still is clearly distinguishable and guides the probe beam with only minor loss after several hours of writing.

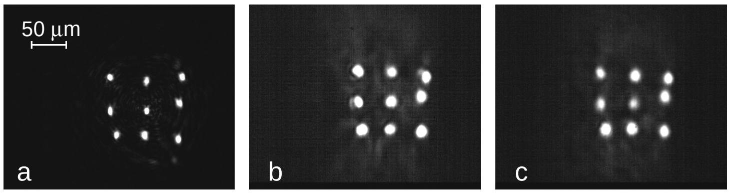

Fig. 2: Creation and probing of a waveguide array induced by photo-refractive solitons. a) soliton array, b) and c) waveguide array probed by the HeNe-beam directly after writing and after 15 h, respectively.

3. CONTROL OF SOLITON CHANNELS

Beneath waveguiding, a controlled interaction between two channels of the array can performed. Therefore, a separate, coherent beam was focused onto the front face of the crystal. This beam in function of a steering beam can be positioned between two spot of the array imaged on the crystals front face. Depending on its relative phase, it can be exploited to fuse or to repel different solitons of the array. Fig. 3 shows the uncontrolled soliton array and a waveguiding configuration, where the control beam was used to fuse the central and lower middle soliton into one single channel. This shows to our knowledge for the first time the control of single channels of an waveguide array just by a beam of light, and illustrates the capability of spatial solitons for the realization all-optical switches and interconnects.

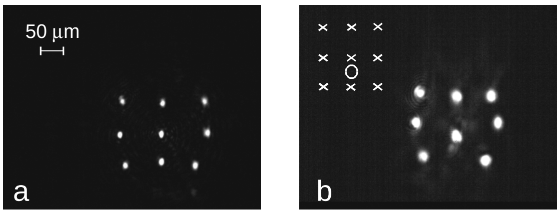

Fig. 3: Optical control of a soliton array. a) The uncontrolled soliton array, b) the controlled array probed by a red beam. The inset shows the control configuration.

4. CONCLUSION

In this paper we presented to our knowledge the first control of an array of photorefractive solitons by a separate beam of light. The principle of this control is based on the interaction behaviour of complex spatial photorefractive solitons combined with their waveguiding properties. We were able to show that a stable propagation of several parallel solitons in an array-geometry and therefore the formation of a waveguide array is possible. Furthermore the all-optical control of single channels of the array was shown by inducing a determined fusion of two channels of the array, creating a y-coupler within the waveguide array.

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