Spatial and discrete photorefractive solitons with ultra short laser pulses

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Abstract: *Spatial and discrete optical solitons are generated with picosecond laser pulses in the visible and infrared spectral region using photorefractive strontium barium niobate. The dynamics of soliton formation and the region of existence are studied in detail.*

Since the first observation of photorefractive screening solitons [1] a lot of interesting phenomena related to the propagation of optical solitons in photorefractive media have been investigated [2]. However, almost all of these experiments have been performed with cw laser light or moderately short laser pulses, and therefore not much is known about the formation of photorefractive solitons with ultra short laser pulses. The question if a spatial soliton can be formed with ultra short laser pulses and if it might be possible to build up a soliton with a single pulse due to the high peak intensity [3] is still under consideration.

In this contribution, we examine the formation of photorefractive screening solitons in strontium barium niobate (SBN) using visible and infrared picosecond laser pulses. The main results are related to the dynamics of the soliton formation with green pulses, and to the soliton existence region. One crucial parameter that determines the existence of solitons is the time delay between the soliton pulse and the background pulse necessary to built up the suitable refractive index profile for stable soliton formation. We find that for the existence of picosecond solitons, the delay between the two pulses should not exceed a certain value depending on the time constant of the photorefractive effect of the material used. Solitons can also build up using picosecond infrared laser pulses that gives the promising perspective to observe solitons in the telecommunications wavelength range. We also demonstrate the generation of discrete solitons with ultra short laser pulses in a two-dimensional photonic lattice.

Pulses with a duration of 1 ps and a repetition rate of 1 kHz are generated by a laser system consisting of a mode-locked Ti:sapphire oscillator, a regenerative amplifier and an optical parametric amplifier (OPA). We have examined the formation of solitons with pulses of 532 nm and of 800 nm wavelength, respectively. One pulse is divided into a signal and a background pulse. The signal or soliton pulse is focused onto the front face of the Cerium-doped SBN crystal (5x5x20 mm) starting with a beam width of approximately 14 μm and pulse energies up to 1 μJ. The pulse is propagating along the long axis of the SBN crystal, whereas the c-axis of the crystal is orientated along one of the short axes. The crystal is biased by an external electric field of E_{ext} = 1 kV/cm that is applied along the c-axis. The soliton pulse is polarized extraordinarily to exploit the largest electro-optic coefficient of SBN. The background pulse can be delayed with respect to the soliton pulse and is expanded with two convex lenses to an elliptical pulse with an area that is larger than the area of the side faces of the crystal. To examine the propagation of discrete solitons in photonic lattices with laser pulses, a two-dimensional refractive index pattern can be induced by means of a spatial light modulator and a green cw laser [4].

A stable soliton can exist in a certain parameter range depending on the applied electrical field, signal beam diameter, signal and background intensity, respectively [5]. With an applied electrical field of E_{ext}=1 kV/cm the soliton width is measured by varying the signal intensity. With decreasing intensity ratio I_{sig}/I_{back} the soliton width is increasing rapidly as can be seen in Figure 1. The smallest soliton width is reached at an intensity ratio of approximately I_{sig}/I_{back}=2. By increasing the signal intensity the soliton widths also increases. For intensity ratios larger than 20, the solitons are no longer stable, i.e., they break up into filaments. The solid line in Figure 1 is calculated considering the saturation of the refractive index change at high light intensities [6].

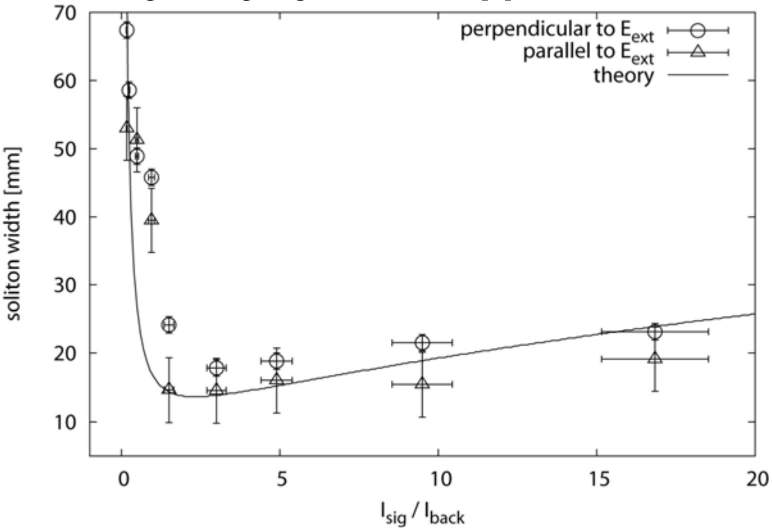

Figure 1: Existence curve for spatial solitons created with picosecond laser pulses at λ = 532 nm with an applied electrical field of E_{ext} = 1000V/cm. The beam widths is measured perpendicular and parallel to the applied electrical field, respectively. The smallest soliton width is reached at $I_{sig}/I_{back} \approx 2$. The solid line is calculated considering the saturation of the refractive index change at high light intensities [6].

The time for the formation of the soliton is of the order of three minutes depending on the light intensity. After this transient formation time, the soliton remains stable. The dynamics of the soliton formation are very similar to cw laser experiments [5]. The build-up time of a soliton with infrared laser pulses (λ = 800 nm) is longer in comparison to the time constant of soliton formation in the visible spectral region. The existence curve exhibits a minimal soliton width of d = 27 μm at an intensity ratio I_{sig}/I_{back} of about 63.

We have also investigated the dependence of the process of soliton formation with picosecond laser pulses on the time delay between the soliton and background pulse. When the soliton pulse reaches the crystal a few pulse lengths (≈50 ps) before or after the background pulse, the process of soliton formation remains the same. Even when the soliton pulse reaches the crystal 2 ns after the background pulse, solitons can still be formed. However, these solitons remain stable for larger intensity ratios I_{sig}/I_{back} in comparison to the measurements with zero delay. Up to a delay of 4 ns, stable solitons can be generated. For larger delays, solitons become unstable. This behavior can be understood by the role of the light-induced charge transport in photorefractive SBN on the soliton formation process. When the background pulse hits the crystal, it excites electrons from Ce^{3+} ions into the conduction band. The lifetime of the electron in the conduction band is of the order of a few nanoseconds [6]. This indicates that the soliton pulse experiences a background conductivity that has already been decreased when the soliton pulse reaches the crystal. Hence, the effective background photoconductivity depends on the time delay between soliton pulse and background pulse. By comparing the existence curves for the different time delays one may deduce the lifetime of excited electrons that is about 4 ns in the SBN crystal used.

In this contribution we will report in detail on the formation of spatial photorefractive solitons with picosecond laser pulses concerning the dynamics and their range of existence. Discrete solitons can be observed in a two-dimensional photonic lattice.

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