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Discrete quadratic solitons in one-dimensional waveguide arrays

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Abstract: We excited the first quadratic discrete solitons in a one-dimensional waveguide array. Soliton characteristics were measured dependent on wave-vector mismatch and diffraction and show the theoretically predicted behavior.

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1. Introduction

There is a constantly growing interest in nonlinear discrete systems because of their unique and fascinating properties. It was shown by Christodoulides and Joseph in 1988 that light propagating in arrays of coupled channel waveguides with a Kerr nonlinearity could undergo diffractionless propagation and self-focusing [1]. Recently spatial discrete solitons were observed in AlGaAs arrays [2] utilizing the cubic nonlinearity of these materials. Theoretical investigations have predicted the existence of spatial solitons in quadratically nonlinear discrete systems [3]. These systems are especially worthwhile an investigation because of their great flexibility. The nonlinearity is easily adjustable, even in sign, just by phase-mismatch variations. Additionally, diffraction can be tailored taking advantage of the unique diffraction properties of discrete systems. In this paper we report the first experimental excitation of one-dimensional quadratic array solitons in Ti:indiffused periodically poled lithium niobate waveguide arrays near the resonance of second-harmonic generation (SHG) for different nonlinearity and diffraction paramers. Their characteristics were found in qualitative and quantitative correct agreement to the theoretical predictions.

2. Samples, experimental conditions and results

On a 7-cm-long Z-cut lithium niobate crystal arrays of linearly coupled waveguides (each array consists of 101 waveguides) were fabricated by in-diffusion of titanium stripes. With center-to-center distances between the waveguides from 14 to 16µm linear coupling length for the FH between 10 and 26mm were obtained. Only the FH fields diffract via field overlap of the modes in the array. The SH field distribution is strongly localized to the channels with negligible field overlap and coupling. For phase-matching SHG between the fundamental-harmonic (FH) and the second-harmonic (SH) TM_{00} waveguide modes a uniform QPM grating was written in the sample by electric field poling. The sample was heated in an oven to higher than 150°C to prevent photorefractive index disturbances and a resulting inhomogeneity of the linear coupling and the wave-vector mismatch distribution. Linear and nonlinear measurements of the discrete diffraction and SHG with single and tilted broad beam excitation confirmed the array's excellent linear properties. It showed that the linear coupling between all of the coupled waveguides in the array needs to be very homogeneous throughout the whole array such that the output pattern of linear discrete diffraction does not deviate significantly from the ideal diffraction pattern (see a good pattern in Fig. 1). Especially, it should not have singular defects because these would be strong attractors for nonlinear beam concentration. This demand is satisfied only by going to the limits of current fabrication technology.

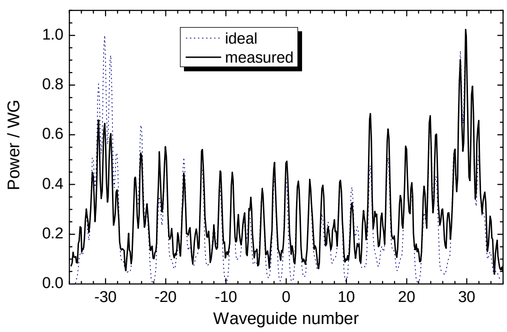

Fig. 1 Linear diffraction pattern for single waveguide excitation

The QPM grating was good but the tuning curves were not the ideal sin(x)/x-curves in the test waveguides close to the arrays. A nonuniformity of the wave-vector mismatch $\Delta\beta L$ of $\pm\pi$ due to a temperature distribution in the oven and a sample nonuniformity was identified to be the reason. However, soliton measurements for a wave-vector mismatch of $|\Delta\beta L|>1.5\pi$ were not influenced by the relatively small nonuniformity of the nonlinearity. The experiments were performed with 7-ps-long pulses from an amplified fiber laser with a wavelengt of λ_{FH}=1557nm and a repetition rate of 4MHz. Only the FH was launched, the necessary SH of the soliton was generated near the input. Elliptically shaped gaussian beams with different transversal widths were carefully aligned relatively to the array to excite neighboring waveguides with the same phase for propagation inside the array parallel to the waveguides. A remarkable incoupling efficiency of the elliptical beam into the array waveguides of approximately 35% was obtained. The output of the sample was observed with cameras for the FH and the SH and with power detectors. At different temperatures with positive and negative $\Delta\beta L$ the output pictures and output powers of FH and SH were measured for varying input power.

In Fig. 2 the FH output for low and high power are compared from two experiments at sample temperatures with a positive and with a negative $\Delta\beta L$. The 62μm wide input beam excites approximately 4 waveguides and diffracts in the array to a 15-waveguides-wide output beam. The maximum of the input beam hits the array at a position with a waveguide. For a positive $\Delta\beta L$ the output beam width decreases with increasing input power until it reaches the input beam width at a peak power of 100W. In that case a stable array soliton with an "odd" profile propagates. At the soliton power the SH shows the same concentration of the power in the non-diffracted beam. When the input beam is shifted such that its maximum hits the array between two waveguides a discrete soliton with an "even" profile is excited. The instability of the "even" discrete soliton was observed in strong flickering camera pictures. For negative $\Delta\beta L$ the nonlinearity can not compensate for the positive diffraction and the beam width is nonlinearly broadened. Reducing the positive $\Delta\beta L$ by increasing the temperature to values closer to SHG phase matching the necessary power for soliton generation decreases due to the increasing positive cascaded nonlinearity. This observations are a strong indication for the quadratic cascaded nonlinearity as the governing effect for the observed solitons. Increasing the diffraction by using a stronger coupled array or by using a narrower input excitation the soliton power increases. This general soliton feature together with numerical simulations of the beam propagation inside the array provide confidence that the observed beams are discrete solitons that have formed shortly after the input when the SH part is generated and propagate with unchanging shape through the sample.

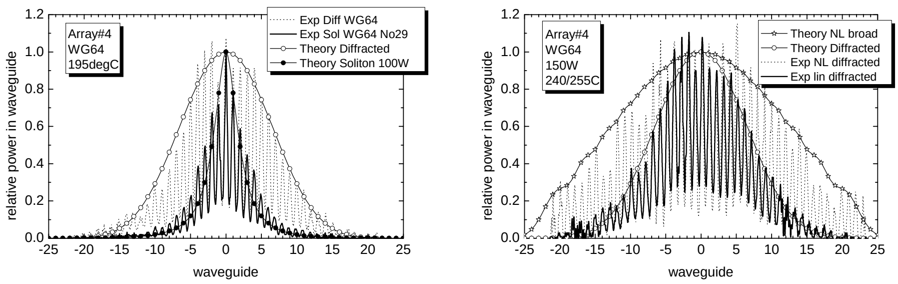

Fig. 2 Array soliton (left) and nonlinearly broadened beam (right) compared to linear diffracted beam.

3. Conclusion

We have observed the first discrete quadratic optical solitons in waveguide arrays. The soliton properties have been measured in very good agreement with theoretical predictions. The unique characteristics of discreteness and quadratic nonlinearity and their combination were identified. The authors gratefully acknowledge support by the European Commission (Information Society Technologies Programme / Future & Emerging Technologies) and an U.S. Army Research Office Multidisciplinary University Research Initiative.

4. References

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