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Moderately localized discrete quadratic solitons in periodically poled lithium niobate waveguide arrays

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Abstract: We report the first observation of moderately localized quadratic discrete solitons in one-dimensional PPLN waveguide arrays. Measured field profiles for both discrete diffraction and solitons versus wave-vector mismatch agree with theory.
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It was predicted by Christodoulides and Joseph in 1988 that light propagating in nonlinear discrete systems with a Kerr nonlinearity would exhibit unique and fascinating properties such as diffractionless propagation and self-focusing, leading to solitons [1]. Spatial discrete solitons were observed in AlGaAs and photorefractive arrays [2] based on an intensity-dependent refractive index. Discrete quadratic spatial solitons consisting of two different frequency components coupled by the second order nonlinearity $\chi^{(2)}$ have also been predicted[3]. Previously we reported high power, strong localization of light into the same single channel initially excited at the input. This occurs at high enough powers independent of any imperfections in the channel-to-channel coupling and second harmonic generation (SHG) efficiency and is not a direct verification of quadratic soliton formation [4]. Collapse of multiple input channels to a soliton was never observed. With better quality samples we now report the first unambiguous observation of discrete quadratic solitons with fields extending over several channels.

Channel waveguide arrays (each consisting of 101 guides) were fabricated on 70mm long z-cut $LiNbO_3$ wafers using standard lithography techniques by Ti-indiffusion. A uniform electric field poled QPM grating was “written” for SHG between the fundamental (FH – 1550nm) TM_{00} and second harmonic (SH – 775nm) TM_{00} waveguide modes. Only the FH field diffracts via field overlap. SH field distribution is strongly localized with negligible field overlap between channels and hence can only grow from the FH in a specific channel. The center-to-center spacing between the arrays' channels varies from 14 to 16μm, corresponding to FH linear coupling lengths from 9.5 to 25.6mm.

We used 7.5ps transform limited pulses at 1557nm. The sample was heated in an oven to temperatures exceeding 180°C to prevent photorefractivity. Only the FH was launched and the soliton's SH was generated near the input. An elliptically shaped Gaussian beam with a horizontal FWHM of 62μm was used to

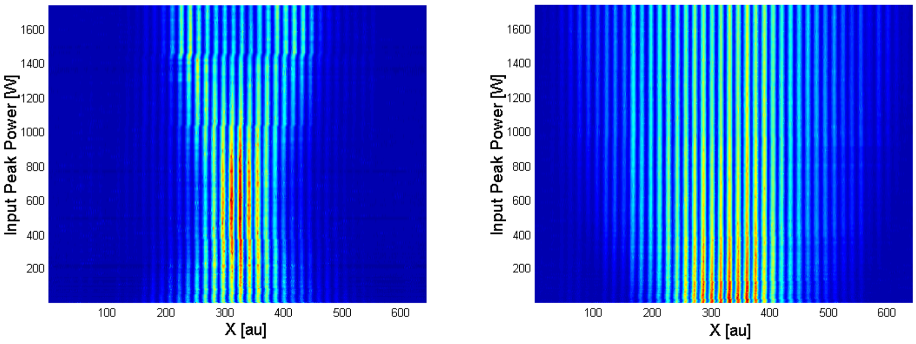

Fig.1. Output energy distribution for two different phase-matching conditions versus input peak power at normal incidence on the array with a coupling length $l_c = 12.2$mm: at 180°C (positive $\Delta\beta L$) a discrete soliton formed at 575W peak power (left) and at 255°C (negative $\Delta\beta L$) nonlinear beam broadening occurs (right).

excite 4-5 neighboring channels. The output was observed with cameras and power detectors for FH and SH separately. The FH output distribution with increasing input peak power is shown in Fig.1 for a positive and a negative phase-mismatch ΔβL. For ΔβL>0 the beam initially self-focuses and forms a soliton for total input peak power of 575W. When the input power exceeds the soliton power, the output beam broadens again and eventually breaks up. For ΔβL<0 the nonlinearity enhances diffraction and the beam nonlinearly broadens with increasing input power. The intensity distributions for both cases are shown in Figure 2.

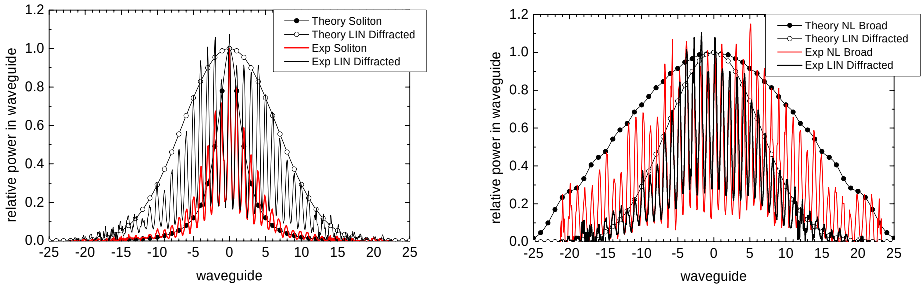

Fig.2. Discrete soliton at 700W input power (left – ΔβL>0) and nonlinearly broadened beam at 1700W input power (right – ΔβL<0) compared to linear diffracted beams for a coupling length l_c = 9.5mm.

Reducing the positive ΔβL by increasing the temperature to values closer to the SHG resonance, the power necessary for soliton generation decreases due to the increasing positive cascaded nonlinearity (see Fig.3). This observation together with the nonlinear beam broadening for a negative phase-matching is 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 leads to an increase in the soliton power.

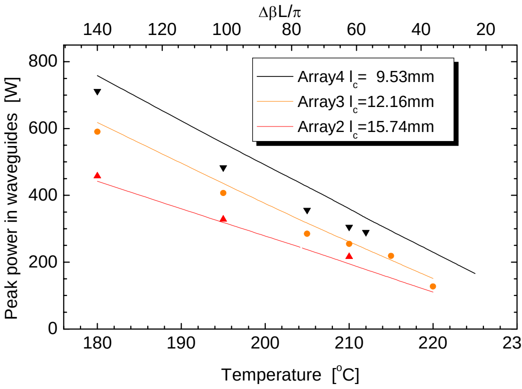

Fig.3. Soliton power as function of ΔβL in 3 different arrays for four-waveguide-wide solitons (scattered data are measured, lines are theoretical data).

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