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Discrete Quadratic Interface Solitons

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Abstract: We report the first experimental observation of discrete quadratic interface solitons existing at the edge of a PPLN waveguide array. Both in-phase and staggered discrete surface solitons were observed.

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Light propagation in discrete systems with a Kerr nonlinearity can exhibit unique properties such as diffractionless propagation and self-focusing, leading to discrete spatial solitons [1]. In recent years, the existence of 1D and 2D discrete solitons has been reported in several studies [2,3]. Another important class of spatial solitons is that guided at the boundary of two different media. In spite of the fact that this latter soliton family was intensively investigated in the 1980s, no experiments were at the time possible [4]. This is because of the stringent condition of maintaining a proper refractive index difference between the two media, which should also be comparable to the nonlinearly induced index change. A waveguide array fabricated from a slab waveguide can yield the required small index difference. We report here the first observation of discrete quadratic interface solitons existing at the edge of a PPLN waveguide array. It has been shown that changing the sign of the phase-matching for the second harmonic generation (SHG) can lead to fields in-phase and out of phase (staggered) between adjacent channels inside the array [5]. This approach was used here to demonstrate both types of interface $\chi^{(2)}$ solitons.

The system was modeled using the discrete nonlinear equations for quadratic nonlinear media. In this structure the FW fields in adjacent waveguides are weakly coupled whereas for the SH the coupling between adjacent waveguides is negligible. The pertinent equations describing the semi-infinite array are thus:

$$i\frac{\partial u_n}{\partial z}+c\left(u_{n+1}+u_{n-1}\right)+\gamma u_n^* v_n=0 \quad ; \quad i\frac{\partial v_n}{\partial z}-\Delta\beta v_n+\gamma u_n^2=0 \quad ; \quad i\frac{\partial u_0}{\partial z}+cu_1+\gamma u_0^* v_0=0 \qquad (1)$$

where u_n and v_n are the peak FW and SH fields in the n-th waveguide respectively, and c and γ are the linear coupling constant and the effective quadratic nonlinear coefficient. Furthermore, $\Delta\beta$ is the wavevector mismatch (and $\Delta\beta L$ the phase-mismatch of an L-long sample) for SHG.

In the continuous half space, the effective index is lower than in the array and the fields exhibit exponential decay. Discrete solitons are stationary solutions of Eqns.1. Solutions are found numerically for the sample parameters by using relaxation methods, and the total power associated with these surface solitons is plotted against the nonlinear phase shift per length unit in Figure 1. Clearly discrete nonlinear surface waves can exist for either sign of $\Delta\beta L$, but only above a threshold power level. Both in-phase and staggered discrete interface solitons are predicted as shown below.

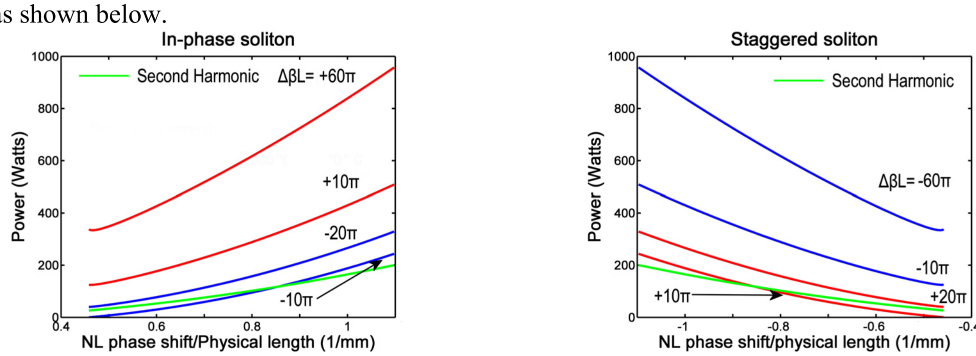

Fig.1. Existence diagrams for in-phase (left) and staggered interface solitons (right) for positive and negative wavevector phase-mismatch between the FW(red,blue) and the SH(green).

The PPLN waveguide arrays, each consisting of 101 channels, fabricated using standard lithography techniques by Ti in-diffusion on part of the surface of 70mm long z-cut $LiNbO_3$ wafers. A uniform electric field poled QPM grating was "written" for SHG between the fundamental (FW – 1550nm) TM_{00} and second harmonic (SH – 775nm) TM_{00} waveguide modes. The non-waveguide region was also poled but for all practical purposes it exhibited no cascading nonlinearity (and SHG) because it was far from the phase-matching condition. In the array region, the center-to-center spacing between the channels was 16μm giving a FW linear coupling length of 25.6mm between adjacent channels due to evanescent field overlap.

Waves for SHG excitation were excited near the array interface by focusing a FW beam onto the first (n=0) channel of the array. Since the SH must be generated with propagation distance by the FW, excitation favors interface solitons with $|\Delta\beta L| >> \pi$. In particular in-phase solitons can occur for $\Delta\beta L > 0$ and staggered solitons for $\Delta\beta L < 0$. Results are shown for both cases in Figures 2. Note that at low powers the linear diffraction pattern for excitation of the edge channel is obtained in both cases.

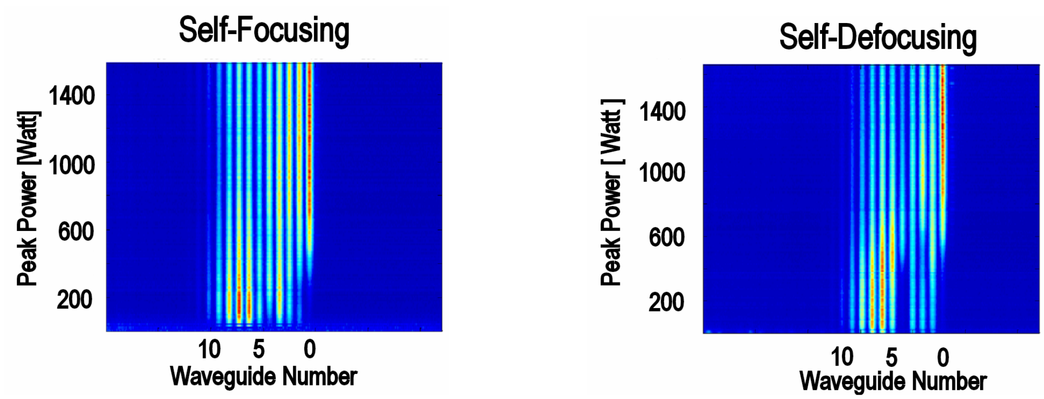

Fig.2. Output intensity for different input peak powers. (left) positive ($\Delta\beta L=49\pi$); (right) negative phase-mismatch ($\Delta\beta L=-39\pi$).

When the power is increased, localization in the first channel (n=0) takes place as predicted by theory. Even though temporal pulses were used in our experiments, there is a power level beyond which collapse into the n=0 channel occurs, indicative of the predicted threshold behavior. Fields, for example for the staggered case, are given in Figure 3.

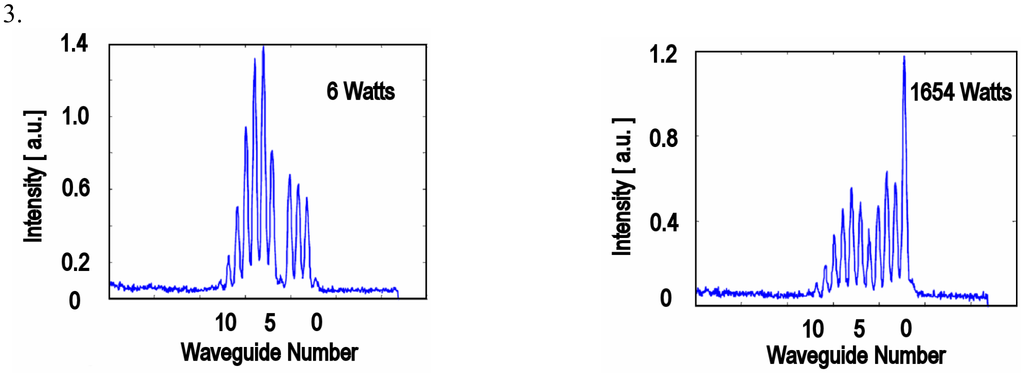

Fig.3. Output intensity distributions for (left) low and (right) high input powers for the staggered case

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