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Space-Time Locking via Parametric Interaction

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Abstract: We present a numerical study of a time locking between fundamental and harmonic pulses despite a strong group velocity mismatch in quadratic nonlinear material during spatial self-trapped propagation. Experimental evidence of such effect is reported.

Introduction

It is well known that quadratic spatial soliton (QSS) propagation rely on the mutual coupling and trapping of fundamental (FF) and second harmonic (SH) waves which overlap in space and time. This type of multicolor spatial soliton exists at different values of the wave-vector mismatch between both waves and their properties are significantly different at each value of the mismatch. The soliton shape, the quantities of power at the SH and at the FF waves, change versus input conditions of excitation [1-4]. The synchronization of the FF and the SH waves is a necessary condition to obtain self trapping operation. The Group Velocity Mismatch (GVM) between the FF and the SH components can play a significant role in the build up of the trapped waves in the case of short pulse excitation and can also prevent the soliton existence [5].

We present in this paper a complete numerical and experimental investigation of the space-time locking between SH and FF waves during the build up of a trapped beam in periodically poled lithium niobate (Ti:PPLN) slab waveguide. This study was realized in presence of significant Group Time Difference (GTD) (19ps) between the FF and the SH compared to the input pulse duration (4ps). We demonstrated that spatial self trapping obtained only for large positive phase mismatch was accompanied by a partial temporal walk off compensation between the SH and the FF. We shown temporal distortion of the SH and FF pulse profiles and we determinated the optimal conditions leading to an efficient space-time locking between the two components.

Numerical and experimental conditions

The studies were performed with a 4 ps pulses duration (FWHM) at 1547.4 nm. The nonlinear medium was a 58mm long Ti:PPLN with a micro domain structure of 16.92 μm. The input beam was shaped in a highly elliptical spot, nearly Gaussian in profile w_{ox}= 56 μm (FWHM) along the waveguide plane and w_{oy}= 3.9 μm along the perpendicular direction, for efficient coupling into the film waveguide. The spatial beam profiles at the output were recorded with an IR camera and the temporal characterizations were realized using non-collinear SHG autocorrelation, and by a symmetrical sum frequency cross-correlation. In these conditions, the crystal length represented 5.8 times the Fresnel length of the input beam and the GTD between the SH and the FF wave due to the propagation along the waveguide was equal to 4.5 time the pulse duration

Numerical simulations

To model the pulse propagation, two different numerical tools have been used. A finite difference vectorial mode solver was employed to determine the linear propagation properties in the slab waveguide, i.e. the mode profiles, $\beta_{\omega o}$, $\beta_{2\omega 0}$, $\beta'_{\omega o}$, $\beta'_{2\omega 0}$, $\beta''_{\omega o}$ and $\beta''_{2\omega 0}$. Finally, we used a finite difference beam propagation technique, to solve the nonlinear coupled equations (eqs. (1)).

$$\begin{aligned} & j\frac{\partial w}{\partial z} - j\beta'_{\omega_0}\frac{\partial w}{\partial t} - \frac{\beta''_{\omega_0}}{2}\frac{\partial^2 w}{\partial t^2} + \frac{1}{2\beta_{\omega_0}}\frac{\partial^2 w}{\partial x^2} + \frac{\chi^{(2)}\omega_0}{2cn_{\omega_0}}\frac{\int V|W|^2 dy}{\int |W|^2 dy} vw^* e^{-j\Delta kz} = 0 \\ & j\frac{\partial v}{\partial z} - j\beta'_{2\omega_0}\frac{\partial v}{\partial t} - \frac{\beta''_{2\omega_0}}{2}\frac{\partial^2 v}{\partial t^2} + \frac{1}{2\beta_{2\omega_0}}\frac{\partial^2 v}{\partial x^2} + \frac{\chi^{(2)}\omega_0}{2cn_{2\omega_0}}\frac{\int V|W|^2 dy}{\int |V|^2 dy} w^2 e^{j\Delta kz} = 0 \end{aligned} \quad (1)$$

β represented the propagation constant, β' the inverse group velocity, β'' the inverse group-velocity dispersion; n was the refractive index, $\Delta k = 2\beta_{\omega 0} - \beta_{2\omega 0} + K_S$, where $K_S = 2\pi/\Lambda$ and $\chi^{(2)} = 2/\pi\ \chi^{(2)}_{z'z'z'}$ was the nonlinear coefficient.

Experiments and numerical simulations were carried out varying phase-mismatch conditions via temperature of the sample and input pulse power, keeping fixed the temporal and spatial widths of the FF injected pulse.

Spatial trapping

We succeeded to observe self trapping behavior in spite of the GTD for a positive phase mismatch between $\Delta kL=+8\pi$ and $\Delta kL=+38\pi$. For negative phase mismatches, the GTD prevented the self trapping effect and we observed a self defocusing which reached a maximum for $\Delta kL=-8\pi$. Moreover, at exact phase matching position no self trapping regime occurred. The output beam width remained large and was equal to four times the input beam size.

Time locking

In a first time we observed the evolution of the fundamental pulse shape versus the phase mismatch and versus the input intensity. In the trapping region, the profile and the duration of the output pulse autocorrelation was identical to that of the input. No significant distortion was observed. Only a small self steepening effect was observed on the numerical pulse profile. At perfect and close to the phase-matching position, the autocorrelation envelope broadened and the profile exhibited several peak. The pattern resulted from the strong depletion of the FF pulse followed by back conversion which broke up the pulse in a temporal distribution with several sharp peaks.

In a second time, we studied the temporal distribution of the SH pulse during its propagation in the non linear crystal versus the self trapped regime.

In the trapping region (from $\Delta kL=+8\pi$ to $\Delta kL=+38\pi$) and for a low input pulse power, the main part of the SH beam was delayed from the fundamental component because of the GVM. In this situation, the SH and the FF waves were separated by 19ps at the end of the PPLN crystal (see figure 1 (left)). Increasing the intensity, and because of the cascading process, we observed an efficient time locking between the fundamental and the SH components leading to an effective acceleration of the harmonic beam. Then, the two wavelengths propagated locked together along the PPLN crystal (figure 1 (right)). This partial compensation of the temporal walk off permitted to keep the two waves temporally superimposed during their propagation in the NLC. We observed then a spatial self trapping behaviour. For a Phase mismatch lower than $\Delta kL=+8\pi$, no efficient time locking between the FF and the SH was observed. Then, no self trapping effect was possible.

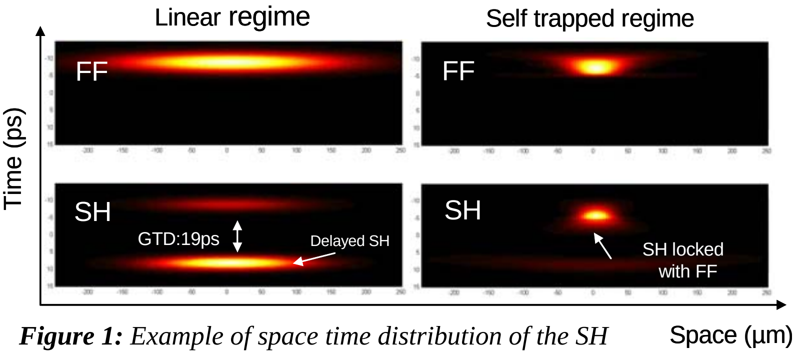

Figure 1: *Example of space time distribution of the SH and FF components. Linear regime (left); self trapped regime (right).*

The same behavior was observed experimentally using a symmetrical cross correlation system.

References

[1] William E. Torruellas, Zuo Wang, David J Hagan, Eric W Vanstryland, G. Stegeman, Lluis Torner, Curtis R. Menyuk, Physical Review Letters, Vol. 74, P. 5036-5039 (1995).

[2] Lluis Torner, Dumitru Mihalache, Dumitru Mazilu, Ewan M. Wright, William E. Torruellas, George Stegeman, Opt. Comm. Vol. 121, p. 149-155 (1995).

[3] D. Mihalache, D; Mazilu, L. C. Crasovan, L. Torner; Opt. Comm., vol.137, 113-117, (1997).

[4] R. H. J. Grimshaw, E. A. Kuznetsov, E. G. Shapiro, Physica D, Vol. 152-53 (2001).

[5] S. Carrasco, J. P. Torres, D. Antigas, L. Torner, Opt. Comm. 192, pp. 347-55 (200).