Ultrafast All-Optical Signal Processing in Engineered Quadratic Nonlinear Waveguides

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The potential of a $\chi^{(2)}$ photonics, implemented in periodically poled Lithium Niobate (PPLN) waveguides with an engineerable quadratic nonlinearity, for ultrafast all-optical signal routing and switching will be evaluated. High bit rate signal regeneration and routing, based on spatial soliton formation in film waveguides, as well as transparent switching, based on parametric amplification in waveguide arrays, will be demonstrated.

Keywords: quadratic nonlinearity, signal processing, waveguide arrays, spatial solitons

Introduction

In order to meet the requirements of future communication networks high bitrate data transmission in optical fiber lines has to be ultimately complemented by ultrafast all-optical signal regeneration, processing and routing, which requires the usage of nonlinear effects.

One option is to use active semiconductor devices with electrically injected free carriers. They are fast and need very low control powers but suffer from the known drawbacks of semiconductor optical amplifiers as limited processing speed, noise, and reduced compatibility with the fiber geometry. Nonresonant nonlinear effects as the cubic or the quadratic interaction are weaker but quasi-instantaneous. The degenerate interaction based on the cubic nonlinearity needs too large control powers and provides only with a phase modulation that needs to be transformed into an amplitude modulation by phase sensitive devices.

On the contrary parametric processes in quadratic nonlinear waveguides provide phase modulation and gain the latter being essential for transparent operation. Moreover, the strength of interaction can be locally controlled by varying the poling characteristic. Light confinement in PPLN film waveguides allows spatial soliton formation with unprecedented low peak powers. We will show that this dichromatic self-trapping of light can be used for effective ultrafast signal routing and regeneration. Moreover, evanescently coupled PPLN channel waveguides form a waveguide array, which exhibits a peculiar refraction and diffraction behavior. We will show that this unusual behavior in conjunction with parametric effects in these waveguides offer novel interesting options for signal routing and switching.

Routing and regeneration of signals in PPLN film waveguides

Recently it has been shown at Université de Limoges that self-trapped beams (or spatial solitons) can form in a 58 mm long Ti:PPLN waveguide, fabricated at the University of Paderborn, at unprecedented low intensities of about 50 MW/cm^2 even if the launched FF beam is as short as 4 ps. The fact that the huge linear temporal walk off can be arrested has important consequences for high bit rate processing in using these solitons.

Self-trapping can be used to clean up pulses from low-intensity pedestals and to compress them. Only the fraction of the input pulse with a power higher than the threshold for spatial soliton formation will be trapped and subsequently pass through the aperture (see Fig.1). The low power parts of the pulse, both in time and space, undergo diffraction and are thus mainly blocked at the output. The device can be understood as a saturable absorber with an ultrafast response similar to a Kerr lens. The width of the aperture placed at the output as a spatial filter was about 88% of the soliton width. The input beam width was 56 µm FWHM.

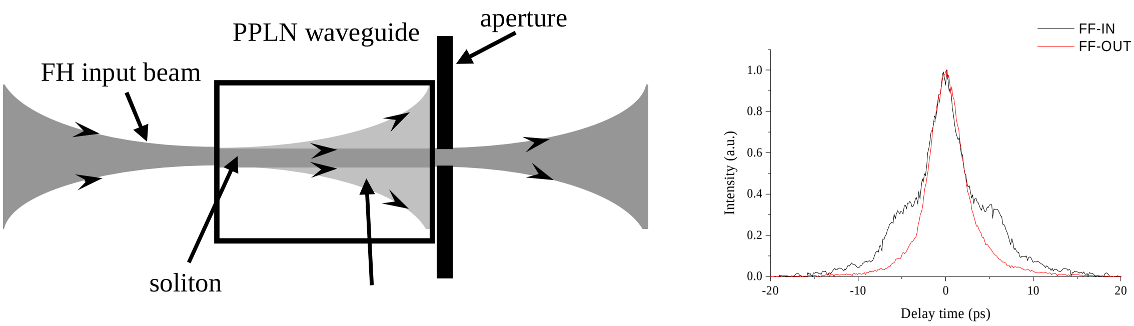

Fig.1 Pulse shape regeneration in a PPLN waveguide with aperture. Input pulse length was 4.3 ps.

Collision-induced soliton formation can be used for high bit rate pulse switching. Both FF beams are forced to interact before a quadratic soliton was formed, i.e., near the input face or a few millimetres inside the waveguide. Two FF beams (control and signal) are launched with

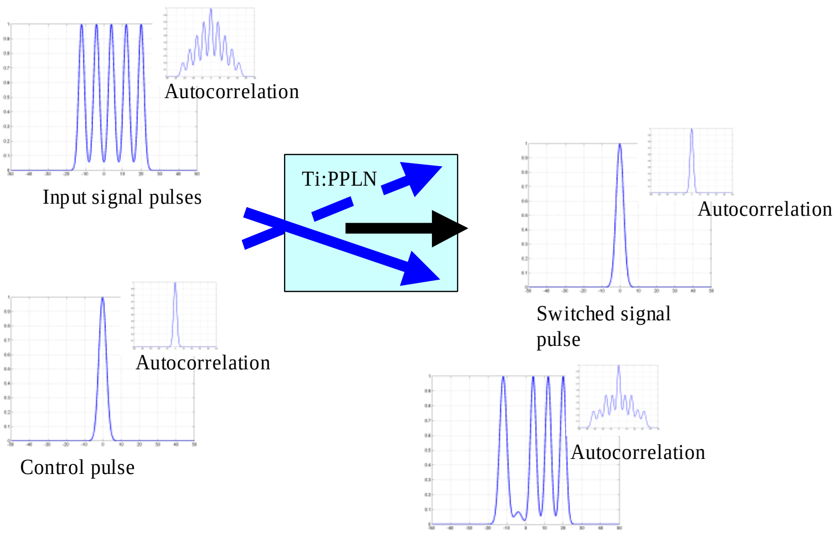

Fig.2 125 Gbit/s pulse routing by collision-induced soliton formation. input angle = 0.4°

different directions into the waveguide (Δθ=0.4° within the crystal). Each beam carried a power sufficiently high to give rise to self-trapping. For zero phase difference a single soliton is formed upon collision, which propagates on-axis. Thus by applying a control pulse routing of a single bit in a high bit rate data stream can be achieved (see Fig.2). At present, the processing speed is limited by the laser pulse length and amounts to 125Gbit/s. The switching efficiency is as high as 90% and the contrast ratio for the switched output is about 20dB.

Parametric switching in waveguide arrays

Although the soliton scheme discussed above provides with exciting new opportunities for ultrafast processing it still lacks from the high signal power required. On the contrary schemes that are based on parametric interaction require only a weak (mW) signal to interact with a stronger local control. Moreover, the parametric gain makes the device transparent and thus cascadable. Evidently this scheme can also be implemented in film waveguides. Here we are concerned with this type of switching in evanescently coupled PPLN channel waveguides. Recently is has been shown that these waveguide arrays exhibit peculiar diffraction properties as zero and negative diffraction for certain input angles of the light beam [2]. It turns out that this behavior in conjunction with the particular phase and amplitude dynamics of a nondegenerate quadratic interaction offers exciting incoherent switching opportunities [3].

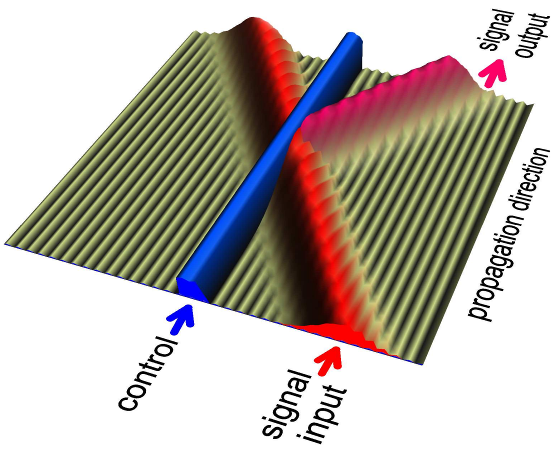

Fig.3 Parametric routing in a PPLN waveguide array

Figure 3 shows how a highly confined SH beam interacts with a diffractionless propagating signal train to route the signal to a definite output port. Experiments performed at CREOL Orlando have confirmed that transparent switching of a few mW signal can be achieved with a 10 ps control pulse of 10 W peak power.

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[1] P. Pioger, V. Couderc, Laurent Lefort, A. Barthélémy, F. Baronio, C.De Angelis, Y. Min, V.Quiring, W. Sohler; 'Spatial trapping of short pulse in Ti:PPLN waveguides', Opt. Lett. 27 (2002)2182.
[2] T. Pertsch, T. Zentgraf, U. Peschel, A. Bräuer, and F. Lederer, 'Anomalous Refraction and Diffraction in Discrete Optical Systems', Phys. Rev. Lett. 88 (2002) 093901.
[3] T. Pertsch, U. Peschel, and F. Lederer, 'All-optical switching in quadratically nonlinear waveguide arrays', Opt. Lett. 28(2003)102.