Technical Digest Topical Meeting "Nonlinear Guided Waves and their Applications (NLGW '04)", Toronto/Canada, March 2004, paper TuA 1

Low power transparent switching in quadratic nonlinear waveguide arrays

Roland Schiek
University of Applied Sciences Regensburg, Prüfeninger Str. 58, D-93049 Regensburg, Germany

Robert Iwanow and George I. Stegeman
CREOL / School of Optics, University of Central Florida, 4000 Central Florida Blvd., Orlando FL-32816-2700, USA

Thomas Pertsch and Falk Lederer
Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, D-07743 Jena, Germany

Yoohong Min and Wolfgang Sohler
University of Paderborn, D-33095 Paderborn, Germany

Abstract: Phase-insensitive all-optical switching and routing of low power optical signals without pulse break-up, based on parametric difference frequency generation in waveguide arrays, was experimentally investigated.

OCIS codes: (190.4410) Nonlinear Optics, parametric processes; (130.3120) Integrated optics devices

1. Introduction

Recently a scheme for efficient all-optical switching and routing of low power signals in waveguide arrays with a second-order nonlinearity was proposed [1]. Based on the combination of parametric frequency down conversion and the unique diffractionless beam propagation in waveguide arrays [2] a low power signal input can be switched to different positions at the output of a waveguide array. The switching is phase-insensitive and all-optically controlled by the power, the wavelength and the position of a pump beam at about half the signal wavelength. Fig. 1 shows a possible simple switching scenario. The signal is launched as a diffractionless propagating beam crossing the array at a certain angle (see Fig. 1a). A high intensity pump power beam is launched into a single waveguide. Since the pump wavelength is approximately half the signal wavelength the mode of the pump is strongly confined, the coupling to neighboring array waveguides is negligible, and the pump beam is trapped in the input waveguide (see Fig. 1b). At the intersection of the signal and the pump beam phase-insensitive parametric interaction results in both, amplification and deflection of the signal and generation of a frequency shifted idler (see Fig. 1c, d) [3]. Since the signal intensity is small and the interaction length is short, pump depletion and pulse distortions are negligible ensuring a cascadibility of the device for high bit rates.

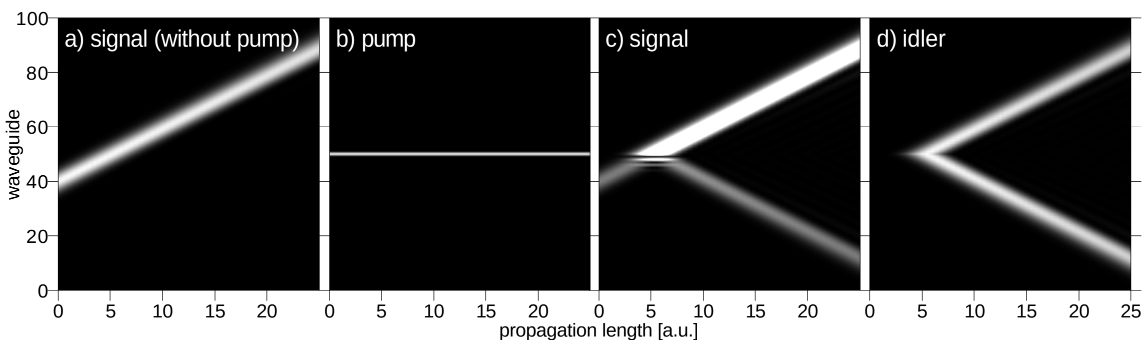

Fig. 1. a) For a phase difference of $\pi/2$ between the modes in adjacent waveguides low intensity signal beams travel diffractionless in the array. b) Short-wavelength pump light does not couple to other guides and is trapped in the input waveguide. c) and d) When signal and pump are injected simultaneously, the signal is amplified and a new diffractionless signal together with two diffractionless idler beams is generated.

For an experimental verification of these ideas we performed parametric mixing experiments in arrays of 101 linearly coupled waveguides.

2. Samples and experimental conditions

On a 5-cm-long Z-cut lithium niobate crystal arrays of linearly coupled waveguides (each array consisting of 101 waveguides) with coupling lengths between 4 and 6mm were fabricated by in-diffusion of titanium stripes. For phase-matching second-harmonic generation (SHG) between TM_{00} waveguide modes at a fundamental and its second-harmonic, QPM gratings were written in the samples by electric field poling. Because measurements even at mW excitation power level (especially of the pump) were not reproducible at room temperature in every detail the samples were heated in an oven to 215°C to prevent index disturbances and resulting inhomogeneities of the linear coupling and the wave-vector mismatch distribution due to photorefraction and pyroelectricity. A detailed characterization of the discrete diffraction in the arrays confirmed the very high quality of the samples' linear properties. SHG in test waveguides and with single and tilted broad beam excitation in the arrays confirmed the samples' high quality nonlinear properties. A pulsed pump beam with a wavelength of 774.35nm and a peak power of up to 65W (average power 30mW) was generated by frequency doubling a NaCl color center laser with 8.5-ps-long transform limited pulses (repetition rate 76MHz) and launched into a single waveguide at variable positions in the array. A low power (mW) cw signal with variable wavelength from a tunable laser diode was launched in the array as a diffractionless beam crossing the array. The crystals were operated at phase matching for SHG of 1548.70nm which is twice the pump wavelength. The waveguides' output was imaged onto a vidicon camera. Through a fiber connector the output of the individual coupled waveguides was separated and spectrally analyzed.

3. Experimental results

The output of the array with a coupling length of 6mm was characterized by spatially resolved scanning of the spectrum (see Fig. 2 left). A 60μm-wide signal beam is injected into waveguides 12 to 17 with a phase difference of π/2 in adjacent guides to launch a diffractionless beam which propagates across the array. The signal exits the array from waveguides -12 to -17 after propagating through the sample. The cw-signal appears in the output spectral scan as very bright narrow lines in wavegides -12 to -17 (see 'cw input signal' in Fig.2). Injecting the pump into waveguide 0 a deflected idler and deflected signal are switched-on in waveguides 12 to 17 (see upper marked circles in Fig. 2). The still visible narrow signal line at the position of the deflected signal represents cw input signal cross-talk due to leakage of the diffractionless beam into the waveguides it has crossed. The limited signal to noise ratio of the spectrum analyzer introduced cross-talk in the spectra and prevented the observation of the amplified signal and the idler in waveguides -12 to -17 in the spectral scans. In order to also characterize the generated idler in these waveguides, we suppressed the signal with a tunable band-pass fiber filter and measured the idler using a Lock-In technique (see Fig. 2 right).

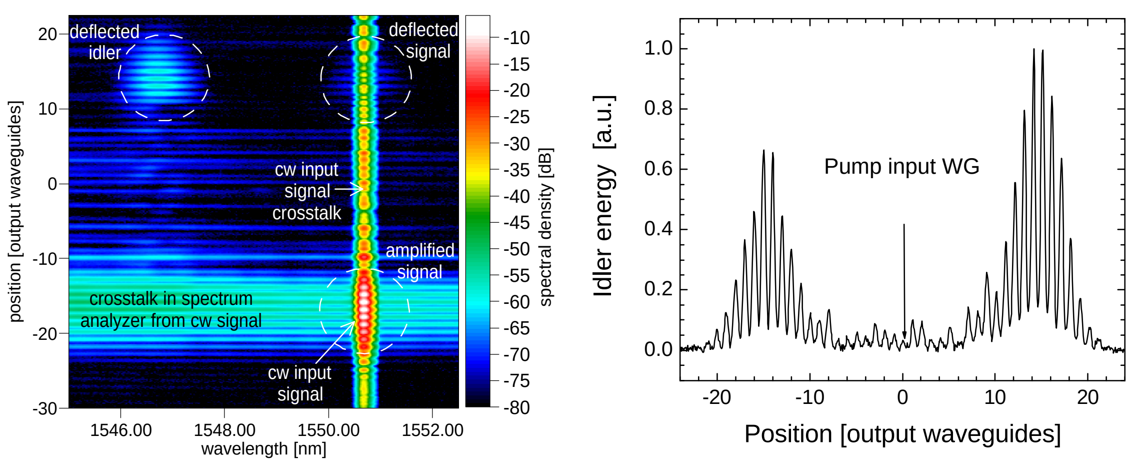

Fig. 2. Left: Spatial-spectral scan of the output of a PPLN waveguide array after parametric interaction of a signal beam (λ_S=1550.7nm) and a pump beam (λ_P=774.35nm) which generates an idler (λ_I=1546.7nm). Right: Idler at λ_I=1546.7nm versus waveguide number measured with a Lock-In technique.

The all-optical control of the output is documented in Fig. 3. The left part of Fig. 3 shows the spatial output distribution of the idler for different input positions of the pump. It demonstrates that, depending on the pump position, four different output positions can be addressed without significant cross-talk. The simultaneous wavelength conversion of the idler over a bandwidth exceeding 20nm is verified in the right part of Fig. 3.

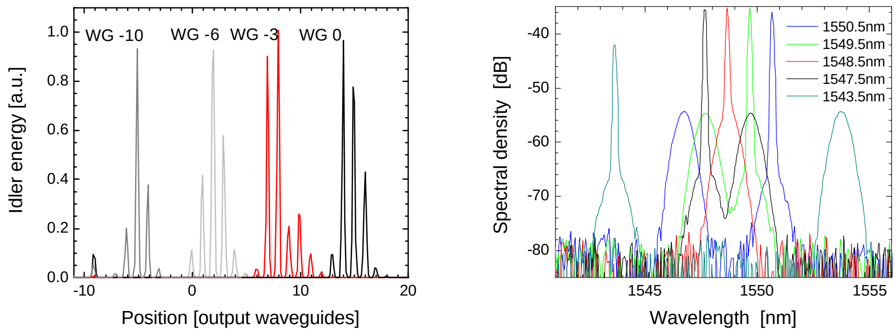

Fig. 3. Left: Spatial idler output distribution for different input positions of the pump beam (waveguides 0, -3, -6 and –10). Right: Spectral output of signal and idler from the waveguide with the maximum generated idler for a number of different signal wavelengths. The narrow high-power peak results from the cross-talk of the cw signal input.

The linear dependence of the idler power on the pump power was observed. For a pump input peak power of 40W a cw 7mW signal beam was switched to idler output pulses with 7mW peak power – hence, realizing a fully transparent switching device. Above 40W pump power the device even provides parametric gain.

The undistorted output spectra together with detailed simulations confirmed the ultrafast switching capability of the device without significant pulse-distortions up to a data-rate of 100 GHz. Fig. 4 compares calculated output pulses at the signal and idler frequency from the waveguide with the strongest deflected signal with the input pump pulse. The remaining small pulse distortions are caused by walk-off effects and would disappear in a system with no group velocity difference between signal and pump.

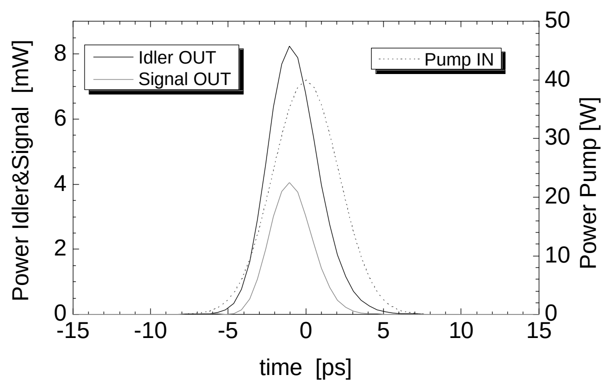

Fig. 4. Calculated pulse shapes of the output signal and idler pulses from the waveguide with the maximum deflected signal and idler in an array. The input pump pulse is shown with a dotted line

4. Conclusion

Phase-insensitive pump-controlled amplification, switching and routing of a signal beam in waveguide arrays due to a quadratic nonlinear parametric interaction was characterized and found to be in very good agreement with the theoretical predictions. Transparent switching with undistorted pulse shapes was observed with control pump powers of 40W. The authors gratefully acknowledge support by the European Commission (Information Society Technologies Programme / Future & Emerging Technologies) and by an U.S. Army Research Office Multidisciplinary University Research Initiative.

5. References

[1] T. Pertsch, U. Peschel, and F. Lederer: “All-optical switching in quadratically nonlinear waveguide arrays”, Opt. Lett. **28**, 102 (2003).

[2] T. Pertsch, T. Zentgraf, U. Peschel, A. Bräuer, and F. Lederer: “Anomalous Refraction and Diffraction in Discrete Optical Systems’’, Phys. Rev. Lett. **88**, 093901 (2002).

[3] G. Schreiber, H. Suche, Y. L. Lee, W. Grundkötter, V. Quiring, R. Ricken, and W. Sohler, “Efficient cascaded difference frequency conversion in periodically poled Ti:$LiNbO_3$ waveguides using pulsed and cw pumping,” Appl. Phys. B 73, 501 (2001).