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Parametric Light Mixing Experiments in Quadratic Nonlinear Waveguide Arrays

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Abstract: An efficient all-optical switching and routing scheme for low power optical signals based on parametric difference frequency generation in combination with the unique discrete dispersion characteristics of waveguide arrays was investigated experimentally.

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 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 output can be switched to different output positions at the output of a waveguide array. The switching is phase-insensitive and controlled all-optically by the power, the wavelength and the position of a pump beam at roughly half of 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 roughly half of 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 beams phase-insensitive parametric interaction results in both, amplification and deflection of the signal and generation of a frequency shifted idler (Fig. 1c, d). Since the signal intensity is small and the interaction length is short, pump depletion and pulse break-up are negligible ensuring a cascadibility of the device for high bit rates.

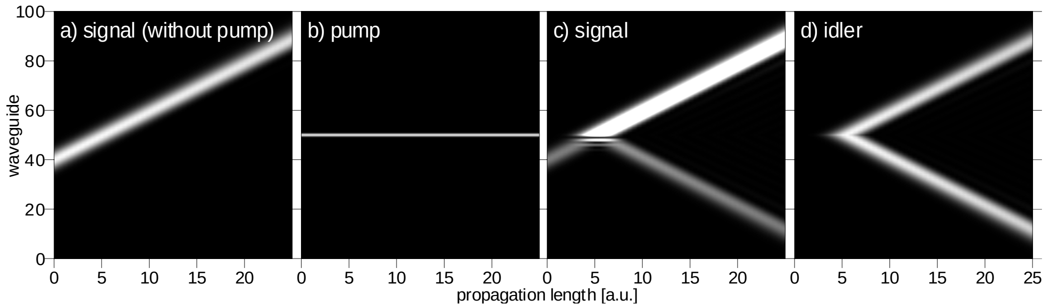

Fig. 1. a) For a phase difference of $\pi/2$ of the modes in adjacent waveguides low intensity signal beams travel diffractionless in the array. b) Short wavelength pump light does not couple to other guides and is trapped in the input waveguide. c) and d) When signal and pump are injected simultaneously,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

2. Samples and experimental conditions

On a 5-cm-long Z-cut lithium niobate crystal arrays of linearly coupled waveguides (each array consists of 101 waveguides) with coupling lengths between 4 and 5 mm were fabricated by in-diffusion of titanium stripes. For phase-matching SHG between the FD and the SH TM_{00} waveguide modes a QPM grating was written in the sample 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 sample was heated in an oven to 215 °C to prevent index disturbances and resulting inhomogeneities of the linear coupling and the wave-vector mismatch distribution. Detailed linear and nonlinear measurements of the discrete diffraction and SHG with single and tilted broad beam excitation in the arrays confirmed the array's very high quality. A pulsed pump beam with a wavelength of 774.35 nm and a peak power of up to 65 W (average power 30 mW) was generated by frequency doubling a NaCl color center laser with 8.5-ps-long transform limited pulses (repetition rate 76 MHz) and launched in a single waveguide at variable positions in the array. A cw signal wave with variable wavelength from a tunable laser diode was launched as a diffractionless beam crossing the array. The crystal with the arrays was operated at phase matching for SHG of 1548.70 nm which is twice the pump wavelength. The array output was imaged onto a vidicon camera. Through a fiber connector the output of the individual array waveguides was separated and spectrally analyzed.

3. Experimental results

Cross sections through the measured 2-dimensional spatial-spectral array output are shown in Fig. 2. The idler output power versus the waveguide number in the array is shown in Fig. 2a (the signal was suppressed with a filter). With the pump switched on two idler beams were detected at the output symmetrically distant to the pump waveguide (here number 0). Fig. 2b shows the changing idler beam position for different positions of the pump beam. By shifting the pump beam by n waveguides the deflected idler moves 2n waveguides (see also Fig. 1d). In Fig. 2c the spectrum of the output from the waveguide with the maximum deflected signal and idler is shown.

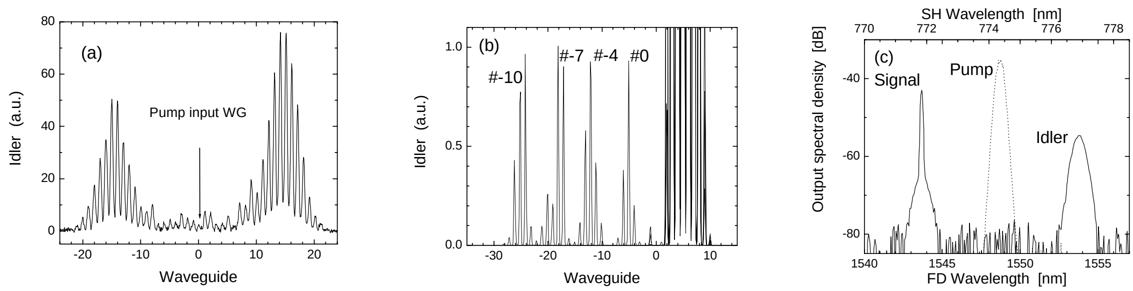

Fig. 2. a) Idler output from the array waveguides with a pump input in waveguide 0 measured with Lock-In technique and filter for signal suppression. b) Idler output for different pump-input waveguides (0, -4, -7 and –10) measured with a spectrometer. The strong components near waveguide number 5 correspond to the diffractionless cw-signal beam that can not be suppressed in the spectrometer sufficiently. c) Spectra of the output of the waveguide with the maximum deflected signal and idler. The narrow signal peak corresponds to cw-signal stray light in the spectrum analyser.

Additionally the frequency shift of the idler wave dependent on signal and pump wavelengths was investigated. The narrow phase-matching bandwidth limits the wavelength-tunability of the idler with the pump wavelength to a few nm wide range. The experimental results are explained in good agreement with time resolved simulations.

4. Conclusion

We found new concepts for the characterization of the quality, i.e. the homogeneity of linear and nonlinear properties of waveguide arrays. Phase-insensitive pump-dependent amplification, switching and routing of a signal beam in an array due to a quadratic nonlinear parametric interaction was characterized in very good agreement with the theoretical predictions. The authors gratefully acknowledge support by the European Commission (Information Society Technologies Programme / Future & Emerging Technologies) and an U.S. Army Research Office Multidisciplinary University Research Initiative.

5. References

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