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Parametric switching and frequency conversion in PPLN directional couplers

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Abstract: Ultrafast all-optical switching is experimentally demonstrated based on quadratic parametric interaction in PPLN waveguide couplers. Transparent on/off switching and frequency conversion of milliwatt signals at 1550 nm is achieved with 2 W switching power.

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We experimentally demonstrate all-optical on/off switching based on second-order nonlinear frequency down conversion in PPLN directional couplers. The studied configuration is based on the parametric interaction of a weak signal ($\lambda \approx 1548.76$ nm–Δ), which carries the optical information, and a stronger 5-ps-long pump pulse ($\lambda = 774.38$ nm), which triggers the phase insensitive parametric process and controls the switching operation (see Fig. 1). The pump pulse is trapped in a single waveguide of the coupler since its short wavelength results in a strongly confined mode without overlap with neighboring guides. In contrast, the signal pulse couples to the adjacent channel via the overlap of the evanescent field. Parametric interaction results in the amplification of the signal pulse and the generation of a frequency shifted idler ($\lambda \approx 1548.76$ nm+Δ). The wavelength of the idler can be controlled by the wavelength of the pump input and the phase matching condition of the three waves.

The experiments were performed in titanium diffused PPLN waveguide couplers with a length of 5-cm. Phase-matching of the TM_{00} pump mode with the TM_{00} signal and idler modes is achieved at a crystal temperature of 202°C with a QPM grating of 16.8 µm [1]. A 0.47 mW cw signal from a tunable laser diode was coupled to a single guide (bar arm) of the coupler. For a waveguide separation of 18.3 µm it coupled almost completely to the adjacent guide (cross arm). Simultaneously, a pulsed pump from a frequency doubled NaCl color center laser (repetition rate: 76 MHz) was coupled to the bar arm. A peak power of 2 W was sufficient for fully transparent switching, i.e, to generate idler pulses of 0.7 mW peak power in the bar arm (see Fig. 2a). A modified switching response was obtained when the pump was launched into the cross arm (see Fig. 2b). In contrast to our previously reported experiments [2] the undistorted output spectra of the pulses together with detailed simulations confirmed the ultrafast switching capability without significant pulse-distortion. This would in principle allow an operation up to a data-rate of 100 GHz. However, the experimental verification of this figure is beyond our laboratory equipment. The switching ratio of the signal was limited by a 4% leakage of the signal into the bar arm since the coupling length was not perfectly matched to the device length.

The demonstrated concept can be scaled to devices for spatial signal routing which would allow to switch an input signal to a number of different output positions in a cascade of coupler devices (see Fig. 3). The presented experimental realization of a single '*basic switching cell*' of this matrix using the Ti:PPLN technology demonstrates the feasibility of this concept. However, due to the decreased parametric interaction length the pump power for transparent switching would grow quadratically with the number of cascaded switching stages on a single 5 cm crystal.

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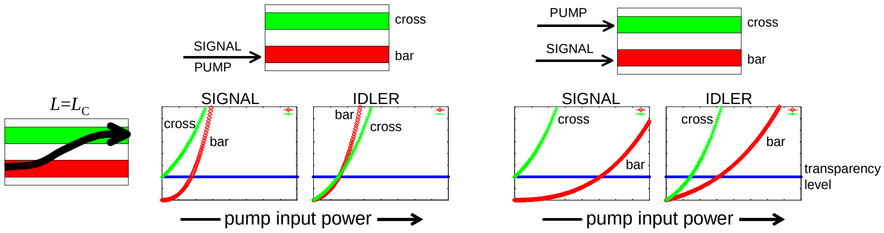

Fig. 1. Parametric interaction in directional couplers. The diagrams show the signal and the idler output for increasing pump input power (arbitrary units) from the two coupler branches. In the left diagrams the pump and the idler are launched in the same coupler arm. The right diagrams show results for pump and signal launched in different waveguides (cw simulations).

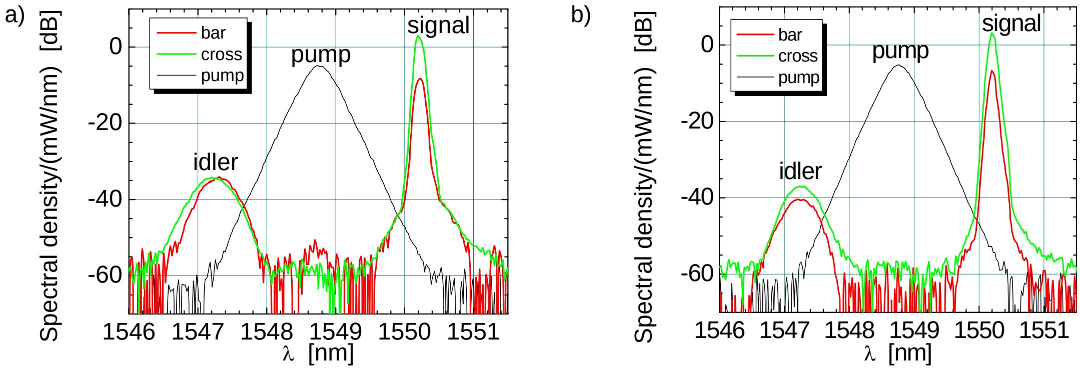

Fig. 2. Measured output spectra from the two coupler arms. a) Pump and signal launched in the bar arm. b) Pump launched in the cross arm. The black line shows the spectrum of the pump versus $2\lambda_P$. (pump peak power: 2 W). The low power level of the pulsed signal and idler as compared to the cw peak of the signal is explained by the low repetition rate of the pulsed pump. However, in real applications signal and pump would be generated by two independent synchronized pulsed lasers.

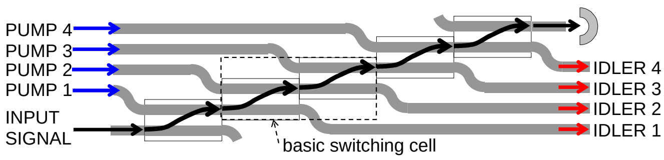

Fig. 3. Multiport switching configuration consisting of a cascade of directional coupler devices. The indicated '*basic switching cell*' of this matrix consists of two coupler stages. In the first stage pump and signal are launched into different arms. At the input of the second stage they are already combined in the same arm. The different switching response of the two configurations (compare left and right side of Figs. 1 and 2) allows for multi-port switching with low cross-talk where the input of the pump at different positions results in the switching of signal and idler to different output ports.