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All-Optical Wavelength Conversion, Amplification and Switching in Periodically Poled Ti:LiNbO$_3$ Waveguide Structures

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Abstract: Quasi-phasematched second order nonlinear optical interactions in periodically poled Ti:LiNbO$_3$ channel waveguides, directional couplers and waveguide arrays are exploited to develop efficient all-optical wavelength converters, parametric amplifiers, time division (de-) multiplexers, and space-, phase-, and polarisation-switches.

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

1. Introduction

During the last years optical channel guides of excellent quality have been developed in Periodically Poled Lithium Niobate (PPLN) using the standard Ti-indiffusion technique. Their excellent homogeneity over a length of up to 90 mm and their low propagation losses (down to 0.03 dB/cm in the mid infrared) enabled the development of very efficient quasi-phasematched quadratic nonlinear integrated optical devices. Moreover, homogeneous nonlinear directional couplers and waveguide arrays with up to 100 coupled channels have been developed to demonstrate new all-optical switching concepts. (Simultaneous multi-) wavelength conversion, parametric amplification, λ-selective time division (de-)multiplexing, phase- and polarisation-switching as well as spatial switching have been demonstrated [1].

2. All-Optical Wavelength Conversion

Second Harmonic Generation (SHG), Difference Frequency Generation (DFG), cascaded SHG and DFG (cSHG/DFG), Sum Frequency Generation (SFG), cascaded SFG and DFG (cSFG/DFG), Optical Parametric Generation (OPG) and Optical Parametric Oscillation (OPO) have all been exploited to develop optimized λ-converters not only for optical communications in the near infrared (NIR), but also for spectroscopic analysis mainly in the mid infrared (MIR). They offer quantum-limited noise, ultrafast response and a broad bandwidth, if suitably desig-

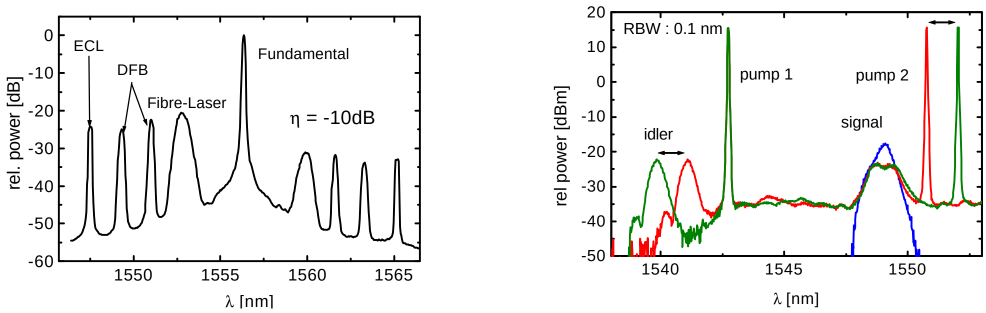

Fig. 1. Left: Output spectrum of a Ti:PPLN wavelength converter for multi-channel operation by cSHG/DFG. Right: Output spectra showing all-optical tuning of the idler by the wavelength of pump 2 exploiting cSFG/DFG.

ned and operated. For example, simultaneous ë-conversion of four ITU-wavelength channels has been demonstrated by cSHG/DFG (see Fig. 1, left) [2]**;** polarisation-independent ë-conversion was tested in a field trial over a 500 km fiber optical link. Another example is optically tunable ë-conversion based on cSFG/DFG using two independent pump sources (see Fig. 1, right) [3].

3. Optical Parametric Amplification

Cascaded difference frequency generation (cSHG/DFG) is always accompanied by optical parametric amplification (OPA) of the signal. Theory predicts that in PPLN waveguides a small signal gain larger than 30 dB can be achieved, high quality waveguides of sufficient length, negligible photorefractive effects and sufficient pump power assumed. Such parametric amplifiers would be attractive devices of quantum limited noise figures for future all-optical transparent communication networks. It is remarkable that the center wavelength of their gain characteristics with a spectral width of 50-70 nm can be adjusted by the period of the microdomain structure alone. Experimentally, a cw-gain of up to 4 dB was observed in a 8.3 cm long structure with 765 mW coupled pump power (λ = 1558 nm). In a pulsed mode of operation (5 ps; 10 GHz) a gain of 11.5 dB was achieved with 325 mW average power. Even longer waveguide structures are currently investigated [1].

3. All-Optical Switching

All-optical wavelength selective polarisation rotation was demonstrated in a polarisation interferometer with a Ti:PPLN waveguide exploiting the ð-phase shift of a signal induced by cSFG/DFG at a pump power level of 1120 mW. Using a polarisation beam splitter even spatial switching could be achieved. The extinction of the signal was measured to be –20.2 dB [4]. This scheme can be extended to an all-optical 2x2 spatial switch.

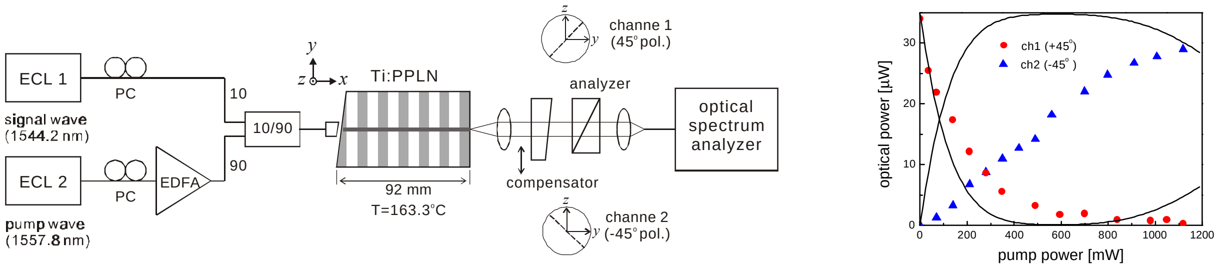

Fig. 2. Left diagram: schematic experimental setup for all-optical polarisation switching. Right diagram: Optical output power in channel 1 and channel 2 versus pump power. Solid lines present the theoretical results.

Moreover, all-optical spatial switching by DFG in two-core Ti:PPLN directional couplers was demonstrated. They are the basic modules of Ti:PPLN waveguide arrays with up to 100 coupled channels. Based on the combination of DFG and the unique diffractionless beam propagation in waveguide arrays [5] signal and generated idler can be switched to different output positions of a waveguide array [6]. 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. The signal is launched as a diffractionless propagating beam crossing the array at a certain angle. A high power pump beam is launched into a single waveguide of the array propagating as strongly confined fundamental mode with negligible coupling to neighboring channels and therefore trapped in the input waveguide. At the intersection of signal and pump beams phase-insensitive parametric interaction results in both, amplification and deflection of the signal and generation of a frequency shifted idler. The experiments showed good agreement with the theoretical predictions.

4. Conclusions

A variety of efficient integrated optical devices with Ti:PPLN waveguide structures (channels, directional couplers and waveguide arrays) has been developed for all-optical wavelength conversion, parametric amplification and all-optical switching with a wide range of applications in the fields of optical communication and sensing.

5. References

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