All-optical channel dropping by sum frequency generation in a Ti:PPLN channel waveguide

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Abstract *Wavelength selective channel dropping by sum frequency generation (SFG) of a 10 GHz channel out of a 4×10 GHz optical time division multiplexed (OTDM-) signal has been demonstrated using two fully packaged Ti:PPLN wavelength converters.*

Introduction

Periodically poled $LiNbO_3$ (PPLN) waveguides can be used for all-optical wavelength conversion as well as for highspeed all-optical signal processing. In particular, all-optical channel add/drop multi-/demultiplexing is one of the key functionalities in future reconfigurable photonic networks. First switches based on sum frequency generation (SFG) have been demonstrated in bulk $LiNbO_3$ and in proton exchanged (APE) and Ti:PPLN waveguides [1-3]. However, all-optical time selective channel dropping using SFG has not been reported up to now. In comparison to time selective channel dropping based on cascaded difference frequency generation (cDFG) [4] the SFG approach has the great advantage, that wavelength selective dropping is possible by changing the pump wavelength.

In this paper we demonstrate for the first time all-optical, ultrafast time and wavelength selective channel dropping based on SFG using two fully packaged Ti:PPLN waveguides. The first device was used to generate the wavelength shifted 10 GHz pump for the SFG process in the second PPLN device.

Ti:PPLN waveguide fabrication and device packaging

On a 0.5 mm thick, 4”-diameter Z-cut $LiNbO_3$ wafer optical waveguides were fabricated by indiffusion (8.5 h @ 1060°C) of photolithographically defined Ti-stripes (7 µm wide, 98 nm thickness) aligned parallel to the X-axis of the crystal. Afterwards, the microdomain structure of 16.6 µm periodicity was generated by the electric field assisted poling technique using liquid electrodes. Details of the poling process are reported elsewhere [5]. Finally, the endfaces of the waveguides were polished to allow endfire coupling to fibres. In addition, the endfaces were AR-coated to avoid Fabry-Perot interference effects. The fibre pigtails were mounted on micromanipulators with a few micrometers separation to the waveguide endfaces. This epoxy-free coupling does not limit the power levels of pump and signal. Moreover, in this way operation at elevated temperatures up to 200 °C is possible to minimize photorefractive effects and to adjust phase matching. Detailed information on the two packaged devices used in the experiment is given in Table 1.

Name of device	PPLN(1)	PPLN(2)
Length	86 mm	77 mm
Waveguide loss	0.11dB/cm	0.12dB/cm
SHG efficiency	700 %/W	760 %/W
Mode size (FWHM) of TM-mode	4.5µm ×3.0µm	4.7µm ×3.4µm
Fibre to fibre insertion loss	5.5 dB (TM)	5.0 dB (TM)

Table 1: Specifications of the two packaged devices

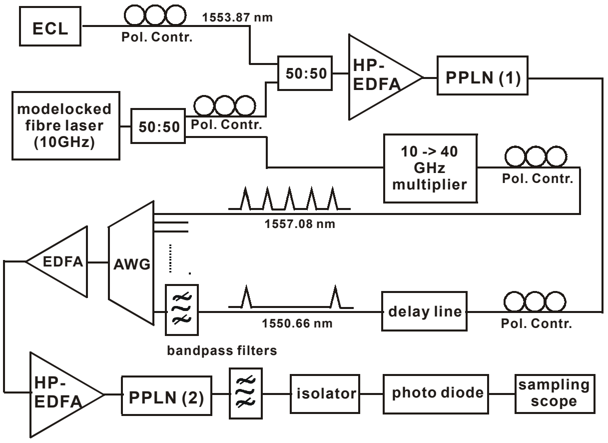

Figure 1: Experimental setup to demonstrate selective channel dropping by SFG

Experimental setup

The experimental setup to demonstrate all-optical, ultrafast, selective OTDM channel dropping is shown in Fig. 1. A modelocked fiber laser, generating 5 ps long, nearly transform limited pulses at λ_s = 1557.08 nm with 10 GHz repetition rate, was used twofold; therefore, a fibre-optic 3 dB power splitter was inserted. The pulses in the upper branch were combined in a second fibre-optic 3 dB power splitter with the cw-output (λ_f = 1553.87 nm) of a tunable extended cavity laser (ECL). Both waves were boosted in a high power erbium doped fibre amplifier (HP-EDFA) and simultaneously coupled to the wavelength converter PPLN (1) operated at 173°C. The ECL-output served as the fundamental wave to generate via cascaded difference frequency generation (cDFG) a 10 GHz idler, wavelength-shifted to 1550.66 nm (see

Fig. 2). The corresponding conversion efficiency was about –9.5 dB with respect to the transmitted signal power at 200 mW coupled fundamental power. The 10 GHz idler served as the pump for the channel dropping experiment in PPLN (2), it passed a tunable delay line and a bandpass filter to suppress the fundamental and the 10 GHz signal waves as well as most of the amplified spontaneous emission (ASE) of the HP-EDFA.

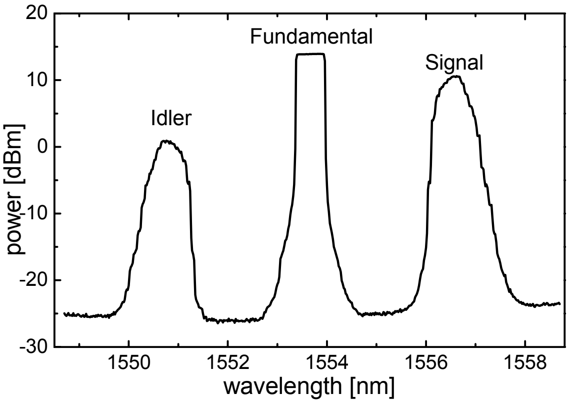

Figure 2: Cascaded difference frequency generation (cDFG) in PPLN (1): output power versus wavelength at 0.5 nm resolution bandwidth of the optical spectrum analyzer.

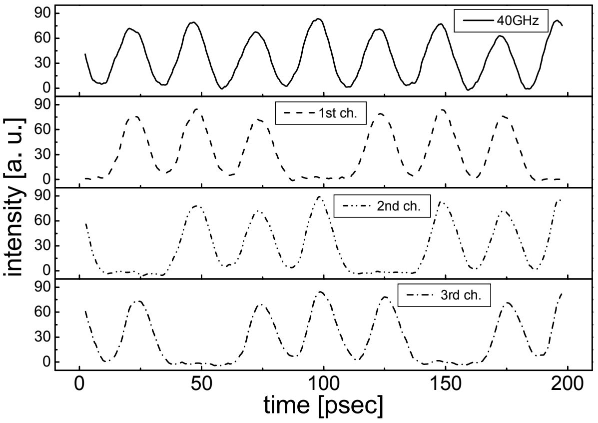

Figure 3: Selective channel dropping by SFG of individual 10 GHz OTDM channels (lower traces) out of the 40 GHz OTDM signal (upper trace)

The pulses of the fibre laser in the lower branch of the power splitter passed a fibre-optic 10 → 40 GHz multiplier to simulate a 40 Gbit/s OTDM-signal. It was superimposed in an arrayed waveguide grating (AWG) with the 10 GHz idler, generated in PPLN (1). Both waves were preamplified in an EDFA, boosted in a second HP-EDFA and coupled into the second wavelength converter PPLN (2), operated at 171°C.

Channel dropping by SFG

If the time delay between the 40 GHz signal ($\lambda_s = 1557.08$ nm) and the amplified 10 GHz idler serving as pump ($\lambda_i = \lambda_p = 1550.66$ nm) was properly adjusted, SFG was observed leading to a depletion of every fourth signal pulse (one of the 4 OTDM channels). This could be observed using an ultrafast photodiode of 50 GHz bandwidth and a sampling scope after bandpass-filtering the signal and blocking the generated sum frequency wave using an isolator. At an average coupled pump power of 100 mW complete depletion of every fourth signal pulse was observed with a channel dropping extinction ratio of < -15 dB. By changing the optical delay of the pump dropping of three individual channels could be achieved (see Fig. 3); the fourth channel was not accessible due to the limited delay range. Channel dropping by SFG was also theoretically analyzed. The group velocity mismatch of the sum frequency pulses on one hand and of signal and pump pulses on the other strongly reduces the conversion efficiency in comparison to an interaction of cw-waves; in that case about 175 mW of coupled pump power lead to full signal depletion. As a consequence, broader pump pulses would increase the conversion efficiency and thus reduce the required pump power. For example, we found that up to -27 dB channel dropping extinction ratio would be possible with pump pulses of 7.5 ps.

Conclusions

For the first time all-optical, wavelength and time selective channel dropping based on SFG was demonstrated using two fully packaged Ti:PPLN waveguide devices. One 10 GHz channel of a 4×10 GHz (OTDM-) signal was selectively dropped using 100 mW of average pump power.

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