Polarization Insensitive All-Optical Wavelength Conversion of 320 Gb/s RZ-DQPSK Data Signals

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Abstract: Polarization insensitive 320 Gb/s RZ-DQPSK single channel wavelength conversion was demonstrated using a Ti:PPLN-waveguide as all-optical wavelength converter in a bidirectional mode of operation. Error free performance of the converted signal was achieved.

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1. Introduction

All-optical wavelength conversion (AOWC) is a key function in future wavelength division multiplexing (WDM) networks [1]. It can offer advantages over optical-electrical-optical (O/E/O) schemes, such as a high signal bandwidth (far beyond 100 Gb/s), simultaneous conversion of several WDM channels as well as transparency to data rate and modulation format. In particular, AOWC exploiting cascaded second harmonic- and difference frequency generation (cSHG/DFG) in a Periodically Poled Lithium Niobate (PPLN) waveguide has attracted considerable research interests due to its ultra-fast response, negligible spontaneous emission noise, wide conversion range and the potential of high conversion efficiency [2-5]. In this paper we report the first polarization insensitive wavelength conversion of single channel 320 Gb/s return-to-zero differential-quaternary-phase-shift-keying (RZ-DQPSK) data using a Ti:PPLN-waveguide as the AOWC.

2. Operation principle

The polarization insensitive PPLN subsystem (Fig. 1 a) is a polarization maintaining loop configuration with bi-directional operation of the PPLN wavelength converter to provide a diversity scheme with an intrinsic equalization of the differential group delay [3]. The two polarization components of the signal are routed by the PBS and PM-fibers contra-directionally as TM-modes through the PPLN-waveguide and the corresponding components of the converted signal are recombined by the PBS and routed to port 3 of the circulator. Polarization insensitive operation is optimized by adjusting the pump polarization state at port 1 using a polarization controller. The conversion efficiency, which is defined as the ratio of the output power of the converted signal at port 3 and the input power of the data signal at port 1 is flat over the complete C-band (Fig. 1 b).

3. Experimental setup

In Fig. 2 the experimental setup for the polarization insensitive all-optical wavelength conversion of 320 Gb/s RZ-DQPSK signals is shown. It included a 320 Gb/s RZ-DQPSK transmitter, the all optical wavelength converter and a 320 Gb/s DQPSK receiver. The 320 Gb/s RZ-DQPSK transmitter consisted of a pulse source, a 10 GHz-to-40 GHz phase stable pulse multiplier, a DQPSK modulator and a 40 Gbaud to 160 Gbaud optical time division multiplexer.

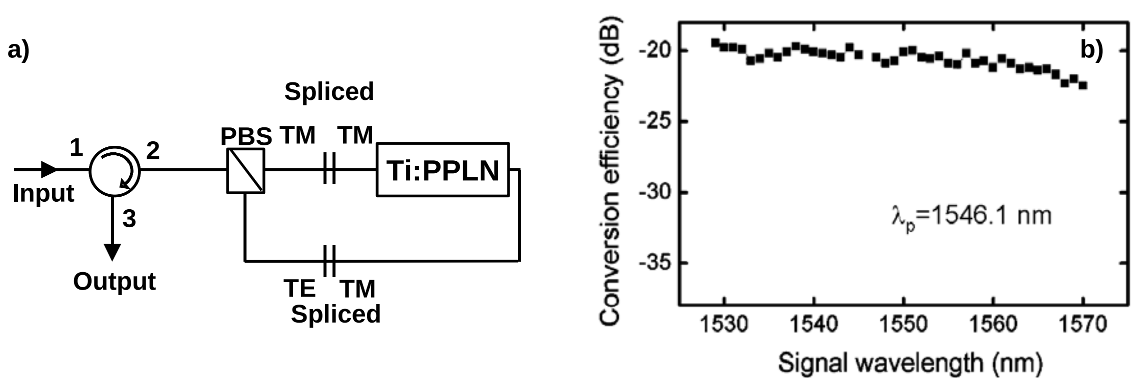

Fig. 1: a) Polarization insensitive PPLN subsystem. b) wavelength dependence of conversion efficiency

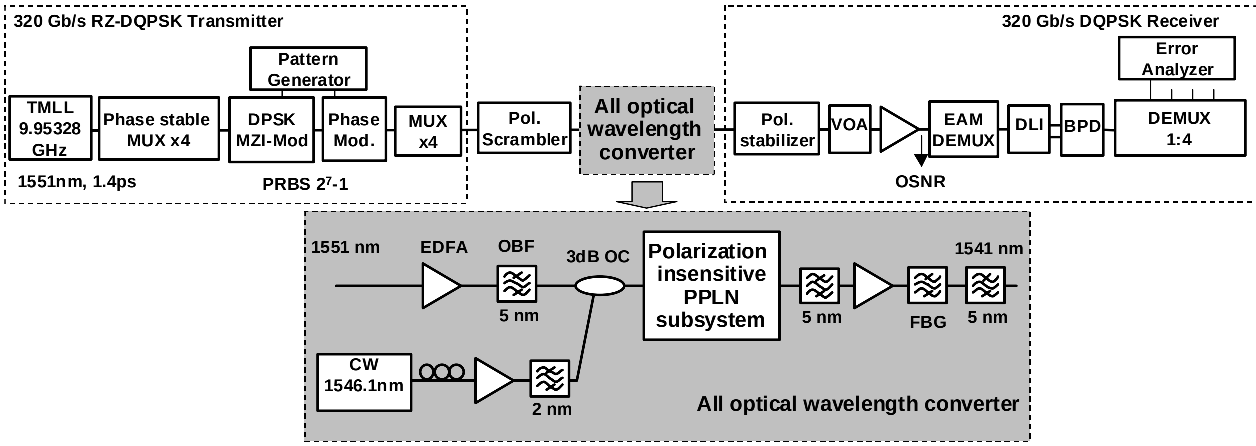

Fig. 2. Experimental setup for polarization insensitive all-optical wavelength conversion of a 320 Gb/s RZ-DQPSK signals.

The pulse source was a tunable semiconductor mode locked laser (TMLL) which produced a 1.4 ps, 10 GHz (STM-64) optical pulse train at 1551 nm, which was multiplied to 40 GHz with a passive phase stable multiplexer. A two stage modulator was used to encode the DQPSK signal. The first stage was a Mach-Zehnder $LiNbO_3$ device driven in push-pull mode by a 40 Gb/s PRBS signal (2^7-1) from a pattern generator to encode the π phase shift. The second stage was a $LiNbO_3$ phase modulator to encode the additional π/2 phase shift, driven by the same electrical signal with a sufficient delay for de-correlation. The modulated 40 Gbaud (80 Gb/s) RZ-DQPSK signal was then multiplexed in time by a passive fiber-delay multiplexer (MUX x4) to generate a 160 Gbaud (320 Gb/s) RZ-DQPS signal.

In the AOWC the generated 320 Gb/s RZ-DQPSK signal was amplified by an EDFA, then filtered by a 5 nm optical bandpass filter (OBF) and finally launched into the polarization insensitive PPLN subsystem through a 3 dB coupler (OC). The signal power was 15.1 dBm at the input of the polarization insensitive PPLN subsystem. The CW pump light at 1546.1 nm was amplified by a high-power EDFA, filtered and launched into the polarization insensitive PPLN subsystem through the second input of the 3 dB coupler. The pump power was 24.4 dBm at the input of the polarization insensitive PPLN subsystem. The polarization controller in front of the EDFA was used to optimize the polarization insensitivity of the conversion efficiency. The PPLN subsystem had a passive loss of 9.2 dB; the temperature of the Ti:PPLN waveguide was set to 179.3°C to avoid photorefraction. At the output of the polarization insensitive PPLN subsystem the signal was launched into a filtering subsystem, which consisted of two 5 nm OBFs, an EDFA in between and a tunable fiber Bragg grating (FBG). The FBG was used to block the pump light, and the OBFs were used to separate the converted signal at 1541 nm from the pump and the original data signal. The polarization of the data signal was scrambled in front of the AOWC. In the DQPSK receiver a polarization stabilizer was used to de-scramble the converted data signal in order to mitigate the polarization sensitivity of the receiver.

The 320 Gb/s RZ-DQPSK receiver consisted of an optical pre-amplification stage, an EAM demultiplexer, a delay line interferometer (DLI), a balanced photo-detector (BPD) directly attached to an electrical demultiplexer (1:4) and an error analyzer (EA). The EAM demultiplexer was used to select one of the four 80 Gb/s (40 Gbaud) OTDM tributaries. The DLI had a free spectral range of 40 GHz and was used to demodulate the I or Q channel from the demultiplexed 80 Gb/s DQPSK signal. Since no DQPSK pre-coder was used in the transmitter, the EA was programmed to the expected bit pattern, which limited the word length in our experiments to 2^7-1. We used a variable optical attenuation (VOA) at the receiver input to vary the received optical signal to noise ratio (OSNR).

4. Experimental results

The spectrum at the input and the output of the polarization insensitive PPLN subsystem is shown in Fig. 3 (a). The conversion efficiency for the 320 Gb/s RZ-DQPSK signal with polarization scrambling is –21 dB. It could be improved if the total insertion loss of the PPLN-subsystem including the fiber-optic components would be reduced. Nevertheless, the internal efficiency of about –10 dB (see Fig 3 (a)) is in good agreement with theoretical calculations assuming 17 dBm of fundamental pump power launched in each direction into the PPLN-waveguide.

To characterize the residual polarization sensitivity of the PPLN subsystem we measured the power of the converted signal versus time (50s) with slow polarization scrambling (HP11890A motorized polarization controller, scan-rate 1). The maximum fluctuation was about 0.5 dB, as shown in Fig. 3 (b).

The BER measurements are shown in Fig. 4 (a) as a function of the received power at the 320 Gb/s DQPSK receiver. BER curves are plotted for the 320 Gb/s DQPSK signal back-to-back before conversion, and for the

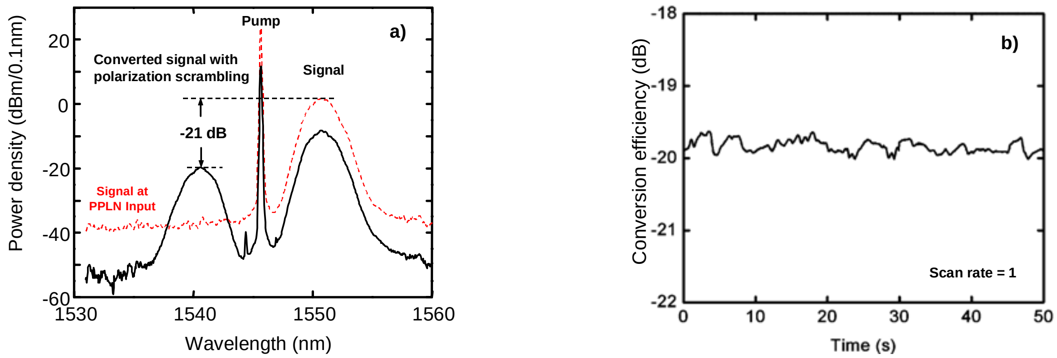

Fig. 3. (a) Spectrum at the input and the output of the AOWC. (b) Power fluctuation of the converted signal with polarization scrambling.

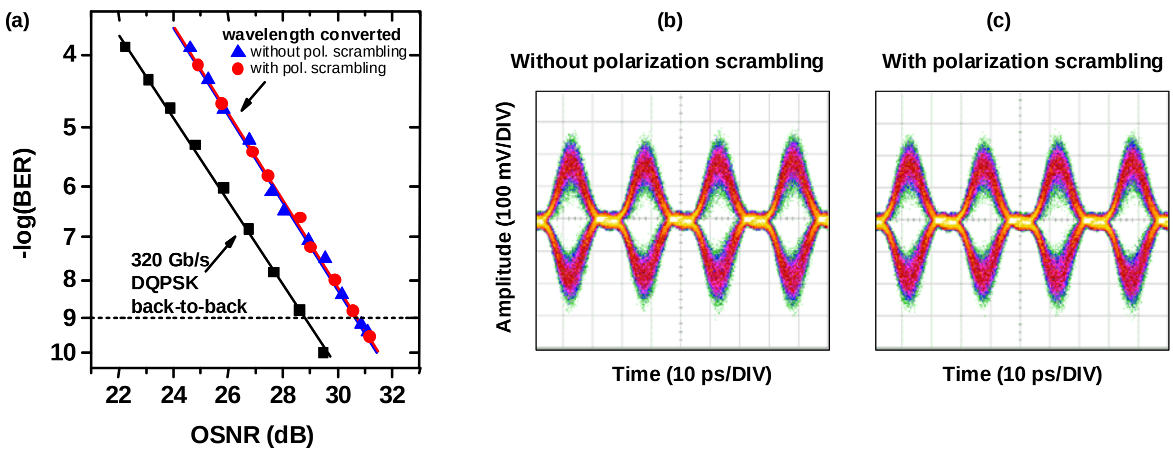

Fig. 4. (a) BER measurements for the 320 Gb/s DQPSK signal back to back, and for the converted 320 Gb/s DQPSK signal with and without polarization scrambling. (b) and (c): 40 Gb/s eye-diagram of the wavelength converted, demultiplexed, and demodulated signal in the DQPSK receiver without and with polarization scrambling.

converted 320 Gb/s DQPSK signal with and without polarization scrambling. The wavelength conversion causes 2 dB received power penalty at the BER of 10^{-9} compared with the back to back case (unconverted signal). However, the additional penalty caused by the polarization scrambling is almost negligible. The measurements shown in Fig.4 are for a single tributary. All tributary channels were measured and the variation of the received power required for BER=10^{-9} was found to be less than 1 dB. The 40 Gb/s eye-diagrams of the converted, demultiplexed and demodulated signal (BER=10^{-9}) without and with polarization scrambling are shown in Fig. 4 (b) and (c).

5. Conclusion

We have demonstrated polarization insensitive 320 Gb/s RZ-DQPSK wavelength conversion using a Ti:PPLN waveguide in a polarization diversity scheme as all-optical wavelength converter. Error free operation with 2 dB receiver penalty for the converted signal was achieved. The BER performance of the converted signal was identical with and without polarization scrambling in front of the AOWC.

6. References

[1] S.J.B. Yoo, "Wavelength conversion technologies for WDM network applications", IEEE Journal of Lightwave Technology, vol. 14, no. 6, p. 955-966, 1996.
[2] C. Langrock, S. Kumar, J.E. McGeehan, A. E. Willner, M. M. Fejer, "All-Optical Signal Processing Using $\chi(2)$ Nonlinearities in Guided-Wave Devices", IEEE Journal of Lightwave Technology, vol. 24, no. 7, p. 2579-2592, 2006.
[3] D. Caccioli, A. Paoletti, A. Schiffini, A. Galtarossa, P. Griggio, G. Lorenzetto, P. Minzioni, S. Cascelli, M. Guglielmucci, L. Lattanzi, F. Matera, G.M. Tosi Beleffi, V. Quiring, W. Sohler, H. Suche, S. Vehovc, M. Vidmar, " Field demonstration of in-line all-optical wavelength conversion in a WDM dispersion managed 40 Gbit/s link", IEEE J. Select. Topics in Quantum Electron., vol. 10, no. 2, 356-362, 2004
[4] B. Huettl, A. Gual Coca, H. Suche, R. Ludwig, C. Schmidt-Langhorst, H. G. Weber, W. Sohler, C. Schubert, "320 Gbit/s DQPSK All-Optical Wavelength Conversion using Periodically Poled $LiNbO_3$", CLEO 2007, Baltimore (USA), paper CThF1, May 6-11, 2007.
[5] S. L. Jansen, van D. Borne, P. M. Krummrich, S. Spälter, G. -D. Khoe, H. de Waardt, "Long-haul DWDM transmission systems employing optical phase conjugation", IEEE J Sel. Top. Quant., vol. 12, no. 4, p. 505-520, 2006.