Proc. Conference on Lasers and Electro-Optics
(CLEO 2007), May 2007, Baltimore, p. 143,
paper CThF1

320 Gbit/s DQPSK All-Optical Wavelength Conversion using Periodically Poled $LiNbO_3$

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Abstract: We demonstrate wavelength conversion of 160Gbit/s DPSK and 320Gbit/s DQPSK data signals by cascaded second-harmonic and difference frequency generation in a periodically poled $LiNbO_3$ waveguide. Error free operation with negligible penalty is obtained.

OCIS codes: (190.4360) Nonlinear optics, devices; (060.4510) Optical communications

1. Introduction

Recently, advanced modulation formats, such as differential (quaternary) phase shift keying (D(Q)PSK) where the phase of the optical signal contains the information were intensively investigated and have proven to be advantageous in certain applications. Hence, schemes for signal processing of phase modulated data signals in high speed optical networks should be developed. All-optical wavelength conversion (AOWC) will be a key function in those networks, increasing their flexibility and transparency. Different nonlinear media have already been investigated for AOWC at 40 Gbit/s and above. Semiconductor optical amplifiers have shown their AOWC capability for DPSK format up to 40 Gbit/s [1]. With schemes using four-wave-mixing in highly nonlinear fibres, conversion of DQPSK signals up to 80 Gbit/s has been demonstrated [2]. AOWCs exploiting nonlinear $\chi^{(2)}$-effects in a periodically poled $LiNbO_3$ (PPLN) waveguide are another attractive solution due to their compactness and large optical bandwidth (e.g. to convert the complete C band [3]). All-optical wavelength conversion of 160 Gbit/s On-Off Keying signals [4] and of 42.8 Gbit/s DQPSK signals [5] in PPLN waveguides has been shown recently.

In this paper we report the first demonstration of single channel DPSK and DQPSK wavelength conversion in a Ti:PPLN waveguide at 160 Gbit/s and 320 Gbit/s, respectively. In both cases an error free performance with a negligible penalty of the AOWC was achieved.

2. Experimental set up

Fig. 1 shows the complete experimental set-up for the transmission experiments, comprising a 160 Gbaud D(Q)PSK transmitter, the AOWC and a 160 Gbaud D(Q)PSK receiver. The central component of the experiment, the AOWC, used a fiber-coupled Ti:PPLN waveguide of a length of 93 mm. Its conversion efficiency was measured to be about 100 %/W with respect to the launched pump power. Wavelength conversion was achieved by cascaded second harmonic generation (SHG) of a cw pump (provided by an external cavity laser ECL and an amplifier, see Fig. 1) and difference frequency generation of SH-wave and the data signal [3]. A pump power of 22.4 dBm (wavelength: 1540.5 nm) was launched into the Ti:PPLN waveguide resulting in a conversion efficiency for the data signal of -8 dB (Fig. 2). The device was operated at an elevated temperature of 206 °C to avoid photorefractive effects.

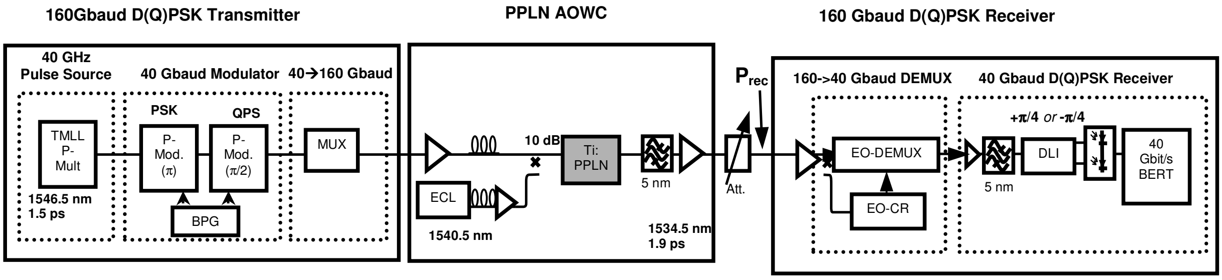

Fig. 1: Experimental set up

In the transmitter the 40 GHz pulse source consisted of a tuneable 10 GHz semiconductor mode locked laser (TMLL, wavelength 1547 nm, pulse width 1.5 ps) and a phase stabilised 10 to 40 GHz pulse multiplier (P-Mult). A two stage phase modulator was used to create either a DPSK or a DQPSK data signal. The modulator used for encoding the π phase shift was a $LiNbO_3$ Mach-Zehnder type driven in push-pull mode by an electrical data signal

(PRBS 2^7-1). The modulator used for encoding the additional $\pi/2$ phase shift for DQPSK was a z-cut $LiNbO_3$ phase modulator driven by the same electrical data signal. The electrical signals which drive the two modulators were decorrelated by a 48 bit delay. The modulated 40 Gbaud signal was then multiplexed in a fibre-delay multiplexer (MUX) to generate up to 160 Gbaud signals as input to the wavelength converter.

In the AOWC the data signal was amplified and launched into the Ti:PPLN waveguide through the weak arm of a 10 dB coupler, giving a signal power of 3 dBm at the input of the waveguide. At the output an optical band pass filter (5nm) was used to block the pump and data input signals and to separate the converted signal at 1534.5 nm. Using this filter configuration, the pump signal was suppressed only incompletely (Fig. 2), which led to a constant 1.8 dB power offset at the 160 Gbaud receiver. This offset could be eliminated by a sharp notch filter, which was not available in our experiments. Therefore, the offset was subtracted in the bit error ratio graphs.

The 160 Gbaud receiver contains an electro-optical clock recovery (EO-CR), which synchronised the electro-optical demultiplexer (EO-DEMUX) to the incoming data signal. Both devices were based on single electro-absorption modulators. After demultiplexing from 160 Gbaud to 40 Gbaud the signal was demodulated in a 25 ps delay-line interferometer (DLI), o/e converted using a balanced detector and bit error rate measurements (BER) were performed. A programmable error detector was used, to avoid a dedicated pre-processing circuit in the transmitter.

3. Results

In Fig. 3 bit error ratio measurements (BER) are shown as a function of the average power at the 160 Gbaud receiver (P_{rec} in Fig. 1). Curves are plotted for back-to-back measurements (b2b, without AOWC) and for measurements of the converted signal (conv., with AOWC). The wavelength conversion of DPSK data (Fig. 3a) caused a negligible penalty in receiver sensitivity (less than 0.5 dB at BER 10^{-9}) for 40, 80 and 160 Gbit/s compared to b2b. All tributary channels were measured and the variation of the receiver sensitivity was found to be less then 1 dB.

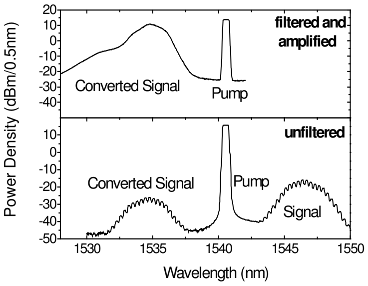

Fig.2 Optical Spectra after AOWC

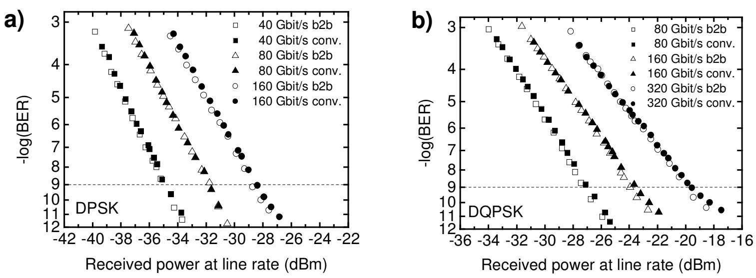

Fig. 3: BER measurements for 40, 80, and 160 Gbit/s DPSK (a), and for 80, 160, and 320 Gbit/s DQPSK (b)

For DQPSK an error free operation with negligible penalty (lower than 0.5 dB for a BER of 10^{-9}) was achieved as well, but in this case for 80, 160 and 320 Gbit/s (Fig. 3b). The measurements showed that the AOWC with Ti:PPLN waveguide did not disturb the phase of the data signals and that its performance was not limited by the bit rate up to 160 Gbaud.

4. Summary

We demonstrated all-optical wavelength conversion of 160 Gbit/s DPSK and 320 Gbit/s DQPSK data by an AOWC with Ti:PPLN waveguide. An error free operation with a negligible penalty was shown for converted data signals with both modulation formats. No bit rate limitation was observed up to a symbol rate of 160 Gbaud.

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