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320 Gbit/s DQPSK All-Optical Wavelength Conversion using Four Wave Mixing

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Abstract: In this paper we demonstrate wavelength conversion of 320Gbit/s DQPSK and 160Gbit/s DPSK data signals by four wave mixing in highly nonlinear fibre. Error free operation is shown for conversion of both DPSK and DQPSK.

OCIS codes: (060.4370) Nonlinear optics, fibers; (060.4510) Optical communications

1. Introduction

In recent years the appearance of new modulation formats for data transmission, where the phase of the optical signal is carrying the information such as differential (quaternary) phase shift keying (D(Q)PSK) have attracted much attention. The main advantage of these modulation formats are improved transmission properties and the possibility to transmit higher data rates for a given symbol rate. As a consequence systems for phase maintaining high speed signal processing for future optical networks have to be developed. To increase the transparency of such future optical networks the signal processing needs to be all-optical. A key signal processing function is wavelength conversion. So far a limited number of schemes for high speed all-optical wavelength conversion (AOWC) of phase modulated data signals have been proposed using different nonlinear media. AOWCs based on semiconductor optical amplifiers have been used in wavelength conversion of close to 40 Gbit/s DPSK data [1]. In $LiNbO_3$ a combination of second harmonic generation and difference frequency generation has been used for wavelength conversion of 42.8 Gbit/s DQPSK data signals in a WDM configuration [2]. A third scheme based on four wave mixing (FWM) in highly nonlinear fibre (HNLF) has been demonstrated for wavelength conversion of DPSK signals at 40 Gbit/s in a WDM configuration, as well as for a single 80 Gbit/s DQPSK signal [3, 4]. Four wave mixing in fibre has the advantage of having potential for very high speed operation due to the fast response of the nonlinear Kerr effect. Furthermore nonlinear fibres with very flat dispersion profile and the close wavelength allocation for FWM allow for conversion with minimal walk-off between signals, reducing signal pulse broadening to a negligible level.

This paper reports on the first demonstration of single channel DPSK wavelength conversion at 160 Gbit/s as well as the first demonstration of DQPSK wavelength conversion at 320 Gbit/s. The wavelength conversion was performed using FWM in HNLF. In all cases error free performance of the wavelength converter was achieved. In the case of converting DPSK signals up to 160 Gbit/s the conversion was penalty free. DQPSK up to 320 Gbit/s also performed error free however with a 4 dB penalty in receiver sensitivity.

2. Experimental procedure

Fig. 1 shows the experimental set-up of the FWM based AOWC consisting of a 160 Gbaud D(Q)PSK transmitter, the AOWC and a 160 Gbaud D(Q)PSK receiver. The transmitter was based on a 10 GHz pulse source (tuneable semiconductor mode locked laser, wavelength 1550 nm, pulse width 1.5 ps). The generated pulse train was multiplied to 40 GHz in a phase stabilised pulse multiplier (P-MULT) and then phase modulated in two stages to create either a DPSK or a DQPSK data signal. The modulator used for encoding the π phase shift was a $LiNbO_3$ Mach-Zender type modulator driven by an electrical data signal (PRBS 2^7-1). The modulator used for encoding the additional π/2 phase shift for DQPSK was a $LiNbO_3$ phase modulator (LN-PM) driven by the same electrical data signal. The two modulators were decorrelated by a 48 bit delay in the driving data signals. 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

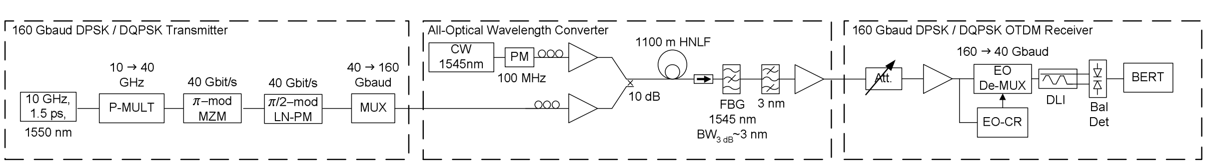

Fig. 1 Experimental set-up.

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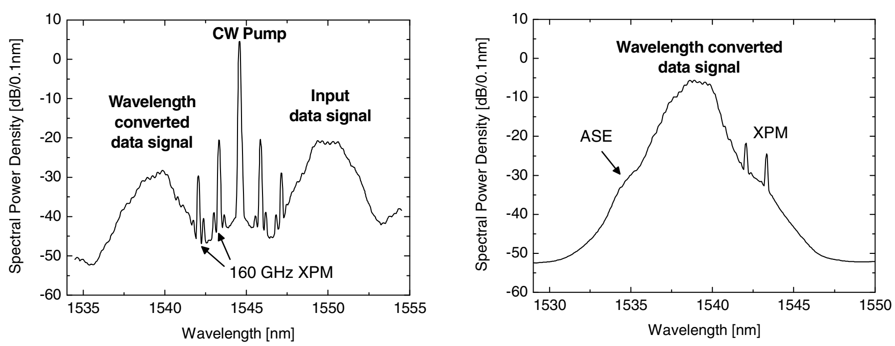
wavelength converter. In the AOWC the data signal was amplified and injected into 1100 m of HNLF (γ = 20.6 W^{-1} km^{-1}, λ_0=1548 nm, S=0.03 ps/nm^2/km) through the weak arm of a 10 dB coupler, giving a signal power in the HNLF of ~ 3dBm. A CW pump at 1545 nm was phase modulated at 100 MHz to suppress stimulated Brillouin scattering (SBS) in the HNLF. The pump was then amplified and coupled into the HNLF through the strong arm of the 10 dB coupler giving a pump power of ~ 22 dBm in the HNLF. At the output of the HNLF an optical isolator blocked the reflected power from a fibre bragg grating (FBG) which was used as a notch filter to suppress the 1545 nm pump. An additional optical band pass filter was used to suppress the 1550 nm input signal, allowing only the converted signal at 1539 nm to pass. The wavelength converted signal was then received in a preamplified 160 Gbaud OTDM receiver, where an electro-optical clock recovery (EO-CR) synchronised the electro-optical demultiplexer (EO De-MUX) to the incoming data signal. Both devices were based on a single electro-absorption modulator. 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. The phase modulation of the CW pump caused a weak modulation of the carrier frequency of the wavelength converted signal. This reduced the maximum contrast between the two output arms of the DLI by 3 dB when demodulating the converted signal compared to demodulating the original data signal.

3. Results of wavelength conversion

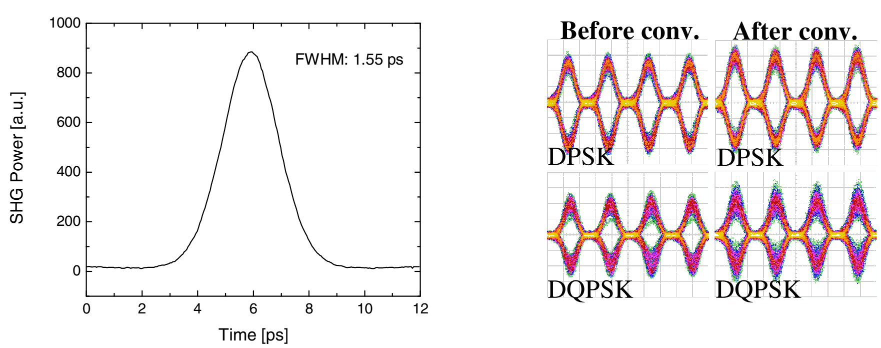
The process of wavelength conversion in the HNLF is shown in Fig. 2 (a).



(a) (b)

Fig. 2 Spectra illustrating the wavelength conversion process.

The input data signal and the CW pump generated FWM when they were co-polarised in the fibre, and the wavelength converted data signal (the idler) was created. As seen in the spectrum the conversion efficiency was about -10 dB, which is determined by the amount of power in the CW pump. For a given pump power appropriate SBS suppression has to be applied. The peaks on either side of the CW pump were generated through cross phase modulation (XPM) between the pump and the input data signal. The peaks were spaced 160 GHz corresponding to the symbol rate of the data signal. In Fig. 2 (b) the spectrum of the filtered and amplified wavelength converted data signal at the AOWC output is seen. Some indication of the XPM broadening of the CW pump is still observed and the shoulders are due to a small amount of amplified spontaneous emission (ASE) after filtering. The optical signal



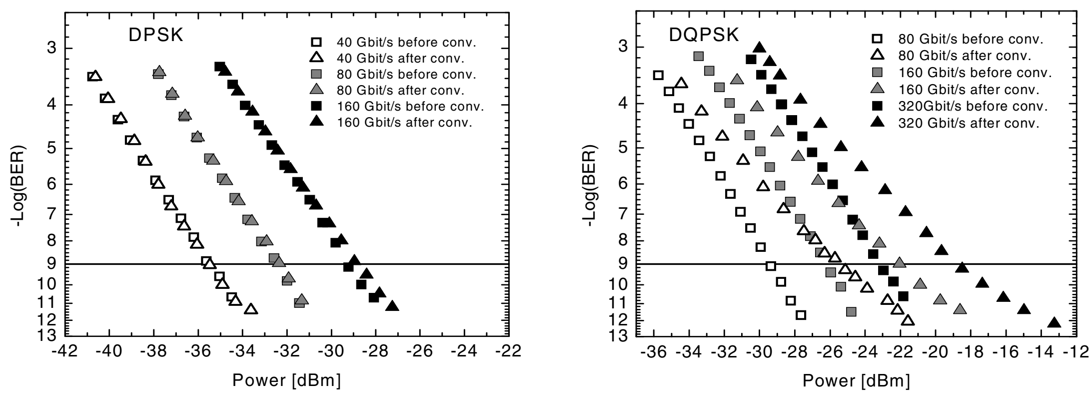
(a) (b)

Fig. 3 (a) Autocorrelation and pulse width of the 160 Gbit/s (80 Gbaud) DQPSK wavelength converted signal . (b) 40 Gbaud eye diagrams from balanced detection of the demultiplexed DPSK and DQPSK signals before and after conversion.

to noise ratio was measured to be ~ 37 dB in the converted signal.

Fig. 3 (a) shows an autocorrelation trace of the wavelength converted data pulses. The pulse width is increased by ~ 50 fs compared to the 1.5 ps pulses in the original data signal. In Fig. 3 (b) the eye diagrams from the balanced detector after demultiplexing and demodulation of the signal are shown for DPSK and for DQPSK. For DPSK the eye is clear and open for both the original and for the wavelength converted signal. When using the DQPSK modulation format the eye opening is somewhat smaller due to the closer spacing of the data carrying phase levels. This means that the system performance is more sensitive to small perturbations of the phase or frequency of the optical signal. The increased amplitude noise in the DQPSK eyes is due to imperfect modulation in the LN-PM used to create the quaternary phase shifts. A small amount of additional noise is seen in the wavelength converted DQPSK eye and is attributed to the reduction in DLI contrast mentioned above.

In Fig. 4 BER measurements before and after the wavelength converter are shown as a function of the average power at the 160 Gbaud receiver. The performance for conversion of DPSK data is shown in Fig. 4 (a) for 40, 80 and 160 Gbit/s. The wavelength conversion is seen to cause a negligible penalty in receiver sensitivity (less than 0.3 dB at BER 10^{-9}). To determine the BER all tributary channels were measured and a variation in receiver sensitivity of ~ 0.5 dB was found.



(a) (b)

Fig. 4 (a) BER measurements for 40, 80, and 160 Gbit/s DPSK before and after the AOWC (b) BER measurements for 80, 160, and 320 Gbit/s DQPSK before and after the AOWC.

For DQPSK the BER measurements for conversion of 80, 160 and 320 Gbit/s data are shown in Fig. 4 (b). Error free operation was achieved with a ~ 4 dB penalty for all bit rates, showing that the performance of the converter was not limited by the bit rate. The penalty for the converted DQPSK signals is expected to be due to the 3 dB reduction in the obtainable contrast in the DLI. Due to the smaller margin for DQPSK demodulation compared to DPSK, this effect only showed up when demodulating the converted DQPSK data signal. Similarly the effect of the reduction in DLI contrast was also only visible in the eye diagram in Fig. 3(b) for the converted DQPSK signal. This signal degradation due to the phase modulation of the CW pump could potentially be reduced by applying a different scheme for SBS suppression, such as fibre heating or stressing [5].

4. Conclusion

Error free and penalty free wavelength conversion of a 160 Gbit/s DPSK single wavelength and single polarisation data signal has been shown using FWM in HNLF. Furthermore error free wavelength conversion of a 320 Gbit/s DQPSK data signal was demonstrated with 4 dB penalty in receiver sensitivity. These results indicate the feasibility of FWM in HNLF for high-speed wavelength conversion of phase modulated data signals for future all-optical networks.

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