40 Gb/s NRZ-DQPSK data wavelength conversion using four-wave mixing in a quantum dash semiconductor optical amplifier

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Abstract – DQPSK modulation is attractive in high-speed optical communications because of its resistance to fiber nonlinearities and its more efficient use of fiber bandwidth compared to conventional intensity modulation schemes. Because of its wavelength conversion ability and phase preservation, SOA four-wave mixing has attracted much attention. We experimentally study the wavelength conversion of 40 Gbit/s (20 Gbaud) NRZ-DQPSK data using FWM in a Quantum Dash SOA with 20 dB gain and 5 dBm output saturation power. Q factor improvement and eye diagram reshaping is shown for up to 3 nm pump-probe detuning and is superior to that reported for a higher gain bulk SOA.

Key words: DQPSK, phase modulation, quantum-dash, semiconductor optical amplifier, four-wave mixing, all optical wavelength conversion.

1 Introduction

The constantly increasing demand for data transmission rates leads to a need to improve the effectiveness of bandwidth use. The Differential Quadrature Phase Shift Keying (DQPSK) format has many advantages over conventional intensity modulation schemes [1-4]. In particular it increases the spectral effectiveness by transferring two bits per symbol and is relatively immune to fibre nonlinearities. In order for the SOAs to be able to optimally work with the fast speed advanced modulation formats, optimisation of the SOA structures are desired. An ideal SOA for advanced modulation data should not only properly amplify signals, but also preserve the phase relations between the symbols. For purely phase encoded signals a low alpha-factor SOA is advantageous [5]. During the past few years, Quantum Dash (QDash) devices have attracted considerable attention. Quantum dot and dash-based SOAs are expected to have reduced noise figure and fast dynamic response compared to quantum-well or bulk SOAs [6-7]. In this paper, we show FWM wavelength conversion for 20 Gbaud (40 Gb/s) NRZ-DQPSK data using a QDash-SOA. Similar work has been demonstrated for multiple quantum-well and bulk SOAs [8-10]. We show significantly increased Q-factor and eye diagram reshaping, when compared to the same operation conducted in a bulk SOA [10]. Wavelength conversion was achieved for a positive detuning of up to 3 nm, with large Q factor improvements obtainable for low quality probe input signals.

2 SOA characteristics

The SOA used is a custom packaged QDash device. The dashes are grown in a dash-in-a-barrier structure where the quantum dash emitting at 1.55 µm is buried in a quaternary barrier of λ_g=1.17 µm [7]. The structure consists of six dash stack layers as shown in Fig 1. The SOA is processed using buried ridge stripe technology with a ridge width of 1.5µm. The waveguides are tilted at 7° and also feature a tilted mode shape convertor. The facets are treated with an anti-reflection coating. The SOA is operated at 500 mA bias current, with an unsaturated gain of approximately 20 dB at 1530 nm, 5 dBm and 8dB saturation output power and polarization sensitivity respectively. The polarization dependent ASE spectrums and saturation characteristics are shown in Fig. 2.

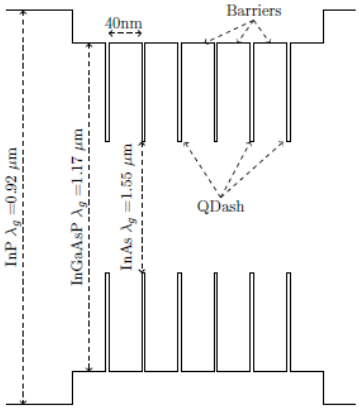

Fig. 1. Dash-in-a-Barrier structure, showing 6 stack layers of InAs QDashes in InGaAsP barriers.

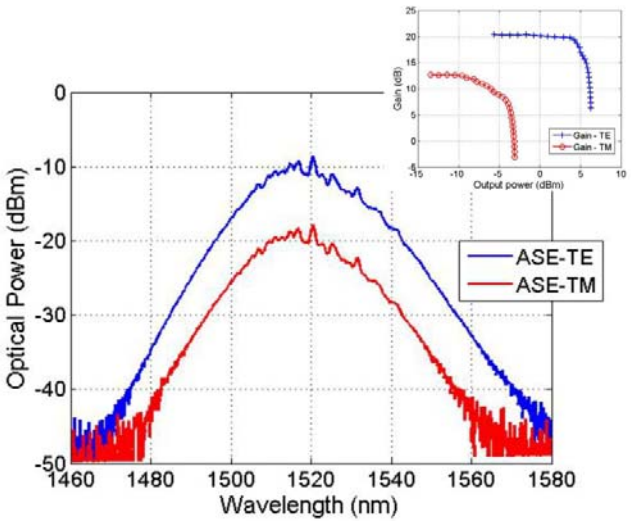

Fig. 2. Unsaturated ASE spectra and polarization dependent gain characteristics (at 1530 nm) for a bias current of 500 mA. The spectral resolution is 1 nm.

Fig. 3 shows the unmodulated FWM efficiency of the SOA for different detuning values. The FWM efficiency is defined as ratio of output conjugate power to the input probe power. The pump was a 1534 nm CW laser and its maximum power of -4 dBm.

For the purpose of wavelength conversion, it was desired to have the conjugate at the highest possible power level, which was obtained by adjusting the probe power for a detuning of 1nm. The maximum was achieved for a probe power of -7 dBm. The FWM efficiency was few dB lower than the one measured for a bulk SOA in our previous work [10].

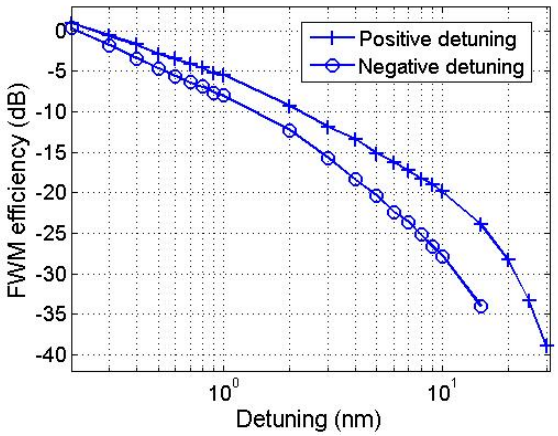

Fig. 3. CW FWM efficiency versus detuning for input probe and pump powers of -7 dBm, -4 dBm respectively.

3 Experiment

The DQPSK FWM experimental setup is shown in Fig. 4. The input pump power is -4 dBm. The probe is a 20 Gbaud/s (40 Gb/s) NRZ-DQPSK 2^{15-1} pseudo random bit pattern. DQPSK modulation was carried out using a commercial modulator (Photline-MODBOX). The signal is amplified by an EDFA and its ASE reduced by a 1 nm filter. In order to separate the conjugate from the amplified pump and probe signals, a cascade of filters was used at the output of the SOA: a 0.2 nm FWHM fiber Bragg grating (FBG) centered at 1533 nm and a 0.5 nm tunable filter. The conjugate signal was then amplified by an EDFA and its ASE filtered out by a 0.5 nm filter. The DQPSK demodulator (Optoplex) consists of two delay-line interferometers that convert the I and Q components of the signal into intensity changes. The optical signals from the interferometer outputs are detected by balanced 23 GHz bandwidth photodiodes (Discovery Semiconductors Lab Buddy) and an 80 GHz electrical bandwidth Agilent 86100C digital communication analyzer. The demodulated I and Q components show almost identical performance. To this effect we concentrate on the I component for analysis purposes. The influence of probe power on the quality of the wavelength converted signal for a detuning of 1 nm was examined. The pump wavelength and power were set to 1534 nm and -4 dBm, respectively. The probe wavelength was set to 1535 nm. The input signal to the demodulator was fixed at -4.5 dBm by adjusting the EFDA gain. The input and conjugate eye diagrams are shown in Fig. 5. The input Q factor increased with an increase in the probe power, whereas the wavelength converted signal Q-factor was highly dependent on the conjugate power, measured at the output of the SOA, reaching its maximum for a probe power of -10 dBm as shown in Fig. 6.

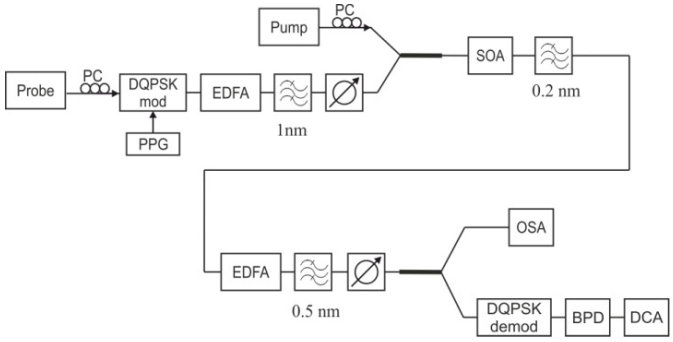

Fig. 4. Experimental setup: PC (Polarization Controller), PPG (Pulse Pattern Generator), OSA (Optical Spectrum Analyzer), BPD (Balanced PhotoDetector), DCA Digital Communications Analyzer).

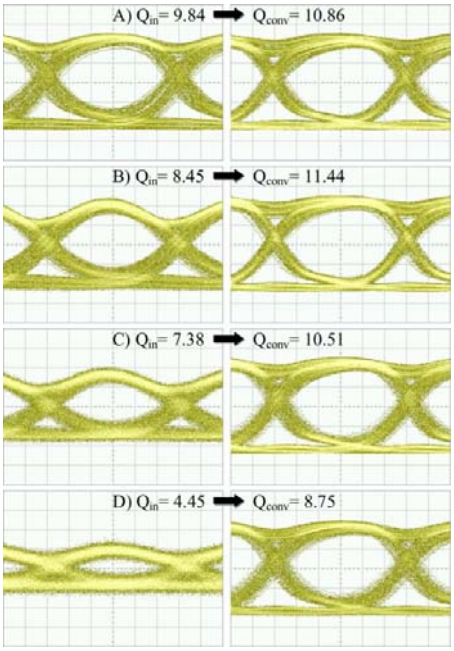

Fig. 5. Eye diagrams of input (left) and converted (right) signals for probe power of: A) -6 dBm, B) -10 dBm, C) -15 dBm, D) -20 dBm. The detuning is 1 nm. The horizontal scale is 8.3 ps/div.

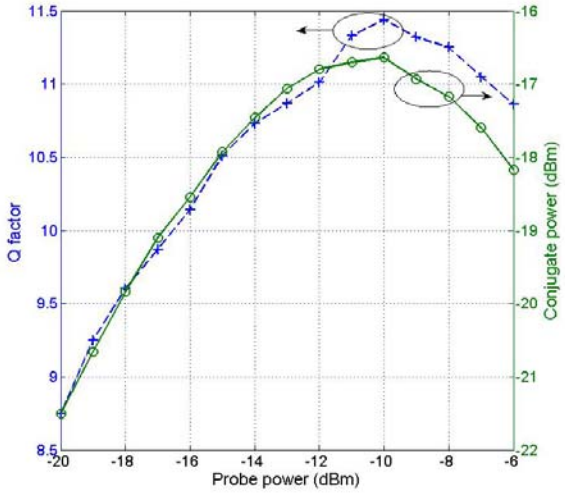

Fig. 6. Converted signal Q-factor and power for a detuning of 1nm.

In contrast to experimental results for a bulk SOA [10], where the converted eye diagram was degraded, large improvements in the converted signal were obtained for all investigated input probe powers, resulting in 2.63 dB improvement for the maximum converted Q-factor (from 8.45 to 11.44) for probe power of -10 dBm and a maximum improvement of 5.87 dB (from 4.45 to 8.75) for probe power of -20 dBm (the minimum investigated value). The quality of the converted signal for different detuning values was measured. Because of a non-tunable filter used, the pump and probe wavelengths were adjusted in order to maintain the conjugate signal at 1533.04 nm. The pump and probe powers were kept at -4 dBm and -10 dBm, respectively. The input Q factor was 8.45. The converted signal power was set to its maximum. The resulting Q-factor and FWM efficiency are shown in Fig. 7. As expected, the maximum obtainable Q-factor value decreases along with the conjugate power. For detuning up to 3 nm the Q-factor was improved, reaching a maximum value of 12.52 for 1 nm down-conversion. Fig. 8 shows a comparison of the eye diagrams for the input and converted signal for different detunings. A clear improvement in the eye diagram shape is seen for low detuning values.

4 Conclusions

40 Gb/s NRZ-DQPSK FWM wavelength conversion in a QDash-SOA was demonstrated. Lossless wavelength conversion was achieved for positive detuning up to 3 nm, with significant improvements in the Q factor as well as eye diagram reshaping. The results are a noticeable improvement over similar experiments carried out using a bulk SOA. The physical reasons for such improvements are unclear but are probably linked to faster gain dynamics in QDash-SOAs compared to that in bulk SOAs. More theoretical work is required to determine the exact physical mechanisms leading to the FWM signal improvements.

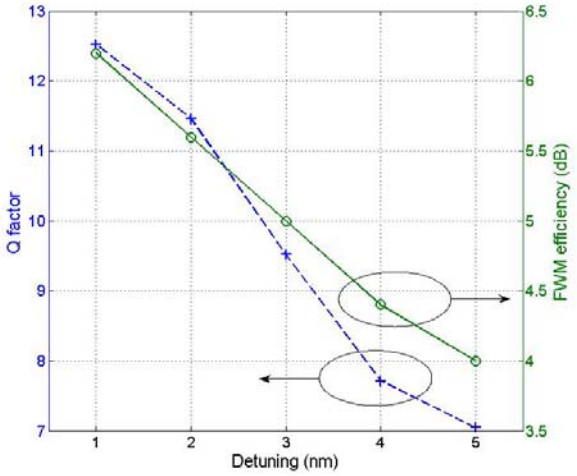

Fig. 7. Converted signal Q-factor and FWM efficiency vs. detuning range.

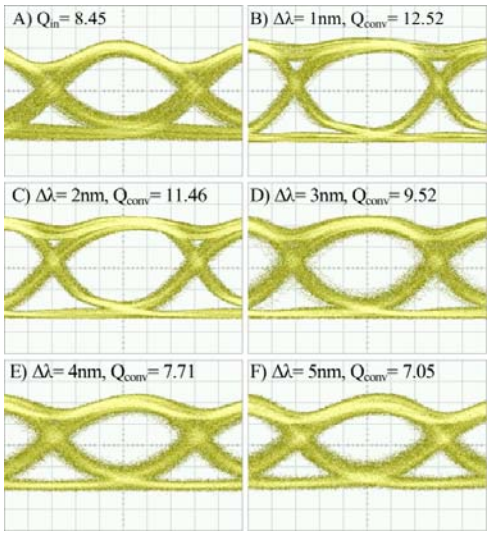

Fig. 8. Eye diagrams for: (A) input probe and (B-F) wavelength converted signals for various positive detunings. The horizontal scale is 8.3 ps/div.

Acknowledgement

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