Polarization Independent Dual Wavelength Converter Based on FWM in a Single Semiconductor Optical Amplifier

Cristiano M. Gallep[1,2], Oded Raz[1] and Harm J.S. Dorren[1]
1 COBRA Research Institute, Eindhoven University of Technology, Eindhoven, P.O. Box 513, NL-5600 MB, The Netherlands - O.Raz@tue.nl.
2 Division of Telecomm. Technology - FT, State University of Campinas, Limeira/SP, P.O. Box 6101, 13484-332, Brazil - gallep@ft.unicamp.br

Abstract: We present a FWM-based dual channel wavelength converter in an SOA with very small variations in conversion efficiency and a minor polarization related power penalty of 0.9dB between best and worst case of polarization states.

OCIS codes: (230.7405) Wavelength conversion devices; (250.5980) SOA; (190.4380) Nonlinear optics, FWM

1. Introduction

All optical wavelength converters (AOWCs) are likely to become key building blocks in future dynamic high-capacity optical networks [1]. Due to their integration potential and power efficiency, semiconductor optical amplifiers (SOAs) have attracted considerable interest as wavelength converters. Error-free wavelength conversion based on cross-gain and cross-phase modulation (XGM, XPM) in a single SOA has been demonstrated at up to 320 Gbps [2]. However, the use of XGM and XPM schemes imply that the same SOA cannot be used to convert signals of different modulation formats or speeds, as required additional manipulation of the signal are needed. Obviously such a solution will not support conversion of more than one channel simultaneously. Recently we demonstrate how by employing a single strong probe and a single SOA, penalty free conversion based on four-wave mixing (FWM) can be achieved for simultaneous two data channels employing different modulation techniques (PSK and ASK) with no noticeable performance variation between them [3], as well as for higher data rates up to 40+10Gb/s (ASK) with some penalty [4]. These demonstrations, however, relied on the accurate alignment of polarization of probe and pumps since the FWM process requires pump and probe signals to have the same polarization inside the active optical cavity.

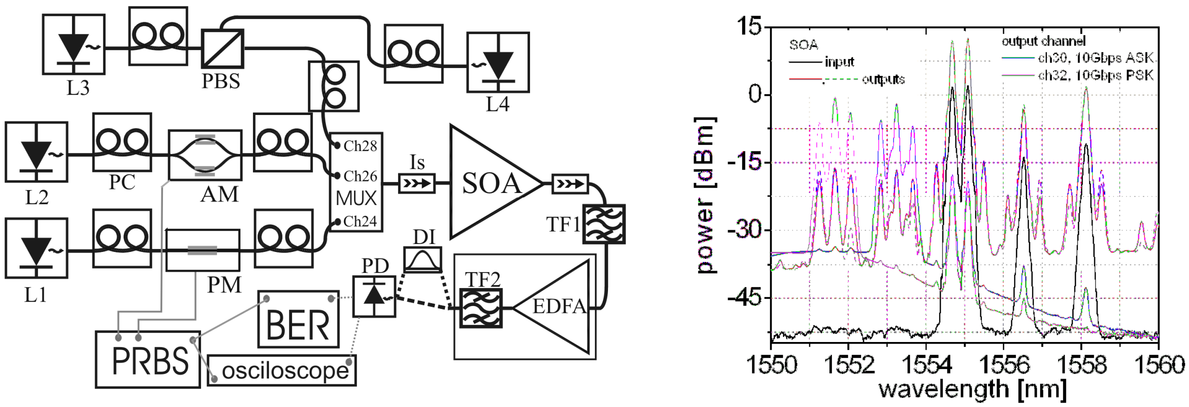
Some schemes proposed in the last decade, aimed to overcome the intrinsic polarization dependence of FWM parametric conversion method [5-8]. In most of these demonstrations only CW channels [5-7] were used. The use of dual orthogonal probes together with an input channel (pump) located at a longer wavelengths to produce a non-degenerated FWM as the converted product, was suggest in [5] but with very low efficiency of -30dB. A modified approach, using the input carrier as well as an output channel located between the two CW probes was also presented [6]. Another CW demonstration used a bi-directional propagation approach in a single-SOA inside a loop enclosing a polarization beam splitter (PBS), but again very low FWM efficiency was obtained [7]. The first experiments showing polarization insensitive FWM, including data over the channels, were shown by Lacey *et al.* [8], using two SOAs, each one performing FWM in a single optical polarization process, enabling 4 x 2.5Gbps conversion. Some OTDM demultiplexing schemes based on FWM in SOA also employed related techniques to minimize the polarization dependence, such as depolarization between pump and probes [9], co-polarized dual-pump (CW+clock) [10] and the already mentioned bi-directional approach, with the signal carrier laying in between the orthogonal CW probes [11].

In this paper we report on an optical polarization insensitive AOWC using two orthogonal CW probes and a single SOA. The CW probes are properly detuned in wavelength in order to avoid non-linear polarization rotation in the FWM components. At the same time multi-carrier output channels' inter beating must remain outside the photo receiver bandwidth. Good results were obtained for dual-channel, 10+10Gb/s (PSK+ASK), with total penalty lower than 3dB and polarization sensitivity below 0.9dB. Additionally we show that the same concept can be extended to support dual-channel with both channels employing ASK modulation format but with different bit rates (20+10Gb/s). Due to larger required OSNR for the 20Gb/s converted data signal the obtained maximum penalty of the 20Gb/s channel was 2.8dB for the 10Gb/s channel 5.5dB for, with polarization sensitivity <0.6dB.

2. Experimental setup, results and discussion

The experimental setup is presented in Fig.1(a). Each data carrier (lasers L1 and L2) passes in a polarization controller (PC) to optimize its modulator performance, with each channel modulated with PRBS 2^{31}-1 sequences and combined by a 100GHz WDM Multiplexer (MUX) with two CW probes (L3 and L4). These probes have equal power and are arranged in orthogonal polarization by passing through PCs and in a polarization beam-splitter (PBS). The combined signal is sent to the SOA, with optical isolators preventing multiple reflections. The PCs just after the modulators are used to change the relative polarization (mis)matching between the data channels and the CW carriers, and so compare the best and worst cases. The PC after the PBS is used to equalize the CW channels' gain in the SOA as well as their own degenerated FWM products' amplitudes.

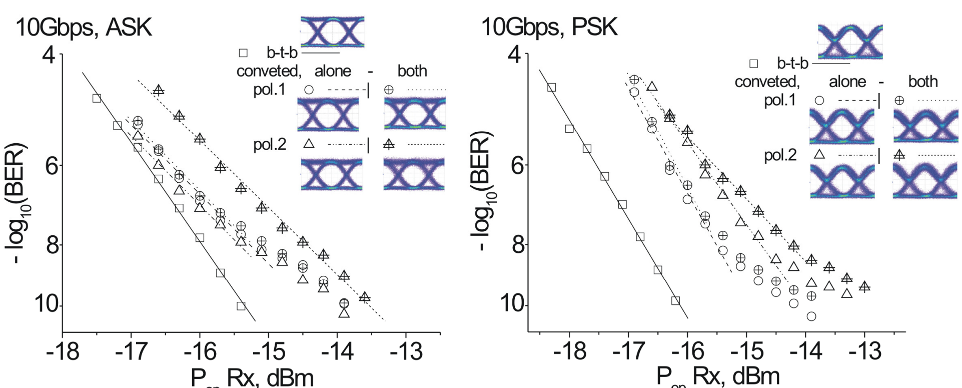
For the 10+10Gb/s test the CW probes were within the ITU-grid channel number 28 (1554.94nm), and are 0.4nm apart (λ_{L3}=1554.74nm, λ_{L4}=1555.14nm); the data channels are located at channel #26 (L2, ASK) and #24 (L1, PSK). Channels #25 and #27 cannot be used since some FWM products due the interactions of the two CW probes with the input data channels are contained within their bandwidth. With this input spectra arrangement the output (converted) channels fits channels. #30 (ASK) and #32 (PSK), and are extracted by a tunable filter (TF1, 0.9nm wideband). The spectra are plotted in Fig.1(b). Once filtered the signals are further amplified by a low noise EDFA amplifier with a gain of 10dB and a noise figure of 4dB and another tunable 1.5nm wide filter (TF2) is used to remove excessive ASE before reaching the photo-diode. The detected signal is connected to a Bit-Error Rate (BER) tester to measure the performance and to an oscilloscope to obtain the eye-diagrams. The PSK channel also passes a properly tuned delay-interferometer (DI) to convert the data into ASK format.



(a) (b)

Fig.1. Dual-channel polarization-robust AOWC: (a) the experimental setup and (b) optical spectra, for 10+10 Gb/s (ASK+PSK) operation.

Although the two detuned CW probes have orthogonal polarizations, some interaction between them still exists leading to FWM components on both sides of the probe signals (these signals are -30dB lower than the probes' power level). The degenerated FWM products due the interaction of each CW probe with each input channel and its replicas lead to a less then trivial spectral composition of the output channels spectra, each one with three adjacent carriers. The individual spectra contain the central (main) component, which is stable in power and two adjacent components who vary as the relative input optical polarization is changed. The small sub-peaks in the valleys in between the output ASK channels' 3 peaks (red and blue lines in Fig.1b) are due to ch.24 (PSK) FWM products, and so exclude the possibility of using the same wavelength scheme for ASK+ASK operation. The eye-diagrams and BER performance for the dual channel operation with 10+10Gb/s is shown in Fig.2, for the converted channels in the best and worst polarizations, alone or with the other carrier, as well as the back-to-back performance. The ASK output (Fig.2a) has maximum penalty of 1.5dB for the worst case, with polarization dependence between zero (single) and 0.9dB (dual channel). The PSK channel (Fig.2b) has maximum penalty of 2dB for the best case and 3dB for the worst, with minimum polarization dependence (respectively 0.3dB and 0.5dB), but presents an error-floor at 10^{-10}.



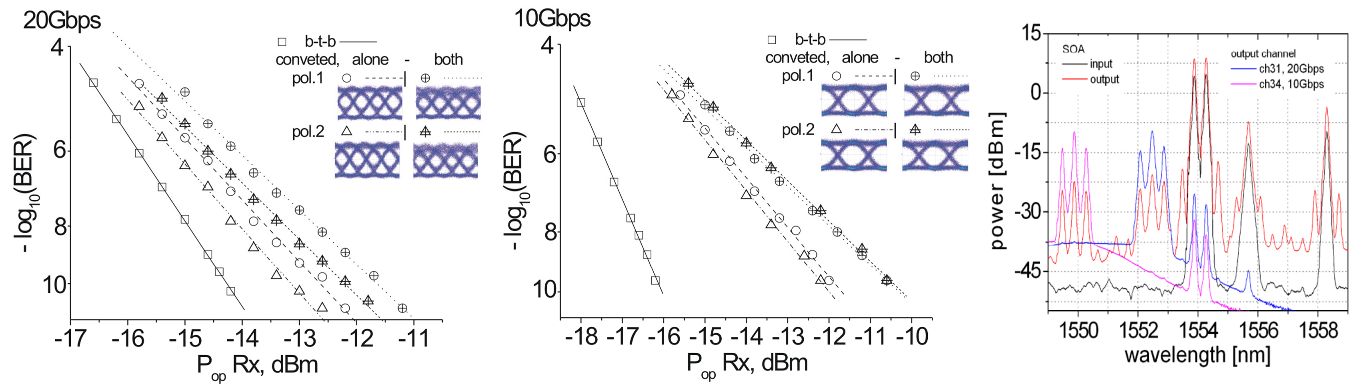
(a) (b)

Fig.2. BER curves and eye-diagrams (10Gbps) for dual channel conversion: (a) the ASK channel (b) the PSK channel.

OWP2.pdf

This floor can be related to power fluctuation and time jitter after the PSK-to-ASK conversion in the 10GHz delayed-interferometer. With its 3 sub-carriers 50GHz apart, the output channel has reasonable part of its energy slightly detuned from the optimum point in the DI transfer function, and so some pattern dependence appears.

The same setup (Fig.1a) was used to test the 20+10Gb/s, both channels in ASK. The same procedure was followed, but with the 20Gb/s input channel carrier (L2) located at ITU ch.27, the 10Gb/s (L1) at ch.24 and the CW probes in the ch.29 band, and so the converted channels filtered out in the ch.31 and ch.34 band, with the extra channel spacing needed to avoid some 2nd order FWM that in the previous channel spacing overlapped with ch.31's band. Fig.3 shows the eye diagrams and BER curves for the 20Gb/s (a) and 10Gb/s (b) channels and the optical spectra (c). The 20Gb/s and 10Gb/s channels have respectively maximum penalty of 2.8dB and 5.5dB for the worst polarization case, and polarization dependence respectively below 0.6dB and 0.2dB. The difference between single and dual-channel operation is larger (1.5dB) for the 10Gb/s channel in comparison with the 20Gb/s channel where it is bellow 1dB.



(a) (b) (c)

Fig.3. BER curves and eye-diagrams for dual channel conversion (ASK+ASK): (a) the 20G channel, (b) the 10G channel; (c) optical spectra.

3. Discussion and Conclusion

The proposed AOWC configuration, with a single SOA and orthogonal dual CW laser, can be used to convert simultaneously 10+10Gb/s (ASK+PSK) and 20+10Gb/s (ASK+ASK) with low input optical polarization sensitivity and reasonable power penalty. Since FWM generates new spectral components only in the presence of pumps and probes, the demonstrated converter is suitable for multiple simultaneous conversion schemes, as well as operation in an asynchronous fashion since conversion penalty is almost identical for single or dual inputs, without the need of input polarization optimization. The larger than expected penalty for the 10Gb/s data signal in the 2nd phase of the experiment was mainly due to the drop in conversion efficiency for the large detuning eventually chosen. However if we use similar bit rate signals (10+10Gb/s) with ASK modulation, the relative input powers of the close and far channels can be re-aligned to improve OSNR and lower the BER penalty of the 2nd converted channel. With no need for strict timing control of local CW source, an optional asynchronous operation as well as being modulation format agnostic [3] we believe this scheme for AOWC will find many suitable applications in all optical packet routers.

Acknowledgements

This work is supported by the Netherlands Science Foundation (NWO) and the Netherlands Technology Foundation (STW) through the NRC Photonics and Vi programs. This work was also partially supported by the EBW – Erasmus Mundus` *Euro-Brazilian Windows*.

4. References

[1] S. L. Danielsen *et al., J. Lightwave. Techn*, Vol. 16, pp.2095-2108, 1998.
[2] Y. Liu *et al*, proceedings of *OFC'06*, paper PDP28, 2006.
[3] O. Raz, C. M. Gallep, H.J.S. Dorren, *Proceedings of IEEE Photonics Society Annual Meeting*, paper WK2, 2009.
[4] C. M. Gallep, H.J.S. Dorren, O. Raz, submitted to Op. Express.
[5] Jopson *et al, Electronics Letters*, vol. 29, pp. 2216-2217, 1993.
[6] A. Mecozzi *et al*, *Appl. Phys. Lett*., Vol. 72, pp. 2651- 2653, 1998.
[7] G. Contestabile *et al*, *Appl. Phys. Lett.*, Vol. 75, pp. 3914-3916, 1999.
[8] J. P. R. Lacey, S. J. Madden and M. A. Summerfield, *IEEE Phot. Tech. Lett.,* Vol. 9, pp.1355-1357, 1997.
[9] T. Morioka *et al.,* proceedings of *OFC'96,* paper WH1, 1996.
[10] C. Porzi *et al.,*", *IEEE Phot. Tech. Lett*, Vol. 17, pp. 633-635, 2005.
[11] C. S. Wong, H. K. Tsang, Vol.. 15, pp.129-131, 2003.