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Polarity-preserving SOA-based wavelength conversion at 40 Gb/s using band-pass filtering

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All-optical wavelength conversion is demonstrated at 40 Gb/s, using a single SOA and a band pass filter. The scheme is very simple, requires an extremely low switching energy of ~ 3 fJ, and preserves data format and polarity.

Introduction: Introducing all-optical wavelength conversion (AOWC) capabilities in WDM network nodes may reduce cost and footprint by circumventing optical-electrical-optical (OEO) conversion, while adding the flexibility of wavelength routing. However, even the most promising integrated, semiconductor optical amplifier (SOA)-based wavelength converters, as e.g. the delayed-interference signal converter (DISC) [1], or Mach-Zehnder interferometer (MZIs) [2], rely on the control of at least two bias currents (SOA bias or phase tuning currents) for optimising the operating conditions. Moreover, to compensate for the inherently low input power dynamic range (IPDR) of these devices, an additional SOA is needed at the data signal input [2]. This adds up to at least three currents, which need to be tuned to accommodate changes of wavelengths, input signal quality, etc. In this letter we report on a very simple AOWC, based on a single SOA and an optical band-pass filter (BPF). The converter operates at 40 Gb/s, preserves the data polarity and RZ format, and does not introduce patterning effects. The single bias current allows for very simple control and stable operation, and in a recent report of a similar OAWC design [3], an open loop IPDR of 11 dB indicates that control of input power fluctuations may not be necessary. We find that the best performance of the AOWC is obtained for a data signal switching energy of only 3 fJ. To our knowledge, this is the lowest switching energy ever reported for polarity-preserving wavelength conversion at 40 Gb/s. The low optical power consumption may save the cost of an Erbium-doped fibre amplifier (EDFA) at the input of the AOWC.

Principle and experimental setup

The principle of operation of the wavelength converter can be understood from the experimental setup in Fig. 1: a gain-switched DFB laser (GS-DFB) emits a 10 GHz train of ~7 ps wide pulses at a wavelength of 1552 nm, which is then modulated with a PRB sequence of word-length 2^{31}-1 before being multiplexed to 40 Gb/s in a passive fibre-based interleaver. The 40 Gb/s RZ data signal is combined with a continuous wave (CW) probe at 1545.08 nm, and launched into the strained-bulk SOA, which is 1 mm long, biased at 300 mA, and has a large optical confinement factor of 0.6. Measured at the SOA input, after the 3 dB coupler, the data and probe average powers are –12.25 dBm (~ 3 fJ/data pulse) and –3.0 dBm, respectively. Inside the SOA the probe is cross-gain modulated (XGM) and thus polarity-inverted, as well as cross-phase modulated (XPM) by the data signal. The leading edge of the modulated probe is shifted towards lower frequencies (red-shifted), whereas the trailing edge is shifted towards higher frequencies (blue-shifted). Due to the low data-to-probe power ratio of –9.25 dB XGM is quite inefficient. This is not the case for XPM, however, and thus a significant broadening of the probe spectrum can be observed. At the output of the SOA, a tuneable grating filter with a bandwidth (FWHM) of 0.22 nm is centred at 1544.58 nm, i.e. detuned

0.5 nm to the blue side of the probe carrier wavelength. The filter selects the blue-shifted sideband of the probe, converting the phase modulation into amplitude modulation, while efficiently suppressing the CW carrier wavelength. Suppressing the carrier corresponds to suppressing the DC content of the polarity inverted probe waveform. As indicated in Fig. 1, this restores the non-inverted polarity of the converted signal, which is important for obtaining good transmission properties [4]. The wavelength converted signal is amplified in an EDFA, and demultiplexed into the four 10 Gb/s tributaries using an electro-absorption modulator (EAM), before bit error-rate (BER) measurements.

Similar schemes have been used to realise polarity-preserving wavelength conversion at bitrates up to 20 Gb/s [5]. Recently, a microelectromechanical system (MEMS) based filter was used to shape the probe output of a 2 mm long SOA in a 40 Gb/s experiment [3]. In that demonstration, the best BER performance for polarity-preserving operation was obtained for an average data input power of 2 dBm, measured at the SOA input. Analogous approaches have been taken to realise non-linear fibre based wavelength converters exploiting ultra-fast, but very power-inefficient, fibre non-linearities [6].

Experimental and modelling results:

The amount of spectral broadening induced by XPM is seen in Fig. 2 by comparing the probe spectra before filtering, with and without the data power turned on. Significant spectral broadening is introduced by the small average data power of –12.25 dBm, while the modulation of the gain is kept at a minimum. This reduces detrimental pattern effects, and consequently the scheme is expected to benefit from a large phase-gain coupling (α-parameter). Fig. 2 also shows the BPF characteristic, and the corresponding probe spectrum after filtering. The probe power after the filter is only -21 dBm, measured in a large optical bandwidth. A low output power is inherent to the scheme because most of the power is contained in the 'carrier peak'. However, using a filter with a steeper slope and higher peak-to-background rejection ratio, a smaller filter detuning would be required to sufficiently suppress the carrier, thus increasing the transmitted power.

Extensive modelling, using a detailed multi-section SOA model, has been carried out to compare with experimental results. The physical input parameters to the model: SOA dimensions, optical confinement factor, bias current, input powers, filter shape, etc., are identical to the experimental parameters. Fig. 3 shows a comparison between experimental (left column), and simulated (right column) eye diagrams of the converted signal. The upper, middle, and bottom rows correspond to filter detunings of –0.5, -0.3 nm, and 0 nm, respectively. As observed, the agreement is very good, qualitatively, as well as quantitatively. For the optimum filter detuning of –0.5 nm, the extinction ratio is ~15 dB, and the data polarity and the RZ format is clearly preserved. Fig. 4 shows the BER performance of all four 10 Gb/s tributaries of the input data signal at 1552 nm and the wavelength converted signal at 1545 nm. The power penalty at BER = 10^{-9} ranges between 1.7 and 2.8 dB for the best and worst tributary, respectively, and is believed to be primarily due to ASE noise added by the EDFA after the filter. The fast response of the converter is clear from Fig. 5, which compares a part of the input data pattern to the pattern of the wavelength converted signal. The only observable difference is the pulse width, which has increased to ~15 ps, measured with a 50 GHz photo diode.

Conclusion

In this letter we have demonstrated a very simple all-optical wavelength converter based on a single 1 mm long SOA and a band pass filter. The converter operates at 40 Gb/s, and preserves the RZ data format and polarity, using only ~ 3 fJ of switching energy per data pulse.

References

[1] Leuthold, J., Mikkelsen, B., Raybon, G., Joyner, C. H., Pleumeekers, J. L., Miller, B. I, Dreyer, K, and Behringer, R., ’All-optical wavelength conversion between 10 and 100 Gb/s with SOA delayed-interference configuration’, Optical and Quantum Electron., 2001, 33, pp. 939-952

[2] Dagens, B., Labrousse, A., Fabre, S., Martin, B., Squedin, S., Lavigne, B., Brenot, R., Nielsen, M. L., and Renaud, M.: ‘New Modular SOA-based active-passive integrated Mach-Zehnder interferometer and first standard-mode 40 Gb/s all-optical wavelength conversion on the C-band’, Proc. ECOC ’02, paper PD3.1

[3] Leuthold, J., Marom, D., Cabot, S., Ryf, R., Bernasconi, P., Baumann, F., Jaques, J., Neilson, D. T., Giles, C. R.: ‘All-Optical Wavelength Converter Based on a Pulse Reformatting Optical Filter’, Techn. Digest OFC ’03, Atlanta, USA, paper PD41.

[4] Durhuus, T., Mikkelsen, B., Joergensen, C., Danielsen, S.L, and Stubkjaer, K.E: ’ All-optical wavelength conversion by semiconductor optical amplifiers’, J. Lightwave Techn., 1996, 14 (6), pp. 942-956

[5] Patrick, D. M., and Manning, R. J. :’20 Gbit/s wavelength conversion using semiconductor nonlinearity’, Electron. Lett., 1994, 30 (3), pp. 252-253

[6] Olsson, B-. E, Oehlen, P., Rau, L., and Blumenthal, D.: ‘A simple and Robust 40 Gb/s Wavelength Converter Using Fiber Cross-Phase Modulation and Optical Filtering’, Photonics Technol. Lett., 2000, 12 (7), pp. 846-848.

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Figure captions:

Fig. 1. Experimental setup for 40 Gb/s wavelength conversion

Fig. 2. Optical probe spectra and filter shape (resolution: 0.07 nm).

Thin, dashed: before BPF, data power off

Thick, solid: before BPF, data power on (-12.25 dBm)

Thin, solid: after BPF

Thick, dashed: BPF characteristic

Fig 3.

Experimental (left column) and simulated (right column) 40 Gb/s eye diagrams of converted signal.

Filter detuning: a. –0.5 nm, b. –0.3 nm, c. 0 nm

Fig. 4.

BER curves for 4x10 Gb/s tributaries of back-to-back and wavelength converted signals.

Solid symbols: back-to-back at 1552 nm; hollow symbols: wavelength converted at 1545 nm.

Fig. 5. 40 Gb/s data patterns. Up: input at 1552 nm. Down: output at 1545 nm

Figure 1.

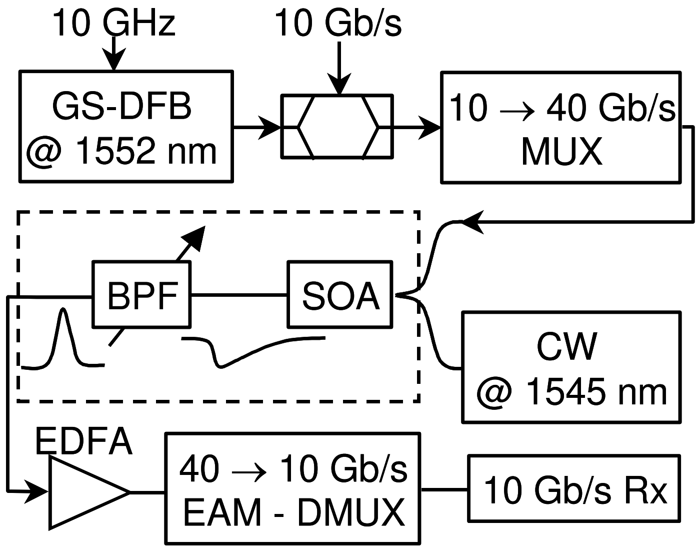
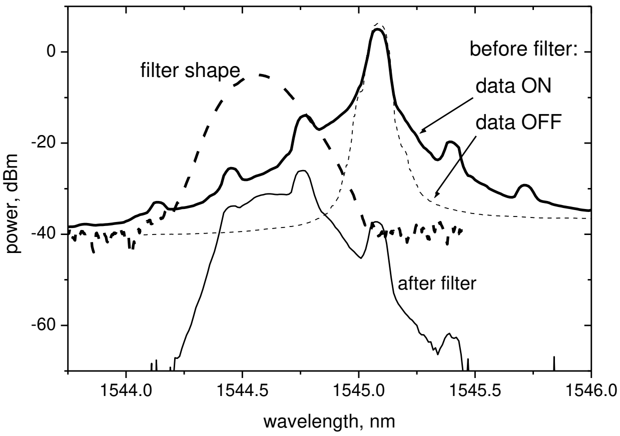

10 GHz
10 Gb/s
GS-DFB
@ 1552 nm
10 → 40 Gb/s
MUX
BPF
SOA
CW
@ 1545 nm
EDFA
40 → 10 Gb/s
EAM - DMUX
10 Gb/s Rx

Figure 2



filter shape
before filter:
data ON
data OFF
after filter
power, dBm
0
-20
-40
-60
1544.0
1544.5
1545.0
1545.5
1546.0
wavelength, nm

Figure 3

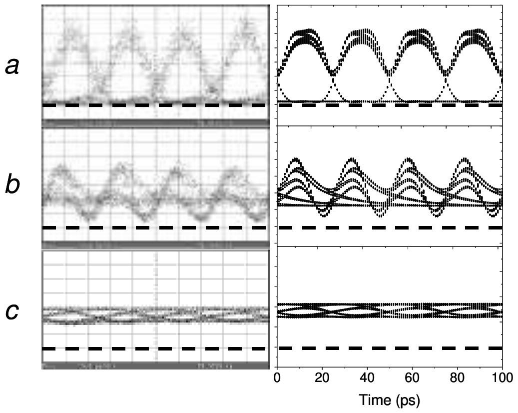


Figure 4.

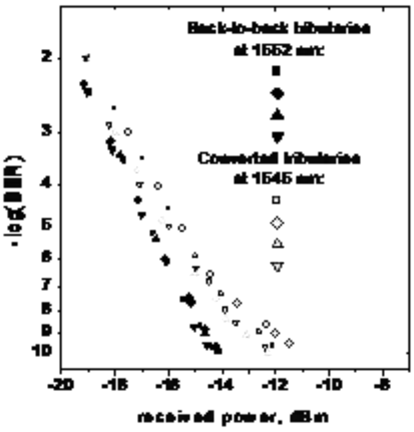
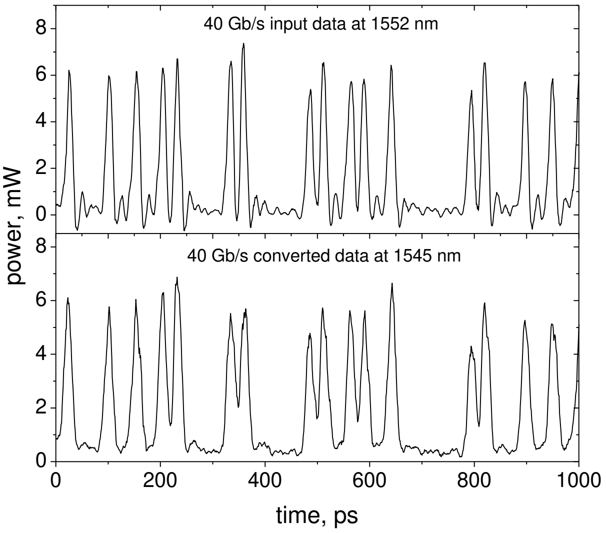

Back-to-back tributaries
at 1552 nm:
■
◆
▲
▼
Converted tributaries
at 1545 nm:
□
◇
△
▽
-log(BER)
2
3
4
5
6
7
8
9
10
-20
-18
-16
-14
-12
-10
-8
received power, dBm

Figure 5.


40 Gb/s input data at 1552 nm
40 Gb/s converted data at 1545 nm
power, mW
time, ps
0
2
4
6
8
0
2
4
6
8
0
200
400
600
800
1000