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All-optical 1310 to 1550 nm wavelength conversion by utilising nonlinear polarisation rotation in semiconductor optical amplifier

J.P. Turkiewicz, G.D. Khoe and H. de Waardt

A 1310 to 1550 nm wavelength converter based on nonlinear polarisation rotation in a single semiconductor optical amplifier is demonstrated. Error-free 1310 to 1550 nm wavelength conversion is shown at 20 Gbit/s.

Introduction: One of the key components in all-optical communication networks using the whole low-loss bandwidth of the silica fibre is an ultra-wideband wavelength converter [1]. Use of all-optical ultra-wideband wavelength converters enhances network flexibility, allowing an all-optical wavelength conversion between different transmission windows, and therefore avoiding the bottleneck of optical-electrical-optical conversion. This will become of particular importance at the network nodes interfacing metro-access systems employing the whole low-loss bandwidth of the silica fibre, and the core network traditionally centred in a 1550 nm window. A number of metro-access schemes utilising simultaneously 1310 and 1550 nm transmission windows have been proposed, e.g. [2, 3]. Ultra-wideband wavelength converters applied in metro-access systems have to deliver high performance while remaining cost-effective. A cost-effective alternative to 1310 to 1550 nm wavelength converters based on expensive LiNbO₃ waveguides [4], are wavelength converters employing semiconductor optical amplifiers (SOAs). Previously demonstrated SOA-based 1310 to 1550 nm wavelength converters which were based on a split contact SOA [5] and a distributed feedback SOA [6] operated at bit rate below 1 Gbit/s. The highest reported, 1.25 Gbit/s error-free 1310 to 1550 nm wavelength conversion was achieved with an SOA operating in Mach-Zehnder interferometer (MZI) configuration [1]. However, a complicated control mechanism is required and the bit rate is limited to below 2 Gbit/s.

In this Letter, we report a novel all-optical 1310 to 1550 nm wavelength converter based on nonlinear polarisation rotation in an SOA. We demonstrate that error-free wavelength conversion from 1310 to 1550 nm can be realised at bit rate 20 Gbit/s by using a single SOA. The nonlinear polarisation rotation in the SOA had been applied previously for demultiplexing [7] or in-band wavelength conversion [8]. However, nonlinear polarisation rotation in the transparency region of the SOA has not been reported.

Fig. 1 Schematic diagram of experimental setup

Setup and principle of operation: Fig. 1 shows a schematic diagram of the experimental setup for the all-optical 1310 to 1550 nm wavelength conversion. An intensity modulated non-return-to-zero (NRZ) signal at 1310 nm enters the wavelength converter through a polarisation controller (PC1). Next, the 1310 nm NRZ signal passes through a 1310/1550 nm wideband coupler (WC1) and finally enters a 1310 nm SOA. The PC1 is adjusted to achieve the optimum wavelength conversion performance. The multi-quantum well SOA employed (produced by Philips, The Netherlands) has an active area with a length of 800 μm . A 1550 nm continuous-wave (CW) signal passes through a second wideband coupler (WC2) and is fed into the 1310 nm SOA. The polarisation of a 1550 nm CW light is adjusted by polarisation controller (PC2) to be approximately 45° to the orientation of the SOA polarisation axes. The 1310 nm SOA is employed in a bidirectional configuration and the 1550 nm signal travels through the

1310 nm SOA in the opposite direction to the 1310 nm NRZ signal. The presence of the WC2 is not essential for the operation of the wavelength converter, and the CW light at 1550 nm coming from the PC2 can be directly fed into the 1310 nm SOA. During experiments we used the 1310 nm output of the WC2 for monitoring purposes. The SOA is generally a birefringent device [9]. The injected 1310 nm light introduces additional birefringence in the SOA via carrier density changes [9, 10]. This causes the transverse magnetic (TM) and the transverse electric (TE) modes of the signals travelling through the 1310 nm SOA to experience a different refractive index, also in the transparency region of the SOA. Therefore, the 1550 nm signal at the SOA output has a changed state of polarisation with respect to a 1550 nm signal without any 1310 nm signal present. After passing through the SOA, the 1550 nm signal is separated from the 1310 nm signal in the WC1 and enters a polarisation filter formed by a polarisation beam splitter (PBS) and a polarisation controller (PC3). The PBS has an extinction ratio better than 20 dB. The PC3 is adjusted in such a way that the 1550 nm signal with the rotated polarisation passes through the PBS. After passing through the PBS, the 1550 nm signal enters a preamplified receiver and the bit error rate (BER) tester. The preamplified receiver consists of a variable attenuator (ATT), an erbium-doped fibre amplifier (EDFA), bandpass filter (BPA) and a 20 Gbit/s data receiver.

Experiments and results: A 19.9066 Gbit/s NRZ signal was generated by modulating a CW signal at 1310 nm in an external Mach-Zehnder modulator with the pseudorandom bit sequence (PRBS) of length $2^{31} - 1$. The average power of the input NRZ 1310 nm signal was set to 5.3 dBm, while the power of the 1550 nm laser CW was set to 7.0 dBm. The 1310 nm SOA driving current was set to 400 mA. Fig. 2 presents optical spectra measured at the 1550 nm output (A in Fig. 1) and 1310 nm output (B in Fig. 1) of the SOA; to perform measurements an additional 3 dB coupler was inserted at the given points. It can be seen that no amplified spontaneous emission (ASE) noise is added to the 1550 nm signal. Because of reflections in the SOA, some of the 1310 nm data signal is also present at the 1550 nm output. These unwanted reflections may reduce available gain and therefore reduce the refractive index changes. The 1550 nm signal experiences high attenuation in the 1310 nm SOA. We measured the SOA attenuation at 1550 nm to be 13 dB at 0 mA SOA current and 20 dB at 400 mA SOA current. This high attenuation value is due to fibre-SOA coupling loss, waveguide scattering and free-carrier absorption. The losses in the 1310 nm SOA can be compensated by applying a 1550 nm CW laser with high output power or by 1550 nm signal amplification after the wavelength converter.

Fig. 2 Optical spectra at outputs of 1310 nm SOA

We investigated the performance of the proposed wavelength converter by measuring BER. Fig. 3a shows the BER curves for a converted and a reference back-to-back signal against measured optical power before a preamplifying EDFA. As a reference we used an optimised 1550 nm NRZ signal generated in the external Mach-Zehnder modulator. The power penalty for the conversion at BER 10^{-9} is 3.8 dB and no BER error floor is observed. Additionally, we verified the wavelength conversion penalty (BER 10^{-9}) at 10 Gbit/s to be as small as 1.7 dB in the same wavelength converter configuration. We attribute these penalties to the pattern effects in the 1310 nm SOA. Figs. 3b and c present 20 Gbit/s eye diagrams captured using a 50 GHz communications analyser. The eye diagram for the converted 1550 nm signal (Fig. 3c) shows clear open eye and indicates excellent operation of the wavelength converter. Some asymmetry in the eye diagram due to the

pattern effects caused by the slow carrier recovery of the SOA can be observed.

Fig. 3 Results of 20 Gbit/s measurements; PRBS $2^{31} - 1$

a BER curves b Input 1310 nm eye diagram
c Output 1550 nm eye diagram

Conclusion: We have demonstrated a novel all-optical 1310 to 1550 nm wavelength converter based on nonlinear polarisation rotation in a single SOA. Error-free 1310 to 1550 nm wavelength conversion at 20 Gbit/s is shown for the first time. The proposed wavelength converter operates at high bit rate, requires moderate input powers, and remains cost-effective, which makes it applicable for interfacing metro-access systems and the core network. The presented wavelength converter concept can be used in principle for any wavelength up-conversion from the gain region of the SOA, making it interesting for applications in networks utilising the whole low-loss bandwidth of silica fibre.

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References

- 1 Lacey, J.P.R., Pendock, G.J., and Tucker, R.S.: 'All-optical 1300 nm to 1550 nm wavelength conversion using cross-phase modulation in a semiconductor optical amplifier', *IEEE Photonics Technol. Lett.*, 1996, **8**, (7), pp. 885–887
- 2 Giles, C.R., *et al.*: 'Single-fiber access PON using downstream 1550 nm WDM routing and upstream 1300 nm power combining through a fibre-grating router'. Proc. 22th European Conf. on Optical Communication (ECOC 1996), Oslo, September 1996, Paper WeB.1.4
- 3 Thiele, H.J., Nelson, L.E., and Das, S.K.: 'Capacity-enhanced coarse WDM transmission using 10 Gbit/s sources and DWDM overlay', *Electron. Lett.*, 2003, **39**, (17), pp. 1264–1265
- 4 Xu, C.Q., Okayama, H., and Kawahara, M.: 'Wavelength conversion between the two silica loss windows at 1.31 and 1.55 μm using difference frequency generation', *Electron. Lett.*, 1994, **30**, (25), pp. 2168–2169
- 5 Barnsley, P.E., and Fiddymont, P.J.: 'Wavelength conversion from 1.3 to 1.55 μm using split contact optical amplifiers', *IEEE Photonics Technol. Lett.*, 1995, **3**, (3), pp. 256–258
- 6 Maywar, D.N., Nakano, Y., and Agrawal, G.P.: '1.31-to-1.55 μm wavelength conversion by optically pumping a distributed feedback amplifier', *IEEE Photonics Technol. Lett.*, 2000, **12**, (7), pp. 858–860
- 7 Patrick, D.M., *et al.*: 'Demultiplexing using polarisation rotation in a semiconductor laser amplifier', *Electron. Lett.*, 1994, **30**, (4), pp. 341–342
- 8 Stephens, M.F.C., *et al.*: 'Demonstration of ultrafast all-optical wavelength conversion utilizing birefringence in semiconductor optical amplifier', *IEEE Photonics Technol. Lett.*, 1997, **9**, (4), pp. 449–451
- 9 Manning, R.J., *et al.*: 'Experimental measurement of nonlinear polarisation rotation in semiconductor optical amplifiers', *Electron. Lett.*, 2001, **37**, (4), pp. 231–229
- 10 Dorren, H.J.S., *et al.*: 'Nonlinear polarization rotation in semiconductor optical amplifiers: theory and application to all-optical flip-flop memories', *IEEE J. Quantum Electron.*, 2003, **39**, (1), pp. 141–147