All-optical logic gates using semiconductor optical amplifier assisted by optical filter


A simple all-optical logic device, composed of an SOA and an optical filter, is proposed. By utilising optical filtering, multi-logic functions (AND, OR and XOR) are demonstrated at 10 Gbit/s using the same setup, under different operation conditions. Simulations indicate that the device can operate at much higher bit rate.

Introduction: All-optical logic gates have received considerable attention in the field of optical networks [1]; they can enable many advanced functions [1, 2]. Many approaches have been proposed to achieve all-optical logic functions, based on the nonlinear effects either in optical fibre or in semiconductor material. Compared with their optical-fibre based counterparts, all-optical logic gates based on semiconductor optical amplifiers (SOAs) are promising due to their power efficiency and potential for photonic integration [1]. Most SOA-based optical logic gates employ interferometric structures requiring several SOAs and complicating the system [1, 3]. Logic gates based on four-wave mixing in SOAs [4] suffer from low conversion efficiency and polarisation dependence.

We propose a simple and polarisation-independent logic gate composed of a single SOA followed by an optical bandpass filter (BPF). We achieve various logic functions with the same setup under different operation conditions. Two pulsed control signals and a continuous wave (CW) probe are injected into the SOA, leading to a broadened probe spectrum owing to carrier density modulation by the control signals. We explain how different logic functions can be realised by filtering the spectrally broadened probe light. We demonstrate AND, OR and XOR logic functions at 10 Gbit/s. Our results agree with the numerical simulations, which show that higher bit rate operation should be possible.

The proposed logic gate structure is shown in the dashed box in Fig. 1a. Two modulated optical return-to-zero (RZ) control signals (data 1, data 2), combined with a CW probe, are injected into the SOA. The control signals might be at different wavelengths but this is not essential. However, the control and probe signals should be at different wavelengths. Due to cross-gain (XGM) and cross-phase modulation (XPM), the falling (rising) edge of the inverted probe signal is red-(blue-)shifted [5]. Hence, the probe spectrum is broadened, as in Fig. 1b, where the BPF shape is shown by the dashed curve. Since the control pulses introduce spectral blue-shift for the probe light, a BPF can be used to reject the central wavelength of the probe light and select the blue-shifted spectrum, so that the probe can only pass through the BPF when the control signal is present. Based on this principle, non-inverted all-optical wavelength conversion at 40 Gbit/s has been demonstrated [6]. The magnitude of the induced blue-shift can be controlled by the individual powers of the input signals. By controlling the power levels and the filter detuning (Δl) in Fig. 1b, different logic functions can be realised.

If control pulses are launched simultaneously at data 1 and data 2, the modulated probe will receive a much stronger spectral blue-shift compared to where only one pulse is present, either in data 1 or data 2, since the SOA works in deeper saturation. The BPF can be used to select this stronger blue-shift while rejecting the weaker blue-shift. Thus, at the output of the BPF, a pulse from the probe will be generated in the presence of control pulses in data 1 and data 2 simultaneously, resulting in an AND gate.

Similarly, the BPF can be adjusted to select the weaker blue-shift and reject the stronger blue-shift. At the output, a pulse from the probe will be generated only when one control pulse appears, resulting in an XOR gate.

When the SOA operates in strong-saturation, the difference in the amount of blue-shift, induced by two simultaneous control pulses or a single control pulse, is small. Both induced blue-shifts can fit in the passband of the BPF resulting in an OR gate.

A rate equation model [5] is employed to simulate the logic functions at a data rate of 10 Gbit/s. Figs. 1c–g using a Gaussian filter of 15 GHz full-width-at-half-maximum (FWHM). The SOA has a carrier lifetime of 200 ps and a linewidth enhancement factor of 6.

Experiment and results: The experimental setup shown in Fig. 2 was constructed using commercially available fibre-pigtailed components. A 10 Gbit/s data stream with 2.3 ps (FWHM) optical pulses, generated by an actively modelocked fibre ring laser, is modulated by an external modulator at 10 Gbit/s to form a 2^7–1 RZ pseudorandom binary sequence (PRBS). The centre wavelength of the data signal is 1549.98 nm. This is then divided into two control channels (data 1 and data 2). Data 2 is delayed by propagating through 2 km of dispersion-shifted fibre to remove the coherence between the two channels. They are then combined, amplified and injected into the optical logic gate with a CW probe. All the couplers used are 3 dB. The attenuators are adjusted to equalise the average powers in data 1 and data 2 are before the SOA. The variable delay is adjusted to synchronise data 1 and data 2. The optical logic is composed of an SOA and a 0.3 nm (FWHM) BPF, centred at 1560 nm. After the optical filter, the signal is amplified by another EDFA before being monitored by an oscilloscope with a specified electrical bandwidth of 50 GHz. The SOA (manufactured by JDS Uniphase) is pumped with a 50 W semiconductor laser. The gain recovery time of the SOA is approximately 150 ps. Note that, in the experiment, we tune the wavelength of the probe to adjust the detuning of the filter (Δl). This detuning attenuates the output power and the attenuation in the experiment is more than 15 dB.

Fig. 3 shows the experimental results. Two input control channels are shown in Figs. 3a and b. The AND (OR, XOR) gate operations are presented in Fig. 3c (d, e), where the input powers of the probe are 1.12
(0.64, 1.06) mW, the powers of both control channels are 0.65 (1.13, 0.27) mW and the filter detunings are 1.82 (0.54, 1.52) nm respectively. We did not observe patterning effect in the experiment. We observed some small residual pulses in the AND and XOR gates output which ideally should not appear. However, this could be improved by optimising the filter transfer function. In Fig. 3 the zero levels of the output signals are not precisely at the ground level. This is due to the fact that the slope of the optical bandpass filter in the experiment is about 0.4 dB/GHz, which is not steep enough to reject the centre part of the probe spectrum. The zero levels can reach the ground level if the filter slope is steeper than 0.6 dB/GHz. This is also experimentally confirmed [6].

Conclusion: A simple optical logic device is proposed and demonstrated at 10 Gbit/s. We explain how this system can realise AND, OR and XOR gate functions based on the same setup but with different operating conditions. The proposed logic gate has a very simple structure and allows photonic integration.

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References