Comparison of All-Optical XOR Gates at 42.6Gbit/s

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Abstract *We report for the first time the 42.6Gbit/s bit-error rate performance of two types of all-optical XOR gates based on semiconductor optical amplifiers. We compare a hybrid integrated Mach-Zehnder interferometer with a dual UNI arrangement.*

Introduction

All-optical logic devices have many applications in high-speed optical time-division multiplexing (OTDM) systems. A number of logic devices have been developed which exploit the nonlinearity of semiconductor optical amplifiers (SOAs). In order to cancel the slow (0.1-1.0ns) tail of the SOA transient response, variants on the 'push-pull' technique are widely used that create switching windows which are much shorter than the recovery time of the SOA. This technique is used in several different types of Mach-Zehnder interferometer (MZI), such as the planar silica hybrid integrated MZI [1], which has an SOA in each interferometer arm, and the ultra-fast nonlinear interferometer (UNI) [2], which has one SOA only.

Two types of high bit-rate all-optical XOR gates in push-pull configuration have been reported, one based on a silica hybrid integrated MZI manufactured by CIP [3], and one using a UNI-based structure [4]. The latter scheme, the dual UNI XOR gate (DUX), has been demonstrated at both 40 and 80Gbit/s [4,5]. Previously, operation of these gates was confirmed only by oscilloscope traces and eye diagrams. Here we present for the first time error-free bit-error-rate (BER) measurements at 42.6Gbit/s on both types of XOR gate.

Hybrid Integrated MZI XOR Experimental Setup

The demonstration of XOR operation requires two separate data (control) channels. To obtain these, we used a single 10.65GHz mode-locked pulse laser source delivering 3ps pulses at 1550nm. This data pulse stream was modulated by a $LiNbO_3$ modulator driven by a pattern generator with a 2^7-1 pseudo-random bit sequence (PRBS). The pulses were then passively multiplexed to form 42.6Gbit/s pulse source. Separate data streams A and B were formed by passing this data through a 50:50 splitter and then time-delaying one stream by a few bit periods with respect to the other. The same data pulse streams were used to test both the hybrid integrated MZI and DUX schemes.

The operation principle of the hybrid integrated MZI XOR gate has been reported previously [1] and the experimental setup is shown in Fig. 1.

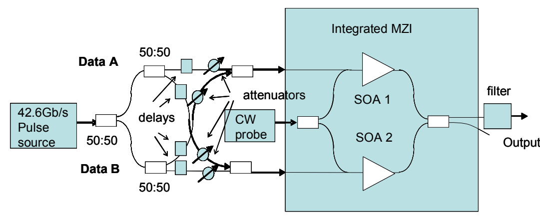

Fig. 1 Experimental setup for the hybrid integrated MZI XOR gate.

The data streams A and B were both further divided into push and pull pulse streams. For both A and B, the relative delay between the push and the pull streams, which defines the switching window, was set to 6ps. Push A was then coupled with pull B, and push B with pull A, and both combined signals were input into the control inputs of the hybrid integrated MZI (Fig. 1), The bias current for both SOAs was 390mA and the power of the input probe CW beam was 4.5dBm at 1563nm. The output of the gate passed through a band-pass filter to remove the control data streams. The average push and pull input powers for data A were 3.5dBm and 1.6dBm respectively, and for B they were 2.5dBm and 0.8dBm, which implies the control pulse energies were between 60fJ and 112fJ.

DUX Experimental Setup

The DUX gate is an extension of the UNI and its operation has been explained previously [2]. The experimental setup is shown in Fig. 2.

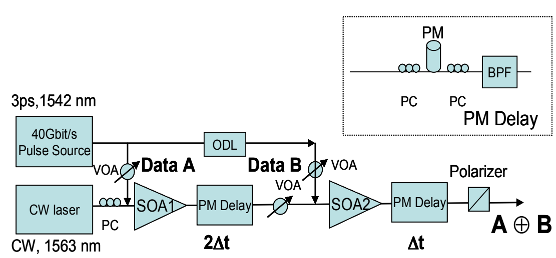

Fig. 2 Experimental setup of the DUX gate. Details of the PM delays shown in insert. PC: polarisation controller, PM: PM fibre, BPF: band-pass filter, VOA: variable optical attenuator, ODL: optical delay-line.

The control pulse wavelength was set at 1542nm and two variable optical attenuators (VOAs) were employed to set the control pulse energies coupled to each SOA. Two Kamelian SOAs were used, both biased at 400mA. A continuous wave (CW) beam with a wavelength of 1563nm was used as the probe. Band-pass filters (BPFs) were used after each SOA to block the control pulses and allow the onward propagation of the probe. A VOA placed between the SOAs was used to adjust the proportion of the probe beam injected into SOA2. The optimum average powers of the probe beam were found to be -3dBm at the input to SOA1 and 2dBm at the input to SOA2, and the average powers of control pulses were 1dBm and 2dBm respectively. This implies that the control pulse energies were 62fJ and 78fJ per pulse. The differential delays of the first and second polarisation-maintaining (PM) fibres were 23ps (1 bit period) and 11.5ps (1/2 bit period) respectively. The polarisation controllers (PCs) in front of the PM fibres were adjusted to ensure that the polarisation of the probe beam was at about 45^0 with respect to the PM fibre axes in order to equalise the amplitude of the TE and TM components propagating in the fibre. The polarisation state of the probe was also adjusted at the inputs to the SOAs in order to ensure that it was linear and aligned with one of the axes of the SOA active layer. This avoided unwanted polarisation rotation in the SOAs in response to the control pulses.

Experimental results

The outputs of both XOR gates were monitored on a 70GHz oscilloscope in order to optimise the output eye diagrams and check correct operation of the XOR logic function. BER measurements are plotted for the hybrid integrated MZI gate in Fig. 3, together with the results for each data input separately (AND function). Error-free operation was obtained in each case.

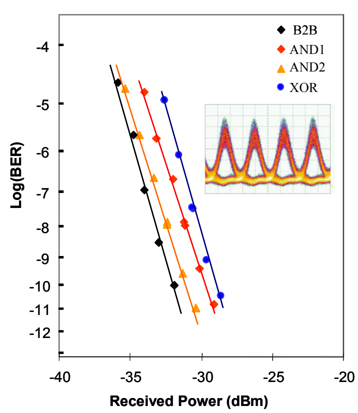

Fig. 3 Hybrid integrated XOR gate BER at 42.6Gbit/s with corresponding eye diagram (insert). Also shown, BERs for A and B separately (AND1 and AND2) and back-to-back measurement (B2B).

The power penalty of the XOR output compared with the back-to-back signal was 3dB at a BER of 10^{-9}.

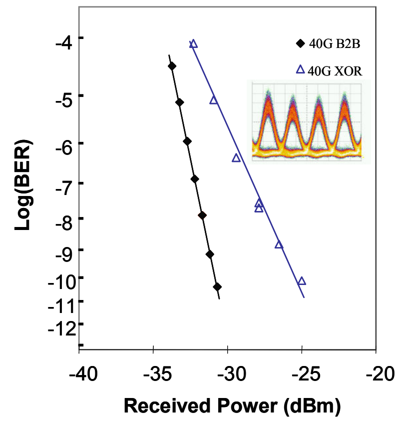

Fig. 4 BER for the DUX gate at 42.6Gbit/s with corresponding eye diagram (insert).

Similarly, BER measurements of the DUX are plotted in Fig. 4. Error-free XOR operation was again observed, but with a larger power penalty of 5dB at 10^{-9} BER.

The hybrid integrated MZI gate was found to be much more stable than the DUX configuration which incorporates two lengths of PM fibre. In both cases, error-free operation was obtained and no error-floor was observed. The difference in power penalties for the two gates is attributed to the different switching windows, 6ps for the hybrid integrated MZI and 11.5ps for the DUX, giving a better OSNR for the hybrid integrated MZI. In the light of this, there appears to be little fundamental difference in performance between the two gates.

Conclusions

We report for the first time BER measurements at 42.6Gbit/s on two types of all-optical XOR gate. The measurements show error-free operation and 3dB and 5dB power penalties for the hybrid integrated MZI and the DUX configuration respectively.

Acknowledgement

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