All-optical AND gate with improved extinction ratio using signal induced nonlinearities in a bulk semiconductor optical amplifier

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Abstract: An all-optical AND gate based on optically induced nonlinear polarization rotation of a probe light in a bulk semiconductor optical amplifier is realized at a bit rate of 2.5Gbit/s. By operating the AND gate in an up and inverted wavelength conversion scheme, the extinction ratio is improved by 8dB compared with previously published work.

OCIS codes: (200.4660) optical logic; (250.5980) semiconductor optical amplifiers.

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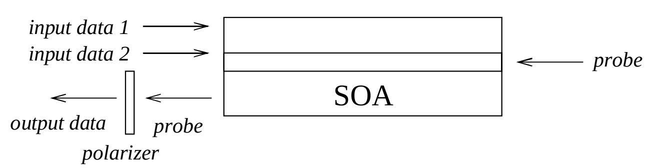
1. Introduction

The semiconductor optical amplifier (SOA), utilized as an active nonlinear optical medium, has demonstrated its feasibilities in all-optical functional applications, such as optical switching, wavelength conversion, pulse generation and optical logic gate Ref. [1]. Cross polarization modulation (XPolM), which is based on optically-induced anisotropy in the SOA, is a promising approach to wavelength conversion Ref. [2-4], and has been applied in the design of all-optical logic gate Ref. [5, 6]. In this paper, we report an optical AND gate with improved extinction ratio by utilizing XPolM in a bulk SOA in an up and inverted wavelength conversion scheme.

2. Principle of operation

The AND gate is based on a wavelength conversion scheme Ref. [3], which is realized by nonlinear polarization rotation due to optically-induced refractive index nonlinearities in a bulk SOA. During the operation, intense pump lights modify the optical properties of the SOA which, in turn, modify a probe light or even the pump lights themselves Ref. [7]. One significant consequence of this pump-probe technique is that the polarization azimuth and the ellipticity angle of the probe are expected to change on propagation through the medium Ref. [8]. If a linearly polarized probe light is coupled into the SOA, upon leaving the SOA, its polarization ellipticity could be elliptical, circular or linear with rotated azimuth depending on the power level of the pump lights in the SOA. An optical polarizer at the SOA output can virtually detect this nonlinear polarization rotation and convert the phase difference into intensity difference. In this sense, one can obtain a logic function because these intensity variations depend on the presence or absence of the pump lights in the SOA. The schematic operation is depicted in Fig. 1, along with truth table. The optical AND gate is carried out by a weak probe beam in a counter-propagation scheme. During the operation, the absence of both data 1 and 2 does not change the state of polarization (SOP) of the probe. One data alone does not change the SOP of the probe dramatically, and this small change cannot be detected by the polarizer right after the SOA output. When both data 1 and 2 are present in the SOA, strong refractive index nonlinearities are induced. Thus the polarization azimuth and the ellipticity angle of the probe are modified, and the polarizer can convert these SOP variations into intensity variations.



data 1	data 2	output ***AND***
0	0	0
0	1	0
1	0	0
1	1	1

Fig. 1 Principle of optical AND gate by XPolM in a counter-propagation scheme, and the truth table.

3. Experiment

The SOA used in this work is a commercially available SOA (Kamelian, OPA series), employing a tensile-strained bulk InGaAsP/InP active region. The experimental setup of the AND gate is shown in Fig. 2, and a counter-propagation scheme is used. The SOA bias current and temperature are maintained at 200mA and 20^0C, respectively. The power of CW probe signal, at 1552.2nm, is around -8dBm at the SOA input. The pump light, at 1546.8nm, is modulated at a bit rate of 2.5Gbit/s via a $LiNbO_3$ Mach-Zehnder modulator, and then split

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into two data trains by a polarization-maintaining (PM) splitter. The applying of an optical delay line (ODL) in one arm is to produce ‘1001’ pulse trains (data 1), which is different from ‘1100’ trains (data 2) in the other arm. After combination by a PM combiner, data 1 and data 2 are amplified by an erbium-doped fiber amplifier (EDFA) and enter the SOA through an optical circulator. A band pass filter (1nm) is placed after the circulator to suppress the spontaneous noise from the SOA. PM fibers and PM isolator are used throughout the experiment. All components in the setup are taped down on the optical bench to preserve the polarizations at each stage. The optical output data is measured on an HP83480A digital communications analyzer with a 20GHz O/E plug-in module (HP83485A). The total power of data 1 and data 2 coupled into the SOA has four values: 1.1dBm when both input data are at high logic level ‘11’; -2.4dBm and -2.9dBm when one of the input data is at high level ‘01’ and ‘10’, respectively; and finally -16.8dBm when both are at low logic level ‘00’.

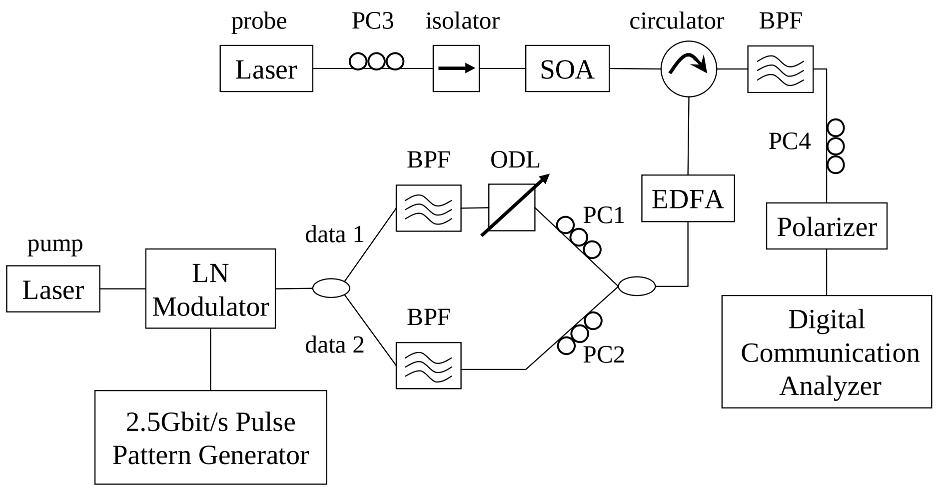

Fig. 2 Experimental setup for optical AND gate by XPolM. PC: polarization controller; BPF: band pass filter; ODL: optical delay line; EDFA: erbium-doped fiber amplifier.

We have reported previously that cross gain modulation (XGM) always takes place simultaneously with XPolM in the SOA Refs. [2, 3]. In terms of wavelength conversion by XPolM, inverted-conversion shows better performance due to positive contribution from XGM. In the operation of optical logic gate by XPolM, the XGM effect in the inverted-conversion scheme essentially reduces the power level of logic ‘0’, and makes it less ripple. Meanwhile by operating the logic gate at longer probe wavelength compared with that of pump light, the power level difference between logic ‘0’ and logic ‘1’ can be further increased due to larger birefringence induced by pump lights in longer wavelength range Refs. [3, 9].

Figure 3 presents the realization of the AND function. The time scale for the optical traces is 400ps/div. Data 1 and 2 are split from pump light, as shown in Fig. 2. The output of AND gate, which is operated in an up and inverted scheme as analyzed above, is shown in “output data A”, and the difference between logic ‘1’ state and logic ‘0’ state is >180μW. This amplitude is large enough to distinguish the two levels.

For comparison, the optical trace of AND function operated in non-inverted scheme is also shown in “output data B” in Fig. 3. This trace is taken from Ref. [6], and the experimental

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difference is that data 1 and data 2 are from two laser sources of different wavelength, 1549.5nm and 1555.8nm respectively. The wavelength of the probe light is the same as this work, 1552.2nm. Therefore the AND operation in Ref. [6] is neither in up- nor in down-conversion scheme. It is easy to see that, in trace A of Fig. 3, the ripples in logic '0' are sufficiently suppressed compared with those in trace B, and logic '1' is much enhanced. While the extinction ratio in trace A is 11.6dB (which is further demonstrated in Fig. 4 for two different time scales), it is only 3.5dB in trace B. Therefore, a significant improvement in extinction ratio has been achieved by using up and inverted wavelength conversion scheme.

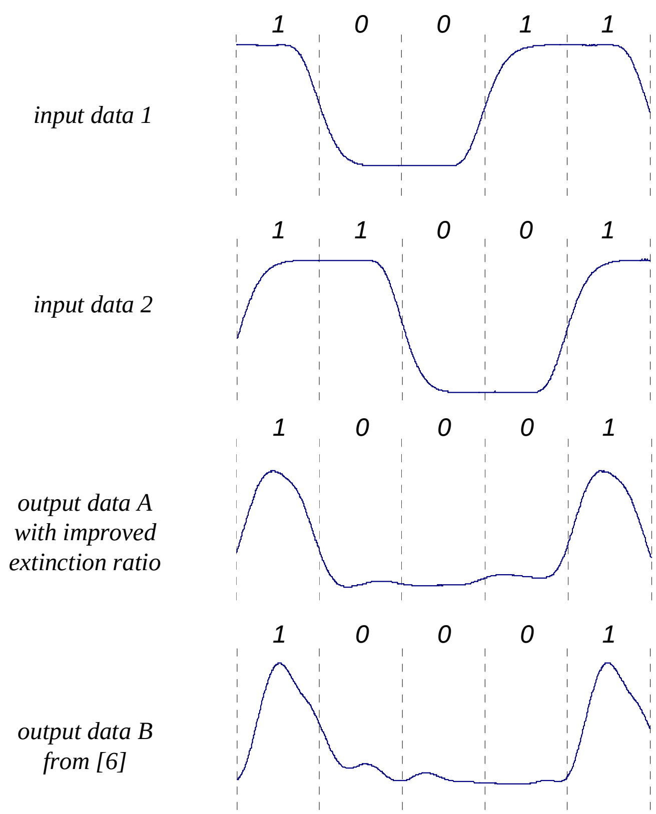
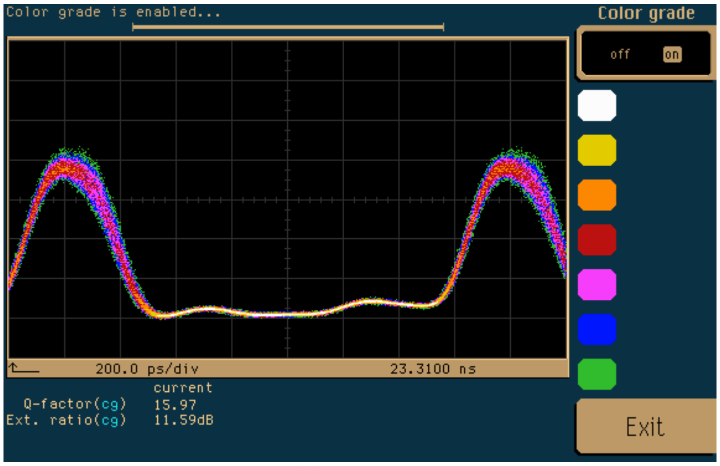


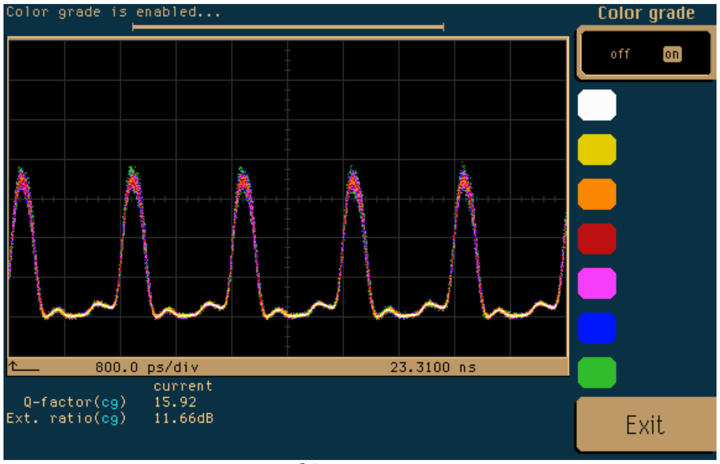
Fig. 3 Optical AND operation. The time scale is 400ps/div. "Output data A" is AND operation using inverted, up-conversion scheme, showing much improve extinction ratio; while "output data B" is AND operation using non-inverted schemes (optical trace is taken from Ref. [6]), showing fluctuations in logic "0" state.

4. Discussion

The key point to improve extinction ratio in this work is to suppress the ripples and reduce the power level of the output logic '0'. This is realized in the up and inverted conversion scheme. During the experiment, it was found that the output logic '0' fluctuated occasionally. This is due to several reasons. First, there is a mismatch between the pump lights polarization and the optical axes of the SOA. The optically induced refractive index nonlinearities appear to be much stronger for a TE or TM polarization of the pump lights Ref. [10]. Unfortunately, due to the polarization sensitive nature of the scheme, they cannot be perfectly matched to each other and maintained all the time during the operation. Secondly, the spontaneous emission noise is more prominent in logic ‘0’ Ref. [11], which results in a more noisy logic ‘0’ state. Third, the power levels of logic ‘10’ and ‘01’ are slightly different, which lead to some discrepancies in optical gain compression, differential gain and differential refractive index at these two power levels. Moreover, the performance of the $LiNbO_3$ modulator is still polarization-dependent, although a PM fiber is utilized for the input pigtail Ref. [12]. Even if these factors are of less prominence in the operation as long as the up and inverted conversion scheme is used, it is, as always, preferable to keep them as low as possible.



(a)



(b)

Fig. 4 Optical traces displayed on the digital communications analyzer with the values of Q-factor and extinction ratio for optical trace A in Fig. 3. (a) 200ps/div; (b) 800ps/div.

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5. Conclusion

An AND function with an improved extinction ratio is demonstrated at a bit rate of 2.5Gbit/s. The improved logic function is realized in up and inverted wavelength conversion scheme by XPolM. Logic operation outside this scheme is also displayed for comparison. Because of sufficient suppression of ripples in the output logic ‘0’, and much enhancement of power level in the output logic ‘1’ in the suggested operation scheme, high extinction ratio is readily achieved. Although this work was conducted at a bit rate of 2.5 Gbit/s using a bulk SOA, it should be noted that by using multiple quantum wells (MQWs) SOA as the nonlinear medium, the data rate could exceed 40Gbit/s. This is largely due to the rapid gain recovery time Ref. [13] and the large differential refractive index in a MQWs structure Ref. [14].

Acknowledgments

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