Technical University of Denmark

DTU

16×10 Gb/s WDM bidirectional gating in a semiconductor optical amplifier for optical cross connects exploiting network connection symmetry

Yu, Jianjun; Buxens Azcoaga, Alvaro Juan; Clausen, Anders; Jeppesen, Palle

Link back to DTU Orbit

DTU Library
Technical Information Center of Denmark

16 × 10 Gb/s WDM Bidirectional Gating in a Semiconductor Optical Amplifier for Optical Cross Connects Exploiting Network Connection Symmetry

Jianjun Yu, Alvaro Buxens, Anders Clausen, and Palle Jeppesen

Abstract—In order to further reduce the number of gating elements in space switches, the performance of 10 Gb/s wavelength division multiplexing (WDM) bidirectional semiconductor optical amplifier (SOA) gating is investigated. We demonstrate for the first time that a conventional SOA can be used for bidirectional WDM gating operation at 10 Gb/s by the use of holding light injection.

Index Terms—Bidirectional gating, optical communication, optical network, semiconductor optical amplifiers, wavelength division multiplexing.

I. INTRODUCTION

THE semiconductor optical amplifier (SOA) is a promising candidate for cascaded optical fiber systems [1], [2] and optical gating [3]–[9] because of the coverage of the entire fiber transmission window and the possibilities for integration and low cost [3]–[7]. A 4 × 4 space switch based on gain-clamped SOA's (GC-SOA's) has been successfully used in a 16 × 10 Gb/s wavelength division multiplexing (WDM) experiment [3]. Increase in optical transmission capacity requires implementation of space switches with very high throughput which can handle over Tb/s data streams. Cross connects using SOA's have been implemented up to 8 × 8 size [4], [5]. The use of SOA gate arrays can allow a reduction of the space-switch package size and gate arrays have been designed using SOA's and GC-SOA's [6]. It is necessary anyway to propose methods which can further reduce the number of gating elements in the space switch. Recently, a method to reduce the complexity of optical cross connects based on the bidirectional symmetry of current long haul networks has been proposed [7] and the bidirectionality of free-space micro-machined optical switches demonstrated [8]. By exploiting the switching symmetry, the complexity of a re-arrangeably nonblocking and strictly non-blocking $N \times N$ cross-connect constructed from $N/2 \times N/2$ constituent switch fabrics can be highly reduced [7]. In this paper, we will demonstrate 16 × 10 Gb/s WDM bidirectional gating in an SOA by using holding light injection to reduce the
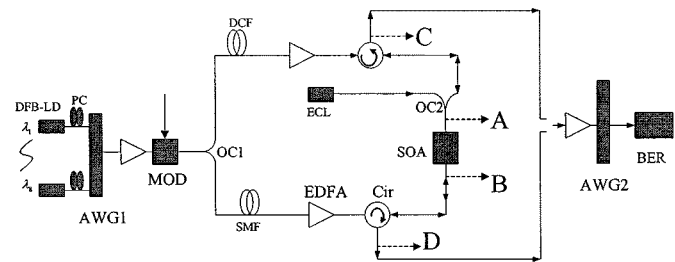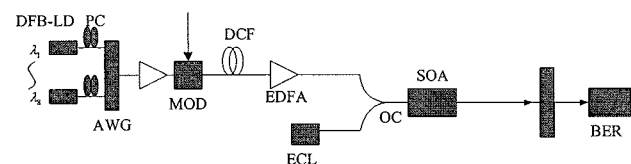
Fig. 1. Experimental setup: (a) bidirectional gating and (b) unidirectional gating.

XGM of WDM signals in the SOA gating [10]. Theoretical investigation [9] has shown that a four-channel system at 10 Gb/s cannot be cascaded over 4 SOA's by using small signal injection or 7 SOA's by using gain-clamped SOA with passive and active distributed Bragg reflection (DBR) regions, mainly due to the extinction ratio degradation of cascaded SOA gating and the limited relaxation frequency of cascaded GC-SOA gating. In order to overcome the limited relaxation frequency, the method of holding light injection is used in our experiment.

The basic physics of the holding light injection technique is that the injected light increases the SOA stimulated recombination rate, which results in reduced carrier lifetime and improved of gain recovery rate [10]. In this way, the extinction ratio can be improved and the XGM of WDM signals in SOA's can be reduced. Because the holding light is injected from outside of the SOA, it is not affected by the limited relaxation frequency like a GC-SOA.
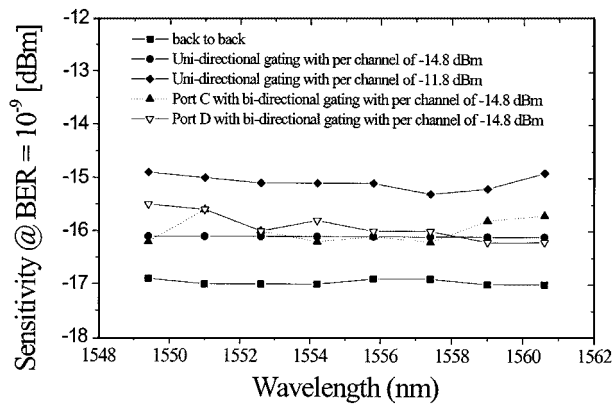
Fig. 2. Receiver power sensitivity versus channel wavelength with holding light power of 5.2 dBm.
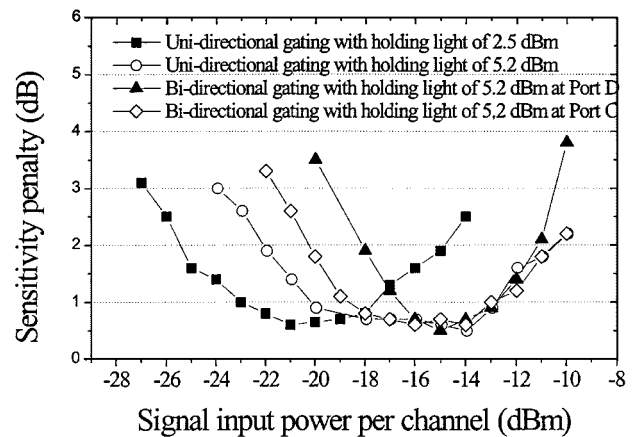

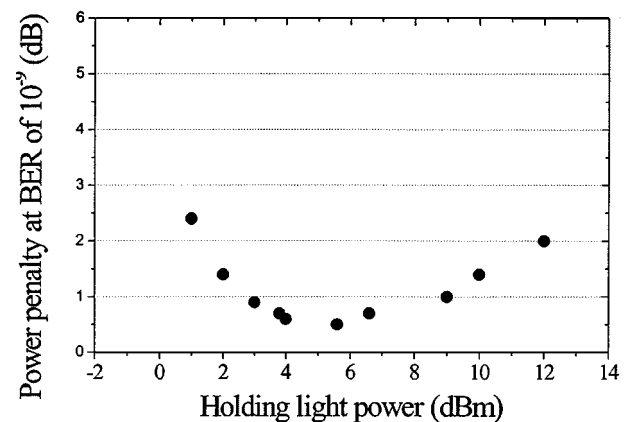Fig. 3. Sensitivity penalty versus signal input power into SOA for channel 6.

Fig. 4. Power penalty at Port C versus holding light power for channel 6 and bidirectional gating with signal input power per channel of −14.0 dBm.

II. EXPERIMENTAL SETUP

The experimental setup is shown in Fig. 1(a). The outputs of eight commercial distributed feedback (DFB) lasers are multiplexed in a commercial arrayed-waveguide grating 1 (AWG1). AWG1 and AWG2 have the same performance, and the channel spacing is 1.6 nm. The operating wavelengths are from 1549.3 nm (channel 1) to 1560.6 nm (channel 8). The amplified signals are modulated at 10 Gb/s with a pseudo-random bit sequence (PRBS) of $2^{31} - 1$. Two sets of 8 WDM channels are obtained after a 3 dB optical coupler. For one set, different channel signals are de-correlated by 300 ps/nm dispersion compensation fiber and transmitted through the SOA from A to B, and for another set, different channel signals are de-correlated by 25 km standard single model fiber and transmitted through the SOA from B to A. The SOA used in the experiment is 1200 μm long and has less than 0.5 dB of polarization dependence, a confinement factor of 0.6 and a peak gain wavelength of 1550 nm. The SOA saturation output power is 7.7 dBm when pumped at 200 mA. The holding light is generated by a commercial external cavity laser (ECL) at 1540 nm. All optical couplers are 2 × 2 couplers with power coupling ratios of 50 : 50. For comparison between unidirectional and bidirectional gating in the SOA the setup of unidirectional gating shown in Fig. 1(b) is implemented.

III. EXPERIMETAL RESULTS AND DISCUSSION

The receiver power sensitivity for each channel is shown in Fig. 2. When the holding light power and signal input power per channel are 5.2 and −14.8 dBm, respectively, there is almost the same receiver power sensitivity with bidirectional or unidirectional gating for all channels. When unidirectional gating is used, it is clearly seen that the receiver sensitivity is poor when the input signal power per channel is −11. 8 dBm. The poor sensitivity is caused by XGM of different channels, not by four-wave-mixing (FWM) components of different channels, because the optical component of FWM is smaller than 25 dB compared to the signal power per channel. It indicates that the holding light power must be large enough in order to overcome the XGM of different channels. It should be pointed out that the penalty induced by unidirectional or bidirectional gating can be

further reduced using a shorter SOA gate with a small confinement factor [2]. The total reflection of the SOA, optical coupler 2 and circulators is smaller than −25 dB in our experiment; in that case the crosstalk caused by reflection has a small effect on the bidirectional SOA gating. The signal-to-noise ratio (SNR) of all channels in a 0.1-nm optical bandwidth is larger than 25 dB after the SOA by using unidirectional or bidirectional gating.

The sensitivity penalty at the bit-error rate (BER) of 10^{-9} versus signal input power of each channel is investigated. As an example, Fig. 3 shows the case of channel 6. With unidirectional gating, it is clearly seen that the optimal input signal power is increased when the holding power is increased. Small input signal power will lead to degradation of SNR, and amplified spontaneous emission (ASE) noise of SOA plays an obvious role, so the power penalty increases. When the signal input power is increased to a certain value which is near to the holding light power, the technique of holding light injection will lose its role and in that case the XGM of different channels will degrade the signal performance. With bidirectional gating, there is nearly the same optimal signal input power into the SOA measured at Port C or D. Comparing bidirectional and unidirectional gating, we find that only a small input signal power can be endured when unidirectional gating is used, which is due to relatively large gain in the SOA in the case of unidirectional gating. Comparing the sensitivity penalty at Port C and D, we can also see that only
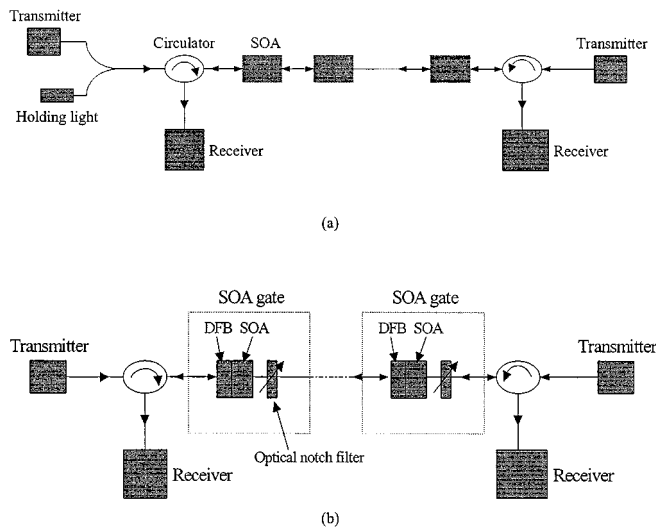
Fig. 5. SOA bidirectional gating cascade in long haul WDM system. (a) Reservoir-channel, (b) DFB and SOA integration.

a small input signal power can be endured at Port C, which is due to the strong holding light accompanying the signals when the BER is measured at Port D. Too strong holding light suppresses the gain of signals when signals and strong holding light are amplified by an EDFA for receiving purposes, so, the small signal will have a large penalty at Port D, which in turn leads to a reduction of the input power dynamic range (IPDR) for bidirectional gating.

As an example, the holding optical power dynamic range of channel 6 with bidirectional gating is shown in Fig. 4. We can see that there is about 7-dB dynamic range of the holding light for 1-dB penalty with signal input power per channel −14.0 dBm. Too strong or too weak holding light will cause a large power penalty because too strong holding light will reduce the gain of signals, and too weak holding light will cause the SOA to have a strong gain saturation effect and will thus induce undesirable XGM and signal waveform distortion.

Considering cascading of SOA gates by using holding light injection, Fig. 5 shows the two kind of models which can be used in a long haul WDM system. One is the same as that used in [1] named after the reservoir-channel method. Our experiment shows that the holding light power is 20.0 dB larger than the signal power of channel 1 before SOA gating, but, after SOA gating, the holding light power is 18.2 dB larger than that of channel 1. So, the relative value between holding light power and signal power is changed. However, from Figs. 3 and 4, we can see that the holding light power plays an important role, too large or too small holding light will degrade the performance of signals. Our numerical simulation shows that 4×10 Gb/s WDM bidirectional signals can be cascaded over 4 SOA gates with 1 dB penalty according to this model, and the maximum number of SOA gates is mainly limited by the decreasing holding light after some SOA gates. In order to overcome the problem, the second model shown in Fig. 5(b) is presented. In this model, each SOA gate includes one holding light source in the form of a DFB-LD which is integrated with the SOA gate in a small chip. Hence, the holding light power P_h at each SOA gate is fixed and not affected by the former SOA gate in the WDM

system. In order to reduce the effect of the holding light on the adjacent SOA gate, an optical notch filter (ONF) is used to suppress the holding light. Our numerical simulation then shows that 4×10 Gb/s WDM bidirectional signals can be cascaded over 12 SOA gates with 1-dB penalty according to this model, and the maximum number of SOA gates is mainly limited by SOA ASE noise accumulation. The model of the SOA in our numerical simulation is the same as in [11]. The SOA is segmented into 50 sections in order that the carrier dynamics can be studied along the length of the amplifier. The SOA in our numerical simulation is 500 μm long, it has a confinement factor of 0.6 and a bias current of 120 mA. The holding light input power into the SOA is 4 dBm.

IV. CONCLUSION

Our experiment shows that a conventional SOA can be used for bidirectional gating at 16×10 Gb/s by employing holding light injection. However, the IPDR of bidirectional gating is a little smaller than that of unidirectional gating. Our numerical simulation shows 4×10 Gb/s WDM bidirectional signals can be cascaded over 12 SOA gates with 1-dB penalty by using an SOA gate integrated with a DFB-LD. These results show that SOA's can be used as gates in cross connects which exploit the bidirectional symmetry of today's long-haul networks, hereby allowing a reduction in complexity of the cross connects.

REFERENCES

[1] Y. Sun, A. K. Srivastava, and S. Banerjee *et al.*, "Error-free transmission of 32×2.5 Gbit/s DWDM channels over 125 km of allWave™ fiber using cascaded in-line semiconductor optical amplifiers," in *Proc. OAA'99*, Nara, Japan, 1999.

[2] D. Chiaroni, N. L. Sauze, and T. Zami *et al.*, "WDM semiconductor optical amplifiers for high-performance all-optical switching systems," in *Proc. Photonics Switching*, Santa Barbara, CA, 1999.

[3] G. Soulage, A. Jourdan, and P. Doussiere *et al.*, "4×4 space-switch based on clamped-gain semiconductor optical amplifiers in a 16×10 Gb/s WDM experiment," in *Proc. ECOC'96*, vol. 4, Oslo, Norway, 1996, pp. 145–148.

[4] S. Takahashi, T. Kato, H. Takeshita, S. Kitamura, and N. Henmi, "10 Gb/s space-division optical cell switching with 8×8 gate type switch matrix employing gate turn-on-delay compensator," in *Proc. Photonics Switching*, Senda, Japan, 1996.

[5] H. Takeshita, S. Takahashi, T. Kato, S. Kitamura, H. Harano, and N. Henmi, "A demonstration of an optical cross-connect system for a self-healing optical network," in *Proc. ECOC'97*, vol. 3, 1997, pp. 335–338.

[6] F. Dorgeuille, W. Grieshaber, F. Pommereau, C. Porcheron, F. Gaborit, L. Guillemot, J. Y. Emery, and M. Renaud, "First array of 8 CG-SOA gates for large-scale WDM space switches," in *Proc. ECOC'98*, vol. 1, Madrid, Spain, 1998, pp. 255–256.

[7] J. M. Simmons, A. A. M. Saleh, E. L. Goldstein, and L. Y. Lin, "Optical crossconnects of reduced complexity for WDM networks with bidirectional symmetry," *IEEE Photon. Technol. Lett.*, vol. 10, pp. 819–821, June 1998.

[8] L. Y. Lin, E. L. Goldstein, J. M. Simmons, and R. W. Tkach, "High-density micromachined polygon optical crossconnects exploiting network connection-symmetry," *IEEE Photon. Technol. Lett.*, vol. 10, pp. 1425–1427, Oct. 1998.

[9] D. Wolfson, "Detailed theoretical investigation and comparison of the cascadability of conventional and gain-clamped SOA gates in multiwavelength optical networks," *IEEE Photon. Technol. Lett.*, vol. 11, pp. 1494–1496, Nov. 1999.

[10] M. Yoshino and K. Inoue, "Improvement of saturation output power in a semiconductor laser amplifier through pumping light injection," *IEEE Photon. Technol. Lett.*, vol. 8, pp. 58–59, Jan. 1996.

[11] M. Asghari, I. H. White, and R. V. Penty, "Wavelength conversion using semiconductor optical amplifiers," *J. Lightwave Technol.*, vol. 15, pp. 1181–1190, July 1997.