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Utilizing 1.2 GHz bandwidth reflective semiconductor optical amplifier for 1.25–10 Gbit/s for colourless and cooler-less wavelength conversion

C. H. Yeh · C. W. Chow · Y. F. Wu · F. Y. Shih

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Abstract In this investigation, we propose and investigate a wavelength converter by using a cost-effective and uncooled TO-can package reflective semiconductor optical amplifier with $\sim$1.2 GHz bandwidth. In this measurement, the converted data rate can support 1.25–10 Gbit/s on-off keying modulation rates by using the cross gain modulation technique.

Keywords Reflective semiconductor optical amplifier (RSOA) · Wavelength converter · Cross gain modulation (XGM)

1 Introduction

Recently, the semiconductor optical amplifier (SOA) and Fabry–Perot laser diode (FP-LD) have been proposed in various all-optical applications, such as wavelength conversion, pulse generation, optical logic gate, and optical switching etc. (Guo and Connelly 2008; Yeh et al. 2009) Based on intensity-modulated gain of SOA, the cross gain modulation (XGM) is a simple and promising method for all-optical wavelength conversion (Manning and Davies 1994; Obermann et al. 2007; Yoo 1996). Here, the attractions of XGM wavelength conversion components lie in their simplicity, high conversion efficiency, polarization independence, and insensitivity to the wavelength of the input data within their effectively gain bandwidth (i.e. colourless operation). In the XGM method, the amplifier gain is saturated by using

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C. H. Yeh (✉)
Information and Communications Research Laboratories, Industrial Technology Research Institute (ITRI), Hsinchu 31040, Taiwan
e-mail: yeh1974@gmail.com; depew@itri.org.tw

C. W. Chow · Y. F. Wu · F. Y. Shih
Department of Photonics and Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu 30010, Taiwan

C. H. Yeh
Graduate Institute of Applied Science and Engineering,
Fu Jen Catholic University, New Taipei 24205, Taiwan

one intensity modulated input signal. Thus, it is possible to modulate the amplifier gain with an input signal and to encode (with an inverted data) a separated continuous-wave (CW) carrier at a desired optical frequency. As mentioned before, the XGM method has the advantage of a simple structure, high conversion efficiency, broadly conversion range and relative polarisation independence. However, the XGM–SOA has been limited due to its high noise figure (NF), chirp and low extinction ratio (ER) (Obermann et al. 2007; Campi and Coriasso 2000).

Furthermore, the reflective semiconductor optical amplifier (RSOA) uses a high reflective (HR) coating and an anti-reflective (AR) coating on its two facets to produce a highly versatile gain medium (Chow et al. 2011). Although, the waveguide structure of RSOA is similar to a traditional SOA (Connelly 2007), the RSOA brings out a lot of different optical characteristics. RSOA offers low NF and high optical gain at low driving current with energy-efficient.

In this letter, we use a 1.2 GHz bandwidth TO-can based RSOA with XGM method for wavelength conversion to support the 1.25–10 Gbit/s on-off keying (OOK) traffic rate at the driving current of 60 mA. Here, the caused power penalties of 2.9, 1.3 and 2.8 dB are measured at the bit error rate (BER) of 10^{-9} after wavelength conversion, respectively, when the modulation rates are 1.25, 2.5 and 10 Gbit/s. As a result, the proposed RSOA-based converter is not only simplification, but also energy-efficient.

1.1 Experiment and discussion

Figure 1 shows the experimental setup of the proposed RSOA-based colourless and coolerless wavelength converter. Here, the proposed wavelength converter is consisted of a 1.2 GHz bandwidth TO-can RSOA (produced by CIP), a 1 × 2 and 50:50 optical coupler (CP), a 3-ports optical circulator (OC), a bandpass filter (BF) and a distributed feedback laser diode (DFB-LD) serving as a CW probe light. In this measurement, the RSOA is operated at 60 mA driving current without cooling, and its effective amplification bandwidth is between 1,530 and 1,560 nm.

In the experiment, the 3 dB bandwidth and average insertion loss of the BF used are around 0.4 nm and 3 dB, respectively. The central wavelength of the BF is set at 1,550.0 nm. The insertion loss of OC is nearly <1 dB. The CW probe light (λ_{probe}) is set at 1,543.0 nm with 8 dBm output power. Here, a CW pump wavelength (λ_{pump}) is set at 1,550.0 nm and launched into a Mach–Zehnder modulator (MZM) for signal modulation. The polarization controller (PC) is used to adjust polarization state and maintain maximum output power, as illustrated

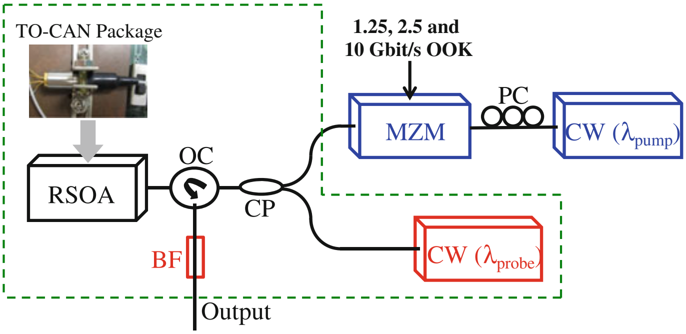

Fig. 1 Experimental setup of the TO-can ROSA-based wavelength converter

in Fig. 1. The λ_{pump} input signal is modulated by a non-return to zero (NRZ) pseudo random binary sequence (PRBS) with a pattern length of $2^{31}-1$ to generate on-off keying (OOK) format at the traffic rates of 1.25, 2.5 and 10 Gbit/s, respectively. Its average power is 2.0 dBm. The λ_{pump} signal passes through the proposed optical converter for wavelength conversion by the XGM mechanism. Then, the probe wavelength λ_{probe} transmits through a BF and carry the inverse modulation data after the XGM.

First of all, to realize the relationship of BER performance and injection powers of λ_{pump} and λ_{probe}, we fix the injection power of λ_{pump} at 2 dBm and vary the injection power of λ_{probe} for measuring its corresponding BER characteristics. A variable optical attenuator (VOA) is used for power adjustment. Figure 2a shows the BER measurements of proposed RSOA-based wavelength converter under different injection powers of λ_{probe}, when the injection power of λ_{pump} is fixed at 2 dBm at the traffic rates of 1.25, 2.5 and 10 Gbit/s, respectively. Moreover, an optical preamplifier, which is constructed by a VOA and erbium-doped fiber amplifier (EDFA) with 17 dBm saturated power and ~5 dB NF, is also utilized to enhance the receiver (Rx) sensitivity. As shown in Fig. 2a, in order to achieve the BER of 10^{-9}, the injection powers of λ_{probe} must be larger than −22, −20 and −11 dBm, respectively, at

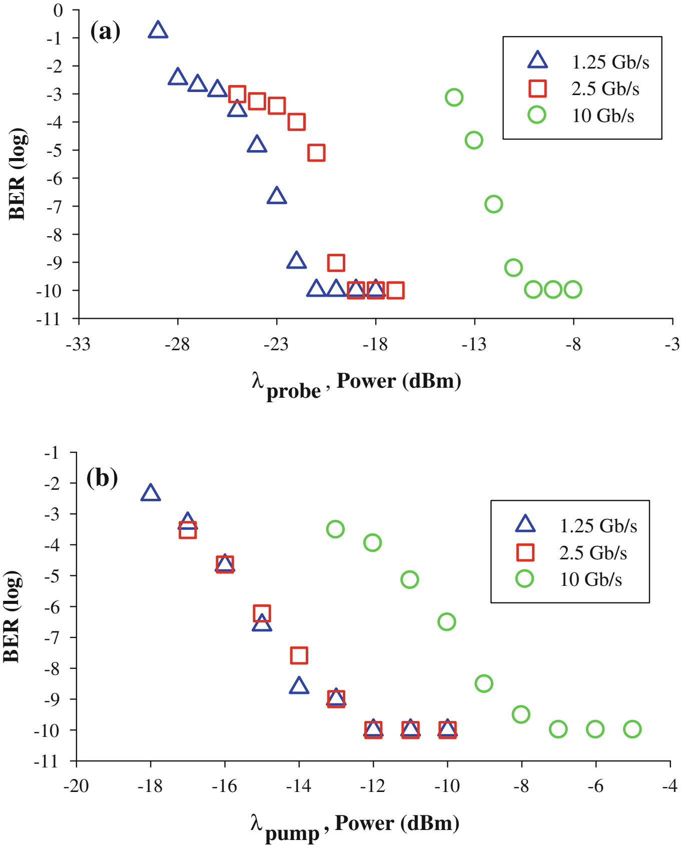

Fig. 2 BER performances at the data rates of 1.25, 2.5 and 10 Gbit/s, respectively, when the **a** λ_{pump} and **b** λ_{probe} powers are both fixed at 2 dBm

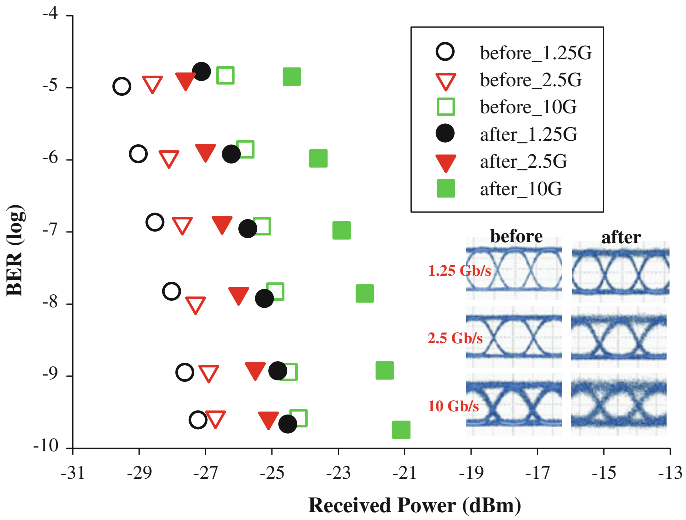

Fig. 3 Measured BER performances after wavelength conversion at the traffic rates of 1.25, 2.5 and 10 Gbit/s, respectively. *Insets* are corresponding eye diagrams

the three modulation rates for wavelength conversion. Therefore, a high data rate requires a larger probe signal power for conversion.

Then, we fix the injection power of λ_{probe} and adjust different injection power of λ_{pump}, the related BER performance can be measured after wavelength conversion. In this performance, a VOA is located in front of MZM for varying the λ_{pump} power. Figure 2b indicates the BER measurement of proposed wavelength converter under different injection powers of λ_{pump}, when the modulation rates are 1.25, 2.5 and 10 Gbit/s, respectively and the λ_{probe} power is fixed at 2 dBm. When the modulation rates are 1.25 and 2.5 Gbit/s, the measured BER curves are similar, as seen in Fig. 2b, and can achieve the BER of 10^{-9} when the λ_{pump} powers are -13 dBm at the two modulation rates. Besides, to achieve the same BER performance, a λ_{pump} power of -8 dBm is needed for wavelength conversion at the 10 Gbit/s data rate.

As mentioned above, in the next measurement, we assume the output powers of λ_{probe} and λ_{pump} are both -2 dBm launching into RSOA for wavelength conversion. Hence, Fig. 3 presents the BER performances of proposed RSOA-based wavelength converter at the modulation rates of 1.25, 2.5 and 10 Gbit/s before and after passing through the converter. The insets of Fig. 3 are the corresponding eye diagrams measured at the BER of 10^{-9}. After passing through the wavelength converter, the measured power penalties are 2.9, 1.3 and 2.8 dB at the BER of 10^{-9} at the data rates of 1.25, 2.5 and 10 Gbit/s, respectively, as shown in Fig. 3. In the measurement, the power penalties at 1.25 and 2.5 Gbit/s are around 2 dB. When the traffic rate increases to 10 Gbit/s, the power penalty is about 2.8 dB. This is due to the limitation of carrier recovery in the RSOA at 10 Gbit/s. Higher wavelength conversion rates is possible by increasing the bias current of the RSOA.

2 Conclusion

In conclusion, W\we have used a 1.2 GHz bandwidth TO-can based RSOA with XGM method for wavelength conversion to support the 1.25 to 10 Gbit/s OOK traffic rates at the driving current of 60 mA. Here, the power penalties are around 2 dB at 1.25 and 2.5 Gbit/s, and 2.8 dB at 10 Gbit/s measured at the BER of 10^{-9} after wavelength conversion. In addition, the relationship of BER performance and modulation rate under different injection power of λ_{pump} and λ_{probe} has also been discussed.

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