Performance improvement of 10-Gb/s XGM wavelength conversion by using polarization control structure

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By utilizing the cross polarization modulation effect in semiconductor optical amplifier (SOA), the extinction ratio of cross gain modulation (XGM) wavelength conversion was enhanced, the pattern effect was significantly reduced, and the power penalty of wavelength conversion was reduced by 5 dB simultaneously. Furthermore, by adjusting the settings of polarization controllers, both inverted and non-inverted wavelength conversion can be achieved right in the same wavelength converter.

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Wavelength conversion can effectively increase the utilization ratio of wavelengths and reduce the blocking rate in network. Thereby the converters increase the flexibility and capacity of the network and can facilitate network management. Depending on their principles, wavelength converters can be classified into three categories: optical gating, wave interference, and wave mixing[1]. All of them exploit nonlinear effects such as cross gain modulation (XGM)[2,3], cross phase modulation (XPM)[4,5] and four wave mixing (FWM)[6]. Consequently the devices used by wavelength conversion are generally semiconductor devices with high nonlinear coefficients and rapid response speeds, such as semiconductor optical amplifiers (SOAs)[7], $LiNiO_3$ waveguides[8] and electro-absorption modulators (EAMs)[9]. Among them SOAs are the most promising devices used as all-optical wavelength converters because of their compact dimension, cascadability, and low power consumption[7].

Among the schemes of SOA-based wavelength conversion, XGM wavelength conversion has the advantage of being simple to realize. Drawbacks of XGM converters are degradation of extinction ratio for up-converted signals and strong pattern effects at high bit rates[7]. In this paper, we propose a novel method to improve the performance of XGM converter based on cross polarization modulation (CPM) in a SOA. A polarization control structure was introduced to the original XGM wavelength converter. With intended control of the polarization states of input and output probe lights, optimized wavelength conversion at 10 Gb/s was achieved with reduced power penalty and pattern effects.

Because of the asymmetric waveguide geometry, the intrinsic birefringence of a SOA can cause a phase shift difference between TE and TM modes of the light fed into the SOA. This difference varies monotonously with the intensity of input light through the SOA. When a probe light and a signal light are fed into a SOA together, the signal-induced birefringence can cause the state of polarization (SOP) rotation of probe light. This phenomenon is called CPM[10]. With a polarizer and a polarization controller (PC), the SOP rotation of probe light can be transformed into power variation. This principle can be applied in wavelength conversion technologies[11,12].

The schematic of our all-optical wavelength converter is depicted in Fig. 1. We add two PCs (PC_1, PC_2) and an on-line polarizer in the original XGM wavelength converter. The continuous wave (CW) laser used here is a semiconductor laser (Alcatel) which provides probe light at 1553.9 nm. Transmitter/receiver is the 10-Gb/s transmitter and receiver module which provide the signal light at 1555.8 nm and receive the converted light at the same wavelength as the probe light. The signal light is modulated by a 10-Gb/s external modulator. The modulation signal is provided by a pulse pattern generator Anritsu (MP1761B). PC_1 and PC_2 are used to adjust polarization state of the input and output probe light passing through the SOA. When the signal is on, adjust the settings of PCs to prevent the probe light from passing through the

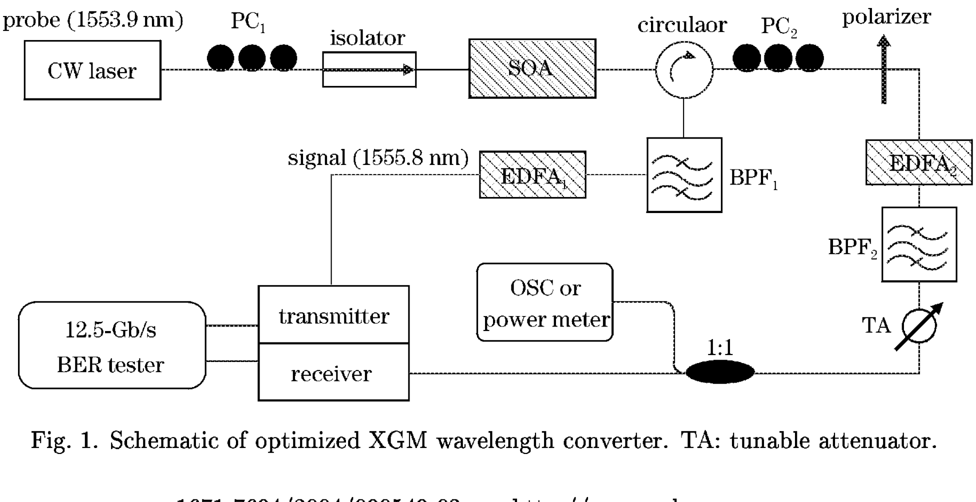

Fig. 1. Schematic of optimized XGM wavelength converter. TA: tunable attenuator.

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polarizer. When the signal is off, the SOP of probe light will change and part of its energy will pass through the polarizer due to the CPM effect in the SOA.

Figure 1 shows the experimental setup. The average powers of probe and signal are 8.3 and −1.0 dBm, respectively. In this wavelength converter, probe and signal intensity should be high enough to get appreciable CPM effect in the SOA. The injection current of the SOA is 90 mA. The modulation signal has a data format of a $2^7 - 1$ non-return-to-zero (NRZ) pseudorandom bit stream. The polarizer has an extinction ratio of 20 dB. Two optical band pass filters (BPF_1: 2-nm bandwidth, BPF_2: 1-nm bandwidth) are used to suppress the noise induced by the SOA and erbium-doped fiber amplifiers (EDFAs). The waveforms and eye diagrams are observed through a 40-Gb/s electrical oscilloscope and the bit error rate (BER) of wavelength conversion is measured by an error detector (Anritsu MP1762A).

By properly adjusting the settings of PC_1 and PC_2, the conversion performance of the converter is significantly improved compared with the original XGM converter. With the combination action of XGM and CPM, we got a static extinction ratio of more than 25 dB and a sharper transfer curve in this converter than in the original XGM converter. Figure 2 shows the converted waveforms with and without polarization control structure. It can be seen from Fig. 2 that pattern effect in wavelength conversion is significantly reduced and the waveform distortion is quite small. Figure 3 compares the eye diagrams of converted lights with and without polarization control structure. The extinction ratio of the converted signal is enhanced and the noise in wavelength conversion is suppressed.

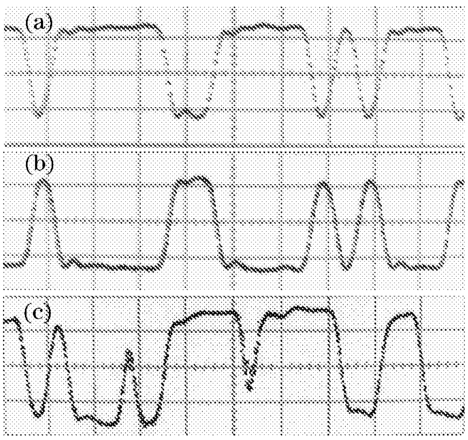

Fig. 2. Waveforms of 10-Gb/s signal and converted lights. (a) Signal; (b) converted light with polarization control; (c) converted light without polarization control. Time base: 200 ps/div; power: 160 mV/div.

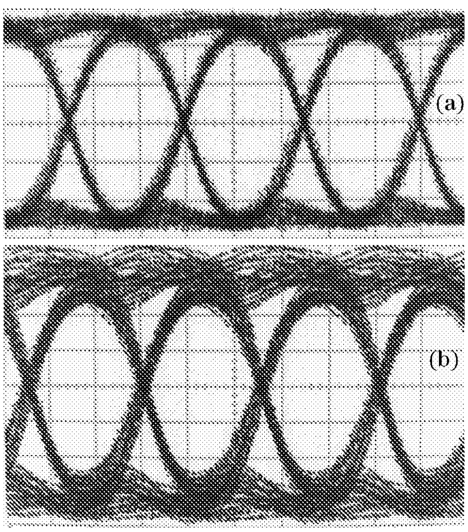

Fig. 3. Eye diagrams of converted lights with (a) and without polarization control (b). Time base: 40 ps/div; power: 80 mV/div.

Figure 4 shows the BER curves of wavelength conversion with and without polarization control structure at the bit rate of 10 Gb/s. It can be seen in the figure that the power penalties of wavelength conversion with and without polarization control structure are about 6.5 and 11.5 dB, respectively. The introduction of polarization control structure leads to a 5-dB penalty reduction at the BER of 10^{-9}.

Finally, waveform non-inverted wavelength conversion

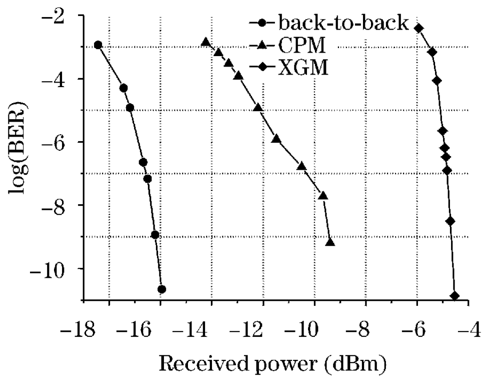

Fig. 4. Comparison of wavelength conversion BER curves at 10 Gb/s with and without polarization control.

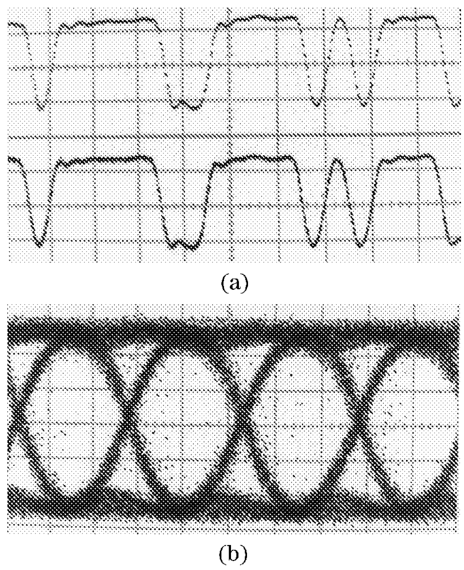

Fig. 5. Non-inverted wavelength conversion at 10 Gb/s. (a): Converted waveform; time base: 200 ps/div; power: 160 mV/div. (b): converted eye diagram; time base: 40 ps/div; power: 80 mV/div.

also can be achieved utilizing CPM in the SOA. The non-inverted conversion results are depicted in Fig. 5. Figure 5(a) is the waveform of converted light and Fig. 5(b) is its eye diagram. Under non-inverted condition, CPM and XGM effects oppose to each other. This can explain the extinction degradation and power penalty increase of non-inverted conversion compared with inverted conversion.

We have investigated a XGM wavelength conversion scheme with polarization control. Performance improvement is observed with enhanced extinction ratio, reduced power penalty and pattern effect. Non-inverted conversion also can be achieved by adjusting the settings of PCs. In this wavelength converter, TE and TM components are similar with the two arms in Mach-Zender interferometer (MZI) wavelength converters[11]. Symmetry requirement for the two arms is naturally satisfied as the TE and TM components propagate and interfere in the same polarization-independent SOA.

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