All-optical wavelength conversion based on nonlinear polarization rotation (NPR) in SOA and AWG filtering

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Received June 29, 2005

An all-optical wavelength converter, based on nonlinear polarization rotation (NPR) in semiconductor optical amplifier (SOA) and array waveguide grating (AWG) filtering, is experimentally demonstrated. The wavelength converter can provide excellent operation including extinction ratio and Q factor. The simultaneous two wavelength conversion outputs are successfully obtained at 20 Gb/s.

OCIS codes: 060.4510, 230.1150.

Wavelength conversion in all-optical networks can reduce the probability of wavelength blocking, provide more flexibility in network management and offer the possibility of data regeneration. Several wavelength conversion techniques have been demonstrated by exploiting nonlinear mechanism in semiconductor optical amplifiers (SOAs) including cross-gain modulation (XGM)[1], cross-phase modulation (XPM)[1], four-wave mixing (FWM)[2] and nonlinear polarization rotation (NPR)[3,4]. Each scheme has its own advantages and disadvantages. For example, FWM has low conversion efficiency, and the conversion speed of XGM, XPM, and NPR is limited by the carrier's recovery time[5]. Recently, novel schemes have appeared that no longer solely exploit nonlinearities in SOA to improve the bandwidth of SOA-based wavelength converters. For instance, pattern independent 100-Gb/s wavelength conversion has been demonstrated by introducing a grating method for the delay interferometer configuration[6]. A wavelength conversion scheme by adding an extra birefringence delay is exploited to enhance the performance of the conventional NPR[5]. A pulse reformatting optical filter is used to realize simultaneous 40-Gb/s wavelength conversion, switching and signal format conversion[7].

In this letter, a wavelength converter is experimentally demonstrated by incorporating NPR with AWG filtering. Although similar configurations have been employed to realize wavelength conversions[3,4], the operation principle is different from ours. In our method, the filter placed after SOA is detuned to red-shifted sideband of the probe wavelength and selects the red-shifted sideband of the converted signal, that is to say, we exploit NPR and AWG red-shifted filtering. In previous papers, the filters placed after SOAs are zero detuning to the probe wavelength, that is to say, the operation of those wavelength converters is solely based on NPR. The wavelength conversion scheme can provide excellent performance including extinction ratio and Q factor. The scheme can effectively improve the bandwidth of devices based on SOA with relatively slow recovery time, and has potential to realize wavelength conversion and other functions at higher bit rates. The simultaneous two wavelength outputs are also successfully obtained at 20 Gb/s. This technology could be useful for broadcast from one point to many destinations.

Figure 1 shows the schematic diagram of the experimental setup to realize simultaneously two wavelength conversion outputs at return-to-zero (RZ) data rates of 20 Gb/s. The SOA bias current is set to 270 mA. The SOA has polarization insensitive gain that is less than 0.6 dB in small-signal gain. Two continuous-wave (CW) probe signals are from two tunable laser sources at 1561.79 and 1560.00 nm respectively. The polarization of two CW signals is adjusted by two polarization controllers (PC1 and PC2) respectively. Then the two probe signals are mixed together by a 3-dB coupler and are fed into a SOA after passing through an optical isolator. The pulses from a 10-GHz tunable mode-locked laser are modulated by a $LiNbO_3$ modulator at 10 Gb/s to form a 2^7-1 RZ pseudo random binary sequence (PRBS). After passing through an erbium doped fiber amplifier (EDFA) and a 0.8-nm (3-dB bandwidth) optical band-pass filter (BPF1) centered at the data source wavelength of 1545.12 nm, the 10-Gb/s data stream is multiplexed to 20 Gb/s by an optical multiplexer. After passing through a polarization controller (PC4), the 20-Gb/s data signal is injected into the SOA in the opposite direction to the probe wave via the optical circulator (OC). The injected 1545.12-nm data signal introduces additional birefringence in the SOA via carrier density changes, leading to a different phase change of transverse electric (TE) and the transverse magnetic (TM) modes of the probe signals, and also resulting in chirp converted signals. Thus the output polarization states of the CW probe signals are modified at

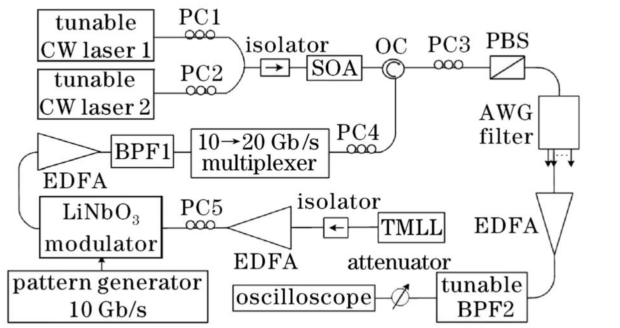

Fig. 1. Experimental setup for two wavelength conversion outputs.

the output facet of the SOA, and the leading edges of the (inverted) modulated probes are shifted towards lower frequencies (red-shifted), whereas the trailing edges are shifted towards higher frequencies (blue-shifted)[7]. The SOA outputs are firstly polarization-filtered by a polarization controller (PC3) and a polarization beam splitter (PBS). At the output of the PBS, two channels of an array waveguide gratings (AWG) demultiplexer are used to get red-shifted filtering effect, the central wavelengths for two channels in an AWG (FWHM 0.4 nm) are at 1562.11 nm (for probe at 1561.79 nm) and 1560.32 nm (for probe at 1560.00 nm) respectively, i.e., detuned 0.32 nm to the red sides of the two probe wavelengths respectively. The AWG filter selects the red-shifted sideband of the probes from the PBS and separates the two converted signals into two different output fibers. After the AWG filter, the converted signals are amplified by an EDFA and then pass through a tunable bandwidth filter (BPF2, 0.8 nm) to suppress the noise of the EDFA before being monitored by an oscilloscope.

It needs to be pointed out that, we tune the wavelengths of the probes to change the relative position of the AWG filter channels with respect to the probe without adjusting the AWG channel center wavelengths.

Firstly, we evaluate the performance of the presented wavelength converter when only one probe wave at 1561.79 nm is injected into the SOA. The mean powers for the probe and data are 0.81 and 5.8 dBm before SOA respectively. The spectra at the PBS output and at the AWG filter output are shown in curves 1 and 2 of Fig. 2, respectively. Curve 3 of Fig. 2 shows filter shape of AWG channel. It can be seen that the blue-shifted part of the converted output spectrum is much more attenuated than the red-shifted part with the narrow band red-shifted filter AWG. Figure 3 shows the eye diagrams of the input RZ data at 1545.12 nm before the SOA and converted outputs from BPF2. Figure 3(a) shows the input data with extinction ratio of 15.6 dB and Q factor of 7.6. With the corresponding AWG filter in place, i.e. by exploiting NPR and AWG red-shifted filtering, the eye diagram for the converted output as shown in Fig. 3(b) is clearly open and very symmetric with extinction ratio of 11.8 dB and Q factor of 6.76. We do not observe pattern effect, which is different from that in Refs. [3,4]. Figures 3(c), (d) show the inverted and non-inverted converted outputs by solely exploiting NPR scheme. They both show nearly closed eye diagram with very low extinction ratio and Q factor. They also show pattern effect. Especially, the non-inverted conversion shows severe pattern effect due to the slow carrier recovery time for the applied SOA. Compared with Figs. 3(c) and (d), Fig. 3(b) shows performance improvement including extinction ratio, Q factor and pattern dependence. Figure 4 shows the waveforms for the input pump and conversion outputs at two output ports of PBS.

Secondly, we complete the simultaneous two wavelength conversion outputs by exploiting NPR and AWG filtering at 20 Gb/s. The input pump signal keeps the extinction ratio and Q factor constant, and the mean power is adjusted to 3.25 dBm. Curves 1, 2 and 3 of Fig. 5 show the spectra at the PBS output, and at one AWG channel output corresponding to probe at 1560.00 nm and the other AWG channel output corresponding to probe at 1561.79 nm, respectively. The eye diagrams

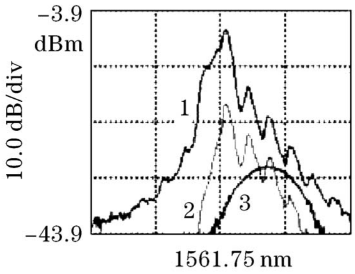

Fig. 2. Optical probe spectra and filter shape. Only one probe wave at 1561.79 nm is injected into the SOA.

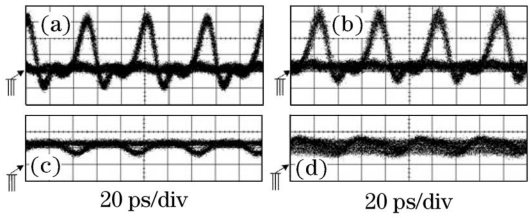

Fig. 3. Eye diagrams for the input RZ data and converted outputs at 20 Gb/s when only a probe wave at 1561.79 nm is injected into SOA. (a) Input data; (b) non-inverted conversion output (0.32-nm AWG filter detuning); (c) inverted conversion output (0-nm AWG filter detuning); (d) non-inverted conversion output (0-nm AWG filter detuning).

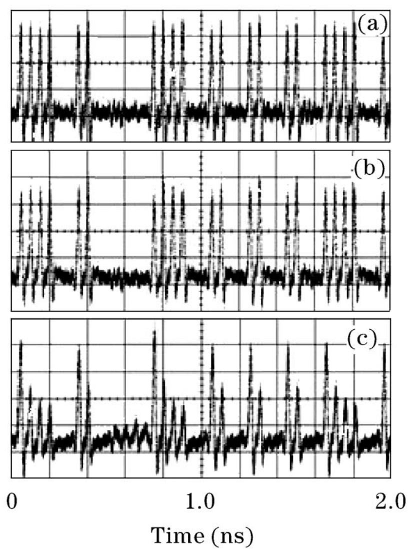

Fig. 4. Waveforms for input pump (a) and conversion outputs at two ports of PBS (b) and (c).

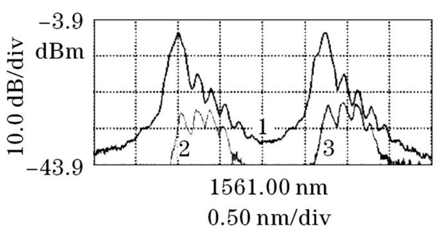

Fig. 5. Optical probe spectra. Two probe waves are injected into the SOA.

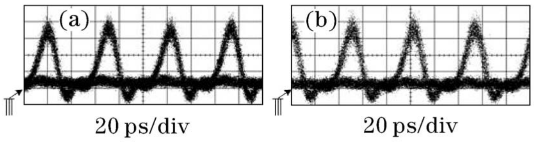

Fig. 6. Eye diagrams for the simultaneous two wavelength outputs for probe at 1560.00 nm (a) and 1561.79 nm (b).

from two AWG channels are shown in Fig. 6. It can be seen that the quality of the converted signal is high. The corresponding AWG channel output for probe at 1560.00 nm has an extinction ratio of 11.42 dB and a Q factor of 6.56. The other channel for probe at 1561.79 nm has an extinction ratio of 11.51 dB and a Q factor of 6.51. In the experiment, the states of the polarization controllers (PC1, PC2 and PC3) are carefully optimized. The mean powers for both probes are −4.1 dBm before SOA.

A wavelength converter is experimentally successfully demonstrated by exploiting NPR in SOA with AWG filtering. The wavelength conversion scheme can provide excellent operation including high extinction ratio and Q factor. The simultaneous two wavelength outputs are also successfully obtained at 20 Gb/s, the obtained extinction ratios are 11.42 and 11.51 dB, and the corresponding Q factors are 6.56 and 6.51. We expect that more converted outputs may be obtained by exploiting more CW lasers.

This work was supported by the National Natural Science Foundation of China (No. 90401025, 60577033), Project of Ministry of Education (No. 1050367), and Project for New Century Excellent Talents in University (No. NCET-04-0116). J. Zhang's e-mail address is zhangjy@cqupt.edu.cn.

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