Single-to-four all-optical wavelength and format conversion

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Abstract—**Single-to-four all-optical format conversions and wavelength conversions are demonstrated based on a single semiconductor optical amplifier (SOA). Using the four-wave-mixing effect, one input non-return-zero (NRZ) signal can be converted to four corresponding return-to-zero (RZ) signals, by pumping with two recovered clock signals. Bit error ratio measurements indicate a ~1.5 dB power penalty for the conversion at 10 Gb/s.**

Keywords - Wavelength conversion; format conversion; semiconductor optical amplifier; four wave mixing; non-return to zero; return to zero.

I. INTRODUCTION

All-optical wavelength and format conversion are key functions in providing flexible management and interfacing for wavelength division multiplexed (WDM) and optical time division multiplexed (OTDM) networks. In the past, the semiconductor optical amplifier (SOA) has been demonstrated as a good candidate for high speed all-optical signal processing including wavelength and format conversion, by utilizing nonlinear effects such as cross gain modulation (XGM), cross phase modulation (XPM) and four wave mixing (FWM). Comparing to XGM and XPM, FWM has some inherent advantages that include large spectral and dynamic range, and relative modulation format and bit-rate transparency. As a result, many papers have proposed and demonstrated FWM based all-optical wavelength conversion as well as format conversion, both for on-off keying (OOK) and phase shift keying (PSK) signals [1, 2]. Non-return-to-zero (NRZ) and return-to-zero (RZ) are the most conventional OOK formats and are widely used in current WDM and OTDM networks, due to their different time and spectral characteristics. However, most of the published papers were based on single-to-single [3] or single-to-dual [4] NRZ-to-RZ operations, which can not provide multicasting capability in addition to wavelength and format conversion.

In this paper, we propose and demonstrate single-to-four wavelength and format conversion using a single SOA. The input NRZ signal is input into the SOA as well as two synchronized clock signals, which are recovered from the input NRZ signal and used as two pump lights. Using both non-degenerate and degenerate FWM effects in the SOA, four resulting RZ signals can be achieved simultaneously at the output, showing that the ability of multicasting. Bit error ratio (BER) measurements show ~1.5 dB power penalty for the proposed conversion at 10 Gb/s. By using an SOA with higher nonlinearity, conversions at higher bit-rates can be achieved.

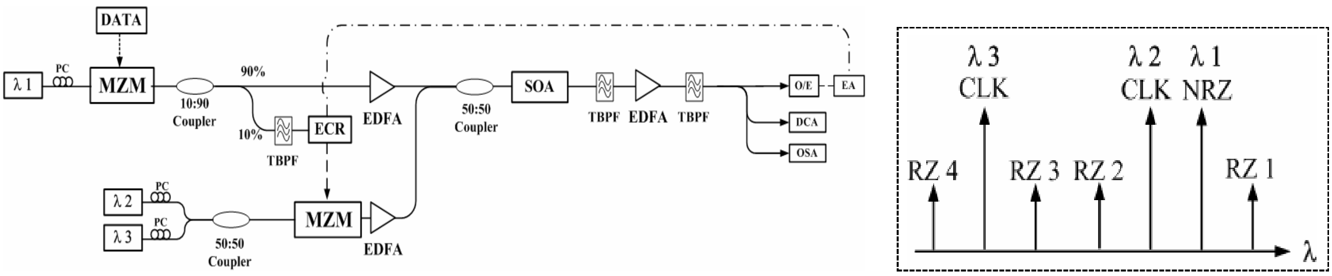
II. EXPERIMENTAL SETUP AND OPERATION PRINCIPLE

The experimental setup is shown in Fig. 1(a). The input NRZ signal is generated by modulating cw light at 1549.5 nm with a Mach-zehnder modulator (MZM). The resulting 10 Gb/s NRZ signal with 2^{31}-1 PRBS length is divided into two parts by a 10:90 coupler, the 10% tap being preprocessed via an optical filter [5] and then used to extract a synchronized RF clock signal; the 90% part being sent to the SOA to achieve wavelength and format conversion. Clock recovery (CR) is performed by a high Q electrical filter (Q≈750), this allowing a low jitter (660 fs) RF clock signal to be achieved. The recovered clock is then used to modulate two other cw channels at 1548.3 and 1543.5 nm using a second MZM, resulting in two synchronized optical clock signals. The three signals are amplified to a sufficient power by EDFAs to achieve the desired FWM effect in the SOA. The input power is 9 dBm for the NRZ signal and 12 dBm for the two clock signals. The SOA used in the experiment is a Kamelian OPA biased at 180 mA. After the SOA, a narrow band optical filter with 0.3nm 3 dB bandwidth and another EDFA are used to extract one of the converted RZ signals, which is analyzed using a digital communication analyzer (DCA), an optical spectrum analyzer (OSA) and an error analyzer (EA).

The format conversion and wavelength conversion are achieved by both non-degenerate and non-degenerate FWM in the SOA, as indicated in Fig. 1(b). Assuming the wavelength for the input NRZ and the two optical clock signals are λ_1, λ_1 and λ_3, the four converted RZ signals will be at $2\lambda_1–\lambda_2$, $2\lambda_2–\lambda_1$, $\lambda_1+\lambda_3–\lambda_2$ and $\lambda_2+\lambda_3–\lambda_1$.It should be noted that although there will also be other new wavelengths generated from the FWM process (for instance $\lambda_1+\lambda_2–\lambda_3$), the conversion efficiency is too low to obtain an RZ signal with a useful optical signal to noise ratio.

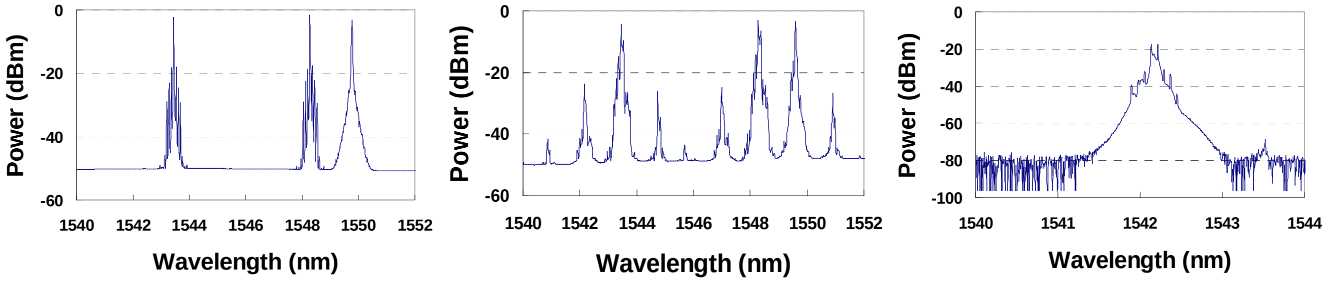
III. EXPERIMENTAL RESULTS AND DISCUSSION

Figure 2(a) shows the input spectra before the SOA. The output spectra after the SOA are presented in Fig. 2(b), showing that four main new wavelength are generated due to the FWM effect. Owing to the use of the clock signals, the wavelength conversions occur along with an NRZ to RZ format conversion. One of the converted RZ spectra is shown in Fig. 2(c).



(a) (b)

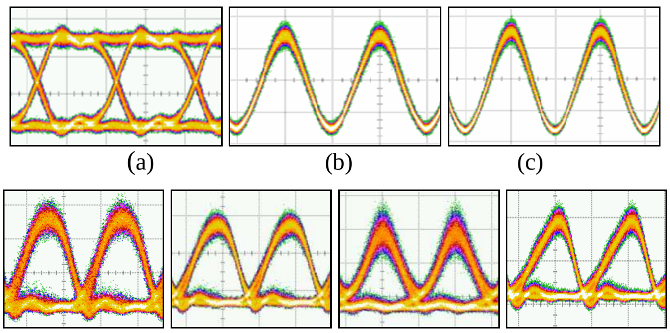
Fig. 1 (a) Experimental setup (b) operation principle



(a) (b) (c)

Fig. 2 Measured optical spectra (a) before SOA (b) after SOA (c) one converted RZ signal

The eye diagrams during the conversion process are shown in Fig. 3. Fig. 3(a) is the input NRZ signal; Fig. 3(b) and (c) are the recovered optical clock signals; Fig. 3(d) to (g) are the four converted RZ signals, corresponding to the RZ1 to RZ4 in Fig. 2(b). From these results we can see that all the converted RZ signals have good open eyes.



(a) (b) (c)

(d) (e) (f) (g)

Fig. 3 Measured eye diagrams before and after the conversions (Time scale: 50 ps/div)

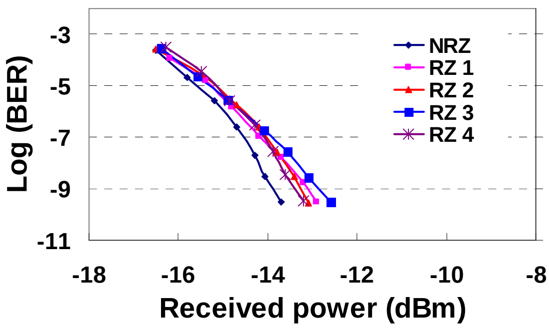


Fig. 4 BER results for the proposed conversion

In order to evaluate the conversion performance, we measured the BER for the input NRZ and output RZ signals, as shown in Fig. 4. Results show that the power penalties for the single-to-four wavelength and format conversion are about 1.5 dB.

IV. Conclusion

In conclusion, we have proposed and demonstrated a one-to-four wavelength and format conversion based on a single SOA. Thanks to the use of non-degenerate and degenerate FWM, four corresponding RZ signals can be realised simultaneously at the output by dual pumping the SOA with two recovered clock signals. BER measurements show ~1.5 dB power penalty for the demonstrated conversion at a data rate of 10 Gb/s.

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