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40-Gb/s All-Optical Wavelength Conversion, Regeneration, and Demultiplexing in an SOA-Based All-Active Mach–Zehnder Interferometer

D. Wolfson, A. Kloch, T. Fjelde, C. Janz, B. Dagens, and M. Renaud

Abstract—All-optical 2R and 3R regeneration techniques are investigated at 40 Gb/s. It is shown that an all-active SOA-based Mach–Zehnder device, employed as a wavelength converter, is capable of improving the OSNR by more than 20 dB at this bit rate, thereby resulting in penalty reduction. Furthermore, simultaneous all-optical wavelength conversion and demultiplexing from 40 to 10 Gb/s is demonstrated showing that the scheme, which also has a 3R regeneration capability, is feasible in a combined OTDM/WDM network.

Index Terms—Amplifier noise, converters, optical amplifiers, optical communication, semiconductor devices.

I. Introduction

OVER THE LAST decade, the telecommunication industry has experienced an enormous increase in need for transmission bandwidth. In order to fulfill these capacity requirements, all-optical point-to-point wavelength-division-multiplexed (WDM) systems have already been installed world-wide. Still, as IP traffic increases at an annual rate in excess of 200%, the next step in optical network evolution will be actual all-optical networking, where routing and switching are performed in the optical domain. However, a very important topic of concern for optical networks is accumulation of, e.g., noise and jitter, which severely limits the network node cascadability. Therefore, key technologies for future large-scale optical networks will be all-optical 2R and 3R regeneration. Several techniques for all-optical regeneration have been investigated and some of the most promising results have been achieved with interferometric wavelength converters [1]. Moreover, as the channel bit rate in the optical network increases to 40 Gb/s or more, a combination of both OTDM and WDM will offer a flexible network, where switching and add/drop functionalities can be accomplished in both the wavelength and time domains. In this scenario a very important need, will be for optical building blocks performing wavelength conversion and demultiplexing, operations which the interferometric devices also are able to perform [2].
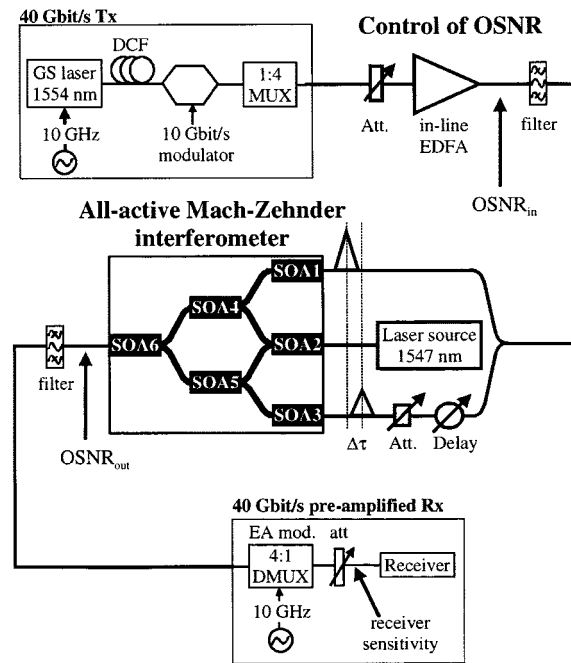
Fig. 1. Experimental setup for all-optical 2R regeneration at 40 Gb/s using an all-active MZI.

Here, we experimentally demonstrate all-optical 2R regeneration at 40-Gb/s in an SOA-based all-active Mach–Zehnder interferometer as well as the suitability for 40 Gb/s 3R regeneration. Furthermore, it is demonstrated that the Mach–Zehnder interferometer (MZI) offers simultaneous wavelength conversion and demultiplexing from 40 to 10 Gb/s suitable for a combined OTDM/WDM network.

II. All-Optical 2R Regeneration

Fig. 1 shows the experimental setup, where the device used for the experiments is an all-active MZI [3]. The 40-Gb/s RZ data signal at 1554 nm (PRBS $= 2^7 - 1$) is generated by passive multiplexing of externally modulated 10 GHz compressed pulses from a gain-switched DFB laser (FWHM ~6 ps after compression). The signal is then injected into a subblock, where the optical signal-to-noise ratio (OSNR) can be controlled. The subblock consists of a variable attenuator followed by an EDFA and an optical filter. Thus, by controlling the input power to the EDFA, the OSNR into the MZI is controlled. After the subblock the signal is split in two and injected into the signal input arms of the all-active MZI, i.e., SOA1 and SOA3, in order to exploit

a differential control scheme for high-speed operation [4]. The signal is converted to a continuous-wave (CW) signal at 1547 nm and regeneration is accomplished. At the output of the converter a filter rejects the original data signal before the regenerated signal is demultiplexed to 10 Gb/s in an EA-modulator and detected for BER measurements.

The excellent performance of the regenerator is illustrated in Fig. 2 showing the BER as a function of the received power for the back-to-back signal and the regenerated signal. Note that the EDFA input power is high, i.e., the OSNR into the regenerator is also high. The inset shows the eye diagram at the output of the regenerator. As seen, the eye diagram is both clear and open with an extinction ratio of ~10 dB. Furthermore, the all-optical 2R regenerator introduces a penalty of only 0.6 dB at 40 Gb/s (a preamplified receiver was used). With regard to the regenerative capabilities, Fig. 3 shows the OSNR (@0.1 nm) at both the input and output of the 2R regenerator as a function of the input power to the in-line EDFA. As illustrated in Fig. 3, the all-optical regenerator is capable of preserving a very high OSNR regardless of the OSNR at the input, since the spectrum after the device is determined by the spectrum of the CW source and the low ASE level from the regenerator. In this case the OSNR is kept above 37 dB even for an OSNR at the input as low as ~13 dB thus resulting in an improvement of ~24 dB. Clearly, the ability to ensure a high OSNR of regenerated signals even at high bit rates is very important when considering cascadability of the all-optical 2R regenerator. Furthermore, maintaining a high OSNR makes it possible to keep repeater spacing high, thus resulting in cost-effective transmission links. The noise suppression capabilities of the regenerator are also illustrated in Fig. 4, showing the excess penalty as a function of the input power to the in-line EDFA. As seen, a noise suppression capability is obtained for EDFA input powers below −20 dBm. As an example, at an excess power penalty of 2 dB (since a preamplifier was used) a ~2 dB lower input power to the EDFA is allowed.

III. ALL-OPTICAL 3R REGENERATION

The all-active MZI shown in Fig. 1 can also be used within an all-optical architecture for 3R regeneration. The only necessary change in the set-up in Fig. 1 is that instead of using a CW-source, a 40-GHz clock signal extracted from the data signal is used. Here, in simulation of such a clock, a gain-switched DFB laser at 1547 nm is modulated at 10 GHz and the resulting 10-GHz optical clock signal is then passively multiplexed to 40 GHz and injected into the MZI at the input of SOA2. With this scheme jitter on the data signal is transferred to minor amplitude modulation [5]. The good performance of the 3R regenerator is illustrated in Fig. 5 giving the BER as a function of the received power for the back-to-back signal and the regenerated signal. The inset shows the eye diagram at the output of the regenerator. The resulting penalty is as low as ~0.5 dB at 40 Gb/s and we note that the RZ signal format is preserved at the output of the 3R regenerator emphasizing the feasibility of this scheme at high bit rates.
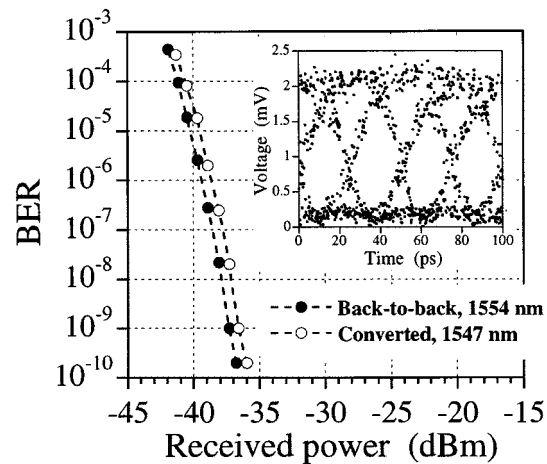

Fig. 2.   BER as a function of the received power for the back-to-back signal at 1554 nm and the 2R regenerated signal at 1547 nm. The inset shows the 40-Gb/s eye diagram at the output of the regenerator. The EDFA input power is 0 dBm.
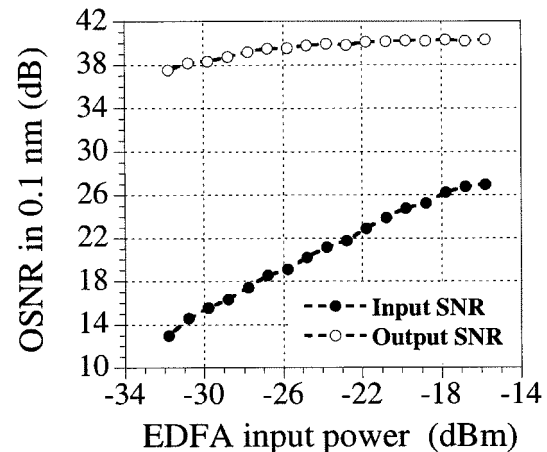

Fig. 3.   OSNR in 0.1 nm at the input and output of the all-optical 2R regenerator as a function of the input power to the in-line EDFA.
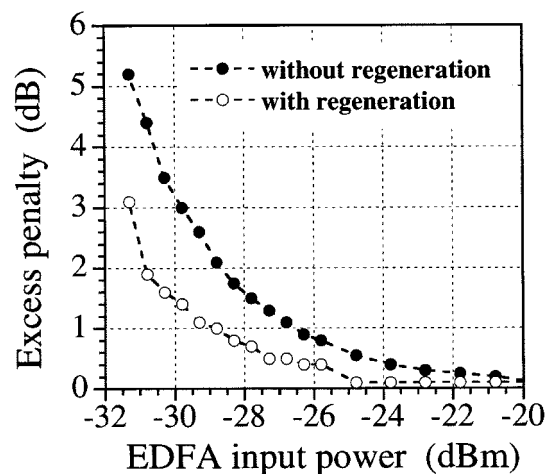

Fig. 4.   Excess penalty with and without 2R regeneration at 40 Gb/s as a function of the input power to the in-line EDFA.

IV. ALL-OPTICAL OTDM/WDM SWITCHING DEVICE

An all-optical OTDM/WDM switching device offering simultaneous wavelength conversion and demultiplexing capability is easy to realize with the all-optical MZI [2]. Referring to
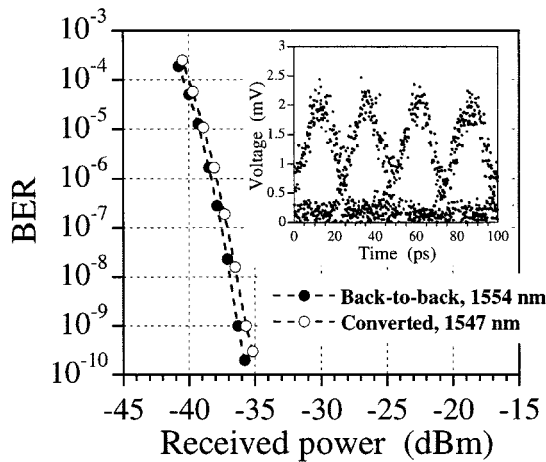
Fig. 5. BER as a function of the received power for the back-to-back signal at 1554 nm and the "3R regenerated" signal at 1547 nm. The inset shows the eye diagram at 40 Gb/s at the output of the regenerator.

Fig. 6. (a) 40-Gb/s input pulse trace at 1554 nm and (b) and (c) two different demultiplexed 10-Gb/s signals at 1547 nm.

Fig. 1, simultaneous wavelength conversion and demultiplexing can be achieved by using an optical clock signal at 10 GHz derived from the data signal instead of the CW laser source. If the clock pulse width is sufficiently short (in these experiments the pulse widths were ~6 ps), then by controlling the time delay of the 10-GHz clock signal, any of the four multiplexed 10-Gb/s signals in the 40 Gb/s signal can be demultiplexed. To verify this Fig. 6(a) shows the pulse trace of a 40-Gb/s signal at 1554 nm, while Fig. 6(b) and (c) shows two different wavelength converted and demultiplexed pulse traces at 1547 nm. It must be mentioned that the reason for the pulse overlap in Fig. 6(a) is due to the limited bandwidth of the photodetector (30 GHz). Still, the pulse traces in Fig. 6(b) ("1110") and 6(c) ("1011") clearly demonstrate that demultiplexing is achieved with a strong suppression of the other three OTDM channels. In order to assess the performance of the technique Fig. 7 shows the BER as a function of the received power for the back-to-back case (demultiplexing performed with an EA modulator as in previous results) and for demultiplexing performed with the MZI. The inset shows an eye diagram at 10 Gb/s after demultiplexing in the MZI. As seen in Fig. 7, the scheme introduces a preamplified penalty of ~3 dB for wavelength conversion and demultiplexing from 40 to 10 Gb/s. It should be emphasized that this scheme inherently has a 3R regeneration capability since a retimed clock signal is used for demultiplexing.

V. CONCLUSION

In this letter, all-optical regeneration techniques based on SOA-interferometers, and suitable for high-speed operation, have been investigated. In particular, all-optical 2R regeneration, and suitability for 3R regeneration, has been demonstrated at 40 Gb/s. It has been shown that the regenerator is capable of improving the OSNR by more than 20 dB thereby resulting in penalty reduction. Furthermore, simultaneous all-optical wavelength conversion and demultiplexing from 40 to 10 Gb/s has been demonstrated showing that the scheme, which also has a 3R regeneration capability, is feasible in a combined OTDM/WDM network. Finally, it is emphasized that all results have been achieved using the same all-active MZI.
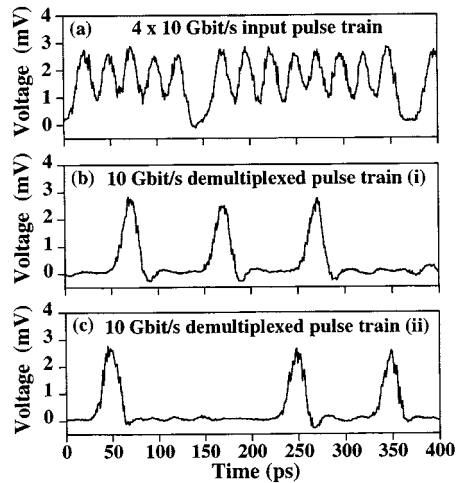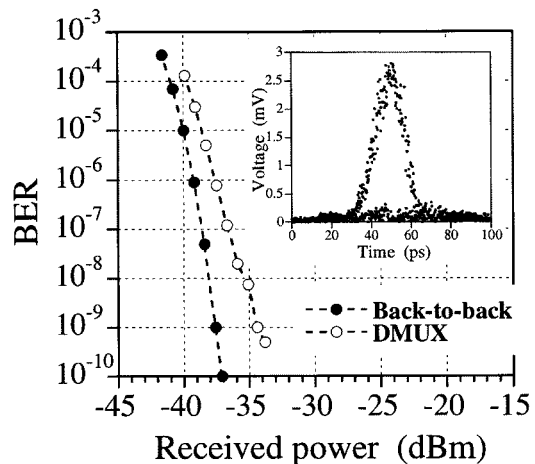

Fig. 7. BER as a function of the received power for the back-to-back signal at 1554 nm demultiplexed with an EA-modulator and the converted signal at 1547 nm demultiplexed by the all-optical Mach–Zehnder interferometer. The inset shows an eye diagram at 10 Gb/s after demultiplexing performed with the MZI.

REFERENCES

[1] B. Lavigne, D. Chiaroni, P. Guerber, L. Hamon, and A. Jourdan, "Improvement of regeneration capabilities in semiconductor optical amplifier-based 3R regenerator," in *Tech. Dig. OFC'99*, San Diego, CA, 1999, paper TuJ3.

[2] M. Duelk, St. Fischer, E. Gamper, W. Vogt, E. Gini, H. Melchior, W. Hunziker, M. Puleo, and R. Girardi, "Full 40 Gbit/s OTDM to WDM conversion: Simultaneous four channel 40 : 10 Gbit/s all-optical demultiplexing and wavelength conversion to individual wavelengths," in *Tech. Dig. OFC'99*, San Diego, CA, 1999, paper PD17.

[3] C. Janz, B. Dagens, A. Bisson, F. Poingt, F. Pommereau, F. Gaborit, I. Guillemot, and M. Renaud, "Integrated all-active Mach–Zehnder wavelength converter with record signal sensitivity and large dynamic range at 10 Gbit/s," in *Tech. Dig. OFC'99*, San Diego, CA, 1999, paper FB3.

[4] B. Mikkelsen, K. S. Jepsen, M. Vaa, H. N. Poulsen, K. E. Stubkjaer, R. Hess, M. Duelk, W. Vogt, E. Gamper, E. Gini, P. A. Besse, H. Melchior, S. Bouchoule, and F. Devaux, "All-optical wavelength converter scheme for high-speed RZ signal formats," *Electron. Lett.*, vol. 33, no. 25, pp. 2137–2139, 1997.

[5] K. S. Jepsen, A. Buxens, A. T. Clausen, H. N. Poulsen, B. Mikkelsen, and K. E. Stubkjaer, "20 Gbit/s optical 3R regeneration using polarization-independent monolithically integrated Michelson interferometer," *Electron. Lett.*, vol. 34, no. 5, pp. 472–474, 1998.