Extended Abstracts of the 2003 International Conference on Solid State Devices and Materials, Tokyo, 2003, pp. 882-883

F-9-2

100-Gbit/s Full-Rate Operation of PD-EAM Optical Gate for Retiming Function

Toshihide Yoshimatsu, Satoshi Kodama, Kaoru Yoshino and Hiroshi Ito

NTT Photonics Laboratories, NTT Corporation
3-1 Morinosato Wakamiya, Atsugi, Kanagawa 243-0198, Japan
Tel: +81-46-240-3231, Fax: +81-46-240-4306, E-mail: ytoshi@aecl.ntt.co.jp

1. Introduction

In future high-capacity high-speed optical communications systems, the data rate per channel will be over 100 Gbit/s. In such systems, an ultrafast optical gate will play an important role. Recently, various types of ultrafast all-optical gates have been reported [1-3], and their operation at full-rate has been demonstrated [2, 4, 5]. In contrast with all-optical ones, EO-based optical gates have the advantages of stability and simplicity. As an ultrafast EO-based device, we have proposed a novel monolithic optical gate consisting of a uni-traveling-carrier photodiode (UTC-PD) [6] and a traveling-wave electroabsorption modulator (TW-EAM) [7] (monolithic PD-EAM [8]), and demonstrated its very short gate opening time of 2.3 ps [8] and error-free 320-to-10-Gbit/s demultiplexing [9]. In addition to these superior characteristics, full-rate operation is also important for realizing functions such as retiming and wavelength conversion. In this work, we achieved full-rate operation of the PD-EAM optical gate at a data rate of 100 Gbit/s.

2. Monolithic PD-EAM

Figure 1 schematically shows the retiming function operation using the monolithic PD-EAM, which is superimposed on a chip photograph. The PD-EAM [9] consists of an InP/InGaAs UTC-PD, a TW-EAM with InAlGaAs/InAlAs multiple-quantum-wells, two bias capacitors, a terminal resistor (R_T), and two thin-film microstrip lines (MSLs) for interconnections. The signal line of the MSLs connects the anode of the UTC-PD and p-metal of the EAM, making the gate transmission type. The R_T and the MSLs were fabricated to be 15 Ω, which matches the characteristic impedance of the TW-EAM. The UTC-PD has an absorption layer of 80 nm and the TW-EAM has a 200-μm active region. The chip size is 1 × 0.4 mm^2.

The UTC-PD has short rise and fall times even if its electrical output saturates. By using this characteristic together with the non-linear extinction characteristic of the EAM, the PD-EAM can exhibit rectangular-like gating waveform as shown in Fig. 1. This is an important feature of the PD-EAM, allowing it to properly achieve the retiming of input data having timing jitter.

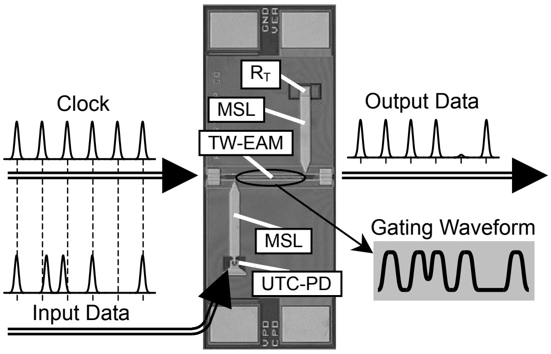

Fig. 1 Retiming configuration of the PD-EAM.

3. Experiment

Figure 2 shows the experimental setup. A 100-GHz optical clock signal was generated by optically multiplexing a 12.5-GHz pulse stream generated from an actively mode-locked fiber ring laser (ML-FL). The wavelength and full width at half maximum (FWHM) of the initial pulse were 1.55 μm and 1.8 ps, respectively. 100-Gbit/s optical data were prepared by using the signal from the same ML-FL by encoding at 12.5 Gbit/s and multiplexing. The clock and the data signals were fed into

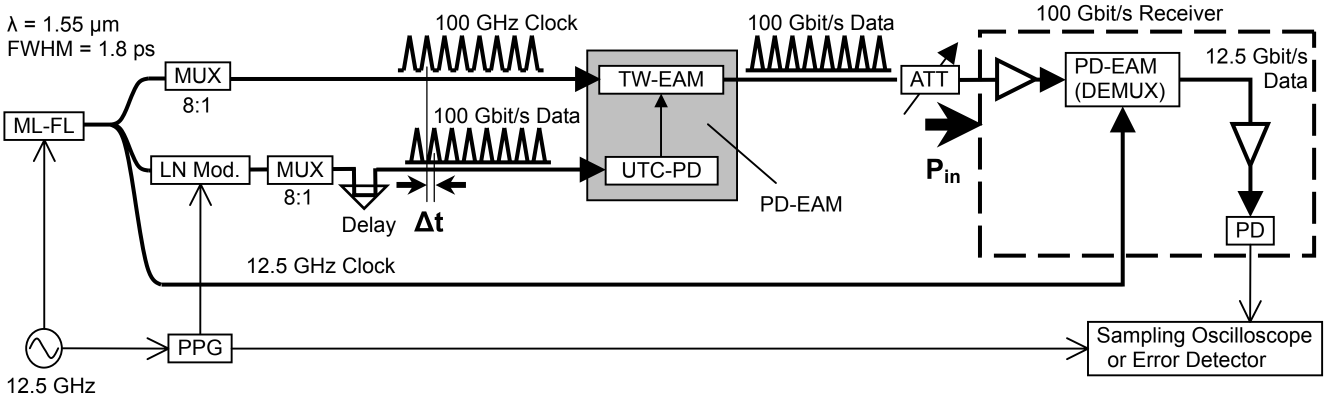

Fig. 2 Experimental setup.

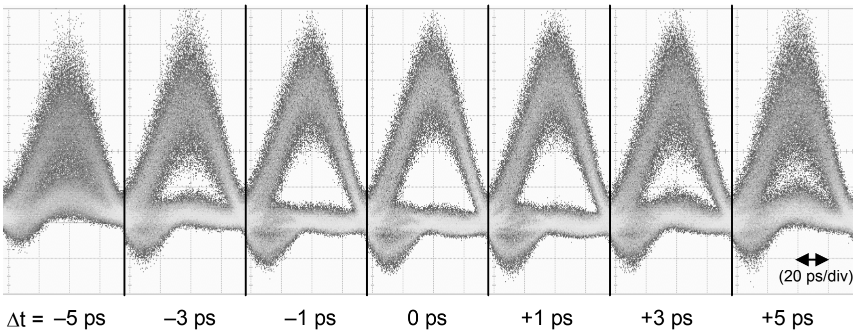

Fig. 3 Demultiplexed 12.5 Gbit/s eye patterns.

the EAM and the PD, respectively. The 100-Gbit/s output data signal from the PD-EAM was demultiplexed to a 12.5-Gbit/s data signal by a 100-Gbit/s receiver system using another PD-EAM as a demultiplexer (DEMUX). To characterize the full-rate retiming operation of the PD-EAM, we made an intentional timing shift between the clock and input data signals using an optical delay line. Received optical power (P_{in}) was defined as the average input power to the 100-Gbit/s receiver system. Input pulse energies to the EAM and the UTC-PD were 50 fJ/pulse and 2 pJ/pulse, respectively. Bias voltages of the EAM and the UTC-PD were kept at –1.7 and –2.0 V, respectively.

4. Results and Discussion

Figure 3 shows eye diagrams of the demultiplexed 12.5-Gbit/s data signals. Here, the timing shift (Δt) between the 100-Gbit/s data signal and the 100-GHz clock signal was a parameter. Clear eye openings were observed at Δt from –1 to +1 ps. This indicates that the PD-EAM has a timing margin of about 2 ps (20% of the time slot) for the full-rate retiming operation at 100 Gbit/s.

To characterize the degradation of the gated signals by the PD-EAM, the bit error rate (BER) was measured at Δt of 0 ps. The BER curve for the retiming operation is shown in Fig. 4 by closed circles. For comparison, the BER curve for the case that the 100-Gbit/s input data was directly received by the DEMUX system is also shown (open squares). As shown in Fig. 4, full-rate error-free operation of the PD-EAM at 100 Gbit/s was achieved with a minimum sensitivity of –27.5 dBm at a BER of 10^{-9}. To our knowledge, this is the fastest full-rate operation ever achieved by an EO-based optical gate. It is also revealed, by comparing the two curves, that the power penalty of the retiming operation using the PD-EAM was very small. These results indicate that the PD-EAM is promising for the use in 100-Gbit/s optical communications systems.

5. Conclusion

We have demonstrated the retiming operation of a PD-EAM at 100 Gbit/s. The timing margin was found to be about 2 ps. Error-free full-rate operation at 100 Gbit/s was achieved with a very small power penalty. These

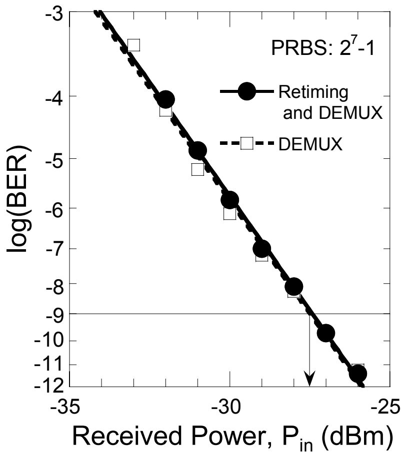

Fig. 4 Bit error rate curves after demultiplexing.

results indicate that PD-EAM is a promising device for full-rate optical signal processing at 100 Gbit/s.

References

[1] N.J. Doran and D. Wood, Opt. Lett. **13** (1988) 56.

[2] C. Schubert, R. Ludwig, S. Watanabe, F. Futami, C. Schmidt, J. Berger, C. Boerner, S. Ferber and H.G. Weber, Electron. Lett. **38** (2002) 903.

[3] K. Tajima, S. Nakamura, Y. Ueno, J. Sasaki, T. Sugimoto, T. Kato, T. Shimoda, M. Itoh, H. Hatakeyama, T. Tamanuki and T. Sasaki, Electron. Lett. **35** (1999) 2030.

[4] Y. Ueno, S. Nakamura and K. Tajima, IEEE Photon. Technol. Lett. **13** (2001) 469.

[5] S. Nakamura, Y. Ueno and K. Tajima, IEEE Photon. Technol. Lett. **13** (2001) 1091.

[6] T. Ishibashi, N. Shimizu, S. Kodama, H. Ito, T. Nagatsuma and T. Furuta, *OSA TOPS on Ultrafast Electronics and Optoelectronics*, eds. M. Nuss and J. Bowers (Optical Society of America, Washington, D.C., 1997) Vol. 13, p. 83.

[7] K. Kawano, M. Kohtoku, M. Ueki, T. Ito, S. Kondoh, Y. Noguchi and Y. Hasumi, Electron. Lett. **33** (1997) 1580.

[8] S. Kodama, T. Ito, N. Watanabe, S. Kondo, H. Takeuchi, H. Ito and T. Ishibashi, Electron. Lett. **37** (2001) 1185.

[9] S. Kodama, T. Yoshimatsu and H. Ito, *Tech. Dig. of Optical Fiber Communication Conference, 2003*, Vol. 2, paper ThX5, p. 588.