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Monolithic PD-EAM Optical Gates for Ultrafast Signal Processing

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1. Introduction

In future optical communications systems, ultrafast signal processing at speeds beyond the limitation of conventional electrical devices will be required. Among optical gates, which are key devices for optical signal processing, electro-optic (EO) ones are very attractive for practical use in terms of device simplicity and stability. However, it has been difficult to realize an ultrafast EO gate, because the gating speed is limited by the bandwidths of the electrical driver amplifier and electrical interconnection between discrete devices. The monolithic optical gate named the PD-EAM [1] is a promising device to overcome the speed problem of conventional EO gates. The PD-EAM monolithically integrates a uni-traveling-carrier photodiode (UTC-PD) [2] and a traveling wave electroabsorption modulator (TW-EAM) [3], in which the electrical output of the UTC-PD directly drives the TW-EAM. The PD-EAM optical gate has already demonstrated an ultrafast gate opening time of 2.3 ps [1]. In this paper, we describe the features of the monolithic PD-EAM optical gate and its applications to ultrafast optical signal processing, such as demultiplexing (DEMUX) and retiming.

2. Monolithic PD-EAM

Figures 1(a) and (b) show a photograph and circuit diagram of the monolithic PD-EAM [4]. The PD-EAM consists of a back-illuminated InP/InGaAs UTC-PD, a TW-EAM with InAlGaAs/InAlAs multiple-quantum-wells (MQWs), two bias capacitors, and a terminal resistor (R_T). All elements are monolithically integrated on a chip (1 x 0.4 mm). The PD anode is connected to the signal line (anode) of the TW-EAM by a thin-film microstrip line (MSL). An optical input (photo-current) generates a positive voltage signal to the EAM. Thus, the device functions as a transmission-type optical gate. The other side of the TW-EAM is connected to R_T by another MSL. Measured characteristic impedances of the EAM and the MSLs are around 15 Ω. The EAM ridge waveguide has a 200-μm-long active region. The junction area of the UTC-PD is 50 μm^2 and its 3-dB bandwidth is around 160 GHz.

3. Ultrafast optical signal processing by using PD-EAM

320-Gbit/s error-free DEMUX

Figures 2(a) and (b) show error-free DEMUX operation of the PD-EAM at data rates of up to 320 Gbit/s [4]. The demultiplexer consists of a monolithic PD-EAM optical

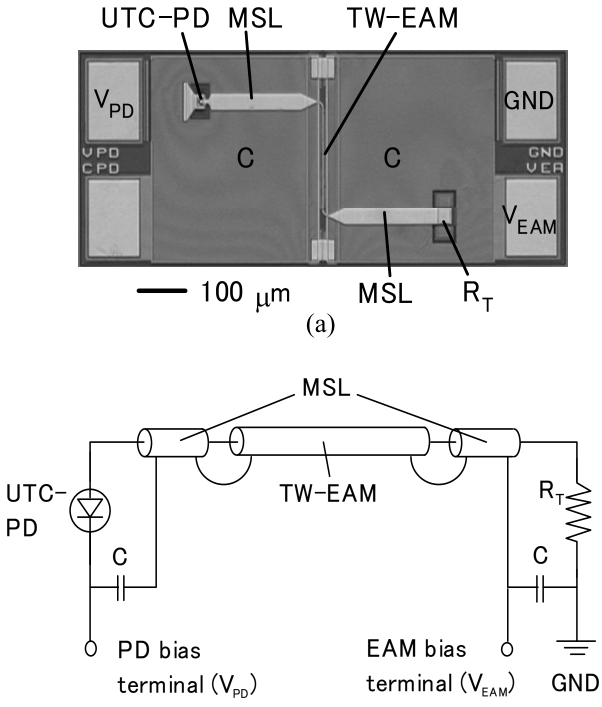
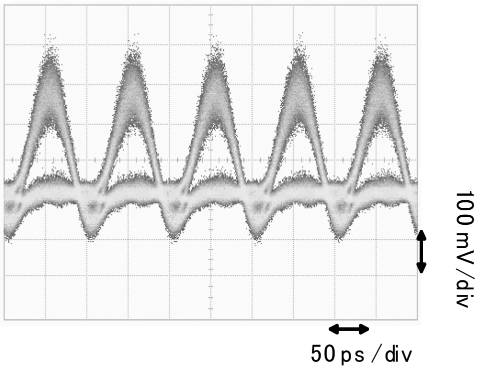


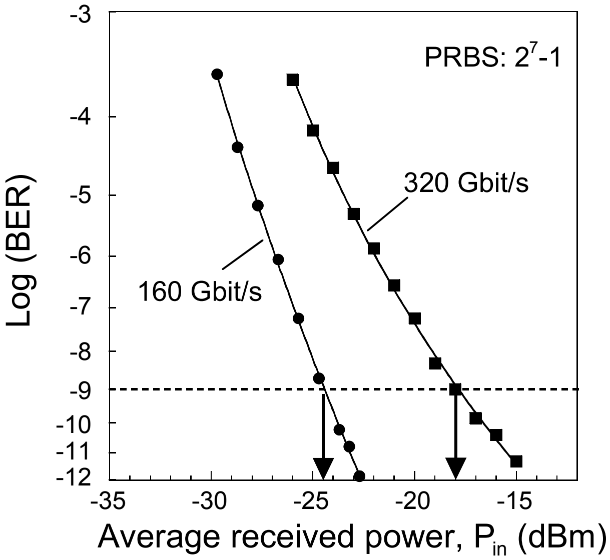
Fig. 1. (a) Photograph and (b) circuit diagram of the fabricated PD-EAM optical gate.

gate, two Er-doped fiber amplifiers (EDFAs) (one in front of the PD and the other in front of the EAM, and a variable optical delay line. The clock signals were prepared using a 1.55-μm optical pulse stream generated by an actively mode-locked fiber ring laser (ML-FL) with a repetition rate of 9.95328 GHz. The same initial pulse stream from the ML-FL was encoded to pseudo-random bit sequence (PRBS) as a 10-Gbit/s optical data signal. The 320-Gbit/s data signal was prepared by optically multiplexing the 10-Gbit/s data signal. Received optical power, P_{in}, is defined as the input to the EDFA in front of the EAM in order to characterize the sensitivity of the receiver including the demultiplexer.

Figure 2(a) is the eye diagram of the demultiplexed 10-Gbit/s data signal at an input data rate of 320 Gbit/s. Clear eye openings are observed. The on/off ratios between on-state channel and off-state channels were evaluated by observing the waveform of output data signal using the cross-correlation technique, and were found to be larger than 12 dB for the adjacent channels and larger than 25 dB for the other channel. Figure 2(b) shows the



(a)



(b)

Fig. 2. Error-free DEMUX operation of the PD-EAM. (a) Eye diagram of the demultiplexed 10-Gbit/s data signal with input data rate of 320 Gbit/s, and (b) bit error rates for the 160-Gbit/s and 320-Gbit/s DEMUX.

measured bit error rate (BER) for the 320-Gbit/s-to-10-Gbit/s DEMUX together with the result for the 160-Gbits data input case. Error-free operation with receiver sensitivites of -18 dBm for 320-Gbit/s DEMUX and -24.5 dBm for 160-Gbit/s DEMUX at a BER of 10^{-9} was achieved. These are the fastest error-free DEMUX operations ever achieved for an EO-type optical gate.

100-Gbit/s Retiming Operation

The optically multiplexed return-to-zero data may not have equivalence due to the fluctuation of physical parameters, such as optical fiber length and phase shifter position. Thus, retiming operation, at full-rate is also an important function for OTDM systems.

Figure 3 shows the experimental results of 100-Gbit/s retiming by using a PD-EAM optical gate. The RZ clock and data pulses were fed into the EAM and UTC-PD, respectively. The clock pulses have the same time interval

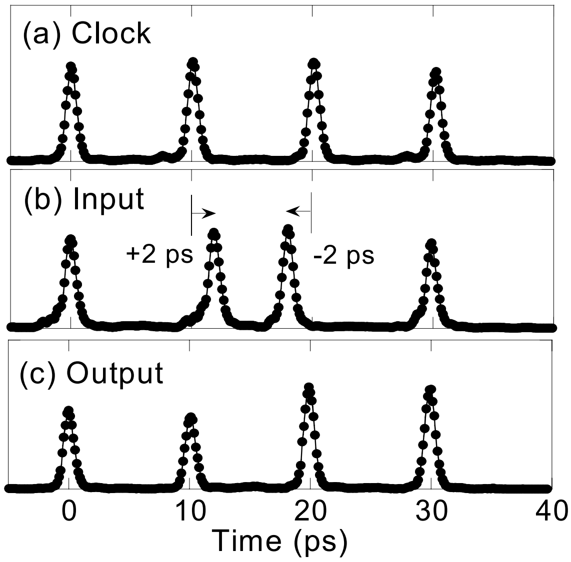


Fig. 3. The signal waveforms of (a) clock, (b) input data and (c) output data for 100-Gbit/s retiming operation of the PD-EAM

of 10 ps [Fig. 3(a)], while the intervals of the data pulses were intentionally shifted by plus-minus 2 picoseconds [Fig. 3(b)]. As shown in Fig. 3(c), the time intervals of the output data pulses are successfully adjusted to those of the clock pulses. This is the fastest retiming operation ever achieved for an EO-type optical gate. Such fast operation could be accomplished because the PD-EAM has a rectangular-like gate operating due to the output saturation of the UTC-PD and nonlinear extinction of the EAM. In a separate experiment, an on/off ratio larger than 10 dB between on- and off-state pulses and intensity fluctuation of less than 2 dB among output data pulses were also achieved with a timing margin of 4 ps.

3. Conclusion

The PD-EAM optical gate has excellent high-speed performance and can be used for various functions such as DEMUX, retiming, signal reshaping, wavelength conversion, and optical sampling. Thus, the PD-EAM optical gate is a promising device for future high-bit-rate optical communications systems.

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References

[1] S. Kodama et al., Electron. Lett., 37 (2001) 1185.

[2] T. Ishibashi et al., OSA TOPS on Ultrafast Electronics and Optoelectronics, 28 (1997) 83.

[3] K. Kawano et al., Electron. Lett., 33 (1997) 1580.

[4] S. Kodama et al., Tech. Dig. OFC 2003, Vol. 2, paper ThX5, p. 588.