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Si フォトニック結晶 MZ 型光変調器のエラーフリー動作

Error-free Operation of Si Photonic Crystal MZI Optical Modulators

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Carrier-depletion, Mach-Zehnder (MZI) type silicon optical modulators can be shortened significantly by incorporating slow-light photonic crystal waveguides (PCWs). Sub-100 μm PCW-MZIs have been demonstrated at speeds up to 40 Gb/s [1]. In this paper, we perform an in-depth study of the 10 Gb/s operation of 200 μm PCW-MZIs, and show that they can achieve error-free operation. The device consists of a pair of 200 μm-long SiO_2-clad, p/n-diode PCWs incorporated into a symmetric MZI [1], where the PCWs have a lattice constant of 400 nm, target hole-diameter of 215 nm, and a third-row lattice-shift of 95 nm [2]. The on-chip insertion loss of the PCW-MZI is 9.2 dB. The device is driven by 10 Gb/s $2^{31}-1$ bit NRZ PRBS signals, in push-pull configuration, in the spectral range where the group index is ~20.

Fig. 1 shows the 10 Gb/s eye patterns of the modulated signal when the device is driven at different bias voltages (V_{DC}), each at a received power of approximately −1 dBm. As shown in (a), the eye is clearly open at V_{DC} = −6 V where the optimal drive voltage V_{pp} is 4.5 V and gives the lowest bit-error rate (BER) well below 10^{-9} and is therefore error-free. When V_{DC} is reduced to −1 V, as shown in (b), V_{pp} drops to 1.4 V and BER rises to 10^{-6}. (c) shows the eye pattern of the RF drive signal for comparison. Fig. 2 shows the variation of V_{pp}, excess loss and extinction ratio (ER) as a function of V_{DC}. The optimal V_{pp} drops with a smaller reverse-bias. While the excess loss remains constant at 1 to 2 dB, ER remains above 6 dB for $V_{DC} \leq -3$ V, but drops to < 2 dB with a weaker reverse-bias, indicating a reduced phase-shift and modulation amplitude, resulting in an increased BER. Fig. 3 shows the BER as a function of received optical power at the photo-detector, for various V_{DC}. While error-free operation with BER < 10^{-9} can be achieved for a strong reverse-bias, the minimum BER rises as the bias is weakened since the ER and modulation amplitudes are reduced. This work was supported in part by the FIRST Program of JSPS.

References: [1] H. C. Nguyen et. al, Opt. Express 20 (2012), 22465. [2] M. Shinkawa et. al., Opt. Express 19 (2011), 22208.

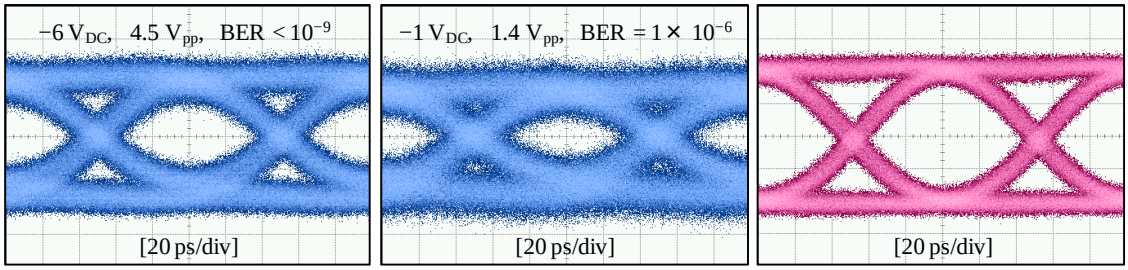

Fig. 1. 10 Gb/s eye patterns for (a) −6 V_{DC} and (b) −1 V_{DC} operations, and (c) RF drive signal.

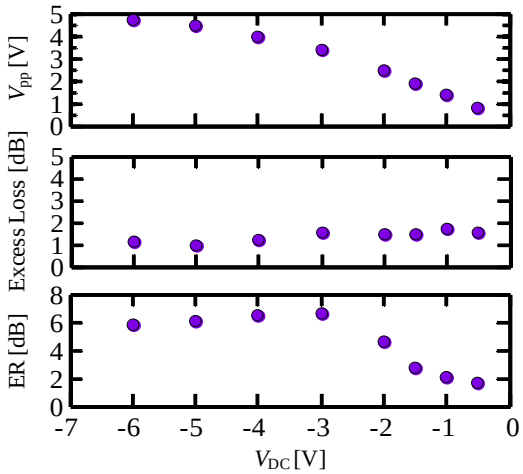

Fig. 2. V_{DC} dependence of drive V_{pp}, excess loss and ER.

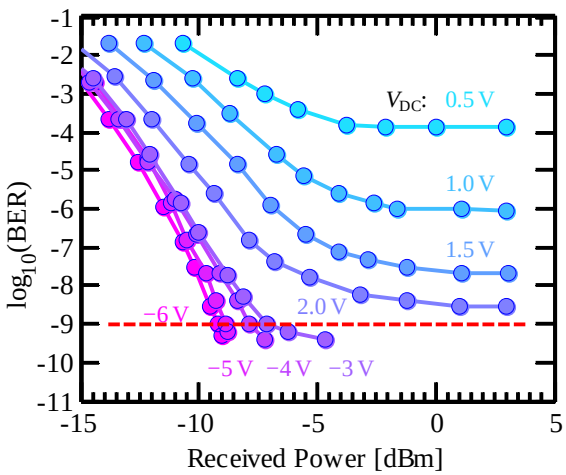

Fig. 3. V_{DC} dependence of BER.