Compact, High Extinction Ratio Silicon Mach-Zehnder Modulator with Corrugated Waveguides

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Abstract: An integrated silicon photonic MZM modulator with a slow-wave architecture to reduce $V_{\pi}L$ is presented. This structure achieves an 80% enhancement in extinction ratio and has a 14GHz bandwidth with 1mm long modulator arms.

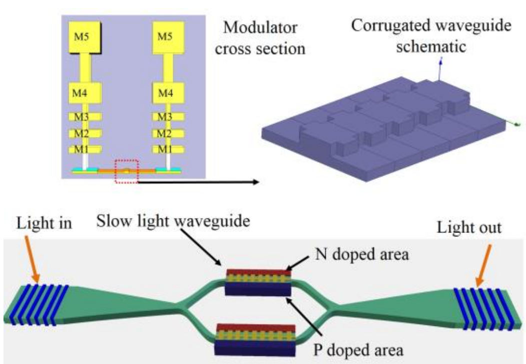
OCIS codes: (130.0130) Integrated optics; (130.4110) Modulators.

1. Introduction

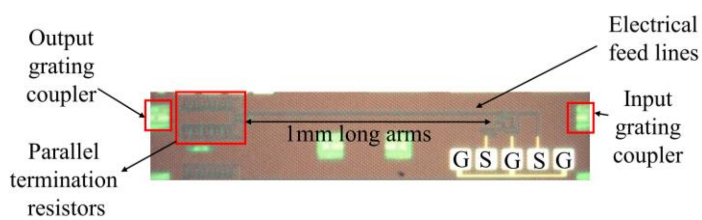
Compact, low-power, and high-efficiency optical modulators are imperative to meet the demands of the expanding data-communication and telecommunications markets. Integrated silicon photonic platforms with monolithic modulators such as Mach-Zehnder modulators (MZMs) and ring modulators are the most promising candidates for the communication market due to their low cost and high yield [1,2]. In particular, MZMs are of great interest due to their high extinction ratio, high optical bandwidth, and insensitivity to process and environmental variations [3]. Despite these advantages, high-speed MZMs typically have a large $V_{\pi}L$ resulting in a trade-off between device length and electrical drive voltage requirements. To break this trade-off, one dimensional slow-light waveguides have been used to reduce $V_{\pi}L$ [4,5]. In this paper, a compact MZM modulator with corrugated waveguides is designed that incorporates the band-edge slow-light effect to achieve a high extinction ratio and a reduced required drive voltage.

2. Corrugated waveguide modulator

The modulator was fabricated through the multi-project wafer (MPW) run at IHP microelectronics. The schematic of the slow-light modulator as well as its cross-section view and schematic of corrugated waveguides are shown in Fig. 1(a). The dimensions of the corrugated waveguide waveguides are as follows: main rib width 340nm, corrugated rib width 170nm, period 300nm, corrugated period 150 nm, rib height 220nm, and slab height 120nm. The bandwidth of the modulator has been modeled using an equivalent circuit model for the PN junction of the photonic modulator in conjunction with the impedances of the metal layers [6,7]. Due to the high confinement of light in the doped region, the slow-light modulator experiences a larger phase shift than conventional rib waveguide modulators. This results in a lower drive voltage requirement.



(a)



(b)

Fig. 1: a) Schematic of the proposed corrugated based slow-light modulator, modulator cross-section view, and schematic of corrugated waveguide b) The die photo of the modulator

The modulator has 1mm long modulator arms with doping concentrations of $5\times10^{17}cm^{-3}$ for both acceptors and donors. The electrical input signal is delivered via a GSGSG probe to the electrical feedlines of the slow-wave modulator. The feedline is terminated with two parallel termination resistors to prevent back-reflection. Each of the termination resistors is a bank of resistors that can be laser trimmed for postfabrication calibration. Simulation results [8] show a 15 GHz electrical bandwidth at 1mm modulator length and 2 V.cm modulation efficiency.

2. Measurement results

The DC response of the modulator is shown in Fig. 2(a) for several wavelengths. The required voltage to achieve a 2π phase shift in 1532.1nm is 2.49V, which reduces to 1.76V at 1533.7nm, the center frequency of the slow-wave regime. The measurement setup for the AC response, optical extinction ratio characterization, and eye diagram measurement is shown in Fig. 2(b). The AC response of the modulator was measured using an external electrical driver and a calibrated photodiode with 40GHz bandwidth as shown in Fig. 2(c). The measured electro-optical bandwidth of the modulator was measured to be 14GHz as shown in Fig 2(c). In Fig. 2(d), the optical extinction ratio of the modulator across several wavelengths was measured for a constant electrical drive of 4.2V peak-to-peak at 1.25GHz using an electrical oscilloscope. Compared to standard rib waveguide modulators, the corrugated waveguide modulator has an 80% enhancement in extinction ratio. The eye diagram for NRZ PRBS7 modulation at 5Gbps without applying pre-emphasis is shown in Fig. 2(e).

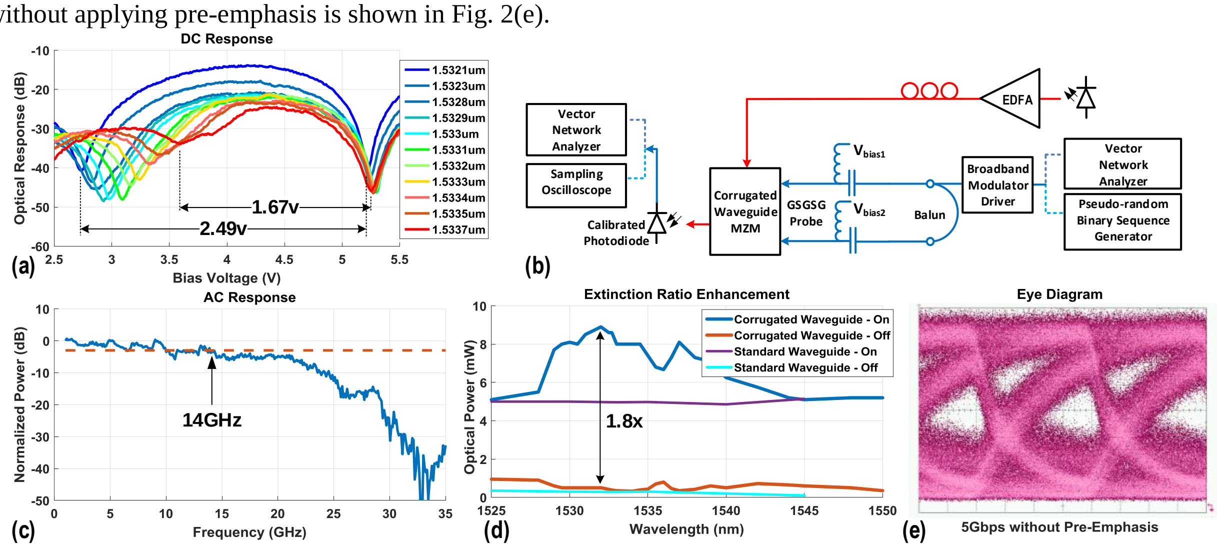


Fig 2. a) DC response of the corrugated waveguide modulator b) Characterization setup c) AC response of the modulator d) Measured extinction ratio of the modulator at 1.25GHz e) Eye diagram for NRZ data transmission at 5Gbps

The slow-light corrugated waveguide modulator showed a 3dB bandwidth of 14GHz with an 80% enhancement in extinction ratio and 67% improvement of modulation efficiency at 1533.7nm wavelength due to the enhanced group index of the structure. We also found that the dominant pole of the structure is at much higher frequency than 14GHz. However, due to impedance mismatch in the electrical path as well as velocity mismatch between the optical and electrical signals, the data transmission rate of the structure is limited to 5Gbps.

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