50 Gbit/s silicon modulator operated at 1950 nm

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Abstract: We have experimentally demonstrated an integrated silicon Mach-Zehnder modulator which operates at 1950 nm wavelength range. 50 Gbit/s intensity modulation is achieved with bit error rate below 3.8×10^{-3}.

OCIS codes: (130.0130) Integrated optics; (230.0230) Optical devices

1. Introduction

Recently, growing efforts have been directed to 2-μm spectral band which is expected to be a new window for optical fiber communications. This waveband promises a rich resource of wavelength channel and holds the intrinsic advantages of low loss and low latency using hollow-core photonic bandgap fiber [1]. Motivated by the prospect for long wavelength optical communications, several subsystem experiments of high-speed data transmission at 2-μm spectral band have been demonstrated using discrete packaged components [2,3]. To reduce the footprint and power consumption of the system, optical integration at this long wavelength range become significant as well. As a proven integration platform, silicon photonic (SiP) devices at 2-μm waveband have attracted much research interests very recently. Shifting the wavelength to 2-μm provide quite a few benefits for silicon photonic devices such as much weaker two photon absorption, more efficient free carrier plasma effect, lower dispersion and latency. Silicon photonic grating couplers [4], optical filters [5], and photodetectors [6] have been reported very recently. However, the primary concern is the absent of high-speed modulator at this new spectral band. Several works have been reported towards silicon modulators in long wavelength regime [7,8], but the modulation speed is limited to 20 Gbit/s which needs significant improvement.

In this paper, we demonstrate a silicon Mach-Zehnder modulator (MZM) which operates at 2-μm waveband. which is the key component for the potential MDM in this spectral band. The modulator is fabricated via CMOS compatible process, and it can support efficient modulation at 2-μm band. The device design and characterization results are presented in this paper. The modulator can achieve intensity modulation with up to 50 Gbit/s data rate.

2. Device Design and fabrication

A depletion type modulator with two series PN junctions connected in push-pull mode is designed on a high-resistance silicon-on-insulator (SOI) wafer with a 220 nm thick silicon layer, a 3 μm thick buried oxide (BOX) and a 700 μm silicon substrate layer. The device is fabricated by 180 nm CMOS process. The SiP MZM is implemented by a rib waveguide with 90 nm thick slab. The waveguide width is chosen to be 600 nm and the active length of the modulator is 2mm. Figure 1 shows the micrograph of the SiP MZM modulator. For a better modulation efficiency, the lateral PN junction interface is offset of 50 nm from the waveguide center to the N type region. The doping concentration of the PN junction is nonuniform in the vertical direction and around 5×10^{17} cm^{-3}. A DC bias voltage is applied to reverse bias the two modulators. GS rail electrode design is used to match the differential driver with impendence of 60 ohm. Two ultra-broadband, low loss 3dB power splitter is used to form the modulator Mach-Zehnder Interferometer (MZI) structure and support broadband operation [9]. Due to the series push-pull (SPP) configuration, the microwave losses decrease. The MZM travelling wave electrode is terminated using on-chip 60 ohm terminations.

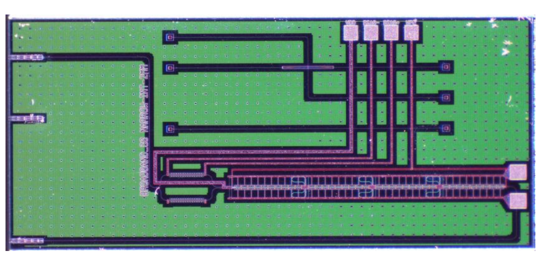

Fig. 1. The micrograph of the broad-spectrum SiP MZM modulator.

3. Device Characterization

To characterize the broadband modulator, a narrow linewidth laser with an output at 1950 nm is used as the light source. The laser output is polarization controlled using a three-paddle controller made with a long SM-1950 jump fiber. The modulator is packaged with lensed fiber for optical coupling and is wire-bonded to apply the electrical bias. The mode size converter is designed to match the mode profile between the silicon waveguide and lens fiber. The measured total insertion loss of the device is 18dB including the coupling loss. A thulium-doped fiber amplifier (TDFA) is used to boost the optical power prior to the chip. The electrical signals and the DC bias for PN junction is applied to the waveguide through the high-speed RF probe and the bias tee. The RF signals transmits in the travelling wave electrodes which is terminated by an on-chip 60 ohm resistor. The output optical power can be measured by an InGaAs power meter. The MZM is designed to be zero path difference between the two arms which avoids the interference fringes in the optical spectrum.

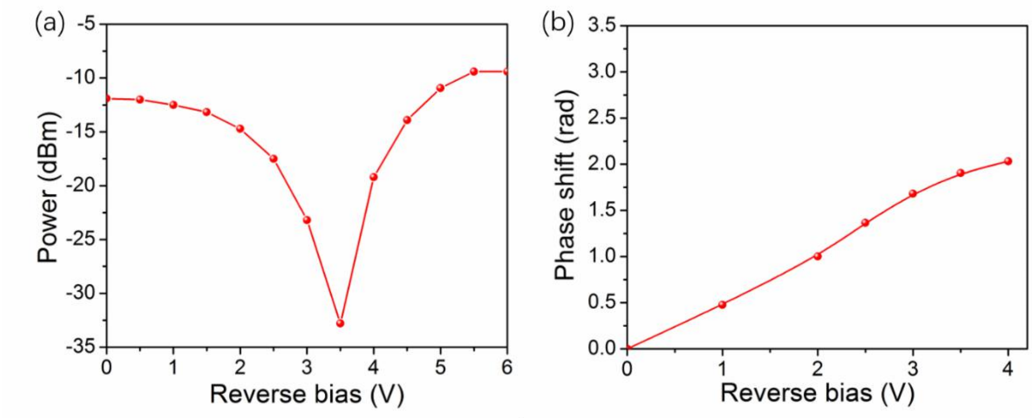

Fig. 2. (a) Optical transmission and (b) Phase shift as a function of reverse bias for a MZM at 1950nm.

We characterize the modulation efficiency by measuring the V_π of the modulator. The incident optical wave experiences a phase shift when the refractive index is varied via the free carrier plasma effect. We measure the output power as a function of the applied voltage and plot the curve in Fig. 2 (a). It can be seen that the V_π is around 5V. The MZM can achieve an extinction ratio of ~20 dB by switching the output on and off. The phase shift is also calculated as a function of the reverse bias as shown in Fig. 2 (b).

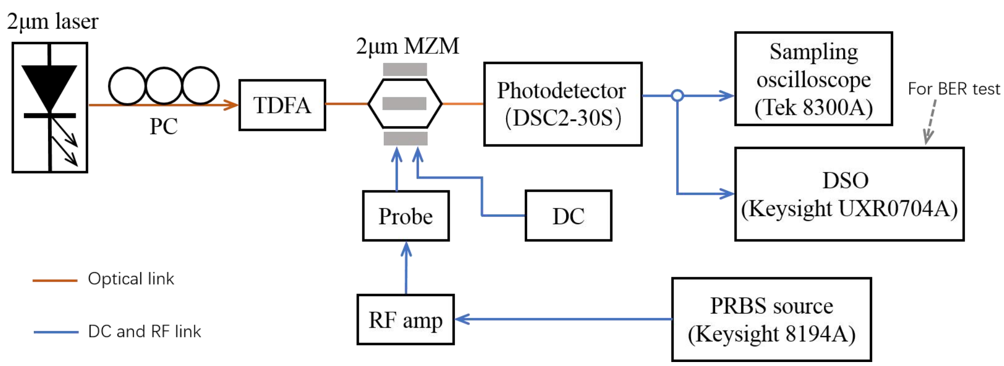

Fig. 3. High-speed RF measurement setup for 2 µm wavelength modulator.

The high-speed data modulation experiment is then carried out, and the system setup is described in Fig.3. The high-speed pseudorandom binary sequence (PRBS) is generated by an arbitrary waveform generator (Keysight 8194A). The baseband signal is amplified by RF amplifier and applied to the modulator via a high-speed electrical probe. The RF signal is boosted to 18 dBm to drive the modulator, and the PN junction is reverse biased. The optical output of the modulator is fed to a commercial high-speed InGaAs photodetector with 22 GHz bandwidth. The photodetector output is monitored by a sampling oscilloscope (Tek 8300A). Then the output of PD is acquired by real-time digital storage oscilloscope (DSO) with sampling rate of 256GS/s (Keysight UXR0704A), and the off-line DSP is processed by computer to get bit error rate (BER). The captured eye diagrams of the modulated output are shown by the insets in Fig. 4. The eye diagram is wide open for 40 Gbit/s modulation and the corresponding BER curve is measured. Increasing the bit rate to 50 Gbit/s degrades the eye diagram significantly. This can be observed from the reduced extinction ratio of the eye. But the BER can still be measured to be below the forward error correction (FEC) limit of 3.8×10^{-3} for hard decision with 7% overhead. The performance degradation of 50Gbit/s signal is due to the bandwidth constraint from the photodetector. Another reason for the limited bandwidth is due to the group velocity mismatch between the RF signal and the 2-µm optical wave. The modulation efficiency can be further improved by either increasing the length or optimizing the PN junction. For both bit rates, the noise comes from the amplified spontaneous emission. It can be improved by narrowband filtering after the optical amplifier.

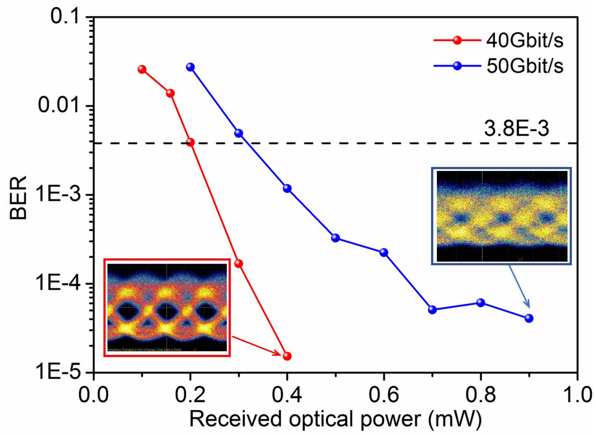

Fig. 4. BER curves for MZM under data rate of 40 Gbit/s and 50 Gbit/s at 1950 nm wavelength. Inset: the eye diagrams of the received modulated signals.

4. Conclusion

In summary, we have experimentally demonstrated a silicon photonic modulator which operates at 1950 nm. Intensity modulation with 50 Gbit/s is achieved with BER below 3.8×10^{-3}. Such a high-speed silicon modulator opens a new avenue for optical communications at 2-µm spectral range.

Acknowledgement

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