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Bragg Reflector Waveguide Modulator toward High-Speed Operations and Low Power Consumption

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Abstract We demonstrate an ultra-compact electro-absorption modulator based on a Bragg reflector waveguide. The peak-to-peak driving-voltage was below 1.0V. The miniature device shows a prospect of ultra-low power-consumption below 100fJ/bit. The modulator's compact size and high performance come from the slowed-down light group velocity.

Introduction

Nowadays, much attentions are paid on optical interconnects with low power consumptions. There have been reports demonstrating modulators with driving voltage below 1 V, however, they are always at a cost of narrow optical bandwidths or long device lengths [1]. We previously proposed an electro-absorption (EA) modulator employing the quantum-confined Stark effect (QCSE) based on a Bragg reflector waveguide [2, 3]. In this paper, we will show its low-voltage and high-speed modulation. We will also discuss a prospect for ultra-large bandwidth as well as ultra-low power consumption.

Device Structure and Principles

The proposed modulator is fabricated on a VCSEL epitaxial wafer. A schematic cross-section view of the device is shown in Fig. 1. An input light is coupled through a lensed fiber to the device and propagates along the waveguide. A so-called 'slow-light' mode is excited inside the waveguide and travels in a zigzag route. It can promote stronger light-matter interaction inside thus we can make the device several times smaller than conventional EA modulator.

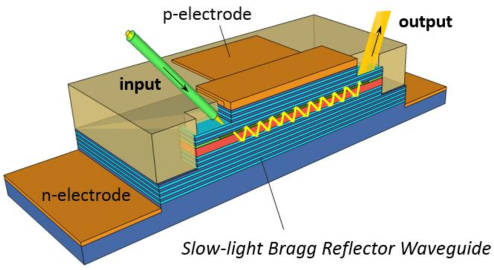

Fig. 1: A schematic cross-section view of the slow-light Bragg reflector waveguide modulator.

Device Characteristics and Power consumption

We first measured the device static characteristics to see the extinction ratio (ER) versus bias voltages V_b. Devices with different modulator lengths were tested and compared (Fig. 2). Over 10dB ER was obtained with a 35 µm device even below 0.8V. We measured the small-signal response result measured on a 35 µm long modulator with a 965 nm input. The modulation bandwidth (f_{3dB}) is over 13GHz when the bias voltage is -0.5V. Large signal NRZ modulation was also carried out. Clear eye-open can be observed for 10Gbit/s NRZ signal (PRBS 2^{31}-1, V_{pp} = 1.0V, V_b= -0.8V) input. It is possible to further downsize the current device volume by a factor of 2~3. The parasitic capacitance will correspondingly decrease thus ultra-high-speed modulation beyond 40Gbps is prospective.

Regarding the power consumption of the modulator, a voltage swing of 500 mV with a 50 Ω termination represents peak-power consumption of 5 mW in the load, which is corresponding to energy consumption per bit of 31 fJ/bit for 40 Gb/s NRZ as shown in Fig. 3. Dynamic dissipation of the device can be given by the relationship $E = CV_{pp}^2/4$ [4], where only the energy required to charge and discharge the capacitance of the device is counted. Assuming C = 100 fF and V_{pp} = 500mV, the NRZ energy per bit is 6.25 fJ for a 40 Gb/s signal.

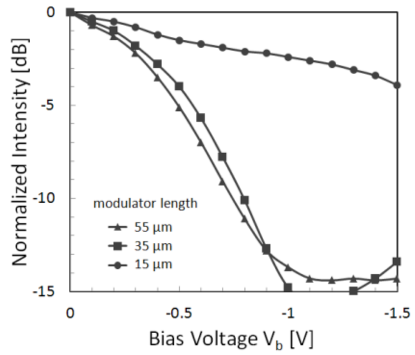

Fig. 2: Normalized intensity versus bias voltage for different modulator lengths for 965 nm input.

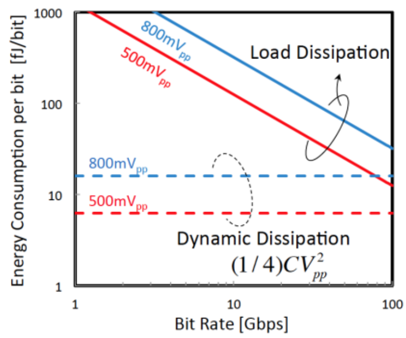

Fig. 3: Prospects for energy power consumption per bit as a function of bit rates. Two factors of the dissipation in 50 ohm load resistor and the dynamic dissipation in capacitive charging and discharging are considered.

Conclusions

We demonstrated an ultra-compact modulator based on a Bragg reflector waveguide. The extremely small volume of the modulator reveals its potential in reaching ultra-high-speed modulation with low power consumptions.

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