Design and Optimization of Photonic Components for High Performance Optical Interconnect

by

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ABSTRACT

High performance silicon-based photonic devices have attracted extensive research efforts in the past few decades, with the goal of building integrated silicon photonics for optical interconnect. The advantages of optical interconnects include lower power consumption, higher speed, no skin effects, and no Electromagnetic Interference.

A typical optical interconnect consists of the electro-optic modulators, the photodetectors, and the passive devices such as the couplers and the switches. This dissertation focuses on the electro-optic modulator and the photodetector. In order to reduce the electro-optic modulator size, we also investigated the slow light effect in the one-dimensional grating, and proposed novel designs to enhance the extinction ratio and reduce the insertion loss.

The design of silicon-based electro-optic modulator faces many challenges, since crystalline silicon has no Pockels effect and only a very weak Kerr effect. The most feasible mechanism for a silicon electro-optic modulator is the free-carrier plasma effect. The objective of this research is to design an electro-optic modulator that can simultaneously provide high speed and high efficiency. We adopted the SiGe heterojunction bipolar transistor as the electrical structure, and demonstrated the concept with a simplified model. We then researched device scaling and optimization by incorporating a more complex but more realistic model. Simulations indicate that the device is as short as 74μm, and its speed is over 10Gbps. By optimizing the waveguide geometry, we reduced the insertion loss to a level that is comparable to or even lower than other injection-type silicon electro-optic modulators.

In order to make more compact electro-optic modulators, we studied the slow light effect in the one-dimensional grating. We proposed a novel multi-segment grating design that is able to reduce the device length by 2/3 yet maintain high transmission and high extinction ratio for any selected wavelength.

On the receiver end, we focused on the simple but fast Metal-Semiconductor-Metal photodetector. Due to the small capacitance per unit area, Metal-Semiconductor-Metal photodetector can support high speed, large area detection in free-space communications and optical interconnect. Simulations indicate that this device can easily achieve multi-

GHz speed. We studied the capacitance, analyzed the filling factors of the photodetector array, and fabricated and tested some silicon Metal-Semiconductor-Metal photodetector / arrays.