Silicon nano- and micro-photonic devices

Ray T. Chen
Nanophotonics and Optical Interconnects Research Lab

Microelectronics Research Center

The University of Texas, Austin, TX 78758, USA

Phone: 1-512-471-7035, Fax: 1-512-4718575, Email: chen@ece.utexas.edu, www.mrc.utexas.edu/chen.html

Abstract

Silicon VLSI plays a key role in information technology. Recent progresses in silicon photonics have significantly moved the conventional silicon VLSI to high bandwidth photonics with lower power consumption for switching and interconnects. These devices include novel waveguides, modulators and detectors that are compatible with Si CMOS fabrication process. There are two major obstacles to build a monolithic nano-photonic system on a silicon chip:

1. lack of a silicon based light source and
2. silicon does not have any electro-optic (X2) effect .

The combination of these two may require a hybrid integration in the foreseeable future. In this presentation, we will present the recent results and the projection of future development.

Introduction

Silicon photonics technology is increasingly important for a myriad of applications [1-7]. Silicon based nanophotonic devices have the advantage of a compact structure with the potential for monolithic integration with optical-to-electrical on-chip conversion and detection [8]. Table 1 Summarize the recent achievements in silicon photonics which will be further detailed in the invited presentation. All components reported from 2002 to 2008 and 2009 are targeted at the realization of photonic system integration on a silicon platform. High bandwidth and low power consumption are pivotal factors in realizing such a system. High speed activities are led by Intel corporation which demonstrated a 40 Gbit/sec silicon modulator using MZ modulator scheme. Due to the space constraint, we will focus our recent achievement on low power photonic crystal slotted waveguide modulator. The slotted waveguide devices recently reported [9, 10] that are able to confine light in a nano-scale low refractive index region are becoming crucial due to the fact that they provide an ideal platform for mode field concentration in the slot region where other materials can be inserted to provide a myriad of new explorations. As another potential solution for sensitivity enhancement in waveguide devices, photonic crystal waveguides (PCWs) are capable to slow down light to a fraction of its original speed in vacuum by hundreds of times and thereby greatly improve the interaction with the waveguide material [11]. In this paper, we report defect-engineered PCWs to provide both guided wave confinement and slow light effect that can constitue 60 times of enhancement. PCW offers slow group velocity and thereby moderately high sensitivity within a continuous spectrum such that the range of the working wavelength extends to 10 nm scale [11], which is two orders of magnitude wider than a microring resonator [9]. We present a universal approach based on phase-shift measurement in order to characterize the sensitivity enhancement of the slot PCW. We also apply plane wave expansion algorithm to simulate the effective index variation of the propagating modes and thus justify the approach of device characterization.

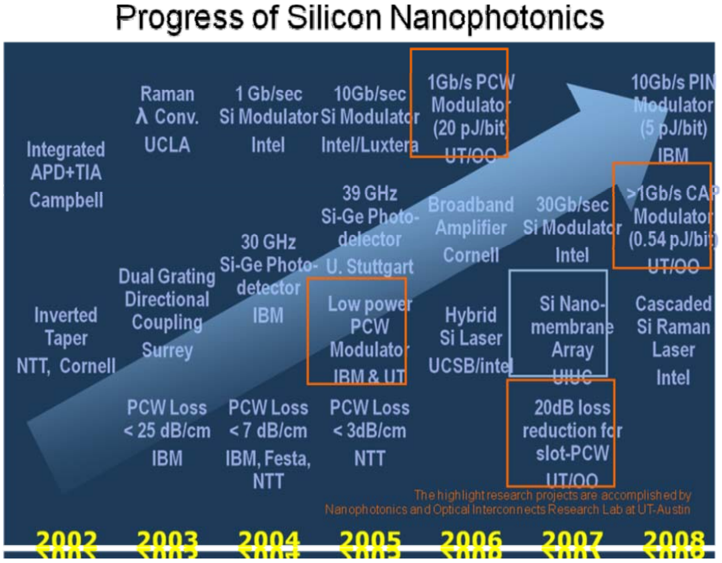

Table 1 Progress of Silicon Nanophotonics

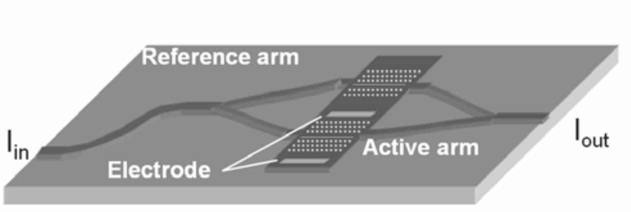

Fig. 1. Schematic diagrams of MZ interferometer with slot PCWs working as the active and reference arm.

A schematic of the dual enhanced slot PCW structure for phase-shift measurement is depicted in Fig. 1. We integrate the slot PCW in a Mach-Zehnder interferometer in order to measure the phase shift $\Delta\phi$. of the active arm from the output intensity, which is given by :

$$I_{out} = \frac{I_{in} + I_{in}\cos(\Delta\varphi)}{2}.$$

One can further derive the effective index change Δn_{eff} of the waveguide mode using the equation:

$$\Delta\phi = \frac{2\pi}{\lambda}\Delta n_{eff} L,$$

where L is the active length of the phase shifter, and λ is the wavelength in the free space. The definition of the waveguide sensitivity is given by

$$S = \frac{\Delta n_{eff}}{\Delta n_c}, \text{[3]}$$

where Δn_c is the refractive index change of the waveguide material. For convenience, we always characterize the sensitivity enhancement by comparing Δn_{eff} with the same Δn_c profile applied for different waveguide structures.

A cross-section diagram of the active arm is depicted in Fig. 2. The enhancements of the waveguide sensitivity are realized out of the combination of slow light effect and tighter confinement of optical guided wave in the slotted PCW [12]. The refractive index change is generated through free carrier dispersion effect [13, 14], and therefore is controlled by the carrier concentration profile. We design the silicon slab layer with a uniform doping profile in order to simplify the device fabrication procedure. Fig.3 shows the device we fabricated and further experimental results will be presented in the conference.

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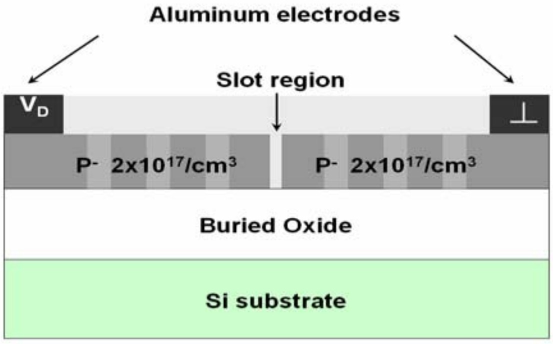
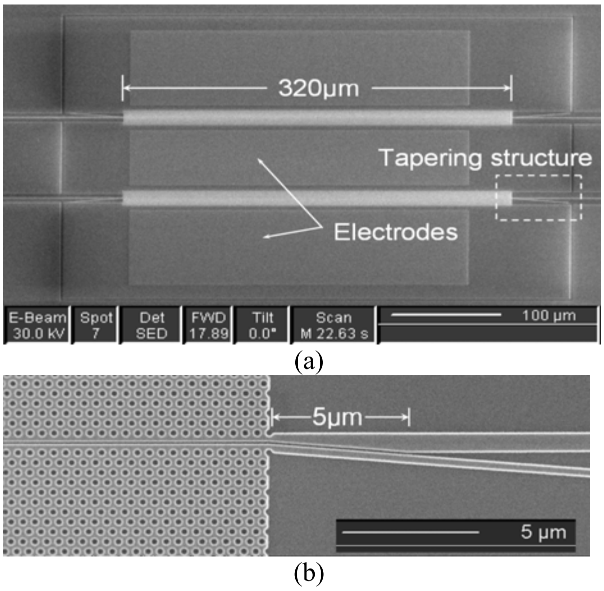


Fig. 2. Cross-sectional view of the slot PCW-based active arm in Mach-Zehnder interferometer.



(a)

(b)

Fig. 3. (a) SEM top view of the active region (b) The enlarged tapering structure.