A 30 GHz Silicon Photonic Platform

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Abstract – We present a 30 GHz silicon photonic platform that includes low-loss passive components as well as high-speed modulators and photodetectors. The platform is available to the community as part of the OpSIS-IME MPW service.

I. INTRODUCTION

The demand for increased communication bandwidth has continued through the past decades and shows no sign of slowing. However, the relative expense of discrete optical components used in standard communication links is a challenge for continued bandwidth scaling. One proposed solution that has gained attention in recent years is building integrated photonics on a silicon platform. Leveraging the investments made in CMOS fabrication, it is possible to build low-cost, high-complexity systems in silicon that achieve close integration between electronics and photonics. Recent efforts have shown that such platforms can achieve impressive performance. Luxtera has developed a 25 Gb/s platform that is fully integrated with CMOS [1]. Kim et al. have demonstrated both modulators and detectors working at speeds of 30 Gb/s [2]. Just recently, IMEC announced the launch of a fully integrated 25 Gb/s platform via the ePIXfab MPW [3].

In this paper, we present the performance of the OpSIS-IME silicon photonics platform. This platform is composed of passive elements such as low-loss grating couplers and waveguides as well as active elements including 58 GHz gain-peaked Ge photodetectors, 45 GHz, high-tunability silicon ring modulators and 30 GHz traveling wave Mach-Zehnder modulators. The high bandwidth of the modulators and photodetectors enable the platform to support a data rate of 50 Gb/s and higher. The platform is available to the community as part of the OpSIS-IME MPW foundry service.

II. FABRICATION

The platform wafers were fabricated at the Institute of Microelectronics (IME), a research institute of the Agency for Science, Technology and Research (A*STAR) [4]. A Silicon-on-Insulator (SOI) wafer with a 220 nm device layer and a 2um buried oxide (BOX) layer is used. Three anisotropic etch steps are used to define silicon heights of 0, 90 nm, 160 nm and 220 nm which are then used to build the grating couplers, rib waveguides and ridge waveguides. Six separate silicon implants (p++, p+, p, n++, n+, n) are used in the modulator and an additional p-type implant is used to define the anode of the Ge photodetector. The implants were followed by a rapid thermal anneal (RTA) of 1030 °C for 5 seconds to activate the dopants. Germanium was then selectively grown in regions defined by a SiO_2 mask layer to a height of 500 nm. Ion implantation in the Germanium was performed to define the photodetector cathode followed by an anneal of 500 °C for 5 minutes. Finally, contact vias and two levels of Aluminum interconnects were fabricated. The platform cross-section is show in Figure 1.

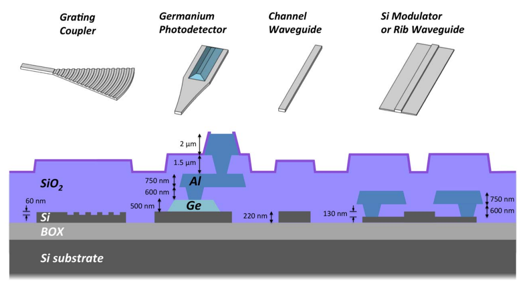

Figure 1. Illustration of the platform cross-section

III. PHOTONIC DEVICE LIBRARY

The platform device library is composed of a large variety of passive and active devices of which a select few are reported here. Extensive wafer-scale testing has been conducted to characterize the performance of these devices. Due to the requirements of testing at high speeds, certain measurements were done on a smaller set of devices. The average and standard deviation measurements that follow are from cross-wafer testing.

A. Passive Devices

High performance passive components are essential for building large-scale photonic systems. Grating couplers are used extensively on our platform to couple light on and off chip and enable efficient wafer-scale testing. The library grating coupler uses a single silicon etch of 60 nm and a non-uniform grating to achieve an insertion loss of 3.1 dB at 1550 nm with a 1.5 dB bandwidth of 50 nm.

Low-loss waveguides were also demonstrated on our platform. The standard routing waveguide consisting of a 1.2 um wide channel was measured to have an average propagation loss of 0.27±0.06 dB/cm. Rib waveguides with 0.5 um width and 90 nm slab thickness had an average loss of 1.5±0.6 dB/cm.

B. Photodetector

The platform photodetectors were built using evanescently coupled, Germanium, p-i-n diodes with 11 um length. Cross-wafer testing measured an average responsivity of 0.74±0.13 A/W and a dark current of 4.0±0.9 uA at 2 V reverse bias. Inductive gain peaking employing a spiral metal inductor placed in series with the diode (see Figure 2a) was used to enhance detector bandwidth [5]. The RF performance of the detector was characterized using a Vector Network Analyzer (VNA) to drive a high-speed Lithium Niobate modulator and detect the electrical response from the photodetector. The frequency response of the modulator was calibrated using an ultrafast (70 GHz) commercial photodetector and was normalized out of the platform photodetector measurement. The resultant 3dB bandwidth was measured to be 58 GHz as seen in Figure 2b. Due to equipment and time limitations, many measurements were taken up to 50 GHz, but only a single trace was taken up to 67 GHz as seen in Figure 2b.

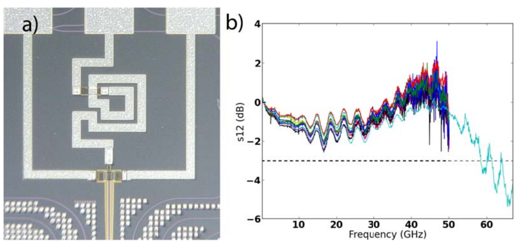

Figure 2. a) Image of gain-peaked photodetector. b) EO response of a number of photodetectors up to 50 GHz and a single high-speed measurement showing 58 GHz bandwidth.

C. Traveling Wave Modulator

Traveling wave Mach-Zehnder modulators were built with 3 mm active lengths, lateral PN junction phase shifters and metal GS transmission line electrodes of 33Ω impedance [6]. Use of intermediate p+ and n+ doping reduced the parasitic resistance of the slab. The net insertion loss of the device excluding routing and coupling was measured to be 7 dB. The arms of the modulator are intentionally unbalanced by 100 um to provide a convenient method of setting the bias point. By applying a DC bias voltage and measuring the spectrum shift, the small signal $V\pi$ was measured to be 7V around 0V bias. The bandwidth of each arm was measured individually by driving the arm with the VNA and terminating with a 25Ω resistor. The EO response of both arms on many devices was measured (see Figure 3b) and the typical 3 dB bandwidth was found to be near 30 GHz at 1V bias. An eye diagram was taken at 40 Gb/s using a differential drive voltage of 2.5 Vpp and .25 V bias (see Figure 3c). The extinction ratio was 5.1 dB and the excess loss due to bias was 1.7 dB.

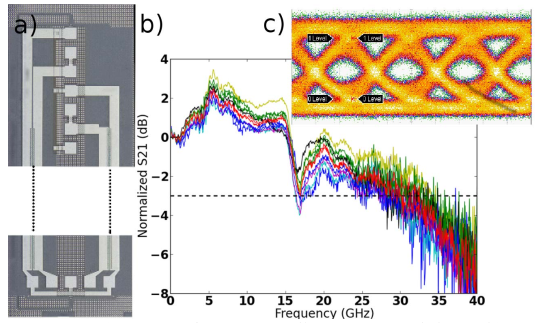

Figure 3. a) Image of 3mm traveling wave modulator. b) RF performance of a number of modulator arms at 1V bias. The amplitude shows a typical 3 dB bandwidth of 30 GHz. c) Eye diagram at 40 Gb/s with differential drive voltage of 2.5 Vpp.

D. Ring Modulator

A ring modulator with a 12 um radius was built using 0.5 um width rib waveguide and a 90 nm slab thickness. A heavily doped PN junction was used to increase tuning efficiency. Typical Q values or 2.8k and FSR of 7.65nm were observed. The small signal tunability was measured to be 28 pm/V by analyzing the spectrum shift as a function of bias voltage. The 3 dB bandwidth was measured by a VNA to be 45 GHz at 0V bias, enabling a 50 Gb/s data rate. It is estimated that these rings will achieve 5dB ER when driven by a 2.4Vpp signal and when the ‘1’ bit is biased to have 7dB modulation loss.

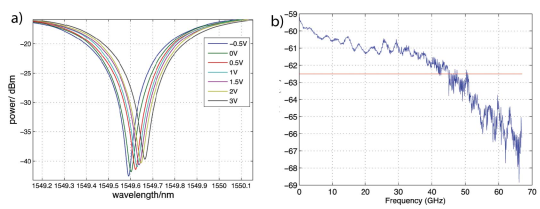

Figure 4. a) Ring resonance shift at different bias voltages. b) EO response at 0 V bias showing a 3 dB bandwidth of 45 GHz.

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V. References

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