A 30 GHz Silicon Photonic Platform

Ari Novack[a,b], Yang Liu[c], Ran Ding[c], Michael Gould[e], Tom Baehr-Jones[c], Qi Li[d], Yisu Yang[c], Yangjin Ma[c], Yi Zhang[c], Kishore Padmaraju[d], Keren Bergmen[d], Andy Eu-Jin Lim[b], Guo-Qiang Lo[b], and Michael Hochberg*[a,b,c]

[a]Department of Electrical and Computer Engineering, National University of Singapore, Singapore; [b]Institute of Microelectronics, A*STAR (Agency for Science, Technology and Research), 11 Science Park Road, Singapore Science Park II, Singapore 117685; [c]Department of Electrical and Computer Engineering, University of Delaware, Newark, DE, USA; [d]Department of Electrical Engineering, Columbia University, 500 West 120th Street, New York, New York, USA; [e]Department of Electrical Engineering, University of Washington, Campus Box 352500, Seattle, WA 98195, USA,

ABSTRACT

Silicon photonics has emerged as a promising material system for the fabrication of photonic devices as well as electronic ones. The key advantage is that many electronic and photonic functions that up to now have only been available as discrete components can be integrated into a single package. We present a silicon photonic platform that includes low-loss passive components as well as high-speed modulators and photodetectors at or above 30 GHz. The platform is available to the community as part of the OpSIS-IME MPW service.

Keywords: Silicon Photonics, Photonics Platform, MPW, foundry, OpSIS

1. INTRODUCTION

In recent years, electrical connections have begun to reach their bandwidth limits. However, the demand for increasing bandwidth shows no sign of slowing. Optical links have shown their dominance in long-range connections, but the relative cost of the discrete components has limited their use in shorter connections. One proposed solution that has gained attention in recent years is building integrated photonics on a silicon platform. Integrating both electronics and photonics in the same chip may prove a viable method for building high speed links for data centers and may prove effective in chip-to-chip and on-chip interconnects.

One of the advantages that silicon photonics offers is the ability to leverage investments that the CMOS industry has made in fabrication. Using the expertise developed by the silicon electronics industry over the past 50 years, a number of efforts have shown success in building photonics platforms on silicon. Luxtera has developed a 28 Gb/s CMOS-integrated platform[1]. Kim et al. have demonstrated both modulators and detectors working at speeds of 30 Gb/s[2]. Recently, IMEC announced the upcoming launch of a fully integrated 25 Gb/s platform via the ePIXfab MPW[3].

We present the performance of the OpSIS-IME silicon photonics platform. The platform is composed of passive devices such as low-loss grating couplers and waveguides as well as high-speed modulators and detectors. This includes 58 GHz gain-peaked Germanium photodetectors, 45 GHz silicon ring modulators and 30 GHz traveling wave Mach-Zehnder modulators. The high bandwidth of the active devices allow the platform to support data rates of 50 Gb/s and higher. The OpSIS Institute is currently offering this platform to the community as part of the OpSIS-IME MPW shuttle.

2. FABRICATION

The wafers were fabricated at the Institute of Microelectronics (IME), a research institute of the Agency for Science, Technology and Research (A*STAR)[4] using a Silicon-on-Insulator (SOI) wafer with a 220 nm device layer and 2 um buried oxide (BOX) layer. Three anisotropic etch steps were used to define available silicon heights of 0, 90, 160 and 220 nm. These layers were used for different devices such as the grating couplers, rib waveguides and ridge waveguides. Six separate silicon implants (p++, p+, p, n++, n+, n) were used in the modulator and an additional p-type

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implant was used to define the anode of the Ge photodetector. The implants were annealed using a RTA of 1030 °C for 5 seconds to activate the dopants. Germanium was grown selectively to a height of 500 um. The Germanium sidewalls were left unetched and remained angled due to anisotropic growth. Ion implantation was performed on the Germanium to provide the cathode of the photodetector p-i-n junction. An anneal of 500 °C for 5 minutes was performed to activate the Germanium dopants and heal lattice damage. Finally, contact vias and two levels of Aluminum interconnects were fabricated. The platform cross-section is shown in Figure 1.

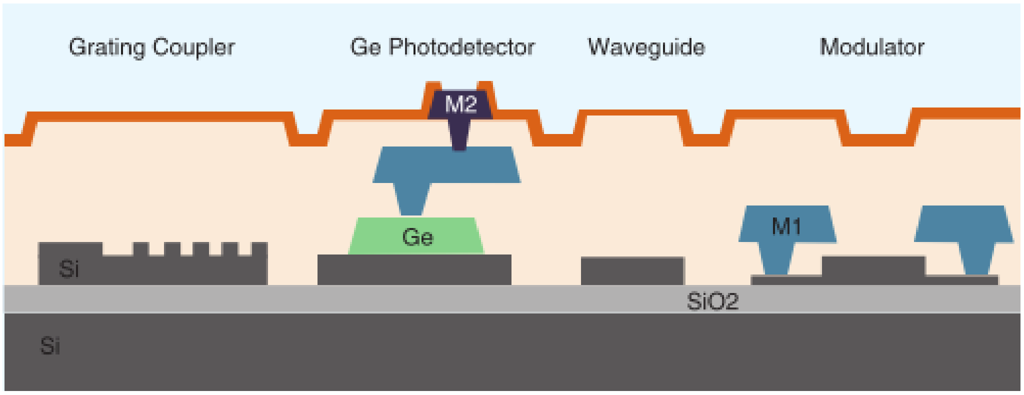

Figure 1. Cross section of the photonic platform showing grating coupler, photodetector, ridge waveguide and modulator

3. PHOTONIC DEVICE LIBRARY

The photonic device library of the platform is composed of a large variety of passive and active devices. A few are selected here to show important passive and active performance characteristics. Extensive wafer-scale testing has been conducted on these devices. The average and standard deviation measurements that follow are from cross-wafer test data. Due to the requirements of testing at higher speeds, certain measurements were only done on a smaller subset of devices.

3.1 Passive Devices

Building large-scale photonic systems requires high performance passive components. Grating couplers are widely used on the platform to couple light on and off chip and enable efficient testing. The library grating couplers used a Silicon etch of 60 nm to define the gratings, which are arranged in a non-uniform pattern to increase coupling. An insertion loss of 3.1 dB at 1550 nm is achieved with a 1.5 dB bandwidth of 50 nm.

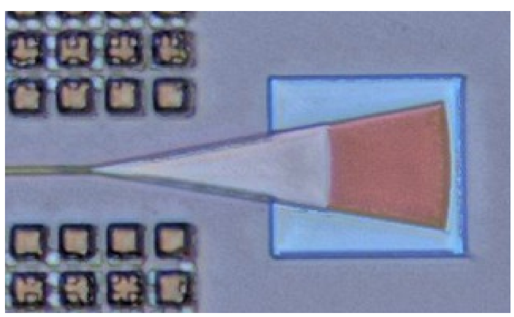

Figure 2. Image of a platform grating coupler. The gratings are in the dark red region.

Los-loss waveguides are another critical component of the photonic platform. The standard routing waveguide is a 1.2 um-wide ridge waveguide that was measured to have a propagation loss of 0.27±0.06 dB/cm. Rib waveguides, which are used in the modulators and built with .5 um width and 90 nm slab thickness, had an average loss of 1.5±0.6 dB/cm.

3.2 Photodetector

The platform photodetectors were built using evanescently coupled Germanium with a length of 11 um. The p-i-n junction was defined by an n-type implant in the Germanium and a p-impant in the Silicon directly below the

Germanium. 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 was use to enhance the bandwidth of the photodetector[5]. A metal spiral was used as the inductor element as seen in Figure 3a. The RF performance of the detector was measured by using a Vector Network Analyzer (VNA) to drive a high-speed Lithium Niobate modulator and detect the photodetector response. The frequency response of the modulator was calibrated using a 70 GHz commercial photodetector and normalized out of the measurement. The resulting 3dB bandwidth of the platform detector was measured to be 58 GHz as seen in Figure 3b. 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 3b.

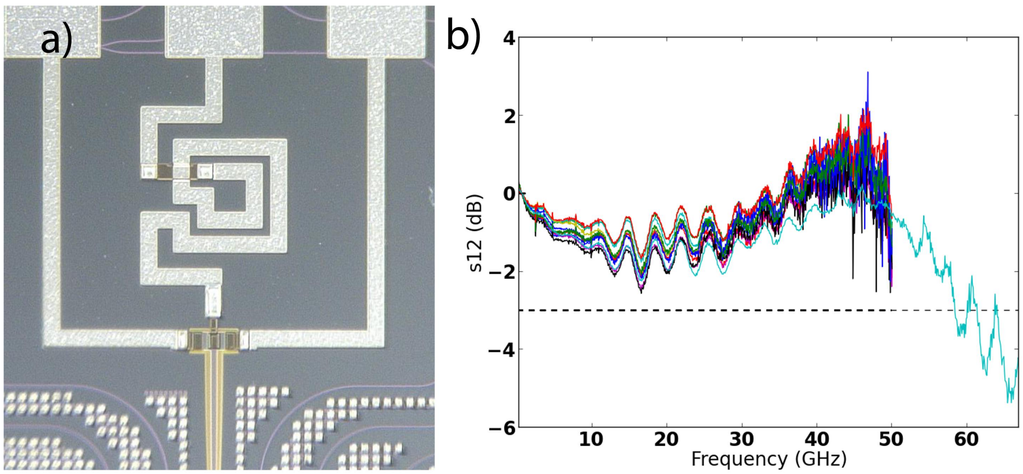

Figure 3. a) Image of the Germanium photodetector showing the inductive gain peaking element. b) EO response of a large number of detectors up to 50 GHz and a single measurement showing a 58 GHz bandwidth.

3.3 Ring Modulator

A ring modulator of 12 um radius was built by slab waveguide of 0.5 um width and 90 nm slab thickness. The tuning efficiency was enhanced by employing a heavily doped PN junction. Typical Q values of 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.

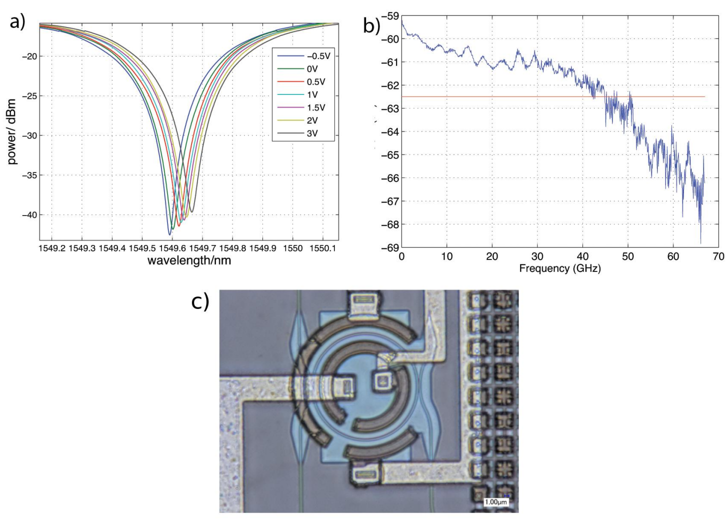

Figure 4. a) Resonance peaks of the ring resonator at various bias voltages. b) EO bandwidth at 0 V bias showing a 3 dB bandwidth of 45 GHz. c) Image of a ring resonator showing the ring, input waveguides and metal wiring.

3.4 Traveling Wave Modulator

The traveling wave Mach-Zehnder modulators were built using slab waveguides, lateral PN junction phase shifter and lengths of 3 mm. The metal GS transmission line had an impedance of 33Ω[6]. Intermediate doping of n+ and p+ was used to reduce the parasitic resistance of the slab while minimizing optical losses due to free carriers. The net insertion loss of the device excluding routing and coupling was measured to be 7 dB. The arms of the modulator were intentionally unbalanced by 100 um to provide a convenient method of setting the bias point. The small signal $V\pi$ was measured to be 7V around 0V bias by applying a DC bias voltage and measuring the spectrum shift. The bandwidth of each arm was measured individually by driving with the VNA and measuring the response of a commercial photodetector. Each arm was terminated with a 25Ω resistor. The EO response was measured for a number of devices and the typical 3 dB bandwidth was found to be near 30 GHz at 1V bias (see Figure 5b). An eye diagram was taken at 40 Gb/s using a differential drive voltage of 2.5 Vpp and .25 V bias (see Figure 5c). The extinction ratio was 5.1 dB and the excess loss due to bias was 1.7 dB.

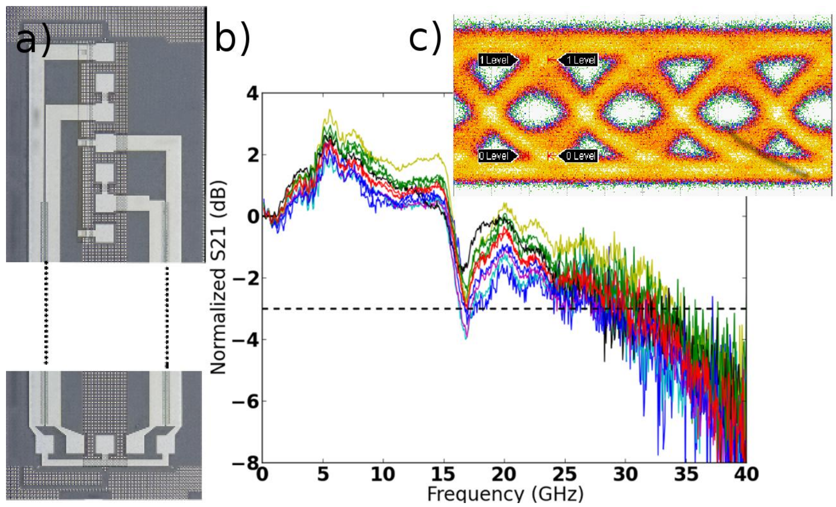

Figure 5. a) Image of the traveling wave Mach-Zehnder. b) RF response of a number of modulator arms showing a typical 3 dB bandwidth of 30 GHz. c) Eye diagram at 40 Gb/s with differential drive voltage of 2.5 Vpp.

4. ACKNOWLEDGEMENTS

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