AIM Process Design Kit (AIMPDKv2.0): Silicon Photonics Passive and Active Component Libraries on a 300mm Wafer

Erman Timurdogan, Zhan Su, Christopher V. Poulton, Matthew J. Byrd, Simon Xin, Ren-Jye Shiue, Benjamin R. Moss, Ehsan S. Hosseini, and Michael R. Watts
Analog Photonics, 1 Marina Park Drive Suite 205, Boston, MA, 02210
erman@analogphotonics.com

Abstract: A new process design kit (AIMPDKv2.0) is introduced that offers a verified silicon photonics component library on 300mm silicon-on-insulator wafers. The library includes multi-layer waveguides, polarization manipulation, switches, filters, and high-speed digital/analog detectors and modulators.
OCIS codes: (130.3120) Integrated optics devices; (250.314) Integrated optoelectronic circuits; (130.1750) Components.

1. Introduction

Silicon photonics enables electronics-like large-scale integration of photonic integrated circuits (PIC) by providing a platform that can produce compact, low-power, and low-cost devices in high volumes. These advantages have attracted interest from the optical interconnect industry, and individual companies have formed their own design teams to develop basic optical building blocks such as couplers, splitters, modulators, and detectors on private silicon photonic platforms. The risks and cost of developing a new platform and optical building blocks are significant and this barrier to entry limits mainstream adoption of silicon photonics. Today, platforms are available that offer multi-project wafer (MPW) runs and process design kits (PDKs) to alleviate these limitations [1,2]. These PDKs focus mainly on digital direct-detection end-to-end links for optical interconnects. However, the application space of silicon photonics is diverse and also includes high radix switches, analog transceivers, coherent and quantum communication, and sensors. In addition to high-bandwidth and low-power-consumption modulators and detectors traditionally offered in a PDK, these applications require new components and specifications such as linearity, phase coherence, and power balancing. Therefore, a new and comprehensive set of PDK component libraries within a silicon photonics platform is needed to cover the growing number of PIC applications.

Analog Photonics provides comprehensive active and passive PDK component libraries (AIMPDK) for the AIM Photonics MPW runs on the SUNY Polytechnic Institute silicon photonics platform [3]. This process uses 300mm silicon-on-insulator (SOI) wafers with one silicon and two silicon nitride layers (First and Second SiN: FN, SN) for optical manipulation and waveguiding, one germanium layer for detection, two metal levels for electrical routing, and a trench for sensor applications. Here, we unveil the highlights of AIMPDKv2.0. This PDK is exhaustive and includes components such as low-loss vertical and polarization independent edge coupling, <1dB/cm loss waveguides, on-chip polarization manipulation, nano-second scale switching, wavelength tunable filters, analog modulators and detectors with >90dB/Hz$^{2/3}$ SFDR, efficient detectors with 50GHz bandwidth, and digital and resonant Mach-Zehnder modulators supporting up to 50Gb/s NRZ, respectively. These PDK components can support the vast application space of silicon photonic systems, and this is illustrated by the wavelength division multiplexed transceiver, switch and coherent digital/analog transmitter PICs in Figure 1-a,b.

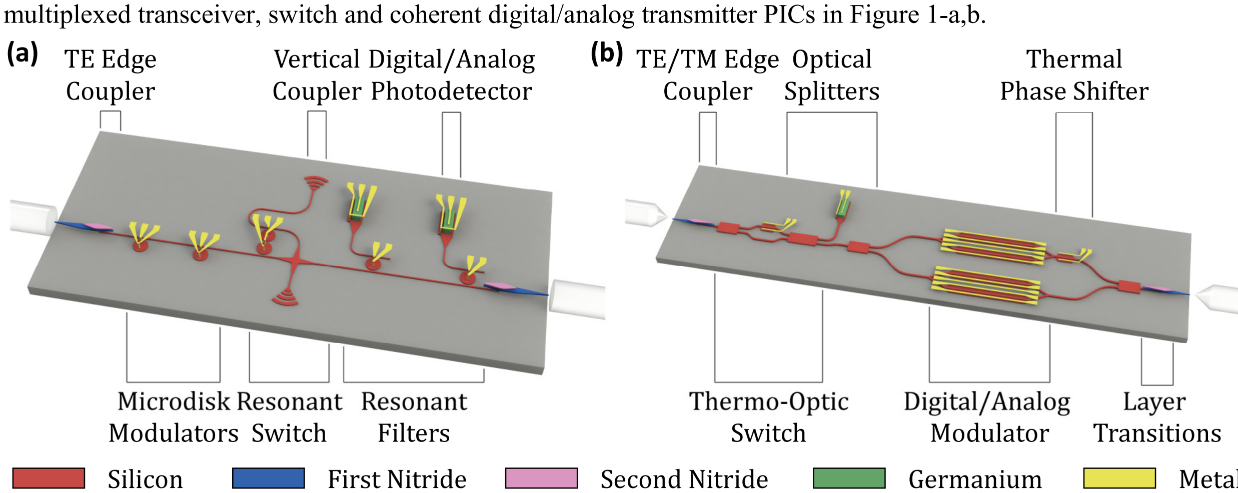

Figure 1. (a-b) 3D sketch of AIMPDK component library in representative PICs and interaction with fibers.

2. Passive Component Library

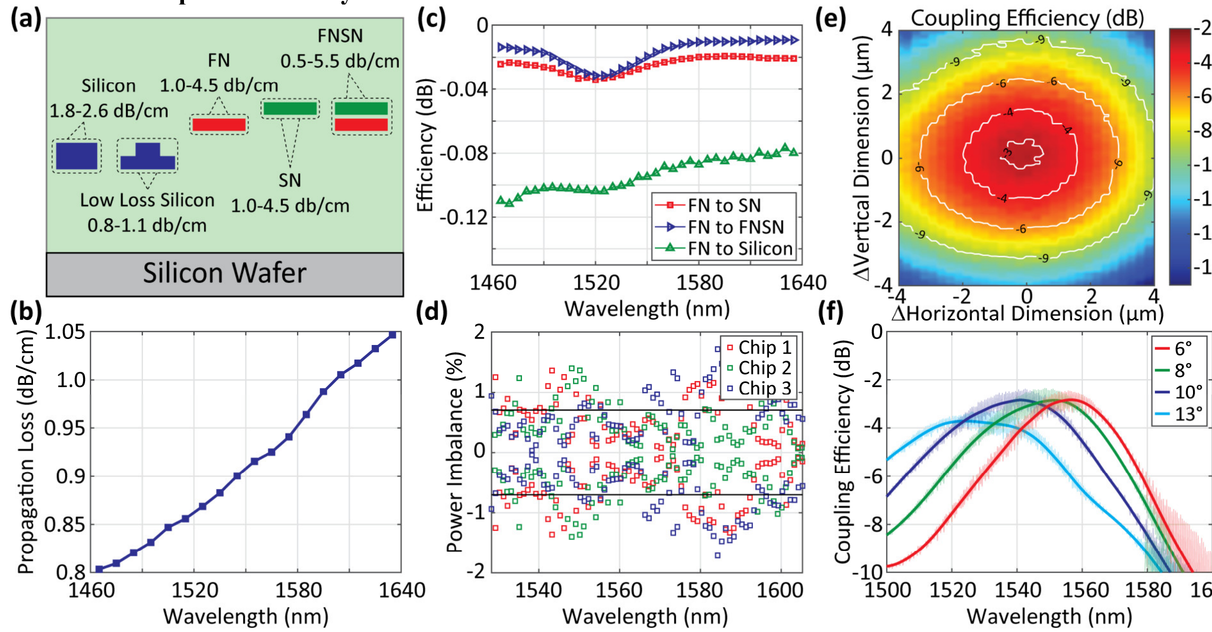

Figure 2. (a) Waveguide types and propagation losses. (b) Propagation loss of the low-loss silicon waveguide. (c) Layer transition efficiencies. (d) Power imbalance of the SiN 3-port splitter. (e) SMF-28e fiber to TE edge couplers coupling efficiency and alignment tolerance. (f) SMF-28e fiber to TE vertical coupler efficiency and angle dependence.

The passive components in AIMPDKv2.0 include waveguides, edge couplers, vertical couplers, 1% and 10% power taps, 3- and 4-port splitters, layer transitions (escalators), polarization rotators, polarization splitter/rotators, and waveguide crossings. The use of both silicon and silicon nitride waveguides is unique to this PDK and essential for supporting low PIC-to-fiber coupling losses, low propagation losses at diverse operation wavelengths, tight bend radii, low polarization dependence, and active functionality for applications ranging from optical computing and interconnect, to sensors and nonlinear optics (Figure 2-a). In addition to the standard silicon and silicon nitride waveguides, a low loss silicon waveguide is also provided with a propagation loss of 0.8-1.05dB/cm over a wavelength range of 1460 to 1640nm (Figure 2-b). The transition between these waveguide layers is supported with escalators that have <0.1dB/transition losses over a broad wavelength range (Figure 2-c).

The splitting ratio between the output ports of optical splitters is key to maximize the extinction ratio in a Mach-Zehnder interferometer or the common mode rejection ratio in a balanced photodetector. AIMPDKv2.0 offers silicon and silicon nitride splitters with a small power imbalance between the two outputs. For instance, the power imbalance of the silicon nitride 3-port splitter has a standard deviation of ~0.7% (Figure 2-d).

To facilitate PIC packaging, TE edge couplers are provided to couple TE polarized light from a standard SMF-28e fiber with a loss of ~2.5dB/facet. These devices have a 3dB alignment tolerance of 6.2µm and 4.6µm in the horizontal and vertical directions, respectively (Figure 2-e). The large alignment tolerance offers compatibility with standard pick and place tools. Apart from an edge coupling solution, TE vertical couplers are also supported with a peak coupling efficiency of ~2.8dB/facet to an SMF-28e fiber at λ~1550nm with a 1dB bandwidth of Δλ~30nm (Figure 2-f). However, TE-only couplers can require costly polarization-maintaining (PM) fibers and are not compatible with communication standards that require dual polarizations or applications that favor TM polarization [4,5]. A TE/TM compatible edge coupler is supplied to couple light from a 3.5µm mode-field diameter lensed fiber with a loss of ~1.8dB/facet (Figure 3-a). Moreover, a polarization splitter/rotator (Figure 3-b) and a polarization rotator (Figure 3-c) are offered with low polarization dependent loss (<0.45dB) and low insertion losses (~0.2-0.9dB) to enable on-chip polarization manipulation. This functionality is a unique PDK offering.

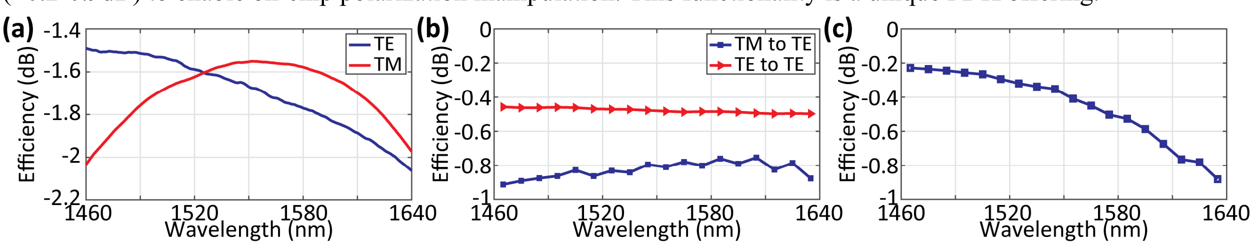

Figure 3. (a) Efficiency of TE/TM edge coupler. Device loss of (b) polarization splitter/rotator and (c) polarization rotator.

3. Active Component Library

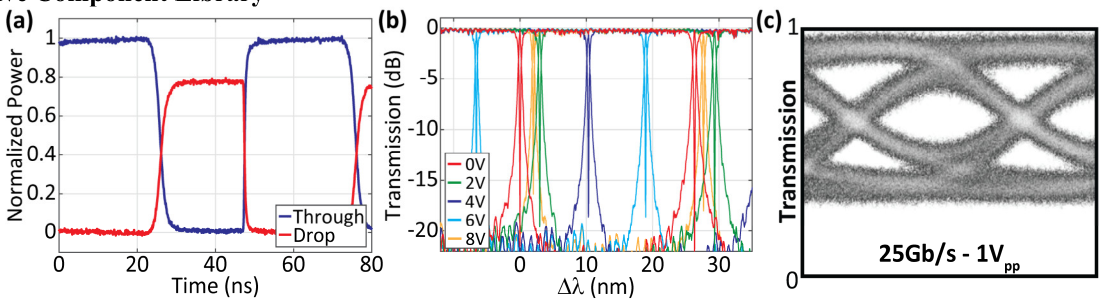

Figure 4. (a) The tunable microdisk switch dynamic drop and through port response, showing nano-second scale switching times. (b) The microring filter tunes across its FSR of 26nm. (c) 25Gb/s transmission eye diagram from the microdisk modulators.

The active components in AIMPDKv2.0 include 4-channel tunable and resonant wavelength division multiplexed microdisk switches, microdisk modulators, and microring filters that share the same free-spectral-range (FSR) of ~26nm over the C-band and contain integrated heaters to compensate for fabrication variations. The resonance of the tunable microdisk switch is rapidly detuned by applying 1V (1mW) across the embedded forward-biased p-i-n junction. This detuning switches the optical routing from the through to the drop port with 1.0dB insertion loss and 16dB dynamic extinction ratio at a nano-second scale switching speed (Figure 4-a). The tunable microring filter has an insertion loss of <0.2dB and can be tuned using the integrated heater with a tuning efficiency of 1nm/mW (7.5μW/GHz) (Figure 4-b). The microdisk modulator has an integrated reverse-biased p-n junction for electro-optical modulation and is capable of transmitting 25Gb/s non-return-to-zero (NRZ) data with >4dB dynamic extinction ratio and <0.1dB insertion loss using only a 1V_{pp} drive (Figure 4-c).

In AIMPDKv2.0, there are also other key active components such as broadband thermo-optic switches and phase shifters, analog and digital Mach-Zehnder modulators (MZM), and analog and digital photodetectors. These components offer high yields and large tolerance to fabrication variations. The digital MZM has a 1mm long reverse-biased p-n junction for electro-optical modulation and a thermo-optic phase shifter for adjusting the operation point, for example to quadrature. The device is characterized to have an optical loss of 2.7dB and $V_\pi L$ of 0.8Vcm at -1V bias and can transmit 25Gb/s (50Gb/s) NRZ data with 7.2dB (6dB) dynamic extinction ratio and 1.0dB (1.4dB) additional insertion loss using only 1.2V_{pp} (0.8V_{pp}) differential dual drive (i.e. 0.6V_{pp} (0.4V_{pp}) per MZ arm), as shown in Figure 5-a,b. The digital photodetector uses a vertical p-i-n junction within the germanium layer for photocurrent generation. At -1V bias, the detector offers >1A/W responsivity at 1550nm and ~50GHz optical-electrical bandwidth (Figure 5-c). The analog MZM has a reverse-biased p-i-n junction designed to offer a linear electro-optic response, as is shown to have a spurious free dynamic range of >90dB/Hz$^{2/3}$ (Figure 5-d). The analog photodetector increases the total absorption area to minimize saturation and nonlinear effects that also have a spurious free dynamic range of >90dB/Hz$^{2/3}$.

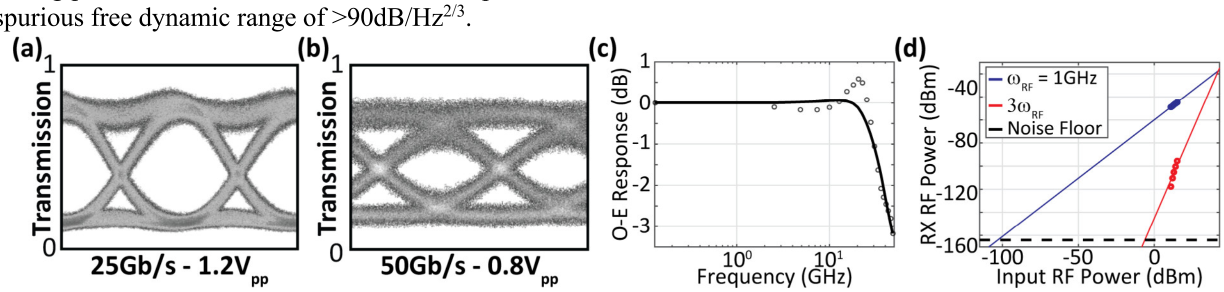

Figure 5. (a) 25Gb/s and (b) 50Gb/s transmission eye diagrams from the digital MZM. (c) Optical-electrical response of the digital germanium photodetector with a 50GHz bandwidth. (d) The dynamic range and linearity measurement of the analog MZM.

4. Conclusion

The AIMPDKv2.0 is a comprehensive active and passive silicon photonics library that provides verified similar to the state-of-the-art performances and enables a wide range of silicon photonics applications to proliferate using AIM MPW runs with CMOS compatible voltages. Future updates will improve component performances and offer verified sub-system performance to further reduce time to market.

Authors acknowledge the support and funding of AIM Photonics and the fabrication of SUNY Polytechnic Institute.

5. References

[1] M. Pantouvaki, et al., Journal of Lightwave Technology, **35**, 631-638, (2017).
[2] A. E. J. Lim, et al., IEEE Journal of Selected Topics in Quantum Electronics, **20**, 405-416, (2014).
[3] http://www.aimphotonics.com/pdk/, http://www.analogphotonics.com/pdk/
[4] P. J. Winzer, et al., Journal of Lightwave Technology, **24**, 4711-4728, (2006).
[5] J. E. Baker, et al., Lab Chip, **15**, 971–990, (2015).