High Performance Silicon Nitride Passive Optical Components on Monolithic Silicon Photonics Platform

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Abstract: We demonstrate low-loss silicon nitride passive optical components including straight and bend waveguides, 1×2MMI, 2×2MMI, directional-coupler and waveguide crossings on a monolithic silicon photonics platform. Hardware performance statistics substantiate the mass manufacturability of the building-blocks.

1. Introduction

Silicon photonics (SiPh) is identified as the most promising technology solution for the bandwidth demand posed by today's data centers. It also finds extensive applications in energy-efficient computation, Lidar, biosensing, signal processing, quantum communication, etc. CMOS compatible process makes SiPh to be mass manufacturable using foundries services without significant changes. Addition of silicon nitride (SiN) waveguiding layer to the SiPh platform further extends the capabilities of silicon (Si)-based integrated photonics. SiN provides low-loss and fabrication tolerant waveguiding features. Additionally, SiN is less sensitive to thermal variations, and it can handle much higher optical power compared to Si waveguides. SiN also enables photonic circuits for visible wavelength on SiPh platform. SiN waveguides and high-Q resonators form essential parts of quantum systems including single photon emitters and strong non-linear effects which can be exploited for entangled photon pair generation [1,2]. GlobalFoundries 45 nm monolithic SiPh technology integrates low loss Si and SiN photonic devices with CMOS electronics on the same platform. In this paper, we summarize the performance figures of passive SiN photonic building blocks on the monolithic SiPh platform, including straight and bend waveguides, 1×MMI splitter, 2×2MMI splitter, directional coupler, and waveguide crossings.

GlobalFoundries' 45SPCLO process design kit includes a comprehensive library of photonics and electronic components. In addition to the industrial engagements, GlobalFoundries collaborates with university partners to develop photonic devices and circuits for communication, computation, and time-of-flight sensors/LIDAR. GlobalFoundries' monolithic platform was recently used for the demonstration of fully integrated energy efficient (0.73pJ/bit) coherent receiver [3], and also for the demonstration of optical phased arrays integrated with modulator and driver circuits for wireless optical communication [4].

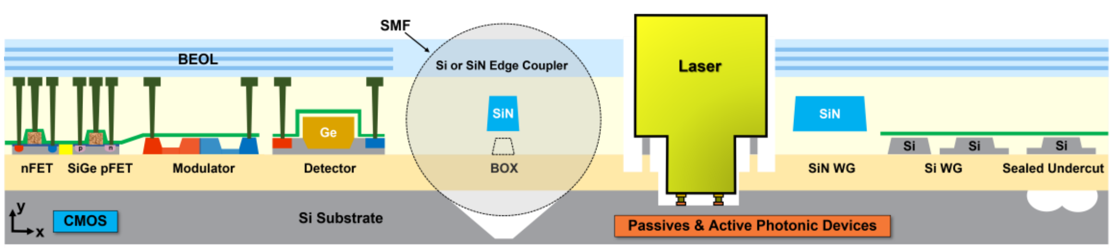

Fig. 1 Schematic cross-section view of monolithic silicon photonics platform including CMOS electronics, active and passive photonic devices, edge couplers for fiber attach and flip-chip bonded laser module [5].

2. Silicon nitride building-blocks

Low loss SiN waveguides are formed on the monolithic platform with high quality SiN layer. Fig. 1 shows the schematic cross-section view of the monolithic platform that includes CMOS electronics, active and passive photonic devices, edge couplers for I/O fiber attachment, and flip-chip bonded laser modules. SiN film is deposited at the middle of the line (MOL), closer to the SOI layer so that light transfer between Si and SiN waveguides can be achieved efficiently. Though GlobalFoundries offers scalable SiN waveguide geometry in terms of width, standard single-mode waveguide is designed to obtain minimum propagation loss and better mode confinement to minimize the bend induced loss. Fig. 2(a) and (f) show the schematic view of the straight waveguide and respective simulated mode profile (TE-polarization at a wavelength of 1310 nm). Propagation loss of the straight waveguide is measured to be -0.34 dB/cm (Fig. 2(k)). 90º waveguide bends were designed with 50 µm radius and insertion loss for the bends were measured to be ~ -0.018 dB (Fig. 2b). Power splitters are important building blocks for on-chip signal routing. We have designed multimode interference coupler (MMIC) and directional coupler (DC) based power splitters. Fig. 2 (g)-(h) shows simulated top views for 3-dB power splitters based on 1×2MMIC (footprint: 55.5µm×8µm), 2×2MMIC (footprint: 105.2µm×7.2µm) and DC (footprint: 69.6µm×11.6µm). Footprints of all the power splitters include s-bends attached to the input/output to suppress coupled mode interaction. MMI splitters provide a fixed power splitting ratio with nearly wavelength independent response. Whereas DC provide a variable split ratio depending on the interaction length of the coupled waveguides. Fig. 2 (l)-(n) show the measured insertion loss of the power splitters and are nearly close to the values predicted by simulations. DC has been characterized in terms of 3-dB coupling length and the measured response is shown in Fig. 2 (s). Waveguide crossing is an essential part of high-density photonic circuits. In contrast to several metal layers in CMOS electronics, integrated photonic platform can accommodate only a limited waveguiding layers/material due to integration constraints. Consequently, direct waveguide crossings are the only option to increase the photonic device density. To ensure low-insertion loss and minimal crosstalk, we designed SiN waveguide crossings (footprint: 26.94µm×26.9µm) using a beam shaping approach [6]. Fig 2. (e) and (j) show the schematic and simulated views of the crossings, respectively. Insertion loss and crosstalk are measured to be -0.06 dB and -50 dB, respectively and found to be very close to the simulated values.

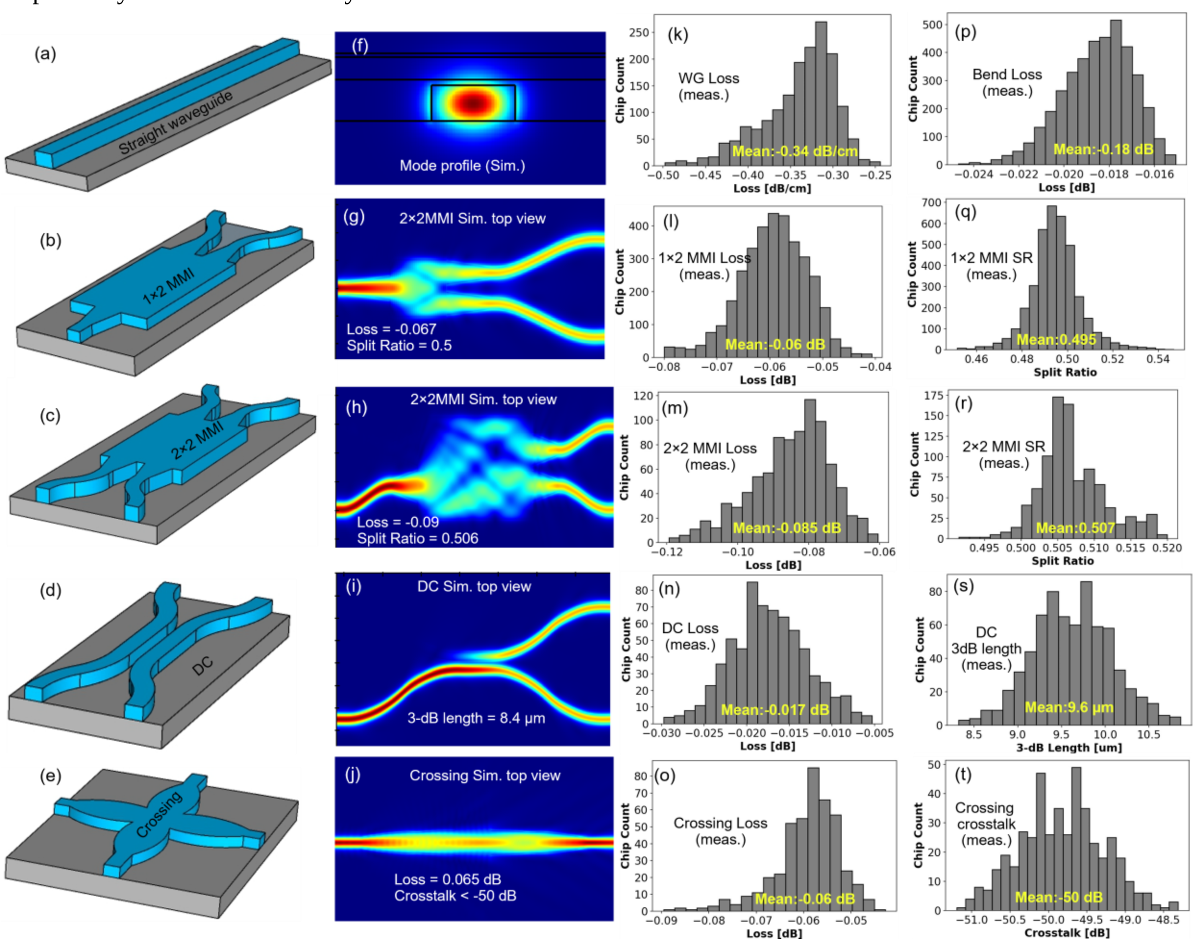

Fig. 2 Performance summary of SiN passive photonic building blocks: SR – split ratio. All components are optimized for TE polarization at 1310 nm.

3. SiN-based Coarse Wavelength Division Multiplexer

To demonstrate the feasibility of implementing photonic circuits using the nitride building blocks, we have designed a coarse-wavelength division multiplexing (cWDM) filter circuit on the monolithic SiPh platform. WDM is the most efficient approach for utilizing bandwidth of optical waveguides. Implementing WDM circuits with Si waveguide demands active control of the delay sections due to fabrication sensitivity and thermo-optic coefficient of the Si material. In addition, Si is also prone to high optical power due to non-linear effects. Whereas SiN material is relatively less sensitive to the thermal variations, capable of handling higher optical power and fabrication tolerant. We selected cascaded Mach-Zehnder interferometer (MZI) structures for obtaining cWDM filter with flat-top response and minimal crosstalk. Fig. 3(a) shows the schematic view of 1×4 cWDM filter based on interleaver architectures. DC based power splitters were used to build the circuit as it demands variable splitting ratios (see Fig. 3(a)). cWDM filter consists of two stages where the first stage separates odd and even channels and the second stage separates each individual channel.

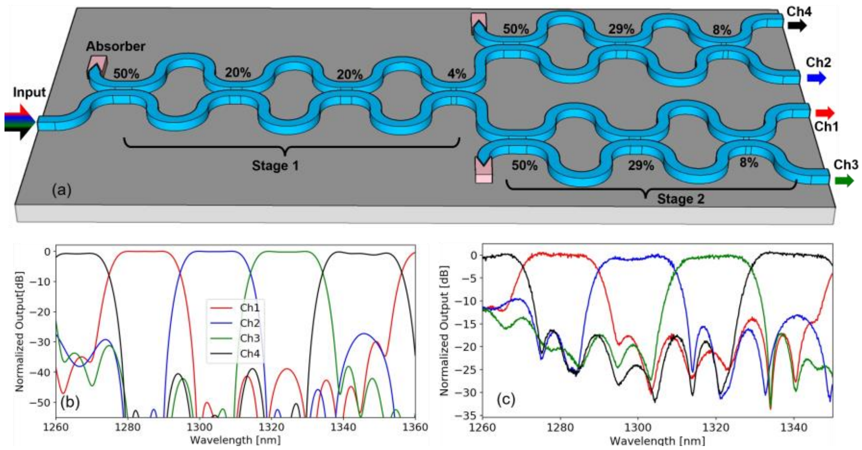

Fig. 3 (a) Schematic view of cWDM filter cascaded MZI structures. Stage 1 separate odd and even channels and stage 2 separate individual channels. (b) Simulated and (b) measured spectrum of the cWDM filter.

Fig. 2 (b) and (c) show the simulated and measured transmission spectrum of cWDM filter, respectively. Measured filter response give a clean spectrum with the channel separation and bandwidth close to the simulated values. Table 1 compares the simulated and measured responses of the cWDM filter. Crosstalk is found to be higher than the design due to minor variations in the splitter (DC) performance. We have confirmed it by separately characterizing each directional couplers in the circuit. Additionally, crosstalk degradation near the band edges (1260nm) indicates the wavelength dependency of the directional couplers. To improve the crosstalk, clean up filters can be incorporated at each stage of the cWDM filter by compromising the insertion loss by 2x.

Table 1. Performance comparison of SiN cWDM filter. IL: Insertion loss, BW: bandwidth, CS: Channel Separation, CT: Crosstalk, PB: Passband

cWDM Filter	IL [dB]	1 dB BW [nm]	CS [nm]	CT [dB]	PB ripple [dB]
Design	0.59	14.2	20	< -30	0.1
Measured	NA	16	20	< -15	0.7

4. Conclusions

We compared simulated and measured responses of SiN basic building-blocks including straight and bend waveguide, 1×2MMIC, 2×2MMIC, DC, and crossings. Performance statistics clearly establishes the manufacturability of low-loss SiN photonic devices on GlobalFoundries' monolithic platform. Additionally, we have demonstrated a proof-of-concept cWDM circuit to prove feasibility of the photonic integrated circuits on SiN.

5. References

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