

Single-Chip Silicon Photonics 100-Gb/s Coherent Transceiver

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Abstract: We demonstrate a monolithic silicon photonics integrated circuit that contains all the optics for a 100-Gb/s coherent transceiver, except the laser. Co-packaged with linear drivers and transimpedance amplifiers, the $27 \times 35.5 \text{ mm}^2$ module consumes only 4.5W.

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1. Introduction

Optical advanced modulation formats combined with coherent reception provide a reduced symbol rate and spectral width along with digital compensation of linear impairments for fiber optic transmission. The combination allows carriers to upgrade 10-Gb/s networks to 100-Gb/s networks with minimal change to the fiber plant. Coherent technology has been mainly deployed in long-haul networks, and it is now starting to be deployed in metro networks. The main impediments have been the cost and footprint of the transceivers, which consist of a tunable laser, an advanced format modulator, a coherent receiver front-end, and a digital-signal processor. Indeed, the dominant cost of optical networks today is in the transceivers.

One way to tackle cost and footprint is optical and electronic integration. Optical integration reduces cost by minimizing assembly touch points, minimizing mechanical adjustments, minimizing test apparatuses, and minimizing the amount of material required. Choices for optical integration platforms include Si, InP, GaAs, silica, and polymer. Si photonics (SiPh) is attractive because of the following: 1) all the waveguides are formed from the original crystal boule instead of epitaxy, except for the Ge photodetectors. This results in nearly zero defects. 2) Si has an ideal oxide, silica, which is easily formed and has excellent properties including very low optical loss, high electrical isolation, large refractive index contrast, hermetic sealing, and wafer bondability—leading to silicon-on-insulator (SOI) technology 3) Because of SOI technology, Si waveguides enjoy high index contrast both horizontally and vertically, resulting in extremely high confinement and hence tight bends for compactness. 4) SiPh modulators use carrier movement rather than band-edge effects, making them less sensitive to temperature [1]. 5) Si is a very low cost and strong material allowing for large 300-mm-diameter wafers.

SiPh is often considered mainly for short-reach interconnects [2] because of perceived performance limitations. However, SiPh may be even better suited for coherent transceivers than for on-off-keying short-reach transceivers. This is because 1) SiPh can construct an optical circuit with tens of elements with high yield, 2) the polarization de/multiplexing of coherent alleviates the difficult-to-meet requirement for polarization-independent integrated optics in a small geometry, 3) SiPh's high index contrast is well-suited for splitting and rotating optical polarization, and 4) the main electro-optic imperfections in SiPh can be compensated in the digital signal processor (DSP) of a coherent transceiver.

SiPh dual-quadrature and dual-polarization coherent receivers [3] and separate SiPh dual-quadrature and dual-polarization modulators [4] have been reported. Demonstrations have shown that both SiPh coherent receivers [5] and advanced-format modulators [6] can achieve high performance. Here we report a full coherent receiver and full advanced format modulator monolithically integrated on a single SiPh chip. Performance comparable to discrete optics is achieved.

2. Design

The SiPh photonic integrated circuit (PIC), block diagram shown in Fig. 1, contains all the major optical functions needed for an optical coherent transceiver except the laser. The chip is $2.7 \times 11.5 \text{ mm}^2$ and comprises Si wire waveguides on a silicon-on-insulator wafer, carrier depletion modulators, and Ge photodiodes. The PIC is co-packaged with

The measured DP-QPSK eye diagram from the transmitter is shown in Fig. 2(b). The transmitter is connected to the receiver on the same PIC, and the resultant real-time-processed constellation is shown in Fig. 2(c).

The measured real-time pre-forward-error-correction (FEC) bit-error rate (BER) vs. received optical signal-to-noise ratio (OSNR) is shown in Fig. 3 at five wavelengths across the C-band, from 191.8 to 195.9 THz, at three case temperatures, and at four transmission distances. OTU-frames with a $2^{15} - 1$ PRBS load were used. Shown for comparison is the performance using discrete optics, i.e., a LiNbO₃ modulator, gold-box drivers, and a hybrid receiver. As mentioned previously, SiPh has very low temperature sensitivity; except for wavelength filters, which we do not use in our PIC; so no temperature control is required. The change in OSNR performance from 10°C to 75°C is very small. Also shown is up to 3000 km of transmission. The lack of penalty from transmission indicates that the chirp of SiPh modulators is likely negligible. We verified the lack of chirp with simulations of detailed models of the SiPh modulators.

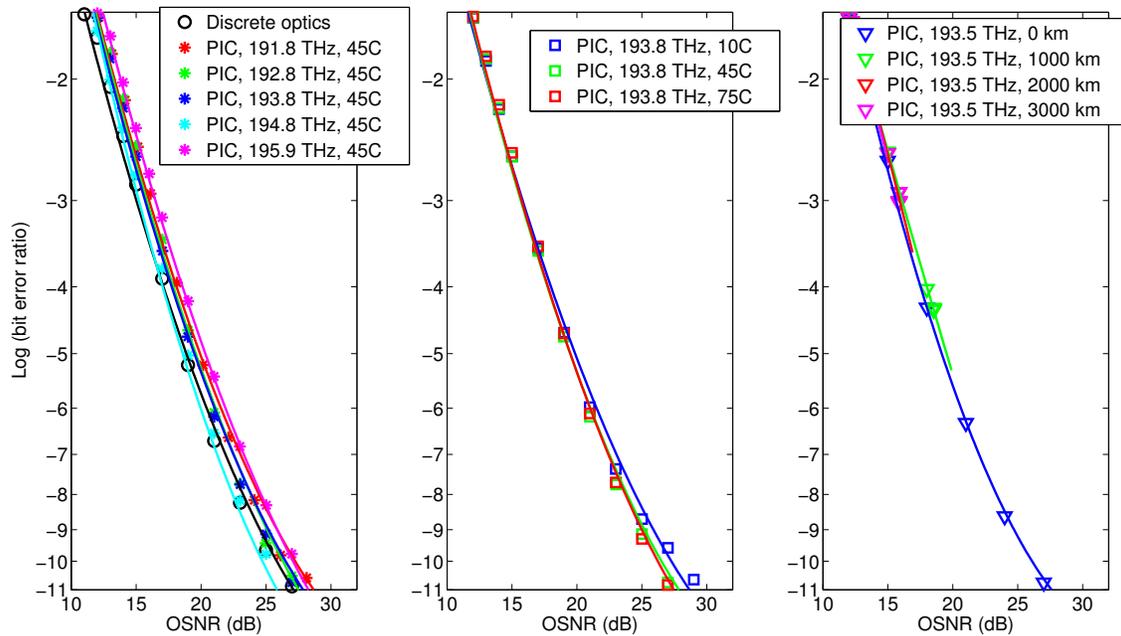


Fig. 3. 120-Gb/s measured real-time BER vs OSNR (0.1-nm bandwidth) optical loop-back performance at various wavelengths, case temperatures, and transmission distances for the PIC.

4. Conclusion

We demonstrated a single-chip 100-Gb/s coherent transceiver in silicon photonics which contains all the required optics except the laser. Consistency of performance over wavelength and temperature supports that 100-Gb/s SiPh is ready for commercialization, particularly in applications where low cost and small factor are important.

References

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