TeraPHY: An O-band WDM Electro-optic Platform for Low Power, Terabit/s Optical I/O

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Abstract

We demonstrate an electro-optic platform enabling a direct optical I/O interface in an ASIC package. The 5.5x8.9mm^2 chiplet uses the Advanced Interface Bus (AIB), a parallel digital interface, to communicate to a host ASIC and integrates high-speed digital/analog circuits, optical modulators, photodetectors, and waveguides. Transmitters and receivers demonstrate data-rates up to 25Gbps at 4.9pJ/bit (Tx+Rx) and <10^{-12} BER error-free operation. We show a 32-channel, 512Gbps aggregate (across 4 Tx ports) wavelength-division multiplexed (WDM) transmit demonstration from a TeraPHY chiplet, running at 16Gbps per wavelength and 8 simultaneous wavelengths per port.

Keywords: optical I/O, transceivers, transmitter, receiver, VLSI, wireline, monolithic, silicon photonics, WDM

Introduction

The TeraPHY chiplet, which consists of approximately 51M transistors and hundreds of optical devices, is built on a 45nm Silicon-on-Insulator (SOI) CMOS process. The silicon body layer, which is used as the transistor body, is also used to form both passive (waveguides, grating couplers) and active optical devices (modulators, photodetectors) [1]. Fig. 1 shows the micrograph of the chiplet and an assembled single-die package[1] (SDP) both with and without the lid. For the SDP package, the chip is assembled via standard flip-chip packaging to an organic substrate, with electrical I/O and power delivered by the substrate. An optical bent fiber array, actively-aligned to the grating coupler fiber coupling array, is used to couple light to/from the fiber from/to on-chip waveguides, which go into/come out of each optical transceiver macro. The Glue block bridges the interface between the transceiver macros and the AIB interface, serving as an on-chip crossbar to map different AIB channels to different lanes in the transceiver macro.

Optical Transceiver Macros

Each optical transceiver macro is capable of transmitting and receiving 8 different wavelengths (λs) of light (8 lanes per macro) at up to 25Gbps per λ, a total of 200Gbps Tx/Rx per macro. There are a total 10 such macros on the chip (80 total lanes), for a total design bandwidth of up to 2.0Tbps optically. Fig. 2 shows micrographs of the optical macro, the architecture for each single-λ slice, and performance characterization at 25Gbps per λ for both the transmitter and receiver. The microring modulator or photodetector in each Tx or Rx slice performs both wavelength selection as well as modulation or photodetection in a single device. A digital thermal tuning controller within each slice performs both initialization and microring wavelength lock, and is capable of tuning the resonant wavelength of each ring by 10nm. At 25Gbps transmitter slice shows open eyes with a >4.6dB extinction ratio and the receiver achieves a sensitivity of -10dBm optical modulation amplitude (OMA) at 10^{-12} BER. Fig. 2g shows a breakdown of the 4.9pJ/bit energy efficiency.

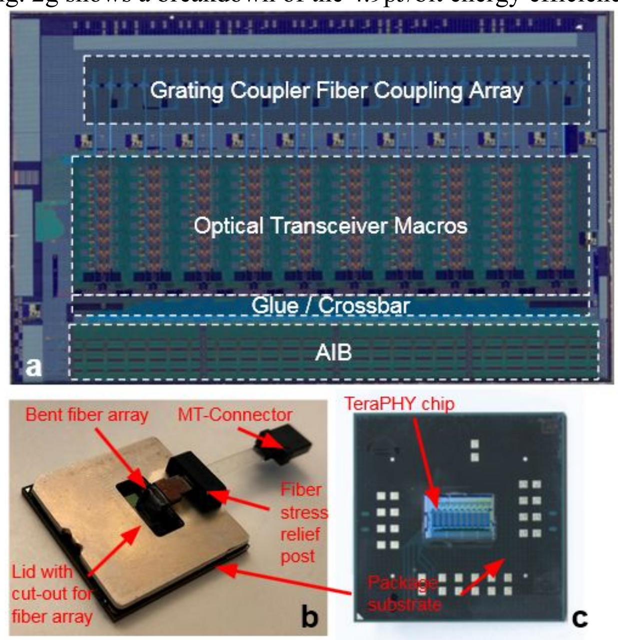

Fig. 1: TeraPHY chiplet (a) and single-die-package with (b) and without lid (c)

We show a 512Gbps transmitter demonstration (Fig. 3a) using 4 macros, each modulating 8λ at 16Gbps/λ (Fig. 3b), limited by the loss through the external laser splitter/combiner. A tunable filter is used before the optical input on the oscilloscope to capture the eye diagram on each λ. The active wavelength locking by the microring, enables clean output eye diagrams and overnight lock stability >15 hours (Fig. 3d), despite imperfect channel spacing and power levels from the input laser array/combiner (Fig. 3c).

[1] Multi-die packages incorporating the TeraPHY, such as the one in [2], are discussed in other works

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The views, opinions and/or findings expressed are those of the author and should not be interpreted as representing the official views or policies of the Department of Defense or the U.S. Government.

References

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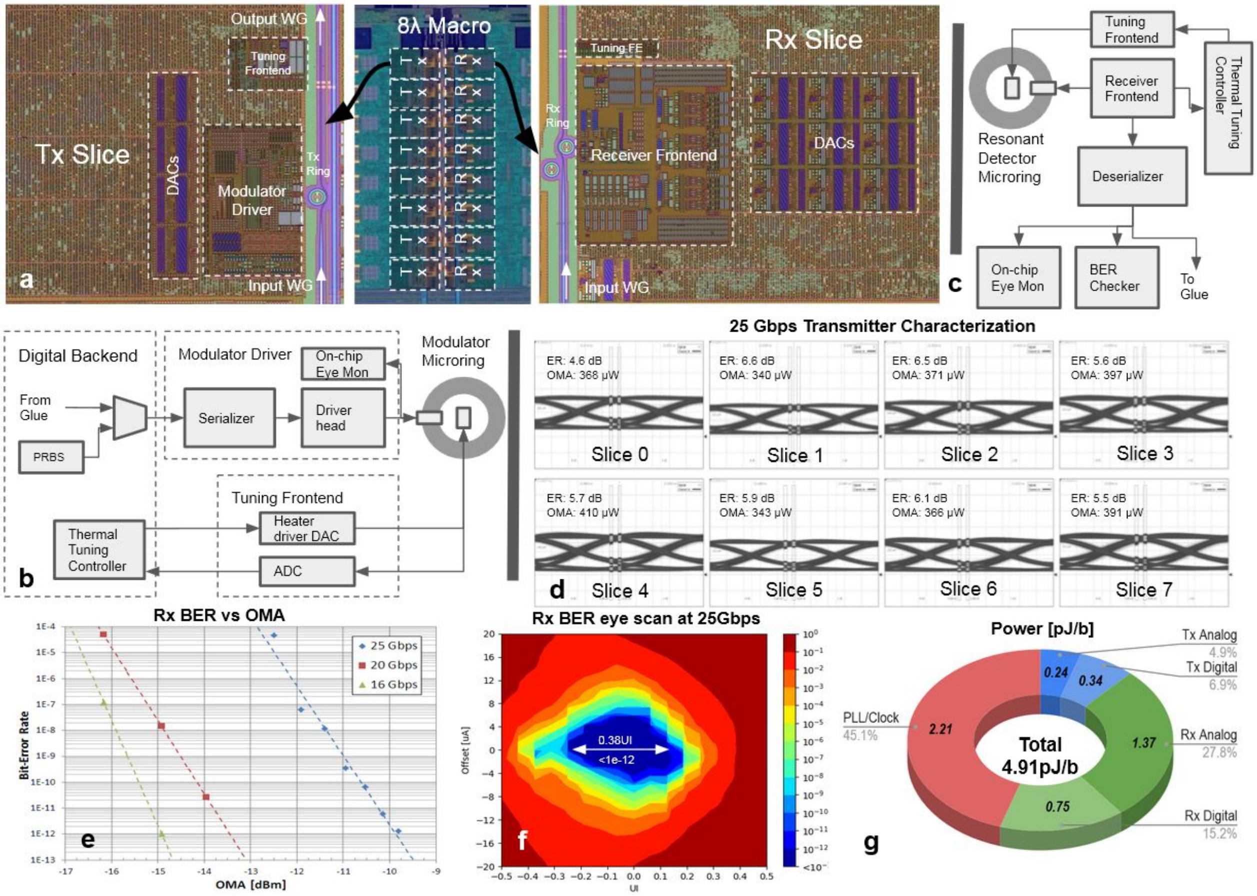

Fig. 2: Micrographs of the 8λ macro and the corresponding single-λ transmit and receive slices (a), block diagrams of the transmitter (b) and receiver (c), 25Gbps transmitter characterization for each of the 8 slices in a macro (d), receiver BER vs. OMA characterization (e) and 25Gbps BER eye scan (f), and measured power breakdown (g). In the receiver BER vs. OMA characterization, note that what is measured in the test setup is a µApp sensitivity, which we translate to OMA through the 0.6 A/W measured responsivity of the photodetector.

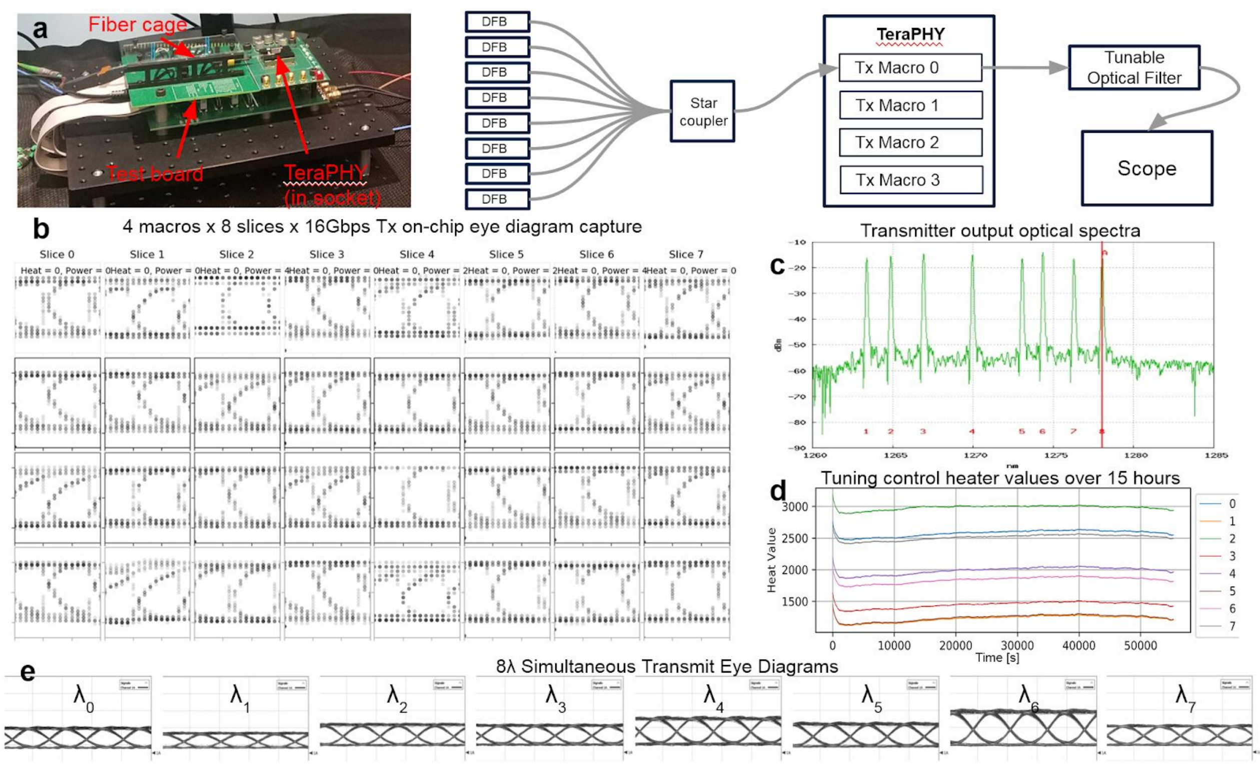

Fig. 3: Demonstration of 4 x 8λ x 16Gbps transmitter for an aggregate 512Gbps transmit throughput. Test setup (a), eye diagram capture of all 32 channels using the on-chip transmit eye monitor (b), transmitter output spectra (c)and thermal tuning stability experiment over 15 hours (d), and optical transmit eye diagrams (with all 8λ on simultaneously) on each transmit output wavelength (e).