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High-density Silicon Optical Interposer for Inter-chip Interconnect

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Abstract

We introduce the silicon optical interposer for inter-chip interconnect. We developed and integrated the optical components on a silicon substrate and achieved a bandwidth density 30Tbps/cm^2 with a channel line rate of 20Gbps for the silicon optical interposer.

1. Introduction

The ICT society has been developed mainly by LSIs and optical communications which transact and transmit information. Recently, IP traffics have been rapidly increasing by cloud computing and big data analysis. Correspondingly, datacenters have been bigger, in which there are many servers connected. On the other hand, LSIs' transaction capabilities in these servers have been increased by Moor's law, but they face the physical limit of micro fabrication in semiconductor. Beyond this limitation, one of the solutions is multi-cores or many-cores in CPUs and the interconnections among CPU chips and between CPU and memory chips have been important for improving the bottleneck in system performance.

In this paper, we will introduce the Photonics-Electronics Convergence System for LSI chips' interconnections and silicon optical interposer in this system.

2. Photonics-Electronics Convergence System

Figure 1 shows our proposed Photonics-Electronics Convergence System for LSI chips' interconnections [1]. In this system, the electrical signal can be converted by optical signal through the silicon optical interposer. By using this system, the printed circuit board with the size of 30-cm square in server can be replaced by the silicon chip with the size of 3-cm square. The silicon optical interposer in this system consists of optical modulators, photodetectors, and light sources, which optically linked each other with optical waveguide. The properties of optical signal, for example, high speed and wide bandwidth enable it to interconnect LSIs with high-density and high-bandwidth without electrical noise. Therefore, it is one of the promising solutions to solve the bottleneck of bandwidth between CPUs and CPUs or between CPUs and memories. The required bandwidth between CPUs and memories in high-end computers is now about 1Tbps and has been increasing double per two years [2]. Although around at 2020s, the required bandwidth will be 10Tbps and normal CPU size will be 2 cm^2, in which half will be occupied by pads for interconnects, the bandwidth density of 10-Tbps/cm^2 will be required.

To realize this high bandwidth, the conventional method connecting the modules of compound semiconductor and glass waveguide devices with fibers has the limitation of compactness and cost reduction. Recently, silicon photonics technology has been exploited to reduce both size and cost of optical modules. It enables to integrate almost all optical components for optical interconnection in a silicon substrate. We have achieved high-density silicon optical interposer by silicon photonics technology.

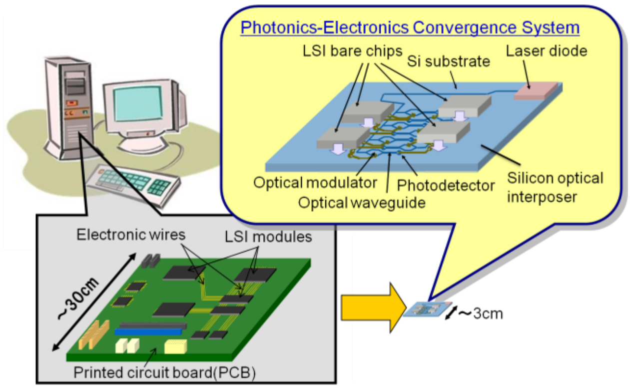

Fig. 1 Photonics-Electronics Convergence System for LSI chips' interconnection.

3. High-Density Silicon Optical Interposer

Figure 2 shows the functional blocks and the optical components in our silicon optical interposer. Our silicon optical interposer consists of continuous wave light source, optical splitter for power divided from light source, converter from electrical signal to optical one (E/O), optical wire for signal transmission and converter from optical signal to electrical one (O/E). All optical components were designed from the view point of both downsizing and high bandwidth. 13-channel arrayed InGaAsP Fabry-Perot LD with 30-μm pitch was employed as a light source for downsizing and high output power that is distributed [3, 4]. For light distributor, 1×4 MMI was introduced as optical splitter. For E/O converter, Mach-Zehnder p-i-n optical modulator with side-wall grating was developed [5]. For O/E converter, p-i-n germanium waveguide detector was developed [6]. Low-loss channel silicon optical waveguide was introduced for optical wire [7]. The bend loss of optical waveguide is almost zero at the radius of more than 5μm.

Therefore, by realizing almost right-angled bend waveguide, all components are able to be linked with each other, compactly.

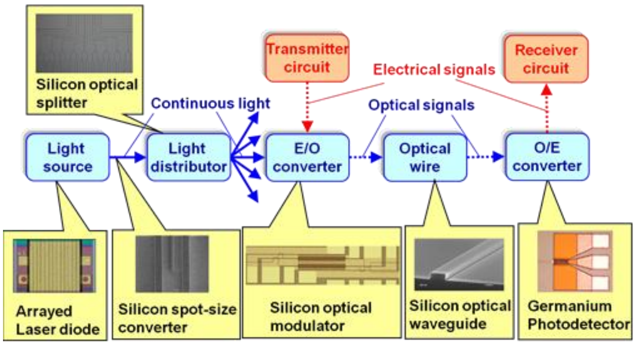

Fig. 2 Functional blocks and optical components in our silicon optical interposer.

The silicon optical interposer was fabricated as shown in Fig. 3. 104 silicon optical modulators and germanium detectors, 26 1×4 MMI splitters and SSCs were linked to each other with silicon optical waveguide and they were monolithically integrated on a silicon substrate by CMOS compatible process. Furthermore, two 13-channels arrayed LDs were hybridly integrated on the substrate. The electrode pad pitches were selected as 100µm for adjusting to flip-chip bonding of LSI bare chips.

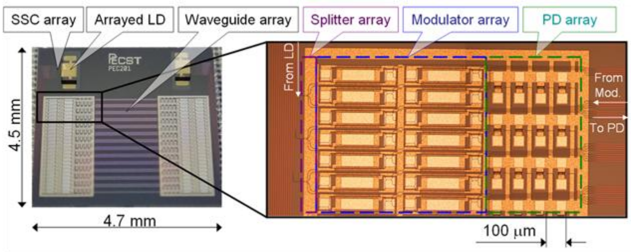

Fig. 3 Fabricated optical silicon interposer.

We measured the transmission speed per a channel. The CW light driven by 13-channels arrayed LD was coupled to the silicon optical waveguide through the SSC. Then, the coupled light was divided into four by a 1×4 MMI optical splitter and each light was introduced into the silicon optical modulators. In the silicon optical modulator, the electrical signal, which was generated from PPG and pre-emphasized through differentiator, was converted to the optical signal. The optical signal was propagated through the silicon optical waveguide and was converted to the electrical signal in the germanium detector. After the electrical signal was amplified by TIA, we measured eye diagrams and bit error rates (BER) of the PD outputs at 20-Gbps NRZ with a 2^7-1 pseudo-random binary sequence (PRBS) as shown in Fig. 4. We confirmed that the BER was less than 10^{-12} when the PD outputs was larger than -5dBm. The total footprint was 0.0677 mm^2 per channel, meaning we could achieve a bandwidth density of 30Tbps/cm^2 with a channel line rate of 20Gbps [8].

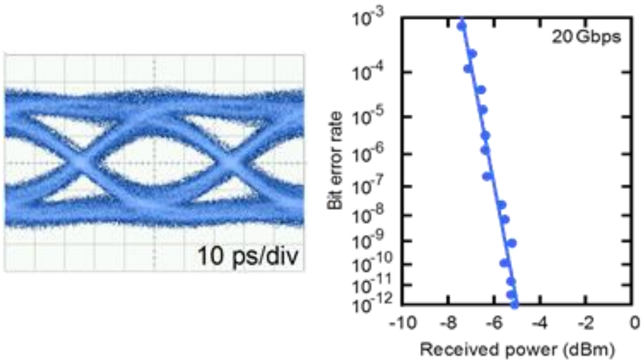

Fig. 4 (a) Measured eye diagram of PD output and (b) Bit error rate at 20Gbps.

4. Conclusions

We introduce the Photonics-Electronics Convergence System and the silicon optical interposer in this system, which will be able to promote high-speed and high-capacity interconnection among LSI chips by replacing electronic wire to optical one. We developed the optical components for the silicon optical interposer and achieved a bandwidth density 30Tbps/cm^2 with a channel line rate of 20Gbps.

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