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On-chip silicon photonics technologies for WDM-based optical interconnects

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Abstract

We report recent progress of on-chip silicon photonics technologies targeted for wavelength division multiplexing (WDM)-based high-density optical interconnects. First, our previous works for optical interconnects based on on-package module between CPUs are briefly reviewed. Second, we present several types of on-chip silicon photonics functional devices for use in a WDM integrated transceiver.

1. Introduction

High-bandwidth interconnects are becoming more and more important for high-performance computing systems (HPC) and mega datacenter (MDC) applications. To date, photonics technologies based on vertical-cavity surface-emitting laser (VCSEL) transceivers with a multimode fiber (MMF) have exhibited a practical way to deliver aggregate data capacity of a few tens of Gbps to the distance of more than a few tens of meters that is almost impossible for electronics based interconnects [1,2]. Considering the scalability of future MDC applications, one should be able to process the total data bandwidth beyond a few Tbps within a system board level between MDCs whose interval would be far more than a few hundreds of meters. This requires the optical transceivers to be made with single-mode fiber (SMF) interface, together with even higher bandwidth. From the viewpoint of high density integrability and potential to use wavelength division multiplexing (WDM), silicon photonics (SiPh) based transceivers could be more satisfied with these requirements than the case of VCSEL based ones.

In our previous works, to facilitate on-package type module that is promising for a small foot print, high communication bandwidth, and low power consumption, we reported novel silicon platform technology consisting of SiPh transceivers integrated with electronics drivers and pseudo central processing unit (CPU) through bridge-type package substrate [3,4] as schematically shown in Fig. 1.

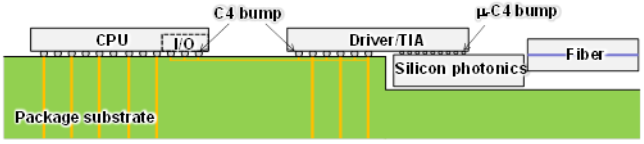

Fig. 1 Schematic of on-package optical module

It was shown that the proposed bridge-type assembly technique is extremely efficient for power integrity by reducing the distance between the CPU and SiPh transceivers to a few centimeters [4]. In addition, since the electronics driver could be mounted on direct top of the SiPh chips, the bridge-type assembly also provided more advantages in terms of signal integrity than wire bond type assembly technique. In this way, 25Gbps error-free optical link transmission was successfully made by the proposed bridge-type assembly structure.

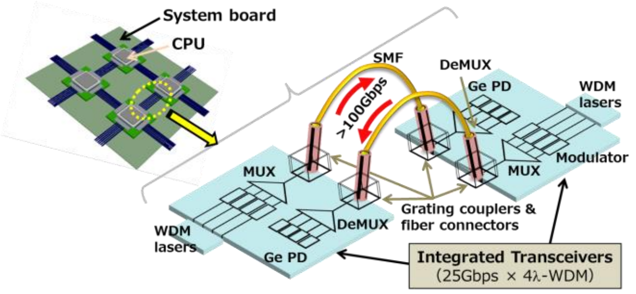

Fig. 2. Schematic of SiPh WDM optical transceivers

Meanwhile, the processing capability of optical interconnects could be further enhanced by implementing WDM schemes. Figure 2 shows SiPh WDM transceivers that PETRA has been developing for high-bandwidth interconnects. For a transmitter, CW signals emitted from each III-V multi wavelength optical sources are modulated at each external modulator at a rate of >25 Gbps. The modulated optical signals are combined by 4:1 WDM multiplexer (MUX), and coupled into a SMF via a grating coupler (GC).

For a receiver, the WDM optical signals propagating in SMFs are coupled to Si-wire waveguide via a polarization-splitting GC (PS-GC). They are split into four waveguides by 1:4 WDM demultiplexer (DeMUX) depending on their state of polarization (SOP) in a SMF. Then, Ge-based photodiodes (PDs) receive each optical signal and transform them into the electrical signals. The modulators and the detectors are electrically connected to drivers and trans-impedance amplifiers and limiting amplifiers.

In this paper, we present recent progress of SiPh functional devices for use in a WDM integrated transceiver.

2. WDM filters for MUX/DeMUX

Not to mention, WDM scheme is one of promising ways of increasing the aggregated bandwidth in a small footprint.

Si-wire waveguide type MUX/DeMUX whose cross-sectional dimensions are matched with modulators and PDs for a monolithic integration is a fundamental building block to transmit and receive the WDM signals. Usually, (De)MUX performances such as insertion loss (IL), spectral crosstalk (XT) and operating window shift (OWS) are mainly degraded by fabrication imperfection and temperature change in a Si substrate.

We verified that these technical barriers could be overcome by optimizing the (De)MUX schemes. First option is to give a flatband spectral response enough to relax the aforementioned degradations in terms of IL, XT and unwanted OWS [5,6]. Meanwhile, tunable function based on tuning of the operating window by micro-heaters [7] can also be an alternative way to pave those drawbacks. Several kinds of (De)MUX schemes will be discussed and compared from the viewpoint of IL, XT and tolerable range for the external temperature change etc.

3. Grating couplers for on-chip polarization handling

It has been well known that a GC is an efficient device for coupling interface to a SMF in a transceiver due to the compatibility to CMOS process and availability of wafer-level testing [8]. Normally, Si-wire DeMUX operates only for a single linear polarization due to relatively large structural birefringence of waveguide.

However, when it comes to launching into the DeMUX at the receiver side, inability to keep the SOP constant in a SMF makes it difficult to fully work as a wavelength filter for a WDM signal. In this case, as briefly mentioned in a previous section, the PS-GC consisting of a grating periodic in two dimensions provides coupling interface to a SMF via a polarization diversity scheme for an input signal with arbitrary SOP [9]. Spectral characteristics for the PS-GC will be discussed from the viewpoint of IL and input SOP dependence.

4. Optical sources by hybrid integration

WDM system normally requires multi-wavelength optical sources for signal generation. For such optical sources, PETRA has developed III-V/silicon hybrid integrated external cavity lasers by combining a III-V-based semiconductor optical amplifier (SOA) and Si-wire-based microring resonator (MRR)-based oscillation mode selector [10,11]. Also, a DFB laser array directly flip-chip bonded on a Si substrate has been developed for a stable multi-wavelength oscillation [12]. It demonstrated high output powers and a uniformly spaced 8 wavelength oscillation with high SMSR under simultaneous drive condition at 70^{o}C. Packaging characteristics of multi-channel optical sources by sealing of resin will also be discussed together with the tolerance through a packaging process.

5. Conclusions

Recent progress of Si photonics functional devices that have been developed in PETRA for WDM-based high-bandwidth optical interconnects. The integrated optical transceiver based on a proposed bridge-type assembly structure exhibited 25 Gbps error free transmission with the good power efficiency.

Acknowledgements

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