Demonstration of Optical Re-Distribution on Silicon Photonics Die Using Polymer Waveguide and Micro Mirrors

A. Noriki(1),(2), I. Tamai (1), Y. Ibusuki(1), A. Ukita(1), S. Suda(1),(2), K. Takemura(1), D. Shimura(1), Y. Onawa(1), H. Yaegashi(1), T. Amano(1),(2)

(1) Photonics Electronics Technology Research Association (PETRA), a-noriki@aist.go.jp
(2) National Institute of Advanced Industrial Science and Technology (AIST)

Abstract *An optical re-distribution based on micro-mirrors and polymer waveguide was demonstrated on a silicon photonics die for advanced co-packaged optics. Low wavelength dependent characteristics was obtained and 28GBaud NRZ signal was also successfully transmitted with negligible signal distortions.*

Introduction

In high performance computer systems and large-scale data centers, data movement becomes a critical problem[1]. Increasing data rates of conventional electrical links causes low latency tolerance, high power consumption, and poor signal integrity, especially for long distance interconnects. To extremely reduce the length of high-data-rate electrical links, co-packaging technologies of optics chips (e.g. silicon (Si) photonics) and high-performance large-scale integration (LSI) chips are attracted much attention. For example, Rockley Photonics showed a switch application specific integration circuits (ASICs) where Si photonics chips were co-packaged at OFC 2018, and dozen ribbon optical fiber cables were connected to it[2].Such massively parallel optical input/outputs (I/Os) will be necessary for high performance LSIs like upcoming high-capacity switch ASICs over 51.2 Tbps.

Recently, as one of the co-packaging solutions, we have proposed a new package substrate called active optical package (AOP) substrate. The bird-view and cross-sectional schematic of the AOP substrate are shown in Fig. 1. The AOP substrate is based on a conventional organic package substrate such as glass-epoxy substrates, and Si photonics dies are embedded in it.

In the AOP substrate, the Si photonics I/Os and single-mode fibers (SMFs) are connected by an optical re-distribution realized with polymer waveguides and micro mirrors as shown in Fig. 1. Direct fiber coupling method is often used for optical I/O of Si photonics die. However, the low-density fiber interface restricts size reduction of Si photonics chip. For example, popular MT-fiber connector has a footprint of 6.4 x 2.5 mm with fiber pitch of 250um, and thus, the I/O pitch of Si photonics is also 250um and the chip size is larger than this footprint. By the optical re-distribution, high-density Si photonics I/O of e.g. 50-um pitch can be re-distributed to the low-density single-mode fiber interface of 250-um pitch. Thus, High-density small Si photonic chip can be realized without I/O-footprint restriction. Because of the required chip size is decreased, the cost per chip can be reduced. The optical re-distribution can be fabricated by optical lithography technologies. Therefore, very fine alignment is available for the Si photonics I/Os. The optical coupling between the polymer waveguides and SMFs are established by the optical connector assembled at the edge of the package substrate[3],[4].

In this paper, the optical re-distribution was demonstrated on the Si photonics die as a feasibility study for that of the AOP substrate. The two micro-mirrors and polymer waveguides were integrated, and those optical characteristics were evaluated.

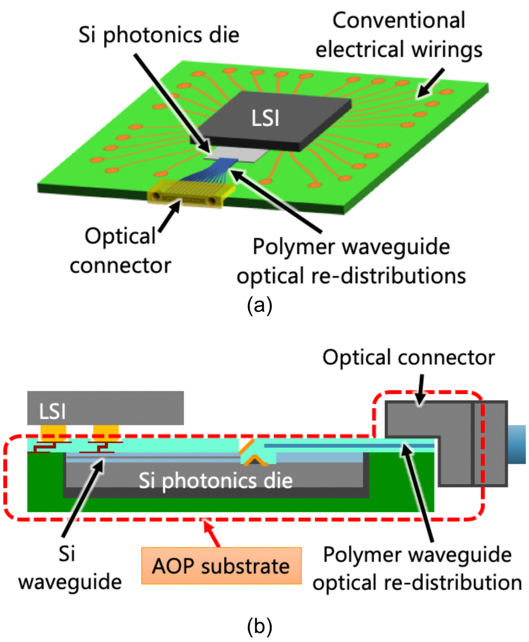

Fig. 1: (a) The bird-view and (b) cross-section schematic of the co-packaged optics using AOP substrate.

Fabrication of optical re-distribution

The fabrication process of the optical re-distribution on the Si photonics die is shown in Fig. 2. First, a cavity was formed on the surface of the Si photonics die to integrate a bottom-side mirror. Next, the mirror was fabricated based on gray-scale lithography as described in a previous work[5],[6]. Then, the mirror was coated with a reflective metal layer and encapsulate by transparent resin. After that, a bottom cladding and core of the polymer waveguide were fabricated. Finally, a top-side mirror and a top cladding were fabricated by same gray-scale lithography process.

A Si inverse taper waveguide was used as a spot size converter (SSC) at the end region of the Si waveguide. The light from the SSC was output to upper side by the bottom-side mirror as described in the previous works[5],[6]. Owing to the curved surface of the bottom-side mirror, the beam waist diameter of the light from the mirror was around 10 μm. The light was reflected again by the flat-surface top-side mirror and coupled to the polymer waveguide with the MFD of around 10 μm.

The laser microscopic images and surface height profiles of the fabricated mirrors are shown in Fig. 3. 45° smooth surfaces were obtained for bottom- and top-side mirrors.

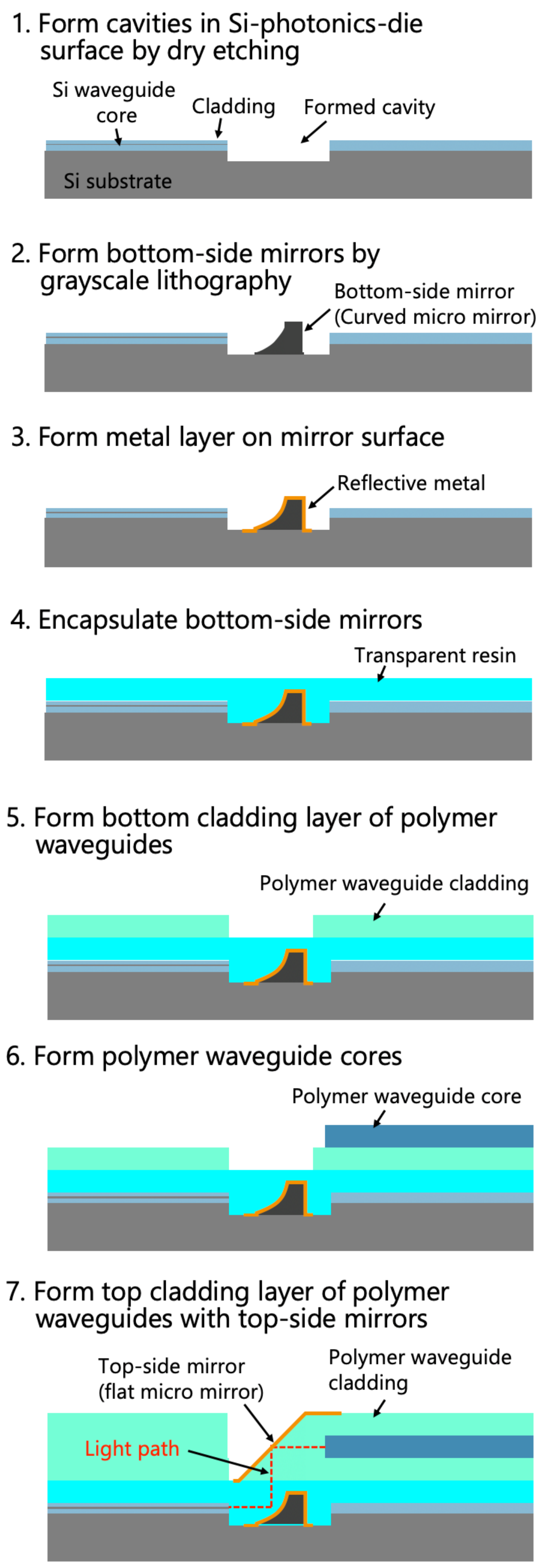

Fig. 2: The fabrication process of the mirrors and polymer waveguide for the optical re-distribution on the Si photonics die.

Evaluations

To evaluate the optical loss of the fabricated optical re-distribution, the insertion loss of the fabricated sample was measured as shown in Fig. 4(a). A super luminescent diode (SLD) was used as a broadband optical source covering S, C, and L band. The light from the SLD was polarized and input to the Si waveguide using a spherical lensed fiber (SLF) with MFD of 3 μm. The light passed through the Si waveguide, mirrors and polymer waveguide was received by a standard SMF with 10-μm MFD and cleaved end facet. Two different kinds of fiber were used

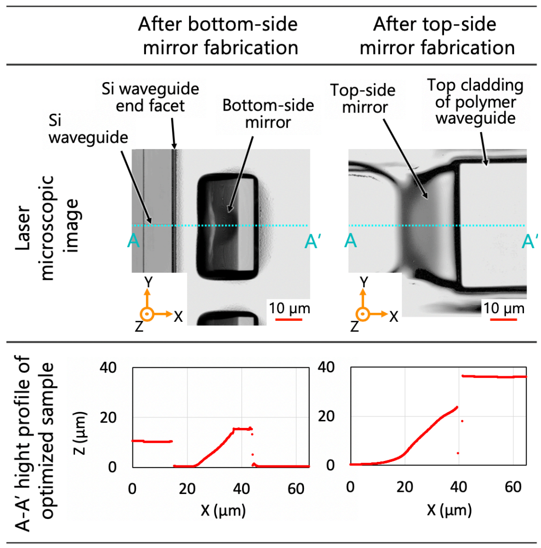

Fig. 3: The laser microscopic images and surface height profiles of the fabricated bottom- and top-side mirrors.

as the input and output fibers to match the MFD of the Si and polymer waveguides, respectively. The insertion loss of the reference sample was also measured as shown in Fig. 4(b). The reference sample is only the Si photonics die as same as that used for the optical re-distribution. That is, the optical re-distribution was not fabricated for the reference sample. The SLFs were used as input and output fiber, since both of input- and output-side end facet of the reference sample was Si waveguide. The total optical loss of the optical re-distribution was obtained by subtracting the insertion loss of the sample not including the re-distribution from that including the re-distribution.

The result is shown in Fig. 5. The average loss of the optical re-distribution was around 4 dB. Low wavelength dependent characteristics of ± 1 dB was obtained over the wavelength range of 1460 to 1600 nm. Minimum loss of 3–4 dB was obtained in S-band.

The optical signal transmission of 28GBaud non-return-to-zero (NRZ) signal was also demonstrated at 1550-nm wavelength. Fig. 6 shows the eye diagrams of the back-to-back case and the output light through the optical re-distribution. As shown in this figure, there was negligible signal distortion and the 28GBaud NRZ signal was successfully transferred through the Si photonics die and optical re-distribution.

Conclusions

The feasibility study of the optical re-distribution for the AOP substrate was demonstrated on the Si photonics die. The bottom-side mirror with the curved surface and the top-side mirror with the flat surface were integrated with the polymer waveguide as the optical re-distribution. The optical re-distribution loss was characterized as average loss of around 4 dB and wavelength dependent loss of ± 1 dB for the wavelength range of 1460 to 1600 nm. An advanced technology to extend the optical re-distribution on the Si photonics die onto a glass epoxy substrate will be developed for the AOP substrate in future works.

Acknowledgements

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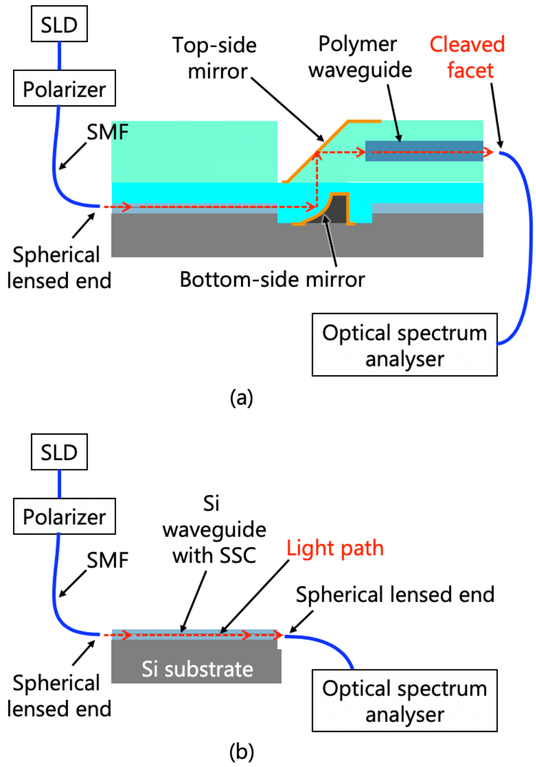

Fig. 4: The measurement setups for insertion loss of the sample (a) with and (b) without the optical re-distribution. A spherical lensed fiber and standard SMF with cleaved end facet was used to receive the light from the Si and polymer waveguide, respectively, to match the MFD.

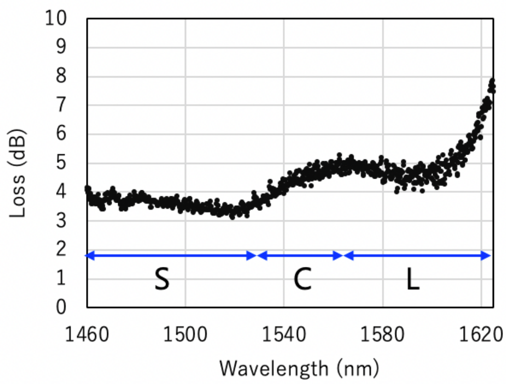

Fig. 5: The measured total optical loss of the optical re-distribution.

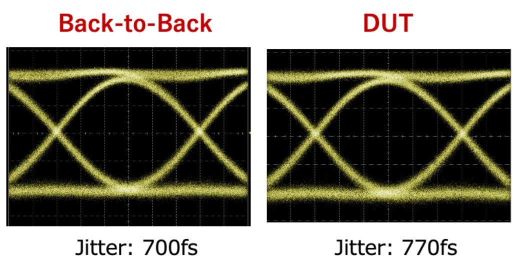

Fig. 6: The measured eye diagrams of 28Gbaud NRZ (28Gb/s) transmission at wavelength of 1550nm

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