Amorphous Silicon Grating-Type Layer-to-Layer Couplers for Intra-Chip Connection

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***Abstract*—Amorphous Silicon (a-Si) grating couplers to couple lights between multilayer a-Si waveguides deposited by PECVD were proposed and demonstrated for the first time. The maximum coupling efficiency of 22% was obtained for the a-Si waveguides with 1 µm distance.**

Keywords-Si photonics; grating coupler; amorphous silicon; multilayer;

I. INTRODUCTION

The miniaturization as known as the scaling law caused signal delays in global wires of complementary metal-oxide-semiconductor (CMOS) technology. Silicon photonics is an attractive candidate to overcome such problem by replacing electrical wires. Optical interconnections on a LSI chip have the advantages of low latency, high bandwidth and low power consumption [1,2].

In order to integrate Si-based optical circuits on the LSI chip through the backend process, all the fabrication processes should be regulated below 400°C to avoid damages to the CMOS layer. Amorphous silicon (a-Si) can be deposited under low temperature conditions around 300°C and thereby attempting to introduce high-index contrast a-Si waveguides for the optical integrated circuits have been widely investigated [3,4]. We demonstrated low-loss multilayer a-Si waveguides and revealed the relationship between the propagation loss and roughness [5].

In addition, vertically stacked a-Si layers paired with SiO_2 provide a high density 3D optical circuit. To realize signal transmission through the optical circuit, a vertical coupling component between two layers is necessary. One of promising approaches is a directional coupler type vertical coupler [6]. This structure, however, needs to keep the distance between two layers around 200 nm, which is too close to achieve optical isolation for other area.

In this paper, we propose grating-type couplers for vertical coupling and demonstrated light coupling between two a-Si waveguides for the first time.

II. DEVICE STRUCTURE AND DESIGN

Grating couplers have been explored to couple lights between a single mode fiber and a photonic waveguide [7-8]. By using the grating structure, light coupling with distance of a few-µm can be realized between multilayer waveguides. Figure 1 illustrates the structure of grating couplers. In order

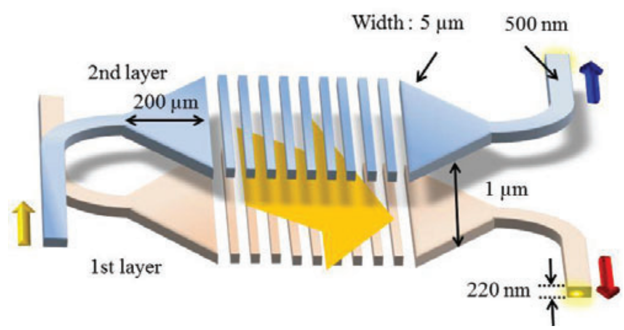
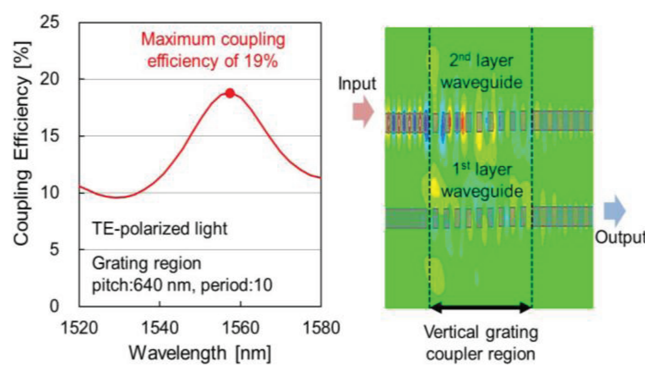


Fig.1 Device structure.



(a) (b)

Fig.2 (a) Calculated coupling efficiency versus wavelength (b) the electric field distribution at grating coupler region.

to avoid the crosstalk between two layers, we fixed the layer distance to 1 µm. The 500-nm-wide a-Si wire waveguides were expanded to a 5-µm-wide waveguide at the grating region to improve the tolerance in alignment mismatch. The taper region with the length of 200 µm was introduced to avoid reflection and excite only the fundamental mode in the wide waveguide. The conversion efficiency of more than 99% was obtained from the eigenmode expansion method simulation.

The thickness of both a-Si layers was 220 nm and the Si-layer was completely etched to form grating. In order to design the gratings, the coupling efficiency was calculated by 3D-FDTD with various grating pitches and periods. The refractive indices of a-Si and SiO_2 were assumed to be 3.48 and 1.45, respectively. We monitored the coupling efficiency while controlling the grating pitches from 580 nm to 700 nm (duty: 50%) and the number of periods from 7 to 15 using

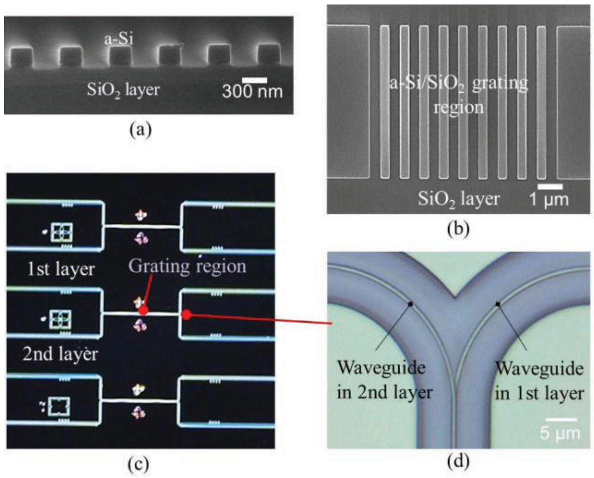


Fig.3 (a) Cross-sectional and (b) top SEM images of gratings (pitch : 640 nm, period : 10), optical microscope images of (c) a plan view of fabricated device and (d) enlarged Y branch.

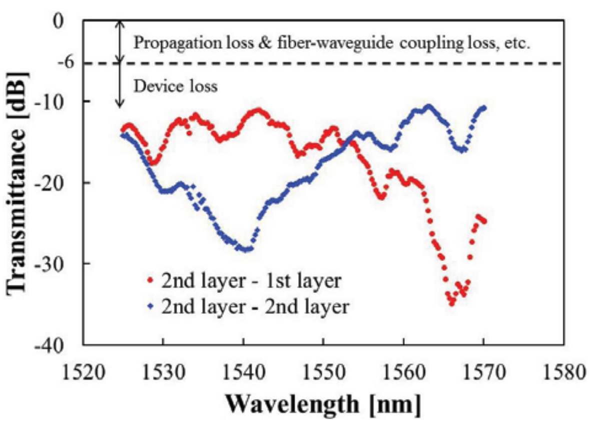


Fig.4 Measured transmitted power versus wavelength.

transverse-electric (TE) polarized light. The maximum coupling efficiency of 19% was obtained at 10 periods of 640 nm-pitch gratings (Fig. 2 (a)). The electric field distribution at the grating region is shown in Fig. 2(b).

III. Fabrication and Measurements

220-nm-thick a-Si film was deposited by PECVD, on a Si substrate covered with a thermally oxidized SiO_2 film (3 μm) and SiO_2 deposited by PECVD (100 nm). Waveguides and gratings were formed by EB lithography and ICP-RIE system. The etch depth of gratings was 220 nm to form the gratings and the wire waveguides in a single step. Figure 3 shows the top and cross-sectional SEM images of gratings. A SiO_2 cladding layer was deposited on the a-Si 1st layer, followed by a chemical mechanical polishing (CMP) process to flatten the surface and control the SiO_2 thickness as 1 μm. After depositing another 220-nm-thick a-Si film as a 2nd layer, gratings and waveguides were also formed in a similar manner above mentioned. Finally, the 2nd a-Si layer was embedded with SiO_2 and flattened again by the CMP process. A plan view of fabricated device and enlarged Y branch, which is located before the grating region, were observed by optical microscope view is shown in Fig.3 (c).

The coupling efficiency of grating couplers were measured for TE-polarized light from a tunable laser. Measured transmission spectra are shown in Fig. 4. In this figure, the red curve is for the light from the 2nd to the 2nd layer and the blue one is the 2nd to the 1st layer. The propagation loss and the coupling loss from single-mode fibers to waveguides, which doesn't include grating loss, were about 6 dB. The maximum coupling efficiency was estimated to be around 22% after subtracting 6 dB from the measured data. Here we didn't introduce partial etching or other ways to improve coupling efficiency since this was the first trial, the coupling efficiency can be improved in the future.

IV. Conclusion

Grating-type vertical couplers consisting of high-index contrast a-Si multilayer waveguides and taper regions were proposed and demonstrated for the first time. The coupling efficiency of 22% was demonstrated between two a-Si layer waveguides with the distance of 1 μm.

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References

[1] D. A. B. Miller, "Rationale and challenges for optical interconnects to electronic chips," *Proc. IEEE*, Vol. 88, No. 6, pp. 728-749, June 2000.

[2] R. Soref, "The Past, Present, and Future of Silicon Photonics," IEEE J. Sel. Top. Quantum Electron., Vol. 12, No. 6, pp. 1678-1687, Nov./Dec. 2006.

[3] S. K. Selvaraja, E. Sleeckx, M. Schaekers, W. Bogaerts, D. V. Thourhout, P. Dumon, and R. Baets, "Low-loss amorphous silicon-on-insulator technology for photonic integrated circuitry," *Opt. Commun.*, Vol. 282, No. 9, pp. 1767-1770, Jan. 2009.

[4] Y. Shoji, T. Ogasawara, T. Kamei, Y. Sakakibara, S. Suda, K. Kintaka, H. Kawashima, M. Okano, T. Hasama, H. Ishikawa, and M. Mori, "Ultrafast nonlinear effects in hydrogenated amorphous silicon wire waveguide," *Opt. Express*, Vol. 18, No. 6, pp. 5668-5673, Mar. 2010.

[5] J. Kang, Y. Atsumi, M. Oda, N. Nishiyama and S. Arai, "Low-loss Amorphous Silicon Multilayer Waveguides Vertically Stacked on Silicon-on-Insulator Substrate," *Jpn. J. Appl. Phys.*, Vol. 50, No. 12, pp. 120208-1-3, Nov. 2011.

[6] R. Sun, M. Beals, A. Pomerene, J. Cheng, C. Hong, L. Kimerling, and J. Michel, "Impedance matching vertical optical waveguide couplers for dense high index contrast circuits," *Opt. Express*, Vol. 16, No. 16, pp. 11682-11690, July 2008.

[7] M. Antelius, K. B. Gylfason and H. Sohlström, "An apodized SOI waveguide-to-fiber surface grating coupler for single lithography silicon photonics," *Opt. Express*, Vol. 19, No. 4, pp. 3592-3598, Feb. 2011.

[8] G. Roelkens, D. Vermeulen, S. Selvaraja, R. Halir, W. Bogaerts and D. Van Thourhout, "Grating-Based Optical Fiber Interfaces for Silicon-On-Insulator Photonic Integrated Circuits," *IEEE J. Sel. Top. Quantum Electron.*, Vol. 17, No. 3, pp. 571-580, May/June 2011.