Apodized Amorphous Silicon Grating Coupler with Metal Mirrors for 3D optical Interconnection

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Abstract

Inter-layer coupling between multilayer waveguides was demonstrated using hydrogenated amorphous silicon (a-Si:H) grating couplers with metal mirrors. The fabricated device which has the inter-layer distance of 2 μm successfully showed wider bandwidth compared with uniform grating structure.

I. Introduction

In order to overcome the speed limitation of global electrical wires in LSIs, the replacement to optical interconnects, which enable large-capacity and high-speed signal transmission, is in progress [1, 2]. For this purpose, hydrogenated amorphous silicon (a-Si:H) is suitable for back-end process integration because it can be deposited below 300 °C without damage to the CMOS logic layer [3]. And a-Si:H has very small extinction-coefficient, which means small absorption, at 1.55-μm-band and high refractive-index close to crystalline silicon. For these reasons, we are aiming at the realization of multi-layered optical waveguides consisting of a-Si:H [4]. So far, we demonstrated >80% layer-to-layer coupling efficiency for an inter-layer distance of 1 μm by a structure with grating couplers and metal mirrors [5]. To increase inter-layer distance and enhance bandwidth, we proposed to introduce apodization and showed numerical analysis [6].

This time, we actually fabricated the apodized grating couplers and demonstrated improved operation properties.

II. Device structure & Design

Figure 1 illustrates the structure of the inter-layer grating couplers with apodization. It enables coupling of light to another waveguide layer by using diffraction effect of the grating couplers and reflection of Au metal mirrors placed at the top and bottom sides of the gratings in order to enhance the coupling efficiency. We used Au as the metal mirror in this work; however, any kind of metal can be used as long as it maintains a high reflectivity. The apodization means modulating the duty ratio L_g/Λ (L_g is the length of the thick region within the period Λ), so we can set the leakage factor at each position of gratings separately [7]. This method is used for providing mode matching condition between a grating coupler and a single-mode fiber [8]. In the case of uniform gratings, the coupling efficiency fluctuates depending on the inter-layer distance due to the existence of multiple round-trips between the receiver side and the transmitter side. In order to eliminate the multiple round-trips, we introduced the apodization to match the radiation mode profile of the transmitter grating with that of the receiver grating. Figure 2 shows the duty ratio and the grating period optimized by FDTD simulation. In addition to the apodization of the gratings, the distance between the a-Si:H layer and the metal mirror was adjusted adequately so that the downward radiation beam overlaps with the upward radiation beam in phase. Simulation result showed high coupling efficiency of about 90% can be obtained without dependence on the inter-layer distance.

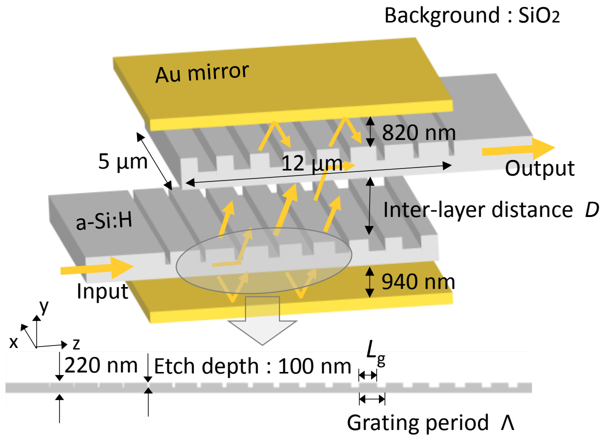

Fig. 1. Device structure.

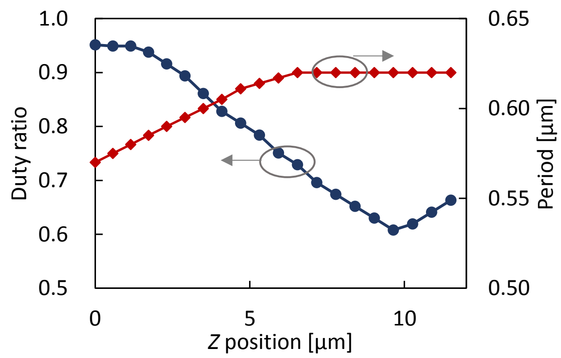

Fig. 2. *Z* position dependence of apodized grating coupler, blue circle: designed duty ratio, red diamond: designed grating period.

III. Fabrication and Measurement

The initial wafer was 2-inch Si wafer with 3-μm-thick layer of thermal SiO_2. In the first step, 100-nm-thick Au film was evaporated on the SiO_2 and the metal mirror, and an alignment mark for EB-lithography was formed by lift-

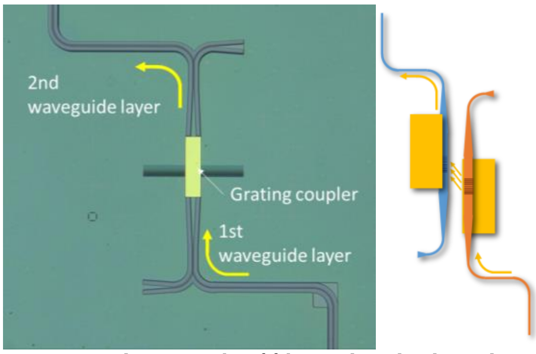

Fig. 3. Optical micrographs of fabricated apodized inter-layer grating coupler and waveguide pattern.

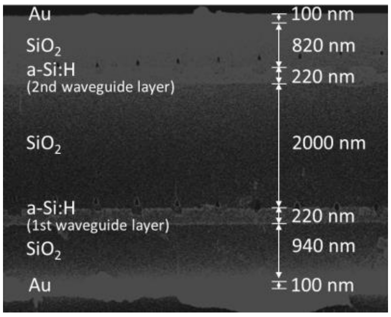

Fig. 4. Cross-sectional SEM image of fabricated apodized inter-layer grating coupler.

off. Its patterns were buried by SiO_2 and then flattened by CMP process. The thickness of the SiO_2 was controlled targeting 940 nm and then, 220-nm-thick a-Si:H layer was deposited on the SiO_2 at 300°C. The apodized grating and waveguide patterns were formed by 2-step EB lithography and ICP-RIE. This time, we deposited 2 µm of SiO_2 layer and flattened again by CMP process. 2nd a-Si:H layer was deposited on the SiO_2 followed by patterning of waveguides and gratings as a similar manner above mentioned. A SiO_2 deposition and a CMP process were done once again to form the target SiO_2 thickness of 820 nm. Finally, Au mirrors were formed.

An optical micrograph of fabricated device is shown in Fig. 3. Figure 4 shows a cross-sectional SEM image. Multi-stacked structure of a-Si:H waveguides with gratings and metal mirrors were confirmed.

Figure 5 shows the coupling efficiency of the inter-layer grating coupler measured at the wavelength range from 1420 nm to 1580 nm using transverse electric (TE)-polarized light (blue line). (The orange line indicates measurement result of previous work, which has uniform gratings and an inter-layer distance of 1 µm [5].) The many noise and ripples were due to stitching error of EB lithography and this can be fixed by system maintenance. Although the spectrum has many noise, much wider wavelength range covering the full range of C-band was observed. If we could eliminate noise, the peak coupling efficiency of -1dB could be achieved.

IV. Conclusions

Apodized inter-layer grating coupler with metal mirrors for vertical signal coupling of multilayer waveguides was

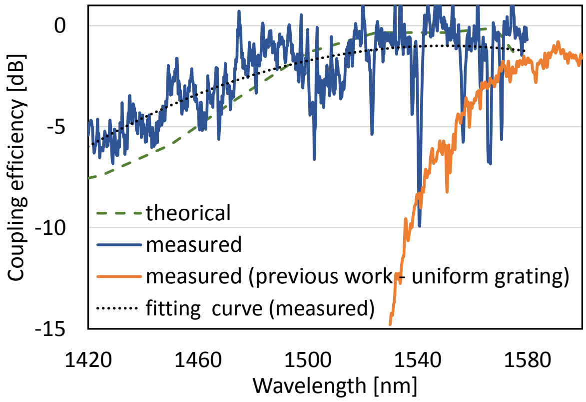

Fig. 5. Measured wavelength dependence of coupling efficiency, grey broken: simulation result, blue solid: measurement result, black dotted: fitting curve of measurement result, orange solid: measurement result of previous work [5].

demonstrated. In the measurement of fabricated device with the inter-layer distance of 2 µm, much wider bandwidth and high coupling efficiency was observed around a wavelength of 1550 nm.

Acknowledgment

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