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Inter-Layer Grating Coupler with Metal Mirrors for 3D Optical Interconnects

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Abstract

Inter-layer coupling between multilayer waveguides was demonstrated using a hydrogenated amorphous silicon (a-Si:H) grating couplers. The grating couplers consist of two vertically stacked waveguides sandwiched by metal mirrors. An enhancement of the coupling efficiency was observed by introducing metal mirrors.

I. Introduction

Optical interconnection is one of the promising technologies for overcoming the speed limitations of electrical interconnects [1]. Given that the current LSI industry is based on the silicon wafer, the most preferable material for optical interconnects would be silicon, which is so-called Si photonics [2,3]. So far, we have focused on hydrogenated amorphous silicon (a-Si:H) as a core material of optical waveguides [4]. a-Si:H can be deposited under low temperature (~300°C) enabling the back-end process integration of optical layers without damage to the CMOS logic layer.

Furthermore, multi-layered optical circuit can be realized by stacking a-Si:H layers and SiO_2 layers which provide higher integration density as well as wider total bandwidth. We have proposed to use a pair of grating couplers for the inter-layer coupling [5]. This structure enables few-µm-apart layer distance, which is difficult to be achieved by a directional coupler type vertical coupler [6].

In this paper, we propose and demonstrated an improved coupling efficiency of the grating coupler by introducing a pair of metal mirrors.

II. Device structure & Design

Figure 1 illustrates a schematic image of the inter-layer grating coupler. Two waveguides are placed parallel to each other with the layer distance of 1 µm. a-Si:H wire waveguides (500 nm width) are used as input and output ports and expanded to wide-width waveguides (5 µm) at the grating region. The thickness of each a-Si:H layer was set to be 220 nm. Shallow etched (70 nm depth) gratings with grating period of 640 nm were used in this work in order to suppress the backward reflection from the gratings instead of fully etched gratings at the first trial of inter-layer grating coupler in Ref. 5. In the previous report, we have achieved 22% coupling efficiency with a simple pair of gratings. In order to enhance the coupling efficiency, we introduced metal mirrors; Au was used in

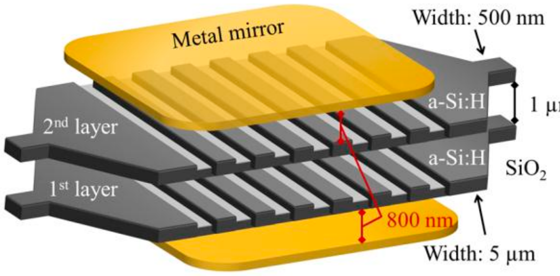

Fig. 1. Device structure.

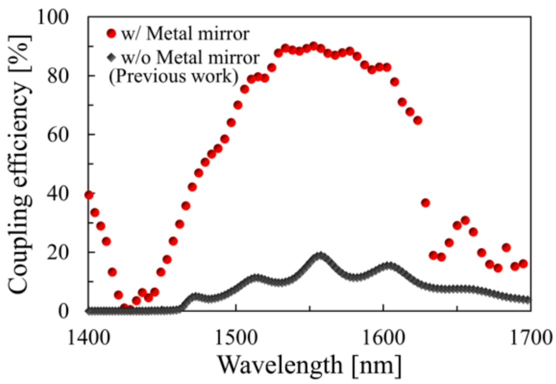

Fig. 2. Calculated wavelength dependence of coupling efficiency. The red and black plots indicate the results with metal mirrors and without metal mirrors.

this work, to the top and bottom side of the grating coupler. However, any kind of metals can be used as long as it maintains a high reflectivity. For example, Al could also be a good candidate since we can apply a dummy-metal process for the fabrication which already exists in the CMOS technology.

In order to optimize the structure of the inter-layer grating coupler, 3D-FDTD simulation was done with two main parameters; the number of grating periods and the distance from a-Si:H layers to metal layers. There was an optimum number of grating periods for each layer-to-metal distance. When the layer-to-metal distance was 800 nm, the peak coupling efficiency of 90% was obtained at 21 periods of gratings. The wavelength dependence of the coupling efficiency with metal mirrors and without metal mirrors is shown in Fig. 2. Compared to the inter-layer grating coupler without metal mirrors in Ref. 5, the peak coupling efficiency was improved to 90%. Within the wavelength range from 1520 nm to 1600 nm, the coupling efficiency was more than 80% which can cover the full range of C-band.

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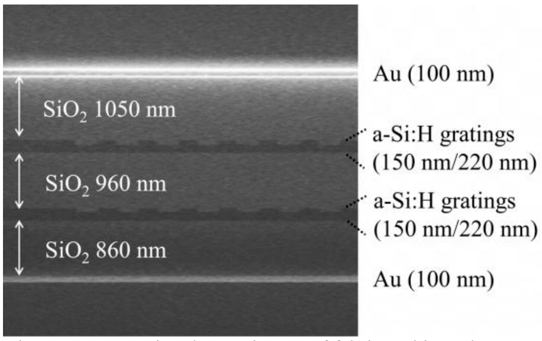

Fig. 3. Cross-sectional SEM image of fabricated inter-layer grating coupler.

III. Fabrication and Measurement

Next, actual structure was fabricated and 2-inch Si wafer with top 3-μm-thick thermally oxidized SiO_2 was used as an initial wafer. First, alignment marks and metal mirrors (consisting of 100-nm-thick Au) were formed by electron-beam lithography (EBL) and lift-off process. Then, a SiO_2 cladding layer was deposited and the surface of the SiO_2 layer was flattened by chemical mechanical polishing (CMP) process to the thickness of 800 nm. As a 1st layer, 220-nm-thick a-Si:H film was deposited and two steps of etching process were delivered for forming waveguides and gratings. Again, a SiO_2 deposition and a CMP process were repeated to the SiO_2 thickness of 1000 nm. 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 800 nm. Finally, upper mirrors were formed.

A cross-sectional SEM image is shown in Fig. 3. Multi-stacked structure of a-Si:H waveguides with gratings and metal mirrors were confirmed. The SEM image shows some thickness error of first and second SiO_2 compared with target thicknesses, although these amounts are within tolerances. In contrast, the amount of thickness error of the SiO_2 between the 2nd a-Si:H layer and the upper metal mirror was 250 nm due to our fabrication mistake which can be easily fixed in the next run. In the additional simulation of the inter-layer grating coupler under the condition of actual fabricated structure, the maximum coupling efficiency was degraded to 31.2% with a grating period of 620 nm at the wavelength of 1540 nm, and 7.9% with a grating period of 640 nm at the wavelength of 1550 nm.

The coupling efficiency of the inter-layer grating coupler was measured at the wavelength around 1.55 μm using transverse electric (TE)-polarized light. We plotted wavelength dependence of the measured coupling efficiency with 3 kinds of grating period (620 nm, 630 nm, 640 nm) in Fig. 4. The peak coupling efficiency was 31% at the grating period of 620 nm which agrees well with the simulation result. Further improvement of the coupling efficiency can be realized with accurate control of SiO_2 thickness.

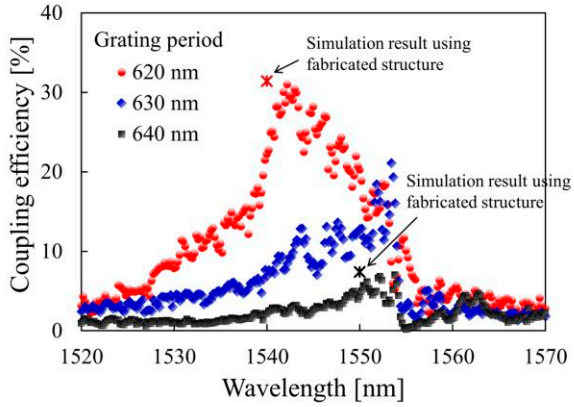

Fig. 4. Measured wavelength dependence of coupling efficiency with 3 kinds of grating period (620 nm, 630 nm, 640 nm). simulation results (asterisk mark in the graph) based on actual fabricated structures are also shown.

IV. Conclusions

Inter-layer grating coupler with metal mirrors was demonstrated by amorphous silicon based multilayer waveguides. We obtained a high coupling efficiency of 90% with optimum structure in a simulation result. In the measurement of fabricated device having SiO_2 thickness error, the peak coupling efficiency of 31% was observed, which values agrees well with the simulation. Further improvement can be expected with accurate control of SiO_2 thickness.

Acknowledgment

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