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High Efficiency Apodized Grating Couplers with Metal Mirrors between a-Si:H Multilayer Waveguides toward 3D Optical Interconnection

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Abstract

A pair of grating couplers with apodized structure sandwiched by metal mirrors are proposed for inter-layer coupling between multilayer waveguides. We theoretically found that an introduction of apodized grating is very effective to obtain high coupling efficiency of about 90% even for long layer distance.

1. Introduction

In order to solve the problem of the speed limitation on the global wires in LSIs, the replacement to optical interconnects which enable large-capacity and high-speed signal transmission, is in progress [1]. 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 [2]. 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 [3]. So far, as a vertical coupling device between multi-layered waveguides, we proposed a structure with metal mirrors placed at the upper and lower sides of a pair of grating couplers. The coupling efficiency of 90% (at 1550 nm) was obtained by 3D-FDTD simulation and 83% (at 1590 nm) was experimentally demonstrated with the layer distance of 1 μm [4]. The grating coupler is applicable to couple light at relatively longer layer-distance in contrast to other types of inter-layer couplers based on evanescent light [5].

In this paper, we propose to introduce an apodization to inter-layer grating couplers in order to achieve highly efficient coupling between multi-stacked layers as well as its stability against the distance between them.

2. Device design

Figure 1 illustrates the structure of the apodized inter-layer grating couplers. An apodization means modulating the duty ratio L_g/Λ (L_g is the length of the thick region within the period Λ, as shown in Fig. 1) of gratings, so we can set the leakage factor at each position of gratings separately [6]. This method is used for providing mode matching condition between a grating coupler and a single-mode fiber [7].

We evaluated the coupling efficiency of inter-layer grating couplers by 2D- and 3D-FDTD simulation, where

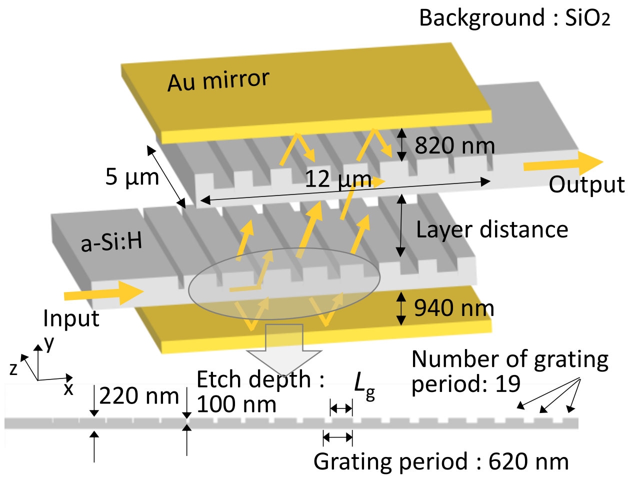

Fig.1 Structure of inter-layer apodized grating couplers.

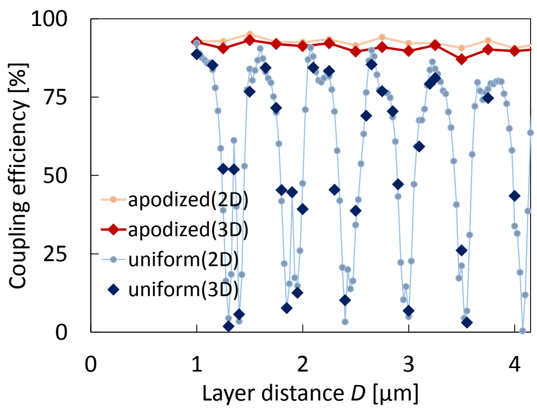

Fig. 2 Layer distance dependence of coupling efficiency.

both a-Si:H waveguides were set to be 5 μm in width and 220 nm for thickness, and the etch-depth of the gratings was set to be 100 nm as shown in Fig.1. Metal mirrors were placed at the top and bottom sides of the gratings in order to enhance the coupling efficiency by reflecting the radiated light which leaks outward. We assumed Au as a metal mirror in this work, however, any kind of metals can be used as long as it maintains a high reflectivity.

In the case of uniform gratings (same structure in the previous work), the coupling efficiency varies greatly in the range of 0-90% depending on the layer distance (Fig. 2)

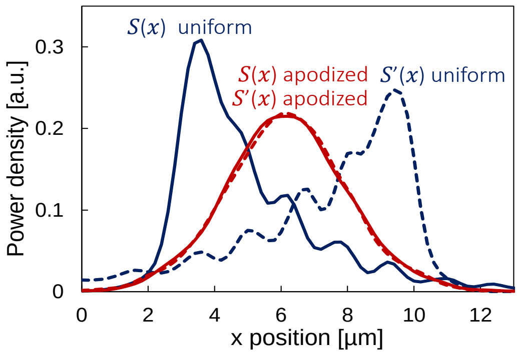

Fig. 3 Beam profile of radiated light from the gratings, $S(x)$ and $S'(x)$.

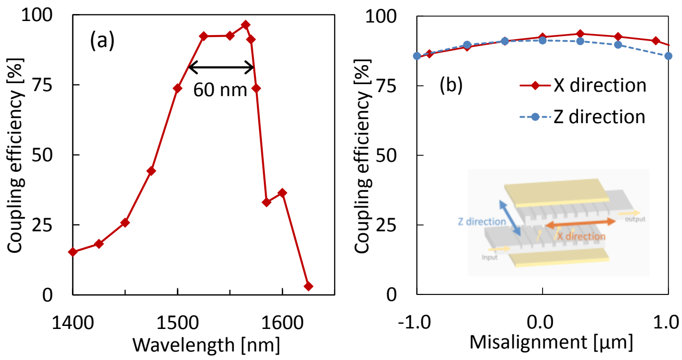

Fig.4 (a) Wavelength dependence of coupling efficiency. (b) Misalignment dependence of coupling efficiency.

because input light travels back and forth of both the receiver and the transmitter gratings. Hence the condition of inter-layer coupling is affected by the layer distance due to these multiple reflections. In order to eliminate these variations due to multiple reflections, we adjusted the duty ratio in the range of 0.6 to 0.95 so that the radiation mode profile of the transmitter grating $S(x)$ matches with that of the receiver grating $S'(x)$ as shown in Fig. 3. Leakage factor $\alpha(x)$ and radiated mode profile $S(x)$ have the following relation [8],

$$\alpha(x) = \frac{S(x)}{2\int_x^{\infty} S(t)\,dt} \tag{1}$$

Thus, we can design $\alpha(x)$ by calculation after determination of $S(x)$. With these gratings, the radiated beam from the transmitter grating couples to the receiver grating at once.

In order to obtain accurate matching of beam profile, it is necessary to introduce x-direction offset of 0.2 µm to the receiver grating for every 1-µm layer-distance in consideration of the diffraction angle of the radiated light.

In addition to apodization of the gratings, the distance between the a-Si:H layer and the metal mirror needs to be adjusted adequately so that the downward radiation beam overlaps with the upward radiation beam in phase. The distance was proved to be 940 nm at lower layer and 820 nm at upper layer by analysis of simulation. This difference is caused by the asymmetric structure of these gratings which resulted in the different center position of the guided modes at the grating.

Again, we plotted the layer distance dependence of the coupling efficiency with apodized gratings in Fig. 2. It was revealed that high coupling efficiency of about 90% can be obtained by introducing apodized grating and it seems to be almost independent of the layer distance while it largely swings in case of uniform grating structure. The difference between the results of the 2D and 3D simulations is caused by a leak ingredient of orthogonal direction (z-direction).

The wavelength dependence of the coupling efficiency is shown in Fig. 4(a). Within the wavelength range from 1510 nm to 1570 nm, the coupling efficiency was more than 80% which can cover the full range of C-band. Fig. 4(b) shows the misalignment dependence of the coupling efficiency. The deterioration of the coupling efficiency was relatively small (less than 0.5 dB) even with 1 µm of misalignment.

3. Conclusions

The inter-layer apodized grating couplers with metal mirrors were proposed and their characteristics were evaluated by using FDTD-simulation. The coupling characteristic was found to be independent of the layer-distance when apodized gratings were used, hence high coupling efficiency of 90% can be constantly obtained for the layer distance of 1-4 µm. The coupling efficiency more than 80% can be obtained for the wavelength range of 60 nm.

Acknowledgments

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