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Double Taper Interlayer Transition Coupler for 3D Optical Interconnection with Heterogeneous Material Stacking

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Abstract

Double tapered directional type interlayer transition coupler is designed for 3D optical circuits. This interlayer transition coupler has simplicity of fabrication and high coupling for 1 µm-thick interlayer despite of short device length.

1. Introduction

Silicon photonics, which consist of crystalline silicon (c-Si) and silicon dioxide (SiO_2), become a crucial technology thanks to its potential for providing high-density optical circuits with high index contrast structures, as well as its compatibility with CMOS fabrication process [1].

To realize higher-density optical circuits compared with that of conventional planer silicon photonics platforms, three dimensional (3D) optical circuits by vertical stacking are attractive. For this purpose, 3D optical interconnection with hydrogenated amorphous silicon (a-Si:H) is being investigated actively[2]. That is because a-Si:H can be deposited at low temperature (~300°C), and vertical stacked structure can be realized without damage to the underlayer optical circuit. For such 3D optical circuit, one of the important components is interlayer transition coupler (ITC) which enables optical signals to transmit from a layer to another layer. So far, two kinds of ITC have been reported, grating couplers and directional type couplers. Grating couplers can be applied for arbitral interlayer thickness in principle, but they require an accurate formation of the grating and several mask processes including metal deposition processes [3]. On the other hand, directional type couplers can be fabricated easily with a few processes [4]. However, a critical drawback of the directional type couplers is that device length becomes very long (more than 1 cm) when the interlayer thickness is more than 1 µm, in which optical crosstalk between stacked circuits can be negligible [2]. To solve this problem, in the previous reports, we proposed and demonstrated trident-shape directional type coupler, which reduced the size of coupler to 295 µm for 0.78-µm interlayer thickness [5].

In this paper, we proposed double tapered directional type ITC (DT-ITC) in order to realize both simplicity of fabrication and overwhelming small footprint for relatively thick interlayer such as 1 µm. This structure can be applied to 3D stacking of Si and InP membrane optical circuits [6].

2. Device design

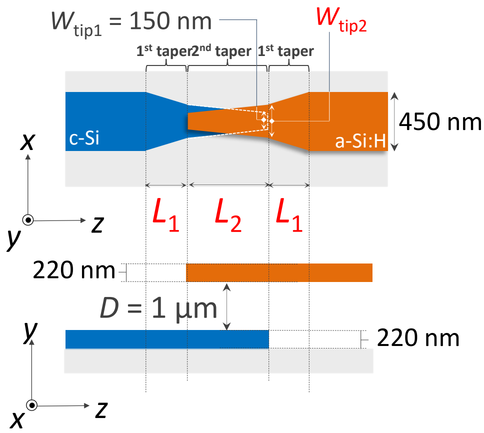

Fig. 1 Schematics of DT-ITC.

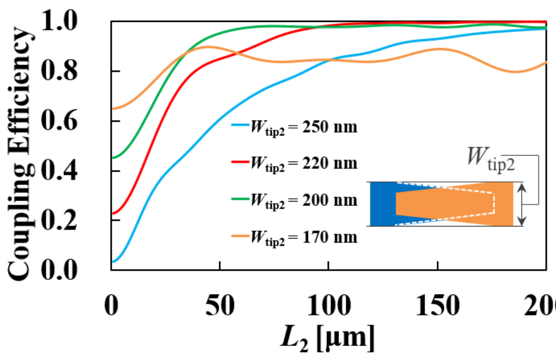

Fig. 2 L_2 dependence of coupling efficiencies for each W_{tip2}.

As a premise for the device design, it was assumed that a wire waveguide materials were c-Si (refractive index: 3.48) or a-Si:H (refractive index: 3.58). These had a height of 220 nm and width of 450 nm and were buried in SiO_2 (refractive index: 1.44). For these conditions, we designed structures at a wavelength of 1.55 µm operating in the TE mode using the Eigen mode expansion (EME) method and the finite-difference method (FDM).

Fig.1 is schematics of DT-ITC. In this work, the tip width of 2nd taper W_{tip1} was fixed to be 150 nm. In addition, the interlayer thickness was also assumed to be 1 µm in order to suppress unintended cross talk between the layers.

First, 2nd taper length L_2 was designed. Fig. 2 shows L_2 dependence of coupling efficiencies for several W_{tip2} width. In this time, 1st taper was not considered and coupling property was calculated using model in which light coupled through 2nd taper from W_{tip2}-width c-Si waveguide to same width a-Si:H waveguide as the inset figure in Fig. 2.

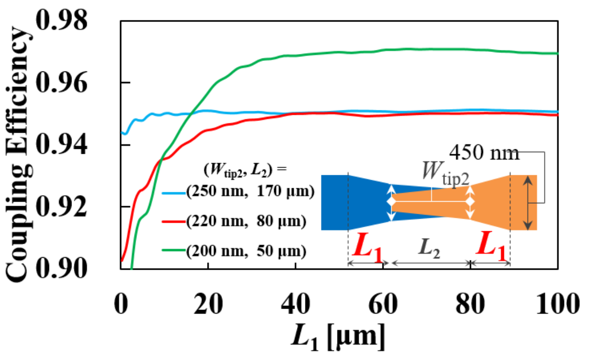

Fig. 3 L_1 dependence of coupling efficiency for each (W_{tip2}, L_2).

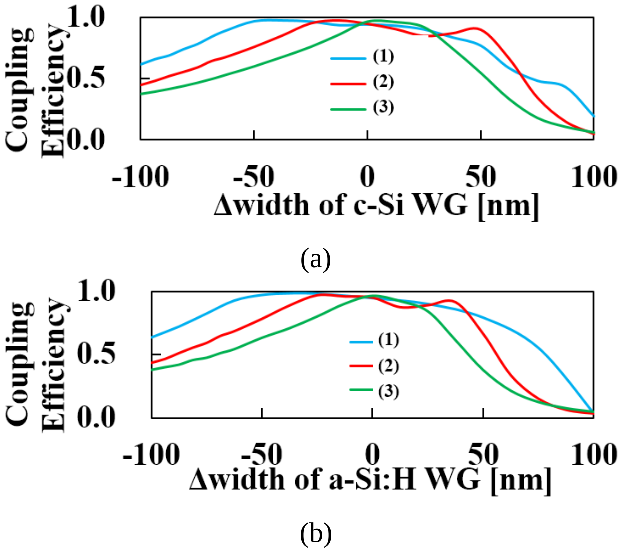

Fig. 4 Tolerance of waveguide width for coupling efficiency. (1):(W_{tip2}, L_2, L_1) = (250 nm, 170 μm, 10 μm), (2):(220 nm, 80 μm, 40 μm) and (3):(200 nm, 50 μm, 30 μm).

When W_{tip2} becomes narrow, the structure shape gets close to rectangular directional coupler, so coupling efficiency becomes more sensitive to the length in W_{tip2} = 170 nm. On the contrary, when W_{tip2} is wide, structure gets close to ordinary adiabatic coupler like the report of [4], and longer taper lengths are needed in order to increase coupling efficiency. From this figure, in order to get more than coupling efficiency of 95%, pairs of W_{tip2} and L_2 should be set to (W_{tip2}, L_2) = (250 nm, 170 μm), (220 nm, 80 μm) and (200 nm, 50 μm).

Next, 1st taper length L_1 was varied. Fig. 3 shows L_1 dependence of the coupling efficiencies for each (W_{tip2}, L_2). From this figure, (W_{tip2}, L_2, L_1) should be set to (1):(250 nm, 170 μm, 10 μm), (2):(220 nm, 80 μm, 40 μm) and (3):(200 nm, 50 μm, 30 μm) to stabilize the coupling efficiency.

In this structure, we need to pay attention to the fabrication tolerance of the waveguide width. Fig. 4 shows width-error dependence of the coupling efficiency. In narrow W_{tip2} condition of (3):(200 nm, 50 μm, 30 μm), the tolerance of waveguide width to keep more than 80% is only ± 10nm. This is because the shape gets close to rectangular directional coupler so coupling property tends to be more sensitive to the change of waveguide width than that for the conventional adiabatic coupler. In design of (1):(W_{tip2}, L_2, L_1) = (250 nm, 170 μm, 10 μm), (2):(220 nm, 80 μm, 40 μm), coupling efficiency retains more than 80% for ±60 nm, ±40 nm-deviation of waveguide width. Thus, the design of (2) is optimum in terms of both wide fabrication tolerance and device length, and Fig. 5 shows the mode profile with the design of (2). The coupling efficiency of 95.0% can be realized for 1-μm-interlayer thickness with 160-μm-device length and reflection is -61dB.

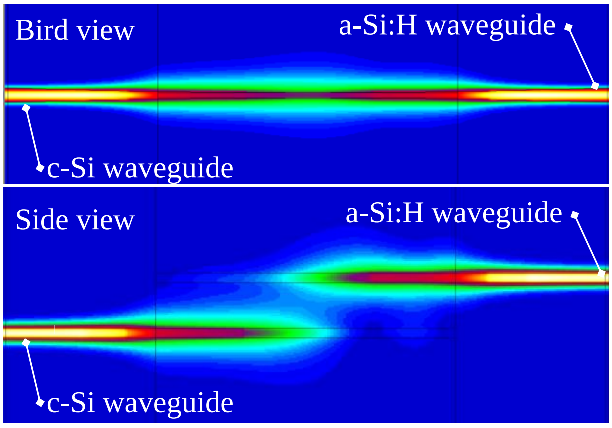

Fig. 5. Mode profile of designed DT-ITC. ((2): (W_{tip2}, L_2, L_1) = (220 nm, 80 μm, 40 μm))

DT-ITC can be applied for various optical platform simply. For example, in the case of hybrid integration of silicon photonics and membrane InP platform [6] for integration of active devices with bonding process, this coupler can be used as a connection from a membrane InP-based laser to Si waveguides. If the DT-ITC between Si and InP membrane waveguides is designed in the same way as described above, the device length is as short as 200 μm and the coupling efficiency of 94.9% and reflection of -39dB can be achieved.

3. Conclusions

DT-ITC is designed for 3D optical circuit. Double taper can lead to efficient adiabatic transform of optical mode, and thus it has both an easiness of fabrication and high coupling for interlayer of 1 μm despite of very short device length. As a result, the proposed structure is practical to realize 3D optical circuits for not only c-Si/a-Si:H but also various hybrid platform such as Si/membrane III-V.

Acknowledgements

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