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Stacked Optical Branched Waveguides for Optical Interconnection on Si Chips

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1. Introduction

In order to overcome the speed limit of the metal interconnection in ultra large scale integrated circuits (ULSIs), the optical interconnection on Si chips is attracting much attention [1]. We have been studying the optical interconnection on Si chips, and previously reported the optically interconnected Kohonen net chip [2] which implements parallel pattern recognition. Since the conventional Y shaped branch consumes large area in the chip, we developed a special compact in-plane branched waveguides using micro corner mirrors to distribute input signal to each processing unit. However, the result was not satisfactory, i.e., the distributed optical power to each branch was greatly scattered as 25±9% for four branches [3]. It was suggested that the large scattering of the data is due to the unduration of the power distribution across the waveguide after branching [3]. Furthermore, the core width becomes wider as the number of branch increases. In the case of four branches, the maximum core width reached 48 μm [3].

In this paper, we have newly developed a compact stacked multiple branched waveguides which distribute optical power with small deviation.

2. Simulation of Stacked Branch

Instead of the in-plane branch, we have developed a stacked branch, whose structure is shown in Fig. 1. When two core layers are approached, the light in one core layer transfers to another core layer. Therefore, the optical power can be divided to the branch by bending the top waveguide after a desired interaction. In this type of branch it is not necessary to broaden the core width even though the number of branches increases. The distributed power (P_{TOP}) to the branch is determined by the interaction length L and the gap distance g which is precisely controlled by the thickness of the deposited intervening SiO_2 film.

The coupling efficiency of the stacked branch was simulated by using "PROLOG" made by Fuji Research Institute Corp, in which a beam propagation method (BPM) is used. In Fig. 2 the cross section of the simulated stacked waveguide is illustrated. The waveguides consist of Si_3N_4 (refractive index: n=2.02) cores and SiO_2 (n=1.46) cladding layers. When the thickness of the Si_3N_4 core layer is 0.3 m, only fundamental mode exists in the vertical direction. The bird's eye view of the simulated light power in the top and bottom waveguides are shown in Fig. 3. Figure 4 shows the coupling efficiency (P_{TOP} / [P_{TOP} + P_{BOT}], here P_{BOT} is the output optical power from the bottom waveguide) as a function of the interaction length L. It is demonstrated that the coupling efficiency is oscillating from ~0 to ~100% as L is changed, and the oscillation period is shorter for the longer wavelength.

3. Fabrication of Stacked Branch

First, the Si substrate was thermally oxidized to a thickness of 0.8 μm, and then the Si_3N_4 film (0.3 μm) was deposited by low-pressure chemical vapor deposition (LPCVD) at 750°C using SiH_2Cl_2 and NH_3. Next, the core layer was patterned by chemical dry etching (CDE) using CF_4+O_2+N_2 plasma after the electron beam lithography. Then, the intervening SiO_2 film of thickness g (0.2 μm) was deposited by tetraethyl orthosilicate (TEOS)+O_3 LPCVD at 700°C. The top core layer (0.3 μm) was fabricated by the same process as the bottom core layer, and finally the top SiO_2 cladding layer (0.8 μm) was deposited by the LPCVD. Figure 5 shows a top SEM micrograph of the fabricated stacked branch. The double-reflection micromirror with a size of 34 μm was used for the bent of the waveguide [3]. It should be noted that there is a step of 0.3 μm height at the corner of the bent waveguide (shown by "Step" in Fig. 5) since we did not use any planarization process this time. It was confirmed from the SEM that the gap g was controlled with a fluctuation of ±5% over the two inch Si wafer used.

4. Performance of Stacked Branch

Figure 6 shows the measured coupling efficiency. The oscillation period for λ=830 nm is about 20 m, and that for 633 nm is about 40 m, which roughly coincides with the simulated period of 16 m for λ =830 nm, and 34 μm for λ=633 nm (Fig. 4). However, the measured maximum coupling efficiencies are low (50% for λ=830 nm and 40% for λ=633 nm). We suppose that the step at the corner of the top waveguide mentioned in the above section causes the light scattering loss, resulting in the reduced coupling efficiency. A relatively large data scattering (±5% for λ=830 nm, ±10% for λ=633 nm) is observed in Fig. 6, which may be generated by an interference between a fundamental mode and a first mode. A little deviation of the core thickness (0.315 μm) from the designed thickness generates the first mode for λ=830 nm. For λ=633 nm the first mode exists for the 0.3 μm core thickness. The reason for the non zero coupling efficiency at L=0 is that there is a triangular part which overlaps to the bottom core layer as shown in Fig. 5.

We have designed a four-branch optical waveguide, based on the experimental result shown in Fig. 6 taking the data fluctuation possibly induced by the interference effect into consideration. The designed shape is shown in Fig. 7(a). The laser light (λ=830 nm) was introduced into the cleaved edge of the waveguide, and the intensity of the output light from the other cleaved edge was measured by the semiconductor powermeter. In Fig. 7(b) the measured ratio of the output power from each branch is shown. The power ratio at each branch is 25±4%. The data scattering of ±4% is roughly consistent with the data scattering in Fig. 5.

5. Conclusion

Compact stacked branched waveguides were newly proposed for the optical interconnection on Si chips. The merit of the stack type branch was confirmed from both of the simulation and the experimental results. An excellent performance (power distribution to each branch of 25±4%) was demonstrated for the realized four-branch waveguides.

References

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[2] S. Yokoyama *et al*, *Proc. Int. Symp. on Future of Intellectual Integrated Electronics, 1999* (1999) p. 453.
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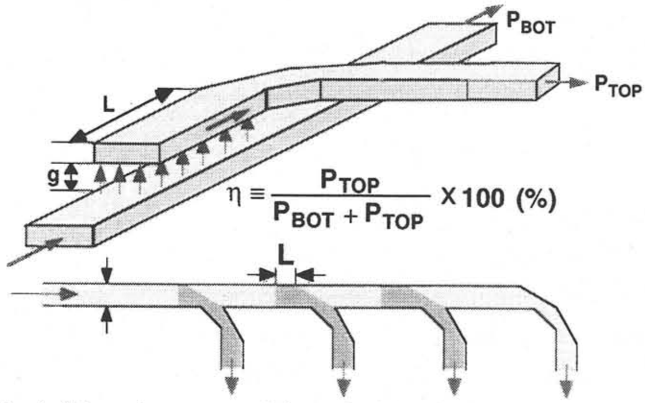

Fig. 1 Schematic structure of the stacked branched waveguide.

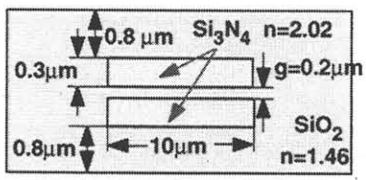

Fig. 2 Cross ssection of the simulated stacked waveguide.

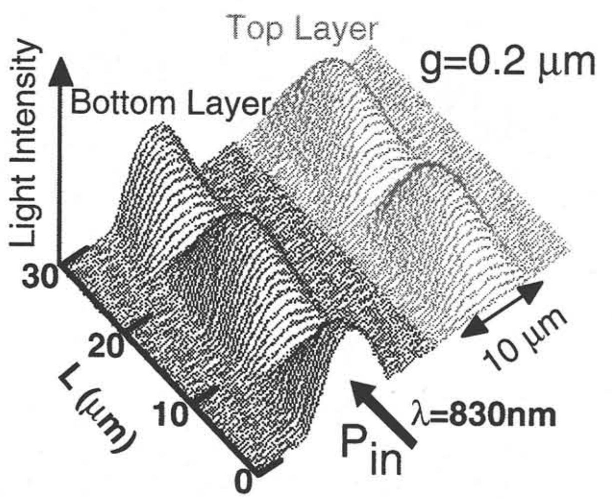

Fig. 3 Bird's eye view of the simulated light power in the stacked optical waveguide.

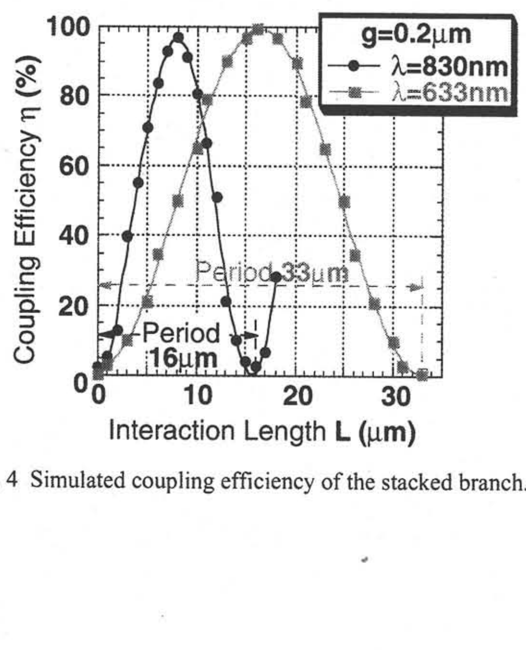

Fig. 4 Simulated coupling efficiency of the stacked branch.

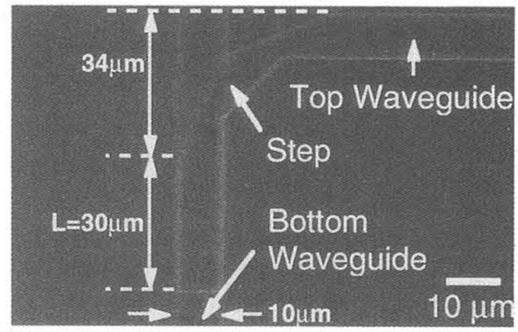

Fig. 5 SEM micrograph of the fabricated stacked branch (top view).

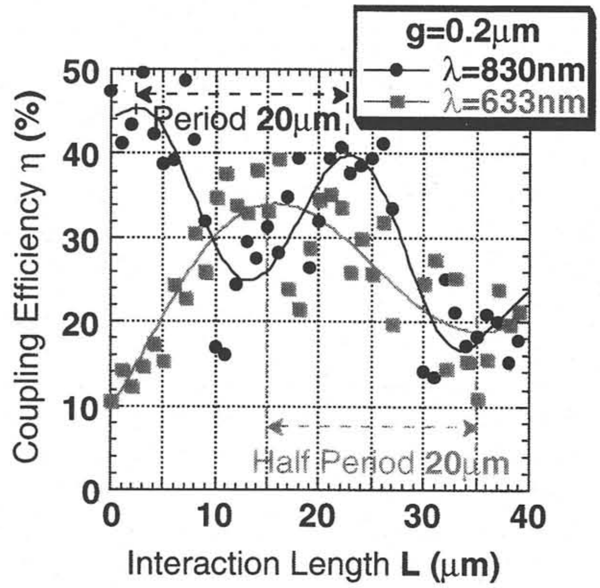

Fig. 6 Measured coupling efficiency as a function of interaction length L for different wavelength.

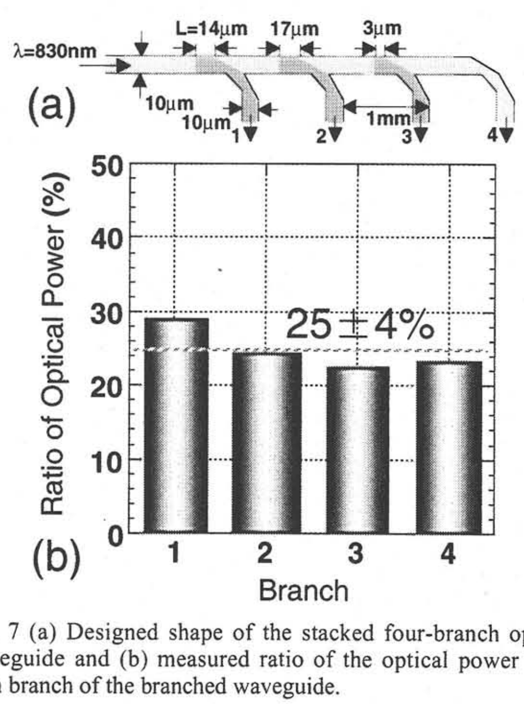

Fig. 7 (a) Designed shape of the stacked four-branch optical waveguide and (b) measured ratio of the optical power from each branch of the branched waveguide.