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Investigation of grating coupler type optical I/O interface at the 1.55 μm wavelength range

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1. Introduction

Si photonic wire waveguides are very attractive for realizing various photonic devices with extremely small size [1, 2] due to the strong optical confinement in the waveguide core and therefore it make possible to bend with small radius of curvature. However, it is difficult to couple light between the waveguide and optical fibers because of the large mode mismatch between them. To deal with this problem, several groups have been studied grating couplers [3-5]. They can be located anywhere on wafers not only edge portions of it. Therefore, grating couplers are expected as optical input-output (I/O) interfaces between optical integrated circuits and optical fibers.

We have been demonstrated grating coupler type optical I/O interface for on-chip optical interconnections with 850 nm wavelength range using SiON waveguides [5]. The interface can couple light beam from almost vertical direction to the chip surface, and combine both optical power diffracted for both sides of the grating. Figure 1 shows the schematic view of our proposed optical I/O interface for 850 nm wavelength. The grating formed in SOI layer was completely etched down to the buried oxide (BOX) layer. Thus the grating structure is very simple and easy to fabricate. Measured coupling efficiency of the interface was approximately 35%. However, when we try to apply the design of the grating for 1.55 μm wavelength range, estimated maximum coupling efficiency will be only about 5%. The reason is that refractive index of Si (3.47) is higher than SiON (1.9). This large index difference between air and Si causes large mismatch of waveguide impedance. This makes difficult to direct diffracted lightwave to the waveguide effectively. This study deals with this problem and find out an optimum structure which realizes high coupling efficiency at 1.55 μm wavelength range by theoretical calculation.

2. Structure and numerical analysis

At first, in order to deal with waveguide impedance mismatch problem at the boundary of Si and air in the grating, we analyzed transmittance of the Si waveguide having single air gap of various widths. Based on this analysis, we determined optimum gap spacing of the grating. Numerical analysis was carried out with 2D-FDTD method. Figure 2 shows transmitted, reflected and scattered light power through the waveguide with a gap of various widths. This figure indicates that transmitted optical power is small, and reflected and scattered power become dominant when gap space becomes larger than 300 nm. On the other hand, when gap spacing is narrow, transmitted light power maintain still large. At 850 nm wavelength, we designed grating with the same line and space (L&S) ratio (L:S=1:1), and this design was convenient for obtaining high optical coupling efficiency. However, if we make the grating for 1.55 μm wavelength with the same L&S ratio, the space width become 340 nm, and it will cause large scattering loss at the gap portion. Thus at 1.55 μm wavelength range, it is important to design grating with narrower gap to eliminate scattering loss at the gap portion.

Figure 3 shows cross-section view of the grating for the optical I/O interface. We decided space and line widths of the grating as 100 nm and 540 nm for easy fabrication. We calculated optical coupling efficiency of this structure by using 2D-FDTD method assuming that incident light beam comes from a single-mode-fiber (SMF) with 10 μm mode field diameter (MFD). Figure 4 shows dependence of optical coupling efficiency as a function of grating periodic number N. Here, the coupling efficiency means optical power coupled to a Si waveguide for one side of the grating. Obtained maximum efficiency at 1.55 μm wavelength was 22% when N = 9. Operating wavelength range was 21 nm when optical coupling efficiency becomes half maximum.

Next, we optimized thickness of BOX layer to minimize optical power diffracted toward Si-substrate. Figure 5 shows optical coupling efficiency as a function of BOX layer thicknesses. Optical coupling efficiency has maximum values periodically for the BOX layer thickness. When the BOX layer thickness is 1.5, 2.1, 2.6 μm, transmitted light power was reduced and the optical coupling efficiency reached about 25%.

When grating period N is 9, total length of grating coupler is 6.4 μm and this is little smaller than the 10 μm MFD. On the other hand, when N = 15, grating length become 9.6 μm and this is almost same as the MFD, however maximum value of coupling efficiency is rather lower than the case of N = 9. This means that there is an optimum value of the MFD of fiber for the total length of the grating. Therefore, we investigated the optimum size of the MFD.

Figure 6 shows calculated results of the dependence of the MFD when BOX layer thickness was 2.6 μm. Optical coupling power became higher as reducing the size of MFD, and the optical coupling efficiency reached 36% when MFD was 4 μm. This means optical fiber with small MFD can improve optical coupling efficiency. Coupled optical spectrum for the optimized grating structure at 1.55μm was shown in Fig. 7. Operating wavelength range was 27 nm.

Finaly, we tried to calculate optical coupling efficiency with 3D-FDTD to obtain exact numerical values. We determined grating width of analyzed model as 6 μm which is large enough to receive total power of the incident optical beam from the fiber. Calculated optical coupling efficiency was 35.3% and it is almost same as that with 2D calculation. In this optical I/O interface, optical output from both side of the grating are combined in same phase as shown in Fig.1. Therefore optical coupling efficiency as an I/O interface is double of the 35.3%, i.e. 70.6%. Thus we confirmed that simple and high efficiency grating coupler can be realized at 1.55 μm wavelength.

3. Conclusion

We investigated almost vertical coupling optical I/O interface with grating coupler for optical interconnection between optical fiber and optical waveguides in optical circuit at 1.55 μm. By optimizing the L&S ratio of the grating and the thickness of the BOX layer, we theoretically demonstrated that optical coupling efficiency will be reached to 70.6%. Although this I/O interface is very simple and no reflective mirror, it has comparable high efficiency such as grating coupler with gold mirror [4] and Si cover layer [5].

Acknowledgement

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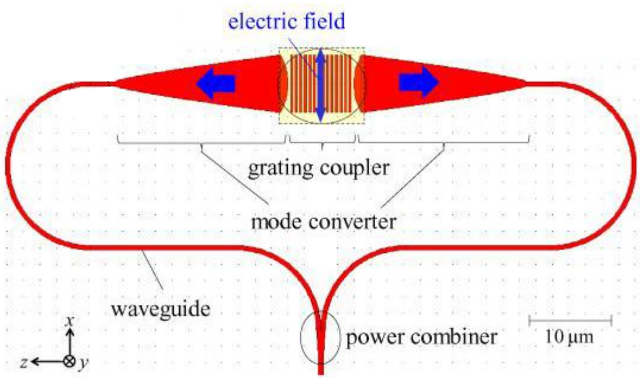

Fig.1 Schematic view of optical I/O interface at the 850 nm wavelength range

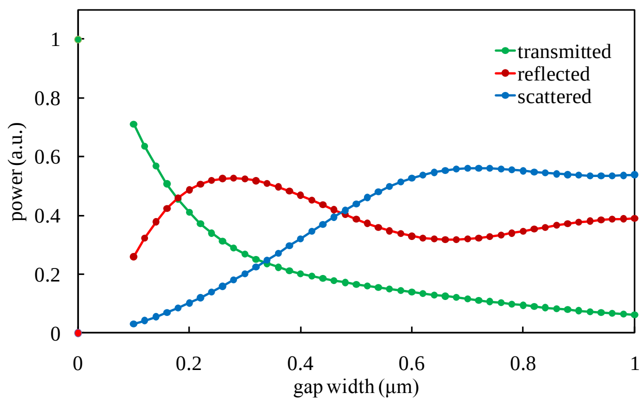

Fig.2 Optical power through a waveguide with single gap

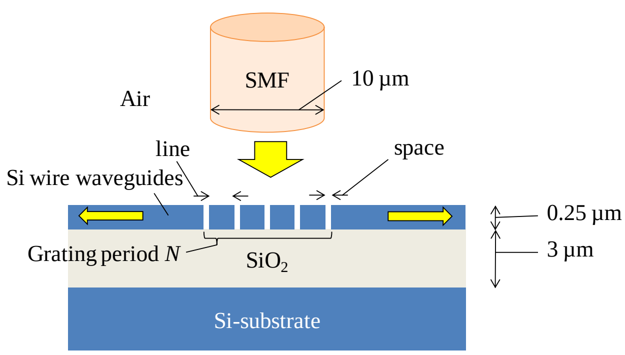

Fig.3 Cross-sectional view of the grating portion

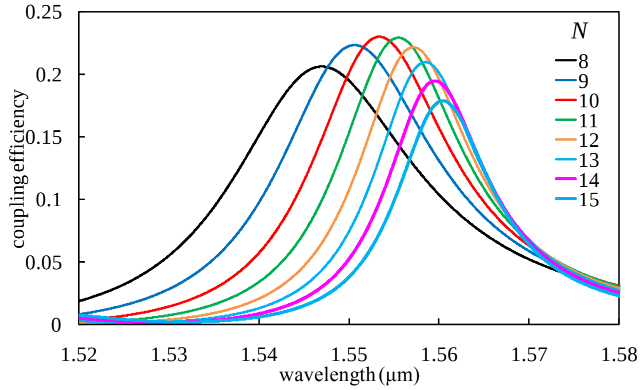

Fig.4 Coupling efficiency dependent on grating periodic number N

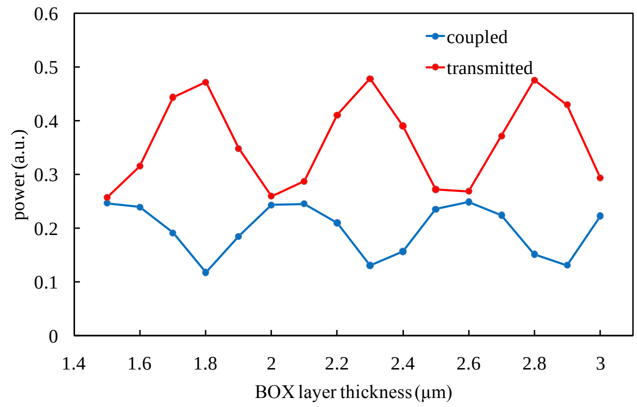

Fig.5 Optical coupling efficiency as a function of BOX layer thicknesses

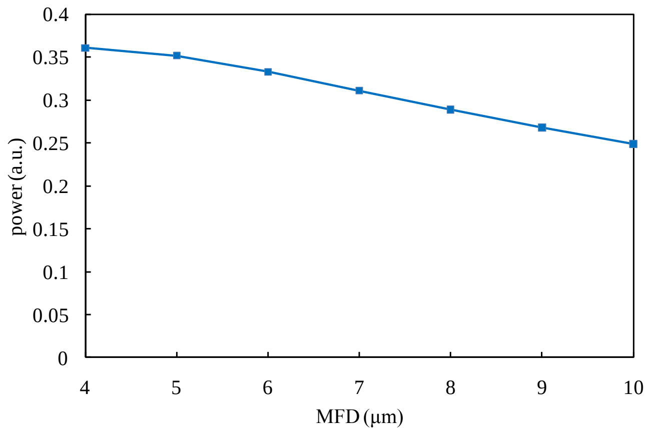

Fig.6 Optical coupling power as a function of the MFD

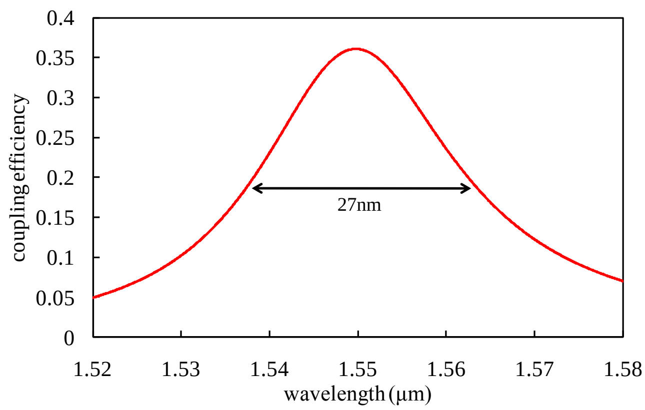

Fig.7 Optical coupling spectrum for the optimized grating structure with small MFD incident optical beam