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Low loss junction of Si-wire waveguides and silica based waveguides for a hybrid waveguide photonic integrated circuit

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1. Introduction

Si-wire waveguides, that is, channel waveguides consisting of Si core and silica (SiO_2) cladding are very attractive for realizing various photonic devices with extremely small size due to the strong optical confinement in the waveguide core, and it make possible to bend with small curvature. Various ultra small photonic devices utilizing them have been demonstrated [1-5] so far. However, propagation loss for the Si-wire waveguide is still large (2~3 dB/cm [1, 6]) compared to conventional silica based waveguides, therefore, it is difficult to guide lightwave for long distance. On the other hand, the propagation loss of the silica based waveguides is very small (< 0.1dB/cm), so it is possible to make large size (several cm) optical circuits. However, large bending curvature (several cm or more) is needed for the silica based waveguide due to the week optical confinement. Under the background, we proposed a hybrid waveguide photonic integrated circuit consisting of Si-wire waveguides and silica based high-Δ waveguides.

The concept of the proposed hybrid waveguide photonic integrated circuit is that silica based waveguide is used for long distance optical interconnection and Si-wire waveguides are used for making sharp bend. However, in order to realize such hybrid waveguide photonic integrated circuits, a junction structure that can connect both waveguides with low loss (0.1 dB or less) is needed. In this paper, we studied for such low loss and compact waveguide junction structure to connect Si-wire waveguides and silica based waveguides. Optical coupling loss between the waveguides should be 0.1 dB or less and as short as possible length of the joint portion (300 µm or less if possible) is desirable as well as easily fabricated structure.

2. Structure and numerical analysis

As the junction structure of Si-wire waveguide (Δ~40%) and silica based high-Δ (Δ~3-5%) waveguide (SiO_xN_y waveguide with SiO_2 cladding), we investigated core taper-type spot size converter (SSC) as shown in Fig.1. This type of SSC has been studied as an optical coupling structure for Si-wire waveguide and single mode optical fiber (SMF) so far, and less than 1 dB optical coupling loss has been attained for the coupling between the Si-wire waveguides and SMFs [1].

The analytical structure and various parameters are shown in the figure. Here, *Tip* and *L* are the width of Si taper end facet and the length of the taper portion, respectively. The refractive indices of Si, SiO_2 and SiO_x are assumed to be 3.47, 1.47 and 1.51, respectively.

The numerical analysis was carried out with 3-D semi-vector finite difference beam propagation method (FD-BPM). The fundamental TE mode (electric field parallel to the surface) of Si-wire waveguide at 1.55 µm was used as launch field from the Si waveguide side. We calculated the mode conversion efficiency into the fundamental mode of SiO_x waveguide and the mode profile after propagating 500 µm length. Figure 2 shows calculated relation between *Tip* and optical coupling loss when *L* = 300 µm. The loss caused by Fresnel reflectivity at the SiO_x waveguide input facet was took into account to estimate the coupling loss values in Fig.2. When *Tip* is 0.08 µm, the coupling loss took a minimum value of 0.141dB.

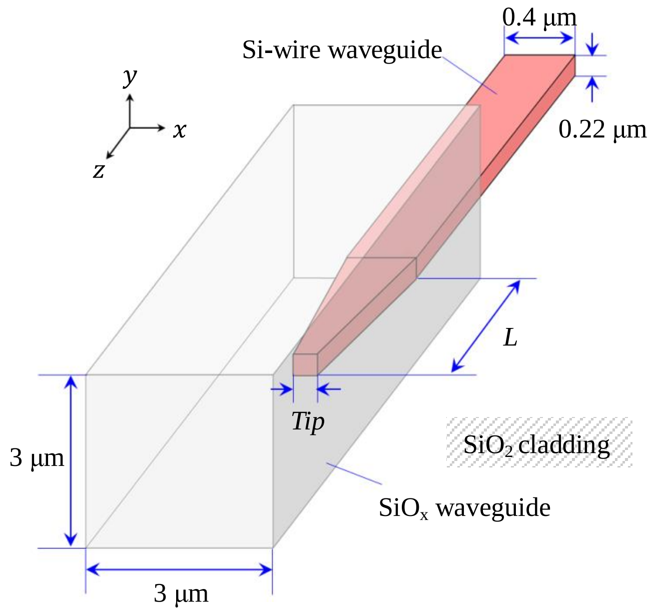

Fig. 1. The analytical structure

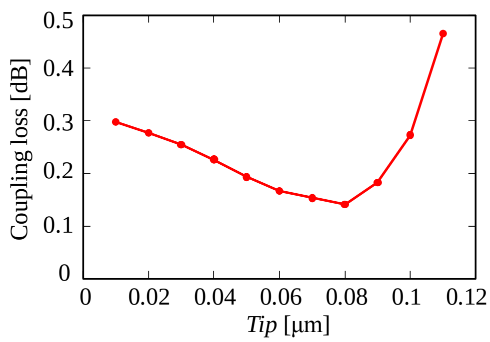

Fig. 2. The relation between *Tip* and coupling loss *L* = 300 µm

3. Measurement result

We also fabricated the waveguide junction structure, and measured the coupling loss. Figure 3 shows a photo of fabricated Si/SiO_x hybrid waveguides. The adiabatic Si core taper-type SSC (L = 300 μm, Tip = 0.08 μm) was used for the joint part of Si-wire waveguide and SiO_x waveguide. Table 1 shows structural parameters and measured losses for the waveguides. Here, L(Si) and L(SiO_x) are the length of Si-wire waveguide and SiO_x waveguide respectively. M is the number of junctions. Figure 4 shows schematic structure of the waveguides.

First, we measured the waveguides of No.1 ~ No.3, with the cut-back method to obtain the propagation loss of Si-wire waveguide. Measured total losses are 11.6 dB, 13 dB and 13.5 dB, respectively. Here, we define optical coupling loss between the optical fiber and SiO_x waveguide for both input and output facets, the propagation loss of Si-wire waveguides and the loss for single waveguide junction as C, P_{Si} and P_M, respectively. By simple calculation, we can estimate the value of P_{Si} as 0.363 dB/mm and this coincident with the value in [1, 6]. Then we obtain the following equation.

$$P_M \times 2 + C = 10 \quad (1)$$

Next, we measured loss for the waveguide No.4. The measured loss was 10.3 dB. When we defined the propagation loss of SiO_x waveguide as P_{SiOx}, we obtained the following equation.

$$P_{SiO_x} \times 5 + C = 10.3 \quad (2)$$

Finally, we measured loss for the waveguides No.5 and No.6 to obtain the loss of single junction. The measured losses are 12.8 dB and 13 dB, respectively. Then we obtained the following equations.

$$P_{Si} \times 2.58 + P_{SiO_x} \times 0.6 + P_M \times 6 + C = 12.8 \quad (3)$$

$$P_{Si} \times 1.7 + P_{SiO_x} \times 0.9 + P_M \times 8 + C = 13 \quad (4)$$

By solving the obtained equations, we estimated the loss of single junction as about 0.235 dB. This value is almost coincident with that of numerical calculation.

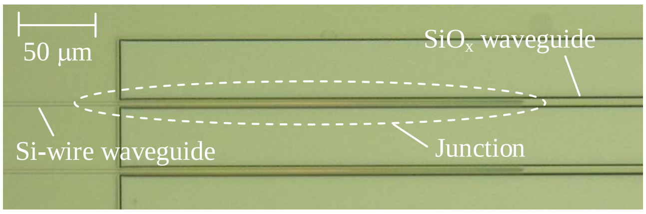

Fig. 3. Photo of fabricated Si/SiO_x hybrid waveguides

Table 1. Structure parameters and measured losses for the waveguides

No.	L(Si) [mm]	L(SiO_x) [mm]	M	Measured Loss [dB]
1	4.4	0	2	11.6
2	6.4	0	2	13
3	9.4	0	2	13.5
4	0	5	0	10.3
5	2.58	0.6	6	12.8
6	1.7	0.9	8	13

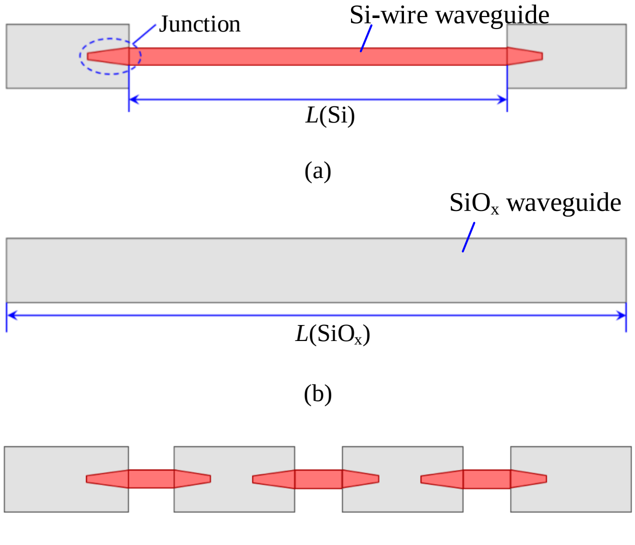

Fig. 4. Schematic structure of fabricated Si/SiO_x waveguides (a) No.1~No.3., (b) No.4., (c) No.5 and No.6.

4. Conclusion

We proposed a hybrid waveguide photonic integrated circuit with Si-wire waveguides and silica based high-Δ waveguides, and investigated low loss, compact and simple waveguide junction structures for the circuit. From both numerical and experimental studies, we found that the 0.2 dB or less optical coupling loss can be attained with a simple and compact (300 μm or less) waveguide junction structure. Therefore the proposed hybrid waveguide photonic integrated circuit with Si-wire waveguides and silica based high-Δ waveguides will be promising platform for realizing various photonic functions with compact size. We will still continue our study for finding more compact and low loss waveguide junction structure for the hybrid waveguide photonic integrated circuits.

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