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Si Slot Waveguide with $Er_xY_{2-x}SiO_5$ Coupled with Si Wire and Distributed Bragg Reflector

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Abstract

Optical coupling between Si slot $Er_xY_{2-x}SiO_5$ waveguide and Si wire waveguide is discussed. Finite-difference time-domain (FDTD) simulation revealed that very low coupling loss of 2% could be obtained in the proposed simple coupling structure. We also proposed DBR structure with the Si slot $Er_xY_{2-x}SiO_5$ waveguide, which could be obtained by the simple process. FDTD simulation also shows -30dB distinction ratio by DBR with only 5period. We have expected the coupling structure to contribute to the high performance emitters combined with Si wire circuits in hybrid silicon photonics.

1. Introduction

Rare earth (RE) silicate including Er, such as $Er_xY_{2-x}SiO_5$, is a candidate of the C-band light source materials for silicon photonics [1-3]. The refractive indexes of RE silicates are ~1.8 and much lower than that of Si. The index mismatch becomes disadvantage for the optical coupling with Si wire waveguide. So far, high index contrast Si slot waveguides have exhibited large optical mode density in the low index thin slot and enhancement of the radiative transition according to Fermi's golden role for TM mode [4][5]. These effects are presented in recent works on Si slot waveguides with Er-doped silica [6-8].

In this study, the optical coupling between Si slot $Er_xY_{2-x}SiO_5$ waveguide and Si wire waveguide is discussed. We have also expected to contribute to the improvement of the RE silicate waveguide emitters combined with Si wire circuits. Then integration of distributed Bragg reflector (DBR) with the Si slot $Er_xY_{2-x}SiO_5$ waveguide is proposed.

2. Structure of optical coupling with Si slot waveguide with $Er_xY_{2-x}SiO_5$, Si wire and DBR

Figure 1 shows schematics of Si slot $Er_xY_{2-x}SiO_5$ waveguide. The refractive index profile is also shown in the figure. Each thickness of two Si layers and $Er_xY_{2-x}SiO_5$ layer is 100nm and 50nm. Figure 2 shows typical profiles of local optical mode density for transverse electric (TE: left) and magnetic (TM: right) modes. Then the mode density is normalized in a micrometer scale by the integration of the total mode profile. TE mode shows two peaks on each of the Si layers and the dip is located at the center of the $Er_xY_{2-x}SiO_5$ layer slotted in to Si. In contrast, high refractive index contrast causes a particular optical electric field in TM mode. It is found that the mode profile indicates the field discontinuity due to the boundary conditions and consequently, strong optical confinement and higher mode density in the $Er_xY_{2-x}SiO_5$ layer. The mode density in TM mode decreases drastically with increasing the $Er_xY_{2-x}SiO_5$ layer thickness. Note that the effective refractive index becomes much higher than that of $Er_xY_{2-x}SiO_5$ layer due to the existence of Si layer.

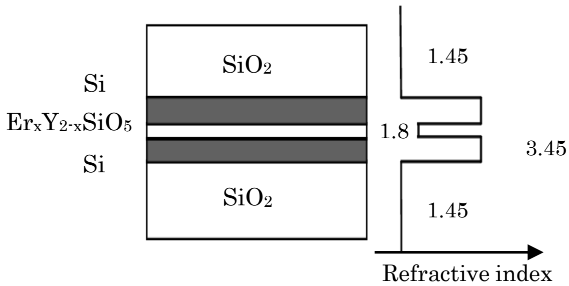

Fig. 1 Schematics of Si slot $Er_xY_{2-x}SiO_5$ waveguide (left) and its refractive index profile (right)

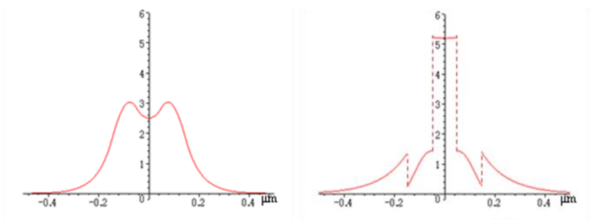

Fig. 2 Optical mode profile in the slot waveguide for TE(a) and TM(b) mode

Then we consider the optical coupling with Si wire waveguide with thickness of 250nm equal to the total thickness of the Si slot waveguide, as shown in Fig.3. We also propose DBR structure in Fig. 3 (right), which is formed by partially remove the Si over layer from the Si slot waveguide.

Fig.3 Schematics of the waveguide coupling among Si wire (left), the Si slot with 12μm long (center) waveguides and DBR (right). Black, gray and white regions indicate Si, $aEr_xY_{2-x}SiO_5$ and SiO_2, respectively.

3. FDTD simulation of optical coupling with Si slot waveguide with $Er_xY_{2-x}SiO_5$, Si wire and DBR

From the effective refractive index method and transfer matrix calculation, we use the values of 900nm for period and 500nm for Si removed gap, for DBR demonstration by finite-difference time-domain (FDTD) method. Figure 4 shows optical power distribution in the waveguide coupling with Si slot waveguide as shown in Fig.3, obtained by FDTD. The TM mode light source with a wavelength of 1.55μm is set in the Si wire waveguide and the light is incident to Si slot waveguide. The optical mode in Si wire shrinks rapidly at the interface to Si slot waveguide. The intense light exists in the Si slot waveguide, and then disappears at around DBR. Note that the scattering light hardly observed.

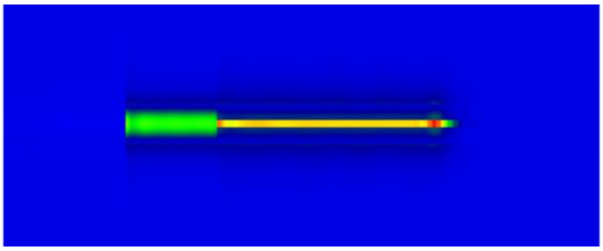

Fig.4 Optical power distribution of the waveguide coupling with Si slot waveguide (12μm long) demonstrated by FDTD. The light source is set on the left side. The incident light is passed through the slot waveguide and reaches DBR.

Figure 5 shows the typical mode distributions before (in Si wire) and after (in Si slot) the coupling. The mode profile changes drastically and shows a typical mode profile to the slot waveguide. However, the optical power integration shows only 2% decrease. The low coupling loss is consistent of the very low scattering. Figure 4 also shows the efficient reflection of DBR. We can obtained -30dB distinction ratio by only 5period DBR. It is due to the large refractive index change in DBR for TM mode.

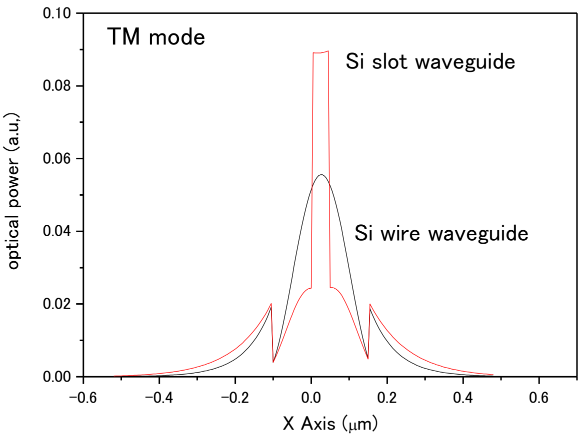

Fig.5 Optical mode profile in Si wire and Si slot waveguides calculated by FDTD, when the incident light goes through from Si wire to Si slot waveguide. The coupling loss is estimated to be only 2%.

It has been already suggested that Si slot waveguide structure contributes improvement of emission properties of the RE silicate waveguide [6-8]. Our proposal can be considered a good way for the high performance emitters combined with Si wire circuits in hybrid silicon photonics.

4. Conclusions

Optical coupler between Si slot $Er_xY_{2-x}SiO_5$ and Si wire waveguides was investigated. FDTD simulation revealed that very low coupling loss of 2% could be obtained in the proposed simple coupling structure. We also proposed DBR structure with the Si slot $Er_xY_{2-x}SiO_5$ waveguide, which could be obtained by the simple process. DBR indicated -30dB distinction ratio by only 5period. We have expected the coupling structure to contribute to the high performance emitters combined with Si wire circuits in hybrid silicon photonics.

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