Luminescence of $Er_xY_{2-x}SiO_5$ in Si Slot Waveguide Structures

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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 for silicon photonics [1][2]. The refractive indexes of RE silicates are ~1.8 and much lower than that of Si. High index contrast Si slot waveguide is expected to contribute to the development of the RE silicate waveguide emitters combined with Si wire circuits. The large optical mode density in the slot layer enhances the radiative transition according to Fermi's golden role and the coupling efficiency into TM modes. These effects are actually presented in recent works on Si slot waveguides with Er-doped silica [6][7].

In this work, we discussed the enhancement of radiative transition in Si slot $Er_xY_{2-x}SiO_5$ waveguide according to the behaviors of optical mode density for the active layer. Also planar Si slot waveguides with Er_2SiO_5 active layer were demonstrated. The optical guided mode dependence of the PL edge emissions was observed to investigate the enhancement of the radiative transition rate.

2. Experimental Approach and Results

Figure 1 shows schematics of Si slot $Er_xY_{2-x}SiO_5$ waveguide. The refractive index profile is also shown in the figure. Optical modes in the slab waveguide were calculated in transverse electric (TE) and magnetic (TM) modes. Figure 2 shows typical profiles of local optical mode density for TE (left) and TM (right) modes. Each thickness of two Si layers and $Er_xY_{2-x}SiO_5$ layer is 100nm, and the position at zero corresponds to the center of the $Er_xY_{2-x}SiO_5$ layer. 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.

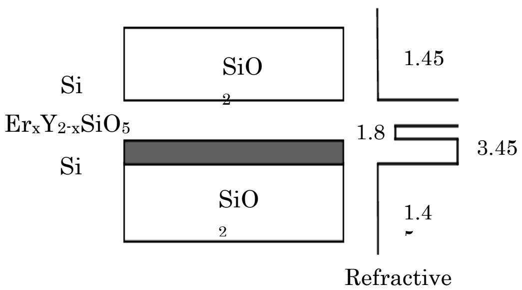
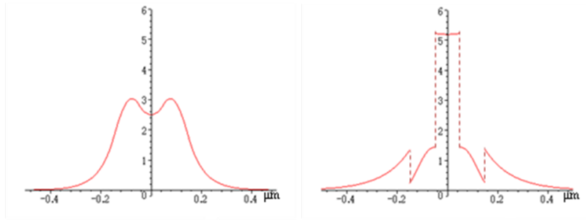


Fig. 1 Schematics of Si slot $Er_xY_{2-x}SiO_5$ waveguide (left) and its refractive index profile (right)



(a) (b)

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

Figure 3 shows the PL efficiency for TM and TE modes as a function of the Er_2SiO_5 layer thickness. The PL efficiency was defined by the integrated PL intensity divided by the Er_2SiO_5 layer thickness. Dash lines also show the average optical mode density calculated for each of the modes. The efficiency for TM decreases with increasing the Er_2SiO_5 layer thickness. It is found that the behaviors of PL efficiencies for both modes are good agreements with those of the average optical mode densities. In the case of 30-nm thick, it is too thin to maintain the crystalline property and consequently, the PL efficiency decreases away from the tendency due to increasing the nonradiative transition. These results also suggest that the large emission enhancement up to about ten times in comparison with the bulk is expected in TM mode.

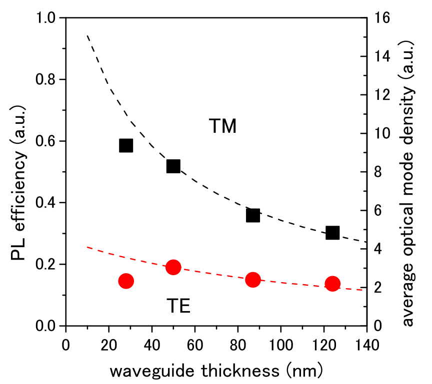


Fig. 3 PL efficiency plotted as a function of waveguide thickness. Calculated average optical mode density for TM and TE mode are also indicated by dash lines.

3. Conclusions

The high optical mode density of TM mode in the low-index slot of $Er_xY_{2-x}SiO_5$ leads to the enhancement of radiative transition. The optical guided mode dependence of the PL edge emission efficiency was indicated the same behavior as the optical mode density. It is expected that the Si-slot $Er_xY_{2-x}SiO_5$ waveguide becomes a potential efficient light emitting waveguide combined with Si wire circuits.