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$Er_xY_{2-x}SiO_5$ compact waveguide slotted into Si photonic crystal

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Abstract

$Er_xY_{2-x}SiO_5$ compact waveguide slotted into Si photonic crystal was demonstrated. Strong optical confinement for C-band light is confirmed in this device. The light propagation loss was also estimated by VSL method.

For future LSI (Large Scale Integration circuits), optical interconnection technology "Silicon photonics" is expected to be in replacement of metal interconnection. Various researches for Si-based optical devices have been worked in order to realize this system. However few researches are concentrating to compact optical amplifiers. In this movement, we suggested $Er_xY_{2-x}SiO_5$ crystal as a new light source material for compact waveguide amplifiers at around 1.5μm. This crystal can contain up to $2\times10^{22}cm^{-3}$ Er atoms as constitution elements of the crystalline matrix [1-3]. Consequently, it's expected that $Er_xY_{2-x}SiO_5$ crystal can be an optical gain medium for waveguide amplifiers with a length less than 1mm[4].

Photonic crystal (PC) possesses useful functions for the optical integration. Especially PC waveguide shows strong optical confinement and "slow light"[5]. It is considered that the slow light enlarges the cross-section of photon in gain medium because the effective coupling length becomes longer. Therefore introducing PC into $Er_xY_{2-x}SiO_5$ waveguide is expected to be a good way for the compact waveguide amplifiers. In this paper, $Er_xY_{2-x}SiO_5$ waveguide slotted into Si PC is reported.

A schematic cross sectional view of the sample structure is shown in Fig1. The refractive index of $Er_xY_{2-x}SiO_5$ crystal of active region is 1.8, which is smaller than Si. Achieving the optical confinement, Si photonic crystal slot (PCS) was formed and filled with $Er_xY_{2-x}SiO_5$ crystal. Photonic band gap (PBG) was designed by Kronig-Penney model using effective refractive index varied by the layer thickness. PBG is set to C-band and shorter wavelength edge is around 1.48μm. Transfer matrix calculation was also performed to determine the slot width in PC. The result of simulation was shown with PL spectrum of $Er_xY_{2-x}SiO_5$ crystal in Fig2.

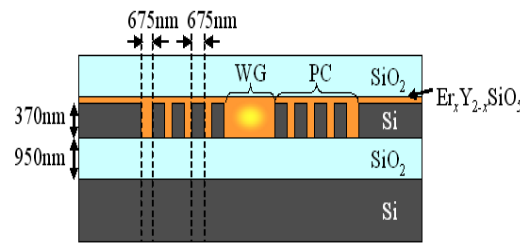

Fig.1 schematic cross sectional view of $Er_xY_{2-x}SiO_5$ waveguide slotted into Si PC.

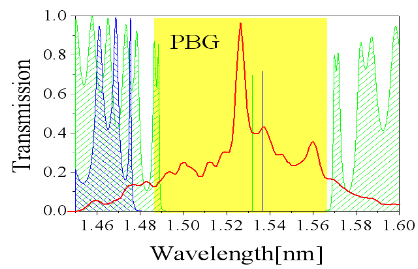

Fig.2 Designed photonic band gap and PL spectrum of $Er_xY_{2-x}SiO_5$ Crystal

Si PCS were formed on SOI wafer. The 2D-PC pattern was drawn by e-beam lithography, and then ICP dry etching was performed. $Er_{0.5}Y_{1.5}SiO_5$ crystal was formed on Si PCS by sol-gel method. Sol solution was spin-coated at 2000rpm in 60s on Si PCS. Then the sample was dried in the air at 120°C for 30min to evacuate a solvent, and baked in Ar atmosphere at 500°C for 30min. This process repeated to get thickness about 370nm. Then the sample was annealed in Ar atmosphere by 1200°C RTA (Rapid Thermal Anneal) using carbon composite heater for the crystallization. From these processes, we have successively obtained $Er_{0.5}Y_{1.5}SiO_5$ crystal combined with Si PCS. Finally, we deposited SiO_2 cladding layer for the vertical optical confinement by PCVD (Plasma enhanced chemical vapor deposition).

Figure 3 shows optical microscope photographs of $Er_{0.5}Y_{1.5}SiO_5$ waveguide slotted into Si PC. Amplified spontaneous emission (ASE) light source of C-band was used for checking the optical confinement. ASE light inputs from the cleaved facet through a lensed fiber. Cooperative upconversion emission (green light) is observed along the waveguide as shown in the middle of Fig.3. This emission corresponded to propagation of ASE light along PCS. On the other hand, infrared light scattering from Si PC region is clearly shown by IR camera in the bottom of Fig.3. However the scattering light from waveguide region becomes weaker. These results suggest the good optical confinement in $Er_{0.5}Y_{1.5}SiO_5$ waveguide slotted into Si PC.

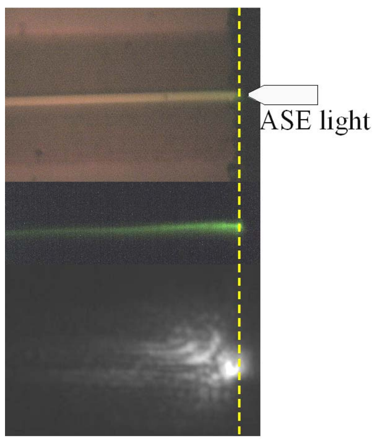

Fig.3 Micro scope Photograph of $Er_{0.5}Y_{1.5}SiO_5$ waveguide (top), cooperative upconversion emission along the waveguide (middle) and IR scattering light (bottom).

We have confirmed the sharp PL emission at 1.5µm from $Er_{0.5}Y_{1.5}SiO_5$ waveguide slotted into Si PC. Variable stripe length (VSL) measurements were also performed for estimation of propagation loss in the waveguide. High power 980nm LD with large emitter size (1x100µm) was used. Then we adjusted the beam size to 10 times by microscope. Pumping power is estimated to be up to 8.9 kW/cm^2. The line shaped pumping light was irradiated along the waveguide. PL emission from the edge of waveguide was corrected by lenzed fiber, and monitored by electrically cooled InGaAs PD array. PL spectra as a function of excitation length are shown in Fig. 4(b). The PL fine structure particular to $Er_{0.5}Y_{1.5}SiO_5$ crystal is also observed. Summarizing plot of the PL integrated intensity as a function of excitation power is shown in Fig.4 (a). All of the plots behave loss characteristics, and solid lines are fitting for loss. The loss factor α is about 18 cm^{-1}, and not so big change to the excitation condition. It is speculated that the propagation loss is due to scattering loss. $Er_{0.5}Y_{1.5}SiO_5$ crystal shows small grain, and the boundary seems to causes the scattering.

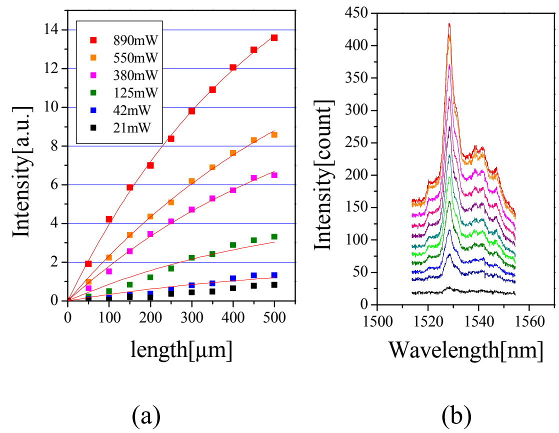

Fig. 4 PL emission through the waveguide measured by VSL method. PL intensity versus excitation length as a function of excitation power (a), and PL spectra (b).

In conclusion, $Er_{0.5}Y_{1.5}SiO_5$ waveguide slotted into Si photonic crystal was demonstrated. Strong optical confinement for C-band light is confirmed in this device. The PL fine structure particular to $Er_{0.5}Y_{1.5}SiO_5$ crystal is also observed through the waveguide structure. The light propagation loss was also estimated to be 18cm^{-1} by VSL method.

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