Enhanced Er$^{3+}$ luminescence of Er silicate through Y and Yb co-doping

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Abstract: Enhanced Er$^{3+}$ luminescence of Er silicate through Y and Yb co-doping were observed in different pump wavelengths of 654nm and 980nm, respectively, and corresponding excited mechanism was discussed.

I. INTRODUCTION

Er silicates (Er$_2$SiO$_5$, Er$_2$Si$_2$O$_7$) have been attracting considerable attentions as new light source materials in silicon photonics. Er silicates contain high density of Er$^{3+}$ ions as one of the constituent elements of the crystals and show emissions around 1.5μm, corresponding to the low-loss window of standard silica based optical fibers [1]. Various methods have been adopted to prepare this new structure, including sol-gel method [1], metal organic molecular beam epitaxy (MOMBE) [2], magnetron sputtering [3-5], and reaction of ErCl$_3$ and Si nanowires [6]. However, such a high concentration leads to upconversion due to near distances of Er$^{3+}$ ions that limits the Er$^{3+}$ luminescence. Therefore, characterizing and controlling Er$^{3+}$ ions distances in such Er silicates are necessary in order to utilize them for new light source materials in silicon photonics.

In this paper, we reported the enhanced Er$^{3+}$ luminescence of Er silicate through Y and Yb co-doping in different pump wavelengths of 654nm and 980nm respectively. Y$_2$SiO$_5$ has lattice constants that are nearly identical to that of Er$_2$SiO$_5$, which should allow uniform dilution of Er by Y, and reduce upconversion of Er, increasing Er luminescence. Yb, as an efficient sensitizer of Er$^{3+}$ at 980 nm excitation wavelength, can absorb more order of magnitude pump power than Er$^{3+}$, leading to strong Er$^{3+}$ luminescence.

II. EXPERIMENTRAL

Er$_x$Y$_{2-x}$SiO$_5$ and Er$_x$Yb$_{2-x}$SiO$_5$ films for (x=0 to 2) were fabricated by using a mixture of Er-O, Y-O(Yb-O) and Si-O (Er(Y or Yb):Si 2:1) sol solutions. The sol solutions were first spin-coated on Si (100) substrates, dried at 140 °C for 30 min in air and baked at 600 °C for 30 min in Ar. This procedure was repeated 5 times to obtain about 360 nm thick films. Finally, the coated surface of the samples were covered with a polished surface of another Si (100) wafer, and then sintered in the well heated furnace at 1200 °C for 30 minutes at a heating rate of 100 °C min$^{-1}$ in Ar atmosphere.

Phase structure of the samples was examined using a Rigaku X-ray diffractometer (XRD) with CuK$\alpha$ radiation. Photoluminescence measurements were measured by two kinds of setup systems. First, the samples were performed by using a semiconductor laser diode with a 30 mW power at 654 nm. This wavelength
corresponds to the direct excitation of Er\textsuperscript{3+} ions from \textsuperscript{4}F\textsubscript{9/2} to \textsuperscript{4}I\textsubscript{15/2}. The PL emissions were detected by a liquid-nitrogen cooled Ge detector. Another system was performed using a 1 W semiconductor laser of 980 nm as the excitation source pumping. The detector is InGaAs. The fluorescent lifetime was detected by a time-gated photon counting method using an electrically cooled InGaAs photomultiplier.

III. RESULTS AND DISCUSSION

Figure 1 shows the XRD patterns of Er\textsubscript{x}Y\textsubscript{2-x}SiO\textsubscript{5} films for (x=0 to 2). It can be seen that strong peaks of (100), (200) and (300) at 10.3\textdegree, 20.6\textdegree and 31.2\textdegree which are typical to the self-organized Er\textsubscript{2}SiO\textsubscript{5} films were observed until x=1(50at.%Y), and became blurred above x=0.5(80at.%Y). The highly ordered crystalline phase of Er\textsubscript{x}Y\textsubscript{2-x}SiO\textsubscript{5} films above x=1.0 obtained here was due to the high ordered Er\textsubscript{2}SiO\textsubscript{5}. However, the preferred orientation decreased with decrease of Er concentration to x=0.5. We guess that the structure is dependent on poor ordered pure Y\textsubscript{2}SiO\textsubscript{5} structure due to high Y concentrations.

Figure 2 shows the PL spectra of Er\textsubscript{x}Y\textsubscript{2-x}SiO\textsubscript{5} films. It can be seen that the PL spectra shape of Er\textsubscript{x}Y\textsubscript{2-x}SiO\textsubscript{5} is similar at different Er concentrations. The main PL peak is at 1528 nm. It is suggested that local environment of Er has no significant change. The PL intensity increased about 30 times when Er concentration was decreased from x=1.9 to x=0.1. For high Er concentrations x=1.6 and 1.9, fast decay time (20\textmu s) was observed, and slow decay time (~ms) appeared for low Er concentration x=0.1. Figure 3 shows the integrated PL intensity and decay time of Er\textsubscript{x}Y\textsubscript{2-x}SiO\textsubscript{5} films. The similar change tendency for decay time and 1530nm integrated PL intensity, indicating the PL intensity increase may be due to increase of decay time when Er concentration was decreased from x=1.9 to x=0.1. Addition of Y can not change the local microstructure of Er, and make Er uniform dilution. Y codoping is a very effective way to decrease upconversion of Er\textsuperscript{3+} for Er\textsubscript{2}SiO\textsubscript{5}. In correlation to this PL intensity, the decay time which was almost constant at ~20\textmu s for Er concentrations above x=1.0 began to increase below x=0.5. The results may suggest the incorporation of cooperative upconversion in the fast decay observed in pure Er\textsubscript{2}SiO\textsubscript{5}. However, since the crystalline structure of Er\textsubscript{x}Y\textsubscript{2-x}SiO\textsubscript{5} films deviated at low Er concentration may have some differences from that of the pure crystalline Er\textsubscript{2}SiO\textsubscript{5}. films, detailed experiments on the possibility of another cause should be carried out.

![Fig. 1 XRD patterns of Er\textsubscript{x}Y\textsubscript{2-x}SiO\textsubscript{5} films](image1)

![Fig. 2 PL spectra of Er\textsubscript{x}Y\textsubscript{2-x}SiO\textsubscript{5} films](image2)
change for different Yb codoping concentration at 654 nm excitation pump wavelength. In order to study the effect of Yb, we use 980 nm wavelength as pump wavelength. It can be seen that PL intensity was increased to 20 time at 95% Yb (Er:Yb=1:20), similar the phenomena have been found in other reference [7]. The detailed excited mechanism at the different wavelength was carrying out.

IV. CONCLUSIONS

The structure and PL properties of Er$_x$Y$_{2-x}$SiO$_5$ and Er$_x$Yb$_{2-x}$SiO$_5$ films have been studied. Enhanced Er$^{3+}$ luminescence of Er silicate through Y and Yb co-doping were observed in different pump wavelengths of 654 nm and 980 nm.

REFERENCES