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Optical and Spectroscopic Properties of 2 % Er and 20 % Yb Co-Doped $YCa_4B_3O_{10}$†

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Optical property of 20 % Yb and 2 % Er ion co-doped YCOB($YCa_4B_3O_{10}$), self frequency doubling non-linear optical crystal, was investigated at the wavelengths of 1.0 and 1.5 µm. The absorption of 20 % Yb ion doped YCOB increased by 2 % Er ion co-doping around absorption band of 1.0 µm. The absorbed energy at 1.0 µm band relayed to Er ion and the fluorescence at 1.5 µm was observed by energy transfer. The fluorescent lifetime of 1.5 µm with temperature was also investigated. It increased form 1.27-1.54 and 1.62 ms with lowering temperature from 300-77 and 6 K, respectively. The fluorescent spectral bandwidth at 1.5 µm was sharpened with lowering temperature, however the red shift of peak wavelength was not observed with co-doping of Er ion.

Key Words: Optical, Spectroscopic properties, Co-Doped $YCa_4B_3O_{10}$.

INTRODUCTION

The industrial need for 1.5 µm laser light source has increased in field of free space communication and fiber optic communication. The wavelength range of 1.5 µm is important in optical communication because silica is the principal material of optical fiber and loss of Rayleigh scattering and infrared becomes the minimum around 1.5 µm. Therefore, the coherent light source of 1.5 µm is getting larger in application of medicine and communication[1,2].

Most light source around 1.5 µm has been studied in Er ion doped material, because it has a large emission spectrum around 1.5 µm. Er ion has a peak absorption around 0.9 µm. Yb ion co-doping is efficient to get more absorption at the pumping wavelength of 0.9 µm, which is able to be pumped by a commercial laser diode of InGaAs. Yb^{3+} ion has larger absorption at 0.9 µm than Er^{3+} ion, which make it possible more absorption of pumping light 0.9 µm and larger emission around 1.5 µm. Absorbed pumping energy by Yb^{3+} ion can be transferred to Er^{3+} ion, therefore, fluorescent yield at 1.5 µm increase. To date many Er^{3+} and Yb^{3+} co-doped materials have been studied to get a stable and efficient light source at 1.5 µm[3,4].

In this study, the optical characteristics of Er^{3+} and Yb^{3+} ions co-doped YCOB[$YCa_4O(BO_3)_3$], which has a self-frequency doubling property, were investigated. Self frequency doubling means that simultaneous lights generation of fundamental and second harmonic wavelength from a single laser host material. YCOB single crystal, developed about 10 years ago, showed excellent frequency doubling property at 1.06 µm. The fundamental laser wavelength of Nd:YAG. YCOB could be grown fast and showed good chemical and mechanical property[5].

RESULTS AND DISCUSSION

Yb:YCOB and Er,Yb:YCOB: The light absorption in range of 900 nm (900 nm, 976 nm) and resultant emission around 1.5 mm can be possible by many transitions of Yb^{3+} and Er^{3+} ion. In most host material, the absorption of Yb^{3+} ion($^2F_{7/2} \rightarrow {}^2F_{5/2}$) is larger than that of Er^{3+} ion ($^4I_{15/2} \rightarrow {}^4I_{11/2}$). On the contrary to the usual case of 800 nm pumping, the absorbed energy of Yb^{3+} ion became to be transferred to Er^{3+} ion. The molecular density of $^4I_{11/2}$ level of Er^{3+} ion may be affected by 3 channels. The first is Er^{3+} ion absorbs pumping light directly ($^4I_{15/2} \rightarrow {}^4I_{11/2}$), the second is resonance energy transfer ($^2F_{5/2} \rightarrow {}^2F_{7/2}$) of Yb^{3+} ion excited to $^2F_{5/2}$ state. The third is the inverse resonance energy transfer ($^4I_{11/2} \rightarrow {}^4I_{15/2}$ and $^2F_{7/2} \rightarrow {}^2F_{5/2}$) that Er^{3+} ion, excited to $^4I_{11/2}$, transfers absorbed energy to Yb^{3+} at ground state. Er^{3+} ions at $^4I_{11/2}$ level then undergoes radiative transition ($^4I_{13/2} \rightarrow {}^4I_{15/2}$) after non-radiative transition ($^4I_{11/2} \rightarrow {}^4I_{13/2}$), therefore, shows fluorescent property at 1540 nm.

YCOB studied in this paper is monoclinic biaxial crystal and has lattice parameters of a = 8.046 Å, b = 15.959 Å,

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c = 3.517 Å, β = 101.19º. Three crystal axes are not perpendicular one another. When b-axis is parallel to y-axis, the angles between x-axis and a-axis is 20º, between z-axis and c-axis is 31º in direction of right hand screw[6]. This study was performed with crystal axis along y-axis, because, however, some other research result also has been reported about crystal axes orientation[7].

Fig. 1 shows the measured absorption spectra of 20 % Yb:YCOB and 2 % Er, 20 % Yb:YCOB with the polarization

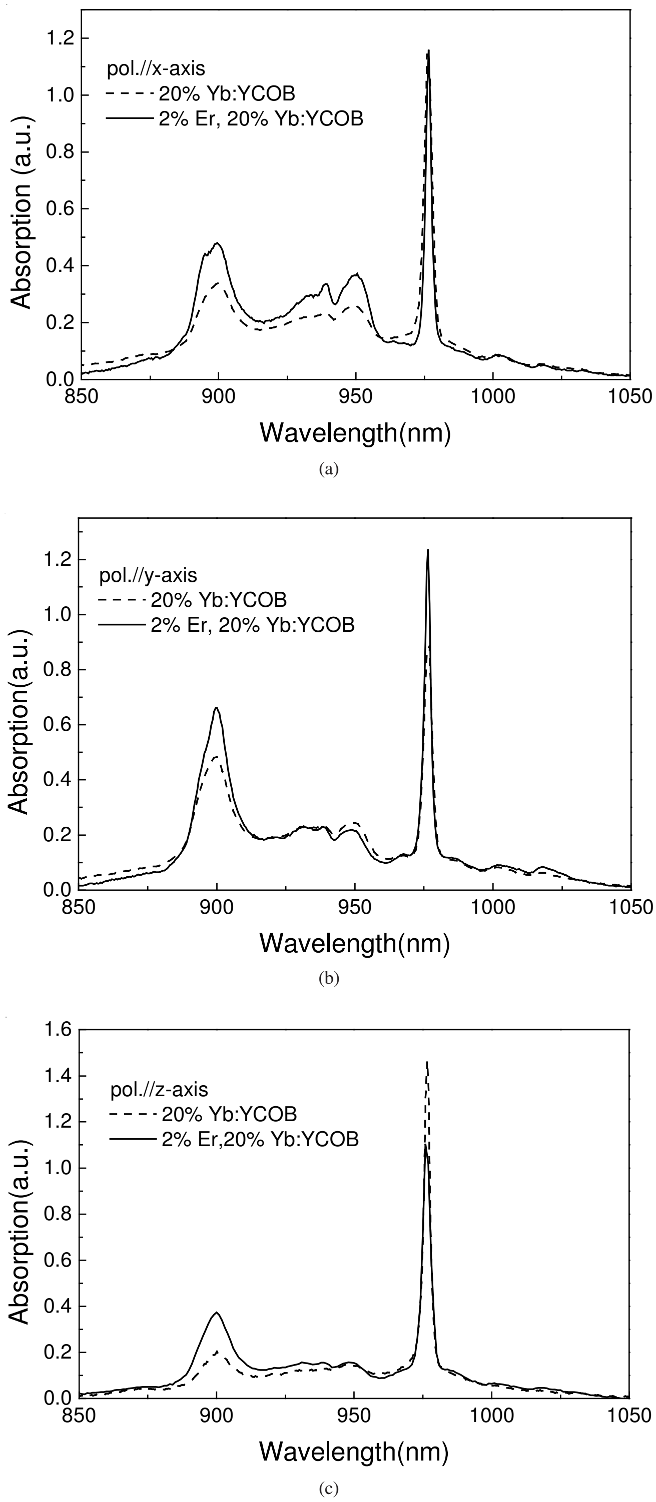

Fig. 1. Comparison of 20 % Yb:YCOB and 2 % Er, 20 % Yb:YCOB in absorption spectra with axes around 1 μm

of incident beam. The largest and peak absorption band is around 900 nm and 976 nm. 2 % Er co-doping increased absorption around 900 nm, which was due to absorption addition of Er^{3+} ion to Yb^{3+} ion absorption. Absorption increase at 900 nm due to 2 % Er co-doping also induced absorption decrease around 950 nm, because the YCOB crystal structure has directivity and the bonding angle of Er-O-B changed owing to Er^{3+} ion co-doping. The variation of absorption spectrum with Er^{3+} ion co-doping to Yb:YCOB crystal was caused by complicated crystal property of Yb:YCOB. Non-linear crystal of YCOB has rare earth ion centered structure of twisted oxygen octahedron. The substitution of Yb^{3+} ion or Er^{3+} ion to the site of Y^{3+} ion may induce cluster distortion or transform, therefore change of non-linear properties such as Raman scattering or crystal field, because the effective radius of Yb^{3+} ion (0.858 Å) or Er^{3+} ion (0.881 Å) is larger than that of Y^{3+} ion (0.900 Å)[8]. The absorption property of rare earth ion doped YCOB was determined by 4*f* inner shell of doping ion. The effective radius of Yb^{3+} or Er^{3+} ion is smaller than that of Y^{3+} ion which has more electrons in 4*f* shell. The absorption increase may comes from that the substitution of Yb^{3+} or Er^{3+} ion to Y^{3+} ion site should enlarge the bonding angle of original Y-O-B structure.

Temperature dependent fluorescent characteristics of Er,Yb:YCOB: Fig. 2 measured fluorescent spectrum of $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition of Er^{3+} ion when the wavelength and polarization of incident beam was 976 nm and y-axis parallel, respectively. The pumping light was OPO pumped by Nd:YAG laser and the sample was placed in vacuumed cooling system. The temperature was controlled to 77 K and 6 K with liquid nitrogen, helium and controller. The polarization of incident beam was controlled by passing through polarizer before collide on sample and the fluorescent light from sample was collected by spectrophotometer and CCD. 1 mm thickness sample was stacked to gold plate for complete cooling, wavelength cutoff filter was also placed before spectrophotometer to separate scattered pumping light.

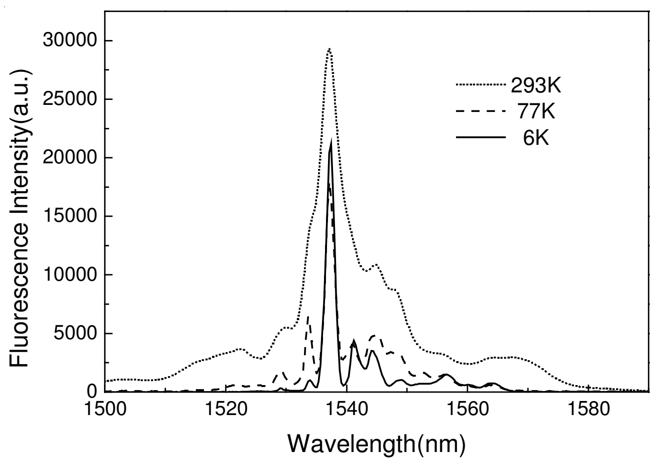

Fig. 2. Fluorescent spectrum of 2 % Er, 20 % Yb:YCOB with temperature (pumping wavelength: 976 nm, polarization: y-axis)

Conclusion

20 % Yb:YCOB has been reported as a optimum concentration for best non-linearity among several rare earth ions for

doping to YCOB host material. In this study, 2 % Er ion co-doped effect on absorption spectrum at 1.06 μm and fluorescent spectrum at 1.5 mm wavelength regions were investigated.

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