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Influence of Er and O doses in Er-related emission in $\text{Al}_{0.70}\text{Ga}_{0.30}\text{As:Er}$

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ABSTRACT

Er ions with doses ranging from $1 \times 10^{13} \text{ cm}^{-2}$ to $1 \times 10^{15} \text{ cm}^{-2}$ were implanted into $\text{Al}_{0.70}\text{Ga}_{0.30}\text{As}$ on GaAs substrates. at 800 °C. Photoluminescence (PL) intensity of Er-related emission around 1.54 μm was enhanced by co-implanted oxygen (O). The optimum dose of Er ion was $1 \times 10^{14} \text{ cm}^{-2}$ and O ion was $1 \times 10^{15} \text{ cm}^{-2}$, respectively. Furthermore, from the temperature dependence of the PL intensity of sample implanted with the optimum dose, we estimated the values of E_1 , E_2 , and E_3 , the activation energies in order to investigate the rapid thermal quenching of Er ion in $\text{Al}_{0.70}\text{Ga}_{0.30}\text{As}$. We found that PL intensity of Er-related emission, in addition to O dose, was enhanced approximately twenty two times at room temperature. And from the temperature dependence of the lifetime of the optimum dose of Er and O, the value 245meV of E_A , the activation energy for the decrease of the lifetime, was nearly equal to the value 235meV of E_3 . Based on the result, the decrease of the lifetime confirms that the radiative efficiency is lower; therefore, we propose that rapid thermal quenching occurs at temperatures above 200 K due to the decrease of the radiative efficiency.

INTRODUCTION

Rare-earth(RE) impurities in III-V semiconductors have attracted much attention due to their potential applications in new emitting devices and based on the internal emission from the 4f levels of the impurity. The intra-4f shell transitions cause sharp and temperature-stable luminescence because of shielding by outer electronic shells. [1,2] Therefore the research on the optical devices, which involves RE element, has been advanced. Er is attractive for obtaining light emitting device in silica-fiber-based optical communication systems. As a matter of fact, the luminescence from Er^{3+} ion occurs at a wavelength of 1.54 μm [3,4], which corresponds to the minimum absorption of silica-based optical fibers.

However Er-doped semiconductors have problems such as low energy transition efficiency from the host semiconductor to the intra-4f-shell of Er^{3+} ions. Therefore it is important that we understand the mechanism of the energy transition. We have

previously reported photoluminescence (PL) properties for the dependence of the composition ratio (x) in $\text{Al}_x\text{Ga}_{1-x}\text{As}$, and the influence of light elements (O, N, and C) on the low dosage $1 \times 10^{13} \text{ cm}^{-2}$ of Er. [4]

In this work, we studied the influence of O on Er^{3+} -related emission with the high Er doses ranging from $1 \times 10^{14} \text{ cm}^{-2}$ to $1 \times 10^{15} \text{ cm}^{-2}$.

EXPERIMENT

Er^{3+} ion of 1 MeV were implanted into undoped $\text{Al}_{0.70}\text{Ga}_{0.30}\text{As}$ (100) grown by molecular beam epitaxy (MBE) with doses ranging from $1 \times 10^{13} \text{ cm}^{-2}$ to $1 \times 10^{15} \text{ cm}^{-2}$ at room temperature. The projected range (R_p) and straggling (ΔR_p) for implant profile were calculated by materials computer program (TRIM) to be 205.7 and 58.4 nm, respectively. O ion were implanted into $\text{Al}_{0.70}\text{Ga}_{0.30}\text{As:Er}$ with doses ranging from $1 \times 10^{13} \text{ cm}^{-2}$ to $3 \times 10^{15} \text{ cm}^{-2}$ at an energy of 130 keV. The R_p of the implanted O ions was almost the same as that of Er ions. After implantation, these samples were isochronally annealed for 10 min. at 800 °C, using the proximity cap method in H_2 atmosphere. In order to characterize the specimens, PL measurements were carried out using a 1 m focal length double monochromator and photo-multiplier (Hamamatsu Photonics R5509-72). Samples were excited by the 488.0 nm line of an Ar ion laser with a power of 10 mW.

RESULTS AND DISCUSSION

In order to optimize the PL intensity of Er^{3+} , dose dependence was investigated. Figure 1 shows the Er-related PL spectra of $\text{Al}_{0.70}\text{Ga}_{0.30}\text{As:Er}$ for doses ranging from $1 \times 10^{13} \text{ cm}^{-2}$ to $3 \times 10^{15} \text{ cm}^{-2}$ measured at 15K. The several peaks were observed around 1500 nm, and the dominant peak is located 1539.6 nm. PL intensity of the dominant peak increased for Er doses ranging from 1×10^{13} to $1 \times 10^{14} \text{ cm}^{-2}$ and decreased for those from 3×10^{14} to $1 \times 10^{15} \text{ cm}^{-2}$. In the sample with Er dose of $1 \times 10^{14} \text{ cm}^{-2}$, the PL intensity of the dominant peak

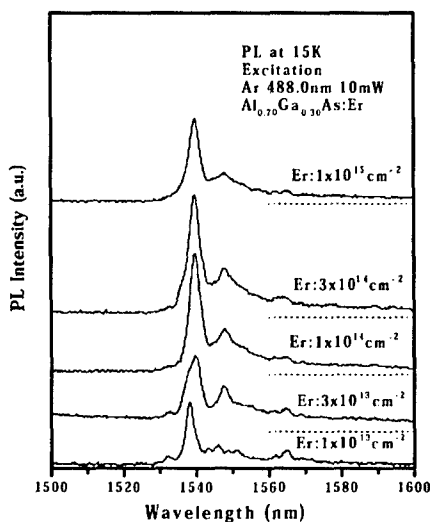


Figure 1. PL spectra of Er^{3+} ion in $\text{Al}_{0.70}\text{Ga}_{0.30}\text{As}$ corresponding to the transition $^4I_{13/2} \rightarrow ^4I_{15/2}$ recorded at 15K with Er doses ranging from $1 \times 10^{13} \text{ cm}^{-2}$ to $1 \times 10^{15} \text{ cm}^{-2}$.

at 1539.6nm was maximum. The dominant peak intensity decreased with increasing the Er doses range above $1 \times 10^{14} \text{ cm}^{-2}$.

Figure 2. shows the PL spectra of $\text{Al}_{0.70}\text{Ga}_{0.30}\text{As:Er,O}$ for different O doses and annealed at 800°C measured at 15K. As the O dose increased from $1 \times 10^{14} \text{ cm}^{-2}$ to $1 \times 10^{15} \text{ cm}^{-2}$, the dominant peak was stronger. In the sample, when O was co-implanted into the $\text{Al}_{0.70}\text{Ga}_{0.30}\text{As:Er}$ with a dose of $1 \times 10^{15} \text{ cm}^{-2}$, the PL intensity of the dominant peak became maximum. The peak intensity decreased with increasing the O doses from $1 \times 10^{15} \text{ cm}^{-2}$ to $3 \times 10^{15} \text{ cm}^{-2}$. We consider that the PL intensity in the sample with the O dose at $3 \times 10^{15} \text{ cm}^{-2}$ decreases because the defects attributed to O co-doping disturb the energy transition efficiency from the host material to the intra-4f-shell of Er^{3+} ions. Based on the results, the O dose required to obtain the maximum PL intensity at the dominant peak is concluded to be $1 \times 10^{15} \text{ cm}^{-2}$.

Figure 3 shows the temperature dependence of PL intensity for $\text{Al}_{0.70}\text{Ga}_{0.30}\text{As:Er, O}$ at Er dose of $1 \times 10^{14} \text{ cm}^{-2}$ and O dose of $1 \times 10^{15} \text{ cm}^{-2}$. From Figure.3, we can observe a peculiar three -step quenching process in PL intensity of $\text{Er:}1 \times 10^{14} \text{ cm}^{-2}$ without O and $\text{Er:}1 \times 10^{14}, \text{O:}1 \times 10^{15} \text{ cm}^{-2}$. The PL intensity rapidly decreased above 200K. Furthermore, at room temperature the PL intensity of Er-related emission from the sample co-implanted with O at a dose of $1 \times 10^{15} \text{ cm}^{-2}$ was twenty two times stronger than that from the sample implanted with

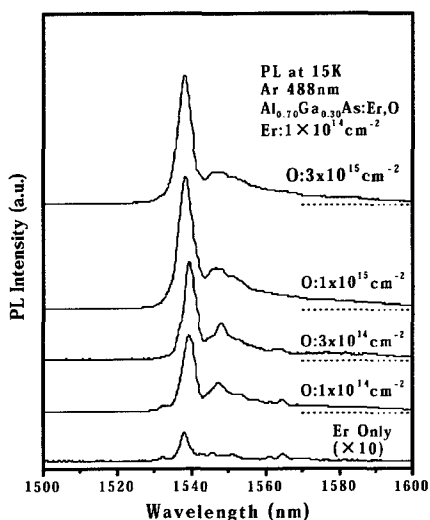


Figure 2. PL spectra measured at 15K for $\text{Al}_{0.70}\text{Ga}_{0.30}\text{As:Er,O}$ with O doses ranging from $1 \times 10^{15} \text{ cm}^{-2}$ to $3 \times 10^{15} \text{ cm}^{-2}$.

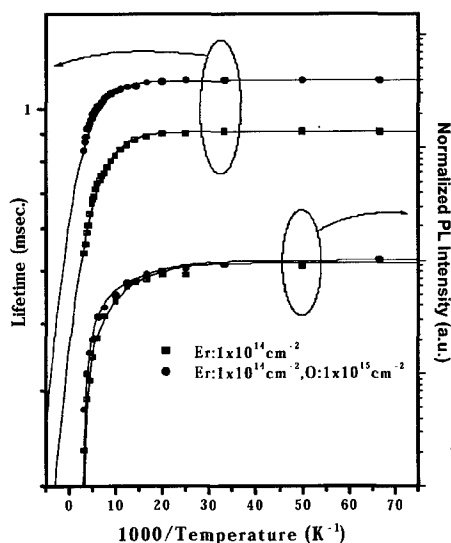


Figure 3. Er^{3+} -related PL lifetime and intensity dependence on temperature for $\text{Al}_{0.70}\text{Ga}_{0.30}\text{As:Er,O}$.

only $\text{Er}:1 \times 10^{14} \text{ cm}^{-2}$. The experimental data for $\text{Al}_{0.70}\text{Ga}_{0.30}\text{As}:\text{Er},\text{O}$ are plotted together with the theoretical lines (solid line) of the best fit obtained using Eq. (1) using parameters ($C_1, C_2, C_3, E_1, E_2, E_3$) shown in table 1.[6-8]

$$I = I_0 / \{1 + C_1 \exp(-E_1/kT) + C_2 \exp(-E_2/kT) + C_3 \exp(-E_3/kT)\} \quad (1)$$

$$1/\tau(T) = 1/\tau_r + 1/\tau_n \quad (2)$$

Where τ_n (the non-radiative lifetime) was assumed as follows:

$$1/\tau_n = C_A \exp(-E_A/kT) \quad (3)$$

Table 1. Activation energies obtained by fitting experimental results to Eqs. (1) and (2).

PL Intensity						
	C_1	$E_1(\text{meV})$	C_2	$E_2(\text{meV})$	C_3	$E_3(\text{meV})$
$\text{Er}:1 \times 10^{14} \text{ cm}^{-2}$	5.0	14.0	50	50	4.0×10^5	235
$\text{Er}:1 \times 10^{14} \text{ cm}^{-2}$ $\text{O}:1 \times 10^{15} \text{ cm}^{-2}$	3.0	11.5	55	60	2.0×10^5	235

Lifetime		
	C_A	$E_A(\text{meV})$
$\text{Er}:1 \times 10^{14} \text{ cm}^{-2}$	1.7	235
$\text{Er}:1 \times 10^{14} \text{ cm}^{-2}$ $\text{O}:1 \times 10^{15} \text{ cm}^{-2}$	0.75	245

In the above equation, I_0 is the intensity when the electron emission from the Er-related trap can be neglected. Hence it corresponds to the intensity at a very low temperature. T is the measuring temperature, E_1, E_2, E_3 and E_A , are activation energies respectively, and k is the Boltzmann constant. C_1, C_2, C_3 and C_A are the coupling coefficient at E_1, E_2, E_3 and E_A , respectively. τ and τ_r are the lifetime and the radiative lifetime, respectively. These E_2 , and E_3 values were 50-60 meV and 235 meV, respectively. Moreover, E_A values were 235-245

meV. On the other hand, the value 235meV of E_3 , the activation energy for rapid thermal quenching, was nearly equal to the value 235-245meV of E_A , activation energy for the decrease of the lifetime. Based Eq. (2), the decrease of the lifetime confirms that the radiative efficiency is lower; therefore, we propose that rapid thermal quenching occurs above 200 K due to the decrease of the radiative efficiency. In addition, we infer that activation energy E_1 is the ionization energies of the e-h pair in the Er^{3+} -related trap level because it has been reported that the ionization energy is about 10 meV.[4,7]

CONCLUSION

In order to increase Er-related emission in $\text{Al}_{0.70}\text{Ga}_{0.30}\text{As}$, we examined dose dependence of Er and O. It was found that the optimum dose range for $\text{Al}_{0.70}\text{Ga}_{0.30}\text{As:Er}$ was $1 \times 10^{14} \text{ cm}^{-2}$, based on the dose dependence, and the optimum O dose range for $\text{Al}_{0.70}\text{Ga}_{0.30}\text{As:Er}$ was $1 \times 10^{14} \text{ cm}^{-2}$, based on the O dose dependence. The PL intensity of Er-related emission, in addition to O dose, was enhanced approximately twenty two times at room temperature. From the temperature dependence of the PL intensity and the lifetime, E_3 (235meV), the activation energy for rapid thermal quenching, was nearly equal to E_A (235-245meV) the activation energy for the decrease of the lifetime. Based on the result, the decrease of the lifetime confirms that the radiative efficiency is lower; therefore, we propose that rapid thermal quenching occurs above 200 K due to the decrease of the radiative efficiency.

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