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Room-temperature 1.54 μm light emission from Er,O-codoped GaAs/GaInP LEDs grown by low-pressure organometallic vapor phase epitaxy

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1. Introduction

Rare-earth doping of III-V semiconductors has attracted increasing interest. Special attention has been paid to Er. Er^{3+} ions show sharp and temperature-stable luminescence at around 1.54 μm due to intra-4*f*-shell transition from the first excited state ($^4I_{13/2}$) to the ground state ($^4I_{15/2}$). The wavelength of 1.54 μm lies in the minimum loss region of silica-based optical fibers. Therefore, these properties are attractive for fabricating optical devices such as semiconductor lasers and optical amplifiers.

Oxygen (O) has been found to play an important role in the production of efficient Er-related luminescent centers in GaAs. Er,O-codoped GaAs (GaAs:Er,O) produces a strong emission intensity and simple photoluminescence (PL) spectrum predominantly from one kind of Er center [1]. The Er center has been identified as an Er atom located at the Ga sublattice with two adjacent O atoms (Er-2O center) [2]. The dependence of the PL spectra on growth temperature revealed the existence of a threshold growth temperature between 560°C and 580°C for Er incorporation into GaAs [3].

In this contribution, we present the first report on room-temperature electroluminescence (EL) due to the Er-2O center in GaAs;Er,O/$Ga_{0.51}In_{0.49}P$ light-emitting diodes (LEDs) grown by low-pressure organometallic vapor phase epitaxy (LP-OMVPE).

2. Experiment

The samples used in this study were grown on (001) Si-doped GaAs substrates, misoriented 2° toward (111)A. Triethylgallium (TEGa), trimethylindium (TMIn), tertiarybutylarsine (TBAs) and tertiarybutylphosphine (TBP) were used as sources. Er doping to a GaAs active layer was carried out with trisisopropylcyclopentadienylerbium ((*i*-PrCp)$_3$Er) as an Er source with an addition of $^{18}O_2$. The O_2 content in growth ambient was set to be 0.2 ppm. The growth sequence was initiated by a 0.1 μm S-doped GaAs buffer layer, which was followed by a S-doped GaInP cladding layer and a 1.2 μm GaAs:Er,O active layer. This was followed by the second cladding layer of Zn-doped GaInP and a 1.5 μm Zn-doped GaAs layer for contact. At each GaAs-GaInP interface, growth was interrupted for 1 min after each layer growth to change the source flow rates. The detail was described in Ref. 4.

3. Results and Discussion

Figure 1 shows in-depth profiles of Er, Ga and As for the GaAs:Er,O/GaInP sample. The profile reveals a uniform distribution of Er along the growth direction in the GaAs:Er,O active layer. Furthermore, in GaInP cladding layers, Er concentration is below the detection limit. Er concentration in GaAs:Er,O active layer, calibrated by using an Er-implanted GaAs sample, was evaluated to be about 8 x 10^{18} cm^{-3}.

Under forward bias, characteristic emission from Er^{3+} ions between the $^4I_{13/2}$ and $^4I_{15/2}$ levels was clearly observed, while the Er-related EL was undetectable under reverse bias. Figure 2(a) shows the room-temperature Er-related EL spectrum for the GaAs:Er,O/GaInP sample under forward bias. The current and the duty cycle were 30 mA and 50%, respectively, at a frequency of 50 Hz. The spontaneous EL emission was measured from a cleaved edge of the sample. For comparison, PL spectrum for a GaAs:Er,O/GaAs sample is also shown in Fig. 2(b). A series of emission lines observed in the EL and PL spectra exhibit the same wavelengths and relative intensities. It suggests that these lines originate from the same Er centers. Dashed lines, shown in Fig. 2, denote the Er-2O lines. This result shows a successful formation of the Er-2O center and an excitation of the center by current injection. Moreover, GaAs band-edge emission was not detected under the measured conditions. Therefore, it indicates that injected carriers contribute effectively to excitation of Er ions.

Figure 3 shows the dependence of the EL intensity of a main line observed at 1538 nm on the current density in the range of 0-40 A/cm^2. The pulse current of 10 μs was flown with the duty of 0.5%. At lower current densities, the EL intensity increases linearly with the current density. Subsequently, the intensity has a tendency to saturate at higher current densities. The analysis of the behavior is now in progress.

4. Conclusions

We have grown GaAs:Er,O/GaInP LEDs by LP-OMVPE. Er was doped selectively in the GaAs:Er,O active layer. Radiant 1.54 μm EL due to the Er-2O center was successfully observed under forward bias at room temperature. Disappearance of GaAs band-edge emission indicates that the Er center is excited effectively by injected carriers.

Acknowledgments

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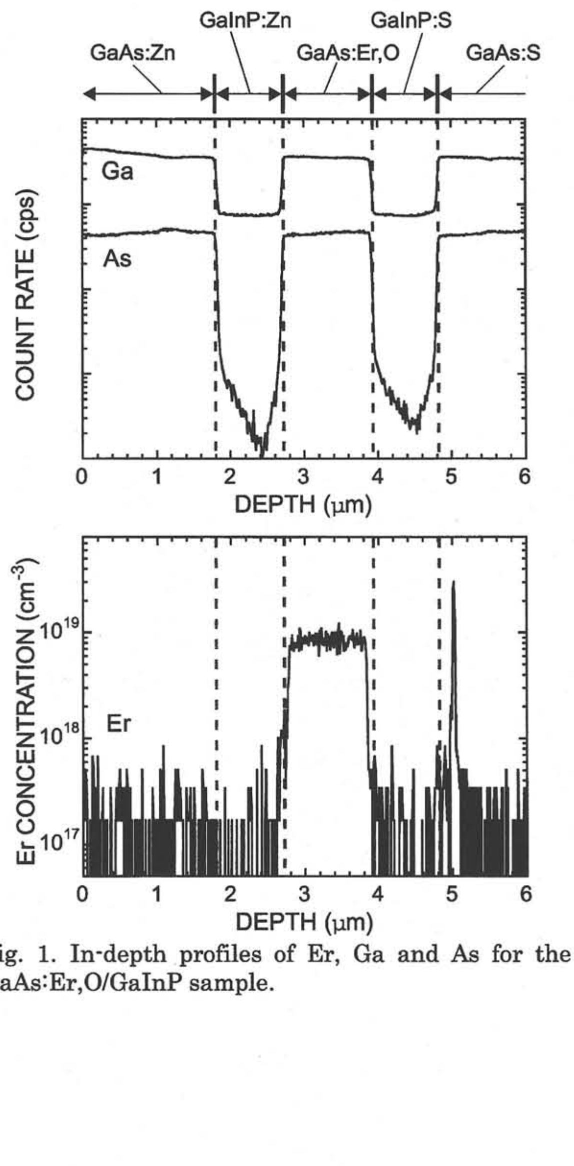

Fig. 1. In-depth profiles of Er, Ga and As for the GaAs:Er,O/GaInP sample.

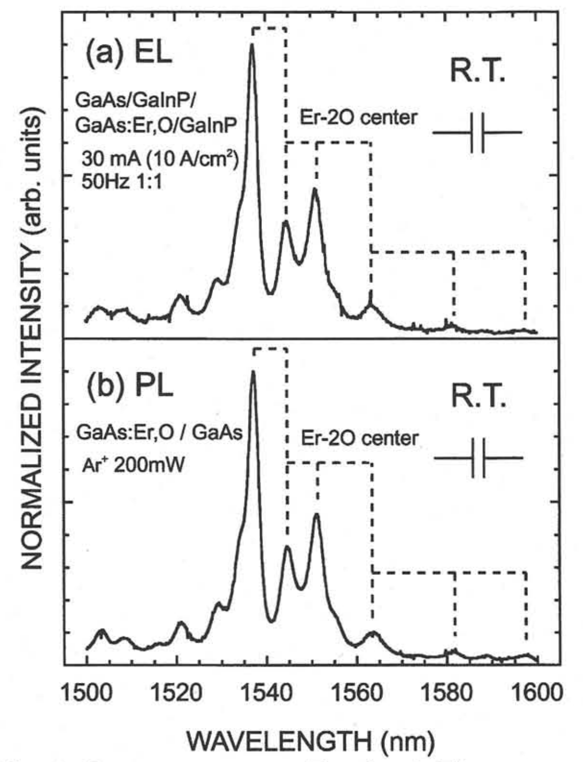

Fig. 2. Room-temperature Er-related EL spectrum for the GaAs:Er,O/GaInP sample at around 1.54 μm under forward bias. The PL spectrum for a GaAs:Er,O/GaAs sample is also shown for comparison.

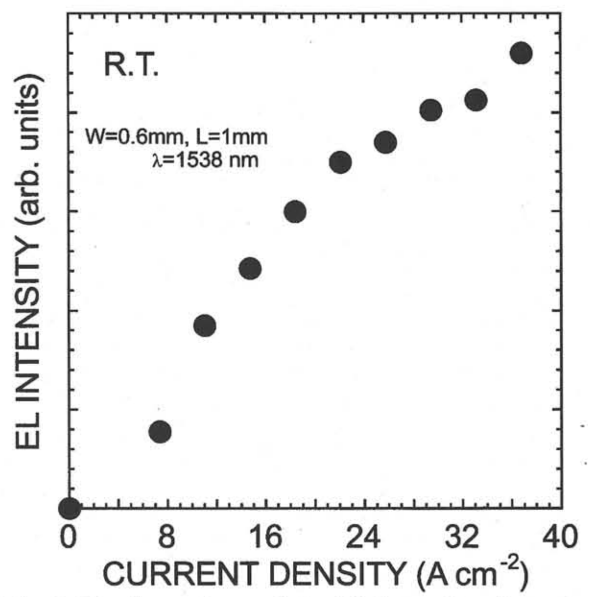

Fig. 3. The dependence of the EL intensity of a main line observed at 1538 nm on the current density.