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First Demonstration of Amplified Spontaneous Emission from Eu Ions Doped in GaN

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Abstract

We developed a novel red light-emitting diode (LED) using Eu-doped GaN (GaN:Eu). The output power has exceeded 1 mW at present. To get a clue to realize the brighter LED, we investigate Eu emission in two types of configurations; conventional surface detection under a spot excitation (SDSE) and edge detection under a stripe excitation (EDSE). The Eu emission is enhanced by a factor of 1.2 in the EDSE configuration compared to the SDSE configuration. The wavelength dependence of the emission enhancement agrees well with a gain spectrum of GaN:Eu. These results clearly indicate that the emission enhancement is attributed to amplified spontaneous emission (ASE). This is the first demonstration of ASE from Eu-ions doped into GaN, implying a possibility to realize a highly efficient GaN:Eu-based superluminescent diodes

1. Introduction

Red light emitting diodes (LEDs) using III-nitride semiconductors have attracted much attention to achieve monolithic full-color integration towards next generation micro-LED displays. We have focused on red LEDs using Eu-doped GaN (GaN:Eu) grown by organometallic vapor phase epitaxy (OMVPE) [1], and their light output power has exceeded 1 mW [2] . However, it was found that the output power of a GaN:Eu-based LED is significantly saturated under high current injections, and the emission efficiency is degraded. The efficiency-droop under a strong excitation is caused by long radiative lifetimes of the intra-*4f* shell transitions in Eu ions (~250 μs) with respect to a typical carrier recombination lifetime in the GaN host. As a result of the long lifetime, most Eu ions are excited under the strong excitation and their trap-levels are fully occupied by injected carriers. Thus, to further improve the emission efficiency of GaN:Eu-based LEDs in theory, novel device-design instead of the conventional LEDs using spontaneous surface-emissions is desired. In this contribution, we report on more efficient sample-edge emission of GaN:Eu through the firstly-demonstrated amplified spontaneous emission (ASE) from Eu-ions doped in GaN.

2. Experimental results

A sample was grown on a *c*-plane sapphire substrate using OMVPE method. The sample consists of an un-doped

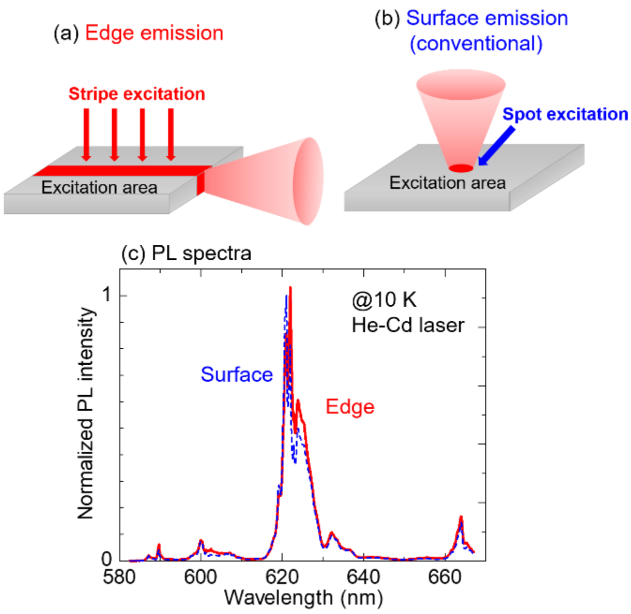

Fig.1 Schematic drawings of PL measurements under (a) EDSE and (b) SDSE configurations. (c) PL spectra from the two configurations at 10 K.

GaN layer (2 μm), an AlInN layer (450 nm), a GaN:Eu,O layer (420 nm), and a GaN capping layer (20 nm). After the sample fabrication, photoluminescence (PL) measurements were performed at 10 K. As an excitation light source, a He-Cd laser was used with the excitation power density varying from 5.3 to 374 mW/cm^2. Figures 1 (a) and (b) show schematic drawings of two types of PL measurement setups. The former is a stripe excitation condition, where excitation light was focused into a stripe with a width of 50 μm and a length of 9.1 mm. The PL signal was detected from a sample-edge (edge detection under a stripe excitation; EDSE). The latter is corresponding to a spot excitation condition, where excitation light was focused into a spot with a diameter of 200 μm. The PL signal was detected from the sample-surface (surface detection under a spot excitation; SDSE). Typical PL spectra obtained under the two configurations are shown in Fig. 1(c). Red emission due to the $^5D_0$-$^7F_2$ transitions (615 to 630 nm) of trivalent Eu ions is clearly observed. Figure 2 shows the excitation power density dependence of integrated PL intensities of the Eu emission. Both the integrated PL intensities were normalized at the weakest excitation condition (5.3 mW/cm^2). The emission saturation under

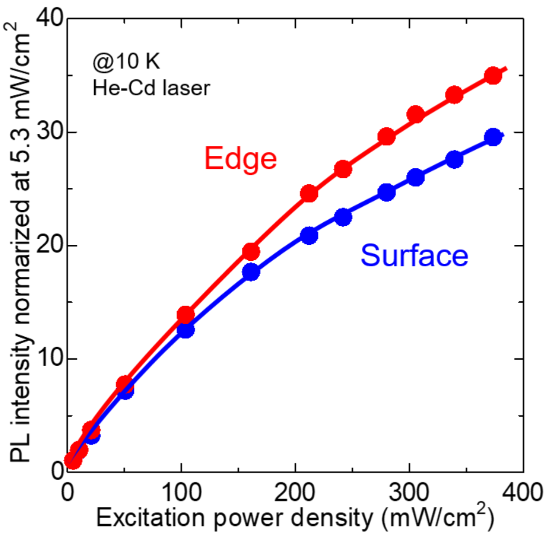

Fig.2 Excitation power density dependences of integrated PL intensities, normalized at 5.3 mW/cm^2.

strong excitation is significantly suppressed using the EDSE configuration. The edge-emission was enhanced by 1.2 times compared to the surface-emission at 374 mW/cm^2. To further elucidate an origin of the emission enhancement, we calculated the ratio of an edge-emission intensity (I_{edge}) under the EDSE configuration to a surface-emission intensity ($I_{surface}$) under the SDSE configuration as a PL enhancement (I_{edge} /$I_{surface}$). The PL enhancement at 374 mW/cm^2 is shown in Fig. 3 as a function of emission wavelength. In addition, we experimentally obtained a gain spectrum in a typical GaN:Eu film using the variable stripe length (VSL) method. It was noteworthy that the PL enhancement agrees well with the gain spectrum. Hence, we conclude that the PL enhancement under the EDSE configuration is attributed to amplified spontaneous emission (ASE). This is the first demonstration of ASE from Eu-ions doped into GaN.

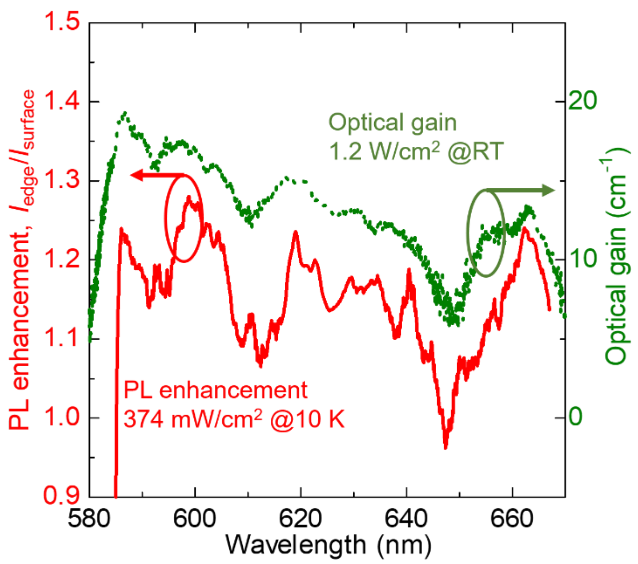

Fig. 3 PL enhancement at 374 mW/cm^2 and net gain as a function of emission wavelength.

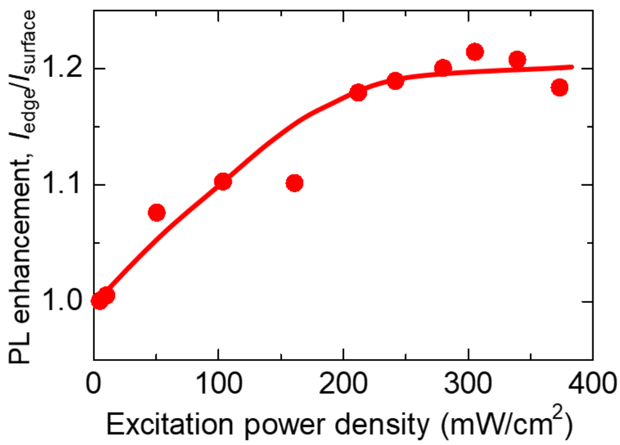

Fig. 4 PL enhancement of Eu emission as a function of excitation power density.

Figure 4 shows PL enhancement of the Eu emission as a function of excitation power density. The PL enhancement increases monotonically with excitation power density, whereas it saturates above 200 mW/cm^2. The result suggests that gain-saturation occurs for sufficiently strong excitations.

3. Conclusions

We investigated the Eu emission in GaN:Eu under the EDSE and SDSE configurations. The Eu emission was enhanced under the EDSE configuration, and we achieved a 1.2-fold enhancement above the excitation power density of 200 mW/cm^2. The PL enhancement depended on the emission wavelength, which is well coincident with a gain spectrum of GaN:Eu. This result indicates that the enhanced Eu emission is attributed to ASE. The enhanced efficiency due to the ASE shows a possibility to realize a highly efficient GaN:Eu-based superluminescent diode.

Acknowledgements

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References

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