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Title	Effect of Doping Process on Luminescence Capability in Rare Earth Doped III-Nitride Semiconductor

Luminescence from $4f$-inner shell transition of rare-earth-ion (REI) in semiconductor characterizes in the manner of atomic spectrum, and can be used in the manner of quantum dot (QD). Especially, thermal quenching of luminescence intensity is attenuated with increasing the band gap of host material. Therefore, REI-doped III-nitride semiconductors are promising candidates for the next-generation light source in the fields of optical computing even at extreme environments. However, not only REI-related luminescence mechanism in III-nitride semiconductors but also incorporation process of REIs is still not fully understood. This doctoral dissertation presents a study on the fundamental properties of REIs-doped III-nitride semiconductors. The goal of the present research is to achieve high luminescence efficiency and to control REIs-incorporation sites. Doping of REIs into III-nitride semiconductors has been conducted by means of both *ex situ* by ion implantation after growth and *in situ* by rf plasma-assisted molecular beam epitaxy (PAMBE) during growth.

For *ex situ* doping, europium (Eu) and terbium (Tb) ions were implanted into AlGaN epitaxial layers at room temperature to investigate ion-beam-induced damage and luminescence capability at various doses of 1×10^{12} - 2.8×10^{16} atoms/cm^2. Rutherford backscattering spectrometry/channeling reveals that ion-beam-induced damage level steeply increases and the damage cannot be fully suppressed even after rapid thermal annealing at 1100 °C, when the dose exceeds 5×10^{14} atoms/cm^2 (peak concentration of 0.16%). However, luminescence intensity related to intra-transition of Eu^{3+} and Tb^{3+} initially increased with increasing the dose and then saturated above the dose of 1×10^{14} Eu/cm^2 (peak concentration of 0.03%) and 1×10^{13} Tb/cm^2 (peak concentration of 0.003%), respectively. Furthermore, transient decay time of REI-related luminescence decreased faster and a fast decay component related to the formation of nonradiative REI-defect complexes became dominant, as the dose increases above the dose at which luminescence intensity begins to saturate. The results suggest that REI-related luminescence properties are much susceptible to defects and nonradiative defects, namely, REI-defect complexes, are formed under low-dose conditions even at a very low structural defect density.

In the case of *in situ* doping, no other processes are required after growth and the effects from such processes can be disregarded. The effects of Eu beam equivalent pressure ratio [$\mathrm{Eu_{BR}} = P_{\mathrm{Eu}}/(P_{\mathrm{Eu}}+P_{\mathrm{Ga}})$] and growth mode were investigated on the Eu-incorporation and luminescence capability of Eu-doped GaN (GaN:Eu) film. The Eu concentration of the GaN:Eu film highly depended on $\mathrm{Eu_{BR}}$ under V-rich condition. However, when the Eu concentration exceeded 1%, segregation of the Eu atoms was occurred leading to abrupt degradation of surface morphology and crystallinity owing to the lattice strain. Luminescence sites of Eu^{3+} depended on the Eu concentration. The luminescence efficiency began to decrease when the Eu concentration exceeded 0.4%, due to the concentration quenching. Growth mode of the GaN:Eu was transferred from three-dimensional (3D) to step-flow and/or two-dimensional (step-flow/2D) with increasing III/V ratios under a constant EuBR. When the GaN:Eu film was grown in 3D growth mode, the Eu concentrations were almost constant, although III/V ratios were varying. However, when the growth mode transferred from 3D to step-flow/2D, precipitates on the surface abruptly increased while the Eu concentration abruptly decreased, indicating the abrupt degradation of Eu-incorporation in the film. Luminescence sites of Eu^{3+} were sensitive to III/V ratio, and Eu atoms have different luminescence sites in both growth mode. Furthermore, luminescence efficiency abruptly increased when the growth mode transferred from 3D to step-flow/2D modes.

From these results, for *ex situ* doping, the ion-beam-induced damage cannot be fully suppressed, and luminescence properties are much susceptible to defects and nonradiative defects are formed under very low Eu and Tb concentration of 0.03 and 0.003% respectively, even at a very low structural defect density. Therefore, it is difficult to control the incorporation site of REI. On the other hand, for *in situ* doping, high luminescence efficiency can be obtained when the GaN:Eu film is grown in step-flow/2D growth mode and no concentration quenching occurred up to Eu concentration of 0.4%. Luminescence sites of Eu^{3+} depend on Eu concentration and growth mode. Luminescence efficiency correlated with luminescence site of REI and the peak β has to be promoted as a luminescence site for high luminescence efficiency. Author can say that the high luminescence efficiency can be obtained in step-flow/2D growth mode and that the REI site can be controlled.