Photoluminescence properties of Eu-doped GaN by ion implantation

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1. Introduction

GaN and related compounds are one of the attracted materials for optoelectronic devices in a UV-visible region, because its band-gap can be varied from 6.2eV for AlN to 1.9eV for InN[1]. Recent progress of crystal growth achieves bright blue/green light-emitting-diodes (LEDs)[2]. In order to realize a full-color display, red light emission from a nitride is indispensable, because it is difficult to fabricate a full-color monolithic LED array if conventional InGaP and/or AlGaAs red-LED is used. However, red-light-emission from the nitrides is hard to difficult due to the growth temperature mismatch between GaN cladding and InGaN active layers.

It is well known that rare earth impurities in a semiconductor act as an effective luminescence center, which has very narrow line width and very small thermal quenching [3]. In the viewpoint of the host material for rare earth impurity, nitrides seem to be fruitful material, because nitrides have wide band-gap and thus, it can allow a transition in visible region. Some researchers reported that GaN doped with Tm, Er, and both Eu and Pr indicate luminescence in blue[4], green[5], and red[6,7] regions, respectively.

In this study, we introduce Eu into GaN by using ion implantation technique and investigation the photoluminescence properties.

2. Experiments

2μm-thick undoped GaN epi-layers were used as the host crystal for Eu implantation. The GaN epi-layers were grown on sapphire (0001) substrate by using organometallic vapor phase epitaxy (OMVPE). Full width at half maximum of GaN (0002) X-ray rocking curve was about 250arcsec. Ion implantation of Eu was carried out at room temperature with the acceleration energy of 100-200keV, and the dose density was 10^{14} and 10^{15} cm^{-2}. According to a simulation using TRIM95, the projected length of Eu was in the range of 60-100nm and the calculated peak concentration was 10^{19}-10^{20}cm^{-3}, as summarized in Table I. After implantation, to remove the implantation damage, the samples were isochronal annealing in 10% NH_3 diluted with N_2 at atmospheric pressure. The annealing was carried out at 950, 1000, 1050, and 1100°C for 60min in each temperature. The crystalline quality of the implanted samples was evaluated by reflection high energy electron diffraction and the photoluminescence properties were measured in the temperature range of 80-280K with He-Cd laser as an excitation light. The excitation power density was about 2W/cm^2.

3. Results and discussion

Figure 1 shows the RHEED patterns of (a) as-grown GaN, (b) as implanted, and (c) after annealing at 1050°C for 60min. For the as implanted sample, RHEED indicates halo pattern, which means that the crystalline structure of implanted region is destroyed. On the other hand, after annealing, RHEED pattern becomes spotty, indicating that the implanted damage is removed. However, as-grown GaN is streak pattern , therefore the surface of annealed Eu-doped GaN seems to be roughed by thermal annealing process, but there is no difference in the surface morphology under the optical microscope observation between the as-grown and the annealed samples.

Figure 2 shows a typical PL spectrum of Eu-implanted sample compared with non-implanted GaN measured at room temperature. It is clearly seen that band-edge and yellow-band emissions of GaN disappear and new strong and narrow red emission peaks, which are assigned as 4f-4f core level transitions of Eu, appear around 600nm from the Eu implanted sample. Most strong peak observed at 621nm corresponds to the transition between $^5D_0$ and $^7F_2$ states in Eu^{3+}. The PL intensity increases with increasing the annealing temperature up to 1050°C and the intensity of most intense 621nm emission is much stronger than that of bang-edge emission obtained form as grown GaN layer. The results indicate that the implantation damage is recovered and implanted Eu

Table I. Parameters for Eu-implantation and the simulated results using TRIM95

Acceleration energy [keV]	Dose [cm^{-2}]	Projected range[nm]	Peak concentration[cm^{-3}]
100	10^{14}	～60 nm	4.3×10^{19}
	10^{15}		4.3×10^{20}
200	10^{14}	～100 nm	2.7×10^{19}
	10^{15}		2.7×10^{20}

impurity is activated effectively.

Figure 3 shows the intensity and peak position of 621nm emission as a function of the PL measurement temperature. The PL intensity slightly decreased with increasing the temperature, and the intensity at 280K is about 40% of 80K. Moreover, the peak position is not dependent on the temperature. The results indicate that Eu-implanted GaN layer is suitable for visible optoelectronic devices.

4. Conclusions

Photoluminescence properties of Eu implanted GaN epi-layer have investigated. The implantation damage could be removed by thermal annealing in N_2 with NH_3 partial pressure of 0.1atm at 1050°C Strong and sharp emission peaks related to Eu^{3+} have successfully observed. The PL intensity and peak position was not dependent on the temperature.

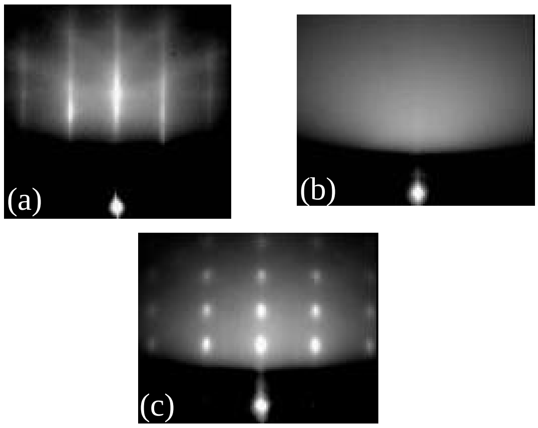

Fig 1. RHEED pattern of (a)as-grown GaN, (b) Eu-doped GaN after ion implantation with Eu dose of $10^{15}cm^{-2}$, and (c)after ion implantation and annealing at 1050℃ for 60min.

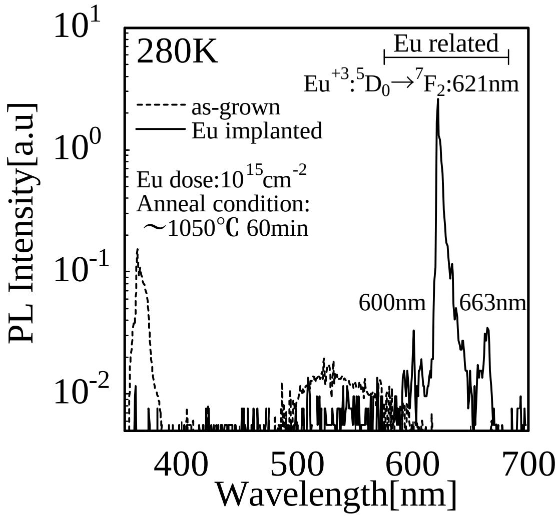

Fig 2. Photoluminescence spectrum of Eu-doped GaN(solid line) and as-grown GaN(dotted line) at 280K

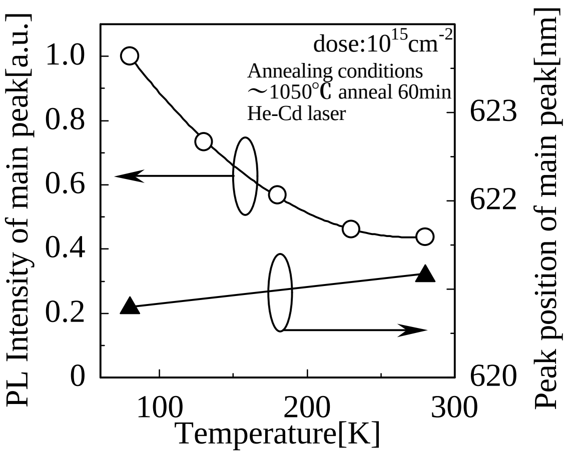

Fig 3. PL intensity (open circles) and peak position (solid triangles) of main emission as a function of the PL measurement temperature

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