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IMPACT OF Mg-ION IMPLANTATION WITH VARIOUS FLUENCE RANGES ON OPTICAL PROPERTIES OF N-TYPE GaN

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(Abstract)

Optical characteristics of Mg-ion implanted GaN layers with various fluence ranges were evaluated. Mg ion implantation was performed twice at energies of 30 and 60 keV on n-GaN layers. The first implantation at 30 keV was performed with four different fluence ranges of 1.0×10^{14}, 5.0×10^{14}, 1.0×10^{15} and 5.0×10^{15} cm^{-2}. The second implantation at an energy of 60 keV was performed with a fluence of 6.5×10^{13} cm^{-2}. After implantation, samples were annealed at 1250 ºC for 1 min under N_2 atmosphere. Photoluminescence (PL) spectrum of the GaN layer with the Mg ion implantation at the fluence range of 1.0×10^{14} cm^{-2} at 30 keV was similar to the one of Mg-doped p-GaN layers grown by MOVPE (Metal-Organic Vapor Phase Epitaxy) on free-standing GaN substrates and those at the fluence ranges over 1.0×10^{15} cm^{-2} were largely degraded.

KEY WORD: GaN, Mg ion implantation, free-standing GaN substrate

I. Introduction

Gallium Nitride (GaN) is suited for high power, high frequency, and high temperature devices, because GaN has a wide band gap, a high breakdown electric field, a high saturation-drift velocity for electrons, and high thermal conductivity [1]. A selective area doping technology, which is frequently used in processing silicon (Si) and silicon carbide (SiC) devices, is also required for making high performance GaN devices. Ion implantation is usually used as a method of the selective area doping but formation of the p-type conductive layer by the ion implantation has been difficult for GaN. Usually, GaN epitaxial layers are grown on the sapphire or SiC substrate. But those GaN epitaxial layers include large misfit-dislocation density over 10^8 cm^{-2}. We reported p-type conversion of Mg-ion implanted n^--GaN layers and the formation of device-quality p-n junction as a result [2], which was realized by using epitaxial layers grown on a high quality free-standing GaN substrate fabricated by void-assisted separation (VAS) method [3-4]; however the irradiation fluence and annealing temperature were not varied [5]. In this paper, we report the impact of Mg ion implantation with various fluence ranges on n-type GaN layers.

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II. Experiment

A 2.5-μm thick lightly Si-doped GaN layer with electron concentrations about 2×10^{16} cm^{-3} was grown by metal-organic vapor phase epitaxy (MOVPE) on the free-standing GaN substrate with low dislocation densities in 10^6 cm^{-2} ranges. A 30-nm sputtered SiN layer was deposited on the top surface of the lightly Si-doped GaN layer for surface passivation. Mg ion implantations were performed twice at energies of 30 and 60 keV on lightly Si-doped n-GaN layers through the SiN layer. The first implantation at 30 keV was performed at four different fluence ranges of 1.0×10^{14}, 5.0×10^{14}, 1.0×10^{15} and 5.0×10^{15} cm^{-2}. The second implantation at an energy of 60 keV was performed at a fluence of 6.5×10^{13} cm^{-2} for all the samples. The conditions are summarized in Table 1 and Mg concentration profiles from SRIM simulation are shown in Fig.1. Figure 2 shows the structure of Mg implanted GaN on n-type GaN grown by MOVPE on free-standing GaN substrate. After implantation, 50-nm thick sputtered SiN film was deposited at the top and the bottom surfaces of the substrate as passivation layers. All of the samples were annealed on a carbon susceptor at 1250 ºC for 1 min in N_2 ambient. PL measurements were performed at 77 K with excitation by a He-Cd laser and PL mapping images were taken at room temperature.

III. Results and discussion

The PL spectra at 77 K indicated three main peaks originated from the Mg related donor-acceptor-pair (DAP) [6-8] recombination, acceptor-bound exciton (ABE) [8], and defects related yellow luminescence (YL), as shown in Fig.3. The first sample with 1.0×10^{14} cm^{-2} fluence clearly showed DAP and ABE emissions, which were the distinct nature of p-type GaN and were often seen with MOVPE grown p-type GaN. In addition, the intensity of the YL emission was the lowest among all the samples. This spectrum suggests that high crystallinity is maintained after the implantation and the annealing for the homo-epitaxial GaN layers on the free-standing GaN substrates. Other samples showed much lower DAP and ABE emissions. Figure 4 shows room temperature PL spectrum. At room temperatures, ABE and DAP emissions were not distinguishable. Furthermore, a single near-band NB emission with shoulder of ultra-violet luminescence (UVL) at about 3.26 eV as Mg related emission [9] was observed. The intensity of the shoulder was used for PL mapping image. Figure 5 shows room temperature PL mapping image of the first sample. Figure 6 shows its spectra. The measured area was 300×300 cm^2. The mapping revealed inhomogeneity of the PL intensity, however, high UVL emissions were observed in the most areas. The inhomogeneity was likely to be caused by partial sight decomposition of the GaN surface and/or segregation of the implanted Mg. The PL mapping images of the other samples showed very bright spotting areas as shown in Fig.7. The local bright areas had very high NB emissions as observed in n-type GaN; hence, their shoulder wavelength for the mapping became high. These spots corresponded to lots of defects and pits when the surface was observed under the optical microscope. These areas were thought to be n-type GaN with donors related to nitrogen vacancies formed by strong decomposition of GaN around threading dislocations. Therefore, these samples consist of non-uniform p-type crystalline areas including localized n-type conduction spots.

Estimated Mg concentration at the surface of the first sample was 3×10^{19} cm^{-3}; hence, the recovery of crystalline quality became absolutely difficult for the samples with Mg beyond this concentration because they were heavily damaged by implantation. The value of 3×10^{19} cm^{-3} coincided with the Mg concentration which gives the highest hole concentration in Mg-doped p-GaN layers grown by MOVPE. It has been reported that Mg doping beyond this critical concentration in MOVPE generated crystalline defects such as inversion domains and reduced the hole concentration [2)]. The similar limitation could be thought for Mg-ion implanted GaN.

IV. Conclusion

High concentration doping of Mg to GaN has been experimented by ion implantation. Optical characteristics of the Mg implanted GaN at fluence range over 1×10^{15} cm^{-2} degraded significantly, which would be an indication that the effective doping limit of Mg by ion implantation might be consistent with that by MOVPE. Mg ion activation was found to be inhomogeneous which should be improved by the annealing process.

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Table. 1. Conditions of Mg implantation.

Fluence ranges [/cm^2]		Implantation energy [keV] 30	Implantation energy [keV] 60
	Sample 1	1.0×10^{14}	6.5×10^{13}
	Sample 2	1.5×10^{14}	
	Sample 3	1.0×10^{15}	
	Sample 4	5.0×10^{15}	

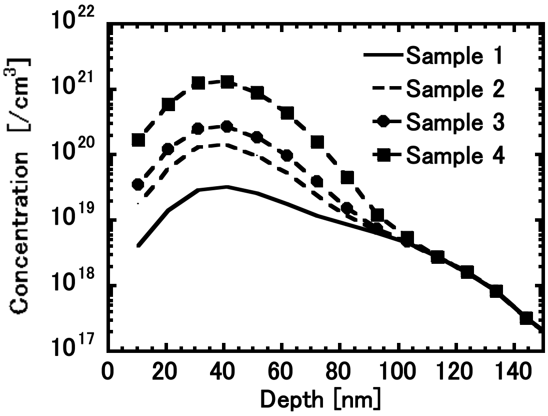

Fig. 1. Mg concentration profile by SRIM simulation.

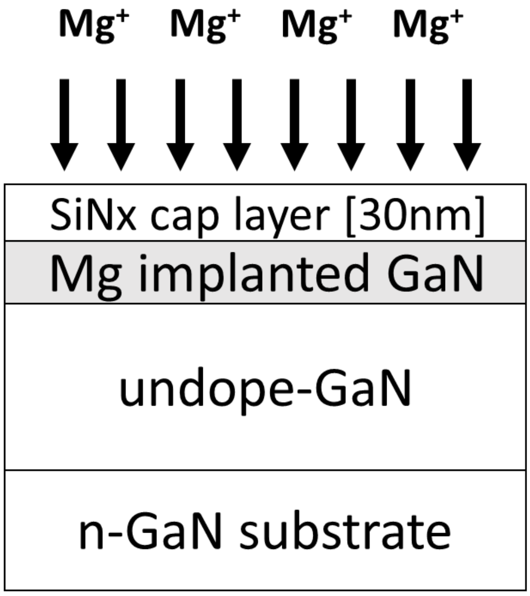

Fig. 2. The structure of Mg implanted GaN.

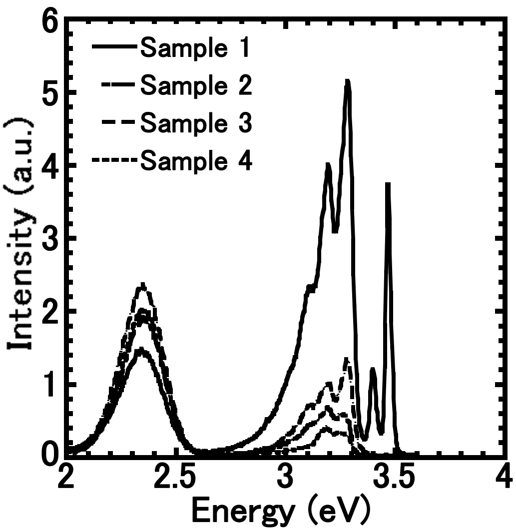

Fig. 3. PL spectrum of Mg ion implanted n^--GaN layer at 77 K.

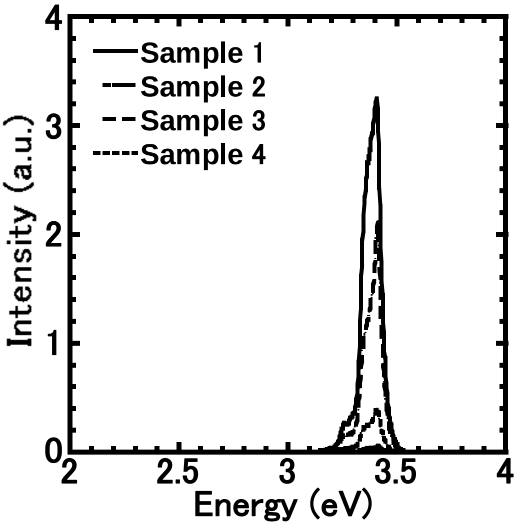

Fig. 4. PL spectrum of Mg ion implanted n^{-}-GaN layer at room temperature.

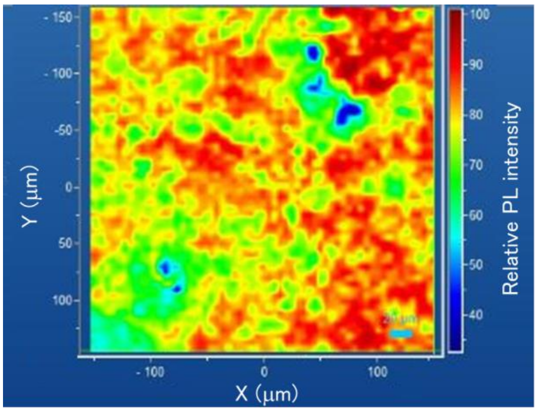

Fig. 5. PL mapping image of Mg implanted GaN layer at room temperature (sample 1).

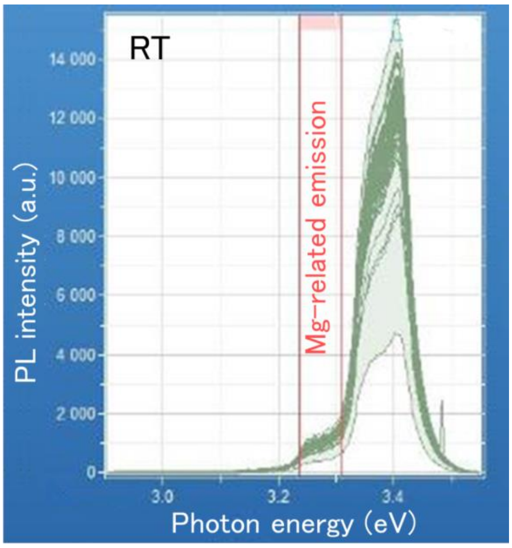

Fig. 6. PL spectrum in mapped region (sample 1).

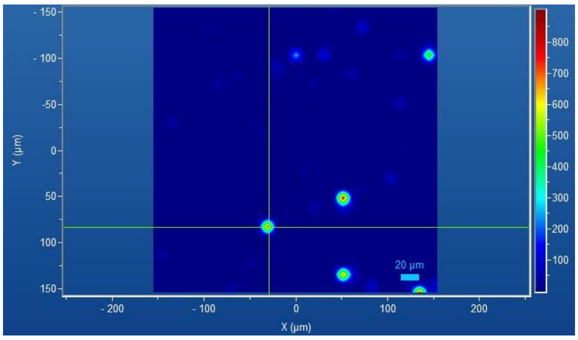

Fig. 7. PL mapping image of Mg implanted GaN layer at room temperature (sample 3).