

Mg이 도핑된 GaN에서의 acceptor가 관련된 재결합 중심들의 공간적 분포

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Spatial distribution of acceptor-related recombination centers in Mg-doped GaN

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ABSTRACT

Inhomogeneous distribution of Mg-related recombination centers were investigated by cathodoluminescence (CL) and scanning electron microscopy (SEM). Spatially resolved monochromatic CL imaging and spectra measurement revealed that two distinct types of acceptor-related recombination centers were identified and preferentially distributed in different regions. We also found that 3.2eV emission was not fully quenched out even in case of highly Mg doped GaN.

1. Introduction

In spite of high performance of recently commercialized blue LEDs and LDs[1], many of detailed characteristics of III-nitrides have not been fully understood yet. In particular, high activation energy of Mg-related acceptors keeps a low resistive p-GaN layer from being routinely grown. Therefore, the optical and electrical properties of p-GaN have been reported to vary significantly depending on the samples under investigation. Regarding room temperature photoluminescence of Mg-doped GaN, it has been reported that there are two dominant transitions observed near at 2.8eV and 3.2eV.[2~10] For highly Mg doped GaN layers, quenching of transitions at 3.2eV was reported to be initiated by several reasons such as Mg-H complex, increased deep donor levels involved in self-compensation, disordering, defect complex and Mg interstitials.[2~5] However, it has not yet been clarified which is responsible. In case of device application which needs growth of p-GaN preferentially or single p-GaN epitaxial layer, it is important to know about the relations with Mg related optical transition characteristics and crystalline defects, degree of strain with layer thickness. It is expected that two dominant transition levels, 2.8eV and 3.2eV, are closely related with crystalline defects and degree of strain.

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In this work, we aimed at finding the cause of spatial variation of Mg-related acceptor activations in relation with defects employing cathodoluminescence (CL). We also investigated the extent of quenching of 3.2eV transition depending on doping concentrations and spatial positions.

2. Experimental

The epitaxial layers of GaN:Mg of about 1 μm were grown on (0001) sapphire substrate by metal-organic chemical vapor deposition (MOCVD). The substrate was preheated for 10minutes at 1010°C and cooled for deposition of GaN nucleation layer. The GaN:Mg layers were grown at 1020°C, while maintaining V/III ratio at 2000. The gallium, nitrogen, and magnesium sources were trimethylgallium (TMGa), ammonia (NH₃), and biscyclopentadienylmagnesium (Cp₂Mg), respectively. Following the growth, the samples were annealed at 1000°C for 20 seconds in nitrogen atmosphere. CL at room temperature and SEM were used to investigate luminescence characteristics near the defect area and different positions in cross section of GaN epitaxial layer. We measured spectral characteristics of various samples, mirror like surface, which have different Mg concentrations. We also investigated CL spectra dependence on various sample depth to exclude the possibility of absorption of high energy side emission at surface region.

3. Results and Discussion

As in the case of PL measurement of Mg-doped GaN samples, the peaks of CL are typically observed at approximately 2.8eV and 3.2eV with a little variation depending on the excitation power. In figure 1, secondary electron image and monochromatic CL images taken at 2.8eV and 3.2eV are shown for the sample of which lateral growth is not completed.

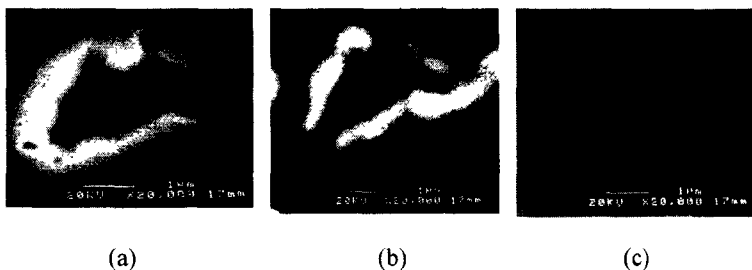


Fig. 1 Images for defect area of GaN:Mg, SEM image(a), CL image at 3.2eV(b) and CL image at 2.8eV(c)

Luminescence at 3.2eV is observed around the crystalline defects which regime is consisted of incomplete lateral merging. In contrast, 2.8eV emission is distributed uniformly except the crystalline defect area. In CL measurements, e-A transition is dominant over DAP because of high excitation intensity producing a large amount of e-h pairs.[3] Thus, more

intense spectrum from 3.2eV is indirect evidence that it is due to e-A transition.

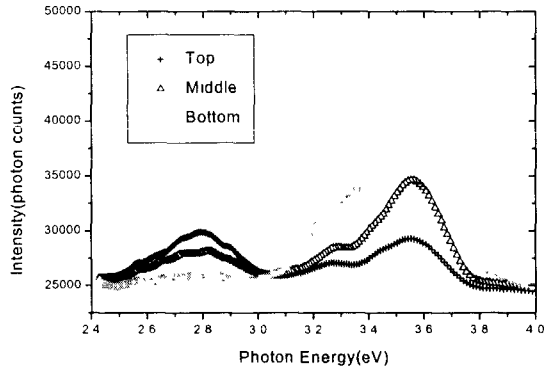


Fig. 2 CL spectra for cross sectional measurement of GaN:Mg

Cross-sectional CL spectra were also measured at three different positions in thickness. As shown in figure 2, the 2.8eV emission increases from the interface between GaN and sapphire to the top surface but the 3.2eV emission shows opposite tendency. The emission peak around 3.6eV is presumably due to sapphire substrate. Even we use a point scan method for cross sectional measurements there is finite volume of excitation in the sample and the excitation volume of sapphire is larger than the GaN epitaxial layer's one. We could confirm the 3.6eV emission was due to sapphire substrate from monochromatic CL image at 3.6eV.

In cross-sectional CL image of GaN:Mg sample, 3.2eV emission is mainly observed around the defect, especially near the merging area as shown in figure 3. We did not show CL image of 2.8eV emission band because its intensity was not strong enough to discern the spatial variation, even we could observed the 2.8eV emission was distributed uniformly except near around defect region on monitor screen of CL system.

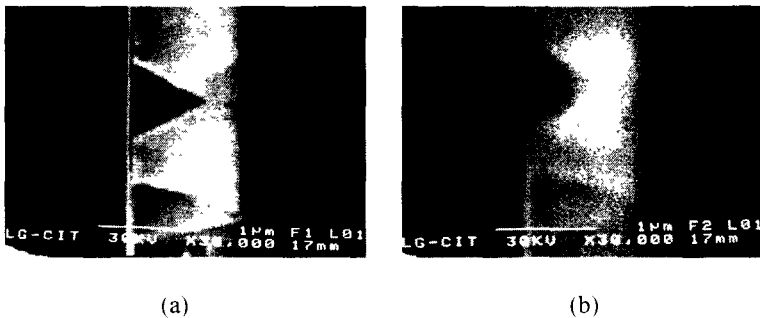


Fig. 3. Images for the cross section of GaN:Mg, SEM image(a), CL image at 3.2 eV(b)

We also measured emission characteristics of GaN:Mg layers which have different Mg concentrations. The Mg concentration was measured by secondary ion mass spectroscopy (SIMS) and all the measured samples have mirror like surface. Figure 4 shows RT CL spectra of Mg-doped GaN as a function of doping concentration. When the Mg concentration is $1.5 \times 10^{19} \text{cm}^{-3}$, emission peak is observed at about 3.2eV. When Mg concentration is $3.2 \times 10^{19} \text{cm}^{-3}$, a shallow acceptor level at about 3.2eV and a deep acceptor level at about 2.8eV are observed. In the very highly doped samples with Mg at a level of $5 \times 10^{19} \text{cm}^{-3}$, the CL spectra are dominated by transitions centered at about 2.8eV.

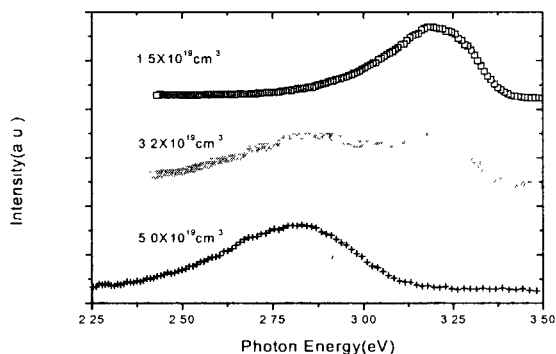


Fig. 4. CL spectra dependence on Mg concentrations in GaN:Mg

The red shift of peak position with the increase of acceleration voltage, therefore, can attributed to either strain effect or/and 2.7eV emission band. More accurate experiment should be performed to clarify which is the origin of red shift. Usually in case of highly doped GaN:Mg which has good crystal quality, the only emission peak is centered at around 2.8eV. It is presumed that this 2.8eV emission peak is due to the transitions of donor and acceptor pairs, conduction band to deep acceptor level or a Mg complex.[2~6,8,9] The emission peak positions is varied by excitation intensity. This variation of peak position has been attributed to change of the quasi-Fermi level for holes[4,8], saturation of PL from distant donor acceptor pair due to their longer life time[2,5] or fluctuation of potential distribution.[4,11]

Figure 5 (a) shows RT CL spectra centered at about 2.8eV emission with a series of beam current ranging from 0.6nA(23W/cm²) to 60nA(2300W/cm²) while maintaining a constant beam accelerating voltage of 20KV. The enhancement of CL intensity and the blue-shifted peak position of Mg-related emission are observed with the increase of beam current. The peak position was varied from 2.76eV(0.6nA) to 2.85eV(60nA) and it showed start to saturate from 10nA(383W/cm²). The linear dependence of CL intensity on beam current could be attributed to the increase of the excitation power, which is proportional to the excess carrier concentration. From this blue shift of peak position, we can attribute 2.8eV emission has its origin in donor acceptor pair(DAP) transition. Figure 5 (b) shows CL spectra centered at about 2.8eV emission taken with a series of beam accelerating voltage

while maintaining a constant beam current of 2nA. Our result exhibits that the peak position of the 2.8eV emission red-shifts from 2.82eV(10KV) to 2.75eV(30KV) with increasing accelerating voltage. For the reason of red shift of peak positions we can think the rise of sample temperature by local focusing of electron beam however in case of CL measurement of GaN:Si, we could not observed red shift of peak position. From the result of CL measurement of GaN:Si, we can exclude the effect of temperature for the reason of red shift. Similar CL results were reported by Trager-Cowan et al., who attributed the red shift to variation of strain with depth.[12] So we can think that the roles of Si and Mg as a dopant in GaN layers have different characteristics with the degree of strain. From considering the result of CL spectra for cross section (Figure 2), we can think that the 2.8eV emission is enhanced by the decrease of strain. However, as will be mentioned later, we found there was another emission band at 2.7eV near interface between sapphire and GaN:Mg epitaxial layer. The red shift of peak position with the increase of acceleration voltage, therefore, can attributed to either strain effect or/and 2.7eV emission band. More accurate experiment should be performed to clarify which is the origin of red shift.

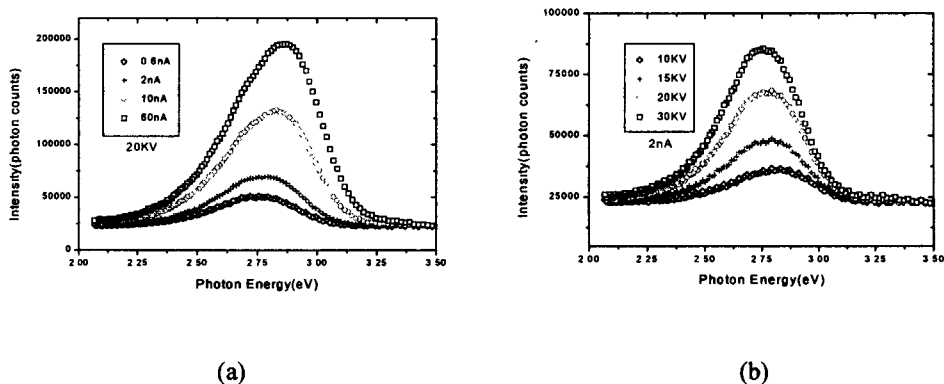


Fig. 5. CL spectra for various excitation conditions for GaN:Mg, dependence on variation of beam current (a), dependence on variation of acceleration voltage (b)

Depth profile of CL was also measured for a heavily doped sample which emits luminescence at 2.8eV. 3.2eV emission was not observed at the top surface, but began to appear apparently as the thickness of GaN was thinned by dry etching as shown in Figure 6. So we can conjecture that even in case of highly Mg doped GaN the emission peak around 3.2eV is not completely quenched out but exist near the interface between the sapphire substrate and GaN epitaxial layer. As mentioned before this remained 3.2eV emission peak is mainly related to the crystalline defects which formed at the stage of initial 2-dimensional lateral growth. And this area has relatively larger strain than top region of epitaxial GaN layer. And also there is another emission band at 2.7eV which origin is not exactly known. we attributed the 2.7eV emission to the one of many Mg

complexes,[13,14] even though more accurate experiments should be performed to identify the origin of this 2.7eV emission exactly.

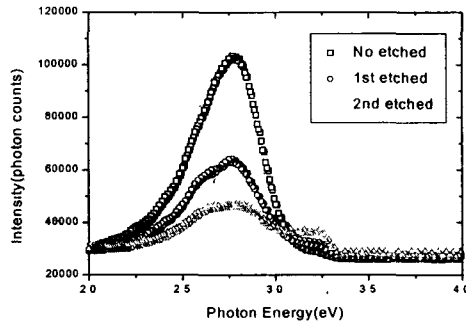


Fig. 6. CL spectra for dry etched GaN:Mg

4. Conclusions

From the cross sectional CL spectra measurement, the 2.8eV emission is distributed in the top region and 3.2eV emission is in the region of interface between sapphire and GaN epitaxial layer. From the result that the 2.8eV emission intensity is stronger at top regime than middle one even though the excitation volume at middle regime is larger than top one, we can conjecture more Mg atoms are activated with the level of 2.8eV band near the surface regime of GaN:Mg and this trend may be due to degree of strain. We can also conclude that the 3.2eV emission band seems to originate from the region where many crystalline defects which can be formed at the initial stage of growth near around merging area from the monochromatic CL image. In case of highly Mg doped GaN layers, dominant emission peak is positioned at near 2.8eV and peak position was varied to high energy side with increasing beam current and to low energy side with increasing acceleration voltage. From the result of CL spectra for dry etched sample, we could know that the 3.2eV emission band is not fully quenched even in case of highly compensated GaN:Mg.

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