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1. Introduction

The III-V nitride wide bandgap semiconductors have become the material of choice for the fabrication of light-emitting diodes for the green, blue, and violet regions of the visible spectrum.¹⁾ Usually, as-grown Mg-doped p-type GaN films grown by MOCVD method show resistivities greater than $10^4 \Omega$.cm because of the formation of Mg-H complexes during growth using NH3 as a nitrogen source.²⁻⁵⁾ Therefore LEEBI treatment or thermal annealing have been performed for these as-grown p-type GaN films to obtain low-resistivity p-type GaN films.⁶⁻⁹⁾ However the p-type activation mechanism is still not well understood.

In this study, the correlation between the activation of Mg-acceptors and annealing condition was investigated on Mg-doped p-GaN layer. The acceptor activation dependence on annealing temperature was investigated in samples exhibiting different x-ray rocking curve widths and defects structure.

2. Experiments and Results

P-type GaN films were grown by the metalorganic chemical vapour deposition (MOCVD) method. Sapphire with (0001) orientation (C-face) was used as a substrate. Trimethylgallium (TMG), ammonia (NH3) and bis-cyclopentadienyl magnesium (Cp2Mg) were used as Ga, N and Mg source, respectively. First, the GaN buffer layer was grown at 510°C and the thickness of this layer was approximately 250 Å. Then, the substrate temperature was incresed to 1025°C to grow p-GaN layer. The thickness of p-GaN was 1.5 μ m. After growth, rapid thermal annealing was performed at different temperature from 600 to 900°C under N₂ flow ambient. The annealing time was 30 min and the N₂ flow rate was 2 LPM during annealing. After thermal annealing, Hall-effect measurement were carried out at room temperature by the van der pauw method. To evaluate the crystal quality, we measured the symmetric (002) and asymmetric (102) plane x-ray rocking curves simultaneously. Since the defects structure in growth region depends on measurement direction. The dislocations density and defects structure in hexagonal p-GaN have also been investigated by transmission electron microscopy (TEM).

Figure 1 and 2 show the Hall measurement results of p-type GaN sample annealed at different temperature. From this figure, two kinds of observation can be made. The first one, for the same sample, hole concentration increase with temperature till to a optimal temperature. then decrease with temperature. Secondly, for each sample, hole concentration in sample 85 increases as the annealing temperature increases from 700 to 800°C and have maximum hole concentration at 800°C and becomes to decrease with temperature. However, the hole concentration of sample 103 have maximum value at 700°C and becomes to decrease as the annealing temperature increases. That is to say, the optimal annealing condition is different for each sample and we assume that the difference in optimal annealing condition caused by the difference in defects structure in p-GaN laver. Since the above four sample were grown at some different condition.

It has been reported that to activate Mgactivation in p-GaN, energy is needed to break Mg-H complex bond. Energy is also needed to make H⁺ ions migration to the surface and remove the H⁺ ion, or neutralized at an extended defect (dislocation).¹⁰⁾ If this does not happen, during returning process to the room temperature after annealing, the Mg-H complex will form again. Higher temperature makes above process more easy to happen, that is to say, hole concentration increase with temperature. But if temperature becomes too high, after all H⁺ ion were removed, nitrogen vacancies which act as an donors will generate and compensate Mg again. So, after a optimal temperature, hole concentration will decrease with temperature.

3. Summary

The optimal annealing condition for the ptype activation was investigated using Mgdoped samples exhibiting different defects structure. In the same sample, hole concentration was found to increase as the annealing temperature increased and reveal a maximum value. But if temperature becomes too high, after all H⁺ ion were removed, nitrogen vacancies will generate and compensate Mg again. So after an optimal temperature, hole concentration will decrease with temperature. In the different samples, the optimal condition for ptype activation have changed as the defects structure in p-GaN was different.

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Fig. 1 Correlation between hole concentration and annealing temperature



Fig. 2 Correlation between mobility and annealing temperature