Selectively Enhanced Mg Incorporation into AlGaN Barrier Layer of Strained Layer Superlattice

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Reduction of electrical resistively of p-type nitride is one of the most important issues in nitride device application. AlGaN/GaN strained layer superlattice (SLS) has been found to enhance the hole generation due to strain induced polarization effect and spontaneous polarization [1, 2], and it was successfully applied to the p-type cladding layer of InGaN-based laser diode [3]. Magnesium incorporation phenomenon under practical growth condition is interesting topics. Here, we report that Mg is selectively incorporated to AlGaN barrier layer of p-type SLS with the period precision as small as 5 nm.

First, we investigated hole generation in GaN and AlGaN. To perform crack-free sample preparation, we used AlN wetting layer for the Mg-doped GaN sample, and AlGaN buffer layer directly grown on an on-axis SiC substrate for the Mg-doped AlGaN sample. Figure 1 shows the result of Hall measurement. The highest mobility of p-GaN was 18 cm^2/Vs with the hole concentration of 1×10^{17} cm^{-3}. The hole concentration increases as the Cp_2Mg supply increases while the mobility still holds as high as 6 cm^2/Vs. When introducing a SLS structure consisting of 2.5-nm-thick GaN and 2.5-nm-thick $Al_{0.16}Ga_{0.84}N$, hole generation is highly enhanced to achieve 2.5×10^{18} cm^{-3}, while hole mobility was 1 cm^2/Vs.

By using the same p-type SLS structure, we fabricated InGaN-MQW-LD as shown in Fig. 2. The ridge waveguide was formed by dry-etching using electron cyclotron resonance plasma of Cl_2. The laser cavity was 8 μm in the width and 550 μm in the length with a couple of cleaved facet mirrors. Figure 3 shows the I-L curve of the device with the driving pulse width of 300 nsec. The threshold current density obtained was 11.3 kA/cm^2, the maximum output power exceeded 10 mW, and the maximum differential gain was expected to be higher than 0.15 W/A.

To metallurgically characterize the p-type SLS structure in this LD sample, we performed secondary ion mass spectrum (SIMS) measurement. Figure 4 shows the SIMS profiles of Al and Mg in the p-type SLS. The top-most of the sample structure was a p-type GaN contact layer. Beneath the GaN contact layer, modulation of Al ion yield was found with the 5-nm-period correspoding to the SLS structure. Flat morphology was important because this Al yield modulation was observed only when the surface morphology was nicely flat.

The striking is that the Mg ion yield modulation is much more enhanced even comparing with that of Al, although the modulation period coincides with the Al yield. As the origin of such behavior, we presently argues the increase of the atomic step density. Comparing with Al, Ga has poor adsorption to the nitride surface[4]. Superior adsorption of Al to Ga is well known in the conventional III-V semiconductor surface[5], such as arsenides. We also see bunched step morphology on GaN more frequently than on AlGaN. This is appropriately explained that strong adsorption of Al to nitride surface induces two dimensional nucleation, resulting in the increment of surface step-density. In other words, Mg species can be incorporated only when they arrive at these chemically active sites, i.e. atomic steps on the surface. To confirm the origin of Mg incorporation enhancement is practically important to design and to grow device structure, although further investigation will be necessary.

In summary, we investigated p-type doping and InGaN-MQW-LD fabrication, and found the enhanced Mg incorporation selectively to the AlGaN layer in the p-type SLS structure.

References

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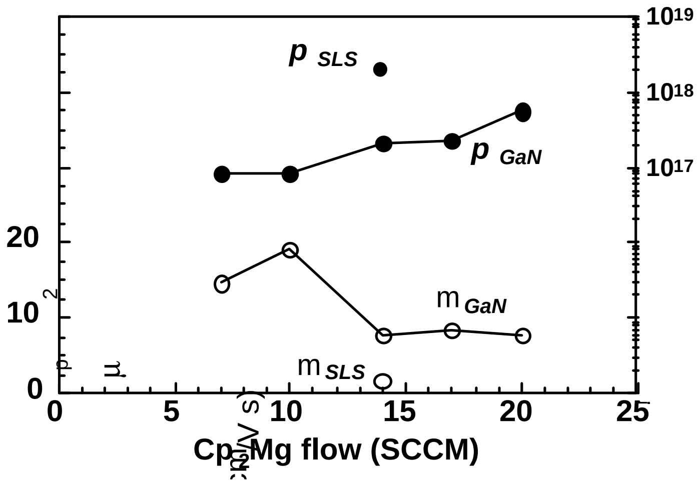

Fig. 1 Hall measurement result of Mg-doped GaN and SLS

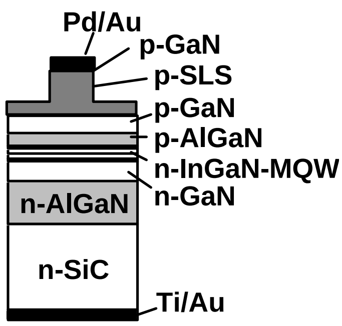

Fig. 2 Structure of InGaN-MQW-LD

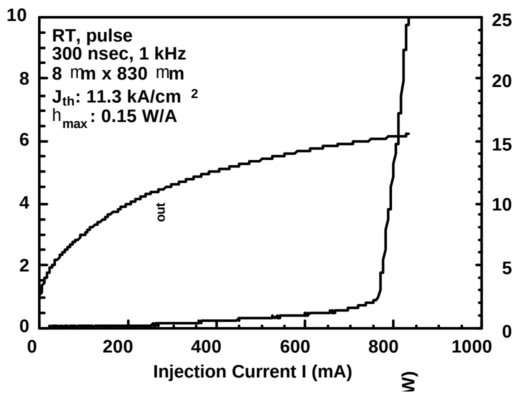

Fig. 3 Pulse operation characteristics of InGaN-MQW-LD

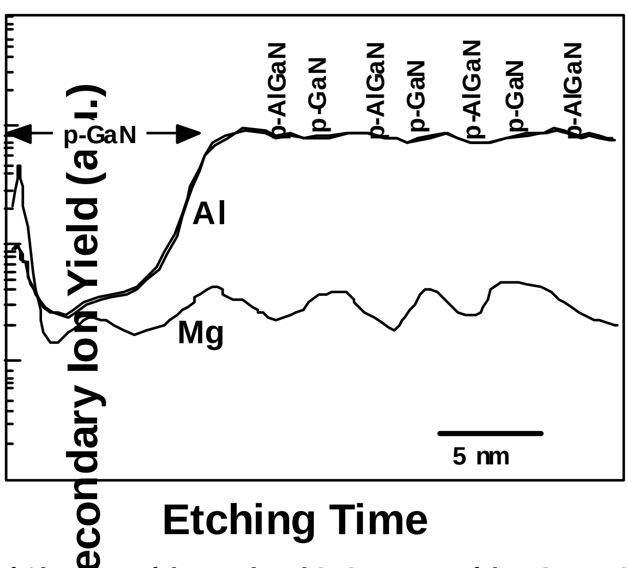

Fig. 4 SIMS profiles of Al and Mg of the Mg-doped SLS structure of the nGaN-MQW-LD sample.