RTA of MOVPE-grown Mg-doped In$_x$Ga$_{1-x}$N (x~0.3) for Mg activation

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Introduction: Achieving highly conductive p-type GaN and related alloys is a key issue in the nitride semiconductor device fabrication. Nakamura et al. reported that the annealing temperature ($T_{\text{act}}$) should be higher than 700°C for achieving low resistivity of Mg-doped GaN films [1]. For InGaN, there is a possibility that the annealing at high $T_{\text{act}}$ can bring about phase separation [2] of grown films. Recently, we have reported that the phase separation in In$_x$Ga$_{1-x}$N (x~0.3) is suppressed by reducing growth temperature to around 570°C [3]. In this paper, we report the rapid thermal annealing (RTA) of Mg-doped In$_x$Ga$_{1-x}$N (x~0.36) grown by MOVPE. P-type samples are successfully obtained by using RTA at around 850°C.

Experiments: The growth of InGaN alloys was conducted using a MOVPE system. TEG, TMI, and NH$_3$ were used for Ga, In, and N sources, respectively. Cp$_2$Mg was used for Mg source. Growth temperature and pressure were fixed at 570°C and 150 Torr, respectively. Two types of substrates, AlN/Si and α-Al$_2$O$_3$, were employed. The growth rate of InGaN was about 0.5 μm/h with In content of 0.36. Finally, samples were annealed in N$_2$ using RTA. For comparison, the furnace annealing was also employed.

Results and discussion: Figure 1 shows the cross-sectional SEM images for as-grown and furnace-annealed (at 650°C for 20 min) samples. The annealed sample has a porous region in the film, showing the decomposition (phase separation) of the InGaN film [3]. Figure 2 shows the cross-sectional SEM images for as-grown and RTA (at 850°C for 10 sec) samples. One can see that no porous region exists in the annealed sample. Thus, it is confirmed that the decomposition of InGaN can be suppressed by reducing annealing time, even if $T_{\text{act}}$ is much higher than growth temperature.

Figure 3 shows the $T_{\text{act}}$ dependence of carrier concentration and Hall mobility for RTA In$_x$Ga$_{1-x}$N (x~0.36) grown at 570°C. As shown in this figure, the carrier concentration is increased and Hall mobility is decreased with increasing $T_{\text{act}}$. The p-type conduction was confirmed by Hall and thermo-voltaic measurements for samples annealed at 850°C. For samples annealed at 700-800°C, p-type conduction was confirmed only by thermo-voltaic measurements. For the rest of samples, conduction type could not be identified. These results indicate that Mg-acceptor activation annealing should be done above 700°C.

Conclusion: This paper reports the rapid thermal annealing (RTA) of Mg-doped In$_x$Ga$_{1-x}$N (x~0.36) grown by MOVPE. P-type samples are successfully obtained by using RTA at around 850°C.

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