Rapid thermal annealing of Si-doped GaN film grown by MOCVD

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The thermal annealing by RTA has been frequently used not only to improve the crystal quality and other physical properties but also to activate the Mg in p-type GaN film. So far, however, only a few reports mentioned the application of RTA in n-type Si-doped GaN film [1]. In this work, we investigated the effects of RTA on the characteristics of n-type Si-doped GaN film grown by MOCVD.

Si-doped GaN/sapphire films were grown by vertical-type high-speed rotating disk MOCVD. Silane (SiH_4) was used as n-type dopant source. The film consisted of the following layers: a thin (300 Å) GaN buffer layer grown at 500 °C, followed by a 2 ㎛-thick n-type GaN epilayer grown at 1030 °C with 25 SCCM SiH_4. The samples, then, were annealed under the flowing N_2 gas in RTA system for 5 min at 750, 950, and 1050 °C. After each annealing step, the samples were characterized by Hall measurement, XRD, AFM, and PL.

Figure 1(a) shows that the electron mobility is increased with increasing annealing temperature up to 950 °C while the electron concentration is decreased. The decrease in the electron concentration with increasing the annealing temperature may indicate that the Ga vacancies (V_{Ga}^{-3}) are formed in n-type Si-doped GaN film by RTA and can act as a compensation center (or deep acceptor). The triply charged Ga vacancy has a lower formation energy, compared to a neutral Ga vacancy, and the formation energy of V_{Ga}^{-3} decreases rapidly with increasing Fermi energy [2,3]. Therefore, the decrease of electron concentration with annealing up to 950 °C is thought to be caused by thermal formation of Ga vacancies during RTA process.

As shown in Fig. 1(a), the electron mobility was much increased with increasing the annealing temperature up to 950 °C. The dependence of mobility on the electron concentration was also examined and the results are compared to the reported data [4, 5] as shown in Fig. 1(b). The data marked by squares were obtained by varying the amount of SiH_4 gas from 5 SCCM to 25 SCCM. The triangle data show that with increasing the annealing temperature up to 950 °C the electron concentration is slowly reduced but the mobility is rapidly increased. The remarkable increase in electron mobility cannot be explained merely by decrease in electron concentration. Figure 2 shows the symmetric (0002) and asymmetric ($10\bar{1}2$) θ −rocking curve widths as a function of annealing temperature. From these data, it can be concluded that with annealing temperature up to 950 °C the mobility is limited by μ_{disl} component due to scattering at charged dislocation lines and the increase in the mobility is caused by the decrease of the dislocation.

Figure 1(a) also shows that at the annealing temperature between 950 °C to 1050 °C, the electron concentration is increased and the electron mobility is decreased in spite of the reduced dislocation density. Here, the increase in the electron concentration may be related to the surface roughness, as seen in Fig. 3. At a high temperature of 1050 °C, the amount of nitrogen and Ga vacancies will be exponentially increased in the n-type GaN film with the temperature. Then, the mobility may be limited by the μ_{ii} component due to the dominant scattering at ionized impurities/vacancies, instead of the μ_{disl} component.

These defects were also found to be related to the origin of the yellow luminescence observed in the PL spectra. Figure 4 shows that a yellow luminescence peak began to appear above an annealing temperature of 1050 °C. This indicates that the origin of yellow luminescence is largely related to the vacancies, not to dislocations, because a considerable amount of vacancies can be formed at a high temperature of 1050 °C but the dislocations seem to be continuously annihilated up to 1050 °C as shown in Fig. 2.

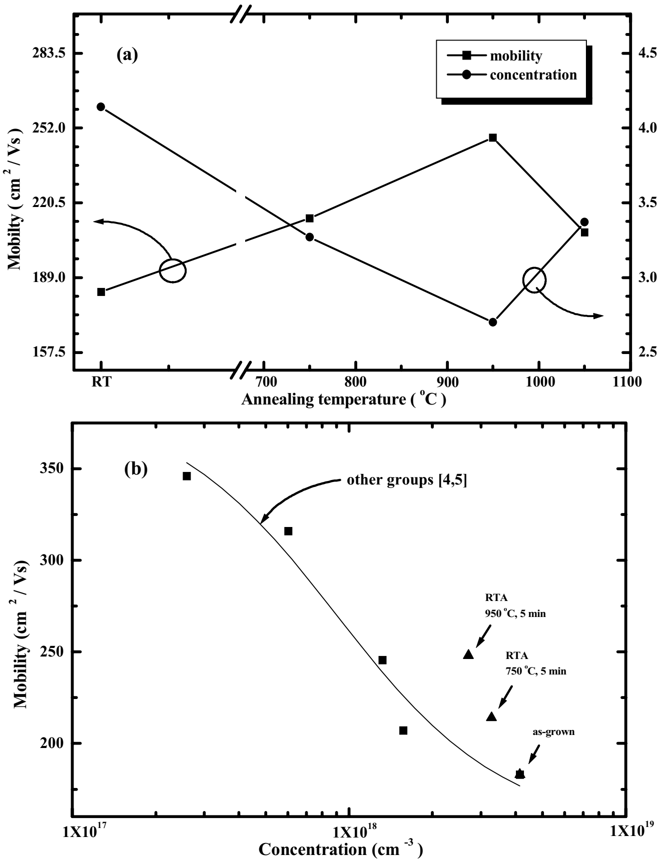

Fig. 1

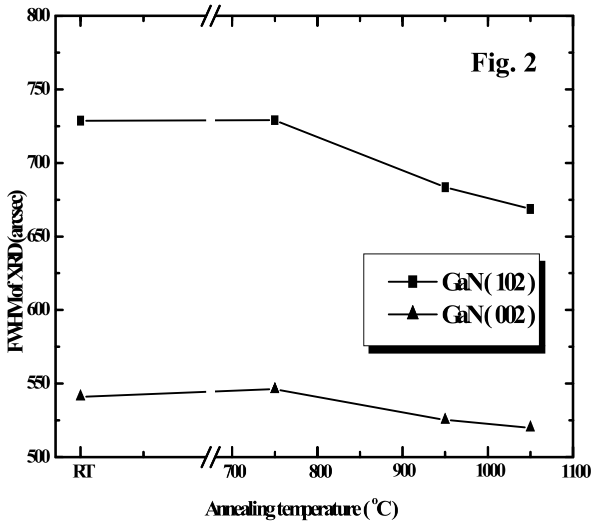

Fig. 2

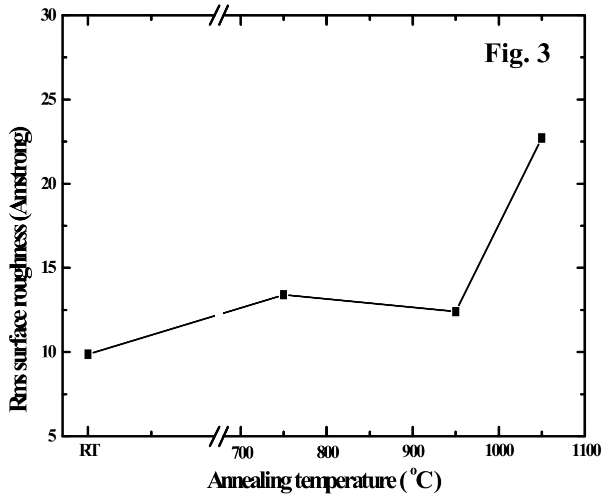

Fig. 3

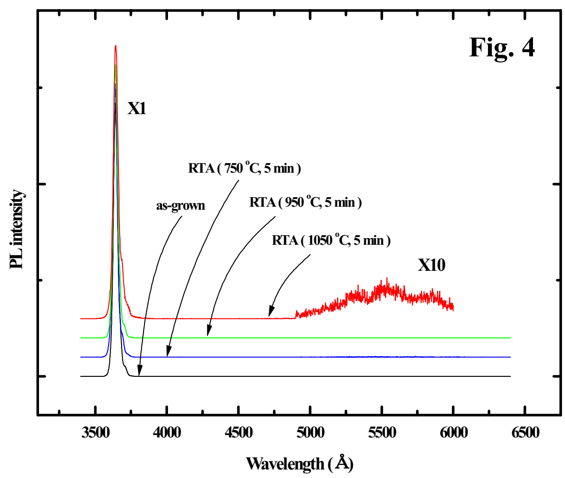

Fig. 4

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