The Effects of Thermal Annealing Treatments on InGaN/GaN Quantum Well Structures

K.S. Kim, G.M. Yang[a)], W.-H. Lee, Y.H. Song, J.W. Yang,

C.-H. Hong, K.Y. Lim, H.J. Lee, H.K. Cho[1], and J.Y. Lee[1]

Department of Semiconductor Science & Technology and SPRC, Chonbuk National University, Chonju 561-756, Korea

[1]Department of Material Science and Engineering, KAIST, 373-1 Kusong-Dong, Yusong-Gu, Taejon 305-701, Korea

[a)]Authors to whom correspondence should be addressed: E-mail: gyemo@moak.chonbuk.ac.kr

A major concern of InGaN alloy is phase separation stems from the 11% large lattice mismatch between InN and GaN. Also, InN and GaN are immiscible in most growth temperature [1]. The major parts of Ⅲ-Ⅴ ternary alloys are predicted to be thermodynamically unstable and show tendency towards clustering and phase separation [2, 3]. However, there have been a few reports on phase separation in the InGaN alloy [1, 4, 5]. Especially, there have been few experimental reports on the effect of thermal annealing in order to understand phase separation properties of InGaN [6-8]. In this study, we report the effects of thermal annealing on the properties of InGaN/GaN quantum wells (QWs).

The samples used in this study were grown on (0001) sapphire substrates by metalorganic chemical vapor deposition. The structure consists of a 50 ㎚-thick GaN capping layer, InGaN/GaN QWs, a 2 ㎛-thick GaN : Si layer, and a 25 ㎚-thick GaN nucleation layer on sapphire substrate. The GaN: Si layer being grown, the growth temperature was reduced to grow the InGaN/GaN QW adopting various growth conditions. And again, the temperature was raised up to 1100 ℃ to deposit the GaN capping layer.

In order to understand this phase separation further, thermal annealing treatments were performed on MQWs by varying the annealing time. In this studies, seven-period $In_{0.26}Ga_{0.74}N$/GaN QW sample (belongs to unstable region) was grown at 770 ℃, which was annealed at 1100 ℃ for 2, 6, and 12 hours, respectively. The indium concentration was determined from HRXRD.

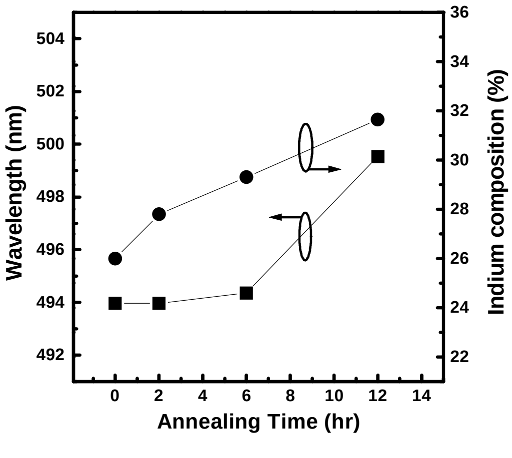

Fig. 1 Dependence of the PL peak wavelength and indium composition of InGaN/GaN MQW structures on the annealing times.

Figure 1 shows the variation of emission wavelengths and indium concentrations of the InGaN/GaN MQWs along with annealing time. The emission wavelengths for the samples annealed for 2 and 6 hours are slightly changed, whereas the emission wavelength for the sample annealed for 12 hours is red-shifted by the amount of 30 meV. By increasing the annealing times from 0 to 12 hr, indium composition is increased from 26 % to 32 %. These results indicate that phase separation is evolved as the annealing process goes on.

We can also observe the reduction of PL intensity by annealing for this case. To prove the existence of the non-radiative defects, TEM measurement was performed on samples before and after annealing. TEM images for the as-grown and the annealed sample for 12 hours are shown in Fig. 2. In the as-grown sample, the boundaries of the interfaces between the InGaN well and GaN barrier are apparently clear indeed. After the sample was annealed for 12 hours, however, a contrast between the quantum wells and the barriers became ambiguous. These observations suggest that the constituent atoms be diffused between the InGaN wells and the GaN barriers during the thermal annealing treatments. Also, there are generated a lot of dislocations in the InGaN QWs and GaN capping layer for the annealed sample comparing to the unannealed sample. This points out that the strain relaxation in InGaN/GaN QWs occurs in the annealed samples, which will be discussed more detail in the symposium. Particularly, the upper capping GaN layer has more dislocations than the GaN layer beneath the InGaN/GaN QW region. The formation of dislocations in the GaN capping layer can be caused by the thermal damage as well as the relaxation of the InGaN/GaN QW. Hence, the reduction of PL intensity may be understood by the generation of dislocations in the QW structure.

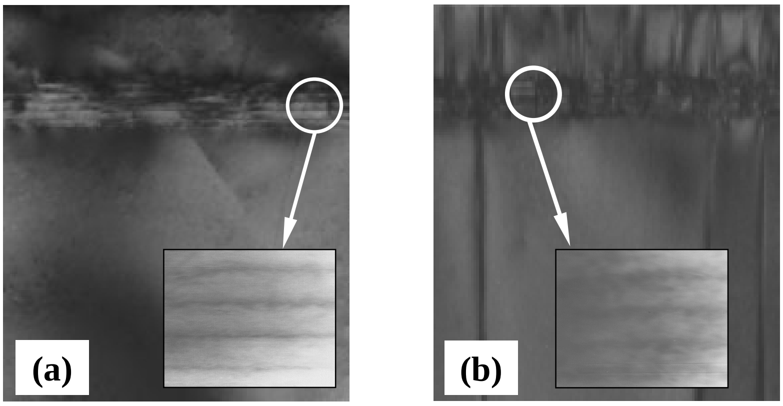

Fig. 2 TEM images of InGaN/ GaN MQWs (a) before and (b) after thermal annealing at 1100 ℃ for 12 hours.

References

[1] I-hsiu Ho and G. B. Stringfellow, Appl. Phys. Lett. **69**, 2701 (1996).

[2] G. B. Stringfellow, J. Cryst. Growth **58**, 194 (1982).

[3] J. L. Martins and A. Zunger, Phys. Rev. B **30**, 6217 (1984).

[4] R. Singh, D. Doppalapudi, and T. D. Moustakas, Appl. Phys. Lett. **70**, 1089 (1997).

[5] C. A. Tran, R. F. Karlicek Jr., M. Schurman, A. Osinsky, V. Merai, Y. Li, I. Eliashevich, M. G. Brown, J. Ferguson, and R. Stall, J. Crystal Growth **195**, 397 (1998).

[6] M. D. McCluskey, L. T. Romano, B. S. Krusor, D. Hofstetter, D. P. Bour, C. M. Kneissl, N. M. Johnson, T. Suski, and J. Jun, MRS Internet J. Nitride Semicond. Res. **4S1**, G3,42 (1999).

[7] L. T. Romano, M. D. McCluskey, B. S. Krusor, D. P. Bour, C. Chua, S. Brennan, and K. M. Yu, J. Crystal Growth **189/190**, 33 (1998).

[8] M. D. McCluskey, L. T. Romano, B. S. Krusor, D. P. Bour, N. M. Johnson, and S. Brennan, Appl. Phys. Lett. **72**, 1730 (1998).