Advanced Materials Research Vols. 287-290 (2011) pp 1456-1459
Online available since 2011/Jul/04 at www.scientific.net
© (2011) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMR.287-290.1456

Effect of Growth Temperature on the Indium Incorporation in InGaN Epitaxial Films

P. C. Chang[1, a], C. L. Yu[2], Y. W. Jahn[2,], S. J. Chang[2,b], K. H. Lee[3]

[1]Department of Electro-Optical Engineering, Kun Shan University, Yong-Kang 71003, TAIWAN

[2]Institute of Microelectronics & Department of Electrical Engineering, Advanced Optoelectronic Technology Center, National Cheng Kung University, Tainan 70101, TAIWAN

[3]National Synchrotron Radiation Research Center, Scientific Research Division, Nano Science Group, Hsinchu 30076, TAIWAN

[a]pcchang@mail.ksu.edu.tw, [b]changsj@mail.ncku.edu.tw

Keywords: InGaN, metalorganic chemical vapor deposition (MOCVD)

Abstract. $In_xGa_{1-x}N$ epilayers have been grown by metalorganic chemical vapor deposition (MOCVD) at different temperatures between 740°C to 830°C. The thickness of InGaN film is 50nm for all samples. The incorporation of indium is found to increase with decreasing grown temperature. The optical properties and film quality of the samples have been investigated by photoluminescence (PL) system and X-ray diffraction (XRD). The Full Width at Half Maximum (FWHM) of PL and XRD decreases with increasing the grown temperature. We also found that the peak emission of PL shifts with changing the grown temperature. The effect of temperature on the film properties was determined. This understanding will lead to better quality control of the optoelectronic devices.

Introduction

III-nitride Semiconductor has attracted much interest in both optoelectronic and electronic devices [1-2]. It is well known that the direct band-gaps of GaN, AlN, and InN are 3.4eV, 6.2eV and 0.8eV, respectively. Therefore, the wavelength of the alloys and heterostructure of these materials can be turned from the visible to the ultraviolet regions. Among the III-nitride compound semiconductors, InGaN thin film has played an important role in optical devices due to its strong band to band emission efficiency and its bandgap tenability from 0.8eV to 3.4eV[3]. With the emission in the blue-green spectral region, a reliable red emission from InGaN films would make it possible to realize high-brightness full color displays or white LEDs using only one material system. Even though the growth of InGaN with high indium content was possible at a low temperature of around 500°C, the relatively large lattice mismatch with GaN have prevented the growth of high quality InGaN thin films by metal-organic chemical vapor deposition (MOCVD). Besides, InGaN thin films are needed for fabricating electronic devices such as GaN/InGaN (AlGaN/InGaN) heterostructure field effect transistiors (HFETs), high-speed electronic devices and operating them at high temperature and hostile environments [4-5]. Therefore, the attempts to increase the efficiency of indium incorporation without structural deterioration of InGaN thin films have been reported by several groups [6-7]. However, most researches are dedicated to the studies on the optical characterization of this material system. So, it is necessary to further investigate the relationship between growth conditions and structural properties of InGaN films. In this study, we investigated the effects of growth temperature of InGaN films grown by MOCVD. X-ray diffraction (XRD), photoluminescence (PL), and the atomic force microscope (AFM) were used to evaluate the characterizations of these epilayers. This study provides evidence to show that the growth temperature plays an important role in the incorporation of indium in InGaN thin films grown by MOCVD. The indium composition of the InGaN was estimated by x-ray diffraction analysis.

Experiments

All epitaxial thin films in this study were grown on c-face (0001) sapphire substrates in Metal-organic chemical vapor deposition (MOCVD) system by using trimethylgallium (TMGa), trimethylindium (TMIn), and ammonia (NH_3). Disilane (Si_2H_6) was used as the n-type doping source. Details of the growth conditions can be found elsewhere [8-10]. After the deposition of the GaN nucleation layer, a 3-μm-thick Si-doped GaN ($n=5\times10^{18}$ cm^{-3}) buffer layer was grown on GaN nucleation layer. Later, we deposited Si-doped $In_xGa_{1-x}N$ layers directly on Si-doped GaN layer. The growth temperature was controlled to vary the indium mole fraction in $In_xGa_{1-x}N$ and observe the relationship between the growth temperature and structural quality of InGaN thin films. The thickness of each Si-doped $In_xGa_{1-x}N$ films was controlled at 50nm, which prevent the $In_xGa_{1-x}N$ layers from being cracking.

The $In_xGa_{1-x}N$ film quality was checked by a high resolution x-ray diffraction measurement and PL measurement. The indium mole fractions of $In_xGa_{1-x}N$ films were calculated by the difference, in x-ray rocking curve (XRD), of the peak position between $In_{1-x}Ga_xN$ and GaN. The 325nm line of a He-Cd laser was used as an exciting source for the room-temperature PL experiments.

Results and Discussion

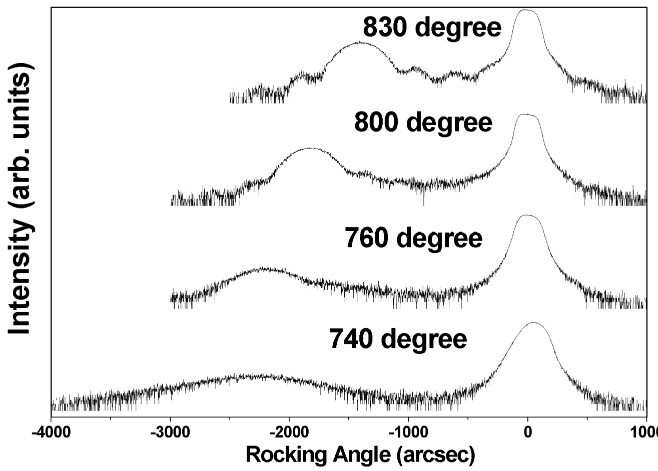

Fig. 1 The (0002) XRD patterns of InGaN under various growth temperatures

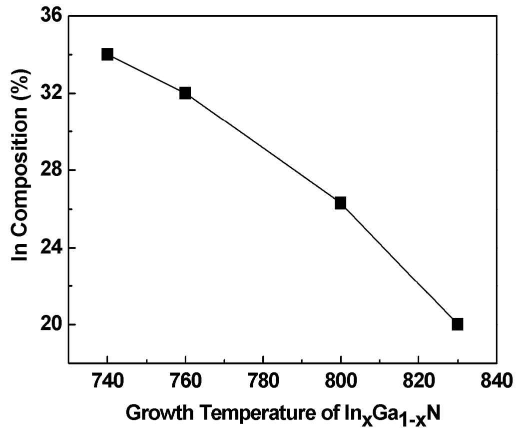

Fig. 2 The relationship between the indium composition of InGaN and growth temperature

Fig. 1 shows the XRD (0002) patterns of InGaN/GaN films grown under various growth temperatures. Every curve shows two peaks, one is the (0002) peak of GaN, and the other is that of $In_xGa_{1-x}N$. The XRD data in Fig. 1 show that the peaks of $In_xGa_{1-x}N$ are shifted to lower diffraction angles from those of GaN films with decreasing growth temperature. The indium mole fraction was estimated from the difference between the peak positions of InGaN and GaN assuming that Vegard's law is valid. Fig. 2 shows the relationship between the indium mole fractions of InGaN thin films and the growth temperature. The calculated In mole fraction of $In_xGa_{1-x}N$ layers as can be seen in Fig. 2 are 0.34 for 740 degree, 0.32 for 760degree, 0.26 for 800 degree, and 0.2 for 830 degree, respectively. The result indicates that the composition of indium in $In_xGa_{1-x}N$ films linearly increase as the growth temperature decreases. Fig. 3 shows the full-width-half-maximum (FWHM) of the (0002) XRD data for $In_xGa_{1-x}N$ layers. As shown in Fig. 3 the FWHM value for the InGaN (002) planes are increased when the growth temperature is reduced from 830 degree to 740 degree, suggesting that the structural qualities of the InGaN thin films is deteriorated with decreasing the growth temperature. The FWHMs of $In_{0.34}Ga_{0.66}N$, $In_{0.32}Ga_{0.68}N$, $In_{0.26}Ga_{0.74}N$, and $In_{0.2}Ga_{0.8}N$ are 631arcsec, 420arcsec, 301arcsec, and 261arcsec, respectively. The deterioration of structural qualities of the InGaN films, which was grown at a reduced temperature can be mainly attributed to the increased In content in the film because the $In_xGa_{1-x}N$ films with a high In composition have been reported to show the deteriorated structural properties due to the large lattice mismatch between GaN and $In_xGa_{1-x}N$.

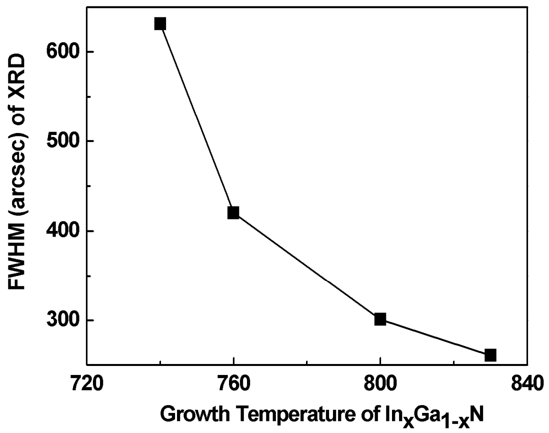

Fig. 3 The XRD FWHM of InGaN under various growth temperatures

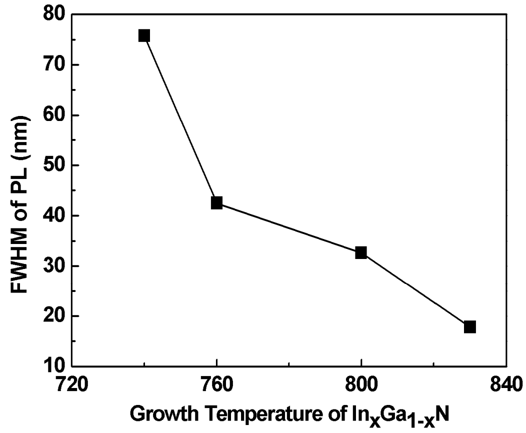

Fig. 4 The PL peak FWHM of InGaN under various growth temperatures

Table 1 shows the room-temperature PL peak of $In_xGa_{1-x}N$ thin films grown under various growth temperatures. We can see that a red-shift in the PL peak is observed with decreasing growth temperature. This result can be attributed to the compositional fluctuation of In, observed in Fig. 1. Fig. 4 shows the FWHM of the PL peak of $In_xGa_{1-x}N$ thin films. The decrease of growth temperature increased the FWHM of the PL peak. The PL peak FWHMs of $In_{0.34}Ga_{0.66}N$, $In_{0.32}Ga_{0.68}N$, $In_{0.26}Ga_{0.74}N$, and $In_{0.2}Ga_{0.8}N$ are 75.7nm, 42.5nm, 32.6nm, and 17.8nm, respectively. It was reported that the decrease of growth temperature increases the In-composition fluctuation in the $In_xGa_{1-x}N$ epilayer [11-12]. The In-rich regions may have a broad composition distribution or size distribution, resulting in an increase in the FWHM of the PL peak. The result agrees with the XRD curve shown in Fig. 1.

Table 1. The relationship between the room-temperature PL peak and the growth temperature.

Growth temperature	PL peak
740	500
760	485
800	458
830	432

Conclusions

The effect of growth temperature on the In composition during the MOCVD growth of $In_xGa_{1-x}N$ thin films was examined. The $In_xGa_{1-x}N$ thin films, which were grown at a low growth temperature, showed the worse structural quality and the red-shift in the PL peak. The XRD analysis showed that this large red-shift in the PL peak can be attributed to the increased In composition in the $In_xGa_{1-x}N$ thin films.

Acknowledgement

This work was financially supported by the National Science Council under contract NSC 97-2221-E-168-051-MY3.

References

[1] S. Nakamura, M. Senoh, S. Nagahama, N. Iwasa, T. Yamada, T. Mukai, Y. Sugimoto and H. Kiyoku, Appl. Phys. Lett. Vol. 69 (1996), p. 4056

[2] C. H. Chen, S. J. Chang, Y. K. Su, G. C. Chi, J. K. Sheu, and J. F. Chen, IEEE J. Sel. Top. Quan, Electron., Vol. 8 (2002), p. 284

[3] T. Matsuoka, H. Okamoto, M. Nakao, H. Harima, and E. Kurimoto, Appl. Phys. Lett., Vol. 81 (2002), p. 1246

[4] N. Okamoto, K. Hoshino, N. Hara, M. Takikawa, and Y. Arakawa, J. Cryst. Growth, Vol.272 (2004), p.278

[5] T. M. Kuan, S. J. Chang, Y. K. Su, J. C. Lin, S. C. Wei, C. K. Wang, C. I. Huang, W. H. Lan, J. A. Bardwell, H. Tang, W. J. Lin, and Y. T. Cherng, J. Cryst. Growth, Vol. 272 (2004), p.300

[6] D. J. Kim, Y. T. Moon, K. M. Song, I. H. Lee, and S. J. Park, J. Electronic Materials, Vol.30 (2001), p. 99

[7] Y. T. Moon, D. J. Kim, K. M. Song, I. H. Lee, M. S. Yi, D. Y. Noh, C. J. Choi, T. Y. Seong, and S. J. Park, Phys. Stat. sol., Vol. 216 (1999), p.167

[8] W. C. Lai, S. J. Chang, M. Yokoyama, J. K. Sheu, and J. F. Chen, IEEE Photon. Technol. Lett., Vol. 13 (2001), p. 559

[9] S. J. Chang, C. H. Kuo, Y. K. Su, L. W. Wu, J. K. Sheu, T. C. Wen, W. C. Lai, J. F. Chen, and J. M. Tsai, "400nm InGaN/GaN and InGaN/AlGaN multiquantum well light-emitting diodes", IEEE J. Select. Topics Quantum Electron., Vol. 8 (2002), p. 744

[10] C. H. Chen, S. J. Chang, Y. K. Su, J. K. Sheu, J. F. Chen, C. H. Kuo, and Y. C. Lin, "Nitride-based cascade near white light emitting diodes", IEEE Photon. Technol. Lett., Vol. 14 (2002), p. 908

[11] S. Keller, B. P. Keller, D. Kapolnek, U. K. Mishra, S. P. Denbaars, I. K. Shmagin, R. M. Kolbas, and S. Krishnankuty, J. Cryst. Growth, Vol. 170 (1997), p.349

[12] W. Van Der Stricht, I. Moerman, P. Demeester, L. Considine, E. J. Thrush, and J. A. Crawley, MRS Internet J. Nitride Semicond. Res., Vol. 2 (1997), p. 16

Applications of Engineering Materials
doi:10.4028/www.scientific.net/AMR.287-290

Effect of Growth Temperature on the Indium Incorporation in InGaN Epitaxial Films
doi:10.4028/www.scientific.net/AMR.287-290.1456