Electronic Materials Letters, Vol. 4, No. 2 (2008), pp. 67-70

Structural and Optical Properties of InGaN/GaN Single Quantum Well Grown via MOCVD

Seung-Kyu Choi[1], Jae Min Jang[1], Woo-Gwang Jung[1,*] Jin-Yeol Kim[1], and Sung-Dai Kim[2]

[1]School of Advanced Materials Engineering, Kookmin University, 861-1, Jeongneung-dong Seongbuk-gu, Seoul 136-702, Korea
[2]Dept. of Quality Non-Destructive Testing, Seoul Sanggye Vocational School 771-2 Sanggye-dong, Nowon-gu, Seoul 139-831, Korea

InGaN/GaN single quantum well (SQW) was grown on (0001) sapphire substrates via metal organic chemical vapor deposition (MOCVD). The InGaN interlayer was deposited at 750°C using trimethylgallium, trimethylindium, and NH_3 with flow rates of 17.7 μmol/min, 27.0 μmol/min, and 3.6 slm, respectively, for 60 seconds. The InGaN/GaN SQW was composed of a 2 μm thick GaN buffer layer, a 20 nm thick InGaN interlayer, and a 150 nm thick GaN capping layer. Auger electron spectroscopy (AES) revealed the composition of the InGaN interlayer to be $In_{0.1}Ga_{0.9}N$. The room temperature photoluminescence (RT-PL) spectrum showed peaks for a GaN buffer layer and an $In_{0.1}Ga_{0.9}N$ interlayer at 362.2 nm (3.41 eV) and 446.6 nm (2.7 eV), respectively. The composition of the InGaN interlayer estimated from the PL peak position agreed well with the value determined by AES.

Keywords: indium gallium nitride (InGaN), single quantum well, metal organic chemical vapor deposition (MOCVD), Auger electron spectroscopy (AES), photoluminescence (PL)

1. INTRODUCTION

Group-III nitrides have been recognized as very important materials for optoelectronic devices operating in the blue or ultra violet (UV) regions, as well as for high-temperature/high-power electronic devices.[1-3] Through their complete miscibility properties and direct band gap, III-nitrides, GaN (Eg = 3.41 eV) and their alloys with AlN (Eg = 6.2 eV) and InN (Eg = 1.9 eV), have the greatest potential for optoelectronic devices from the green to UV region of the spectrum. InGaN-based light emitting diodes (LEDs) are used in large outdoor full-color displays, where they provide the green and blue components of the required RGB color scheme (red, green, blue), and in traffic lights, resulting in lights that are brighter, more directional, and last 1000 times longer than incandescent bulbs, though the electrical power consumption is 1/10 that of incandescent bulbs. Violet laser diodes (LDs), which are expected to become commercially available in the near future, are anticipated to have a plethora of innovative uses. Therefore, the extension of nitride technology to wide wavelengths, particularly to blue emitters, is of considerable importance for applications of III-V based materials in displays and white light devices. Recently, the InGaN common part has been used as an active layer or as a layer in multiple quantum wells (MQW) to trap electrons and holes for their efficient recombination by a 2-dimensional electron gas layer. In order to realize these devices, it is essential to control the indium (In) concentration in the solid InGaN and to optimize the growth conditions for high-quality InGaN thin-films.

This paper reports the fabrication of an InGaN/GaN single quantum well (SQW) structure by metal organic chemical vapor deposition (MOCVD) along with the observed structural and optical properties.

2. EXPERIMENTAL DETAILS

The InGaN/GaN SQW was deposited using two-flow MOCVD equipment. The reactor pressure was maintained at 200 torr throughout the growth process. Trimethylgallium (TMG) and trimethylindium (TMIn) were used as the Ga and In precursors, and high-purity ammonia (NH_3) gas was used as the nitrogen source. High-purity hydrogen (H_2) gas was used as a carrier gas during the growth of the GaN buffer layer. High-purity nitrogen (N_2) gas was used as the carrier gas during the growth of the InGaN interlayer and GaN capping layer, and as well as a purging gas during the process. Sapphire (0001) substrates were cleaned using organic solvents (trichloroethylene, acetone, and methanol),

*Corresponding author: wgjung@kookmin.ac.kr

and etched in a H_2SO_4 : H_3PO_4 = 3:1 solution at 140°C ~ 160 °C. The oxide layer on the sapphire substrate was removed by dipping in a 10% HF solution and rinsing several times in deionized water followed by drying in nitrogen gas. After the surface had been cleaned, the sapphire substrate was loaded onto a silicon carbide coated graphite susceptor in the MOCVD reactor.

The sapphire substrate was thermally cleaned in a stream of hydrogen gas for 10 minutes at 1050°C, and a GaN nucleation layer of 30 nm thick was deposited for 6 minutes at 500 °C. A 2 μm thick GaN buffer layer was deposited for 30 minutes at 1030°C. During the growth of the GaN buffer layer, the NH_3 and TMG flow rates were 1.8 slm and 89 μm/min, respectively. A 20 nm thick InGaN quantum well layer was deposited at 750°C using TMG, TMIn, and NH_3 with flow rates of 17.7 μmol/min, 27.0 μmol/min, and 3.6 slm, respectively. The growth time was 60 seconds. The GaN capping layer was grown for 3 minutes, and the thickness of the final GaN capping layer was 50 nm.

The surface roughness of the GaN capping layer was measured by atomic force microscopy (AFM) in non-contact mode. The structural properties of the sample were characterized by field emission scanning electron microscopy (FE-SEM, JEOL, JSM-7401F, and operating voltage 10 kV) in compositional mode, as well as by high-resolution X-ray diffraction (HR-XRD, Bruker, D8) using Cu-Kα radiation, including a ω-2θ scan. The composition of the InGaN/GaN SQW was confirmed using Auger electron spectroscopy (AES). The optical properties and crystal defects of the InGaN/GaN quantum well structure were determined using room temperature photoluminescence (RT-PL, Accent, RPM 2000), with excitation at 266 nm, using a Nd-YAG laser.

3. RESULTS AND DISCUSSION

Figures 1(a) and 1(b) show AFM images of the GaN buffer layer and GaN capping layer surfaces (interlayer: InGaN) with root mean square (RMS) roughnesses of 0.66 nm and 3.79 nm, respectively. The RMS of the InGaN SQW was higher than that of the GaN buffer layer. The RMS of the InGaN/GaN SQW was higher, while the quality of the GaN capping layer was lower, due to the low growth temperature and the use of nitrogen carrier gas. Usually, GaN buffer layers for device quality are grown at temperatures greater than 1000°C. The higher growth temperature can lead to less impurity incorporation in the GaN layer and improved crystal quality. However, when the InGaN interlayer and GaN capping layer are grown at high temperatures, there is more indium diffusion in the InGaN interlayer. Moreover, the rate of indium decomposition increases with increasing temperature. This leads to an increased surface roughness on the capping GaN layer. Therefore, the growth temperature needs to be lower.

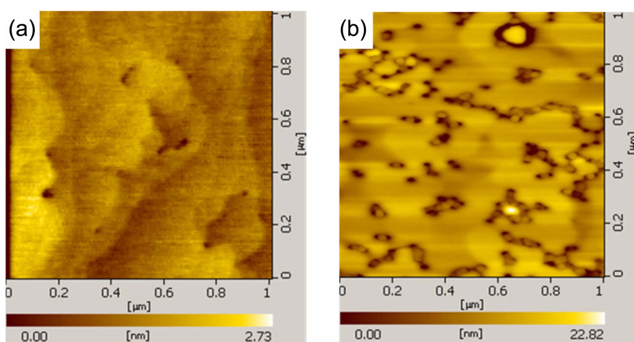

Fig. 1. 1×1 μm^2 AFM non-contact mode images of the sample surface morphology: (a) GaN buffer layer and (b) capping GaN layer (interlayer InGaN).

Auger electron spectroscopy was performed to determine the chemical composition of the InGaN interlayer. Figure 2 shows the AES results of InGaN/GaN SQW grown by

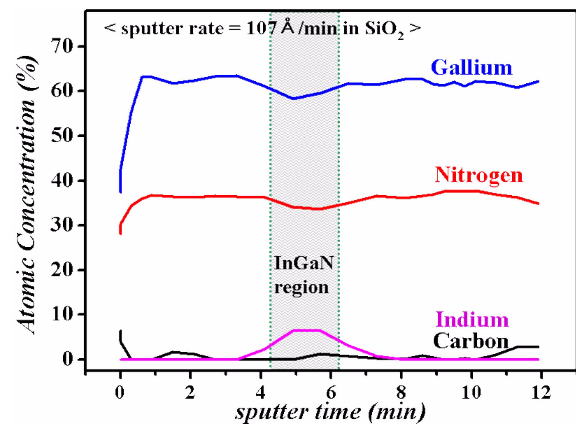

Fig. 2. Atomic concentration profile of the InGaN/GaN SQW determined by Auger electron spectroscopy (AES). The interlayer corresponds to $In_{0.1}Ga_{0.9}N$.

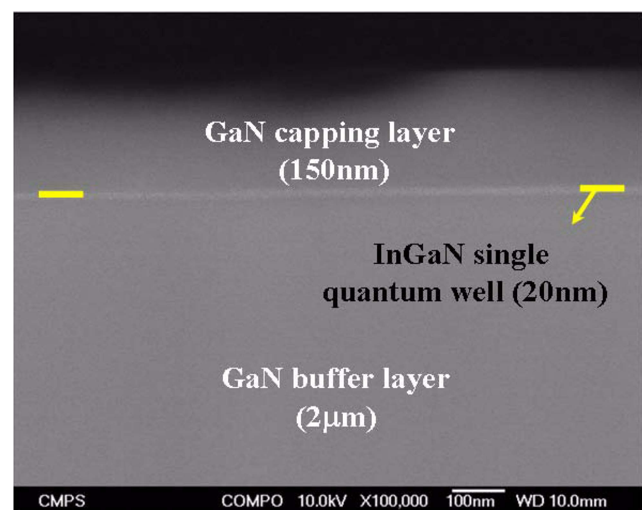

Fig. 3. FE-SEM compositional mode image of an InGaN/GaN SQW deposited on a sapphire substrate. (GaN capping layer: 150 nm, InGaN interlayer: 20 nm, GaN buffer layer: 2 μm).

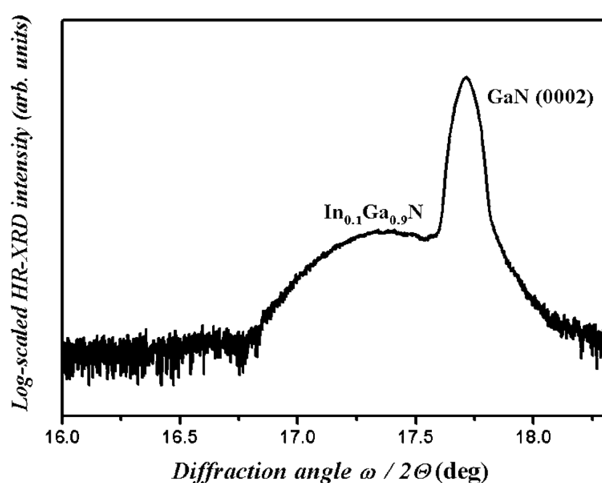

Fig. 4. High resolution X-ray diffraction ω/2θ profile of the $In_{0.1}Ga_{0.9}N$/GaN SQW structure.

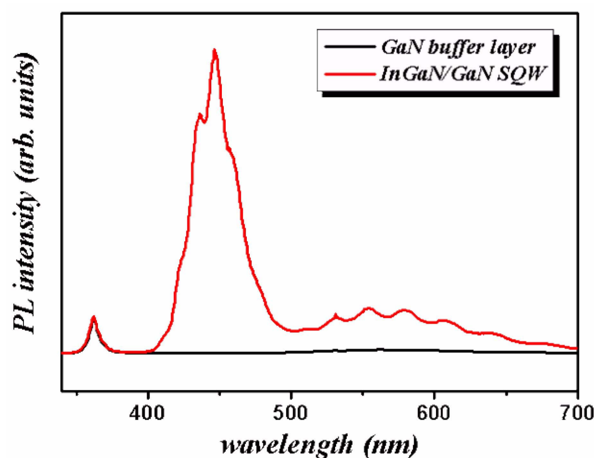

Fig. 5. The room temperature PL spectra of the GaN buffer layer and InGaN/GaN SQW structure.

MOCVD. The result showed the chemical composition and layer thickness of the GaN capping layer and InGaN interlayer. The thicknesses of the GaN capping layer and InGaN interlayer were 50 nm and approximately 20 nm, respectively. AES revealed the indium composition in the InGaN interlayer to be stoichiometric Ga: In = 58.37: 6.48 ($In_{0.1}Ga_{0.9}N$). The In concentration in the InGaN interlayer decreases with decreasing InGaN interlayer thickness because the rate of In diffusion is faster in a thinner InGaN interlayer.

Figure 3 shows FE-SEM images in compositional mode of a cross section of the InGaN/GaN SQW. The thickness of the InGaN interlayer was approximately 20 nm (bright field), which is in accordance with the AES results, and the GaN capping layer was approximately 150 nm.

Figure 4 shows the HR-XRD ω/2θ profile for the (0002) reflection of the InGaN/GaN SQW structure. The strongest peak originated from the GaN buffer layer. In this study, the InGaN interlayer was grown sufficiently thick to confirm the growth of the InGaN/GaN SQW structure. The satellite peak for InGaN was quite broad, which was attributed to the thick InGaN interlayer.

The optical properties of the InGaN/GaN SQW were characterized by the RT-PL. Figure 5 shows the RT-PL spectra of the GaN buffer layer and InGaN SQW. The PL spectrum of the GaN buffer layer showed a peak at 362.2 nm (3.41 eV). For the InGaN/GaN SQW structure, the PL spectrum peak was observed at 446.6 nm (2.7 eV). Despite the very thin InGaN interlayer, a very strong PL peak was observed in the InGaN/GaN SQW structure. The peak position in the PL measurement spectra for $In_xGa_{1-x}N$ is reported elsewhere.[4,5] According to these reports, the peak position at 446.6 nm in the PL spectra corresponds to $In_{0.1}Ga_{0.9}N$. This agrees well with the results obtained by AES analysis. This is comparable to the PL peak at 435 nm (2.86 eV) reported previously for $In_{0.14}Ga_{0.86}N$ quantum dots.[6] On the other hand, a yellow emission band from 530 nm to 600 nm was also observed in the RT-PL spectrum. The yellow emission band was attributed to the formation of impurities, as well as to oxygen and nitrogen vacancies in the InGaN/GaN SQW.

4. CONCLUSIONS

InGaN/GaN single quantum well was grown on a (0001) sapphire substrate via metal organic chemical vapor deposition. The InGaN interlayer was grown at 750°C using TMG, TMIn, and NH_3 with flow rates of 17.7 μm/min, 27.0 μm/min, and 3.6 slm, respectively, for 60 seconds. The InGaN/GaN SQW was composed of a 2 μm thick GaN buffer layer, a 20 nm thick InGaN interlayer, and a 150 nm thick GaN capping layer. AES revealed the composition of the InGaN interlayer to be $In_{0.1}Ga_{0.9}N$. The optical properties of the InGaN/GaN SQW, as determined by RT-PL, showed peaks at 362.2 nm (3.41 eV) and 446.6 nm (2.7 eV) for the GaN buffer layer and $In_{0.1}Ga_{0.9}N$ interlayer, respectively. The composition of the InGaN interlayer estimated from the PL peak position agreed well with the value determined by AES.

ACKNOWLEDGEMENTS

This study was supported by the ERC (Center for Materials and Processes of Self-Assembly) program of MOST/KOSEF (R11-2005-048-00000-0) and the Korea Research Foundation Grant funded by the Korean Government (MOEHRD) (KRF-2006-311-D00548).

REFERENCES

1. S. Nakamura, M. Senoh, S. Nagahama, N. Iwase, T.

Yamada, T. Matsushita, Y. Sugimoto, and H. Kiyoku, *Jpn. J. Appl. Phys.* Part 2 **36**, L1059 (1997).
2. V. Y. Davydov, A. A. Klochikhin, R. P. Seisyan, V. V. Emtse, S. V. Ivanov, F. Bechstedt, J. Furthmuller, H. Harima, A. V. Mudryi, J. Aderhold, O. Semchinova, and J. Graul, *Phys. Stat. Sol.* (b) **229**, R1 (2002).
3. W.-G. Jung, S.-H. Jung, P. Kung, and M. Razeghi, *Nanotechnology* **17**, 54 (2006).
4. D. M. Graham, A. S. Vala, P. Dawson, M. J. Godfrey, M. J. Kappers, T. M. Smeeton, J. S. Barnard, C. J. Humphreys, and E. J. Thrush, *Phys. Stat. Sol.* (b) **240**, 344 (2003).
5. L. S. Wang, S. J. Chua, K. Y. Zang, and S. Tripathy, *Phys. Stat. Sol*. (c) **0**, 2082 (2003).
6. S.-K. Choi, J.-M. Jang, J.-K. Jhin, and W.-G. Jung, *Phy. Stat. Sol.* (a) **205**, 300 (2008).