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Growth and Characterization of High Quality a-plane InGaN/GaN Single Quantum Well Structure Grown by Multi-buffer Layer Technique

Hooyoung Song[1,2], Jin Soak Kim[1], Eun Kyu Kim[1], Yong Gon Seo[2] and Sung-Min Hwang[2]

[1]Quantum-Function Spinics Laboratory and Department of Physics
Hanyang University, Seoul 133-791, Korea
Phone: +82-2-2220-0914 Fax: +82-2-2295-6868 E-mail: ek-kim@hanyang.ac.kr
[2]Green Energy Research Center,
Korea Electronics Technology Institute, Gyeonggido 463-816, Korea

1. Introduction

Recently, GaN of wurzite structure grown in nonpolar and semipolar orientations are attracting attentions, since strained active layers on nonpolar templates are not affected by native internal fields caused by the spontaneous and piezoelectric polarizations[1], which is called quantum-confined Stark effect (QCSE) decreasing the device efficiency by the reduction of the wavefunction overlap between hall and electron. In spite of several advantages of nonpolar structure, the growth of the nonpolar structure is more difficult than that of the polar structure due to high Ga-polar to N-polar wing growth rate ratio[2]. In order to produce high quality films suitable for growing quantum wells, defect reduction and surface roughening techniques have been extensively researched[3-7]. Some groups used low lattice-mismatched substrates such as nonpolar GaN bulk[3-4] or $LiAlO_2$ substrates[5-6]. But these substrates are too expensive for commercialization. Therefore, the growth techniques such as a two-step growth process[7] for lowering the threading dislocation density on sapphire substrates have been investigated. The first step will promote growth normal to the surface over lateral growth to form three-dimensional nucleation which is the origin of epitaxial growth. The second step uses the condition to take advantage of lateral growth. Line defects such as threading dislocations propagate along the growth direction, and annihilate during lateral growth. Also many growth parameters have been studied including V/III ratio and reactor pressure to achieve the surface roughening on a-plane templates.

In this study, we prepared *a*-plane-oriented nonpolar GaN templates by using multi-buffer layer technique. Especially, growth conditions of nucleation layer (NL) and buffer layer (BL) I were intensively studied because those conditions are key factors for high crystallinity. With optimized growth conditions, phi-dependent x-ray rocking curves of the GaN templates showed the high crystalline structure and the nonpolar growth orientation. And then InGaN single quantum well (SQW) was grown to investigate the characteristics of polarization-free structure. The results of optical measurements will be discussed for confirming that the strained InGaN/GaN single quantum well is free from the QCSE.

2. Experiments

The InGaN/GaN SQW (4.5 nm) structure was grown on multi-buffer layer template by using metal-organic chemical vapor deposition system (AXITRON 11x2 in). At first, low temperature NL (60-260 nm) was grown under nitrogen condition as a carrier gas with a reactor pressure of 100 mbar on *r*-plane sapphire substrate, and then BL I was deposited at a high-temperature of 1050-1160 ^{o}C with a reactor pressure of 400-600 mbar for high crystallinity for the high V/III ratio (800). In the growth of BL II, a surface roughening process occurred by low V/III (400) ratio at a relatively low temperature of 1000 ^{o}C. When grown at low V/III ratio, and low pressure, the growth of GaN is planar, smoothed by preferential growth along the in-plane axis. Through the growth of BL III, the crystallinity of *a*-plane GaN template was further improved. The sample structure of the InGaN/GaN SQW was schematically given in Fig. 1.

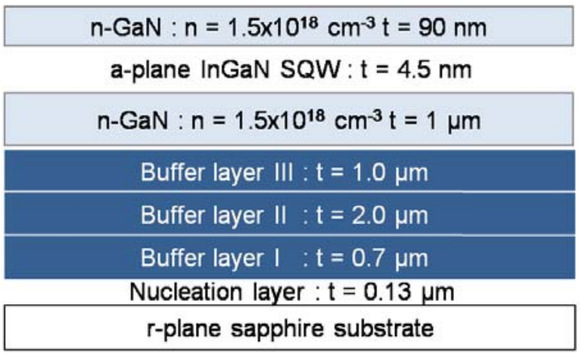

Fig. 1 The schematic of InGaN/GaN SQW structure on multi-buffer layer template.

Then, the structural properties were investigated by using high resolution x-ray diffraction (HR-XRD) measurements. For the measurements of temperature-dependent photoluminescence (TDPL), He-Cd laser (325 nm) with low temperature cryostat was used as an excitation source.

3. Results and Discussion

In Fig. 2, HR-XRD characterizations of the a-plane GaN template grown by the multi-buffer layer technique shows anisotropy in the peak width of the symmetric omega rocking curve with respect to the in-plane orientation. This anisotropy indicates the formation of discrete islands growth with (10-11), (01-11), and (000-1) faces. The coalescence is incomplete under 120 nm. And the precession behavior of symmetric phi-dependent full-width half maximum (FWHM) was inverted when the thickness of NL is thicker than 120 nm. This is originated from the enhancement of (0001) facet and depression of (1-100) facet.

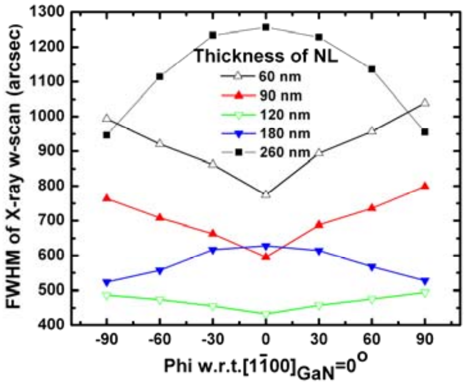

Fig. 2 XRD (11-20) FWHM anisotropy with respect to the in-plane orientation. Films were grown at various thickness of NL with 60-260 nm.

The reactor-pressure dependence of structural anisotropy was shown in Fig. 3 (a). Different growth rates of island facets can be controlled by reactor pressure. Other growth conditions including growth temperature and V/III ratio were also investigated to find the optimized growth conditions. As shown in Fig. 3 (b), for the optimized growth conditions the omega FWHM along the m-axis of the multi-buffer layer sample is 430 arcsec. This value is lower than the previous record of 530 arcsec[7].

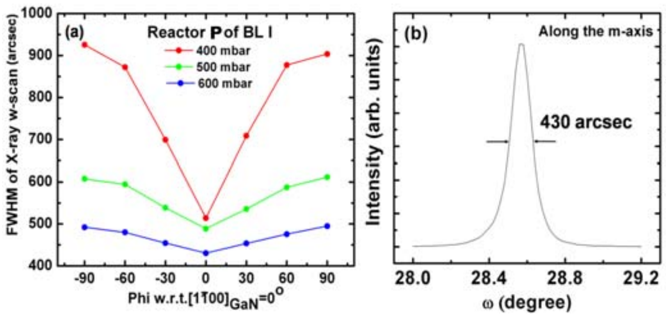

Fig. 3 HR-XRD results (a) reactor-pressure dependence of the (11-20) FWHM anisotropy (b) the omega rocking curve along the m axis for optimized growth conditions.

The characteristics of polarization-free structure can be analyzed by using the shift of TDPL transition energies compared with the Varshni relation in Fig. 4, assuming the validity of the relation for a rectangular SQW. The details of simulations in Fig. 4 (b) include the Varshni's equation with Varshni parameter α=8x10^{-4} eV/K and β=834 K[8]. As for the SQW transition, blueshift of the emission energy with the decrease of the temperature was shown. The good agreement between the peak shift and the Varshini relation indicates the lack of QCSE in nonpolar SQW. For confirming polarization-free effects in InGaN SQW, cathodoluminescence (CL) and bias-dependent PL will be further studied. The control of beam current for CL measurement can figure out the existence of internal electric fields, and the bais-dependent PL measurement is related with the influence of external electric fields in SQW structure.

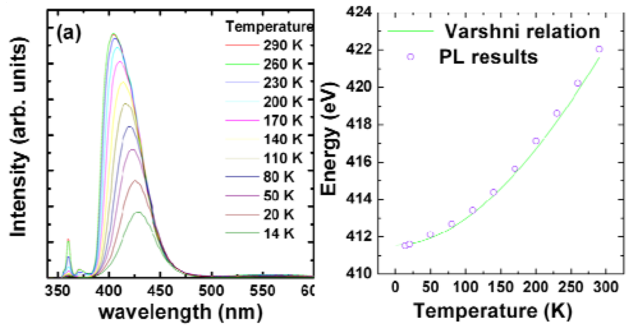

Fig. 4 (a) TDPL spectra from 14 to 290 K and (b) simulated total fields in SQW as a function of temperature.

4. Conclusions

We fabricated the high crystalline *a*-plane-oriented nonpolar SQW GaN structure by using multi-buffer layer technique. The FWHM of omega rocking curve along the *m*-axis was 430 arcsec, among the lowest reported for as-grown *a*-plane GaN on sapphire substrate. Temperature-dependent internal field behavior shows the extremely low magnitude of internal electric fields in a-plane InGaN/GaN SQW compared with c-plane cases.

Acknowledgements

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References

[1] F. Bernardini and V. Fiorentini, Phys. Rev. B **56** (1997) R10024.

[2] S X. Ni, Ü. Özgür, Y. Fu, N. Biyikli, J. Xie, A. A. Baski, H. Morkoç and Z. Liliental-Weber: Appl. Phys. Letts. **89** (2006) 262105.

[3] C T. Onuma, H. Amaike, M. Kubota, K. Okamoto, H. Ohta, J. Ichihara, H. Takasu, and S. F. Chichibu: Appl. Phys. Letts. **91** (2007) 181903.

[4] T. Zhu, D. Martin, R. Butte, J. Napierala, and N. Grandjean: J. Cryst. Growth **300** (2007) 186.

[5] Yue Jun Sun, Oliver Brandt, Uwe Jahn, Tian Yu Liu, Achim Trampert, Sven Cronenberg, Subhabrata Dhar, and Klaus H. Ploog: J. Appl. Phys. **92** (2002) 5714.

[6] D.R. Hang, MitchM.C.Chou, LiuwenChang, Y.Dikme, M.Heuken: J. Cryst. Growth **311** (2009) 452.

[7] J. L. Hollander, M. J. Kappers, C. McAleese, and C. J. Humphreys: Appl. Phys. Letts. **92** (2008) 101104.

[8] M. Leroux, N. Grandjean, B. Beaumont, G. Nataf, F. Semond, J. Massies, P. Gibart: J. Appl. Lett. **86** (1999) 3721.