Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 676-677

P-8-2

Polarization field effect on the electrical and electronic band characteristics at the interface between metal and strained GaN/InGaN layer

Ja-Soon Jang[1], Seong-Ran Jeon[2], Min-Chul Jung[3], Hyun-Jun Shin[3], and Hyun Hwi Lee[3]

[1]Korea University, Research Institute of Engineering and Technology
Seoul 136-713, Korea
Phone: +82-62-970-2346, E-mail: jjscontact@yahoo.co.kr
[2]Korea Photonics Technology Institute, Epitaxy Laboratory
Gwang-Ju 500-460, Korea
[3]Pohang Accelerator Laboratory (PAL), POSTECH, Pohang 790-784, Korea

1. Introduction

Recently, the use of polarization-induced layers has been considerably attracted as a promising method for achieving high quality ohmic and Schottky contacts on GaN-based materials.[1-4] Strain-induced spontaneous polarization and external dopant-induced piezoelectric polarization in strained layers give rise to an increase of the sheet charier concentration for ohmic contact [1-2] and an enhancement of Schottky barrier height (SBH) for Schottky one.[3-4] Although strained InGaN/GaN layers have been extensively studied to obtain good contact layer in the light emitting diodes (LEDs), only a few studies on electrical and electronic energy band characteristics of strained *u*-GaN/InGaN layers have been reported so far.

In this work, we have investigated polarization field effect on the electrical and spectroscopic characteristics at the Pd and strained *u*-GaN/InGaN layer before and after Si doping. It is shown that polarization charges originated from two dimensional electron gas (2DEG) sheet concentration is considerably dependent on the growth temperature, and surface Fermi level is pinned irrespective of growth conditions due to highly accumulated surface defects.

2. Experiment

Metalorganic chemical vapour deposition system was used to grow a 2-μm-thick unintentionally doped GaN (*u*-GaN) layer on a 30-nm-thick nucleation layer/(0001) sapphire substrate. This was followed by the growth of 120 nm-thick *n*-$In_xGa_{1-x}N$ and then a 2 nm-thick u-GaN capping layer. In this work, an In composition (x) in the InGaN layer measured by a x-ray diffraction were determined to be 17 % and 12 % for the InGaN grown at 740 °C and 760 °C, respectively. In this work, we prepared 4 types of samples: (i) *u*-GaN/*u*-$In_{0.17}Ga_{0.83}N$, (ii) *u*-GaN/ *n*-$In_{017}Ga_{0.83}N$, and (iii) *u*-GaN/*u*-$In_{0.12}Ga_{0.88}N$, and (iv) *u*-GaN/ *n*-$In_{0.12}Ga_{0.88}N$. Sheet carrier concentrations were determined by Hall-Effect measurement whose results are shown in the table I. Prior to the fabrication of Schottky and ohmic patterns, the surfaces of u-GaN/InGaN layers were ultrasonically degreased with acetone, methanol, and ethanol for 5 min in each step, and then rinsed with deionised water (DI). Ohmic and Schottky patterns were formed using Metal shadow mask. The radius of the Schottky and the ohmic dot metal is 150 and 500 μm, respectively. The ohmic electrode was formed using Ti/Al/Pd/Au (20/30/20/50 nm) scheme annealed at 500 °C in a flowing N_2 atmosphere. The Pd (50 nm) Schottky metal was then deposited by an electron beam evaporation. Current-voltage (*I-V*) data were obtained using a semiconductor analyzer (HP 4155A). X-ray photoelectron spectroscopy (XPS) and x-ray diffraction (XRD) were carried out at Synchrotron Photoemission spectroscopy beam line (8A1) and x-ray diffraction beam line (10C1) in PAL.

Table I. Summary of the Hall and XRD results for strained GaN/InGaN layers

	N_s [cm^{-2}]	μ_n [$cm^2V^{-1}s^{-1}$]	In comp. [x, %]
u-GaN/*u*-InGaN at 740 °C	5.5×10^{12}	221	17
u-GaN/*u*-InGaN at 760 °C	38.5×10^{12}	264	12
u-GaN/*n*-InGaN at 740 °C	46.2×10^{12}	57.4	17
u-GaN/*n*-InGaN at 760 °C	59.2×10^{12}	139	12

3. Results and Discussion

Table I shows summary for the Hall and XRD results. It is shown that the mobility and the sheet carrier concentration of *u*-GaN/*u*-InGaN and *u*-GaN/*n*-InGaN layers grown at 760 °C is considerably increased as compared to that of both samples at 740 °C. These behaviors indicate that strained GaN/InGaN layers give rise to an enhancement of polarization field, leading to an increase of polarization charges.

Figure 1 shows the *I-V* characteristics of the Pd contacts on strained GaN/InGaN layers. It is shown that the *I-V* curves for *u*-GaN/*n*-InGaN contacts become ohmic behavior while those for *u*-GaN/*u*-InGaN contacts seem to be Schottky behavior. As for *u*-GaN/*u*-InGaN contacts (in Fig. 1(a)), reverse (@ -5V) and forward (@ 1V) leakage currents of the contact grown at 760 °C are significantly reduced as compared to those of the sample at 740 °C. On the contrary, for *u*-GaN/*n*-InGaN contacts (in Fig. 1(b)), linear-

ity of the sample grown at 760 °C becomes improved as compared to that of the sample at 740 °C. These behaviors could be strongly due to the polarization effect. The specific contact resistance was calculated using the relations (1)-(3) given by [5]

$$R_{SC} = \left(\partial V / \partial J\right)_{V \to 0} \quad (1)$$

$$R_{sc}^{-1} = \left(\frac{q}{2\pi\hbar d_{\min}}\right)^2 \left(\hbar + d_{\min}\sqrt{q m_h^* \Phi_B}\right) \exp\left(-\frac{2 d_{\min}}{\hbar}\sqrt{q m_h^* \Phi_B}\right) \quad (2)$$

$$d_{\min} = \frac{\Phi_B}{E} = \frac{q\Phi_B}{q N_S^{2D}} \quad (3)$$

where $\hbar$ is Plank constant ($h/2\pi$), m_e^* the effective electron mass, N_S^{2D} the surface charge density, E electric field. In equation (3), the minimum thickness of the strained *u*-GaN ($d_{\min}$) is defined as a thickness that produces maximum electron accumulation at the metal/strained layer interface, at which tunneling transport across the Schottky barrier occurs, when potential drop in the GaN is equal to or larger than the Schottky barrier height. From the calculation, the specific contact resistance was determined to be 1.6×10^{-4} and 3.8×10^{-5} Ωcm^2 for the contacts grown at 740 and 760 °C, respectively. It is noted that the contact resistance is sensitively dependent on the polarization field if considering the Hall measurement results (Table I).

In order to investigate the surface energy band-bending of the strained GaN and InGaN layers, XPS measurement was carried out. Figure 2 shows the valence energy band of *u*-GaN/*u*-InGaN at 740 °C, *u*-GaN/*n*-InGaN at 740 °C, and *u*-GaN/*n*-InGaN at 760 °C. It is clearly shown that the surface Fermi level for all samples is pinned at the energy position of 2.4 eV. This behavior may be strongly associated with the surface defect types and densities. Therefore, it can be expected that the the surface energy band-bending (conduction band minimum (CBM)-surface Fermi level) could be mainly affected by polarization field and surface defect density.

More detailed electronic transport and electronic energy band structure will be described and discussed later.

4. Conclusions

We have investigated polarization field effect on the electrical and electronic energy band structure characteristics at the Pd and strained *u*-GaN/InGaN layer before and after Si doping. The use of Si doping into InGaN layer gives rise to the formation of ohmic contact while unintentionally doped GaN/InGaN leads to the formation of Schottky contacts irrespective of InGaN growth temperatures. In addition, surface Fermi level is pinned at the energy position of 2.4 eV above VBM, indicating that the pinning could be due to highly accumulated surface defects.

Acknowledgements

Authors would like to thank Dr. J.-Y. Choi for the technical support at 10C1 x-ray diffraction beam line (PAL).

References

[1] X. Guo and E. F. Schubert, Appl. Phys. Lett **78**, 3337 (2001).

[2] J. K. Sheu, J. M. Tsai, S. C. Shei, W. C. Lai, T. C. Wen, C. H. Kou, Y. K, Su, S. J. Chang, and G. C. Chi, IEEE Electron. Device Lett. **22**, 460 (2001).

[3] E. J. Miller, X. Z. Dang, and E. T. Yu, J. Appl. Phys. **88**, 5951 (2000).

[4] Z. Lin, H. Kim, J. Lee, and W. Lu, Appl. Phys. Lett. **84**, 1585 (2004).

[5] E. F. Schubert, J. E. Cunningham, W. T. Tsang, and T. H. Chiu, Appl. Phys. Lett. **49**, 292 (1986)

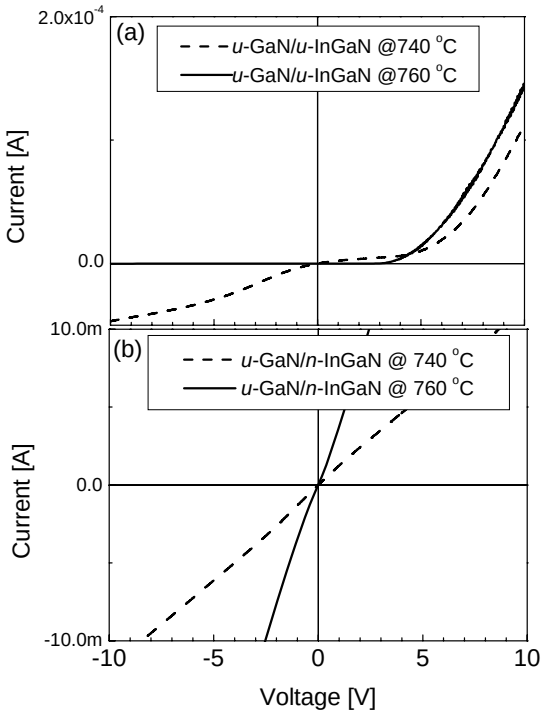

Fig 1. The *I-V* characteristics of Pd contacts on (a) *u*-GaN/*u*-InGaN and (b) *u*-GaN/*n*-InGaN layers.

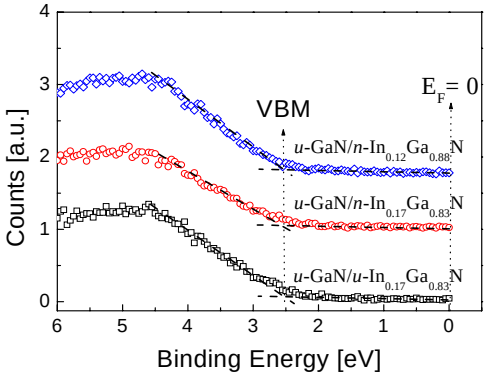

Fig. 2. Photoemission spectra peaks of valence energy band for *u*-GaN/*u*-InGaN and *u*-GaN/*n*-InGaN layers. It is shown that the surface Fermi level for all samples is pinned at the energy position of 2.4 eV above the VBM.