G-1-4
Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp868-869

Electrical Characteristics of N-polar p-type GaN Schottky Contacts

Toshichika Aoki[1], Tomoyuki Tanikawa[2], Ryuji Katayama[2], Takashi Matsuoka[2] and Kenji Shiojima[1]

[1] Graduate School of Electrical and Electronics Engineering, Univ. of Fukui
3-9-1, Bunkyo, Fukui 910-8507, Japan
Phone: +81-776-27-8560 E-mail: aoki0529@u-fukui.ac.jp
[2] Institute for Materials Research, Tohoku Univ.
2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan

Abstract

We have investigated electrical characteristics of N-polar p-GaN Schottky contacts by using current-voltage (I-V), capacitance-voltage (C-V) and internal photoemission (PR) measurements. The obtained Schottky barrier heights ($q\phi_B$) were by more than 1 eV lower than that of Ga-polar samples. In addition, the memory effect, which is caused by the carrier capture and emission processes from Ga vacancy defects located at the interface, was not observed in the I-V characteristics. It is consistent with the fact that no peak was detected in the high-temperature isothermal capacitance transient spectroscopy (H-ICTS) spectra. Therefore, it is suggested that the top N layer can suppress the out-diffusion of Ga on the N-polar surface.

1. Introduction

Since the N-polar crystal plane of nitride semiconductors is the opposite orientation to the conventional Ga-polar plane, the internal polarization fields is also opposite. It can be expected that devices fabricated on the N-polar crystal plane have improved the performance in light emitting diodes [1] as well as heterostructure field-effect transistors [2]. However, the epitaxial growth of N-polar p-GaN tends to result in the hillock formation. Thus, there are few reports related to the electrical characteristics of N-polar p-GaN. We have succeeded to grow it without hillocks on a vicinal *c*-plane sapphire substrate [3]. On the other hand, we have been studying on the current transport mechanism for metal/p-GaN contacts with Ga polarities. We have reported a large $q\phi_B$, a strong Fermi level pinning, and a large density of acceptor-type mid-gap defects in the vicinity of the interface for metal/*c*-plane Ga-polar p-GaN contacts [4, 5]. In this paper, we investigated the basic electrical characteristics of N-polar p-GaN Schottky contacts comparing with Ga-polar contacts.

2. Sample preparation

N-polar GaN films were grown on vicinal sapphire substrates with a tilted angle of 0.8^{o} around *a*-axis by metalorganic vapor phase epitaxy as shown Fig. 1. After a nitridation of the sapphire surface, a low-temperature GaN buffer layer, 250-nm-thick undoped GaN and 1-μm-thick p-type GaN films (the ratio of precursor sources Mg/Ga was set at 6.67×10^{-3}) were grown on the substrate. After a hydrochloric acid treatment, 50-nm-thick Ni films were

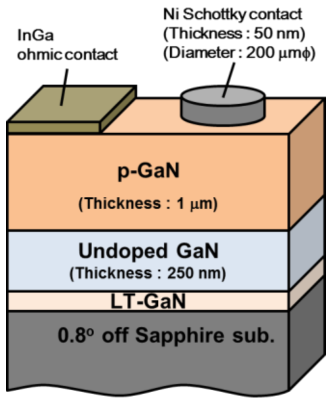

Fig. 1 Sample structure of a N-polar p-GaN Schottky contact.

deposited by electron-beam evaporation to form Schottky contacts. We also prepared Ga-polar p-GaN (Mg doping concentration: 1.0×10^{18} cm^{-3}) samples as a reference.

3. Experimental results and discussion

Fig. 2 shows typical I-V curves of the N- and Ga-polar p-GaN Schottky contacts. The forward current increased exponentially between –0.1 and –0.2 V, and $q\phi_B$ was obtained to be 0.91 eV for the N-polar samples. The obtained ideality factor was as low as 1.20. The reverse current of N-polar sample was larger than that of Ga-polar sample, but significant rectification characteristics were obtained.

In the C-V results, p-type conduction was observed, and the $1/C^2$-V plots were found to be linear. The obtained $q\phi_B$ was 1.24 eV and the carrier concentration was 3.52×10^{17} cm^{-3} for the N-polar samples.

In the internal photo-emission measurements (Photoresponse: PR) [6], a significant difference between two polarities was found: the proportional-relationship regions were observed in a cubic root plot of photorenponce Y for the N-polar sample, while in a square root plot of Y for the Ga-polar sample. Because in this process, holes around the Fermi level in Ni were excited to the top of the valence band of p-GaN, the energy distribution of density of states in the valence band might be responsible for this difference. A cubic law dependence of Y was also reported in Ni/*a*-plane p-GaN and An/SiO_2/Si systems [7, 8]. The $q\phi_B$ was determined to be 1.30 eV from the threshold energy, which is in a good agreement with that from the C-V results.

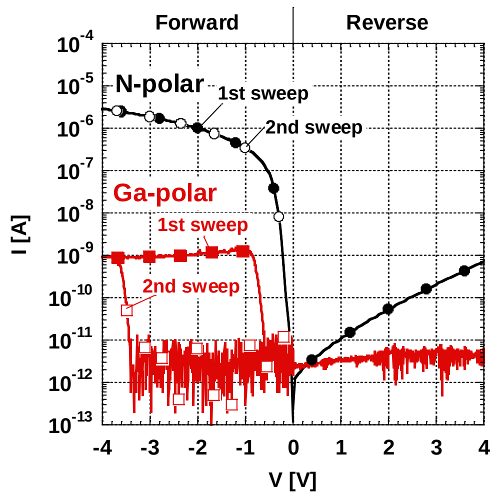

Fig. 2 Typical I-V curves of N- and Ga-polar p-GaN Schottky contacts.

Table I shows the summary of the obtained $q\phi_B$ values. For the N-polar samples, $q\phi_B$ is as low as 0.91 ~ 1.30 eV. In contrast, as for the Ga-polar samples, $q\phi_B$ is as high as 2.20 ~ 2.40 eV, which is by more than 1 eV higher than that of the Ga-polar sample. These results suggest us that the better ohmic contacts may well be formed on the N-polar surface.

As shown in Fig. 1, when we conducted forward voltage sweeps consequently twice, the N-polar samples showed the identical I-V curves. In contrast, the Ga-polar samples showed completely different I-V curves between first and second I-V curves. This is a memory effect, due to the carrier capture and emission processes from the deep level defects in the vicinity of the interface. Thus we conducted H-ICTS measurements under a large forward voltage condition for a filling pulse (V_{fill}) to investigate the interfacial defects. As expected, the Ga-polar sample showed a large single peak at 100s, whereas no peak was detected from the N-polar sample. From the Arrhenius plot of the peak, the defect was identified to Ga vacancy (V_{Ga}) at 1.1 eV above the valence band [9]. It is suggested that the topmost N atomic layer can suppress Ga out-diffusion in case of the N-polar sample, depicted as the schematic diagrams in Fig. 4.

4. Conclusions

We have investigated the electrical characteristics of N-polar p-GaN Schottky contacts by using I-V, C-V and PR measurements. The $q\phi_B$ was obtained to be 0.91, 1.24 and 1.30 eV from I-V, C-V and PR measurements, respectively, which were by more than 1 eV lower than that of Ga-polar sample. These results suggest the possibility of the better ohmic contacts formation on the N-polar surface. In addition, the N-polar samples showed no memory effect in the I-V characteristics and no peak originated from V_{Ga} was detected in the H-ICTS spectrum. Therefore, it is suggested that the N atomic layer can suppress Ga out-diffusion in case of the N-polarity.

Table. I The summary of obtained $q\phi_B$ values of Ni/p-GaN.

Polarity	Schottky barrier height [eV]		
	I-V	C-V	PR
N-polar	0.91	1.24	1.30
Ga-polar	2.40	2.20	2.39

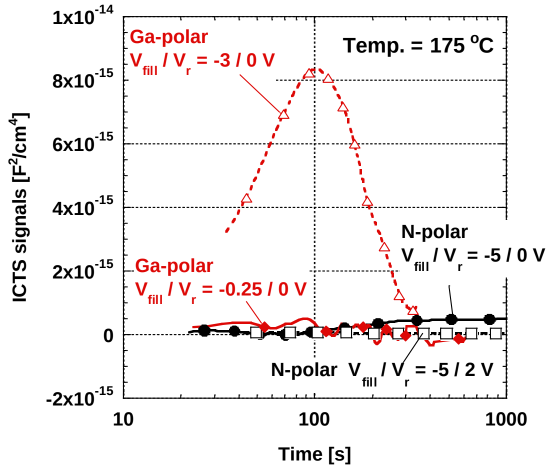

Fig. 3 High-temperature ICTS spectrum of the N- and Ga-polar samples.

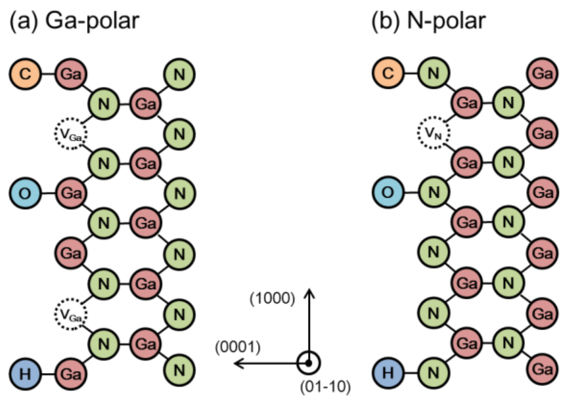

Fig. 4 Models for a surface crystal structure of N- and Ga-polar GaN.

Acknowledgements

A part of this work was supported by a Grant-in-Aid for Scientific Research C from the Ministry of Education, Culture, Sports, Science, and Technology.

References

[1] F. Akyol et al., Appl. Phys. Lett. **100**, 111118 (2012).
[2] O. Ambacher et al., J. Appl. Phys. **85**, 3222 (1999).
[3] T. Tanikawa et al., Jpn, J. Appl. Phys. **53**, 05FL05 (2014).
[4] K. Shiojima et al., Appl. Phys. Lett. **77**, 4353 (2000).
[5] Y. Fukushima et al., Phys. Status Solidi (c) **6**, S856 (2009).
[6] R. H. Fowler, Phys.Rev. **38**, 45 (1931).
[7] R. J. Powell, J. Appl. Phys. **40**, 5093 (1969).
[8] M. Naganawa et al., Phys. Status Solidi (b) **252**, 1024 (2015).
[9] K. Shiojima et al., Appl. Surf. Sci. **190**, 318 (2002).