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Electrical and Photo-response Properties of Titanium Contacts on n-type N-face and Ga-face GaN Layer for Vertical Power Devices Prepared by ELOG and Laser Lift-off

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1. Introduction

The laser lifted-off (LLO) method provides many advantage of detaching a sapphire substrate from GaN film so that flipped N-polar GaN structure can be realized for vertical light emitting diodes [1-3]. Epitaxial-lateral overgrowth (ELOG) technique is proven as a powerful technique to produce GaN laser devices with the operation lifetime exceeding 10000 hours [4,5]. Our group reported vertical type GaN Schottky barrier diode (SBD) for high power applications on the LLO GaN layer [6].

In this paper, we characterized the schottky and ohmic behavior of the contacts on both N-face and Ga-face GaN using the back-to-back diode and TLM patterns. Also, optical properties of M-S contacts on N-surface GaN layer were compared with those on Ga-face GaN.

2. Experiment

Two kinds of GaN samples were prepared with ELOG. This ELOG GaN was grown to reduce the defects of the GaN layer. The first GaN sample was grown on (0001) sapphire with 2 step temperature (low-temperature and high-temperature with doping concentration of $4x10^{16}$ cm^{-3}) by MOCVD, and the surface had a Ga face polarity. The second sample was also grown with similar 2 step temperature by MOCVD but doped highly with SiH_4. Continuously, the aluminum alloyed silicon (Al-Si) was utilized as a layer for the adhesive bonding of N-face GaN, and Sn/Au (30/800nm) were deposited on n^+-GaN layer with doping concentration of $6x10^{18}$ cm^{-3}. After LLO, N-face sample was etched by dry etching system over 1 um to get the high quality interface of N-face-GaN. We obtained Ga-face GaN grown on the sapphire (sample 1) and N-face GaN on n^+-GaN/Al-Si/Sn/Au (sample 2). After photolithography with circular transfer length method (CTLM), Ti/Al/Ni/Au films were evaporated respectively on the two samples. Figure 1 shows the structure of the Ga-face GaN (a) and N-face GaN (b).

3. Results and Discussions

Figure 2 shows the typical I-V characteristics of Ti-GaN back-to-back schottky diodes fabricated on Ga-face and N-face GaN, which was epitaxial grown by the same growth procedure designed for highly resistive n-type. The reverse current was as low as 7×10^{-11} A at 20 V for Ga-face GaN, but was 5×10^{-4} A at 20 V for N-face-GaN. It is attributed to the different surface states which affects the barrier height of the M-S junction by the distributed states in between the two band edge. Figure 3(a) shows I-V characteristics of Ga-face GaN diodes according to the RTP temperatures. It shows that the leakage current increases as annealing temperature changed from 500 ^oC to 900 ^oC. After 1000 ^oC annealing, it changes into ohmic property for Ga-face GaN as shown in Figure 3(b), while the contact resistivity was evaluated quite high as 8.2×10^{-2} [$\Omega\cdot cm^2$] through TLM method. Figure 4 shows the change of electrical properties of N-face-GaN schottky diode according to the RTP temperatures. The leakage current was enhanced as the annealing temperature increases, and the best annealing condition for the ohmic contact may be found to be over 700 ^oC in this work. Figure 5 shows the spectral photo-responsivity characteristics of N-face and Ga-face GaN before RTP. In the N-face GaN schottky diode, the UV-visible extinction ratio was only about 10^2, and the visible responsivity was enhanced steeply from the yellow region. However, in the Ga-face diode, UV-visible extinction ratio is shown over 10^4. It implies that N-face GaN surface has the higher density of deep traps than Ga-face GaN one. The spectral photo-responsivity of Ga-face diode was greatly improved in terms of UV-visible extinction ratio, by the facts that the visible responsivity of 610 nm wavelength was diminished, and the peak sensitivity of the bandgap wavelength was improved by 500 ^oC annealing in an N_2 ambient, as shown in Figure 6(b). The surface defects were thought to be attributed with the visible response. For the N-face GaN schottky diode, the thermal stabilization effect was not significant as shown in Figure 6(a), since the defect density is still higher, as shown in the TEM micrograph of the N-face GaN layer at the right bottom in Figure 7, where the dislocation density was as the crystal growth direction (upward). The inset of Figure 6 shows PL spectra of the Ga-face GaN sample, where a 563 nm (2.2 eV) peak is commonly appeared in the undoped GaN samples and explained as the transitions from the shallow donor to the deep acceptor or from the deep donor to the shallow acceptor.

4. Conclusions

We examined the electrical and optical properties of M-S contacts of Ga-face and N-face GaN on which vertical power devices can be fabricated. The reverse leakage current of the back-to-back Ti schottky diode on Ga-face GaN was up to far lower than that on N-face GaN. UV/visible rejection ratio of Ga-face GaN was also two orders of magnitude higher, which is in line with the reverse leakage current by surface density of the dislocations in GaN.

Acknowledgements

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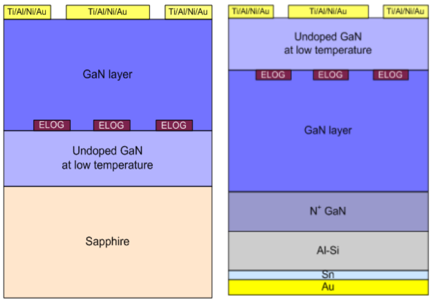


(a) (b)

Fig. 1. Structures of (a) Ga-face and (b) N-face-GaN

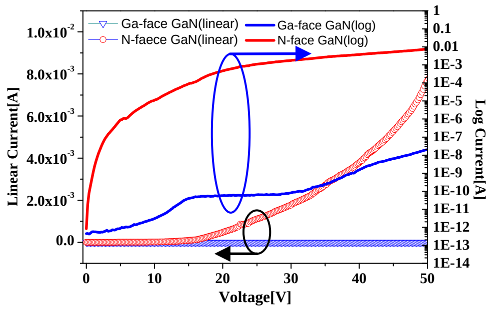
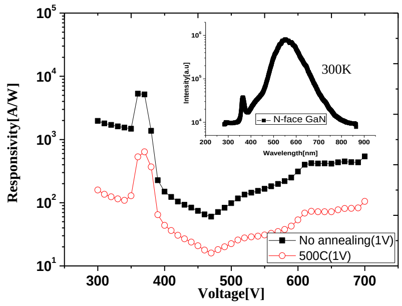
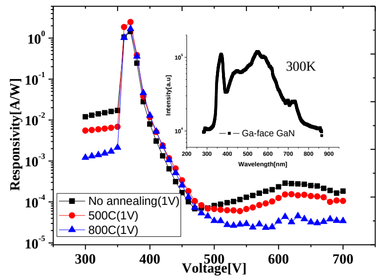


Fig. 2. I-V Characteristics of Ti-GaN back to back diode on the N-face GaN and Ga-face GaN

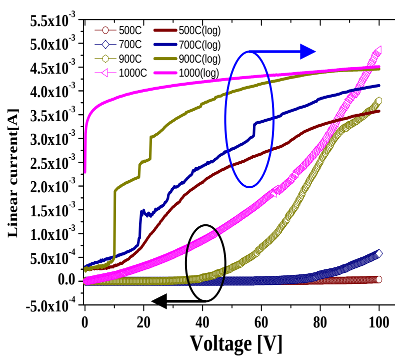


(a)

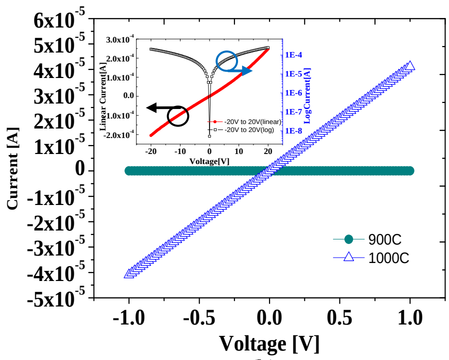


(b)

Fig. 6. Optical characteristic of Ti-GaN back to back diode fabricated on the N-face GaN (a), and Ga-face GaN (b) GaN at 1 V bias. Insets show the PL spectra.

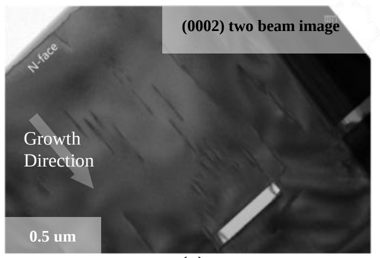


(a)

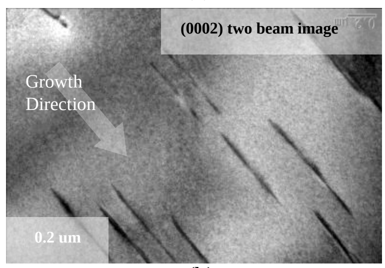


(b)

Fig. 3. I-V characteristic of Ti-GaN back to back diode with Ga-face-GaN after RTP (a) and ohmic behavior about linear graphs of Ga-face GaN at 900 ℃ and 1000 ℃ (b). In addition, inset is I-V curve after RTP at 1000 ℃



(a)



(b)

Fig. 7. TEM image of N-face GaN layer, where vertical dislocations are shown (a) and enlarged image (b).

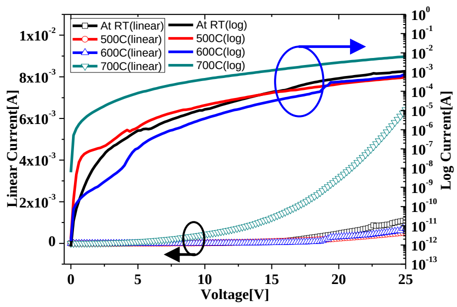


Fig. 4. I-V characteristic of Ti-GaN back to back diode with N-face-GaN after RTP: linear and log scale graphs

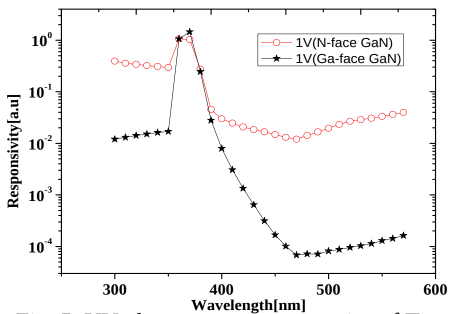


Fig. 5. UV photo-response properties of Ti-GaN back to back diode with two samples at 1 V bias