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High-Temperature Behaviors of GaN Schottky Barrier Diode

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1. Introduction

GaN has an excellent potential for use in electronic devices in the high temperature environment of its wide band gap and chemical stability. The band gap of GaN that is 3.4 eV at room temperature means that the intrinsic temperature is very high. Therefore, the high-temperature-operating electronic devices will be realized by GaN. For electronic devices, it is necessary to fabricate the Schottky contact, which is used as the gate metal for transistors such as metal-semiconductor field-effect transistor (MESFET) and the high-electron-mobility transistor (HEMT). GaN has a suitable nature for high-temperature-operating electronic devices. However, the behaviors of GaN-based Schottky diodes at high temperature were not reported.

We have already reported GaN-based Schottky diode[1)] and GaN-based MESFET[2)] with excellent electronic properties under room temperature. In this study, we studied the electronic characteristics of GaN-based Schottky diode at high temperature up to 500 °C.

2. Experimental

A GaN thin film was grown on the mirror polished (0001) sapphire substrate using the horizontal atmospheric pressure metalorganic chemical vapor deposition (MOCVD) method. Trimethylgallium (TMG) and NH_3 were used as source materials, and SiH_4 diluted in H_2 (10 ppm) was used as the n-type dopant. The sapphire substrate was heated at 1100 °C for 10 min in a hydrogen ambient. A 30-nm-thick GaN layer was deposited as the buffer layer at 530°C. Then, the substrate was heated up to 1050 °C and a 2.4-μm-thick Si-doped GaN was grown on the GaN buffer layer. The Hall mobility of this film was 530 and 1300 $cm^2/V{\cdot}s$ with the carrier concentration of 6.7×10^{16} and $1.2\times10^{16}\,cm^{-3}$ at 300 K and 77 K, respectively. The full width at half maximum of the double crystal X-ray rocking curve was 200 arcsec. Si-doped GaN has a smooth surface and pits and hillocks were not observed over the surface.

As shown in Fig. 1, Schottky diodes were fabricated on the Si-doped GaN film with a guard ring configuration. After cleaning by organic solvents with ultrasonic agitation, the sample was cleaned in conc. HCl. Ti (25 nm), Al(150 nm) and Pd (20 nm) were evaporated using the conventional lift-off technique. Pd was used as the hardening-metal to make the alloy with Al as to obtain a high thermal stability at high temperature. The sample was annealed at 900 °C for 60 sec in order to obtain ohmic characteristics. Then, Pt (10 nm) and Au (100 nm) metals were evaporated using the conventional lift-off technique. The Schottky contact area was $1.77\times10^{-4}\,cm^{-2}$. Pt and Au with high workfunction metals were used as to make a high barrier height.

We measured current-voltage (I-V) and capacitance-voltage (C-V) characteristics of the Schottky diodes on the hot plate in nitrogen ambient at various temperatures.

3. Results and Discussion

The temperature dependence of the forward I-V characteristics of Au/Pt/GaN Schottky diode is shown in Fig. 2. The characteristics of I-V of diode is generally proportional to exp(V) without series resistance. Under 300 °C, this is proportional to exp(V) but not above 400 °C. This result shows that the barrier height is very small above 400 °C. The reverse I-V characteristics is shown in Fig. 3. Reverse leakage current changes under 200 °C, but the current is order of μA under a few voltage bias at 300 °C. The saturation characteristics of reverse current is observed under up to 300 °C. The rectification of the diode degrades under high temperatures as shown in Fig. 2 and Fig. 3.

We measured C-V characteristics from room temperature to 450 °C in order to study the mechanism of the large reverse current. $1/C^2$ plots from C-V characteristics is shown in Fig. 4. The slopes of $1/C^2$ plots are almost constant under the temperatures from room temperature to 450 °C, which indicates the ionized donor concentrations are the same. The independence of the ionized donor concentration on the temperature is caused that the activation energy of Si in GaN is as small as 29 meV. The dependence of the diffusion potential on temperature is shown in Fig. 5. The diffusion potential decreases from 1.0 eV at room temperature to 0.2 eV at 450 °C. These results indicates the large leakage currents of I-V characteristics under high temperature is caused by the decrease of the diffusion potential.

The decrease of the diffusion potential is caused by the Fermi level shift, which results from the dependence of the Fermi level on the donor and acceptor activations. The differences of the Fermi level by the donor activation is about 0.2 eV between room temperature and 450 °C. This change of the Fermi level due to the donor activation is small. The effective mass of hole in GaN is $1.2m_0$, which is larger than that of the electron. Therefore, the effective state density of acceptor is larger than that of the donor. The Fermi level shift is thought to be related to the acceptor.

4. Conclusions

We observed the electronic properties of GaN Schottky diode under high temperatures. The I-V characteristics of the GaN Schottky diode change at 500 °C.

The change in the I-V characteristics at high temperature can be explained by the effective state density of acceptor. However, the GaN Schottky diode after the high temperature shows the rectification characteristics at room temperature.

References

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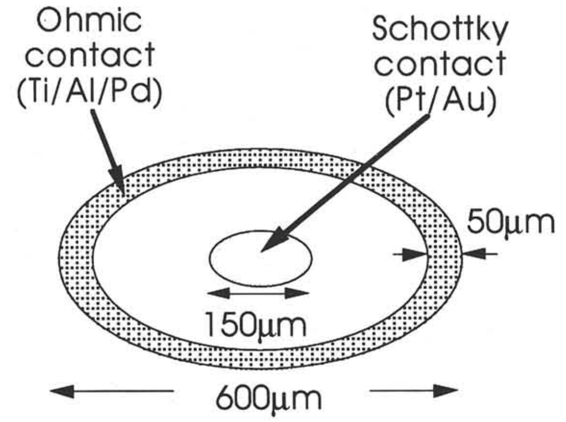

Fig. 1. Schematic structure of GaN Schottky diode.

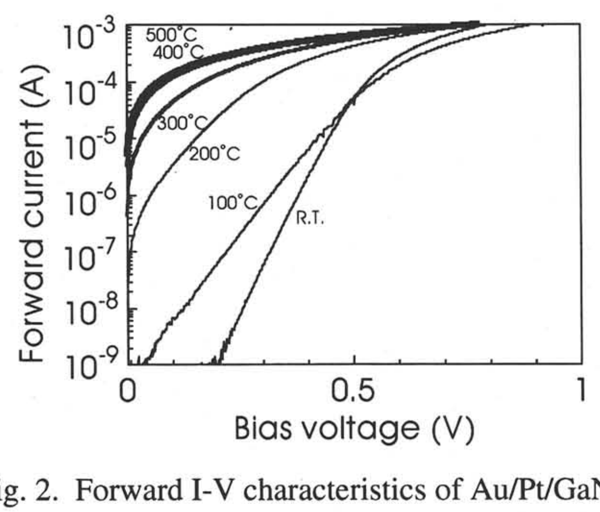

Fig. 2. Forward I-V characteristics of Au/Pt/GaN Schottky diode.

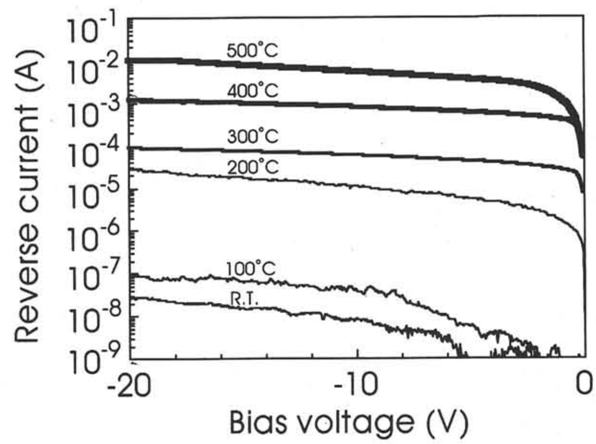

Fig. 3. Reverse I-V characteristics of Au/Pt/GaN Schottky diode.

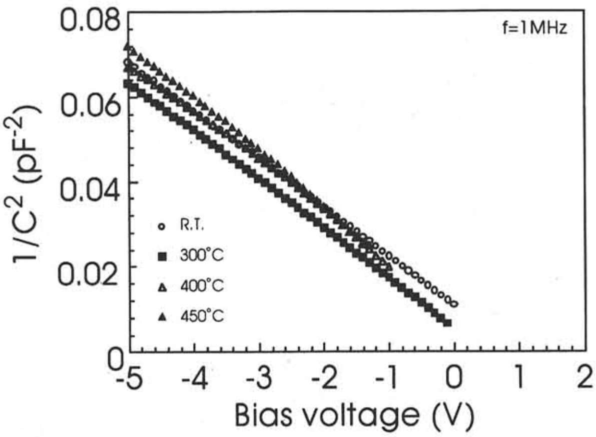

Fig. 4. 1/C^2 plot of Au/Pt/GaN Schottky diode.

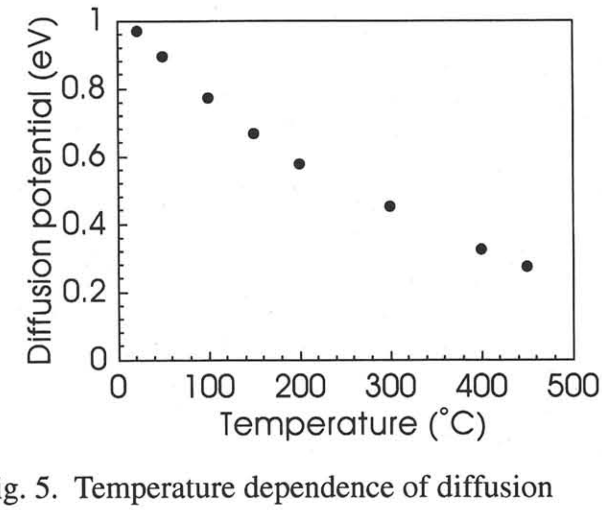

Fig. 5. Temperature dependence of diffusion potential of Au/Pt/GaN Schottky diode.