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Temperature Characteristics AlGaN/GaN Heterojunction Field Effect Transistors

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1. Introduction

AlGaN/GaN heterojunction field effect trasistors (HJFETs) are promising for high-temperature and high-power microwave applications, and their high temperature operations at 300-450℃[1-3], and at 800℃[4] have been demonstrated. In these studies, however, the degradation of the DC characteristics at high temperature has been observed as follows: i) saturation drain current is suppressed, ii) transconductance decreases, iii) gate leakage current increases, and iv) pinch-off characteristic becomes vague. However, the mechanism of these degradations at high temperature has not yet clarified.

Therefore, in this study, we fabricated AlGaN/GaN HJFET and measured the DC operating characteristics at high temperature. We systematically investigated the temperature dependence of the DC characteristics, and found the increase of the gate leakage current at high temperature is main reason for the degradation of the operating characteristics.

2. Experiment

AlGaN/GaN heterojunction structure was grown on sapphire (0001) substrates by nitrogen plasma-assisted molecular beam epitaxy. This structure for device consists of 300-nm AlN buffer layer, 1.0-μm GaN layer, 15-nm n-GaN channel layer, 2-nm i-$Al_{0.2}Ga_{0.8}N$ spacer layer, 15-nm n^+-$Al_{0.2}Ga_{0.8}N$ barrier layer and 10-nm i-$Al_{0.2}Ga_{0.8}N$ cap layer. The GaN channel layer is doped by Si at the level of 1.0×10^{17}cm^{-3}, and the n^+-$Al_{0.2}Ga_{0.8}N$ barrier layer is doped at the level of 1.0×10^{19}cm^{-3}. The electron mobility and sheet carrier density at room temperature were 400cm^2/Vs and 1.0×10^{13}cm^{-2}, respectively. Mesa isolation was performed by reactive ion beam etching with Cl_2. Contact metals of Ti/Al/Pt/Au for the source and drain were deposited by e-beam evaporation and annealed by RTA at 600℃ for 1 min in N_2 atmosphere. Schottky contact for the gate was formed by Ni/Au e-beam evaporation. The gate width of the device is 60μm, and the gate length is 1μm. The distance between the source and drain electrodes is 3μm.

The DC characteristics of the sample were measured in vacuum chamber with pressure lower than 50 Torr. Semiconductor parameter analyzer (HP4156B) was used to measure the DC characteristics. The sample was set on the stage that consists of sapphire plate, Au seat, Ti plate, sapphire plate and the heater. During the DC measurement, temperature was monitored by thermo couple set under the heater.

3. Results and Discussion

The DC characteristics of the HJFET were measured from room temperature to 500℃. Figure 1(a) shows the drain current-voltage characteristics of the HJFET at room temperature. The gate voltage V_{GS} has been changed from -5 to +2V by steps of 1V. The threshold voltage of the HJFET is –4V. When the drain voltage V_{DS} is high, the drain current I_D is saturated and becomes constant. Maximum transconductance g_{mmax} was 52mS/mm, and maximum drain current I_{Dmax} was 190mA/mm. Figure 1(b) shows the drain current-voltage characteristics at 300℃. In this case, the saturation characteristic becomes vague, and I_D is not completely saturated. Also, sufficient pinch-off characteristic is not observed.

Figure 2 shows the temperature dependence of g_{mmax}. When temperature increases over 300℃, the value of g_{mmax} decreases. The value of g_{mmax} at 500℃ was 24mS/mm. However, after cooled down to room temperature, the HJFET showed to the initial characteristics before increasing temperature. Thus, the Schottky contact metal for the gate electrode was not annealed by high temperature operation.

In order to investigate these temperature characteristics, we show, in Fig. 3, the temperature dependence of the drain current I_D and the gate leakage current I_G where V_{DS} and V_{GS} are fixed to 6V and 1V, respectively. Temperature behavior of I_D is similar to that of I_G as shown in Fig. 3. When temperature rises over 300℃, the both I_D and I_G increases drastically. These increasements of I_D and I_G over 300℃ well describe the temperature dependence of g_m.

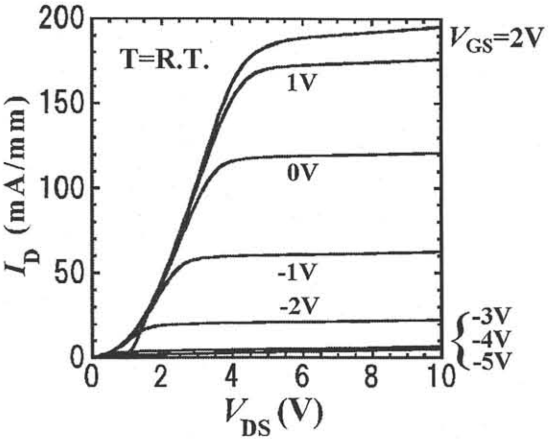

Fig. 1(a): Drain current I_D as a function of drain-source voltage V_{DS} at room temperature.

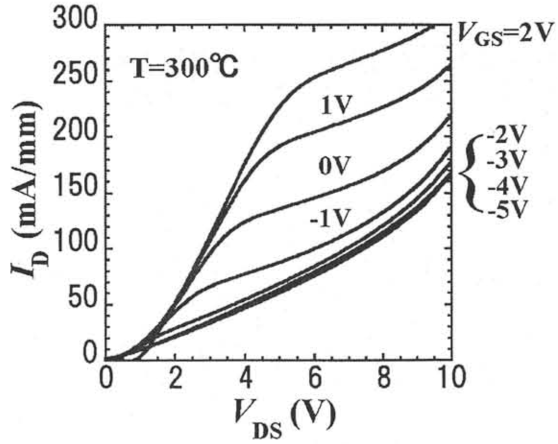

Fig. 1(b): Drain current I_D as a function of drain-source voltage V_{DS} at 300℃.

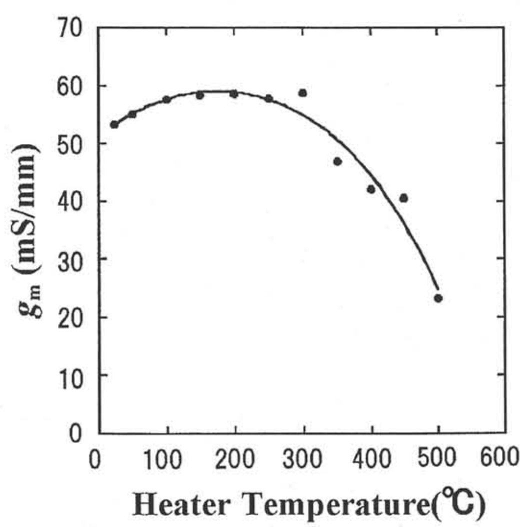

Fig. 2: Temperature dependence of maximum transconductance.

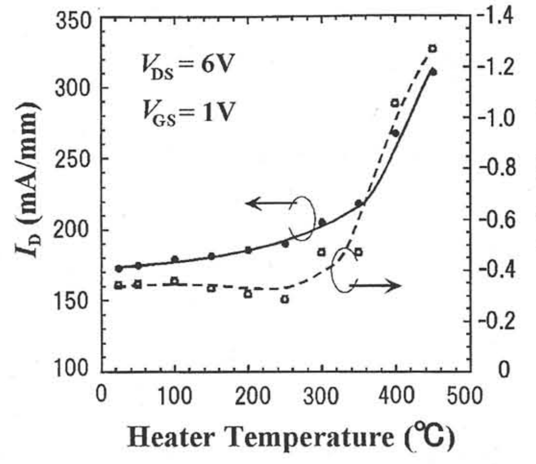

Fig. 3: Temperature dependence of drain current I_D and gate current I_G.

Although there are considered to be other reasons for the operation characteristic degradation at high temperature, such as low saturation drift velocity at high temperature, we consider that the degradation of our device characteristics at high temperature is mainly caused by the increase of the gate leakage current due to the low height of the Schottky barrier. We think that the high temperature operating characteristics will be improved by optimizing the gate Schottky contact structure, aluminum content in the barrier layer and so on.

4. Summary

In this study, AlGaN/GaN HJFET has been fabricated, and the DC operating characteristics were measured from room temperature to 500℃. We systematically investigated the temperature behavior of the gate leakage current, and found that the operating characteristic degradation of our device at high temperature is mainly caused by the increase of the gate leakage current due to the low height of the Schottky barrier.

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