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Temperature Dependence and Current Collapse of AlGaN/GaN Super Heterojunction Field Effect Transistor

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1. Introduction

Conventional AlGaN/GaN hetero-structure field-effect transistors (HFET) have the problems of current collapse which is a phenomenon of the decreasing drain currents. Surface passivation by insulation films and metal field plate designs are widely used as techniques to suppress current collapse in AlGaN/GaN based HFETs. The metal field plate enables reduction of the electric field concentration on the gate edge.

As an another way, the electric field concentration can be decreased by the coexistence of two-dimensional electron gas (2DEG) and two-dimensional hole gas (2DHG) generated by AlGaN/GaN polarization junctions [1-4]. The coexistence of high density 2DHG and 2DEG is achieved by optimizing the growth of GaN/AlGaN/GaN double hetero structures. Here, we report the results of our investigation on the DC characteristics of the fabricated super HFETs.

2. Experiment

The schematic cross sectional view of the fabricated HFETs are shown in Fig. 1 (a) and (b). The heterojunction structures were grown on a 2" sapphire substrate by metal organic chemical vapor deposition (MOCVD). The layer structure consists of a 1 μm thick undoped-GaN layer, a 45 nm thick undoped $Al_{0.23}Ga_{0.77}N$ layer, a 10 nm thick undoped-GaN layer and a 30 nm thick Mg doped p-GaN (3×10^{19} cm^{-3}) layer.

Electrical isolation was performed by forming mesa structure with reactive ion beam etching. The p-GaN layer on the channel was left and the dry etching was done on the AlGaN surface. The source and drain ohmic electrodes were formed by electron beam evaporation of Ti/Al/Ni/Au and rapid thermal anneal at 600 ˚C for 120 s in nitrogen. The specific contact resistance measured using the transmission line model was 3×10^{-5} Ωcm^2. The Ni/Au gate was formed by electron beam evaporation. There were no surface passivations. The AlGaN/GaN HFET was also fabricated on same wafer to compare the characteristics. The electrical behaviour of the fabricated HFET were measured using Agilent B1505A semiconductor parameter analyzer and Cascade Microtech Tesla Probe Station Platforms.

3. Results and Discussion

Figures 2 (a,b) and Fig. 3(a,b) show the temperature dependence of on state I_d-V_d characteristics and the off state drain leakage, respectively. In super HFET, the device gate length, p-GaN layer length, source-drain distance and gate-drain distance were L_g = 2 μm, L_p = 8 μm, L_{sd} = 22 μm, and L_{gd} = 17 μm respectively. At 25 ˚C, the threshold voltage V_{th} was -5.7 V, Id_{max} = 207 mA/mm, Gm_{max} = 54.7 mS/mm, the specific on resistance $R_{on}A$ = 3.9 Ωcm^2 and the breakdown voltage was V_B = 850 V. In super HFETs, on resistance increased with temperature because of mobility reduction. However, it operated normally even at 250 ˚C. The super HFET had good pinch-off properties at 250 ˚C. On the other hand, conventional HFET did not operate beyond 175 ˚C as it could not be turned off. For SuperHFET, the drift region between the base and drain is depleted at the off state at low drain voltages beyond which the drift region acts as an intrinsic region. Consequently, the tunnel current by heat is decreased. Because of the reduction in the drain leakage current, the high temperature operation became possible.

The on resistance before and after a stress were compared to assess current collapse. The applied stress was V_g = -15 V and V_d = 20-350 V. The applied stress time was 1 second. Figure 4 show the current collapse characteristics of super HFET and conventional HFET. On resistance of super HFET increases by 11 % under the 350 V stress voltage. On the other hand, on resistance of conventional HFET rose to 566 % even at 100 V stress voltage. At off state, the total charge is uniformly distributed in polarization junction area and a flat field distribution can be achieved. Therefore, it seems that the electric field to gate edge is eased and the current collapse is suppressed.

4. Conclusions

We investigated the temperature dependence and current collapse characteristics of the super HFET. The current collapse was improved by the polarization junction structure and the high temperature operation became possible. Therefore, it was shown that polarization junction structure by GaN/AlGaN/GaN double hetero structure is effective as a new electric field easing technology.

References

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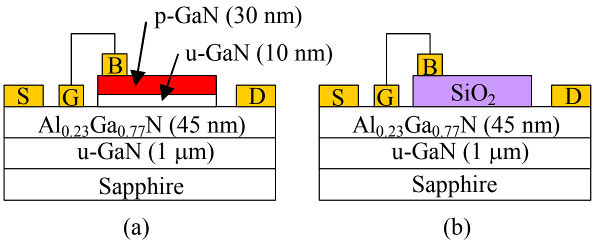

Fig.1. Schematic of (a) a super HFET, (b) a reference of conventional HFET. Structural dimensions are the same for both.

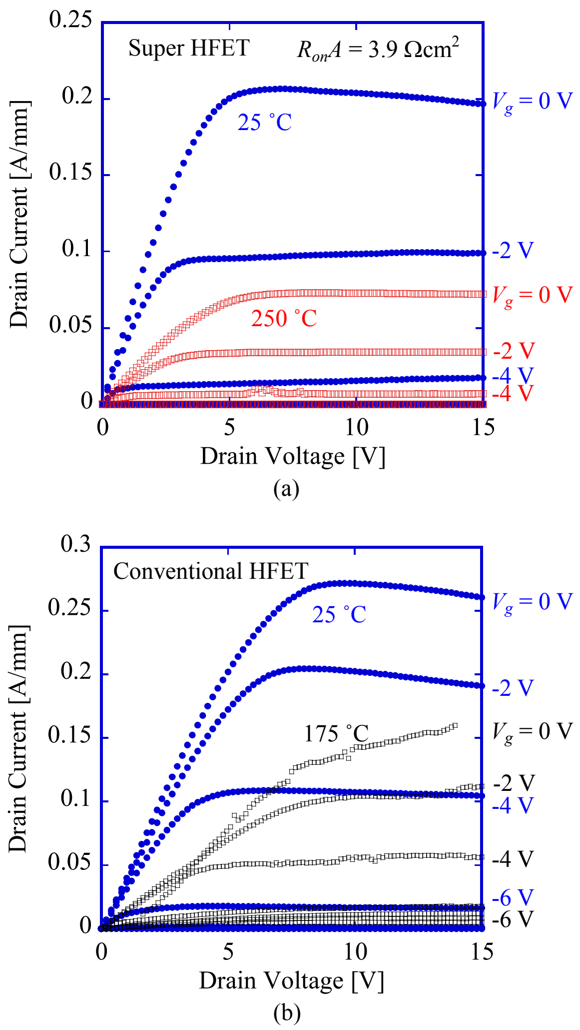

Fig.2. Temperature dependence of I_d-V_d characteristics of (a) the super HFET (b) the conventional HFET.

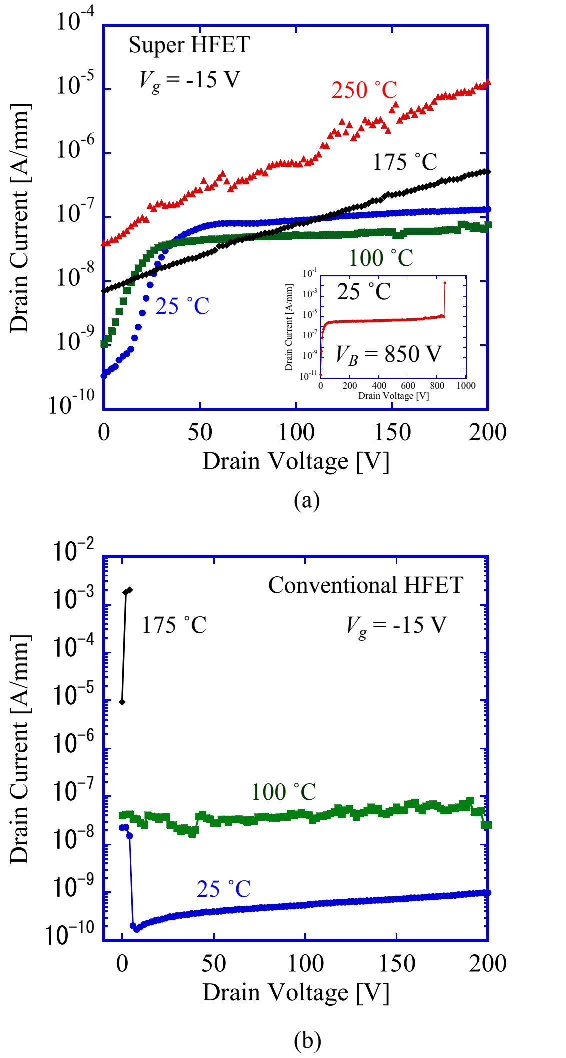

Fig.3. Off state I_d-V_d characteristics of (a) the super HFET (b) the conventional HFET. The inset shows the breakdown behavior of super HFET.

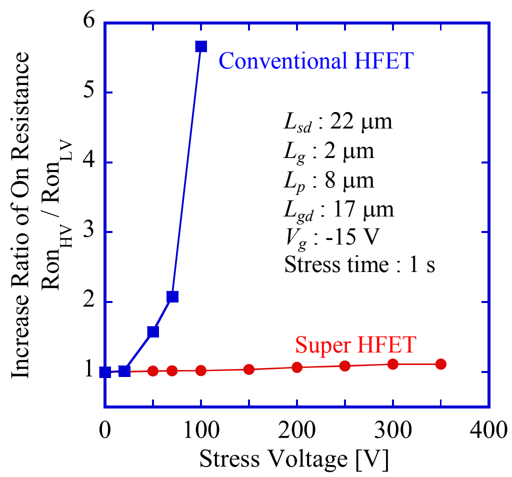

Fig. 4. Current collapse characteristics.