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AlGaN/GaN HFET using AlN/GaN Superlattice Barrier Layer

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1. Introduction

The AlGaN/GaN heterostructure field-effect transistor (HFET) has been attracting attention for its high voltage and high speed switching applications, since GaN has a high breakdown field strength of 3 MV/cm, and AlGaN/GaN HFETs have a two-dimensional electron gas channel with a low sheet resistance. In our previous study, we introduced a quasi-ternary alloy, an AlN/GaN superlattice, as the barrier layer of the heterostructure [1]. The employment of the AlN/GaN superlattice barrier layer is expected to reduce the alloy scattering and enhance the polarizations [2], and we obtained a low sheet resistance of less than 200 Ω/□. Thus, in this study, we fabricated a quasi-AlGaN/GaN HFET and investigated the advantage of its device characteristics as compared with a conventional AlGaN/GaN HFET using normal AlGaN alloy.

2. Experiments

The AlN/GaN superlattice-based quasi-AlGaN/GaN heterostructure was grown on a GaN template by rf-MBE. The growth conditions is detailed elsewhere [1]. The AlN/GaN superlattice has a period of 5-11, and the top layer was GaN layer. The thicknesses of the layers were 0.6-1.4 nm for the AlN and 0.3-4.7 nm for the GaN, as measured by XRD. The Al composition was determined from the thickness of the AlN and GaN layers. The total quasi-AlGaN layer thickness was 5-30 nm.

The HFET was fabricated using the quasi-AlGaN/GaN structure with Al composition of 31 %. The sheet resistance was 250 Ω/□. For electrical isolation, mesa structure was formed by reactive ion beam etching with chlorine gas. The source and drain ohmic electrodes, Ti/Al/Ni/Au were deposited by electron beam evaporation and annealed by rapid thermal annealing at 780 ˚C for 30 s in nitrogen gas ambient. The specific contact resistance measured with transmission line model was 1.2×10^{-5} $\Omega\cdot cm^2$. The gate metal with Ni/Au was formed by electron beam evaporation. No insulating layer under the gate was used.

For comparison, we also fabricated the HFET using conventional alloy-AlGaN/GaN heterostructure with an Al composition of 25 %. The thickness of the alloy-AlGaN barrier was 15 nm and the sheet resistance was 500 Ω/□.

The DC characteristics of the device were measured using Keithley 4200 semiconductor parameter analyzer.

3. Results and Discussion

Figure 1 and Fig. 2 show the I_d-V_d curves for the quasi-AlGaN/GaN HFET and the alloy-AlGaN/GaN HFET, respectively. Figure 3 and Fig. 4 show the G_m curves. The gate length L_g, source-gate distance L_{sg} and gate-drain distance L_{gd} were 2 μm, 2 μm and 8 μm, respectively.

The quasi-AlGaN/GaN HFET had good pinch-off properties. The threshold voltage V_{th} was -5.2 V, $I_{d,max}$ = 830 mA/mm, $G_{m,max}$ = 210 mS/mm, and on resistance R_{on} = 4.3 Ωmm. In contrast, the alloy-AlGaN/GaN HFET had the following properties: V_{th} = -3.1 V, $I_{d,max}$ = 175 mA/mm, $G_{m,max}$ = 80 mS/mm, and R_{on} = 30 Ωmm. The quasi-AlGaN/GaN HFET showed better DC characteristics than the alloy-AlGaN/GaN HFET due to its low sheet resistance. Especially, the on resistance was lowered for the quasi-AlGaN/GaN HFET was 1/7th lower than that of the alloy-AlGaN/GaN HFET, which is considered to be caused not only by the low sheet resistance but also by the influence of the current collapse.

Therefore the drain currents before and after a DC bias stress were measured in order to investigate current collapse characteristics. The applied DC stress was V_g = -10 V and V_d = 100 V. After the stress, Id-Vd curves were measured at V_g = 0 V at the seep mode. Figure 5 and Fig. 6 show the results of quasi-AlGaN/GaN HFET and alloy-AlGaN/GaN HFET, respectively. In the quasi -AlGaN/GaN HFET, the drain current change after the stress was slightly less than 3 %. On the other hand, the alloy-AlGaN/GaN HFET showed the large drain current reduction due to current collapse. We think that the AlN layers in the superlattice prevent the accelerated channel electrons from passing through the barrier layer, and reduce the number of electrons trapped at the barrier surface levels.

4. Conclusions

We investigated the DC and current collapse characteristics of the quasi-AlGaN/GaN HFET. By employing the AlN/GaN superlattice barrier layer, the characteristics of AlGaN/GaN HFETs were significantly improved due to the low sheet resistance. Moreover, the influence of the current collapse of the quasi-AlGaN/GaN HFET was drastically suppressed as compared with the alloy-AlGaN/GaN HFET.

References

[1] Y. Kawakami et al., App. Phys. Lett. **90** (2007) 242112.
[2] Y. Kawakami et al., J. Cryst. Growth **300** (2007) 168.

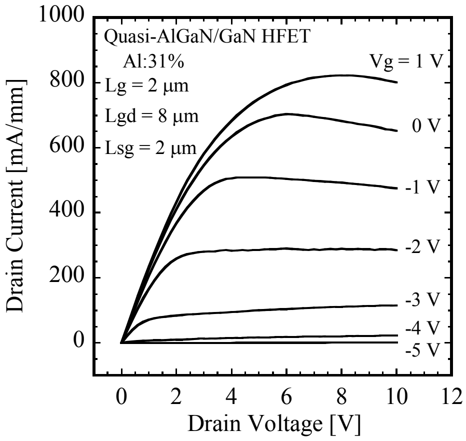

Fig. 1. I_d-V_d curve for the quasi-AlGaN/GaN HFET with an Al composition of 31 %.

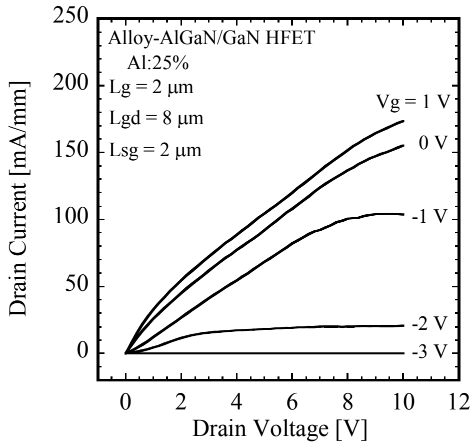

Fig. 2. I_d-V_d curve for the alloy-AlGaN/GaN HFET with an Al composition of 25 %.

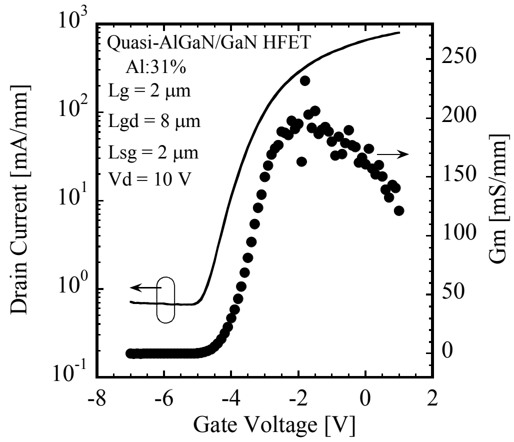

Fig. 3. G_m curve for the quasi-AlGaN/GaN HFET with an Al composition of 31 %.

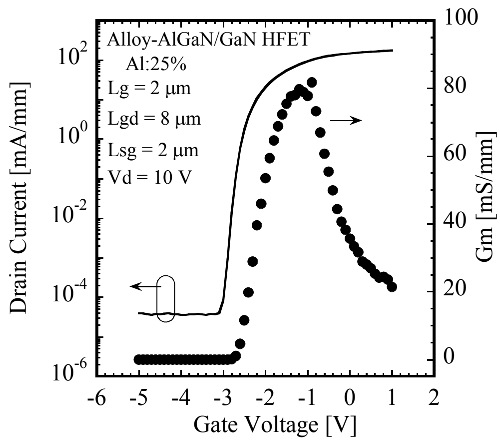

Fig. 4. G_m curve for the alloy-AlGaN/GaN HFET with an Al composition of 25 %

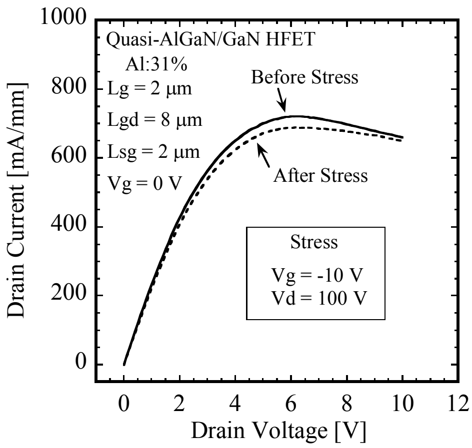

Fig. 5. Drain currents before and after stress of quasi-AlGaN/GaN HFET. Difference between currents $I_{d,max}$ was about 3 %.

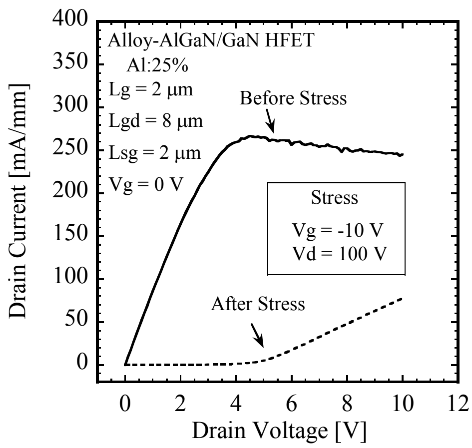

Fig. 6. Drain currents before and after stress of alloy-AlGaN/GaN HFET. The large difference between these drain currents was due to current collapse.