Electron Transport Properties in AlGaN/GaN
Heterostructure Field Effect Transistors at High Electron Densities

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AlGaN/GaN heterostructure field effect transistors (HFET) have recently being attracted intense attention, because they have emerged as promising candidates for high-voltage, high-power, and high-temperature microwave applications. For further improving device performances, understanding electron transport properties at high electron densities is indispensable, because the advantage of nitride HFETs is largely ascribed to their larger two-dimensional electron gas (2DEG) densities (in the order of 10^{13} cm^{-2}) compared to those in FETs of other materials. We have examined electron transport properties in AlGaN/GaN HFETs at high electron densities by magnetoresistance and Hall effect measurements at low temperatures.

Figure 1 shows the result of the magnetoresistance (R_{xx}) measurement at 0.3 K for a HFET sample (300 Å Si-$Al_{0.13}Ga_{0.87}N$/1 μm undoped GaN/1000 Å AlN/SiC substrate). The Shubnikov-de Hass (SdH) oscillations are observed, which can be fitted by the compositions of two oscillations. The electron densities deduced from the short and long periods are 5.8×10^{12} and 1.6×10^{12} cm^{-2} (excited energy level), respectively. Hence, the total 2DEG density determined by SdH oscillation is estimated to be $N_{SdH} = 7.4 \times 10^{12}$ cm^{-2}. On the other hand, the electron density determined by Hall effect measurement at 0.3 K is $N_{Hall} = 1.38 \times 10^{13}$ cm^{-2}. Therefore, excess electrons of $N_{Hall} - N_{SdH} = 6.4 \times 10^{12}$ cm^{-2} are expected to exist in the AlGaN layer, because GaN channel layer is insulating.

To examine the location of excess electrons in HFET, the Hall effect measurement was performed at 4.2 K under gate-voltage application for a HFET sample with almost the same structure (300 Å Si-$Al_{0.15}Ga_{0.85}N$/1 μm undoped GaN/1000 Å AlN/SiC substrate). Figures 2 and 3 show the dependence of the 2DEG density (N_S) on the gate-voltage (V_g), and the dependence of the 2DEG mobility on N_S, respectively. Since the mobility is observed to decrease above $N_S = 9 \times 10^{12}$ cm^{-2} in Fig. 3, excess electrons are expected to exist at $N_S = 1.06 \times 10^{12}$ cm^{-2} in this sample. However, N_S is observed to almost linearly change with V_g up to this N_S value in Fig. 2, indicating that the capacitance of HFET ($\propto dN_S/dV_g$) is kept to be almost constant. This indicates that excess electrons exist not in the midst of the AlGaN layer but near the AlGaN/GaN interface. Figure 4 shows the simulated results of the 2DEG distribution at $N_S = 1.05 \times 10^{12}$ cm^{-2}, showing that excess electrons exist near the heterointerface. This result is consistent with the above expectation. Therefore, excess electrons are not expected to seriously damage the device performance, because excess electrons are thus accommodated near the heterointerface so that the capacitance of the device is kept almost constant.

In conclusion, we have examined electron transport properties in AlGaN/GaN HFETs at high electron densities over 10^{13} cm^{-2} by magnetoresistance and Hall effect measurements at low temperatures. In AlGaN/GaN HFET, excess electrons are accommodated not in the midst of the AlGaN but in the AlGaN barrier near the interface. This situation is different from that in the case of AlGaAs/GaAs HFETs but is akin to that in the case of Si-MOS FETs. This feature originates from the existence of the large polarization charges at the AlGaN/GaN heterointerface, and is favorable for high-power device operation with high electron densities.

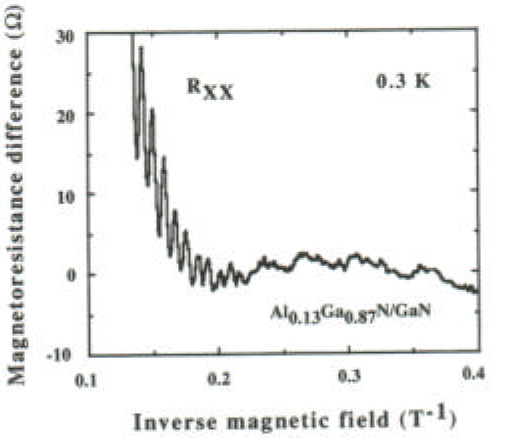

Fig. 1 Magnetoresistance (R_{XX}) of $Al_{0.13}Ga_{0.87}N/GaN$.

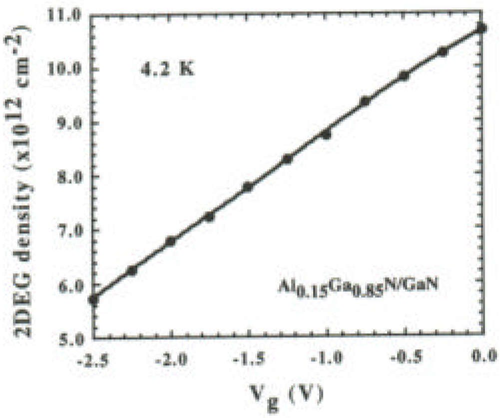

Fig. 2 Dependence of 2DEG density on gate-voltage (V_g) in $Al_{0.15}Ga_{0.85}N/GaN$.

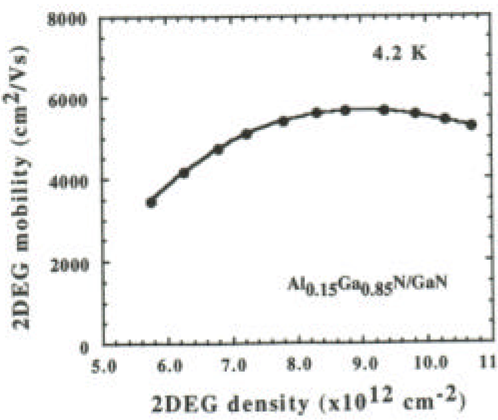

Fig. 3 Dependence of 2DEG mobility on 2DEG density in $Al_{0.15}Ga_{0.85}N/GaN$.

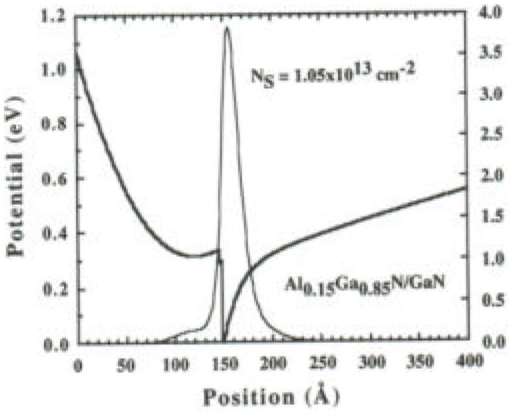

Fig.4 Simulated electron distribution in $Al_{0.15}Ga_{0.85}N/GaN$.