Fabrication of AlGaN/GaN HEMTs with buried p-layers

Kenji Shiojima, Naoteru Shigekawa*, and Tetsuya Suemitsu

NTT Photonics Laboratories, NTT Science & Core Technology Laboratory*
3-1 Morinosato Wakamiya, Atsugi-shi, Kanagawa 243-0198, Japan
Tel. +81-46-240-2787. Fax +81-46-240-2872, E-mail: shiojima@aecl.ntt.co.jp

GaN-based FETs are being investigated for high-power and high-frequency applications. GaN has a higher breakdown field and larger saturation velocity than GaAs and also exhibits excellent ballistic conduction (larger velocity over shoot effect) under a high electric field (>100 kV/cm). Designing an FET structure with shorter gate length (Lg) and larger electrical field in the channel could exploit these advantages. Scaling down a device so that Lg is around 0.1 μm, would produce a short channel effect which would result in poor pinch-off characteristics. In addition, because of the high field, device breakdown due to impact ionisation would be observed [1]. In III-V devices, such as GaAs and InP FETs, these problems are overcome by inserting lightly-doped buried p-layers under the channel layers [2, 3]. The buried p-layer raises the potential barrier height for electrons in the channel and reduces it for holes. Therefore, electron confinement is improved, which results in a reduction of the short channel effect, and holes are likely to escape from the channel, which reduces the possibility of avalanche breakdown. In this paper, we describe the application of buried p-layers to AlGaN/GaN HEMTs.

Figure 1 shows the cross-sectional device structure. The epitaxial layer structure was grown by metal organic chemical vapor deposition (MOCVD) and comprises a Mg-doped GaN buried p-layer (1.5 μm, $N_A=4\text{x}10^{16}$ cm^{-3}), an undoped-GaN channel layer (400 nm), and an undoped $Al_{0.15}Ga_{0.85}N$ barrier layer on a (0001) plane sapphire substrate. Piezo-polarization induced charges without doping at the AlGaN/GaN interface. Ti/Al metallization layers were evaporated and annealed at 800° C for 30 s to form ohmic contacts. Ni/Au metallization layers were used for gate Schottky contacts. The device isolation was done by electron-cyclotron-resonance reactive-ion-etching (ECR RIE) using Cl_2 gas. Devices with Lgs of 1.5 μm, and gate widths of 100 μm were fabricated without surface passivation.

Figure 2 shows typical I-V curves for a 1.5-μm-gate AlGaN/GaN HEMT with a buried p-layer. Good saturation and pinch-off characteristics were observed. The maximum drain current (Id) was 92 mA/mm. The on-state breakdown voltage was 70~90 V. Figure 3 shows the gate-voltage (Vg) dependencies of Id and the transconductance (g_m) when the source-drain voltage is 15 V. Typical HEMT's characteristics, in which Id increases linearly with Vg, were seen. The threshold voltage was –2 V, and the maximum g_m was about 25 mS/mm.

To evaluate the effect of the buried p-layer, one-dimensional calculations by solving the Poisson equations were carried out for metal/AlGaN/GaN Schottky contacts with or without buried p-layers. Depth profiles of potential and electron density under the gate were simulated for the structure shown in Fig. 1. The Schottky barrier height on metal/AlGaN was 1.1 eV. Taking account of piezo-polarization, we found that a sheet carrier density of $5\text{x}10^{12}$ cm^{-2} was induced at the interface of AlGaN/GaN. The background impurity concentration for undoped-GaN channel layer was assumed to be $1\text{x}10^{15}$ cm^{-3}. Either a buried p-layer or an undoped GaN layer ($1\text{x}10^{15}$ cm^{-3}) was under the GaN channel. Figures 4 (a) and (b) show the results for with and without a buried p-layer, respectively. They clearly show that the buried p-layer raises the potential under the channel and cuts off the tail of the carrier profile.

For observation of the carrier confinement by the p-layer of the real devices, capacitance-voltage (C-V) measurements were conducted for circular large-area (100 μmϕ) Schottky contacts to eliminate the fringe-capacitance contribution. We prepared a control sample with a HEMT structure on undoped GaN (undoped-AlGaN(5 nm)/Si-doped n-AlGaN (10 nm, $Nd=1\text{x}10^{19}$ cm^{-3})/ undoped -AlGaN(3 nm)/ undoped -GaN(3 μm)), which has almost same threshold voltage of -2 V. Figure 5 shows the carrier profiles for samples with and without the p-layer. A steeper profile with the p-n junction was confirmed, and this could be used to suppress the short channel effect.

In conclusion, we have demonstrated, for the first time, AlGaN/GaN HEMTs with buried p-layers. A

1.5-μm-gate device showed good pinch-off characteristics, a g_m of 25 mS/mm, and a breakdown voltage of 70~90 V. Carrier confinement by the p-n junction was confirmed. These results indicate that the insertion of p-layers can be applied to GaN FETs in the same manner as III-V semiconductor electron devices.

References

1 N. Dyakonva, A. Dickens, M. S. Shur and R. Gaska, Electron. Lett., 1998, **35**, pp. 1699-1700.

2 T. Suemitsu, T. Enoki, and Y. Ishii, Electron. Lett., 1995, **31**, pp. 758-759.

3 K. Nishimura, K. Onodera, K. Inoue, M. Tokumitsu, F. Hyuga, and K. Yamasaki, IEICE Trans. Electron., 1995, **E78-C**, pp. 907-909.

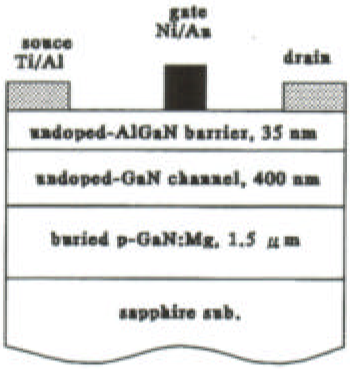

Fig. 1 Schematic cross-section of AlGaN/GaN HEMTs having lightly-doped buried p-layers under the channel.

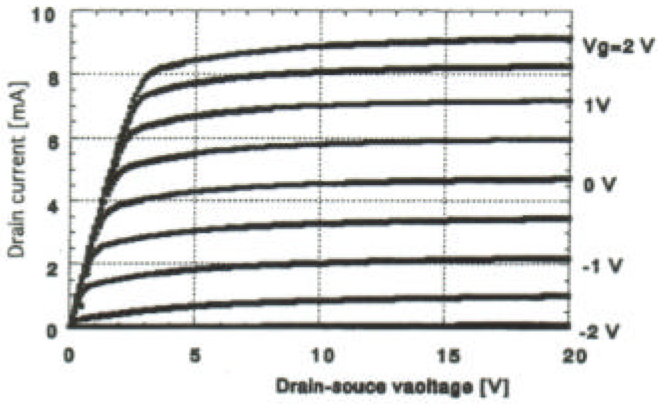

Fig. 2 Typical I-V characteristics for a 1.5-μm-gate AlGaN/GaN HEMT with a buried p-layer.

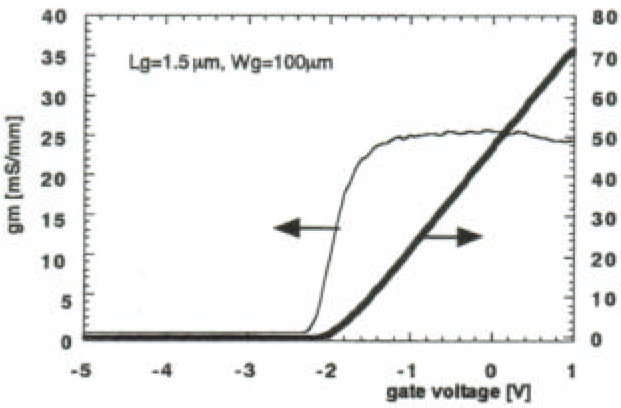

Fig. 3 Gate-voltage dependencies of drain current and transconductance.

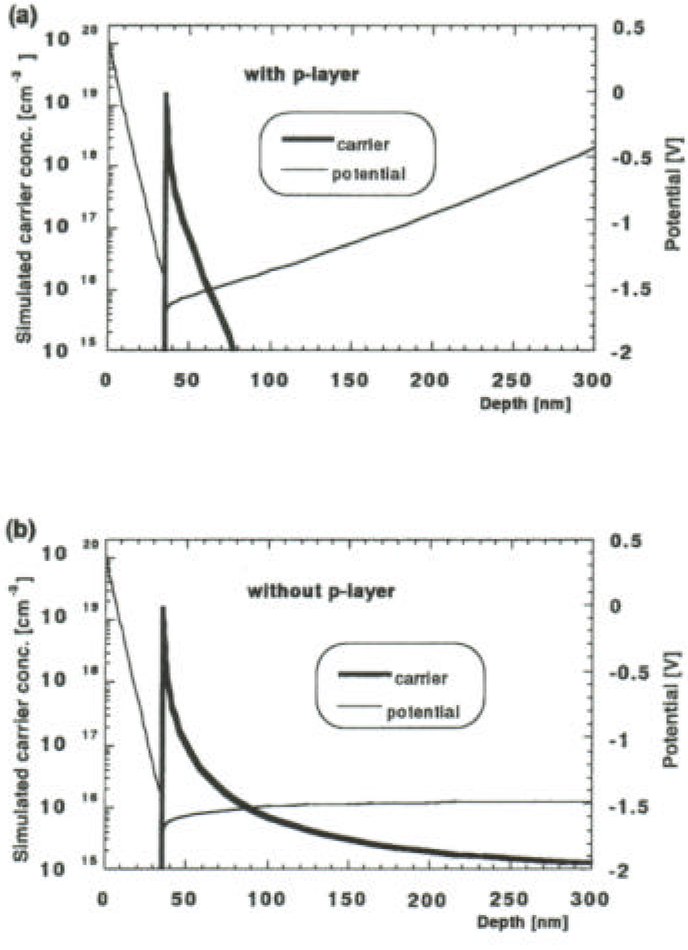

Fig. 4 Simulation results of the depth profiles of potential for electrons and electron density for metal/AlGaN/GaN Schottky contacts: (a) with and (b) without a buried p-layer.

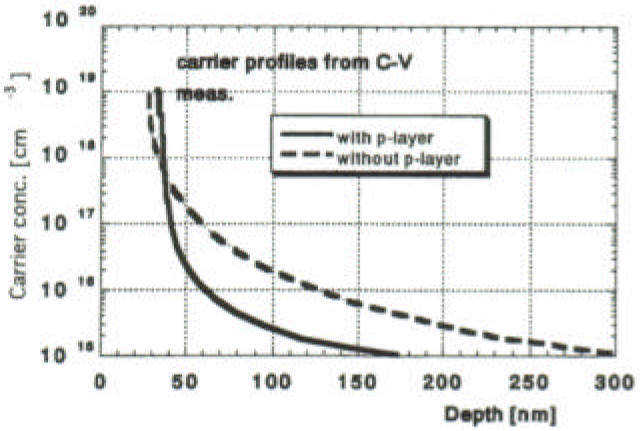

Fig. 5 C-V carrier profiles for metal/AlGaN/GaN structures with and without a buried p-layer.