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DC characteristics in Nearly Lattice-Matched InAlN/AlGaN Heterostructure Field-Effect Transistors

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Abstract

A nearly lattice-matched InAlN/AlGaN HFET was fabricated and evaluated for the first time. The fabricated device showed a good pinch-off characteristic with a high breakdown field. Simple device calculation based on experimental results showed a possibility that a low specific on-resistance below 2 mΩ cm² can be obtained in the case where contact resistivity is lower than 1 × 10^{-5} Ω cm².

1. Introduction

Recently, AlGaN-channel 2DEG heterostructures and field effect transistors (FETs) have been attracting much attention owing to their high breakdown voltages [1]. We also reported that nearly lattice-matched InAlN/AlGaN heterostructures with high 2DEG densities were successfully grown by MOCVD, and discussed their low 2DEG mobilities as well as high 2DEG mobilities [2,3]. To consider the actual application of the InAlN/AlGaN heterostructures to high-power electronic devices, it is necessary to evaluate their device characteristics. In this paper, we present the results of the fabrication and characterization of InAlN/AlGaN HFETs.

2. Experimental

An $In_{0.12}Al_{0.88}N/Al_{0.21}Ga_{0.79}N$ heterostructure was grown in a horizontal metalorganic chemical vapor phase deposition (MOCVD) system (Taiyo Nippon Sanso SR2000). A 2-in-diameter AlN/sapphire template (DOWA Electronics) was used as an underlying substrate, which had a 1-µm-thick epitaxial AlN film on a c-face sapphire. The sample structure consisted of, from bottom to top, a 2-µm-thick AlGaN channel layer, a 1-nm-thick AlN interfacial layer, and a 10-nm-thick InAlN barrier layer. The 1-nm-thick AlN interfacial layer was employed for the purpose of not only enhancing 2DEG carrier confinement in the channel, but also of protecting the AlGaN surface during the growth interval. The InAlN barrier layer was grown to be nearly lattice-matched to the underlying AlGaN channel layers. The basic electrical properties of the sample are summarized in Table 1.

Table I. 2DEG density (N_s), 2DEG mobility (μ) and sheet resistance (R_{sh}) of InAlN/AlGaN heterostructures measured by Hall effect [2,3]

Sample structure	N_s (cm^{-2})	μ (cm^2/Vs)	R_{sh} (Ω/sq.)
$In_{0.12}Al_{0.88}N/Al_{0.21}Ga_{0.79}N$	2.8 x10^{13}	162	1,477

The device fabrication was conducted using conventional photolithographic method. Ohmic patterns were formed by the evaporation of Ti/Al (15/60 nm), which were subsequently annealed at 550 °C in nitrogen atmosphere. Gate Schottky electrodes were formed by the evaporation of Pd/Ti/Au (40/20/60 nm). The device dimensions were as follows: source-to-drain distance L_{sd} = 9 µm, gate-to-drain distance L_{gd} = 4 µm, gate length L_g = 2 µm and gate width W_g = 15 µm. Current–voltage (*I*–*V*) characteristics were measured using a semiconductor parameter analyzer.

3. Results and discussion

Fig. 1 shows a typical DC characteristic for the fabricated InAlN/AlGaN HFET. As seen in this figure, the fabricated device exhibited a good pinch-off property. The maximum drain current density was measured to be approximately 80 mA/mm.

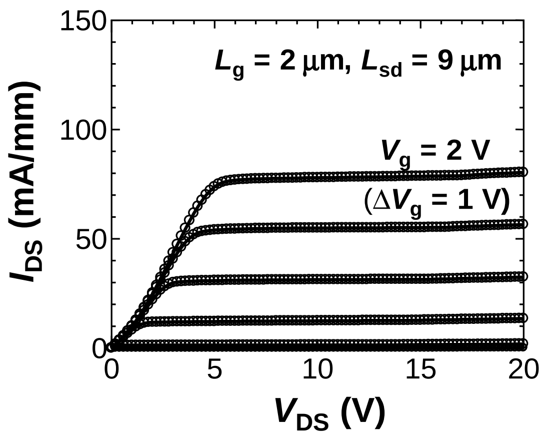

Fig. 1. Drain-to-source *I-V* characteristic for InAlN/AlGaN HFET.

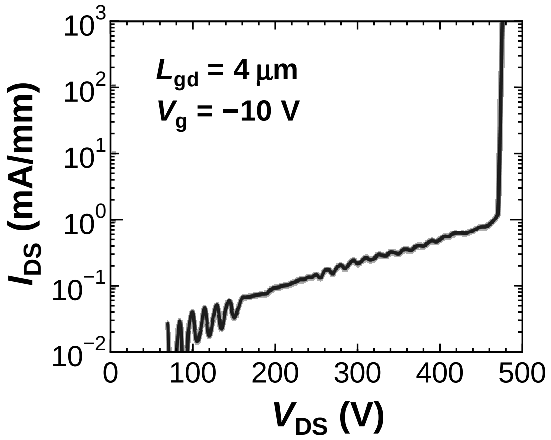

Fig. 2. The result of three terminal off-state breakdown voltage measurement.

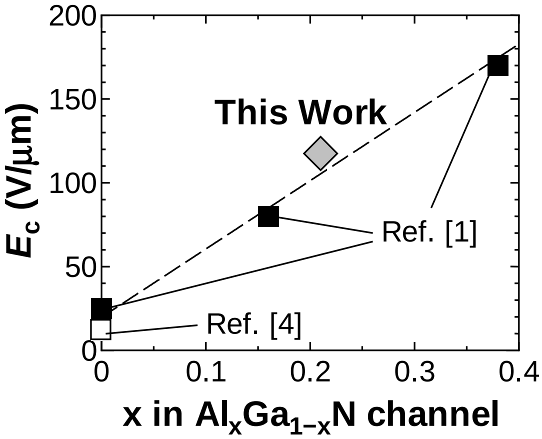

Fig. 3. Relationship between critical electric field and Al content in AlGaN channel layers in HFETs. All the data are measurement results for FETs without FP electrodes.

Using transmission line model (TLM) patterns, the contact resistivity (ρ_c) was measured to be over 2 × 10^{-3} Ω cm^2, which means that the contact resistance occupies a considerably large part of the total device resistance. In other words, we can expect a better drain current property by lowering the contact resistance value.

Three terminal off-state breakdown voltage (V_B) was measured at an applied gate voltage of -10 V and by increasing the drain-to-source voltage. The measurement result is shown in Fig.2. As seen in this figure, the breakdown voltage was measured to be 470 V at drain current density of 1 mA/mm. Correspondingly, the critical electric filed at the off-state breakdown (E_c) was estimated to be 118 V/µm. Fig.3 plots of the relationship between E_c and Al content in AlGaN channel layers, in which the results of AlGaN/AlGaN HFETs reported in Ref. [1] and [4] are also plotted. All the data are results of FETs without filed-plate (FP) electrodes. When comparing with the reported values, our present data seems to be reasonable.

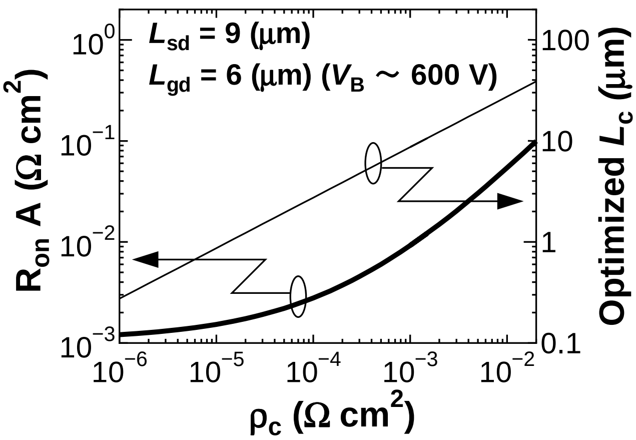

Fig. 4. Calculated relationships of Ron*A vs. ρ_c and of optimized contact length (L_c) vs. ρ_c for optimized InAlN/AlGaN HFETs with a breakdown voltage of 600 V. The calculation was conducted in accordance with Ref. [4], on the basis of FETs without FP electrodes.

We attempted to calculate specific on-resistance (Ron*A) limits for InAlN/AlGaN HFETs. Fig. 4 shows the calculation result about the dependence of Ron*A on ρ_c. This result was obtained by assuming an $In_{0.12}Al_{0.88}N$/$Al_{0.21}Ga_{0.79}N$ HFET with L_{gd} = 6 µm, which corresponds to $V_B \approx 600$ V, without FP electrodes. For the Ron*A calculation, drift resistance was estimated on the basis of R_{sh} in Table 1, and source and drain electrode lengths were optimized by means reported in Ref. [4]. Fig. 4 indicates that a low Ron*A value below 2 mΩ cm^2 can be obtained in the case where ρ_c is lower than 1 × 10^{-5} Ω cm^2. This value seems to be comparable with Ron*A limits for optimized GaN-channel HFETs with FP electrodes [4]. This means that further improvement can be expected in InAlN/AlGaN HFETs with FP electrodes.

4. Conclusions

A nearly lattice-matched InAlN/AlGaN HFET was fabricated and evaluated for the first time. The fabricated device showed a good pinch-off characteristic with a drain current density of approximately 80 mA/mm and with a breakdown field of 118 V/µm. Simple device calculation based on experimental results indicated that a low Ron*A value can be obtained at a breakdown voltage of 600 V, even without the use of FP electrodes, by achieving a contact resistivity value of lower than 1 × 10^{-5} Ω cm^2.

Acknowledgements

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