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High-Gain Multi-Finger AlGaN/GaN HJFETs with 0.3-μm Gate-Length for K- and Ka-Band Applications

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1. Introduction

Heterojunction field effect transistors (HJFETs) based on the AlGaN/GaN material system are promising for high-power applications at microwave frequencies. In fact, a number of AlGaN/GaN HJFETs have demonstrated a power density several times larger than what is possible in GaAs FETs [1]. Though these power densities have mainly been measured at frequencies lower than 10 GHz, AlGaN/GaN HJFETs are also candidates for higher-frequency applications, such as used as K- and Ka-band power amplifiers in satellite communication systems. To date, though, only the power performance at f=18 GHz of an AlGaN/GaN HJFET with a narrow gate of 76 μm has been reported [2].

We have fabricated AlGaN/GaN HJFETs with a structure suitable for near-millimeter wave applications; *i.e.*, with a sub-half-micron gate-length made by electron-beam (EB) lithography, and multi-gate fingers with air-bridge interconnection. The fabricated multi-finger FETs exhibit a small-signal power gain high enough to enable K- and Ka-band applications as well as very uniform dc performance. In addition, the air-bridge interconnection prevents SiO_2-film-induced current-collapse as well as reducing the parasitic capacitance.

2. Device Fabrication

A cross-sectional view of the fabricated AlGaN/GaN HJFET is shown in Fig. 1. The AlGaN/GaN modulation-doped structure was grown on a C-plane sapphire substrate by MOVPE. Source and drain ohmic contacts were formed with Ti/Al by annealing at 650℃ for 30 s. The contact resistance was 2.0 Ωmm The devices were isolated by N-ion implantation with a dose of 1×10^{14} cm^{-2} at energies of 20 keV and 100 keV. A T-shaped gate was patterned from two layers of PMMA/P(MMA-MAA) resists which were exposed in a single step using direct-write EB lithography. The Schottky gate was formed with Ni/Au by a lift-off method. The minimized gate length L_g was 0.25 μm, and the minimized source-gate L_{sg} and gate-drain L_{gd} distances were 0.5 μm, as measured by SEM.

A comb-type multi-gate configuration is usually used in microwave power FETs. In this structure, the gate bus-line must cross over the source electrode. We formed the crossover structures by air-bridge interconnection instead of by inserting an insulating SiO_2 film since we found an SiO_2 film on the surface induced significant current collapse in our preliminary experiments on AlGaN/GaN HJFETs (Fig. 2). Three unit-gate widths W_{gu} of 25 μm, 50 μm and 120 μm were fabricated. The multi-finger FETs were made with an offset gate structure; *i.e.*, L_g=0.3 μm, L_{sg}=0.5 μm and L_{gd}=0.9 μm. An SEM image of 0.3-μm multi-gate-fingers and air-bridge overlay structure is shown in Fig. 3.

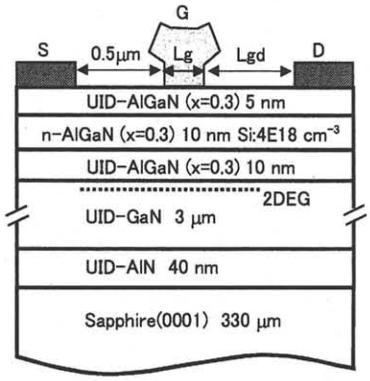

Fig. 1 Schematic cross-section of AlGaN/GaN HJFETs, L_{gd}=0.5 μm for L_g=0.25 μm, and L_{gd}=0.9 μm for L_g=0.3 μm

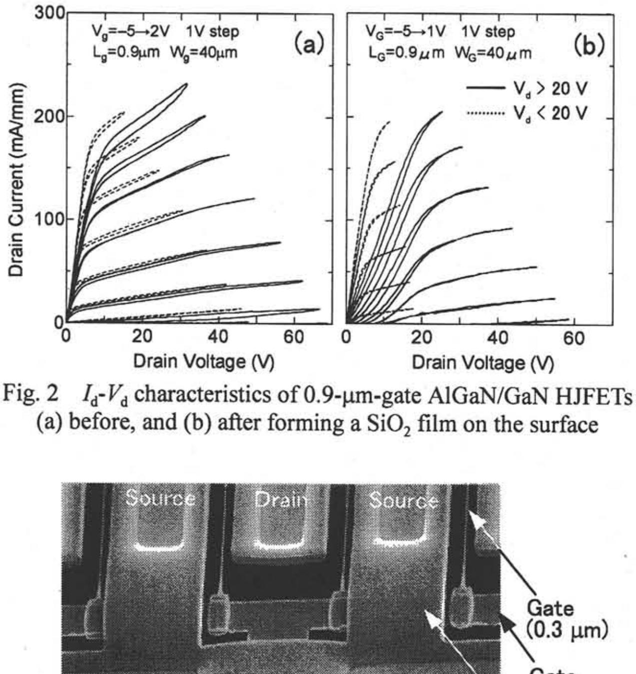

Fig. 2 I_d-V_d characteristics of 0.9-μm-gate AlGaN/GaN HJFETs (a) before, and (b) after forming a SiO_2 film on the surface

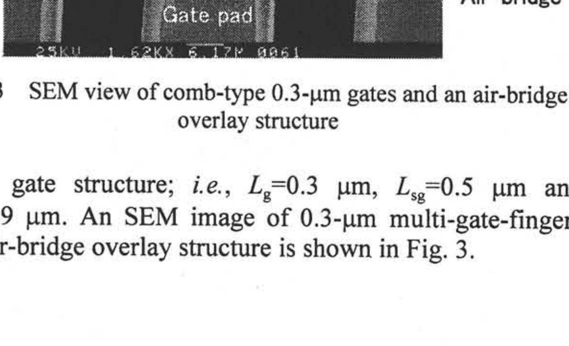

Fig. 3 SEM view of comb-type 0.3-μm gates and an air-bridge overlay structure

3. Multi-finger FET Performance

The I_d-V_d characteristics of the fabricated HJFETs with the 0.3-μm gate-length and different gate peripheries are shown in Fig. 4. Each gate-finger operated so uniformly that the drain current was almost proportional to the total gate-width from 50 μm to 1.2 mm (120 μm×10). The peak transconductance g_{mmax} was 127 mS/mm. The off-state breakdown voltage was higher than 100 V when L_{gd}=0.9 μm. No significant current collapse was observed since a SiO_2 film was not used on the surface.

Figure 5 shows the current gain $|h_{21}|^2$, the maximum available power gain *MAG*, and the unilateral power gain G_{umax}, calculated from on-wafer s-parameter measurements of the fabricated HJFETs with L_g=0.25 μm and L_{sg}=L_{gd}=0.5 μm. A peak cut-off frequency f_T of 40 GHz and a peak maximum oscillation frequency f_{max} of 97 GHz were obtained by extrapolating $|h_{21}|^2$ and G_{umax} at -6 dB/octave. An intrinsic f_T of 58 GHz and an intrinsic f_{max} of 130 GHz are obtained by subtracting the measured parasitic impedance of the open- and short-pad patterns. The relatively high f_{max}/f_T ratio came from the suppression of short channel effects by using a thin (25 nm) AlGaN layer.

The measured *MAG* and maximum stable power gains *MSG* of 0.3-μm gate FETs with various gate peripheries are compared in Fig. 6. Two- and six-finger FETs with W_{gu}=50 μm demonstrate very similar RF performance; *i.e.*, *MSG*=13 dB at *f*=18 GHz and *MAG*=9.5 dB at *f*=30 GHz. These gains are comparable with those of 0.35-μm gate-length AlGaAs/InGaAs PHEMTs used in K-band power applications [3]. The values of f_T and *MSG* increased slightly with the unit-gate width since the influence of the parasitic capacitance became weaker. When the gate periphery became large (W_g=120 μm×10), however, the *MSG/MAG* break-point frequency $f_{K=1}$ decreased due to the increased gate resistance, resulting in a degraded power gain at $f > 10$ GHz. These findings will be useful for designing a unit-cell layout suitable for the required frequency. In addition to an inherently high breakdown voltage, AlGaN/GaN HJFETs exhibit small-signal gains comparable with AlGaAs/InGaAs PHEMTs. Therefore, these results convince us that AlGaN/GaN HJFETs are promising candidates for use in K- and Ka-band amplifiers and MMICs

4. Summary

We have successfully fabricated multi-finger AlGaN/GaN HJFETs with 0.3-μm gate-length using air-bridge interconnection. The fabricated multi-finger HJFETs showed a small-signal power gain high enough for K- and Ka-band applications, due to the sub-half-micron gates and the minimized parasitic capacitance, as well as uniform dc characteristics. In addition, they were free from current collapse because no SiO_2 film was used on the surface. These results demonstrate the high potential of AlGaN/GaN HJFETs for near-millimeter-wave applications.

Acknowledgements

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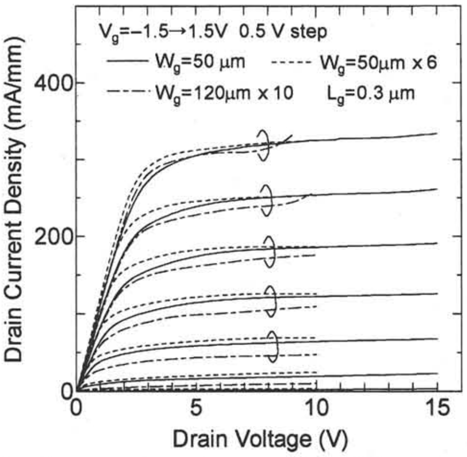

Fig. 4 Current-voltage characteristics of 0.3-μm-gate AlGaN/GaN HJFETs with different gate peripheries

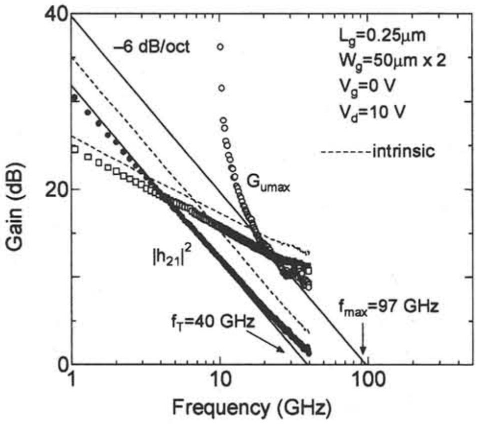

Fig. 5 Small signal gains of 0.25-μm-gate AlGaN/GaN HJFETs as a function of frequency

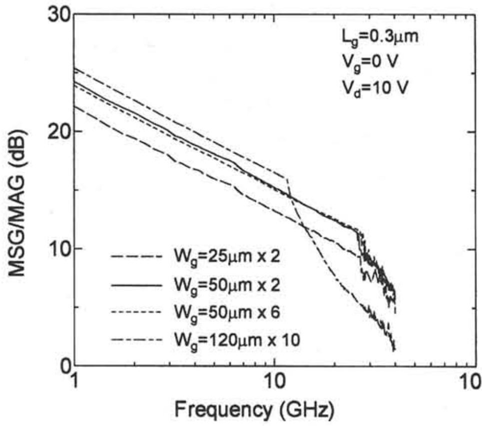

Fig. 6 MSG/MAG of 0.3-μm gate AlGaN/GaN HJFETs with different gate peripheries

References

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