77 GHz Power Amplifier MMIC using 0.1 μm Double-Deck Shaped (DDS) field-plate gate AlGaN/GaN HEMTs on Si Substrate

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Monolithic Microwave Integrated Circuits (MMICs) are essential components of modern communication and radar systems at millimeter-wave frequencies [1]. GaAs and InP technology has limited the high-power amplifiers due to the properties of those semiconductor materials. AlGaN/GaN high electron mobility transistors (HEMTs) on SiC substrates which have better lattice match and good thermal management are expected for high frequency power applications for the next generations, although SiC substrates are lacked for large-size wafer availability [2]. GaN HEMTs grown on high-resistivity Si (111) substrates provide low cost solutions with good thermal conductivity, but more seriously suffer from current collapse effects. Recently, good current collapse and off-state breakdown characteristics were reported with advanced epitaxial structures in 0.1 μm AlGaN/GaN HEMTs on Si with maximum oscillation frequency up to 200 GHz [3]. However, only GaN on Si power amplifier for millimeter-wave with output power of over 12 dBm at 76 GHz was reported [4]. In this work, we have developed highly uniform double-deck shaped (DDS) [5] field-plate gate GaN HEMTs on Si with f_{max} of 160 GHz (f_T = 70 GHz) and demonstrated 3-stage power amplifier with 20.1 dBm at 77 GHz for 18 V drain bias.

Fig.1 shows a device structure used in GaN HEMTs MMICs. Sample was pre-deposited with 30 nm SiNx film before ohmic contacts and mesa isolation processes were performed. After 60 nm SiNx film was re-deposited, gate electrodes with gate length of 0.1 μm were formed. The 50 nm gate field-plate was defined to mitigate current collapse phenomena and gate-to-drain breakdown. DDS gate structure was fabricated with etch-back process of thick resist to reduce gate resistances which is the most important factor of increase f_{max}. A NiCr TFR with targeted sheet resistance of 20 Ω/sq and metallization of coplanar waveguide (CPW) line were followed.

Fig. 2 shows gate-to-drain breakdown voltage characteristics with gate field-plate and without gate field-plate. We recorded breakdown voltage at I_G = 1 mA/mm and more than 40 V higher breakdown voltage was achieved with gate field-plate device. The uniformity of the fabricated devices was simply estimated with transfer curves of 35 devices and highly uniform characteristics were shown in Fig. 3 with the average maximum extrinsic transconductance of 427 mS/mm at V_{DS} = 5 V and the threshold voltage variation of ±270mV. A maximum drain current of the device with DDS field-plate gate structure was 910 mA/mm at V_{GS} = 0 V. Fig. 4 shows current collapse effects investigated with pulsed I-V measurements for 500 ns pulse duration at V_{GS} = 0 V. Even with 50 nm field-plate length for small parasitic capacitances, the current collapse phenomena were effectively suppressed by more than 50% at V_{GSQ} = -5V and V_{DSQ} = 20V compared with no gate field-plate HEMTs. The unity current gain cut-off frequency (f_T) and the maximum oscillation frequency (f_{max}) were each determined by the extrapolation of the current gain $|H_{21}|$ and the Mason's unilateral power gain U as shown in Fig. 5, and the value of f_{max} was 160 GHz for DDS-field-plate gate HEMT (f_T = 70 GHz).

For the design of the millimeter-wave MMICs, DDS field-plate gate HEMTs with a gate width of 4×37 μm and 8×37 μm were chosen. These devices were selected through the parametric study on GaN-on-Si HEMTs performed in our previous work [6]. Fig. 6 shows the chip image of the fabricated 77 GHz power amplifier MMIC. The circuit was designed with 3-stage common source type which consists of device with gate width of 4×37 μm at the first and second stage, and 8×37 μm at the third stage. Because the SRF (Self Resonance Frequency) of MIM capacitors cannot cover up to W-band range, coupled lines and λ/4 open stubs are applied for the purpose of DC block and RF short. Fig. 7 shows the measured S-parameter results. The measured power gain was 3.9 ~ 5.0 dB from 70.5 GHz to 78 GHz and the input/output return loss was below -10 dB from 71 GHz to 77.5 GHz. Fig. 8 (a) and (b) represents the measured output power at 77 GHz and the saturated power sweep according to frequencies. The fabricated 77 GHz PA MMIC represent the output power of 20.1 dBm at 77 GHz and 19 ~ 22 dBm from 72 GHZ to 78 GHz (the peak power at 72 GHz)

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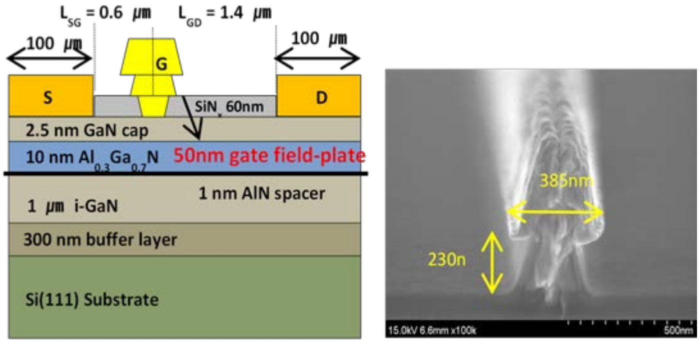

Fig.1 Cross-sectional of fabricated device with DDS gate field-plate structure used in GaN MMIC power amplifier.

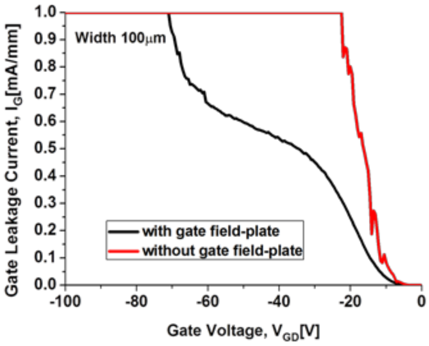

Fig.2 Three-terminal breakdown characteristics of gate-to-drain with gate field-plate and without field-plate.

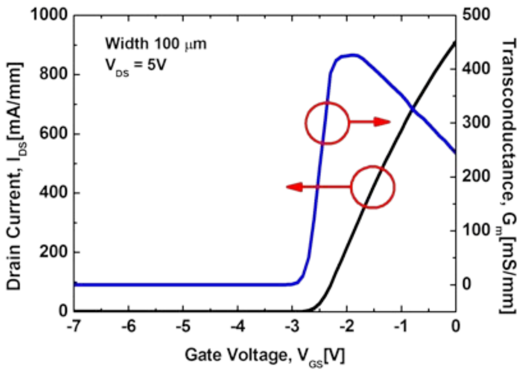

Fig.3 Transfer characteristic of device with DDS field-plate gate structure at V_{DS} = 5V.

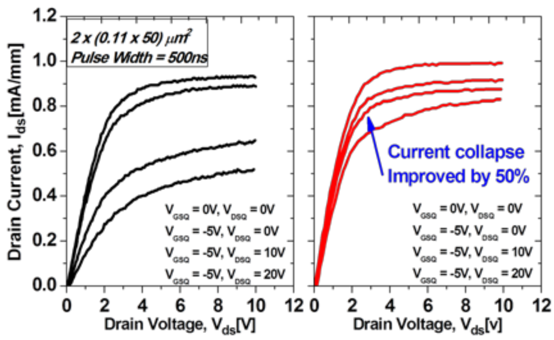

Fig.4 Pulsed I-V characteristics of the devices with T-shaped gate (left) and DDS field-plate gate having50 nm field-plate length (right).

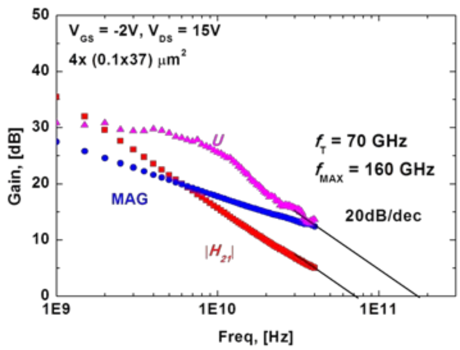

Fig.5 RF performances of HEMTs with DDS field-plate gate measured at V_{DS} = 15V and V_{GS} = -2V.

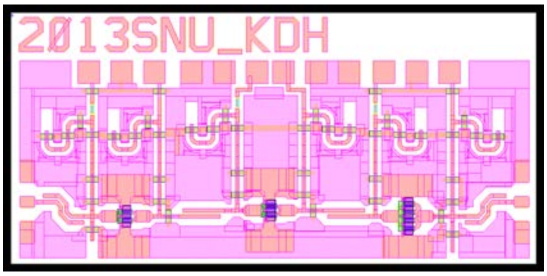

Fig.6 Chip image of 77 GHz power amplifier MMIC using GaN DDS field-plate gate HEMTs (size : 2.3×0.9 mm^2).

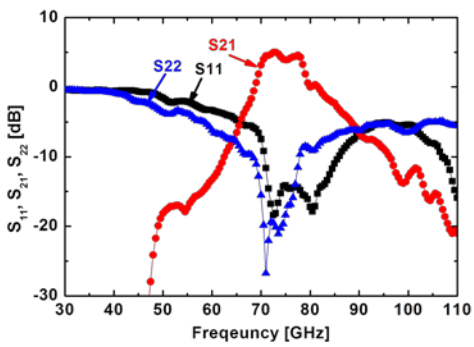

Fig. 7 Measured S-parameter result of the fabricated 77 GHz power amplifier MMIC.

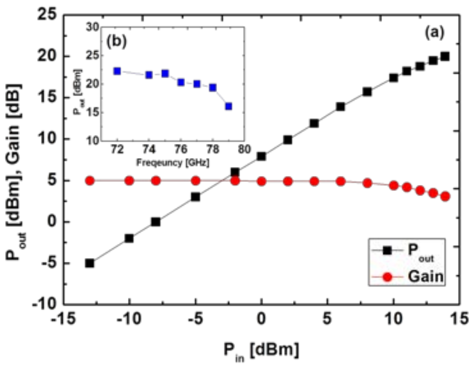

Fig. 8 Measured output power of 77 GHz power amplifier MMIC ((a) P_{out} at 77 GHz (b) P_{sat} according to power sweep).

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