High-Power 0.15-μm V-band Pseudomorphic InGaAs–AlGaAs–GaAs HEMT

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Abstract—**The dc and RF power performance of double heterostructure pseudomorphic InGaAs–AlGaAs–GaAs HEMT's at V-band is reported. A 0.15-μm × 400-μm device has demonstrated output power of 225 mW (0.55 W/mm) with 4.5-dB power gain and 25.4% PAE at 60 GHz. A 0.15-μm × 320-μm device demonstrated 31.1% PAE with 170 mW (0.53 W/mm) output power and 5.3 dB power gain. These data represent the highest reported combination of output power, power gain and power-added efficiency reported for a single device at V-band.**

I. Introduction

THERE is considerable need and interest for high power pseudomorphic InGaAs–AlGaAs–GaAs high electron mobility transistors (PM InGaAs HEMT's) operating at V-band. Previously reported work includes a single quantum well InGaAs MISFET demonstrating 1 W/mm output power with 3.2 dB gain and 27% efficiency at 60 GHz [1], and a PM InGaAs HEMT demonstrating 139 mW output power with 3.0 dB gain and 28% efficiency [2]. Recently, InP-based HEMT's have demonstrated 150 mW (0.33 W/mm) with 2.6 dB gain and 20% efficiency at 57 GHz[3]. We also previously reported excellent power results from planar-doped channel PM InGaAs HEMT's exhibiting 184 mW (0.46 W/mm) with 4.6 dB gain and 25% power added efficiency[4], which is the highest output power measured at V-band for a single device prior to this work.

In this letter, we are reporting the 60 GHz power performance of improved PM InGaAs HEMT's which now represent the best combination of output power, power gain and power-added efficiency reported for a single device in this frequency range. The improvement from our previous results is due to the combination of reducing the gate length to 0.15 μm and employment of a double heterostructure layer design.

II. Device Design and Fabrication

The new PM InGaAs HEMT structure is similar to the planar doped channel structure which has been previously reported [4]. The growth and fabrication process have been described elsewhere [4], [5]. A key modification was the employment of a double heterostructure layer design (shown in Fig. 1) in place of the planar doped channel design. Simulations of the conduction band and electron concentration using the one-dimensional field simulator FISH-1D indicate that using a double heterostructure design has the advantage of higher current density and superior carrier confinement. Also, Hall mobility measurements on calibration wafers have indicated a room temperature 2DEG concentration of 3.5 × 10^{12} cm^2 with a mobility of 5300 cm^2/V-sec. The room temperature mobility is a 30% improvement compared to the planar doped channel structure. The second modification was to decrease the gate length to 0.15 μm to improve device gain. The device profile was designed to ensure that a high aspect ratio is attained for gate lengths as small as 0.1 μm [6]. A high aspect ratio, defined as the ratio between the gate length and the gate to channel separation, is essential for high gain, high efficiency operation at millimeter-wave frequencies. These devices have also been passivated with plasma-enhanced chemical vapor deposition silicon nitride.

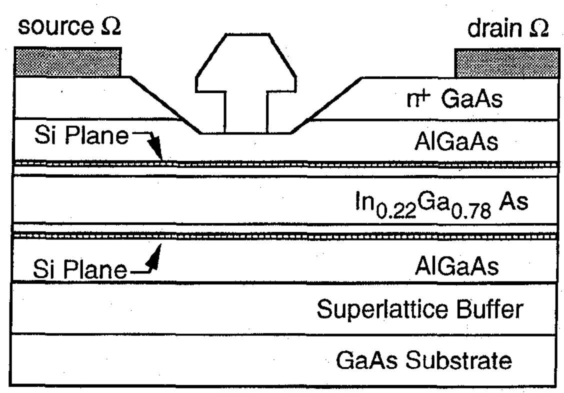

Fig. 1. Layer structure of the pseudomorphic double heterostructure InGaAs power HEMT.

III. Device Performance/Discussion

The devices exhibit a maximum transconductance greater than 500 mS/mm and a maximum current density greater than 600 mA/mm. The gate-to-drain breakdown voltage defined at 1 mA/mm is typically greater than 10 V. The devices also demonstrate very low output conductance of less than 25 mS/mm and excellent pinchoff characteristics as shown in the device I–V characteristics in Fig. 2. On-wafer RF measurements from 1–40 GHz on an 80-μm device demonstrate a typical cutoff frequency of 90 GHz and maximum oscillation frequency of 200 GHz at a drain bias of 2 volts.

The devices were tested for power performance in single stage MIC fixtures at 60 GHz. Eight-finger devices with 320-μm and 400-μm total gate periphery were characterized. Fin-

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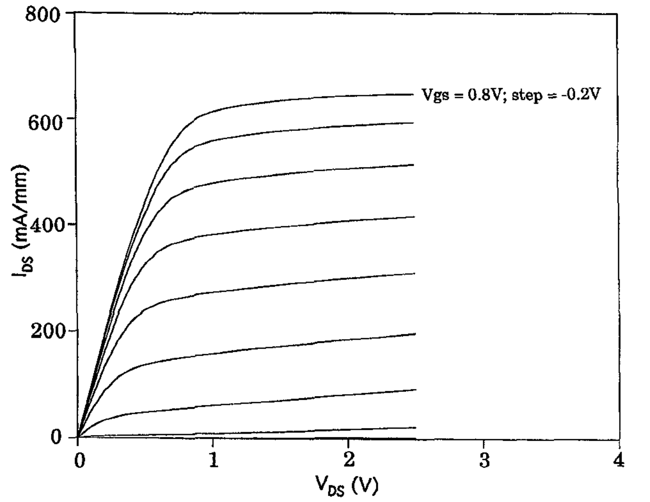

Fig. 2. Device Id-Vd characteristics for a 0.15-μm × 80-μm PM DH InGaAs power HEMT.

line waveguide to microstrip transitions fabricated on quartz substrates are used and the total fixture loss including the back-to-back transitions is 1.0 dB at 60 GHz. The experimental data presented here has been corrected for this loss. The devices were biased at 4.5–5.0 volt drain bias for high power added efficiency and for high output power and gain, respectively. These bias conditions are conservatively chosen to ensure good device reliability. The highest power measured was 225 mW (0.55 mW/mm) with 4.5-dB power gain and 25.4% power-added efficiency at a drain bias of 5 volts on the 400-μm device. The 320 μm device exhibited the highest power-added efficiency of 31.1%, 170 mW (0.53 mW/mm) output power and 5.3-dB power gain at a drain bias of 4.5 volts. A summary of the power data is shown in Table I. The measured device power and efficiency characteristics are shown in Fig. 3(a) and 3(b) for the 400 μm device. The 320-μm gate width device showed better power density and gain compared to the 400-μm gate width device probably due to a better tuned input match.

In comparison to the 450-μm InGaAs–InAlAs–InP power HEMT devices reported recently [3], the power data presented here are superior in terms of power (225 mW vs. 150 mW), gain (4.5 dB vs. 2.6 dB) and power-added efficiency (25.4% vs. 20%). The main advantages of pseudomorphic InGaAs HEMT's compared to InGaAs–InAlAs–InP HEMT's are the higher gate-drain breakdown voltage which allows for higher drain bias operation and lower output conductance. In addition, InAlAs–InGaAs–InP power HEMT's suffer from low channel breakdown which limits the device breakdown independent of the gate-drain breakdown voltages. This has severely limited the power performance of InAlAs–InGaAs–InP power HEMT's to date [3], [7]. As a result, pseudomorphic InGaAs–AlGaAs–GaAs power HEMT's have consistently demonstrated the best power performance at millimeter-wave frequencies.

IV. Conclusion

We have demonstrated an output power of 225-mW (0.55 W/mm), 4.5-dB power gain and 25.4% PAE for a 0.15-μm × 400-μm pseudomorphic InGaAs–AlGaAs–GaAs power HEMT with a double heterostructure layer design. A 320-μm device also demonstrated a maximum power-added efficiency of 31.1% with an output power of 170-mW and 5.3-dB power gain. These results represent the highest combination of output power, gain and power-added efficiency ever reported for a single V-band power device.

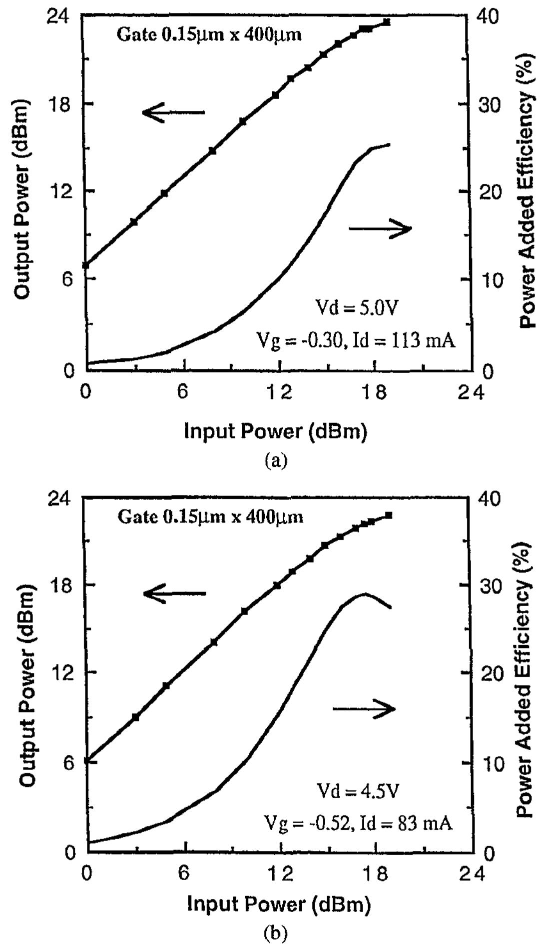

Fig. 3. Measured power characteristics for a 0.15-μm × 400-μm PM DH InGaAs power HEMT: (a) biased for high output power and gain and (b) biased for high power-added efficiency.

TABLE I
Summary of Measured Power Data on 0.15-μm Gate Length PM DH InGaAs Power HEMT

Gate Width (μm)	Drain Voltage (V)	Output Power (mW)	Power Gain (dB)	PAE (%)
400	5.0	225 (0.55 W/mm)	4.5	25.4%
400	4.5	174 (0.44 W/mm)	4.4	28.8%
320	5.0	191 (0.60 W/mm)	5.1	28.7%
320	4.5	170 (0.53 W/mm)	5.3	31.1%

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