K-Band High-Power/Efficiency/Breakdown GaInAs/InP Composite Channel HEMT's

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***Abstract*— This letter reports the power performance of $Ga_{(0.47)}In_{(0.53)}As$/InP Composite Channel InP HEMT's at 18 GHz. Devices with 0.15-μm gatelength exhibit a peak transconductance of 720 mS/mm and full channel current of 500 mA/mm while achieving a two-terminal (three-terminal) breakdown voltage of 13.3 V (10.4 V) at 1 mA/mm. Devices with 450-μm gatewidth exhibit 0.75-W/mm output power with 53% power-added efficiency (PAE) and 11.9-dB gain. The highest efficiency achieved was 57% at 5.0 V (V_{ds}) for 600-μm-wide devices producing an output power density of 0.5 W/mm. Further, devices with 900-μm gatewidth exhibit 0.59-W/mm output power with 53% PAE and 10.5-dB gain.**

***Index Terms*— InP, MODFET's, microwave power FET's, power-semiconductor devices.**

I. Introduction

A TYPICAL high-performance (0.15 μm gatelength, with high transconductance and high current density) InP-based power HEMT has a two-terminal breakdown voltage limited to approximately 7 V [1], and the on-state breakdown voltage (with $V_{gs} = 0$ V) is typically 2.5 to 3.5 V. By using a combination of a thin layer of GaInAs and InP as the channel material it is possible to form a composite channel that combines the advantages of both materials (high mobility of GaInAs at low fields and high breakdown and saturation velocity of InP at high fields) [2].

GaInAs/InP composite channel HEMT's [2] have previously demonstrated high breakdown voltage and high-frequency performance, subsequently exhibiting excellent power performance from C- to V-band [3]–[6]. This work reports a record combination of power density, power-added efficiency (PAE), and gain at K-band. In addition, this performance is achieved with high two-terminal and three-terminal breakdown voltage.

II. Device Structure

The material structure studied is the GaInAs/InP composite channel device structure shown in Fig. 1. The layers were grown using a gas source Varian Gen II molecular beam epitaxy (MBE) machine. The Al-content in the upper Schottky layer is 60% for the purpose of improving the gate Schottky barrier [7]. The InP sub-channel consists of 100-Å InP and is uniformly-doped at 2×10^{18} cm^{-3} (Si). A 50-Å InP channel spacer layer is inserted between the doped InP and the GaInAs channel layer.

Based on Hall measurements, the 70-Å structure had a sheet charge density of 3.3×10^{12} cm^{-2} with a mobility of 8600 cm^2/V-s. The HEMT's were fabricated using a planar process. Source and drain ohmic contacts were formed using Ag/AuGe/Ni/Au alloyed at 330 °C for 35 s. The measured sheet resistance and specific contact resistance from transition-line matrix (TLM) measurements are 230-Ω/square and 0.25-Ω mm, respectfully. A study of the ohmic contact characteristics for various channel compositions is given elsewhere [8], [9].

Boron ion implantation was used for device isolation. A 0.15-μm T-shaped gate was deposited after adjusting the threshold voltage via a wet recess etch. The unit finger width of the HEMT's whose power performance is studied was 56 μm, 60 μm, and 75 μm. The devices were passivated with 1000 Å of SiN. The wafer was thinned to 2 mil, then the vias etched, followed by the backside metallization. Finally, the devices were die-attached on a copper carrier for testing.

III. Device Performance

A normalized plot of dc transconductance for a 300-μm-wide device from the same wafer as the 450- and 900-μm devices tested is shown in Fig. 2. The characteristics were measured at a drain voltage of +1.5 V. The peak gm and maximum channel current are 720 mS/mm (at $V_{gs} = -0.4$ V) and 520 mA/mm (at $V_{gs} = +0.5$ V). The device has a gm of 300 mS/mm over the current range of 40 to 480 mA/mm. A high transconductance over such a wide current enables high-efficiency operation of the transistor.

The gate diode characteristics are plotted in Fig. 3. The first characteristic is the two-terminal gate-drain (source floating) diode characteristic. The two-terminal breakdown voltage measured at 1 mA/mm is −13.3 V. The second characteristic is the three-terminal gate-drain (source grounded) diode characteristic. The three-terminal breakdown voltage measured at 1 mA/mm is −10.4 V.

The power transfer characteristics (see Fig. 4) from devices with three different peripheries (8 finger × 56 μm ($W = 450\,\mu$m), 10 finger × 60 μm ($W = 600\,\mu$m), and 12 finger × 75 μm ($W = 900\,\mu$m) were measured using an active harmonic load-pull system at 18 GHz. The devices were biased at $V_{gs} = -0.5$ V and $V_{ds} = +6.5$ V. The load was tuned only at the fundamental frequency. The quiescent drain current

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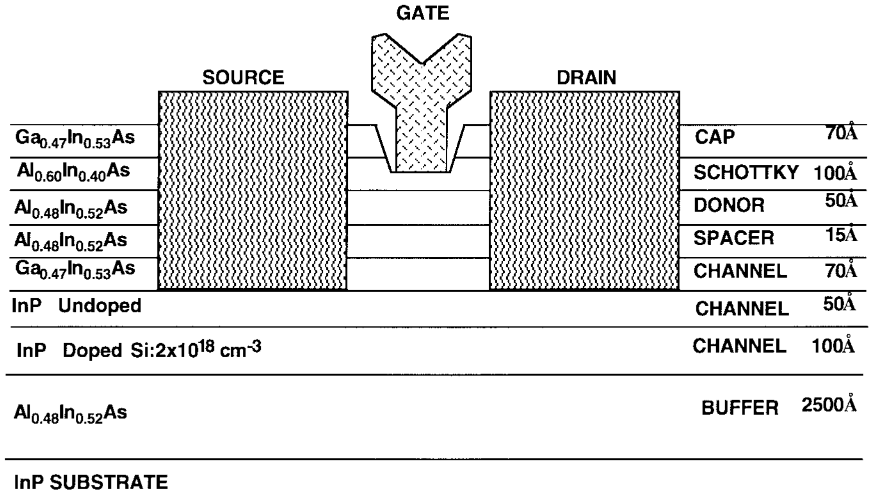

Fig. 1. GaInAs/InP composite channel HEMT structure. The source-to-drain spacing is 2 μm.

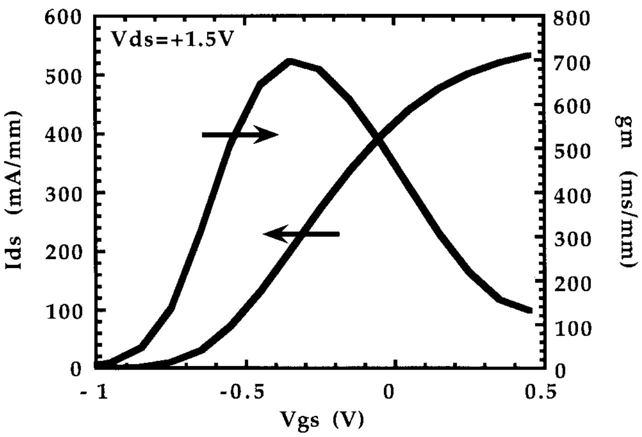

Fig. 2. Plot of dc transconductance and drain current versus gate voltage at $V_{\rm ds} = +1.5$ V for a 0.15 $\times$ 300 μm GaInAs/InP composite channel HEMT.

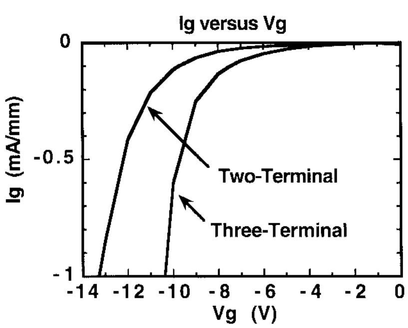

Fig. 3. Reverse gate diode characteristics for two-terminal gate-drain (source floating) and three-terminal gate-drain (source grounded) diode configurations.

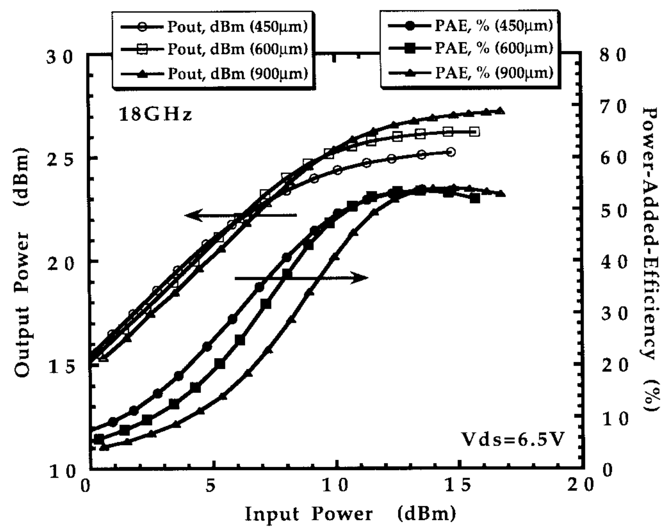

Fig. 4. Output power and PAE versus input power for 450-, 600-, and 900-μm-wide GaInAs/InP composite channel HEMT's at 18 GHz.

(with RF off) for the 450-, 600-, and 900-μm devices was 160, 152, and 135 mA/mm, respectively. The output power density (gain, PAE) at the 3-dB compression point for the 450-, 600-, and 900-μm devices was 0.75 W/mm (11.9 dB, 53%), 0.70 W/mm (11.5 dB, 53%), and 0.59 W/mm (11.0 dB, 56%), respectively. The load gamma magnitude (angle) for the 450-, 600-, and 900-μm devices was 0.464 (114°), 0.534 (125°), and 0.600 (135°), respectively. When backed off to operate at $V_{\rm ds} = +5.0$ V, the output power density (gain, PAE) at the 3-dB compression point for the 450-, 600-, and 900-μm devices was 0.52 W/mm (13.1 dB, 56%), 0.50 W/mm (12.3 dB, 57%), and 0.44 W/mm (12.0 dB, 55%), respectively.

IV. Conclusion

In conclusion, state-of-the-art power performance is achieved at 18 GHz using 70-Å $Ga_{(0.47)}In_{(0.53)}As$/InP composite channel HEMT's. The highest output power density (0.75 W/mm) was achieved with 53% PAE at 6.5 V $(V_{\rm ds})$ using a 450-μm-wide device. The highest output power measured was 528 mW with 10.5 dB and 53% at 6.5 V $(V_{\rm ds})$ using a 900-μm-wide device. The highest efficiency achieved was 57% at 5.0 V $(V_{\rm ds})$ for a 600-μm-wide device. The combination of high output power density, high efficiency, high gain, and high breakdown voltage demonstrate the advantages of GaInAs/InP composite channel HEMT's for power applications.

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