AlGaAs/InGaAs Power P-HEMTs for High-Efficiency, Low-Voltage Portable Applications

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Abstract - Power Pseudomorphic High Electron Mobility Transistors (P-HEMTs) with unprecedented efficiency are being produced for low-voltage portable wireless products. 12-mm devices operating at 3.5 V achieve more than 75% power added efficiency, 1.5 W output power, and 11.5 dB gain, simultaneously, at a frequency of 850 MHz.

I. INTRODUCTION

The continual drive to manufacture increasingly smaller portable electronic devices such as cellular phones has placed new demands on the power transmitter for wireless communications. Since the size and weight of portable wireless devices in most cases is dominated by the battery, the need to reduce the size and weight of batteries is driving the need for higher efficiency power devices operating at lower voltages. These needs, when combined with the output power requirements, have been difficult to achieve using conventional GaAs MESFET technologies [1, 2]. An alternative device technology capable of meeting these requirements is the Pseudomorphic High Electron Mobility Transistor (P-HEMT) [3-6]. P-HEMTs use epitaxially grown heterostructures which take advantage of the differences of band structure between materials, such as AlGaAs and InGaAs, to give higher mobility and improved carrier confinement.

II. DESIGN AND FABRICATION

The heterojunction structure, illustrated in Fig. 1, is grown by Molecular Beam Epitaxy

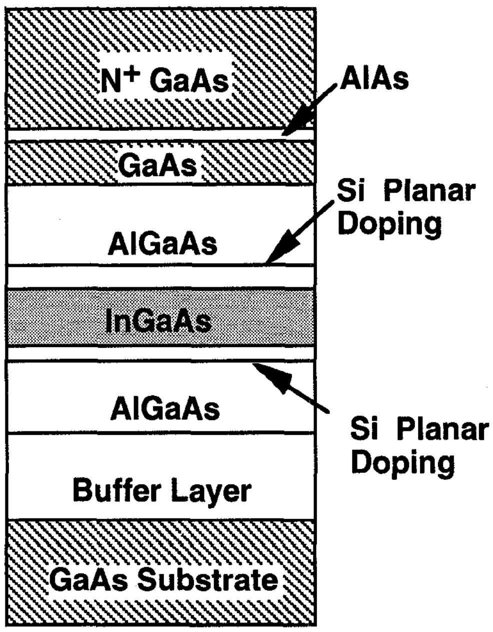

Figure 1: Schematic of heterostructure used to produce power P-HEMTs

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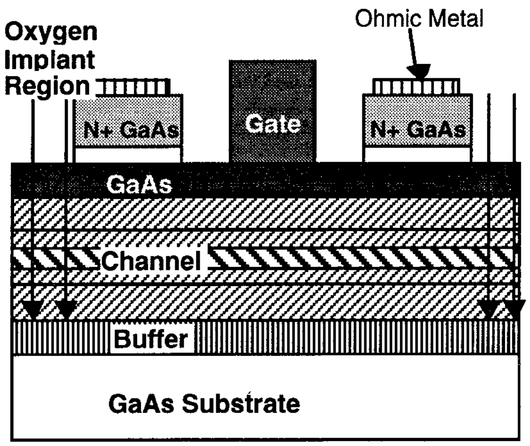

Figure 2: Schematic of finished P-HEMT not showing interconnect metal.

(MBE) on semi-insulating GaAs substrates by outside vendors.

The epitaxial structure starts with a superlattice buffer layer which acts as a physical barrier to inhibit interface defects from propagating into the channel. The channel layer is formed using a narrow bandgap InGaAs channel layer sandwiched between wider bandgap AlGaAs carrier confining layers. Above the layers comprising the device channel are a thin GaAs layer, an AlAs etch-stop layer, and a heavily-doped N+ ($5x10^{18}$ cm^3) GaAs cap layer.

Device fabrication begins with the patterning and selective wet etching of the N+ GaAs layer using a citric acid-based solution on a custom, automated etching tool. The N+ layer is removed everywhere but in a region that will enclose the ohmic contacts. The wet N+ etch is designed to be selective to the AlAs etch stop layer. A refractory gate electrode is patterned and etched using reactive ion etching over a region where the N+ GaAs layer was previously removed. Device isolation is accomplished via ion implantation of oxygen. Electrical contact to the heterojunction is made using Ni-Ge-W contacts to the top N+ layer [7]. Fig. 2 shows a schematic cross-section of a

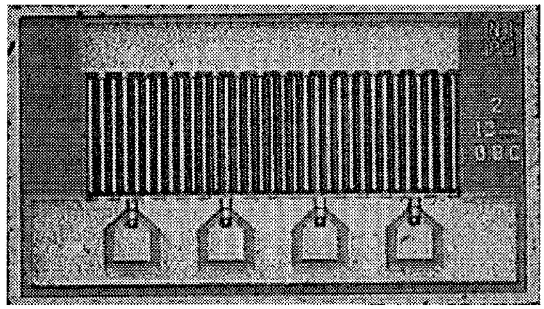

Figure 3: Photomicrograph of finished P-HEMT.

finished device. Fig. 3 shows a photomicrograph of a finished device.

III. DEVICE PERFORMANCE

The P-HEMT devices exhibited good DC characteristics as evidenced by Figure 4. Typical results were Idss of more than 250 mA/mm, g_m of more than 200 mS/mm, gate-to-drain breakdown (BV_{GDO}) of more than 18 V, and on-resistance (R_{on}) of less than 0.25 Ω for a 12 mm total gate width. (Extended paper will include optimization studies.)

Finished wafers were thinned, sawn, and packaged in an engineering package for evaluation (similar performance is seen in production packages). RF testing was performed on a Maury load-pull system using a transistor with a 12-mm width and a nominal gate length of

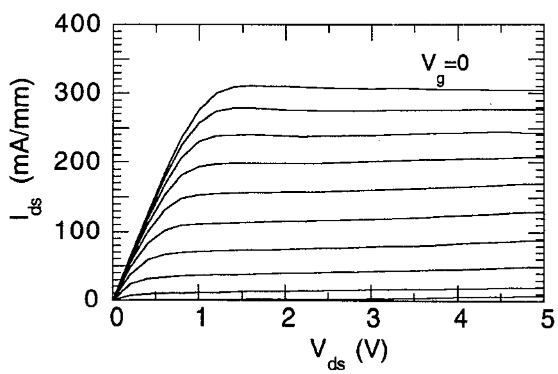

Figure 4: Current-voltage characteristics for power P-HEMT (voltage steps are 0.25 V).

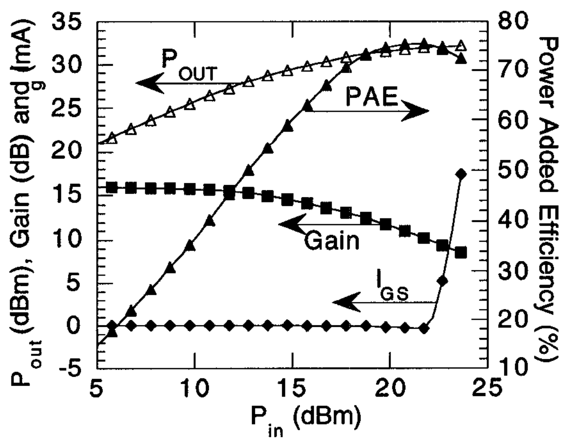

Figure 5: RF characteristics of 12 mm P-HEMT with drain bias of 3.5 V.

0.8 μm.

RF test results for a supply voltage of 3.5 V are as follows: When tuned for maximum power-added efficiency (PAE), efficiencies of greater than 80% are typically achieved. When tuned for maximum output power, powers of greater than 1.5 W are typical. When tuned for a trade-off favoring efficiency, the P-HEMT device achieves an output power of 31.7 dBm, PAE of greater than 75%, gain of more than 11.5 dB, and negligible leakage current at an input power of 100 mW and a frequency of 850 MHz. This is the best known performance for any technology under these low voltage conditions, suitable for many wireless applications. Figure 5 shows a plot of these RF parameters under the trade-off conditions. (The extended paper will include plots for all conditions as well as RF performance at different supply voltages.)

IV. CONCLUSIONS

An optimized P-HEMT power transistor for 3.5 V applications has been developed for manufacture. The 0.8 μm gate length P-HEMT with a total device width of 12-mm has demonstrated performance of 31.5 dBm output power, and greater than 75% PAE at 3.5 V for 850 MHz operation. The device produces unprecedented, high-efficiency RF performance which is needed for portable applications, and is fabricated in a manner consistent with high-volume/high-yield production.

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