High-Performance Double-Recessed InAlAs/InGaAs Power Metamorphic HEMT on GaAs Substrate

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***Abstract*— Double-recess power metamorphic high electron mobility transistors (MHEMT's) on GaAs substrates were successfully demonstrated. The $In_{.53}Al_{.47}As/In_{.65}Al_{.35}As$ structures exhibited extrinsic transconductance of 1050 mS/mm and breakdown of 8.3 V, which are comparable to that of the InP power HEMT. Excellent maximum power added efficiency (PAE) of 60.2% with output power of 0.45 W/mm and record associated power gain of 17.1 dB were realized at 20 GHz. A maximum output power of 0.51 W/mm has also been demonstrated with the device. This is the first demonstration of high-efficiency K-band power MHEMT's.**

***Index Terms*—Metamorphic high electron mobility transistor, MHEMT, power MHEMT.**

I. Introduction

In recent years the development of metamorphic HEMT's (MHEMT's) has attracted considerable interest [1]–[3]. By using graded buffer these metamorphic structures on GaAs substrates enabled researchers to realize high-performance high indium mole fraction InP-based HEMT's on GaAs substrates. Therefore, the advantage of higher electron saturation velocity, higher conduction band discontinuity, and lower access resistance of InP based HEMT's can be achieved along with the advantage of less expensive, higher quality, larger size substrates, and more mature backside processing technology of GaAs-based HEMT's. Furthermore, researchers were able to explore device structures with any indium mole fractions between 40% and 100% in the channel. This dimension of freedom was unattainable with conventional InP-based HEMT approach due to the critical thickness limitation of pseudomorphic structures [4].

In this letter, we present the first double-recessed 0.1-μm $In_{.53}Al_{.47}As/In_{.65}Al_{.35}As$ MHEMT's on 3-in GaAs substrates with dc transconductance, current density, breakdown voltage, and power performance at K-band exceeding those of the published InP-based power HEMT's [5].

II. Material Structure and Device Fabrication

The metamorphic epi material, as shown in Fig. 1, was grown on semi-insulating 3-in GaAs (100) substrates using an in house Intervac/Varian Gen II MBE system. The metamorphic buffer consisted of a 1–2-μm-thick graded $Al_{0.5}Ga_{0.5}As_xSb_{1-x}$ to transform the lattice constant of GaAs to that of the desired material structure. [2]. On top of this metamorphic buffer, a double-doped double-recess power pHEMT structure with the conventional combination of $In_{.53}Al_{.47}As/In_{.65}Al_{.35}As$ were grown for a direct comparison with InP-based HEMT's. The caps were tailored for fully selective double recess process to achieve excellent reproducibility, better uniformity across the wafer, and higher gate to drain breakdown voltage. Furthermore the double doped, double heterojunction and $In_{.65}Al_{.35}As$ pseudomorphic channel layer design provided higher carrier concentration and superior electron transport properties in the channel. The mobilities were 9700 and 25 000 cm ^{2}/V·s, with carrier concentrations of 3.9×10^{12} and 3.6×10^{12} cm^{-2} at room temperature and 77 K, respectively. The sheet resistance was around 170 Ω/sq. These results are comparable to those of our standard InP-based power HEMT with typical mobilities of 9600 and 22 000 cm ^{2}/V·s and carrier concentrations of 3.5×10^{12} and 3.3×10^{12} cm^{-2} at 300 and 77 K, respectively. The room temperature sheet resistance was 190 Ω/sq.

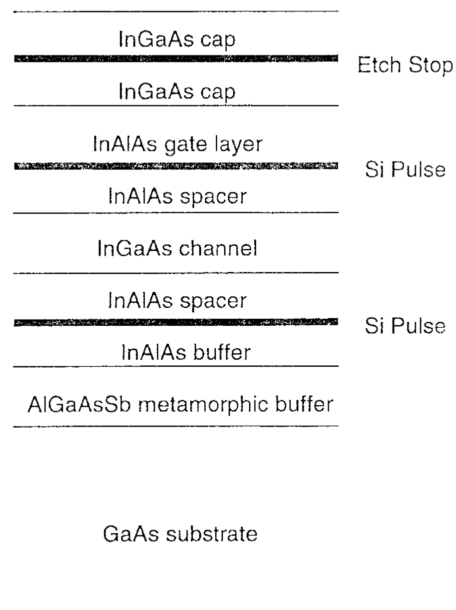

Fig. 1. Epi structure of the double-doped double-recess InAlAs-InGaAs power MHEMT.

Discrete devices were fabricated using our standard InP HEMT front-side process and GaAs pHEMT back side process. After mesa isolation, ohmic contacts were formed

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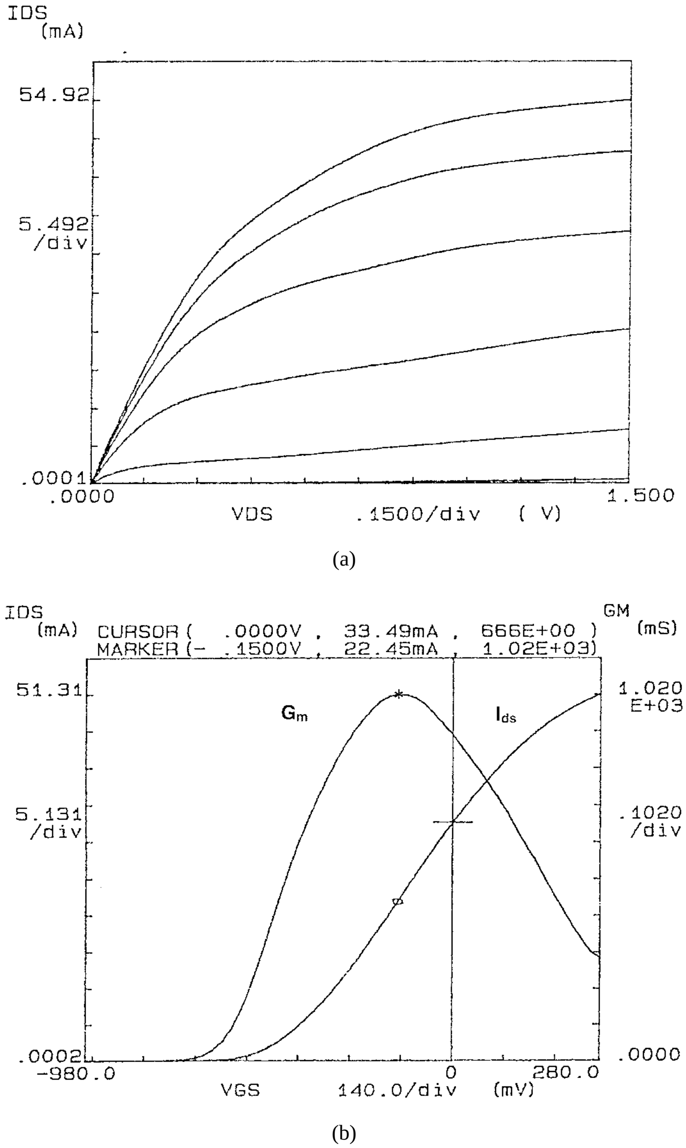

Fig. 2. (a) DC I–V characteristics and (b) transfer characteristic of a 0.1 × 75 μm MHEMT. The top curve in (a) is at the gate to source bias of 0.4 V and the step is −0.2 V.

with an optimized AuGe-based metallization and a rapid thermal annealing scheme. Contact resistance of 0.15 Ω-mm or better were achieved. The 0.5-μm first recess and 0.1-μm T-shaped gates were defined by a Leica/Cambridge EBMF10.5 electron beam direct write system at 30 and 50 kV, respectively. The total gate width was 300 μm distributed in four fingers. Both the first and gate recess were done with a fully selective wet chemistry process. Ti/Pt/Au and ECR SiN_x were used for Schottky metallization and device passivation, respectively. Airbridges and top metal were formed with 2 μm of evaporated Au. The wafers were thinned to 50- and 20-μm-wide slot via holes were formed under source pads using a reactive ion etch process. Then the back-side ground planes were formed with plated Au.

III. Device Charactreistics and Discussion

These 0.1-μm MHEMT's achieved an extrinsic transconductance of 1050 mS/mm with a full channel current density of 750 mA/mm and a breakdown voltage of 8.3 V, comparable to that of the InP HEMT's [5]. The output I–V and transfer characteristics are shown in Fig. 2.

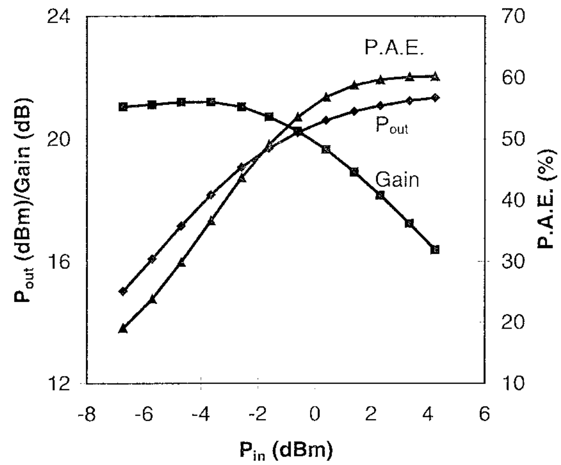

Fig. 3. Measured 20-GHz power output, gain, and PAE of a 4 × 75 μm MHEMT at Vds = 3 V.

TABLE I
Load Pull Test Results of 20-GHz Power Permanence at Different Drain-to-Source Bias

Vds (V)	Power-Added Efficiency	Power Gain (dB)	Output Power (mW)	Power Density (mW/mm)
2.0	55.7%	15.7	72	240
2.5	60.5%	16.9	106	355
3.0	60.2%	17.1	136	454
3.5	56.7%	16.7	153	509

These MHEMT's were tested for power performance at 20 GHz using a load pull structure with 300-μm gate peripheral. Probe stage mounted Maury automatic coaxial tuners were used to achieve optimum source and load impedance for best power performance. Table I summarized the measured 20-GHz power performance. The output power, gain, and power-added efficiency (PAE) plots of the power MHEMT are shown in Fig. 3. No input and output impedance loss was corrected in the test. Comparing to the published InP HEMT which had 47.1% PAE, 7.1-dB associated gain, and 645-mW/mm output power density at Vds = 4 V [5], these devices exhibited much higher associated power gain and PAE at 20 GHz. The excellent power result of the MHEMT indicates high material quality of the epi structures.

IV. Summary

Double-recess power MHEMT's have been successfully designed and fabricated for the first time. Excellent dc and radio frequency (RF) characteristics were demonstrated. These structures exhibited extrinsic transconductance of 1050 mS/mm and breakdown of 8.3 V which are comparable to the InP-based power HEMT results. In addition, record PAE of over 60% with extremely high associated power gain of 17.1 dB were realized at 20 GHz, demonstrating a strong potential of MHEMT technology for very high performance and low cost manufacturing.

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