V-Band High-Efficiency High-Power AlInAs/GaInAs/InP HEMTs

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ABSTRACT

In this paper we report on the state-of-the-art power performance of InP-based HEMTs at 59 GHz. Using a 448 μm wide HEMT with a gate-length of 0.15 μm, an output power of 155 mW with 4.9 dB gain, and power-added efficiency of 30.1% were obtained. By power combining two of these HEMTs we were able to achieve an output power of 288 mW with 3.6 dB gain and power-added efficiency of 20.4%. This is the highest output power reported with such a high-efficiency for InP-based HEMTs, and is comparable to the best results reported for AlGaAs/InGaAs on GaAs pseudomorphic HEMTs at this frequency.

I. INTRODUCTION

InP-based HEMTs have demonstrated record low-noise performance at V-band [1,2]. But little work has been done on InP-based HEMTs for power applications due to the low gate-to-drain breakdown voltage and low Schottky barrier height of these HEMTs. At V-band the highest output power previously reported for a single AlInAs/GaInAs/InP HEMT has been 26 mW with power-added efficiency of 33% [3]. So far the most promising results have been obtained on pseudomorphic AlGaAs/InGaAs on GaAs HEMTs [4-6]. InP-based HEMTs offer a number of advantages over GaAs-based HEMTs for power applications. The thermal conductivity of InP is 40% higher than GaAs allowing a lower operating channel temperature for the same power dissipation. Due to the larger conduction band discontinuity between $Al_{0.48}In_{0.52}As$ and $Ga_{0.47}In_{0.53}As$ higher electron densities can be achieved in AlInAs/GaInAs/InP HEMTs than AlGaAs/InGaAs/GaAs HEMTs. Coupled with the higher electron velocity in the channel, higher current densities can be achieved.

We previously reported that by proper device layer design it is possible to overcome the drawbacks of InP-based HEMTs for power applications, and achieved power densities as high as 1 W/mm and power-added efficiencies as high as 59% at 12 GHz [7]. In this paper we report on the power performance of δ-doped channel AlInAs/GaInAs on InP HEMTs. Using this layer structure we have achieved state-of-the-art power performance at 59 GHZ. The results are comparable to the best reported performance for AlGaAs/InGaAs on GaAs HEMTs at this frequency.

II. DEVICE STRUCTURE

The HEMTs were fabricated on a δ-doped layer structure shown in figure 1. The layers were grown by MBE lattice matched to a semi-insulating InP substrate. It consists of a 2500 Å AlInAs buffer layer followed by a 300 Å GaInAs channel. A plane of Si atoms with a concentration of $1.5X10^{12}$ cm^{-2} was inserted at the center of this channel. In addition a 50 Å AlInAs layer doped $6X10^{18}$ cm^{-3} separated by a 15 Å undoped AlInAs spacer layer was grown on top of the channel. To improve the Schottky barrier height of the gate, and the gate-to-drain breakdown voltage, a 250 Å undoped layer of $Al_{0.60}In_{0.40}As$ was then grown. Finally a 70 Å doped layer of GaInAs layer was grown to facilitate ohmic contact formation. The gate-to-drain breakdown voltage was also improved by decreasing the donor concentration in the top donor layer and adding them into the channel.

The material used for the fabrication of the power HEMTs had an electron sheet charge density of $4.2X10^{12}$ cm^{-2} with a mobility of 8500 cm^2/V-s. The HEMTs were

$Ga_{0.47}In_{0.53}As$	CAP	70 Å	
$Al_{0.60}In_{0.40}As$	SCHOTTKY	250 Å	
$Al_{0.48}In_{0.52}As$	Si DOPED	50 Å	
$Al_{0.48}In_{0.52}As$	SPACER	15 Å	
$Ga_{0.47}In_{0.53}As$	CHANNEL	150 Å	
			Si δ-DOPED LAYER
$Ga_{0.47}In_{0.53}As$	CHANNEL	150 Å	
$Al_{0.48}In_{0.52}As$	BUFFER	2500 Å	
InP SUBSTRATE			

Figure (1) Cross-section of the AlInAs/GaInAs on InP HEMT with δ-doped GaInAs channel.

fabricated using a planar process. Source and drain ohmic contacts were formed using AuGe/Ni/Au alloy with drain-to-source spacing of 2 μm. Boron ion implantation was used for device isolation. The gates with a T-shaped cross-section and a footprint of 0.15 μm were formed by Ti/Pt/Au metallization. The HEMTs had a unit gate-finger width of 56 μm and a total gate-width of 448 μm with a gate-to-gate spacing of 20 μm. The picture of the device is shown in figure 2. The completed wafer was thinned to a thickness of 50 μm and source vias were etched using a wet-etch process. The vias were approximately 75 μm in diameter on the back of the wafer and 25 μm in diameter at the source pads. The back of the wafer was then metallized and plated with 8 μm of gold to add support to the wafer.

III. DEVICE PERFORMANCE

The 448 μm wide HEMTs had a peak transconductance of 600 mS/mm at a drain-to-source voltage of 1.5 V. The device has a full channel current of 670 mA/mm measured at a gate-to-source voltage of 0.4 V. The gate-to-drain breakdown voltage measured at 1 mA/mm of gate current was 7 V with a gate-to-drain turn-on voltage of 0.65 V. The HEMTs had a typical current gain cutoff frequency (f_T) of 140 GHz at a V_{ds} of 1.5 V.

To measure the performance of the power HEMTs at 59 GHz the devices were mounted in RF test fixtures with finline waveguide-to-microstrip transitions. The waveguide fixtures had a total loss of approximately 1.2 dB at 59 GHz. The power characteristics of a 448 μm wide HEMT is shown in figure 3. The transistor was biased at a drain-to-source voltage of 3.5 V. The device has a maximum power-added efficiency of 30.1% with an output power of 155 mW and 4.9 dB gain. The transistor has a linear gain of 8 dB and a saturated output power of more than 180 mW with 3 dB gain. To achieve higher output powers at 59 GHz branch-line couplers fabricated on alumina substrates were used to power combine two 448 μm wide HEMTs. Figure 4 shows the power characteristics of the two devices combined. The discontinuity in the output power is due to retuning of the amplifiers at that input power level. The output power at the maximum power-added efficiency of 20.4% is 288 mW with a gain of 3.6 dB. The combiner has an output power of more than 320 mW with power-added efficiency of 19%.

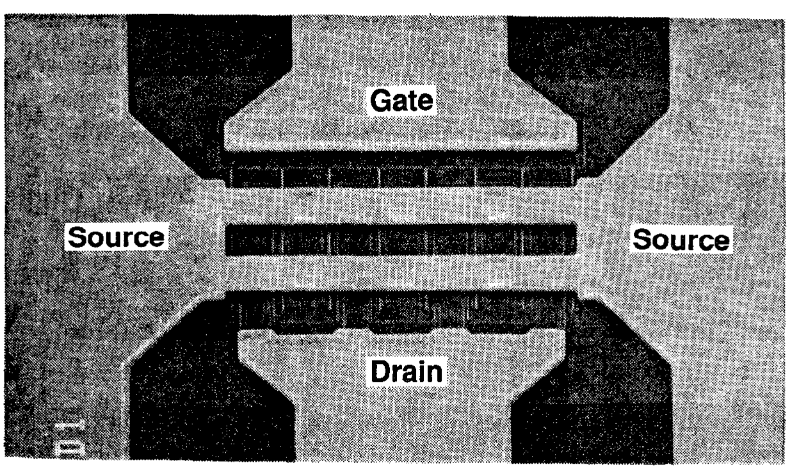

Figure (2) SEM of 0.15 μm X 448 μm InP-based power HEMT.

IV. CONCLUSION

A comparison of state-of-the-art power performance for HEMTs at 60 GHz is shown in figure 5. As can be seen from a comparison of output power and power-added efficiency the data presented in this paper on AlInAs/GaInAs/InP HEMTs is comparable to the best results reported on AlGaAs/InGaAs/GaAs PHEMTs. With further optimization of the material layer structure and device structure improvements in output power and gain of the transistors is expected.

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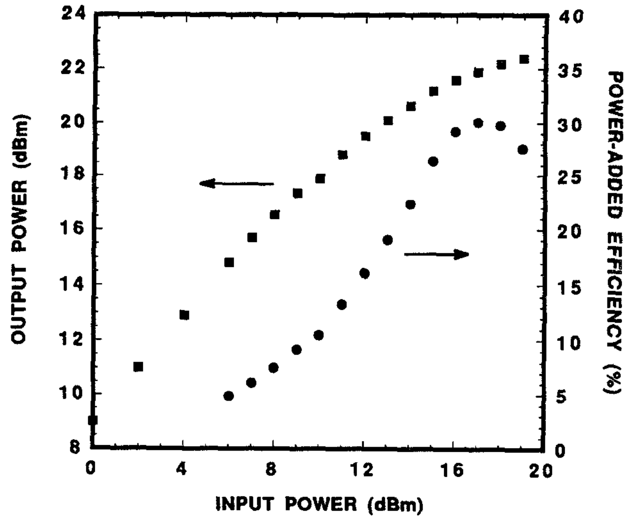

Figure (3) Power characteristics of a 448 μm wide HEMT at 59 GHz.

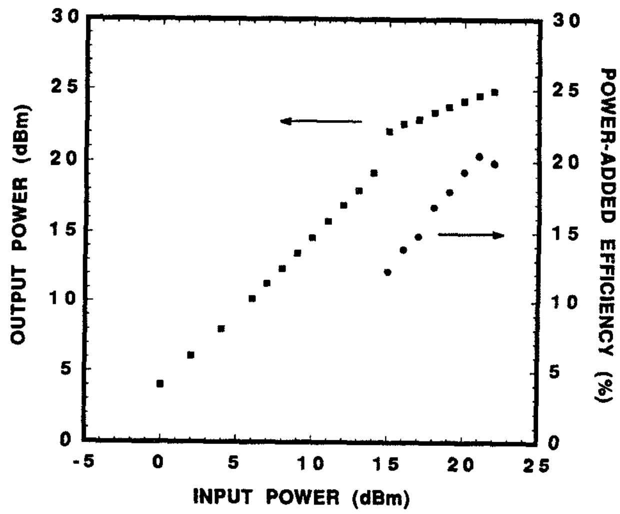

Figure (4) Power characteristics of power combined two 448 μm wide HEMTs at 59 GHz.

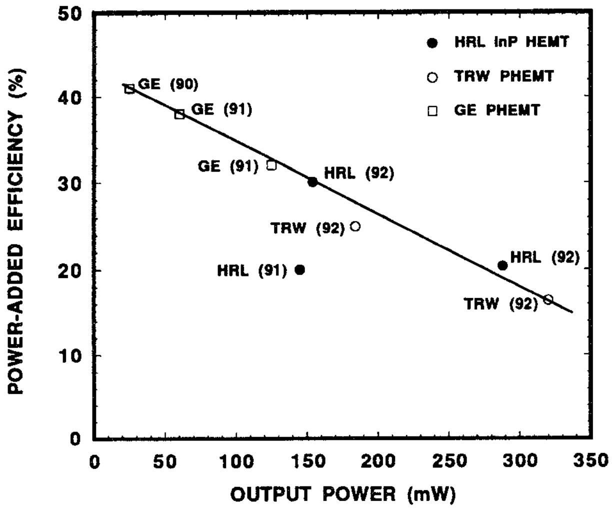

Figure (5) Comparison of the-state-of-art power performance for HEMTs at about 60 GHz.