HIGH POWER AND HIGH EFFICIENCY AlInAs/GaInAs ON InP HEMTs

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Abstract

In this paper we report on the development of AlInAs/GaInAs on InP power HEMTs. Output power densities of more than 730 mW/mm and 960 mW/mm with power-added efficiencies (PAE) of 50% and 40% respectively were achieved at 12 GHz. When biased for maximum efficiency, PAE of 59% and output power of 470 mW/mm with 11.3 dB gain were obtained. These results are the first reported power performance of InP-based HEMTs and demonstrate the viability of these HEMTs for power amplification.

I. Introduction

In recent years InP-based HEMTs have demonstrated record low noise [1, 2] and high frequency performance [3, 4]. But little work has been done on InP-based HEMTs for power applications due to high gate leakage current and low breakdown voltage. On the other hand, these HEMTs offer a number of advantages over GaAs-based HEMTs. Due to the larger conduction band discontinuity between $Al_{0.48}In_{0.52}As$ and $Ga_{0.47}In_{0.53}As$ the density of the electrons in the GaInAs channel will be larger. Coupled with the higher electron velocity in the channel, higher current densities can be achieved. Also, InP has a higher thermal conductivity than GaAs allowing more dissipated power per unit chip area. In this paper we report on the power performance of InP-based HEMTs. The results show the potential application of these devices for power amplification with comparable performance to GaAs-based HEMTs [5, 6].

II. Device Structure

The cross-section of AlInAs/GaInAs power HEMT used in this study is shown in Figure 1. The layers were grown by molecular beam epitaxy lattice matched to a semi-insulating InP substrate. The AlInAs layers on both sides of the GaInAs channel were doped while the GaInAs channel was undoped. The GaInAs channel was about 300 Å thick and was separated from the doped AlInAs layers by thin undoped AlInAs spacer layers. The bottom AlInAs layer was δ-doped and the top layer was uniformly doped. By removing some of the donors from the top AlInAs layer to the bottom AlInAs layer (away from the gate), the V_{DS} breakdown voltage of the HEMTs was increased from 4 V to over 9 V while maintaining high electron densities in the channel. The electron density in the channel was 4.1×10^{12} cm^{-2} with a mobility of 8500 cm^2/V-S.

The source and drain ohmic contacts were formed using AuGe/Ni/Au and the gate with a T-shape cross-section was formed by Ti/Pt/Au metallization. The devices tested had a gate-length of 0.22 μm and a gate-width of 150 μm. A plot of transconductance and drain

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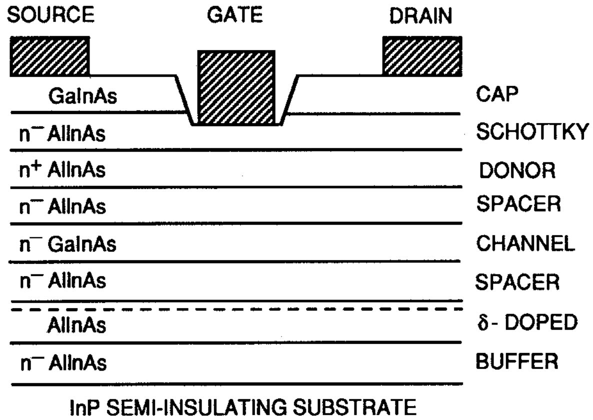

Fig. (1) Cross-section of the AlInAs/GaInAs on InP power HEMT.

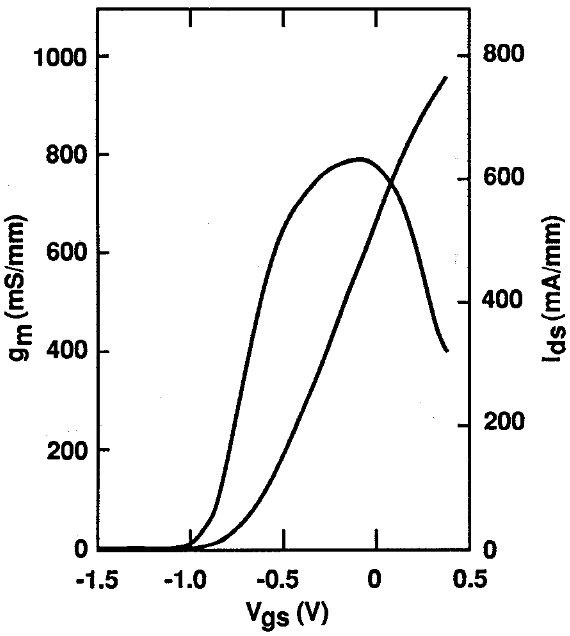

Fig. (2) Plot of transconductance and drain current versus gate-to-source bias at $V_{DS} = 1V$ for the $0.22 \times 150\ \mu m\ Al_{0.48}In_{0.52}As/Ga_{0.47}In_{0.53}As$ HEMT.

current versus gate-to-source bias of a typical $0.22 \times 150\ \mu m$ HEMT is shown in Figure 2. The characteristics were measured at a drain-to-source bias of 1 V. The device has a peak transconductance of 800 mS/mm and a full channel current of 770 mA/mm measured at a gate bias of 0.4 V and a drain bias of 1 V. The transistor has a transconductance of more than 400 mS/mm across a current range of 50 to 730 mA/mm.

III. Device Performance

Small signal S-parameters of the power HEMTs were measured from 1-50 GHz using a Wiltron 360 Automatic Network Analyzer. Based on extrapolation from measured S-parameters, the f_T and f_{max} of the HEMTs were 100 GHz and over 200 GHz respectively. The power performance of the HEMTs were measured at 12 GHz using an on-wafer RF probe system shown in Figure 3. The mechanical tuners were adjusted to obtain maximum output power or maximum power-added efficiency (PAE). The measured output power was corrected for the loss of the RF probes and the tuners. The measured power performance and PAE of the $0.22 \times 150\ \mu m$ HEMT optimized for maximum output power is shown in Figure 4. The device was biased at a V_{DS} of 4 V and I_{DS} of about 50 mA. The output power of the device is 110 mW (730 mW/mm) at maximum PAE of 50% with 11.1 dB gain. The saturated output power of the device is 117 mW (780 mW/mm) with PAE of 47% and 8.4 dB gain. The measured power performance and PAE of the same device optimized for maximum PAE is shown in Figure 5. The device was biased at a V_{DS} of 3 V and I_{DS} of about 37 mA. Maximum PAE of 59% was obtained with output power of 70 mW (470 mW/mm) and 11.3 dB gain. The gain in the linear region for both cases was about 15 dB. The power performance of a $0.22 \times 300\ \mu m$ HEMT was also measured at 12 GHz. This device had a peak transconductance of 860 mS/mm with a full channel current of over 870 mA/mm. A saturated output power of 288 mW (960 mW/mm) with 40% PAE was obtained from this device.

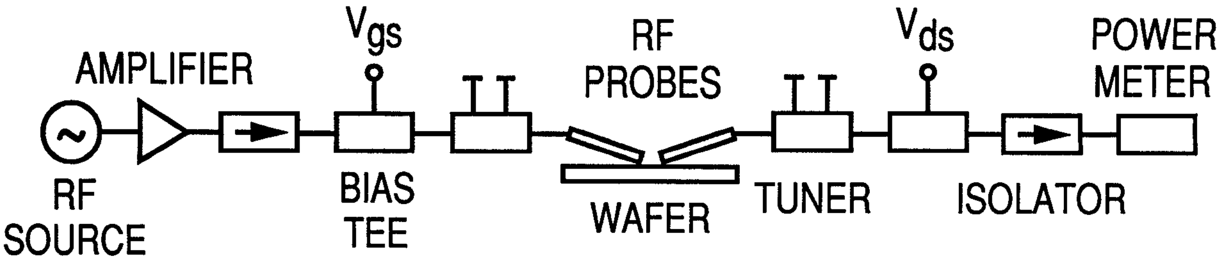

Fig. (3) On-wafer RF probe system for measuring power performance of the HEMTs.

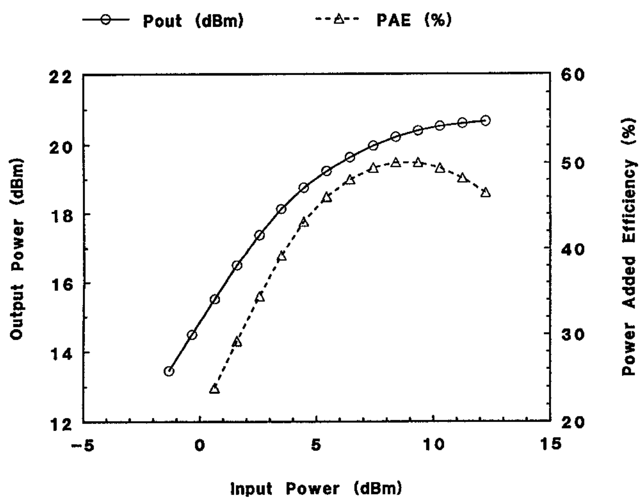

Fig. (4) Output power and PAE versus input power at 12 GHz for the 150 μm wide HEMT optimized to maximize the output power.

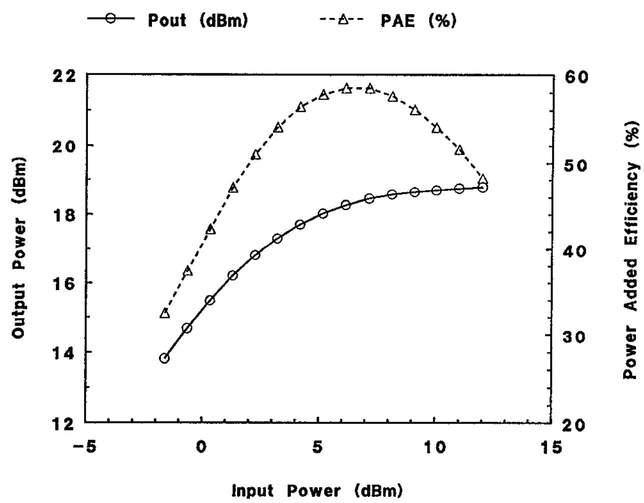

Fig. (5) Output power and PAE versus input power at 12 GHz for the 150 μm wide HEMT optimized to maximize the PAE.

IV. Conclusion

The first power performance of InP-based HEMTs was presented. Both high power densities and high efficiencies were achieved using these HEMTs at 12 GHz. With further optimization of the device and material structure, power densities greater than 1 W/mm are expected in the near future. Also considering that these HEMTs have an f_{max} of over 200 GHz they should also have good power performance at millimeter wave frequencies.

References

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