X-BAND InGaP PHEMTs WITH 70% POWER-ADDED EFFICIENCY

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Abstract

This paper describes the low-noise and power performance of InGaP/InGaAs PHEMTs lattice-matched to GaAs substrates. The 0.15-µm x 600-µm PHEMTs exhibited extrapolated f_t and f_{max} of 70- and 150-GHz, respectively. At 10-GHz, 200-µm devices yielded a low noise figure of 0.58-dB with very high associated gain. Furthermore, we have also demonstrated output power of 27-dBm, P.A.E. of 70.1%, and power gain of 13.2-dB at 9-GHz on a 1200-µm gate width InGaP PHEMT. This is the first reported demonstration of excellent low-noise and power performance at microwave frequencies from PHEMT with an InGaP Schottky barrier.

Introduction

The motivations for replacing the conventional AlGaAs Schottky barrier layer in the Pseudomorphic High Electron Mobility Transistor (PHEMT) structure with an InGaP layer lattice-matched to GaAs are three-fold. First, InGaP does not have the DX-centers that are present in AlGaAs; consequently, there are several orders of magnitude less deep level defect centers in the InGaP layer. Second, use of InGaP as a Schottky layer also eliminates the presence of the reactive AlGaAs. The Al-free InGaP Schottky layer with much less deep-level traps has great potential to make PHEMT operation more reliable. Lastly, the InGaP also serves as an excellent etch-stop layer during gate recess etch and improves gate recess uniformity which could greatly enhances GaAs MMIC yield and performance.

Experimental results on InGaP and InAlGaP PHEMTs have been reported over the last several years [1]-[4]. But, no power result has been presented and all the material was grown either by gas source MBE or by MOCVD which are a divergence from industry standard MBE reactors used for PHEMT epitaxial growth. This study addresses these two issues. We explore the use of solid source for high quality P-containing epitaxial growth and optimized processing technology to achieve good low-noise and power performance simultaneously.

Fabrication

Double heterojunction PHEMT wafers with an $In_{0.48}Ga_{0.52}P$ barrier layer on top of an undoped InGaAs channel were grown in a solid-source Molecular Beam Epitaxy (MBE) reactor equipped with a baffled

0-7803-4471-5/98/$10.00 (c) 1998 IEEE

polycrystalline GaP cell which was used as the source for phosphorus. The layer structure of the InGaP PHEMT is described in Fig. 1. The thickness of the InGaP Schottky layer that replaced AlGaAs is 130-Å. The ohmic metal was formed using AuGe/Ni alloy. The contact resistance of ohmic metal was measured to be 0.1-ohm-mm. PHEMTs based on the InGaP/InGaAs/GaAs heterostructure were fabricated with double recessed and 0.15-µm gate length T-shaped gates using Ti/Pt/Au metals.

GaAs Cap
GaAs Cap (Lightly Doped)
InGaP Schottky
Silicon Pulse Doped Layer
InGaP Spacer
InGaAs Channel
AlGaAs Spacer
Silicon Pulse Doped Layer
Buffer

Fig. 1 The layer structure of the InGaP/InGaAs PHEMT.

Small Signal and Power Results

I-V curves of an InGaP PHEMT consisting of two 75-µm fingers is shown in Fig. 2. It exhibits a small knee voltage, high g_m of 500-mS/mm and high current density of greater than 540-mA/mm. The device gate to drain breakdown voltage was evaluated to be 9.5-V at 1-mA/mm.

An InGaP PHEMT with gate width of 600-µm was on-wafer measured at V_d = 3V and V_g = -0.28V for S-parameters from 1- to 50-GHz. As shown in Fig. 3, device yielded an extrapolated f_t of 70-GHz at a slope of –20-dB per decade. Same gain roll-off can be applied to determine the other figure of merit: f_{max}. An extrapolated f_{max} based on the MSG at 34-GHz and 6-dB per octave decay is approximately 150-GHz.

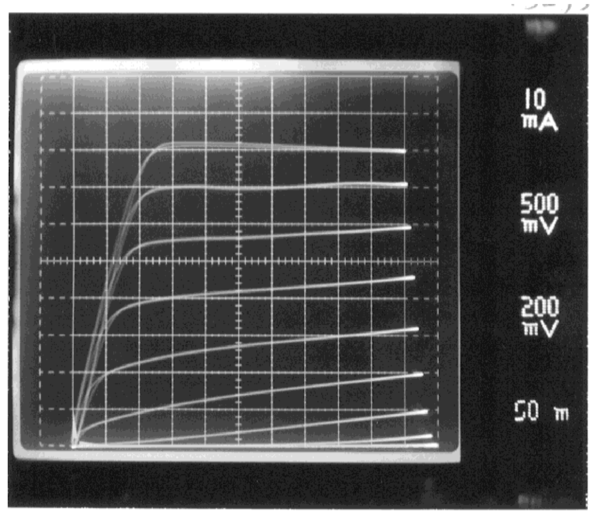

Fig. 2 I-V curves of a 0.15-µm x 150-µm PHEMT. V_g of top curve is 0.8 volt.

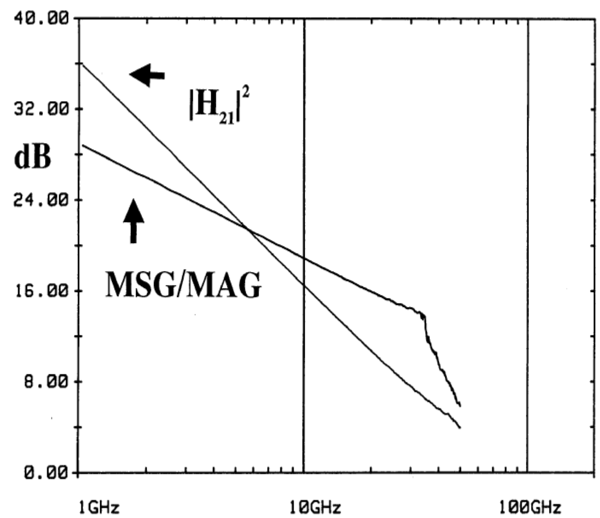

Fig. 3 Plots of $|H_{21}|^2$ and MSG as a function of frequency for a 600-µm wide InGaP PHEMT.

200-µm wide InGaP PHEMTs were mounted in a fixture and tested at 10-GHz for noise and gain performance. Device yielded about 0.6-dB noise figure across a wide range of drain currents from 12- to 32-mA.

When tuned for minimum noise figure at 10-GHz, the transistor has a noise figure of 0.58-dB and associated gain of 16.7-dB at V_d = 1.5-V and I_d = 22-mA as illustrated in Fig. 4. The measured small signal RF

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performance is comparable with that of the best measured AlGaAs/InGaAs PHEMTs.

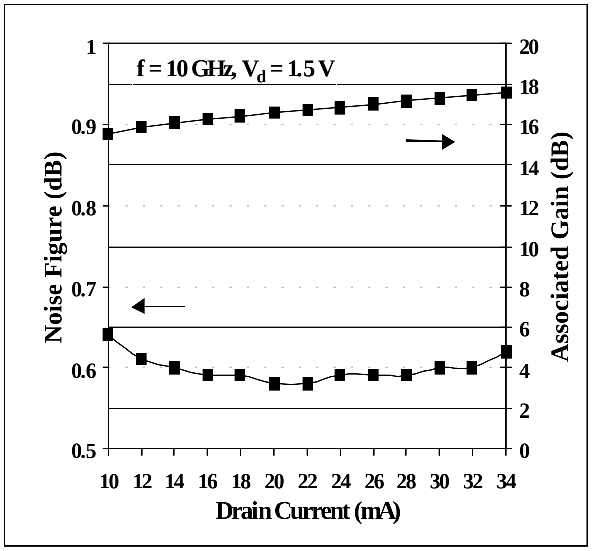

Fig. 4 Plot of minimum noise figure and associated gain versus drain current at 10-GHz.

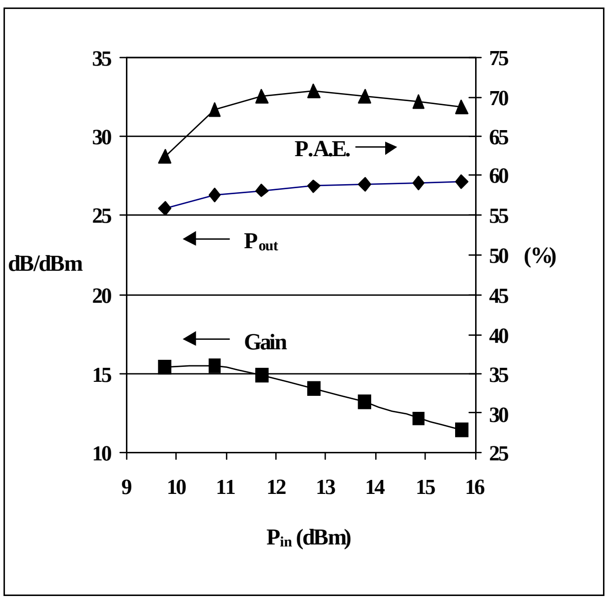

Fig. 5. 9-GHz power performance as a function of input power. The DC bias conditions were V_d = 5.5-V, V_g = -0.7-V.

The 0.15-µm x 1200-µm PHEMTs with 12 gate fingers were tuned for maximum P.A.E. and tested at 9-GHz for drain voltages from 2- to 6.5-V. The power performance at a drain bias of 5.5-V and a drain quiescent current of 53-mA is illustrated in Fig. 5. At P_{in} = 13.8-dBm, the device delivered an excellent P.A.E. of 70.1-percent, power gain of 13.2-dB and an output power of 27-dBm. In addition, the same device exhibited 28.2-dBm output power and 63.5% P.A.E. at V_d=6.5-V. As drain bias went down to 2 volts, we observed substantial decrease in output power and power gain, but steady peak P.A.E. of around 60%.

Conclusions

The first demonstration of very high efficiency X-band power performance for a new family of PHEMTs at a range of operating voltages from 2 to 6.5 volts are reported. Additionally, the use of an industry-standard solid source MBE reactor for growing wafers in this study and the superior intrinsic properties of InGaP make it an attractive and direct replacement for the AlGaAs Schottky layer.

We have demonstrated that the InGaP/InGaAs/GaAs PHEMT is an excellent microwave device for low-noise and power applications. It also has great potential for achieving better performance, lower cost production and more reliable device operation while keep other critical characteristics of the PHEMT intact.

Acknowledgement

We would like to thank R. Smith for RF measurements. Technical assistance from L. Tweddle, P. Aldert, and R. Thomason are also appreciated.

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