InGaP PHEMTs for Wireless Power Applications

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Abstract **This paper shows that we have successfully fabricated a InGaP PHEMT device with tight threshold voltage distribution of 22 mV by using InGaP as barrier layer material. Fabricated device performance is similar to our standard AlGaAs PHEMT for low voltage operation. A 15 mm device delivers 30 dBm output power, 10.2 dB associated gain, and 67% power added efficiency at 1dB compression point while operated at 3.5 V and 1.9 GHz.**

I. INTRODUCTION

There has been great interest in replacing AlGaAs with InGaP material in GaAs based InGaAs channel PHEMT device structures for several well-known reasons. First, InGaP does not have oxidation and deep level traps as in the case of AlGaAs material, which is good for low noise and reliable device operations. Secondly, there is good etch selectivity between GaAs and InGaP materials, which improves process yields and reduces die costs. Thirdly, InGaP material lattice matched to GaAs breaks down at a higher electric field than the AlGaAs material normally used in the AlGaAs PHEMTs. In previous work InGaP PHEMTs have been used in X band low noise amplifiers [1-3], 76 GHz automotive radar [4], and fundamental device studies [5-6]. In this paper, we present the DC characteristics and RF power performance of our InGaP PHEMT device at 1.9 GHz, and its performance compared to production AlGaAs PHEMT device.

II. FABRICATION

The InGaP PHEMT is grown by metal organic chemical vapor deposition (MOCVD) on semi-insulating GaAs substrate by outside vendors. The epitaxial structure is a double heterojunction structure with a lattice matched InGaP Schottky barrier layer on top of an undoped InGaAs channel, as illustrated in Figure 1. The nominal sheet charge and mobility is 2.0E12 cm^{-2} and 6500 cm^2/Vs, respectively at room temperature. Device fabrication process is similar to the filled gate AlGaAs PHEMT process [7-8], except that H_3PO_4/HCl was used for removing the InGaP etch stop layer.

GaAs Cap
InGaP Etch Stop
GaAs Recess
InGaP Schottky
Si-δ doping
InGaP Spacer
InGaAs Channel
AlGaAs Spacer
Si-δ doping
AlGaAs Barrier
Buffer Layer
GaAs Substrate

Figure 1. Double heterojunction structure of the InGaP PHEMT.

III. DC PERFORMANCE

The I-V characteristics of a 06 μm x 600 μm InGaP PHEMT device are shown in Figure 2. Typical DC parameters of this InGaP PHEMT are lisited in Table I. Data for the standard AlGaAs PHEMT is listed as well for comparison purposes. As can be seen, the DC performance of the InGaP PHEMT is as good as that of the AlGaAs PHEMT in Idss, Imax, Gm, and On-resistance. Idss of 214 mA/mm, Imax of more than 400 mA/mm, Gm of more than 250 mS/mm, and On-resistance of 2.3 Ω-mm, were measured. In addition, InGaP PHEMT shows dramatically improved gate-drain breakdown voltage. This can be attributed to the high quality larger bandgap InGaP material (Eg_InGaP=1.86 eV vs. Eg_AlGaAs=1.77 eV), which breaks down at a higher field than the AlGaAs material [9]. As shown in Figure 3, the standard deviation in the hreshold voltage of 22 mV was attained due to good chemical etch selectivity between GaAs and InGaP. The data in Figure 3 was from four wafers out of two different lots. Standard deviation of the threshold voltage for the AlGaAs PHEMT process is around 60 mV, but it may not be a fair comparison due to very limited statistical database available on the InGaP PHEMTs.

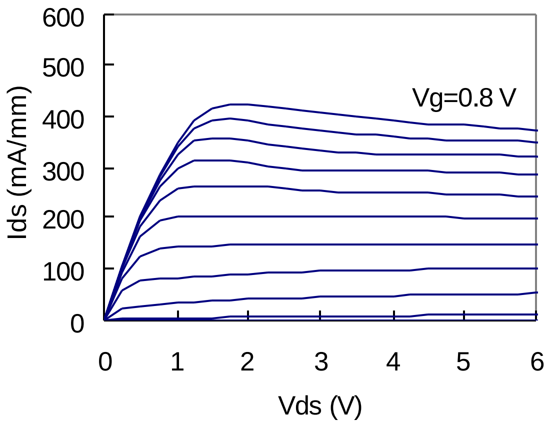


Figure 2. I-V characteristic of a 0.6 µm x 600 µm InGaP PHEMT (gate voltage steps are 0.2 V).

TABLE I

DC Data Comparison between AlGaAs PHEMT and InGaP PHEMT

Parameter	AlGaAs PHEMT	InGaP PHEMT
Idss (mA/mm)	214	214
Imax (mA/mm)	401	414
Gm (mS/mm)	280	265
Bvgdo @ 1mA/mm (V)	21	29
Vth @ 1mA/mm (V)	-0.91	-1.10
On-resistance (Ω-mm)	2.6	2.3

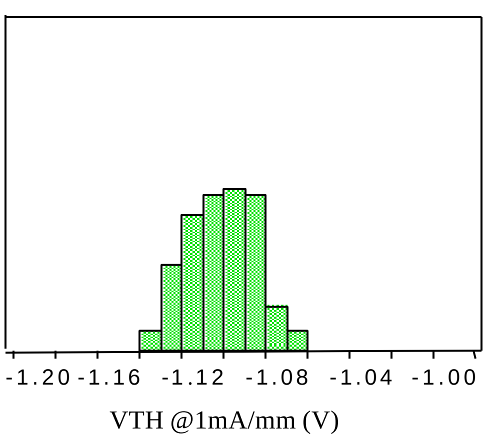
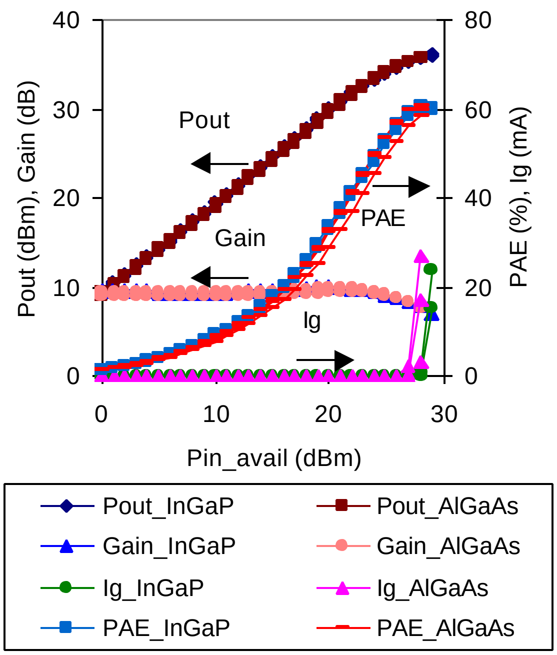


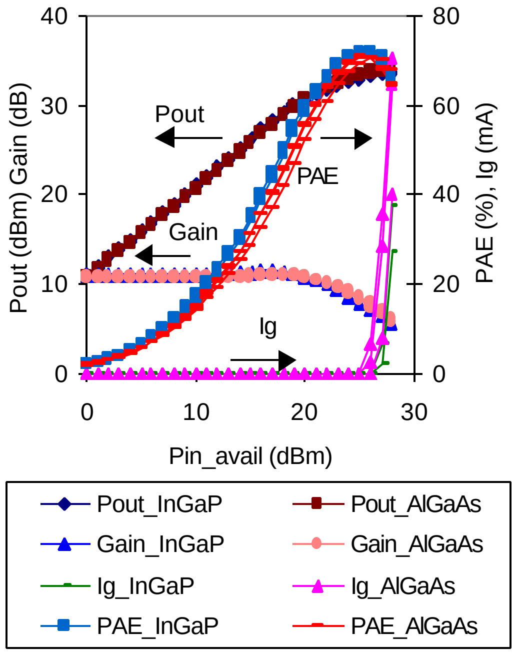
Figure 3. Threshold voltage histogram of the InGaP PHEMTs with mean value of –1.10 V and standard deviation of 22 mV.

IV. RF PERFORMANCE

The RF characteristics of a 15 mm InGaP PHEMTs were obtained using a Maury load pull system at 1.9 GHz. Measurements were performed with the device biased in class AB, Vds=3.5 V and Idq=150 mA. Figure 4 shows the output power, gain, power-added efficiency, and gate current as a function of available input power for the maximum power (Figure 4(a)) and maximum efficiency (Figure 4(b)) load states. Similar sweeps for the AlGaAs PHEMT are also included in the same figure for comparison. In order to determine the uniformity of the epitaxial material and device processing, three die were picked from each wafer for this evaluation. It can be seen that our InGaP PHEMT has nearly identical power performance as the production AlGaAs PHEMT at 3.5 V operation for the cellular handset power amplifier application. At a trade-off load state between the maximum power and the maximum efficiency conditions, the device achieves 30.0 dBm output power, 10.2 dB associated gain, and 67% power added efficiency at 1dB compression.



4 (a)



4 (b)

Figure 4. Output power, gain, and power-added-efficiency versus available input power at 1.9 GHz with device biased at 3.5 V and 150 mA for the (a) maximum power and (b) maximum efficiency load states.

V. CONCLUSION

InGaP PHEMTs have been fabricated in Motorola CS1 production fab with the standard deviation of threshold voltage as tight as 22 mV. DC characteristics of this InGaP PHEMT are similar to the AlGaAs PHEMTs. At 1.9 GHz, a 15 mm InGaP PHEMT delivers 30.0 dBm output power, 10.2 dB associated gain, and 67% power added efficiency at 1dB compression point while operated at 3.5 V.

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