X-BAND GaInP/GaAs POWER HETEROJUNCTION BIPOLAR TRANSISTOR

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ABSTRACT

We report on the large-signal performance of GaInP/GaAs HBTs at X-band. A c.w. output power of 1.0 W is obtained from a GaInP/GaAs HBT consisting of ten 2 x 30 μm^2 emitter fingers, corresponding to a power density of 3.33 W/mm. The associated power gain is 5 dB and the power added efficiency is 40 %. In addition, record-high f_T of 50 GHz and f_{max} of 116 GHz are measured from a 2-finger HBT. These results compare favorably with those measured from AlGaAs/GaAs HBTs, demonstrating that GaInP/GaAs HBTs are suitable for microwave power applications.

INTRODUCTION

Heterojunction bipolar transistors (HBTs) based on the $Ga_{0.5}In_{0.5}P$/GaAs material system have received considerable attention [1]. Etching to reach the base layer in GaInP/GaAs HBTs is achieved with great accuracy and uniformity because simple wet etchants offer high selectivity of etching away the GaInP emitter and stopping at the GaAs base. To date, near-ideal d.c. I-V characteristics with constant current gain over 5 decades of collector current and greater than unity current gain at ultra-small current densities ~ 10^{-6} A/cm^2 have been demonstrated [2]. Small-signal microwave performance with comparable cutoff frequency (f_T) and maximum oscillation frequency (f_{max}) as those of AlGaAs/GaAs HBTs has also been shown [3,4]. However, no large-signal power result was reported.

In this work, we report the first microwave large-signal power results measured from GaInP/GaAs HBTs. These HBTs consisting of ten 2 x 30 μm^2 emitter fingers are fabricated in the common-emitter configuration. Output power levels greater than 1 W c.w. are obtained at X-band. The corresponding power density is 3.33 W/mm. Measured f_T and f_{max} of 2-finger HBTs are 50 and 116 GHz, respectively, representing the highest reported values for GaInP/GaAs HBTs. Both these large-signal and small-signal results either surpass or are comparable to those measured from AlGaAs/GaAs HBTs having similar device sizes and epitaxial structures.

DEVICE DESCRIPTION

The GaInP/GaAs wafer was grown by metalorganic chemical vapor deposition (MOCVD). The epitaxial structure is schematically shown in Fig. 1. The devices were fabricated using Texas Instruments' self-aligned HBT process, except for an etching step to remove the GaInP emitter [5,6]. Both the emitter and collector contact metals were alloyed AuGe/Ni/Au, and the base contact metal was Ti/Pt/Au. A schematic layout of the 10-finger device is shown in Fig. 2. As shown, a 3 µm thick gold airbridge was used to connect the collector contacts between the emitter fingers. The wafers were lapped to a 4 mil thickness and the emitter pads were grounded to the Au-plated backside.

SMALL SIGNAL PERFORMANCE

Both the d.c. and r.f. performances of the fabricated GaInP/GaAs HBTs were characterized. Measured d.c. common-emitter I-V characteristics demonstrate that the devices have an offset voltage of ~ 300 mV and a emitter-collector breakdown voltage (BV_{ceo}) of ~ 20 V. The base-collector junction breakdown voltage (BV_{cbo}) is measured to be 31 V, a value which is consistent with the 1 µm collector

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used for the epitaxy. The knee voltage is ~ 0.8 V and the d.c. current gain values range between 10 and 15. Figure 3 shows the measured Gummel plot of a 2-finger GaInP/GaAs HBT. The base-collector bias was maintained at 0 V.

Figure 4 illustrates the measured r.f. small-signal performance of a 2-finger device. The operating collector current density was 2.1 x 10^4 A/cm^2, and the collector-emitter bias was 2 V. The values of f_T and f_{max} extrapolated using a 20 dB/decade slope are 50 and 116 GHz, respectively. These high frequency results are the best reported values for HBTs based on the GaInP/GaAs material system. These results are especially remarkable since the device structure is not aimed at achieving the best small-signal performance. Instead, the epitaxial structure which includes a thick collector doped at low concentration is designed for large-signal power amplification.

LARGE SIGNAL PERFORMANCE

The large-signal performance of a 10-finger HBTs was tested at X-band (10 GHz). The devices were tuned with external tuners having a 15:1 VSWR tuning range. The collector bias maintained at 12 V while the c.w. input power was varied between 40 and 320 mW. Figure 5 shows the operating d.c. collector and base currents as a function of the r.f. input power. Both d.c. currents increase monotonically with the input power, indicating that the devices was operated in the class-AB mode. The operating collector currents per finger range between 6.2 and 14.2 mA, corresponding to current densities between 1.0 x 10^4 and 2.4 x 10^4 A/cm^2.

Figure 6 illustrates the r.f. output power and power-added efficiency (P.A.E) as a function of r.f. input power. An output power level of 1.0 W and 40 % P.A.E are achieved with an associated power gain of 5 dB. The linear power gain at lower operating power levels is 6.7 dB. These results are the first report of power amplification using GaInP/GaAs HBTs. The highest power density obtained from these HBTs with 300 μm emitter length is 3.33 W/mm. These values of power gain, P.A.E., and power density are comparable to those achieved from AlGaAs/GaAs HBTs with similar device geometries [5]. Therefore, this work further demonstrates that GaInP/GaAs HBTs are suitable for microwave power applications.

SUMMARY

We report for the first time the large-signal microwave power performance of GaInP/GaAs HBTs. A highest output power of 1.0 W is obtained from a HBT having a 300 μm emitter length. The associated gain is 5 dB and the power added efficiency is 40 %. The linear power gain at lower power levels is 6.7 dB. These results compare favorably with those measured from AlGaAs/GaAs HBTs, demonstrating that GaInP/GaAs HBTs are suitable for microwave power applications.

ACKNOWLEDGMENT

The authors would like to acknowledge P. Bartusiak and T. Wolford for performing the microwave measurements and J. Ramzel for her excellent technical assistance.

REFERENCES

[1] M. J. Mondry, and H. Kroemer, "Heterojunction bipolar transistor using a (Ga,In)P emitter on a GaAs base, grown by molecular beam epitaxy," IEEE Electron Dev. Lett., vol. 6, pp. 175-177, 1985.

[2] W. Liu, and S. K. Fan, "Near-Ideal I-V characteristics of GaInP/GaAs heterojunction bipolar transistors," IEEE Electron Dev. Lett., vol. 13, pp. 510-512, 1992.

[3] P. Zwicknagl, U. Schaper, L. Schleicher, H. Siweris, K. H. Bachem, T. Lauterback and W. Pletschen, "High speed non-selfaligned GaInP/GaAs TEBT," Electron. Lett., vol. 28, pp. 327-328, 1992.

[4] W. Liu, S. -K. Fan, T. Henderson, and D. Davito, "Micorwave performance of a self-aligned GaInP/GaAs heterojunction bipolar transistor," IEEE Electron Dev. Lett., to appear in the April issue, 1993.

[5] B. Bayraktaroglu, R. D. Hudgens, M. A. Khatibzadeh, and H. Q. Tserng, "2.5 W CW X-band

heterojunction bipolar transistor," IEEE MTT-S International Microwave Symposium, pp. 1057-1060, 1989.

[6] A. Khatibzadeh, B. Bayraktaroglu, and T. Kim, "12 W monolithic X-band HBT power amplifier," Monolithic Circuits Symposium, Albuquerque, New Mexico, pp. 47-50, 1992.

Material	Thickness (Å)	Composition	Doping (cm^{-3})
n- GaAs	2000		5×10^{18}
n- $Ga_{1-x}In_xP$	800	0.5	3×10^{17}
p- GaAs	800		3×10^{19}
n- GaAs	10000		1×10^{16}
n- GaAs	10000		3×10^{18}

Semi-Insulating Substrate

Fig. 1 A schematic epitaxial strucutre of the GaInP/GaAs HBTs under investigation.

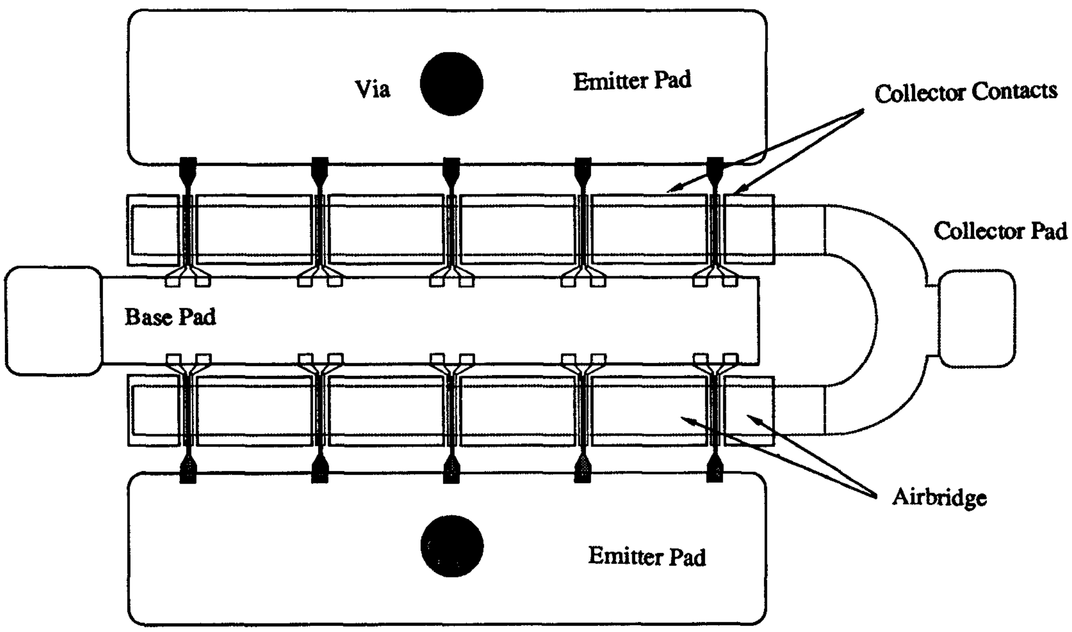

Fig. 2 A schematic device layout of the 10-finger HBTs.

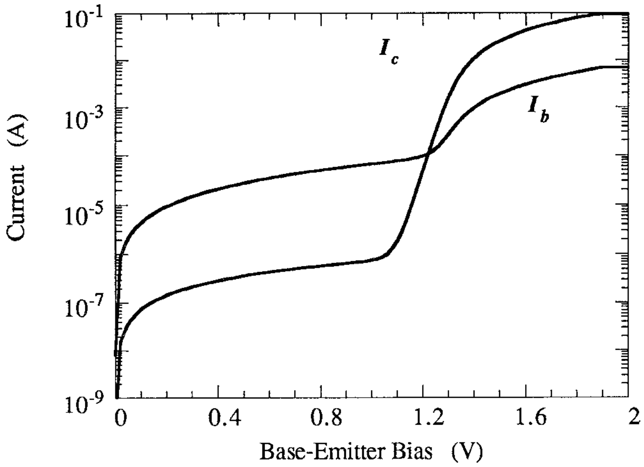

Fig. 3 Measured base and collector currents of a 2-finger device (total area: 2 x 60 μm^2) as a function of the base-emitter bias.

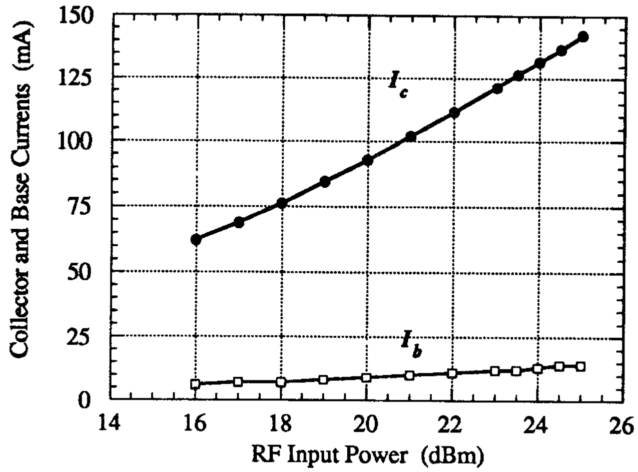

Fig. 5 The bias collector and base currents as a function of the r.f. input power. The tested device is a 10-finger HBT and the collector bias is 12 V.

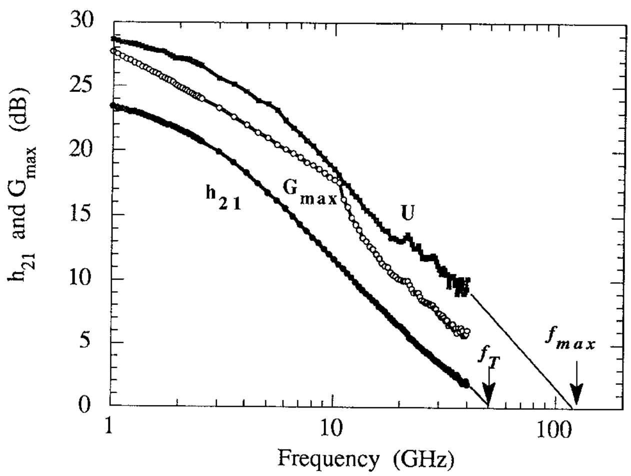

Fig. 4 Measured forward current gain, maximum available gain, and unilateral gain of a 2-finger device as a function of frequency.

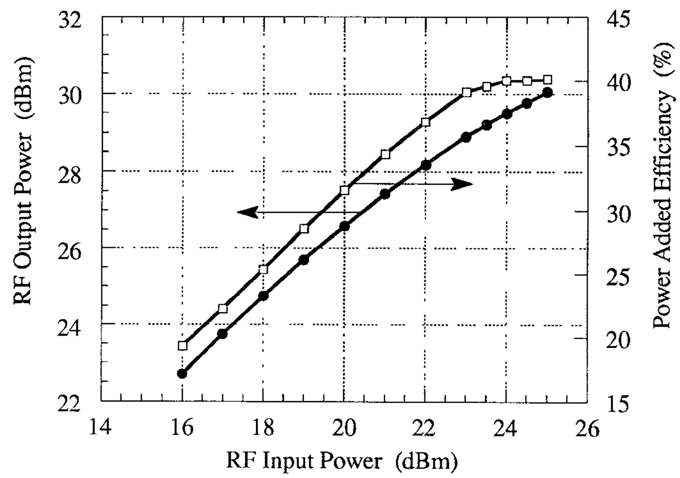

Fig.6 R.F. output power and power-added efficiency as a function of r.f. input power for the 10-finger HBT.