Microwave Noise and Power Performance of Metamorphic InP Heterojunction Bipolar Transistors (HBTs)

S. Halder, Y. Z. Xiong, G. I. Ng, H. Wang, H. Q. Zheng and K. Radhakrishnan

Microelectronic Centre, School of Electrical and Electronic Engineering, Nanyang Technological University, Nanyang Avenue, Singapore 639798

James C. M. Hwang

Compound Semiconductor Technology Laboratory, Lehigh University
5 East Packer Avenue, Bethlehem, PA 18015, USA

ABSTRACT

For the first time, microwave noise and power performance of metamorphic InP HBTs (MM-HBTs) grown on GaAs substrates are reported. We find that microwave performance of MM-HBTs are comparable to that of lattice-matched InP HBTs (LM-HBTs) of identical design but fabricated on an InP substrate. The preliminary results imply that the superior performance of InP HBTs can be confidently exploited with the more mature manufacturing technology of GaAs.

I. INTRODUCTION

The purpose of this work is to assess the viability of InP MM-HBTs that are fabricated on a GaAs substrate. We report, for the first time, microwave noise and power performance of InP MM-HBTs grown on GaAs substrate. We find the performance of InP MM-HBTs comparable to that of InP LM-HBTs of identical design but fabricated on an InP substrate. This finding implies that high-performance InP HBTs can be manufactured at lower cost and higher volume by the better established GaAs foundries.

HBTs lattice-matched to InP (LM-HBTs) have demonstrated superior microwave noise and power performance [1], [2] to that of GaAs HBTs. However, the brittle nature, small size and high cost of InP substrates hinder high-volume and low-cost manufacture. These limitations can be alleviated by growing the InP structure metamorphically on a GaAs substrate. Metamorphic HEMTs have already exhibited excellent performance and reliability [3][4]. By contrast, little has been reported on metamorphic HBTs. The following is the first comprehensive comparison of microwave noise and power performance of MM-HBTs with that of LM-HBTs.

II. DEVICE DESCRIPTION

Table I lists the HBT layer structure that was grown metamorphically on a GaAs substrate by using solid-source MBE. The structure includes an InP emitter, an $In_{0.53}Ga_{0.47}As$ base, and an $In_{0.53}Ga_{0.47}As$-InP composite collector. A linearly graded (x = 0.48 to 1) $In_xGa_{1-x}P$ buffer layer is used to relieve the strain between GaAs and InP. The InGaAs/InP composite collector structure is used to avoid current blocking. A dipole doping is employed at the InGaAs/InP interface in the composite collector to further reduce the current blocking effect [5]. Device fabrication is essentially the same as that for the LM-HBTs which employs standard mesa isolation process.

TABLE I
LAYER STRUCTURE OF METAMORPHIC INP HBT

Layers	Composition	Doping cm^{-3}	Thickness nm
Cap	InGaAs	$2x10^{19}$ SI	100
	InP	$2x10^{19}$ SI	60
Emitter	InP	$3x10^{17}$ SI	90
Base	InGaAs	$2x10^{19}$ Be	47
Collector	InGaAs	$5x10^{15}$ SI	40
	InGaAs	$1x10^{18}$ Be	10
	InP	$1x10^{18}$ SI	10
	InP	$5x10^{15}$ SI	290
	InP	$5x10^{18}$ SI	8
	InGaAs	$5x10^{18}$ SI	450
Buffer	InP		50
	$In_{0.48}Ga_{0.52}P \rightarrow InP$		1500
	GaAs		100
GaAs (100) S.I. Substrate			

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Detailed of the fabrication technique is reported elsewhere [6].

TABLE II

Comparison of DC and RF Characteristic for MM and LM DHBTs with 5x5 μm^2 emitter

	β @ I_C=10mA	BV_{CE0} (V)	Peak f_T (GHz)	Peak f_{max}(GHz)
MM HBT	40	9.8	48	42
LM HBT	180	9.2	73	52

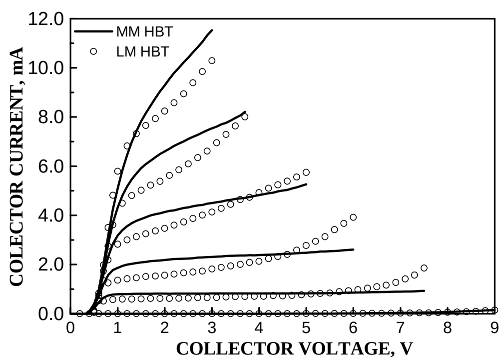

Fig. 1. Collector characteristics of an MM-HBT and an LM-HBT with a 5x5 μm^2 emitter. I_B = 0, 50, 100 …250 μA bottom up.

Fig. 1 shows typical collector characteristics of an MM-HBT with an emitter area of 5x5 μm^2. The common-emitter current gain β of the MM-HBT peaks at 40, while that of an LM-HBT of comparable size peaks at 180. Detailed analysis shows that the lower current gain is probably due to a rougher base-emitter interface as well as increased bulk recombination in the base. The open-base breakdown voltage BV_{CEO} is greater than 9V and is comparable between MM- and LM-HBTs (Table 2). As shown in Fig. 2, the cut-off frequencies f_T and f_{MAX} of the MM-HBT are 48 and 42 GHz, respectively. f_T and f_{MAX} of the LM-HBT are higher at 70 and 50 GHz, respectively. Detailed analysis suggests that the lower f_T and f_{MAX} values of MM-HBT are due to higher base and collector transit time τ_B and τ_C rather than the base-collector capacitance (C_{BC}) and base-emitter capacitance (C_{BE}) and resistances, as they are found to be the same for both types of devices.

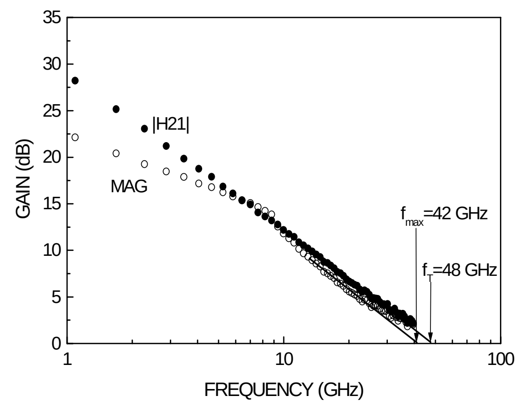

Fig. 2. Maximum available gain (MAG) and current gain (|h12|) showing f_T and f_{max} for a 5x5 μm^2 MM-HBT

III. Microwave Noise Performance

For evaluation of microwave noise performance several 5x5 μm^2 devices have been measured using ATN NP5 automated noise-pull measurement system. Fig. 3 compares the minimum noise figure F_{MIN} and associated gain (G_A) at 2 GHz and different collector current. As expected F_{MIN} decreases linearly with lower collector current for both types of devices and reaches a minimum and then rises again at very low collector current (I_C <

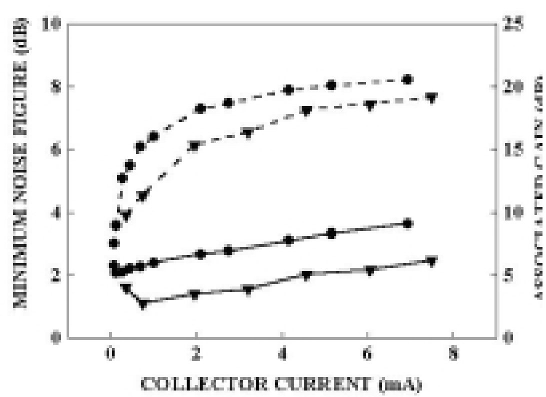

Fig. 3. Comparison at 2 GHz of (–) minimum noise figure and (---) associated gain between (●) an MM-HBT and (▼) an LM-HBT. In both cases, emitter area = 5x5 μm^2 and V_{CE} = 1.5V.

1mA). F_{MIN} reaches as low as 2 dB for MM-HBTs whereas the same approaches 1.0 dB for LM-HBTs,

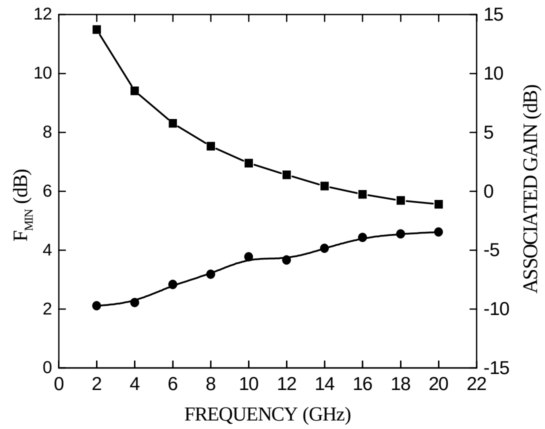

Fig. 4. Frequency vs. F_{MIN} (●)and associated gain (■) for a 5x5 μm^2 emitter area MM-HBT at I_C= 1 mA, Vce = 2 V.

which is comparable to reported results [1]. With I_C = 2.1 mA, the MM-HBT exhibits an F_{MIN} of 2.7 dB and G_A of 18 dB. In comparison, the LM-HBT has both lower F_{MIN} and lower G_A. The lower F_{MIN} is probably due to lower bulk recombination in the LM-HBT. These results are typical of more than ten HBTs of each type. It is worth noting that one particular LM-HBT with a lower β (45) and, presumably, higher bulk recombination, performs similarly to the MM-HBT with an F_{MIN} of 2.3 dB and a G_A of 18 dB at I_C = 2.1mA. As seen in Fig. 4, the F_{MIN} increases with frequency, contrary to the reported results[1], presumably because of lower f_T values of these devices.

IV. Microwave Power Performance

Microwave power measurements on these HBTs were carried out using ATN LP1 load-pull system. Fig. 5 compares the power performance of an MM-HBT and an LM-HBT. Both HBTs have an emitter area of 5x20 μm^2 and are biased Class AB with maximum-power match at 7.5 GHz with a constant current source at the base. Under a collector-emitter voltage V_{CE} of 3 V, the MM-HBT exhibits a maximum output power of 12 mW with a power-added efficiency of 43% and small-signal gain of 10dB. In comparison, the LM-HBT exhibits comparable, but somewhat inferior power performance, probably because power performance is not very sensitive to bulk recombination or dc β. The lack of RF power is due to absence of self-bias current affected by use of a constant current source at the base.

At 2.5GHz, the MM-HBTs maintains similar power

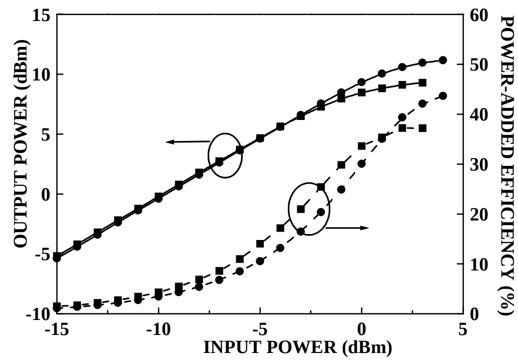

Fig.5 Output power and (---) power-added efficiency between (●) an MM-HBT and (■) an LM-HBT at different collector voltages. $I_C \cong 7$ mA emitter area = 5x20 μm^2.

performance with higher power-added efficiency of 51% and small-signal gain of 17 dB. Fig. 5 shows also that both MM- and LM-HBTs exhibit adequate power performance when the collector voltage is reduced from 3 to 2 V. On the other hand, higher bias voltage or current is not possible due to on-state breakdown. This implies that better power performance can be achieved by increasing the collector thickness beyond the present 3500 Å.

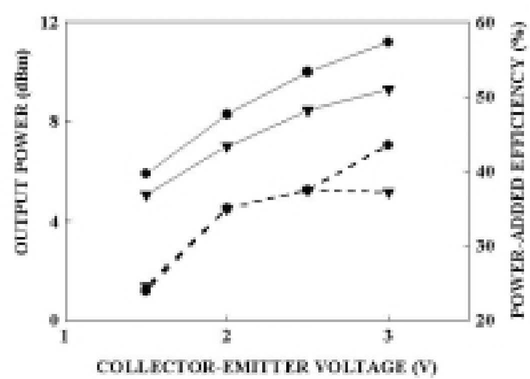

Fig. 6. Comparison at 7.5 GHz of (–) maximum output power and (---) power-added efficiency between (●) an MM-HBT and (▼) an LM-HBT at different collector voltages. $I_C \cong 7$ mA emitter area = 5x20 μm^2.

V. Conclusion

In conclusion, MM-HBTs and LM-HBTs exhibited comparable microwave performance, with MM-HBTs better in power while LM-HBTs better in noise. The difference in performance can be attributed to interface roughness and base layer quality. With continued improvement in metamorphic growth technique, the performance of MM-HBTs is expected to be on par with that of LM-HBTs. These encouraging preliminary results imply that the superior performance of InP HBTs can be exploited with the more mature manufacturing technology of GaAs.

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