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Material Design and Qualification on Power InGaP HBTs for 2.4 GHz Transmitter Application

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Abstract

To meet the requirement for today's 2.4GHz high power circuit applications, we designed and processed high power heterojunction bipolar transistors (HBTs) . The InGaP/GaAs HBTs with current gain 52.2, BV_{CEO}=16.1V, BV_{BCO}=24.6V, f_t=39GHz and f_{max}=139GHz were archieved from a 3x10μm^2 emitter contact. The performance meets the specifications required.

Introduction

The InGaP/GaAs HBT has become an excellent candidate for high power, high frequency applications due to its superior performance and reliability. To meet the requirement for today's 2.4GHz high power circuit applications, we designed and processed high power HBTs with high uniformity and manufacturability. The specifications of the power devices are, current gain β>50, emitter-collector breakdown voltage BV_{CEO} >14V, base-collector breakdown voltage BV_{CBO} >20V, f_t>30GHz and f_{max}>50GHz. Based on the theoretical predictions [1] and previous published works [2], three layer structures were proposed. The samples were then grown by MOCVD and processed on the 3-inch GaAs wafers. The current gain and breakdown voltage are compared in the small and large emitter area devices. Finally, high frequency response f_t and f_{max} are discussed.

To fabricate high power, i.e., high breakdown voltage (especially BV_{ceo} and BV_{bco}) devices, a tradeoff is made in f_t vs BV_{CEO} (and BV_{BCO}), since high speed and high power applications require different layer structures. A thinner collector is required for high speed devices, while a thicker collector and lower doping are desired for high power applications. In this work, to increase the breakdown voltage, BV_{CEO}, from 5V [2] to 14V, we doubled the thickness of the collector layer from the high frequency layer design[2, 3]. F_t is therefore decreased but still far above the current demand of 2.4GHz blue tooth wireless circuit applications.

Layer Structures

The layer structures are shown in Table 1. We compared the performance of three wafers with various collector designs. Sample A and B employed a collector thickness 800nm with doping 10^{16}cm^{-3} and 3x10^{16} cm^{-3}, respectively. Sample C has a thicker collector, 900nm, and a collector doing density, 10^{16}cm^{-3}.

Device Processing

The InGaP/GaAs HBT process begins with a deposition of emitter contact (TiPtAu), which is also used to mask the emitter etch. The InGaAs contact layer and GaAs emitter cap were etched in a citric acid-based etch, while InGaP emitter was selectively etched in an HCl-based etch. The TiPtAu base metal was deposited and base and collector layers were etched. After the isolation etching, AuGeNiAu collector metal were deposited and alloyed. Polymide planarization was followed and then a TiAu metallization was coated for cascade probing. Finally, Au air-bridge was evaporated to connect emitter and ground plane.

DC performance for devices with emitter size 60x60μm^2

A typical gummel plot is shown in Fig. 1, with base and collector ideality factor for sample C 1.06 and 1.0, respectively. The common emitter current gain at Ic=1mA is 117.6. Table 2 summarizes the DC results for sample A, B and C. The BV_{CEO} in each sample is larger than 16V and BV_{BCO} is larger than 22V due to their thicker collector layers. The typical I_c-V_{ce} curves for sample C are shown in Fig. 2 with Ib ranging from 0 to 180μA and Vce=0 to 10V. Those

Layer Designation	Material	Sample A	Sample B	Sample C
Emitter Cap	InGaAs (50%)	30nm, Si=2e19	30nm, Si=2e19	30nm, Si=2e19
Emitter Cap	InGaAs(Grade)	30nm, Si>1e19	30nm, Si>1e19	30nm, Si>1e19
Emitter Cap	GaAs	100nm,Si=4e18	100nm,Si=4e18	100nm, Si=4e18
Emitter	InGaP(In(0.49)	30nm, Si=3e17	30nm, Si=3e17	30nm, Si=3e17
Base	GaAs	140nm, C=2e19	140nm,C=2e19	140nm, C=2e19
Collector	GaAs	800nm,Si=1e16	800nm,Si=3e16	900nm,Si=1e16
Etch-stop	InGaP (50%)	20nm, Si=5e18	20nm, Si=5e18	20nm, Si=5e18
Subcollector	GaAs	500nm,Si=5e18	500nm,Si=5e18	500nm, Si=5e18
Substrate	GaAs	S.I.	S.I.	S.I.

Table 1. Layer structures for sample A, B and C

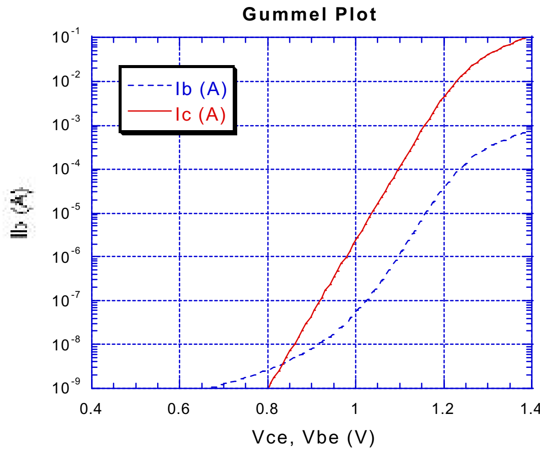


Fig. 1 Gummel plot for Sample C with a 60x60μm^2 emitter contact

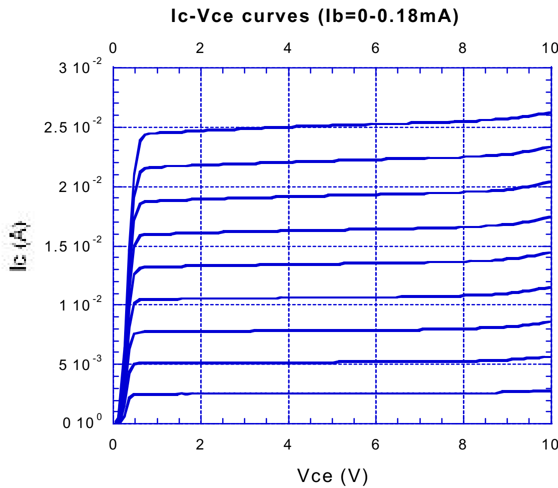


Fig. 2 Common emitter Ic-Vce characteristic for Sample C with the base current from 0 to 180uA in 20μA steps. The emitter size is 60x60μm^2

DC parameters are in excellent uniformity across the 3 inch wafers.

DC performance for devices with emitter size 3x10μm^2

In Fig. 3, the decrease of current gain was observed in devices with smaller Area/Perimeter (A/P) ratio due to the base layer surface recombination. The current gain of sample C is reduced from 117.6 of emitter size 60x60μm^2 to 51.8 of 3x10μm^2 under the same collector current, Ic=1mA. A passivated ledge structure can be a good resolution to avoid the decrease in current gain. Within a 1μm emitter–base spaing (the emitter layer undercut is around 0.2μm), the surface recombination current doesn't change too much. However, we saw a decrease in current gain when the Emitter-Base spacing is above 2μm.

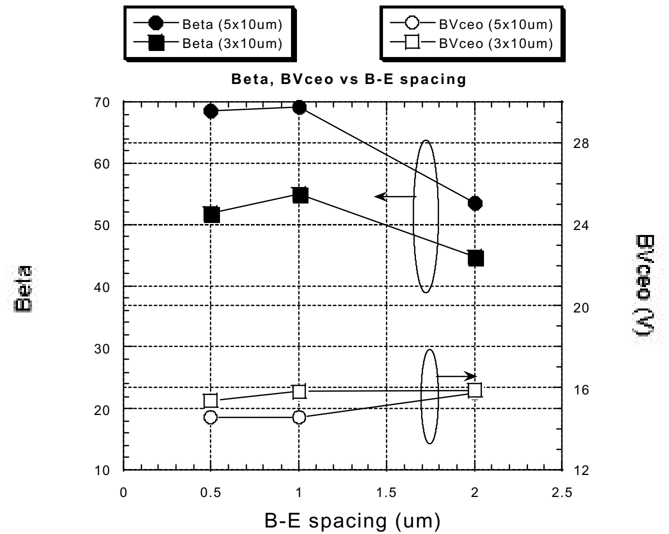


Fig. 3 Beta and BVCEO vs Base-Emitter spacing of sample C.

Sample	Avg / Std	n_b	n_c	V_{th} 1 µA	ß@10 µA	ß@1 mA	$ß_{max}$	V_{off} (mV)	BV_{cb} (V)	BV_{ce} (V)	Bv_{eb} (V)	Res (/sq)	Rbs (/sq)
A	µ	1.032	1	0.982	70.7	82.2	97.9	180	24.6	16.4	6	71.3	216.4
	σ^2	0.004	0	0.002	2.02	2.85	3.32	0	0.89	1.48	0	1.09	1.817
B	µ	1.054	1	0.982	67.9	81.26	88.8	180	22.5	19.8	6.16	96.88	293.2
	σ^2	0.009	0	0	3.25	2.688	3.1	0	0	1.57	0.09	1.13	5.119
C	µ	1.058	1	0.977	87.0	117.6	150	180	26.8	16.4	5.54	106.9	306.8
	σ^2	0.004	0	0.001	1.92	5.27	5.79	0	0.45	1.54	0	13.8	9.783

Table 2. DC performance of sample A, B and C.

Sample	BV_{CEO} (V)	Beta	f_t (GHz)	f_{max}(GHz)
A	15.5	37.1	38.0	132.0
B	18.2	38.0	38.9	135.0
C	16.1	52.2	39.1	139.0

Table 3. DC and RF performance of devices with emitter size 3x10µm^2

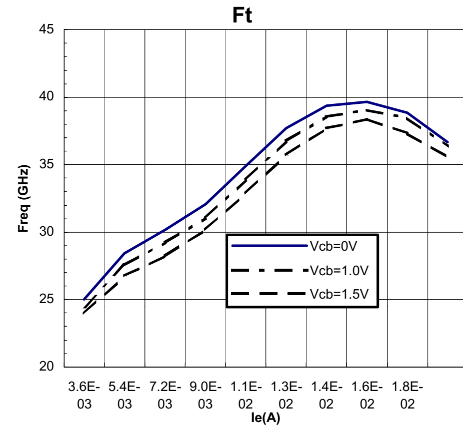
We also compared the current gain and breakdown voltage BV_{CEO} in both devices with emitter size 3x10µm^2 and 5x10µm^2. The increase in BV_{CEO} of 3x10µm^2 device is related to a smaller impact ionization due to the smaller current gain.

RF performance for devices with emitter size 3x10µm^2

The DC and RF performance for emitter size 3x10µm^2 is shown in Table 3. The transit time increases as the depleted collector thickness increases. The f_t is therefore decreases in power structures compared with high speed structures. Fig. 4 shows the f_t–Ic and f_{max}–Ic curves with Vcb=0.5V, 1.0V and 3.0V for sample C. The emitter size is 3x10 µm^2. The peak f_t and f_{max} are around 40GHz and 140GHz at Ic=14mA, respectively. A comparison of ft versus BVceo shows a strong relation to the collector thickness. We previous reported BVceo=11V and ft=69GHz with collector thickness 500nm, and BVceo=6V and ft=93GHz with collector thickness 250nm[2].

Conclusions

We designed and processed 3 power InGaP HBT structures. Though the surface recombination current decreases the current gain of smaller devices 3x10 µm^2, the DC and RF performance meet the requirements for 2.4GHz circuit applications for sample C.



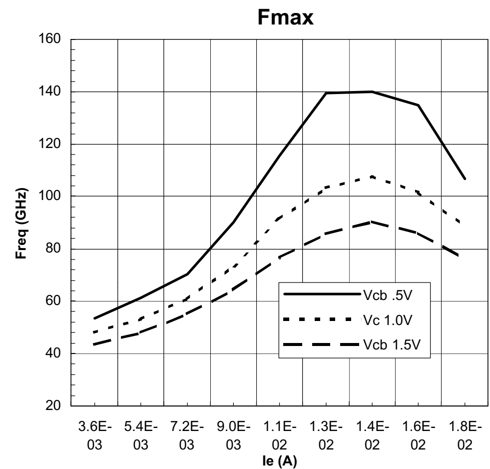


Fig. 4Ft and fmax of sample with a emitter size 3x10 µm^2

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