200 GHz $f_{\max}$, f_{τ} InP/In$_{0.53}$Ga$_{0.47}$As/InP Metamorphic Double Heterojunction Bipolar Transistors on GaAs Substrates

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Abstract

InP/In$_{0.53}$Ga$_{0.47}$As/InP Double Heterojunction Bipolar Transistors were grown on GaAs substrates using a high-thermal-conductivity InP metamorphic buffer layer. InP metamorphic buffer was selected because it has a large thermal conductivity, which is very important in high power device operation. 200 GHz $f_{\max}$ and 200 GHz f_{τ} were obtained. This $f_{\max}$ is the highest reported for a metamorphic HBT. The breakdown voltage BV_{CEO} was 6 V and the DC current gain β was 27. The base-collector reverse leakage current was 54 nA at V_{CB} =0.3V.

I. Introduction

Double heterojunction bipolar transistors [1,2,3] (DHBTs) have applications in high frequency communications and radar. HBTs using InGaAs or GaAsSb epitaxial base layers and InGaAs or InP epitaxial collector layers -- lattice-matched to InP -- currently exhibit significantly higher current-gain and power-gain cutoff frequencies than GaAs-based HBTs. However, InP substrates are expensive and are available only in smaller diameters than GaAs substrates. Additionally, 100-mm-diameter InP substrates are fragile and are readily broken during semiconductor manufacturing. This has motivated the investigation of metamorphic growth of InP-based DHBTs on GaAs substrates [4]. As reported earlier [5,6,7], the buffer layer thermal conductivity has a large impact upon the device thermal resistance, especially for high speed applications where power densities must be high in order to minimize CΔV/I charging times. We therefore use InP metamorphic buffer layers. We had earlier reported MHBTs with 207 GHz f_{τ} & 140 GHz $f_{\max}$ [5]. We here report metamorphic HBTs (MHBTs) with greatly improved $f_{\max}$ resulting from improved base Ohmic contacts. 200 GHz $f_{\max}$ and 200 GHz f_{τ} were obtained. In this work, Pd (30Å)/ Ti (200Å)/ Pd (200Å) / Au (400Å) base Ohmic contacts were used. These provide specific contact resistance well below 10^{-6} Ω cm^2. The base-collector leakage current was found to be 54 nA at V_{CB}=0.3V. Though this leakage is higher than the 2 nA I_{cbo} for lattice matched DHBTs in our laboratory, it is still acceptable for most circuit applications.

II. Growth

InP/In$_{0.53}$Ga$_{0.47}$As/InP DHBTs were grown on GaAs substrate using a Varian Gen II MBE system equipped with a valved phosphorous (P) cracker cell and a valved arsenic (As)

Table 1 The sample structure of MHBT

Layer	Material	Doping (cm^{-3})	Thickness (Å)
Emitter Cap	$In_{0.53}Ga_{0.47}As$	2×10^{19} : Si	300
Grade	$In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$	2×10^{19} : Si	200
N$^+$ Emitter	InP	1×10^{19}: Si	700
N$^-$ Emitter	InP	8×10^{17} : Si	500
Grade	$In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$	4×10^{17} : Si	280
Base	$In_{0.53}Ga_{0.47}As$	4×10^{19} : Be	300
Set back	$In_{0.53}Ga_{0.47}As$	2×10^{16} : Si	300
Grade	$In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$	2×10^{16} : Si	240
Delta Doping	InP	3.6×10^{18} : Si	30
Collector	InP	2×10^{16} : Si	1430
Sub collector	$In_{0.53}Ga_{0.47}As$	1×10^{19} : Si	250
Sub collector	InP	1×10^{19} : Si	1250
Buffer	InP	undoped	15000
GaAs (100) semi-insulating substrate			

cracker cell. Key features of the layer structure include an InP emitter, a 280-Å $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$ base-emitter grade, a 300-Å-thick InGaAs base with 52 meV band gap grading for base transit time reduction, a 240-Å $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$ base-collector heterojunction grade, and a 2000-Å InP collector. Significant base dopant migration into the base-collector grade will produce a conduction-band energy barrier. For this reason, a 300Å undoped $In_{0.53}Ga_{0.47}As$ setback layer was introduced between the base and the base-collector grade. The 1.5 μm InP metamorphic buffer layer was grown at 470°C directly on the GaAs substrate. During buffer layer growth, the reflection high energy electron diffraction (RHEED) showed strong streaks, indicating two-dimensional growth, though the RHEED intensity was slightly smaller than observed with lattice-matched growth. The sample structure was shown in table 1.

III. Fabrication and Measurement

HBTs were fabricated in a triple-mesa process using optical projection lithography and selective wet chemical etching. Use of narrow emitter-base and collector-base junctions reduces both the base resistance and the collector-base capacitance [8]. While the emitter contact metal is 0.7 $\mu\text{m} \times 8\ \mu\text{m}$, lateral undercutting during the HCl-based etch of the InP emitter forms an emitter-base junction whose dimensions are approximately $0.4\ \mu\text{m} \times 7.5\ \mu\text{m}$. Collector-base capacitance is reduced by employing narrow base Ohmic contacts of 0.25 μm width on either side of the emitter stripe, producing a small $1.2\ \mu\text{m} \times\ 11\ \mu\text{m}$ base-collector junction area. Polyimide is used both for passivation and for mesa planarization prior to interconnect deposition. Figure 1 shows the common emitter characteristics, measured from 0-400 kA/cm^2 current density. The measured DC current gain is approximately 27, the common-emitter open-circuit breakdown voltage at low current densities BV_{CEO} is greater than 6 V, while $V_{CE,SAT} < 0.8$ V at 400 kA/cm^2 current density.

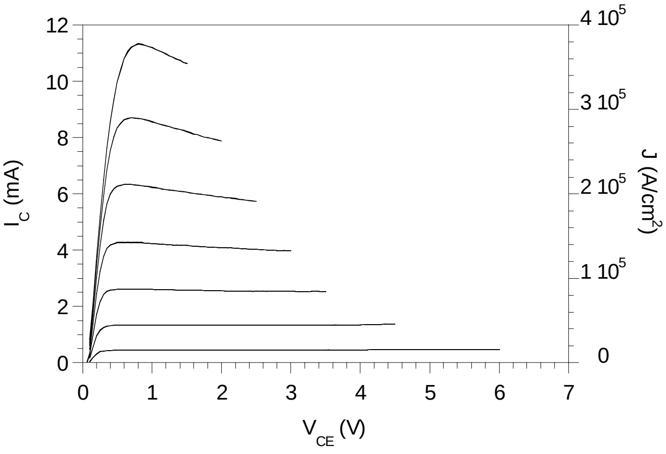

Figure 1: Common emitter DC characteristics of $0.4\ \mu\text{m} \times 7.5\ \mu\text{m}$ emitter device. The base current steps are 100 μA .

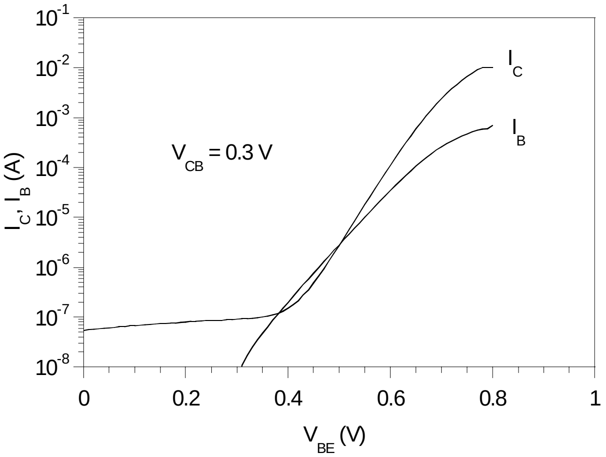

Figure 2 : Metamorphic HBT Gummel characteristics of an HBT with a $0.4\ \mu\text{m} \times 7.5\ \mu\text{m}$ emitter-base junction and a $1.2\ \mu\text{m} \times 11\ \mu\text{m}$ base-collector junction.

Figure 2 shows the HBT Gummel ($\log(I_C, I_B)$ vs. V_{CE}) characteristics, indicating a collector current ideality factor of 1.06 and a base current ideality factor of 1.48. The characteristics are measured with non-zero (0.3 V) reverse bias applied to the collector-base junction, so that base-collector

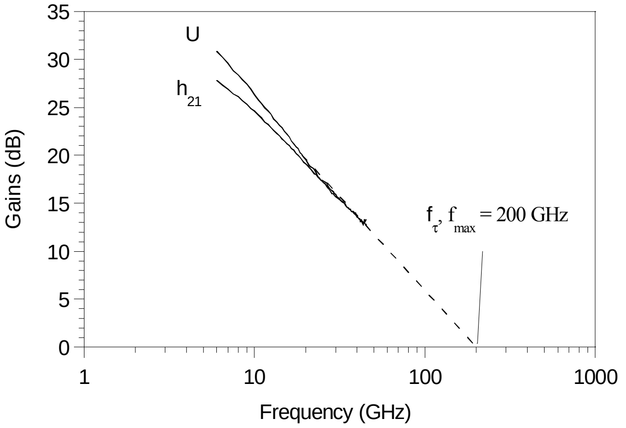

Figure. 3 : Measured short-circuit current gain h_{21} and Mason's unilateral power gain U vs. frequency for an HBT with a $0.4\ \mu\text{m} \times 7.5\ \mu\text{m}$ emitter-base junction and a $1.2\ \mu\text{m} \times 11\ \mu\text{m}$ base-collector junction. I_C =16.0 mA and V_{CE} =1.8 V.

junction leakage, if present, will be observed. Fig.2 indicates a low leakage current I_{cbo} = 54 nA at V_{CB} = 0.3 V, for a device with a 1.2 μm x 11 μm base-collector junction. Though this leakage is higher than the 2 nA I_{cbo} for lattice matched DHBTs in our laboratory, it is still acceptable for most circuit applications. The cut-off frequencies f_τ =200 GHz and $f_{\max}$ = 200 GHz were determined by a -20 dB/decade extrapolation of h_{21} and Mason's unilateral power gain, respectively (figure 3). The device was biased at I_C = 16 mA and V_{CE} = 1.8 V. This $f_{\max}$ is the highest value reported for a metamorphic HBT. Figure 4 shows the variation of f_τ and $f_{\max}$ with emitter current density, as measured at V_{CE} = 0.7 V and at V_{CE} = 1. 5 V. The observed decrease in f_τ at high current densities is due to the Kirk effect.

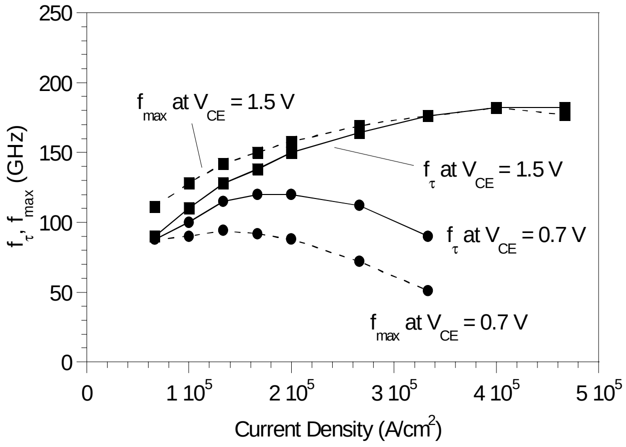

Figure. 4 : Measured current-gain cutoff frequency f_τ and power-gain cutoff frequency $f_{\max}$ vs. current density at V_{CE} =0.7 Volts and at V_{CE} =1.5 Volts.

IV. Conclusion

InP/ $In_{0.53}Ga_{0.47}As$/InP DHBTs were fabricated using InP metamorphic buffer layers on GaAs substrates. f_τ =200 GHz and $f_{\max}$ = 200 GHz were observed in a device with a 0.4×7.5 μm^2 emitter-base junction. The reverse leakage current I_{cbo} = 54 nA at V_{CB} = 0.3 V with a 1.2 μm x 11 μm base-collector junction.

Acknowledgement

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