LOW LEAKAGE CURRENT METAMORPHIC InGaAs/InP DHBTs WITH f_τ and f_{max} > 268 GHz ON A GaAs SUBSTRATE

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Abstract

Metamorphic InP/$In_{0.53}Ga_{0.47}$/InP double heterojunction bipolar transistors (mHBT) were grown and fabricated. An f_τ and f_{max} of 268 and 339 GHz were measured, respectively—both records for mHBTs. The DC current gain β is ≈ 35 and $V_{BR,CEO}$ = 5.7 V. The collector leakage current I_{cbo} is 90 pA at V_{cb} = 0.3V. A 70 nm SiO_2 dielectric sidewall was deposited on the emitter contact to permit a longer InP emitter wet etch and increase device yield. The metamorphic buffer layer is InP—employed because of its high thermal conductivity for minimum device thermal resistance [1,2].

I. Introduction

InP based double heterojunction bipolar transistors (DHBT) have been aggressively pursued because of their superior material properties over SiGe and GaAs [1]. This is demonstrated by the increased value of small signal unity current gain f_τ and unity power gain f_{max}, higher operating current density J_e, and lower thermal resistance that InP devices possess at a given scaling generation [2,3]. Recent InP DHBT results demonstrate that this material system is capable of supporting circuits in fiber IC chipsets at 160 Gb/sec and microwave analog to digital converters (ADC) of increased bandwidth. However, compared to SiGe and GaAs, InP substrates are much more expensive and fragile—often breaking during semiconductor manufacturing. In recent years, metamorphic growth of InP-based DHBTs on GaAs substrates has been investigated as a means of accessing the properties of InP in a GaAs manufacturing environment with lowered costs. For these devices to be useful in high speed circuit applications, a low C_{cb}/I_c ratio (high J_e) is necessary [4]—this requires the device operating temperature be addressed during device design [5]. Because the metamorphic buffer layer has a large impact on the thermal resistance of the HBT, InP is used for its higher thermal conductivity [6]. Here we report InP-based metamorphic DHBTs (mHBT) with a 268 GHz f_τ and 339 GHz f_{max}, and low collector leakage current of 90 pA at V_{cb} = 0.3 V. These values of f_τ, f_{max}, and collector leakage current I_{cbo} are consistent with DHBT performance from lattice matched devices of the same layer structure. Previous mHBT results from our laboratory produced a 216 GHz f_τ, 284 GHz f_{max} and I_{cbo} = 1.2 nA at V_{cb} = 0.3 V [7]—the improvements in performance reported here are mostly attributed to process changes and the use of benzocyclobutene (BCB) as the passivation dielectric.

II. Growth

InP/$In_{0.53}Ga_{0.47}$As/InP DHBTs were grown on a GaAs substrate using a Varian Gen II molecular beam epitaxy (MBE) system. Growth was initiated with a 100 nm undoped GaAs buffer layer, followed by growth at 470°C of a 1.5 µm undoped InP metamorphic buffer layer. The remaining DHBT layers were then grown (table 1). Details of the DHBT layer structure design can be found in [8].

Thickness (nm)	Material	Doping cm^{-3}	Description
10	InAs	3E19 : Si	Emitter Cap
30	$In_{0.53}Ga_{0.47}$ As	3E19 : Si	Emitter Cap
80	InP	3E19 : Si	Emitter
10	InP	8E17 : Si	Emitter
30	InP	3E17 : Si	Emitter
30	$In_{0.53}Ga_{0.47}$ As	4E19 : C	Base
20	$In_{0.53}Ga_{0.47}$ As	2E16 : Si	Setback
24	InGaAlAs	2E16 : Si	Base-Col Grade
3	InP	3E18 : Si	Delta doping
153	InP	2E16 : Si	Collector
25	$In_{0.53}Ga_{0.47}$ As	2E19 : Si	Sub Collector
375	InP	3E19 : Si	Sub Collector
20	InP	undoped	Buffer
20	InAlAs	undoped	Current blocking layer
1500	InP	undoped	Metamorphic buffer
Substrate	SI : GaAs		

Table One: mHBT layer composition

III. Fabrication

After emitter contacts were put down, 80 nm of SiO_2 was deposited on the wafer by PECVD and subsequently etched back by RIE at low pressure to leave a dielectric sidewall of 70 nm around the contact. This was done to permit a longer wet-etch of the InP emitter semiconductor—to ensure that all emitter material around the emitter contact was removed prior to self aligned base contacts being deposited. Emitter contact widths vary from 0.4-2.0 μm and base contacts extend 0.35, 0.5, or 1 μm on each side of the emitter metal [7]. The emitter and collector contacts are Ti/Pd/Au, while the base contact is Pd/Ti/Pd/Au [9]. After device passivation with benzocyclobutene (BCB), 200 nm was etched back and 100 nm of SiN deposited to act as an adhesion layer between BCB and interconnects. Vias were then etched to expose device contacts before final deposition atop the BCB of interconnect metal—50 Ω CPW transmission-lines, along with the on-wafer microwave calibration structures. A cross-sectional SEM of a fabricated mHBT with 0.6 μm emitter junction width and 1.0 μm base contact width is shown in figure 1.

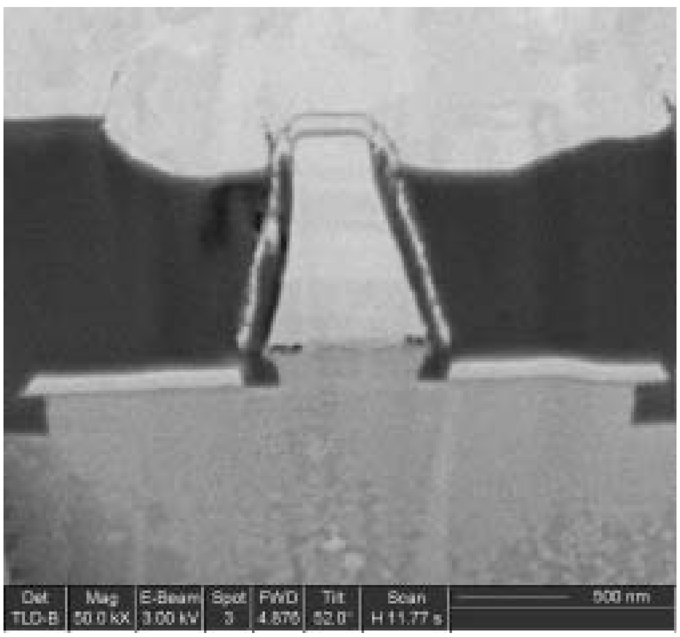

Figure 1: Crossectional SEM of mHBT

IV. Measurements and results

TLM measurements show the base $\rho_s = 1000$ Ω/sq and $\rho_c \approx 14$ $\Omega\cdot\mu m^2$, and the emitter $\rho_c \approx 20\text{-}24$ $\Omega\cdot\mu m^2$. The base metal sheet resistance is 0.5 Ohm/sq. The mHBTs have a DC current gain β of 32-37 and the common emitter breakdown voltage $V_{BR,CEO}$ is 5.7 V. A plot of the common emitter *I-V* characteristics is shown in fig 2. HBT Gummel characteristics show a collector current and base current ideality factor of 1.24 and 1.68 respectively, and a base-collector leakage current I_{cbo} = 90 pA at V_{cb} = 0.3 V offset (fig. 3). This leakage current is less than a tenth of the previously reported I_{cbo} current for UCSB mHBTs [7]. The current reduction can be attributed to the transition from polyimide to BCB for device passivation, and the placement of device interconnects on 1.4 μm thick BCB rather than thin SiN on undoped InP. The leakage current of 90 pA is within a factor of two compared to BCB passivated lattice-matched DHBTs from our laboratory—the leakage current per base-collector area of lattice matched DHBTs and metamorphic DHBTs being 3.3 pA/μm^2 and 6.0 pA/μm^2 respectively

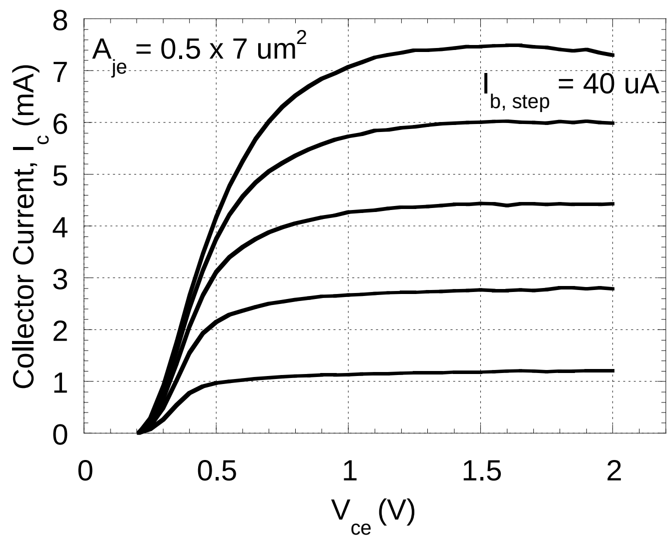

Figure 2: Common-emitter I-V characteristics

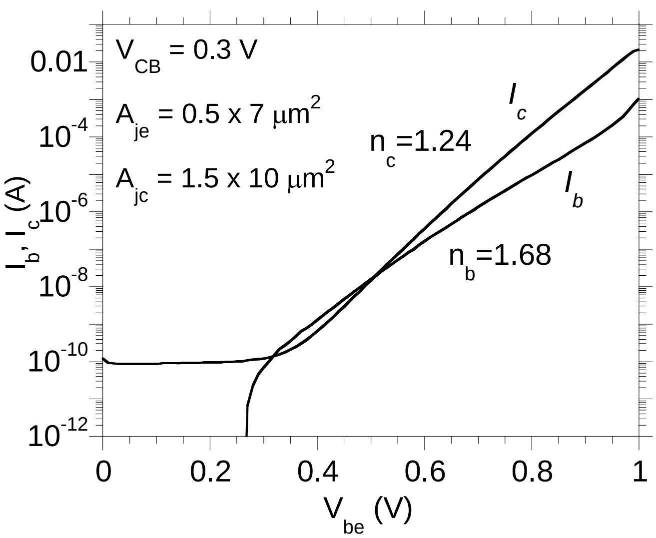

Figure 3: mHBT Gummel characteristics

5-30 GHz RF measurements were performed using on wafer LRL calibration structures. All calibrations resulted in a $|S_{21}|$ << 0.1 dB for a zero-effective length transmission line. The HBTs exhibited a maximum 268 GHz f_τ and 339 GHz f_{max} (fig. 4) at I_c = 10 mA and V_{ce} = 1.75 V (J_e = 2.9 mA/μm^2, V_{cb} = 0.8 V). This device has a 0.5 × 7 μm^2 emitter junction and

0.35 µm base ohmic contact width—1.3 µm measured base mesa width. At these DC bias conditions and HBT dimensions, the device experiences an emitter junction to ambient temperature increase $\Delta T \cong 51$ K. Peak f_τ and f_{max} is between J_e = 2.5-3.0 mA/µm^2 at V_{cb} = 0.8 V for different HBTs on the wafer.

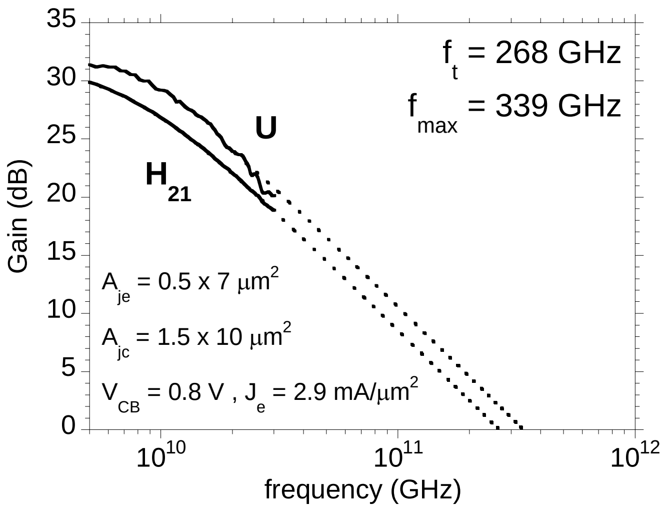

Figure 4: Measured microwave gains

V. Conclusion

InP/In$_{0.53}$Ga$_{0.47}$/InP DHBTs were fabricated on a GaAs substrate employing an InP metamorphic buffer layer. A maximum 268 GHz f_τ and 339 GHz f_{max} were measured from a 3.5 µm^2 device—both records. The I_{cbo} was 90 pA for V_{cb} = 0.3 V. These values of DC and high frequency performance demonstrate how metamorphic HBTs can duplicate lattice matched DHBT performance for the same InP/In$_{0.53}$Ga$_{0.47}$/InP layer structure.

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