High speed, low leakage current $InP/In_{0.53}Ga_{0.47}As/InP$ metamorphic double heterojunction bipolar transistors

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$InP/In_{0.53}Ga_{0.47}As/InP$ double heterojunction bipolar transistors were grown on GaAs substrates using a high-thermal-conductivity InP metamorphic buffer layer. 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 $V_{CB} = 0.3$ V.

Introduction: Double heterojunction bipolar transistors (DHBTs) have applications in high frequency communications and radar [1, 2]. Though HBTs with layers lattice-matched to InP substrates presently show the best high frequency performance, the high cost and the poor mechanical properties of InP substrates are major disadvantages in InP HBT manufacturing. For these reasons, InP-based DHBT grown metamorphically on GaAs substrates is an active topic of research [3, 4]. As reported previously [4, 5], the buffer layer thermal conductivity has a large impact upon the device thermal resistance. We therefore use InP metamorphic buffer layers. We had previously reported MHBTs with 207 GHz f_τ and 140 GHz f_{max} [4]. 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 (30 Å)/Ti (200 Å)/Pd (200 Å)/Au (400 Å) base ohmic contacts were used. These provide specific contact resistance well below 10^{-6} Ωcm^2. The base-collector leakage current was found to be 54 nA at $V_{CB} = 0.3$ V. 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.

Growth: $InP/In_{0.53}Ga_{0.47}As/InP$ DHBTs were grown on GaAs substrate using a Varian Gen II MBE system. Key features of the layer structure include an InP emitter, a 300 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 bandgap 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 300 Å 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.

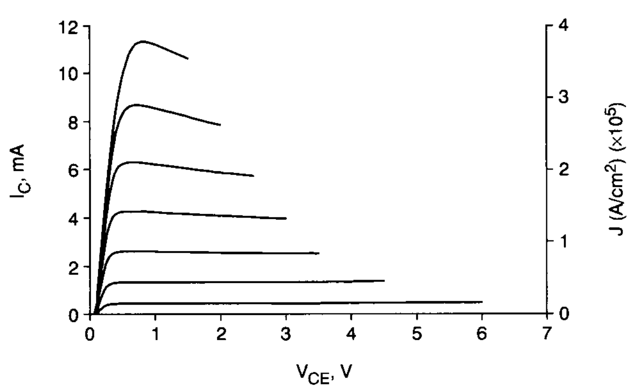

Fig. 1 *Common emitter DC characteristics of 0.4 × 7.5 μm emitter device*
Base current steps are 100 μA

Fabrication and measurement: Triple-mesa HBTs were fabricated using optical projection lithography and selective wet etching. The emitter-base junction dimension for the measured device is 0.4 × 7.5 μm, and the base-collector junction is 1.2 × 11 μm. Fig. 1 shows the common emitter characteristics; $\beta = 27$ is obtained. The Gummel characteristics (Fig. 2) indicate a low leakage current $I_{cbo} =$ 54 nA at $V_{CB} = 0.3$ V, for a device with a 1.2 × 11 μm base-collector junction. The cutoff frequencies $f_\tau = 200$ GHz and $f_{max} = 200$ GHz were determined by a −20 dB/decade extrapolation of h_{21} and Mason's unilateral power gain, respectively (Fig. 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. Fig. 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.

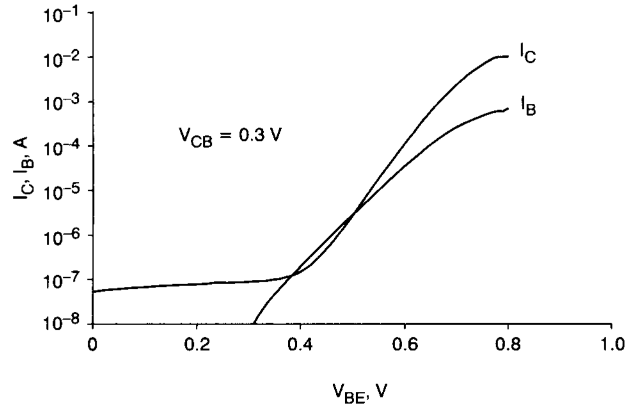

Fig. 2 *Metamorphic HBT Gummel characteristics of HBT with 0.4 × 7.5 μm emitter-base junction and 1.2 × 11 μm base-collector junction*

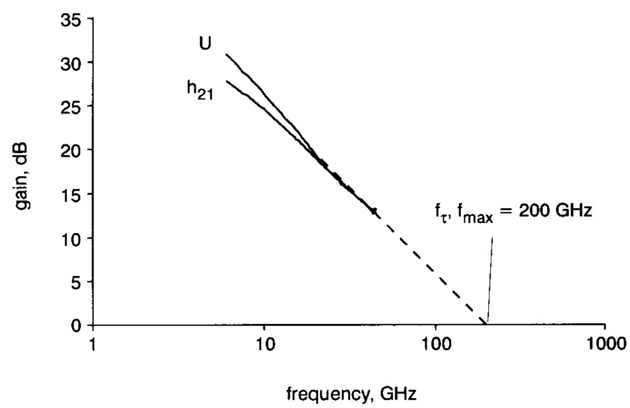

Fig. 3 *Measured short-circuit current gain h_{21} and Mason's unilateral power gain U against frequency for HBT with 0.4 × 7.5 μm emitter-base junction and 1.2 × 11 μm base-collector junction*
$I_c = 16.0$ mA, $V_{CE} = 1.8$ V

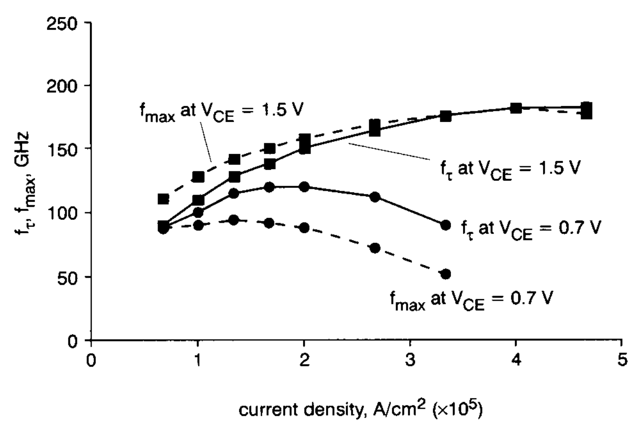

Fig. 4 *Measured current-gain cutoff frequency f_τ and power-gain cutoff frequency f_{max} against current density at $V_{CE} = 0.7$ V and $V_{CE} = 1.5$ V*

Conclusion: $InP/In_{0.53}Ga_{0.47}As/InP$ DHBTs were fabricated using InP metamorphic buffer layers on GaAs substrates. $f_\tau = 200$ 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 1.2×11 μm base-collector junction.

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