High speed, low leakage current InP/InGaAs/InP metamorphic double heterojunction bipolar transistors

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InP/InGaAs/InP double heterojunction bipolar transistors were grown on GaAs substrates using a high-thermal-conductivity InP metamorphic buffer layer. 200 GHz $f_{\text{max}}$ and 200 GHz $f_t$ were obtained. This $f_{\text{max}}$ is the highest reported for a metamorphic HBT. The breakdown voltage $BV_{\text{CEO}}$ was 6 V and the DC current gain $\beta$ was 27. The base-collector reverse leakage current was 54 nA at $V_{\text{CB}} = 0.3$ 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 HBTs 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 MHB Ts with 207 GHz $f_t$ and 140 GHz $f_{\text{max}}$ [4]. Here we report metamorphic HBTs (MHB Ts) with greatly improved $f_{\text{max}}$ resulting from improved base ohmic contacts. 200 GHz $f_{\text{max}}$ and 200 GHz $f_t$ 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 $10^{-4}$ Ω cm$^2$. The base-collector leakage current was found to be 54 nA at $V_{\text{CB}} = 0.3$ V. Though this leakage is higher than the 2 nA $I_{\text{cho}}$ for lattice-matched DHBTs in our laboratory, it is still acceptable for most circuit applications.

Growth: InP/InGaAs/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 InGaAs base-emitter grade, a 300 Å-thick GaAs base with 52 meV bandgaps grading for base transit time reduction, a 240 Å InGaAs 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 InGaAs 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.

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 x 7.5 μm, and the base-collector junction is 1.2 x 11 μm. Fig. 1 shows the common emitter characteristics; $\beta = 27$ is obtained. The Gummel characteristics (Fig. 2) indicate a low leakage current $I_{\text{cho}} = 54$ nA at $V_{\text{CE}} = 0.3$ V, for a device with a 1.2 x 11 μm base-collector junction. The cutoff frequencies $f_t = 200$ GHz and $f_{\text{max}} = 200$ GHz were determined by a -20 dB/decade extrapolation of $f_{\text{max}}$. The maximum current gain $f_t$ and power gain $U$ against frequency for HBT with 0.4 x 7.5 μm emitter-base junction and 1.2 x 11 μm base-collector junction $I_e = 16.0$ mA, $V_{\text{CE}} = 1.8$ V

Conclusion: InP/InGaAs/InP DHBTs were fabricated using InP metamorphic buffer layers on GaAs substrates. $f_t = 200$ GHz and $f_{\text{max}} = 200$ GHz were obtained. This $f_{\text{max}}$ is the highest reported for a metamorphic HBT. The breakdown voltage $BV_{\text{CEO}} = 6$ V and the DC current gain $\beta = 27$. The base-collector reverse leakage current was 54 nA at $V_{\text{CB}} = 0.3$ V. The observed decrease in $f_t$ at high current densities is due to the Kirk effect.
$f_{\text{max}} = 200 \text{ GHz}$ were observed in a device with a $0.4 \times 7.5 \text{ \mu m}^2$ emitter-base junction. The reverse leakage current $I_{\text{leak}} = 54 \text{ nA}$ at $V_{\text{CB}} = 0.3 \text{ V}$ with a $1.2 \times 11 \text{ \mu m}$ base-collector junction.

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