High speed (207 GHz f_τ), Low Thermal Resistance, High Current Density Metamorphic InP/InGaAs/InP DHBTs grown on a GaAs Substrate

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Introduction

Double heterojunction bipolar transistors (DHBTs) have applications [1-2] in GHz fiber optics, ADCs and DACs. While InP-based DHBTs outperform GaAs-based HBTs, InP substrates are available only in small diameters. 100-mm InP substrates are readily broken during processing. This motivates development of metamorphic InP-based DHBTs (M-DHBTs) on GaAs substrates [3]. Reported M-DHBT bandwidths have been well below that of lattice-matched DHBTs. Further, thermal performance has not yet been addressed.

Wideband DHBTs operate at high power densities. UCSB's 75 GHz ECL logic ICs [4] operate at $J_e \sim 180\,\text{kA/cm}^2$ and $V_{ce} \sim 1.1$ V, hence $P/A_E \sim 200\,\text{kW/cm}^2$. Current density must further increase as logic speed is increased. W-band DHBT power amplifiers operate at similar power densities. As shown in seminal work by Liu and Chau [5,6], because of the diverging heat flux, DHBT thermal resistance is critically dependent upon the thermal resistance of layers lying immediately below the DHBT collector, and thick layers of low-thermal-conductivity ($\kappa = 5\,\text{W/k-m}$) InGaAs must be avoided in the subcollector. M-DHBTs face a similar difficulty, because (as measured in our laboratory), InAlAs and AlGaAsSb metamorphic buffer layers also have very low thermal conductivity (10.5 W/K-m, and 8.4 W/K-m respectively). These layers are typically 1.5 μm thick and lie immediately below the DHBT subcollector.

Here we report InP-based DHBTs grown on GaAs using InP as the metamorphic buffer layer. This layer has a measured 16.1 W/K-m thermal conductivity. The current-gain and power-gain cut-off frequencies are f_τ=207 GHz and f_{max} = 140 GHz , both records for M-DHBTs. An M-DHBT with 0.4 μm x 7.7 μm emitter area has a measured 2.8 K/mW thermal resistance, and exhibits a small measured 35 K junction-ambient temperature rise even when biased at $J_e = 190\,\text{kA/cm}^2$ and $V_{ce} = 2$ V ($P/A_E = 380\,\text{kW/cm}^2$). At V_{CE}=1.5 V, f_τ and f_{max} collapse due to Kirk effect (collector field screening) which occurs at a high $J_e = 450\,\text{kA/cm}^2$ current density.

Growth

Layers were grown by MBE. The 1.5 µm InP metamorphic buffer layer was grown at 470°C directly on the GaAs substrate. During buffer layer growth, the RHEED pattern showed strong streaks, indicating two-dimensional growth, though the RHEED intensity was slightly smaller than observed with lattice-matched growth. The 400 Å InGaAs base is Be-doped at $4 \cdot 10^{19}/\text{cm}^3$, and the InP collector is 2000 Å thick. The emitter is InP. Thin, short-period InAlAs/InGaAs chirped superlattices are present in the emitter-base and collector-base junctions.

Results

Triple-mesa HBTs were fabricated using optical projection lithography and selective wet etching. The emitter-base junction is 0.4 μm by 7.7 μm, while the base-collector junction is 1.2 μm x 11 μm. The measured base sheet resistance of the M-DHBTs is 1019 Ω/ as compared to 933 Ω/ for lattice matched DHBTs. Fig. 1 shows the common emitter characteristics; β = 76 is obtained. Current-gain and power-gain cut-off frequencies f_τ=207 GHz and f_{max} = 140 GHz were measured (fig. 2), records for M-DHBTs. High f_τ and f_{max} are obtained even at $J_e = 450\,\text{kA/cm}^2$ (figs. 3,4). A 2.8 K/mW thermal resistance was measured by the method of [5].

References

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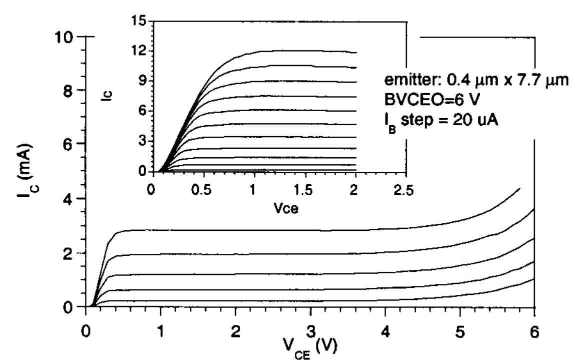

Fig. 1: Common-Emitter characteristics

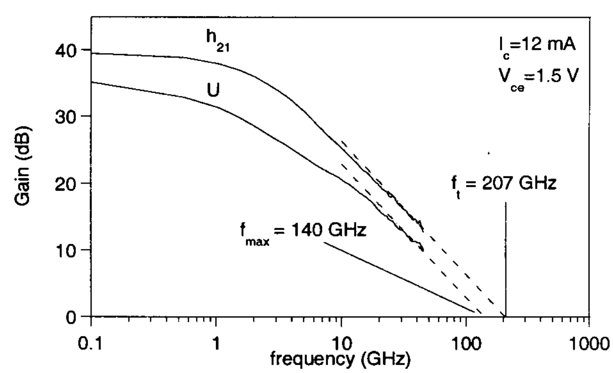

Fig. 2 : HBT current and unilateral power gains

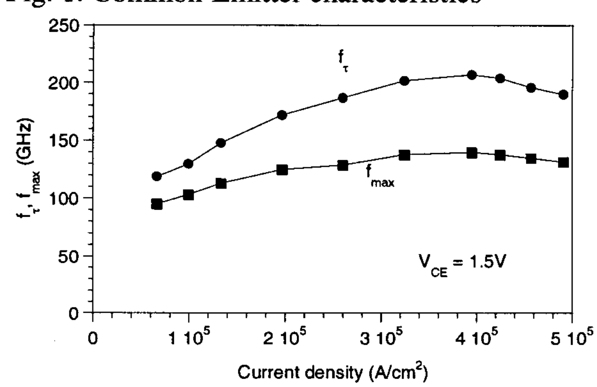

Fig. 3: f_{τ}, $f_{\max}$ vs. current density

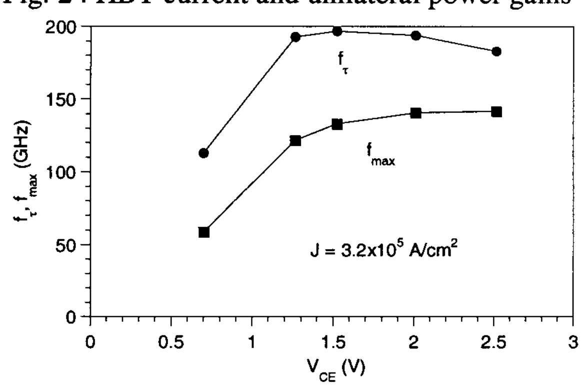

Fig. 4 : f_{τ}, $f_{\max}$ vs. V_{CE}