Ultra-Wideband DHBTs using a Graded Carbon-Doped InGaAs Base

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Abstract

We report an InP/InGaAs/InP DHBT, fabricated using a conventional mesa structure, exhibiting a 282 GHz f_t and greater than 450 GHz f_{max}, which is to our knowledge the highest f_{max} reported for a mesa HBT. The DHBT employs a 30 nm carbon-doped InGaAs base with graded base doping, and an InGaAs/InAlAs superlattice grade in the base-collector junction.

Introduction

Development of analog and digital systems operating at clock speeds of 80-160 GHz requires improved transistor performance [1]. Target HBT specifications for 160 Gb/s include greater than 3 Volts breakdown, f_t and f_{max} higher than 440 GHz, greater than 10 mA/μm^2 current density at 0.7 Volts Vce, and low base-collector capacitance ($C_{cb}/I_c<0.5$ ps/V). Prior to this work, the highest f_{max} reported for a mesa DHBT is 300 GHz at a current density of 4.1mA/μm^2, using an InP/GaAsSb/InP epitaxial design [3] and the highest fmax for a transferred substrate DHBT is 425 GHz [4].

Design and theory

To achieve simultaneously high f_t and f_{max} in a mesa HBT, the base-collector capacitance must be minimized, while maintaining a low base resistance. Since contact resistance decreases exponentially with the inverse square root of the base doping, the InGaAs base was carbon-doped at 6 10^{19} cm^{-3}. At high base doping levels, current gain is reduced due to increased Auger recombination in the neutral base. To increase current gain and decrease base transit time, a 30 nm thin base was selected, and a built-in drift field was introduced by decreasing the doping concentration through the base The emitter and the collector are InP, but with a 20 nm InGaAs and a 24 nm CSL at the collector-base junction. The subcollector is n+ InP, with only a thin n+ InGaAs contact layer to minimize thermal resistance [5].

Material and processing

The structures were grown by IQE Inc on 3" SI-InP wafers. Initial experiments for devices showed low DC current gain (<10), whereas structures with abrupt emitter-base junctions showed improved gain (~18). To improve DC gain and base transit time, improved layer structures used either base doping grading or bandgap grading. The final HBT wafer use a doping grading over the base but with constant bandgap. The HBTs were fabricated in an all wet chemical etching standard mesa process with emitter widths varying from 0.4-2.0 μm and base contacts extending 0.25, 0.5, or 1 μm on each side of the emitter metal. The narrow base contacts reduce C_{cb}, but require a very low base contact resistivity in order to maintain low base resistance. A single layer of interconnect metal forms interconnects and 50 Ω CPW transmission-lines for the on-wafer microwave calibration structures.

Results

TLM measurements showed a base sheet resistance of 580 Ω/sq, and a base contact resistance ~1 10^{-8} Ωcm^2. The HBTs have a DC current gain of 22-28 (fig.1). HBTs can be biased up to current densities of 10 mA/μm^2 at V_{ce}=2.0 V without device destruction. This indicates a low thermal resistance. Kirk effect limits the usable current density to 5 mA/μm^2 at V_{ce}=1.7 V. The common-emitter breakdown voltage $V_{BR,CEO}$ was 7.5 V.

It is progressively harder to calibrate and measure at very high frequencies, especially for devices with high gain in the measurement range. A further complication is given by coupling of the CPW mode to substrate modes in the 660 μm thick InP substrate. To reduce this coupling the wafer is thinned down to 90 μm and placed on a ferrite microwave absorber. 6-45 GHz and 75-110 GHz were performed on the wafer as-is and then the 75-110Ghz and 140-220 GHz were done after wafer thinning, resulting in a marked improvement in the calibration quality in the 75-110 GHz band.

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The HBTs exhibited a maximum 282 GHz f_t and greater than 450 GHz f_{max} at J_c=2.3 mA/μm^2 and V_{CE} = 1.5V. This device had a 0.7 by 8 μm^2 emitter and 1.0 μm base ohmic contact width (fig.2). The power gain U for a 0.5x8 μm^2 device was 15.0 dB at 110 GHz and 12.7 dB at 220 GHz. F_r is relatively constant over a broad range of collector current densities and voltages as well as between devices, but peak f_t generally occurs at V_{CE}=1.7 V and 3.5 mA/μm^2 current density. The RF data suggests that the base resistance r_{bb} is very low and that the effective collector electron velocity is approximately 4 10^5 m/s.

Conclusions

InP/InGaAs/InP DHBTs with heavy carbon base doping can obtain high current densities and high bandwidths even in conventional mesa structures. Unlike earlier wideband mesa DHBTs that employed either MOCVD-grown InP/GaAsSb/InP or InP/InGaAs/InGaAsP/InP layer structures, the DHBTs reported here employ both InGaAs base layers and InAlAs/InGaAs base-collector superlattice grades, and are readily grown by MBE. High f_t and record f_{max} are obtained due to low base transit time and low base contact resistivity. Firstly, f_{max} is a poor indicator of excess collector capacitance due to the reduction of $r_{bb}C_{cb}$ for devices with extremely low r_{bb}. Secondly, reduction of excess collector capacitance reduction in the base contact pad area is now a major priority.

References

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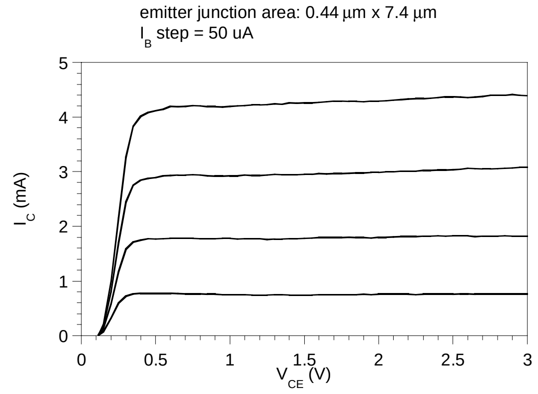

Figure 1 (left): emitter is 0.6x8 μm, base current step is 50 uA

Figure 2 (below): Emitter 0.7x8 μm, base extends 1.0 μm. I_c=12 mA V_{ce}=1.7 V