High current (100mA) InP/InGaAs/InP DHBTs with 330 GHz f_{max}

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Abstract

We report high f_{max} and high current InP/InGaAs/InP DHBT in transferred-substrate technology. The common base device with equivalent emitter size of 128 um^2 exhibits f_{max} of 330 GHz at the current of 100 mA. The common emitter device with emitter area of 64 um^2 shows f_{max} of 371 GHz when biased at 57 mA. The breakdown voltage of these DHBTs is up to 7 volts at low current density. All the devices are realized in multi-finger structure that was deliberately designed to improve the thermal stability at high power operation and to reduce the parasitics. To our knowledge, this is the highest f_{max} for a DHBT biased at such high current.

Introduction

Several groups have recently reported InP-based double heterojunction bipolar transistors (DHBTs) with > 300 GHz oscillation power-gain cut-off frequency (f_{max}) and collector breakdown voltage (BV_{CE})> 6 V. Reported wideband InP-based DHBTs [1] [2] were small-area devices with < 16 mA maximum collector current. High currents are nevertheless required: for a 5-V-breakdown DHBT, 160 mA peak collector current is required for 100 mW unsaturated class-A output power. Large-emitter-area power HBTs face additional design difficulties. Thermal instabilities result in current crowding between emitter fingers, decreasing the allowable HBT current at before bandwidth collapse due to Kirk effect. Further, large-area HBTs have large C_{cb} and very small intrinsic base resistance R_{bb}, due to the large number of emitter fingers. Small residual excess base resistance arising in either the base metallization or base contact interconnects can substantially increase the total base resistance, decreasing the device f_{max}. Here we report large-junction-area InP DHBTs with f_{max}=330 GHz when measured at a high 100 mA bias current and 3.6 Volts collector-emitter bias voltage. 371 GHz fmax is measured at 57 mA bias current on a smaller device.

Device design and fabrication

Multi-finger power HBTs were fabricated in a transferred-substrate processes [3]. The layer structure and fabrication process are similar to [1]. The DHBTs have either four or eight parallel fingers, each with a 1 µm x 16 µm emitter and a 2 µm by 20 µm collector.

The HBT maximum class-A output power is

$$P_{\max} = I_{\max}(BV_{CE} - V_{CE,sat})/8$$

where I_{max} is the maximum current and $V_{ce,sat}$ is the collector-emitter saturation voltage. Using the process reported in [1], multi-finger DHBTs with large emitter areas were fabricated. These have high current-carrying capability I_{max}. A device cross-section DHBT is shown schematically in Fig.1.

Current crowding and thermal stability determine the maximum bias current and maximum voltage of large-area power HBTs. Current crowding can occur within an individual emitter finger, or between fingers in a multi-finger device. In the presence of current crowding, those emitter areas carrying disproportionally high current density undergo premature bandwidth collapse due to the Kirk effect. By measuring ft vs. current density for HBTs of differing emitter areas, we determined that DHBTs with 1 µm by 16 µm area could be biased at 100 kA/cm^2 current density without current-crowding within a single emitter finger.

In a multi-finger device, current crowding between fingers is avoided if the thermal stability factor

$$K=\frac{dV_{be}/dT}{KT/qI_c+R_{ex}+R_{bal}}\cdot Vce\cdot\theta_{th}$$

is less than unity.

Here, dV_{be}/dT is the thermal-electric feedback coefficient, Rex is the parasitic emitter resistance, (3 Ohms for a 16 square micron emitter), $R_{ballast}$=8 Ohms is the external ballast resistance per finger, and θ_{th} is the HBT thermal resistance per emitter finger (units of C/W).

Since the device junction temperature rise is

$$T_j=\theta_{th}V_{CE}I_c$$

Given dV_{be}/dT=1.1 mV/ C [4], the thermal resistance of a single emitter finger is measured by plotting I_c vs. V_{be} with V_{ce} as a parameter (fig. 2), measuring the rate of change of V_{be} versus V_{ce} at constant I_c:

$$\theta_{th}=\Delta V_{be}/I_c\Delta V_{ce}(-dV_{be}/dT)$$

The measured thermal resistance of a single 1 μm by 16 μm emitter finger is 3.03 C/mW. At 7 μm emitter finger spacing, a 0.25 C/mW finger-finger mutual thermal resistance is also obtained; the total per-finger thermal resistance for a multi-finger device is therefore 3.28 C/mW. An 8-Ohm ballast resistor results in thermal stability (K=0.8) for a per-finger bias of 16 mA (100 kA/cm^2) at V_{ce}=3V, with thermal instability reached at V_{ce}=3.75 Volts. Thermal stability at larger V_{ce} requires increased emitter ballasting or reduced thermal resistance.

The second design difficulty faced with mm-wave power is resistance in the base contact metallization. The HBT oscillation power-gain cutoff frequency

$$f_{\max}=\sqrt{f_T/8\pi R_{bb}C_{cbi}}$$

is determined by the base resistance and the collector-base capacitance. C_{cbi} and R_{bb} vary in direct and inverse proportion to the number of emitter fingers, hence in large-area power DHBTs, R_{bb} is very small and C_{cbi} very large. Addition of small amounts of additional base resistance from the base metallization, or its contact, then rapidly degrades the HBT f_{max} and power gain.

The base contact is formed by a self-aligned evaporation with of 800 Å Au/ Pt with a measured 0.3 Ohm/square sheet resistance. Initial power HBT designs used this metallization to distribute the base input signal among 8 emitter fingers; these HBTs had f_{max} approximately 2:1 smaller than single-finger HBTs. To reduce the base feed resistance on the HBTs here reported, an additional 8000 Å Au is evaporated on the base metallization, surrounding the emitter fingers. In this manner, a DHBT with four 1 micron by 16 micron emitter fingers exhibits R_{bb}=3.3Ω and C_{cbi}=63.7fF.

In multi-finger common-base DHBTs, the input impedance is extremely small. An inductive microstrip feed network (fig.3) reduces the difficulty of input impedance matching.

DC and microwave performance

Fig.4 and Fig.5 show the DC characteristics of the 4-finger (64 μm^2 emitter area) common-emitter and 8-finger (128 μm^2 emitter area) common-base DHBTs. For the common emitter device, I_{max}=64 mA, $V_{ce,sat}$=1.5 V, while BV_{CE}=7 V at low currents. For the common base device, I_{max}=138mA, $V_{ce,sat}$=1.5 V, while BV_{CE} =8V at low currents. Figures 6 and 7 show the measured RF characteristics at high current levels with a significant collector-emitter bias voltage. f_{max} and f_T are extrapolated at -20dB/decade from measured Mason's Gain (U) and short-circuit current gain. The common-emitter device exhibits f_{max} =371 GHz and f_T=107 GHz when biased at I_c=57mA and V_{ce}=2.5V. The common-base device exhibits 330 GHz f_{max} when biased at I_c=100mA and V_{cb}=2.9V (V_{ce}=3.6 V).

Conclusions

We have developed high-current and high-breakdown-voltage DHBTs. Devices with 128 square microns emitter area demonstrate 330 GHz f_{max} at 100mA bias, a 7-Volt low-current breakdown voltage, and are thermally stable at a simultaneous V_{ce}=3.6 Volts and 100 mA bias. With these HBTs, medium-power power amplifiers are feasible at W-band and higher frequencies.

Acknowledgement

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Reference

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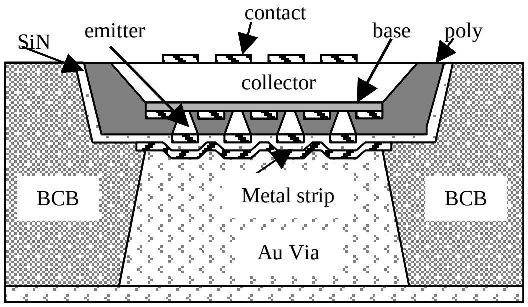

Fig.1 cross-section of multi-finger TS DHBT

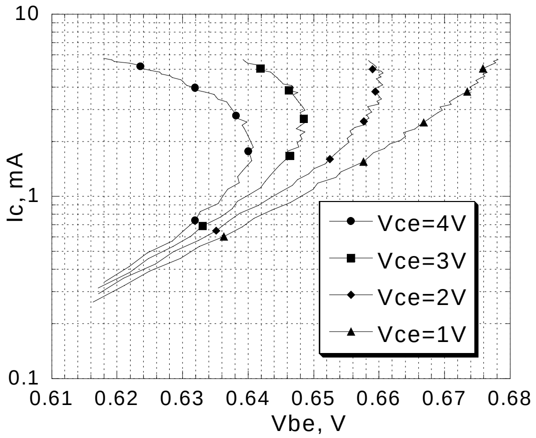

Fig.2 regression plot of single finger DHBT with varying the collector voltage by step of 1 volt

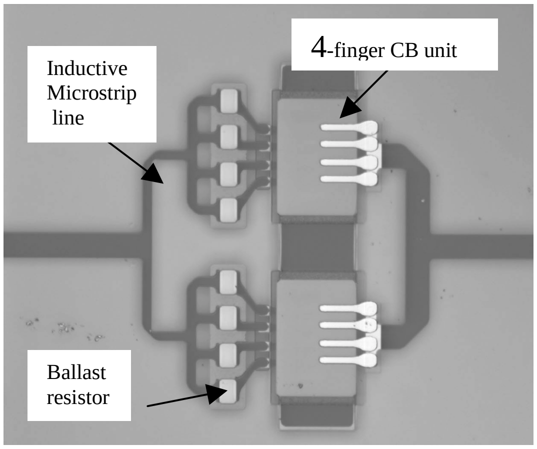

Fig.3 8-finger CB TS DHBT

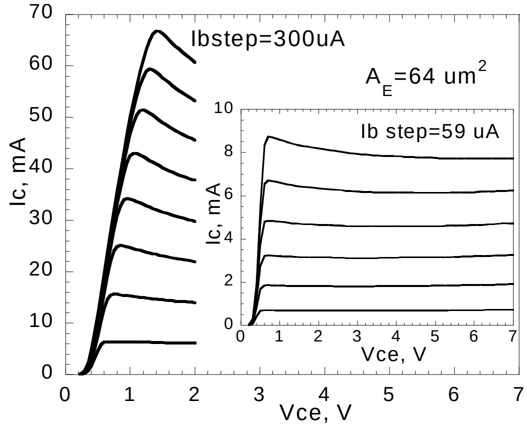

Fig.4 I-V plot of 4 finger CB TS DHBT

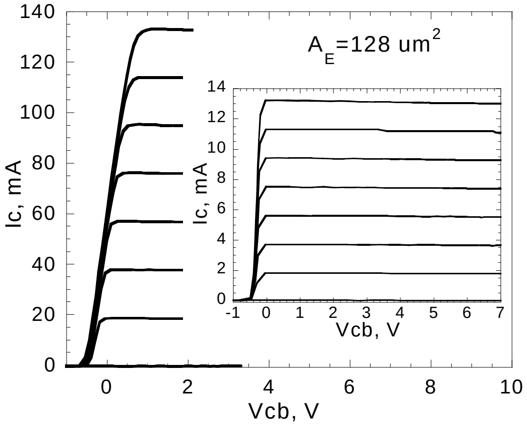

Fig.5 I-V plot of 8 finger CB TS DHBT

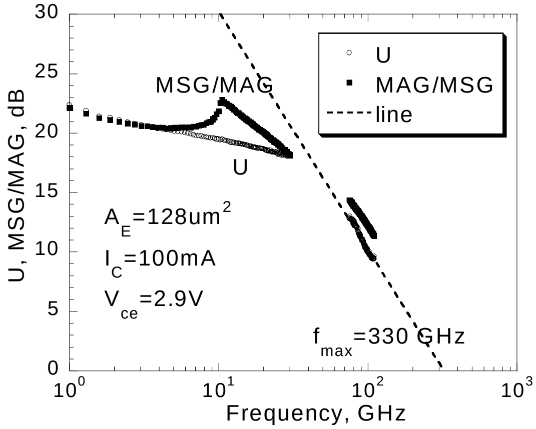

Fig.6 microwave and RF plot of 4 finger CE DHBT

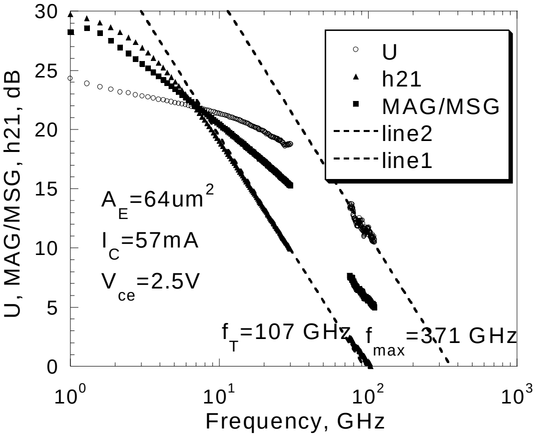

Fig.7 microwave and RF plot of 8 finger CB DHBT