A 50 GHz Feedback Amplifier with AlInAs/GaInAs Transferred-Substrate HBT

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Abstract

Transferred-substrate heterojunction bipolar transistors (HBTs) have very high f_{max} and are potential candidates for very high-speed integrated circuit applications. We report a wideband amplifier with AlInAs/GaInAs transferred-substrate HBTs. A simple Darlington configuration with resistive feedback is used and has 13 dB gain, 50 GHz 3-dB bandwidth. This is the first demonstration of a integrated circuit in the transferred-substrate HBT process.

Introduction

Heterojunction Bipolar Transistors (HBTs) are used in fiber-optic ICs, analog-to-digital converters and direct digital frequency synthesis [1, 2]. High circuit bandwidths demand very high device bandwidths. Future multi-gigabit systems will require transistors with power-gain cutoff frequencies (f_{max}) and current-gain cutoff frequencies (f_τ) in the 200-300 GHz range and above [3]. In general, device bandwidths are increased by scaling down the critical lithographic dimensions of the device. f_τ can be improved by vertical scaling of the device and improvements in the semiconductor layer structure. f_{max} $(= \sqrt{f_\tau/8\pi r_{bb}C_{cb}})$ depends both on f_τ and the base-resistance collector-base-capacitance ($r_{bb}C_{cb}$) time constant. Lateral device scaling is required to reduce the $r_{bb}C_{cb}$ product. Double-mesa HBTs are difficult to scale laterally because the base-collector junction area must be substantially larger than the emitter width to accommodate the base Ohmic contacts and base contact pads. Transferred-substrate HBTs are fabricated in a flip-chip process with narrow and aligned emitter and collector stripes on opposite sides of the base epitaxial layer. The $r_{bb}C_{cb}$ time constant becomes proportional to the (nearly equal) emitter and collector stripe widths and f_{max} rapidly increases with scaling. We have earlier demonstrated devices with a record $>$ 400 GHz f_{max} [4].

In addition to high device bandwidths, integrated circuits processes must incorporate a low capacitance wiring environment and low ground return inductance. Efficient heatsinking is important for HBTs operating at high current densities. The transferred-substrate HBT IC process uses benzocyclobutene (BCB), a low-loss, low dielectric-constant ($\epsilon_r = 2.7$), spin-on dielectric as the substrate for microstrip interconnects, thus providing low capacitance. The thin ($\simeq 10\mu$m) BCB substrate with a gold ground plane underneath also provides low inductance ground vias. Transistor heatsinking is through electroplated gold thermal vias.

This paper presents the first demonstration circuit in the transferred-substrate HBT IC process. Feedback amplifiers are suitable for technology demonstration because of their simple design, low integration levels, few passive components and easy testability. A Darlington amplifier with series and shunt resistive feedback and 50Ω input/output impedance [5] was designed and fabricated. The measured gain of the amplifier is 13 dB and the 3-dB bandwidth is 50 GHz.

Technology

The device technology used here is similar to our earlier work [4]. The MBE layer structure is similar but with a thinner base layer (400$\mathring{A}$) and a thinner collector layer (2500$\mathring{A}$). This im-

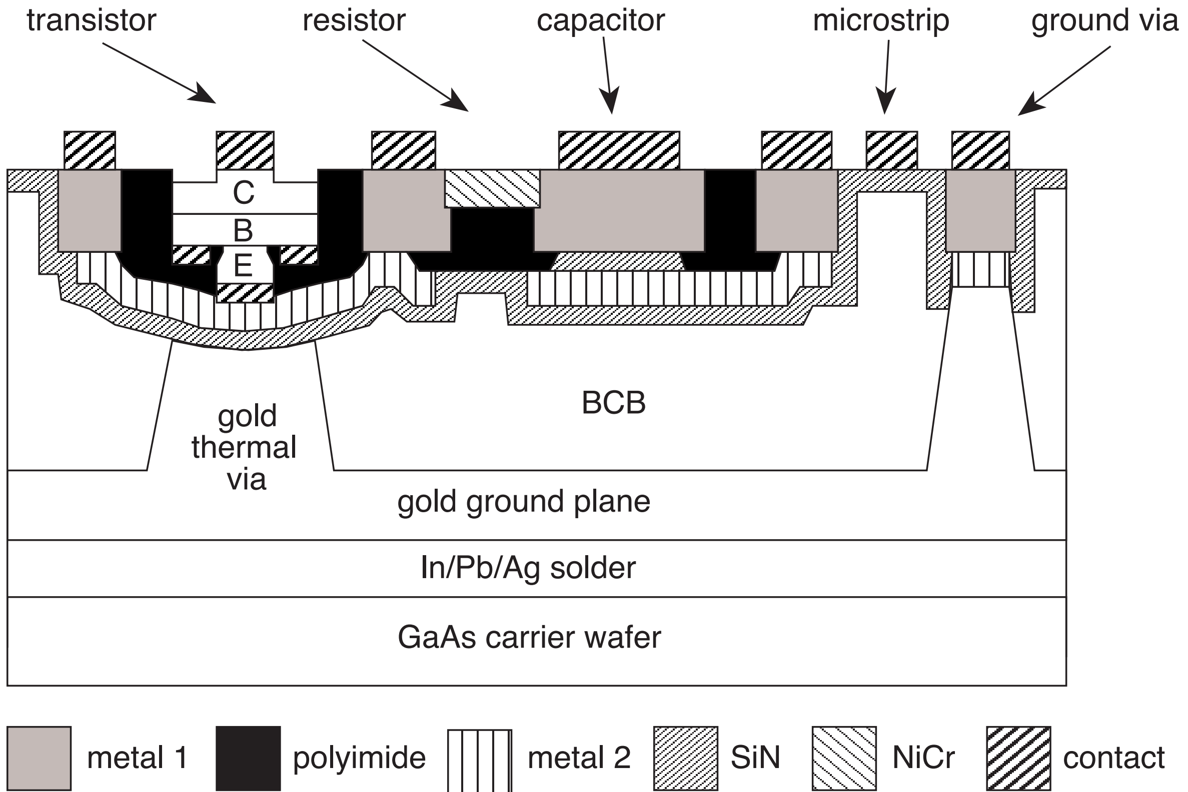

Figure 1: Schematic cross-section of the IC fabrication process.

proves f_τ at the cost of reduced f_{max}. The device fabrication procedure is basically same as that described in [4]. Fig. 1 shows a schematic cross-section of the IC fabrication process. Resistors are made with thin-film NiCr and have $50\Omega/\square$ sheet resistivity. MIM capacitors with 4000 $\AA$ SiN as the insulator material are used. At this point, only bypass (ground) capacitors have been incorporated in the process. Two levels of interconnect wiring are included. Devices with non-grounded emitters and bypass (ground) capacitors are formed by a SiN etch-protect layer (not shown here).

Devices with 0.8μm wide emitters and 1.8μm wide collectors were fabricated on this wafer. The common-emitter DC characteristics of the devices are similar to [4]. The small signal current gain at DC, β is 65. Figs. 2 and 3 show variation of f_τ and f_{max} with emitter current density J_E and collector-emitter voltage V_{CE} respectively. Peak f_τ is 175 GHz and peak f_{max} is 233 GHz. f_τ is larger and f_{max} is lower than those reported in [4] due to the reduced layer thicknesses used here. Higher base Ohmic contact resistance and a larger emitter stripe width (0.8μm vs. 0.6μm) on the ICs reported here also result in f_{max} lower than that reported earlier.

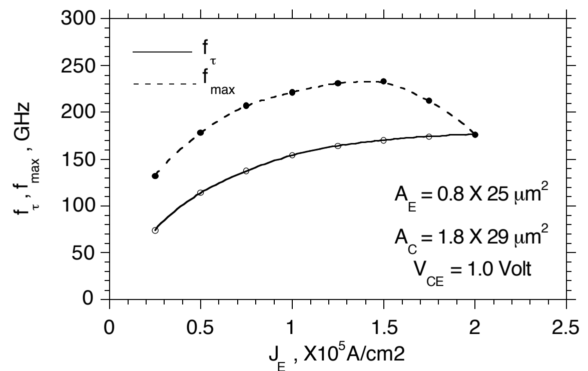

Figure 2: Variation of f_τ and f_{max} with emitter current density J_E.

Circuit Design

Fig. 4 shows a schematic circuit diagram of the amplifier. The dotted line shows the

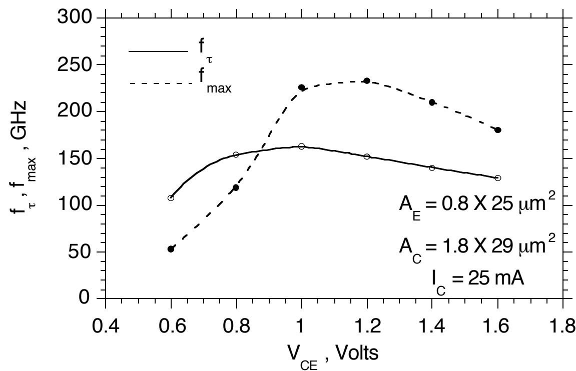

Figure 3: Variation of f_τ and f_{max} with collector-emitter voltage V_{CE}.

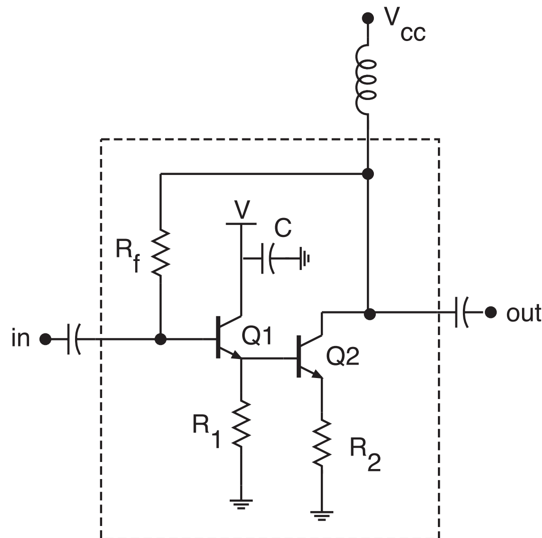

Figure 4: Schematic circuit diagram of the Darlington feedback amplifier.

chip boundary. Q1-Q2 form the Darlington pair. The emitter stripe lengths of Q1 and Q2 are selected to maximize bandwidth. If the emitter stripe length of Q1 is large, its input capacitance is large, degrading bandwidth; if it is too small, its base and emitter resistances are large, increasing the driving impedance for Q2 and degrading bandwidth. Large Q2 emitter stripe length increases its Miller-multiplied base-collector capacitance whereas a small emitter stripe length increases the base resistance, through which the (degenerated) device input capacitance must be charged. Hence there optimum emitter stripe lengths for Q1 and Q2. R_f, the shunt feedback resistor, is chosen to provide an input impedance of 50Ω. R_1 is the series feedback resistor in the emitter of Q1 and sets the Q1 emitter current density close to peak f_τ bias. R_2 sets the degenerate transconductance of Q2 (and hence of the circuit) to provide the desired gain and 50Ω output impedance. The circuit is biased with V_{CC} and an off-chip resistor connected through a bias-tee at the output. The collector of Q1 is not connected to the output, but is biased with and independent supply to eliminate Miller multiplication of its base-collector capacitance. The IC consumes 46 mW DC power. Fig. 5 shows a photograph of the amplifier. The chip dimensions are 0.4 X 0.37 mm.

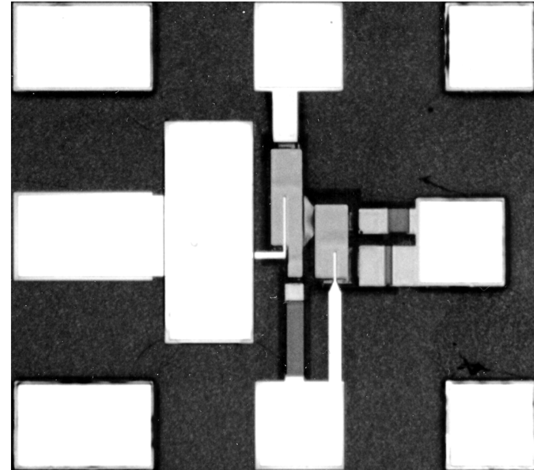

Figure 5: Photograph of the amplifier IC (0.4 mm X 0.37 mm).

Results

The amplifier characteristics were measured with a network analyzer to 50 GHz. Fig. 6 shows the forward gain s_{21} of the amplifier. The low-frequency gain is about 13 dB and the 3 dB bandwidth (relative to the low-frequency gain) is 50 GHz. The gain peaking at high frequencies is due to the second (internal) pole in the feedback loop created by the emitter resistance of Q1 and the base resistance and input capacitance of Q2. The bandwidth is below the potential of the technology for several reasons. First, f_{max} is low on the current ICs due to high base Ohmic contact resistance. Secondly, the resistor current carrying capability was lower than expected, forcing us to bias the

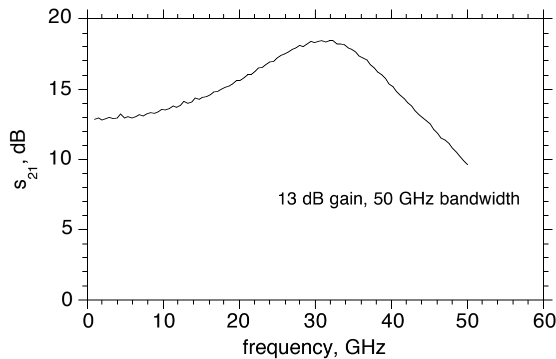

Figure 6: Measured forward gain s_{21} of the amplifier.

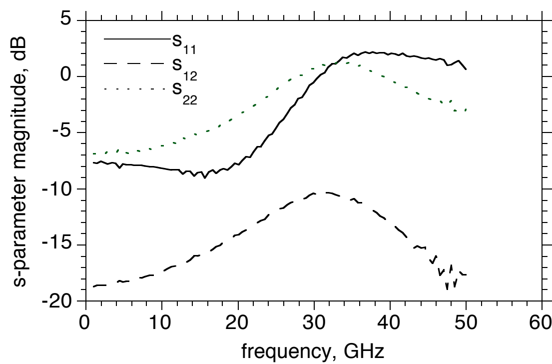

Figure 7: Measured input return loss s_{11}, output return loss s_{22}, and reverse isolation s_{12} of the amplifier.

transistors at less than the intended design conditions. At the bias conditions at which the amplifier measurements were taken, the transistor f_τ and f_{max} are 120 and 175 GHz respectively. Fig. 7 shows the input and output return losses and the reverse isolation of the amplifier.

Conclusions

We have demonstrated a resistive feedback Darlington amplifier with AlInAs/GaInAs transferred-substrate HBTs. The amplifier has 13 dB gain and 50 GHz 3-dB bandwidth. This is the first demonstration of a integrated circuit using transferred-substrate HBTs. With the high device bandwidths that transferred-substrate HBTs have demonstrated, and with improvements in the IC technology, high performance ICs are possible and are now in development.

Acknowledgements

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