Deep Submicron Transferred-Substrate Heterojunction Bipolar Transistors

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Using E-beam lithography and combined reactive-ion and wet-chemical etches, we have fabricated transferred-substrate heterojunction bipolar transistors (HBTs) with 0.2 μm emitter and 0.6 μm collector widths and a measured DC current gain of 14. Devices with 0.4 μm emitter and 1.0 μm collector widths obtain record 500 GHz f_{max}.

HBTs with several hundred GHz bandwidth will permit submillimeter-wave amplification and microwave analog-digital conversion. HBTs having high power-gain cutoff frequencies f_{max} can be fabricated using substrate transfer processes. Narrow emitter-base and collector-base junctions are formed on opposing sides of the base epitaxial layer (fig. 1). As junction widths are reduced, $R_{bb}C_{cb}$ decreases and f_{max} progressively increases. Transferred-substrate HBTs with 0.6μm emitter widths obtained $>$ 400 GHz f_{max} [1], with much higher f_{max} anticipated as the junctions are scaled to 0.1–0.2 μm. Deep submicron scaling requires precise emitter/collector alignment and precise dimensional control of the emitter/base etch. Further, degradation of β due to surface leakage is a major concern.

The material and fabrication process are similar to [1]. Emitter contact metal is defined by E-beam lithography at 0.3 μm and 0.5 μm linewidths. The emitter-base junction is formed by reactive ion etching with subsequent selective (acetic/HBr/HCl) and nonselective citric based wet etches. The etch undercuts 0.05 μm, producing 0.2 μm and 0.4 μm emitter widths (fig. 2). Subsequent steps include base Ohmic contact deposition, passivation/planarization, and emitter airbridges. The substrate transfer process includes BCB deposition, etching and plating to form vias and ground planes, bonding to a transfer substrate, and InP host substrate removal in HCl. Collector metal, with a "T" cross-section, is then defined by E-beam lithography at 0.5, 0.7, and 1.1 μm contact widths (fig. 3). An isotropic collector recess etch to 0.05 μm depth forms collector-base junctions with a tapered profile (fig. 1), reducing C_{cb} while maintaining latitude for emitter-collector misalignment. After etching, collector junction widths are 0.4, 0.6, and 1.0 μm.

DC current gains of the deep submicron devices show the expected reduction with scaling (figs. 4,5), with 0.4 $\times$ 25 $\mu\mathrm{m}^2$ emitter/0.6 $\times$ 29 $\mu\mathrm{m}^2$ collector devices exhibiting β=24, and 0.2 $\times$ 25 $\mu\mathrm{m}^2$ emitter/0.6 $\times$ 29 $\mu\mathrm{m}^2$ collector devices exhibiting β=14. W-band gain measurements (fig. 6) of 0.4 $\times$ 25 $\mu\mathrm{m}^2$ emitter/1.0 $\times$ 29 $\mu\mathrm{m}^2$ collector devices indicate record 500 GHz f_{max} and 152 GHz f_τ. To avoid measurement errors (in S_{12}, hence U) arising from microwave probe-probe coupling, the HBTs are separated from the probe pads by 320-μm-length on-wafer microstrip lines. Losses of these lines have not been de-embedded in determining the 500 GHz f_{max}; correcting for these leads to an estimated $\sim$ 600 GHz f_{max}. Devices with 0.2 μm emitter and 0.6 μm collector widths obtain 100 GHz f_τ and 345 GHz peak f_{max} . The relatively low f_{max} results from base pushout at low current densities, caused by emitter-collector misalignment. With improved emitter/collector registration, the HBTs with 0.2 μm emitter and 0.6 μm collector widths should obtain power-gain cutoff frequencies well in excess of 500 GHz, permitting analog and digital ICs [2,3] operating above 100 GHz.

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[1] R. Pullela, *et. al.*, 1997 Device Research Confernce, Ft. Collins, Co., June.
[2] B. Agarwal *et. al.*, 1998 IEEE MTT Symposium, Baltimore Md., June.
[3] R. Pullela *et. al.*, 1998 IEEE Indium Phosphide Symposium, Tsukuba, Japan, May.

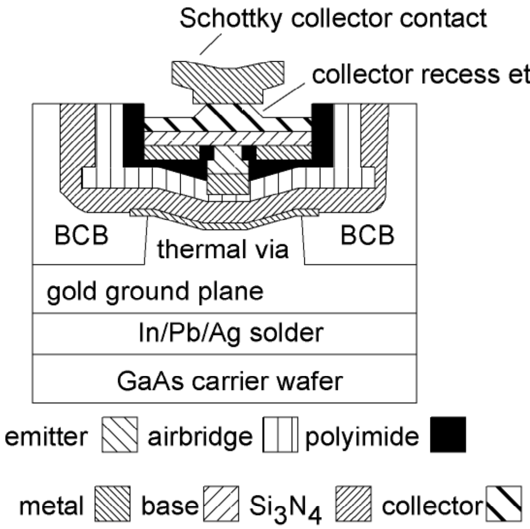

Fig. 1: Schematic cross section.

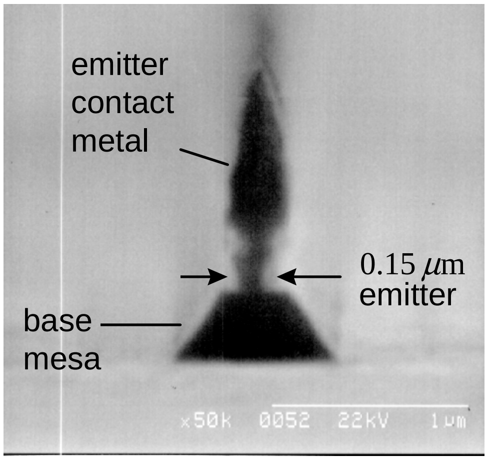

Fig. 2: 0.15 µm emitter-base junction. (structure for cleaved cross-sections, omits base Ohmic contacts & collector)

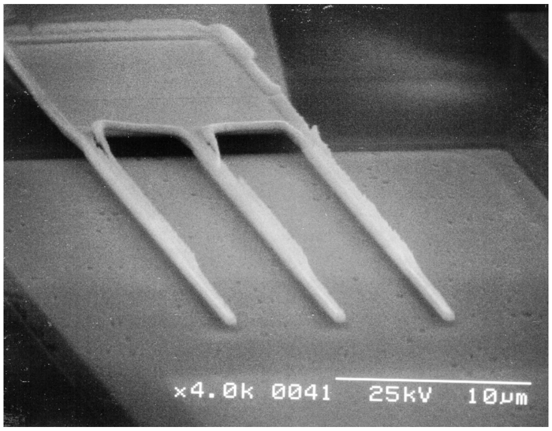

Fig. 3: Collector view of triple-finger HBT with 0.4 µm x 29 µm collector stripes and 0.2 µm x 25 µm emitter stripes. Measured β=11.

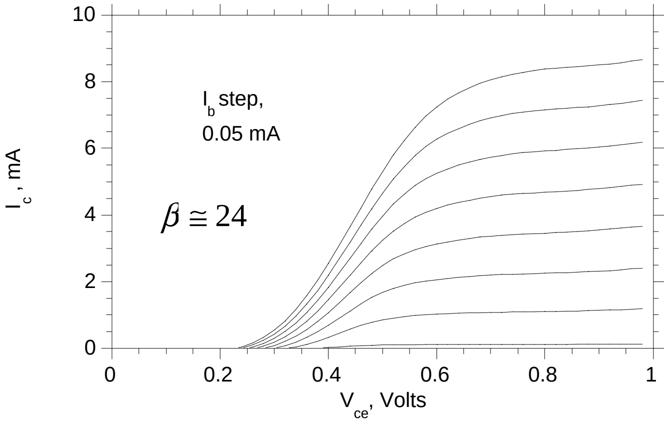

Fig. 4: Common-emitter characteristics of device with 0.4 x 25 µm^2 emitter and 0.6 x 29 µm^2 collector

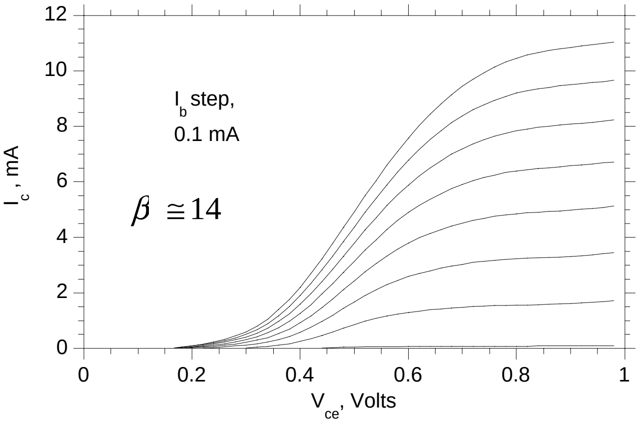

Fig. 5: Common-emitter characteristics of device with 0.2 x 25 µm^2 emitter and 0.6 x 29 µm^2 collector

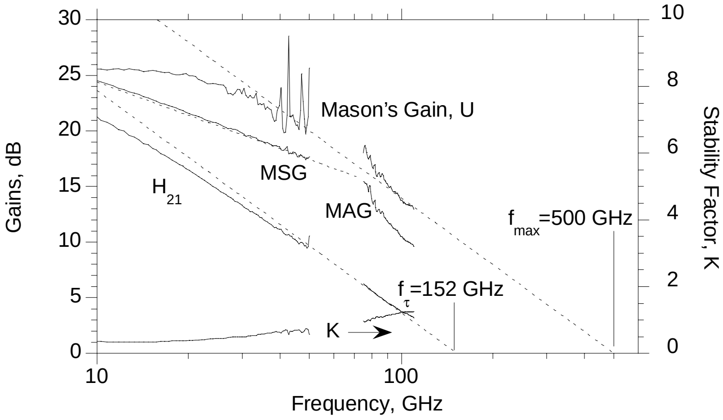

Fig. 6: Gains of 0.4 x 25 µm^2 emitter and 1.0 x 29 µm^2 collector HBT . Theoretical -20 dB/dec. (H_{21}, U) and -10 dB/dec. (MSG) gain slopes are indicated.