Ultrafast transferred-substrate heterojunction bipolar transistor ICs for high speed fiber-optic transmission

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Heterojunction bipolar transistors (HBTs) are used in Gb/s fiber-optic ICs, GHz analog-digital converters and microwave PLLs. For 50 GHz clock rates and beyond, transistor bandwidths of several hundred GHz are required. Increased bandwidths in CMOS VLSI and III-V high electron mobility field effect transistors (HEMTs) have been achieved by scaling device lithographic dimensions . In contrast, conventional double mesa HBT bandwidth has not increased with reduced lithographic dimensions due to non-scalable collector-base capacitance (fig. 1). We have developed a transferred substrate HBT process, with significant changes to the device structure which render the device scalable [1]. The process also has significant potential advantages in low parasitic wiring environment, microstrip ground plane, low thermal impedance for high power operation and increased packing density. HBTs with $f_{\max}$ > 400 GHz have been demonstrated and 50 GHz bandwidth feedback amplifiers have been fabricated. Some medium scale ICs like decision circuits, multiplexer/demultiplexer circuits and variable gain amplifiers are currently under development. Target applications include 100 Gb/s fiber transmission, microwave analog-digital converters and mm-wave frequency synthesis.

In typical double - mesa HBTs, the transfer length of the base Ohmic contacts sets a minimum size for the base-collector junction, and hence the base-collector $r_{bb}C_{cb}$ time constant is not appreciably reduced by device scaling. By using a substrate transfer process, HBTs can be fabricated with narrow emitter and collector stripes aligned on opposing sides of the base epitaxial layer. The $r_{bb}C_{cb}$ product becomes proportional to the process minimum feature size, and $f_{\max}$ increases rapidly with scaling.

To build the device, conventional base-emitter processing, mesa isolation, polyimide passivation and planarization, and electroplated gold airbridges is followed by benzocyclobutene (BCB) deposition, dry via etch and Au electroplating. Transistor epitaxial layers with thermal vias are then bonded to the transfer substrate using In/Pb/Ag solder. Schottky collector metal is deposited after the InP growth substrate is selectively etched away (fig. 3). The interconnects, microstrip on BCB, have a low ($\varepsilon_r = 2.7$) dielectric constant for low capacitance and a ground plane for low ground-return inductance.

The smallest devices fabricated with 0.6 μm emitter and 0.8 μm collector widths have $f_{\max}$ in excess of 400 GHz. Integrated circuits use 0.6 μm emitter and 1.8 μm collector devices with f_τ =164 GHz and $f_{\max}$ = 400 GHz. As a first demonstration of the transferred substrate IC process a 13 dB gain, 50 GHz 3-dB bandwidth Darlington feedback amplifier with resistive feedback has been fabricated [2]. Decision circuits with projected clock rate of 80 GHz are currently in fabrication (fig. 5).

[1] R.Pullela et. al., DRC Tech. Dig., 1997, pp. 68-69.
[2] B. Agarwal et. al., to be presented at IEDM, December 1997.

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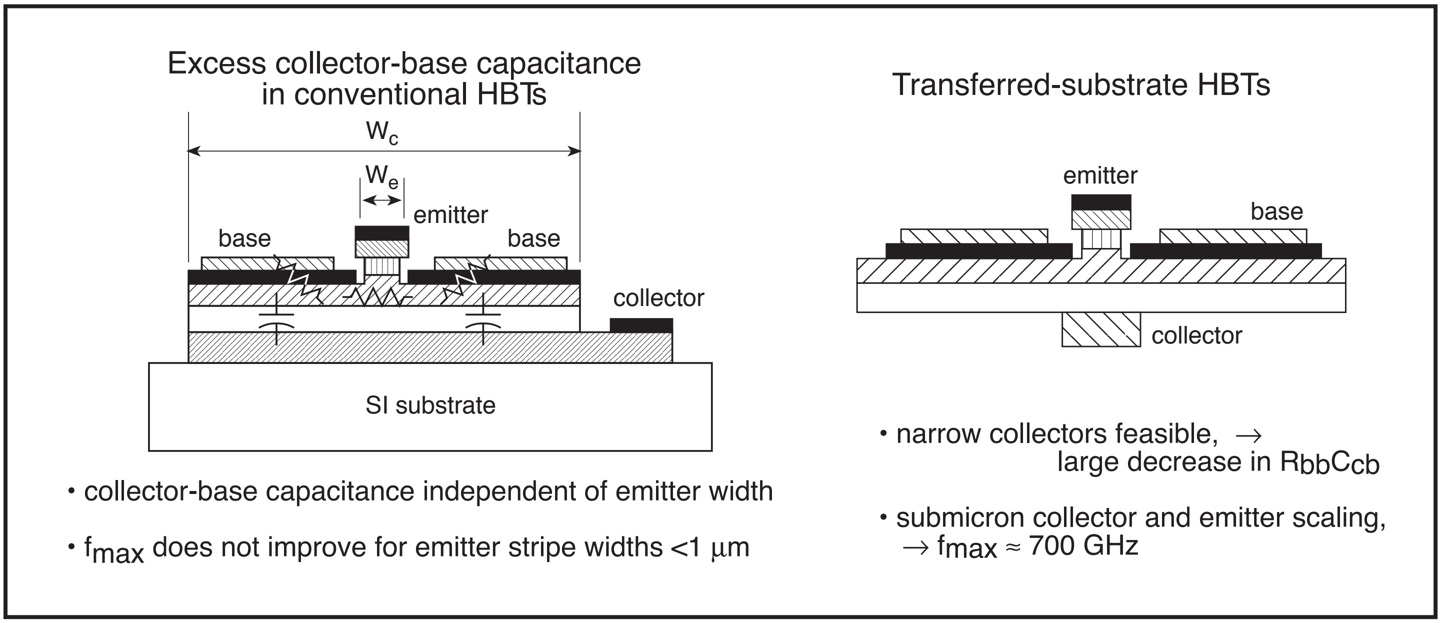

Fig. 1 HBT scaling, conventional and transferred-substrate HBT

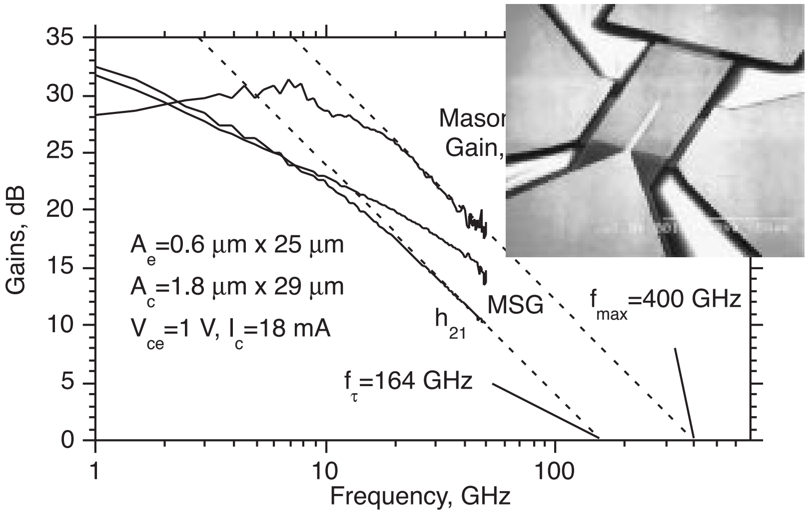

Fig. 2 Transferred-substrate HBT; performance & SEM photograph

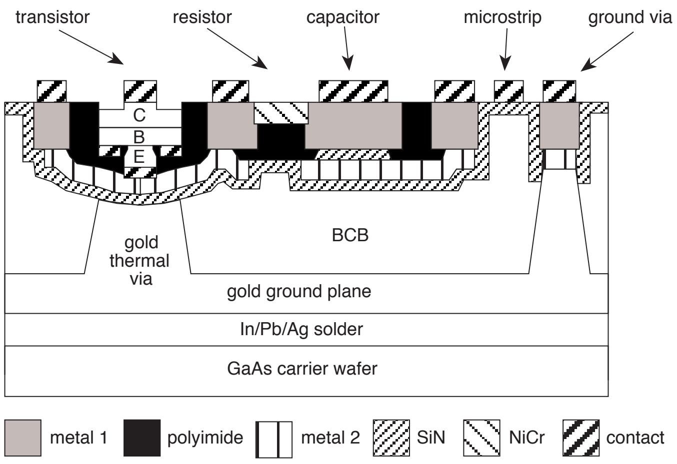

Fig. 3 Transferred-susbstrate IC cross-section

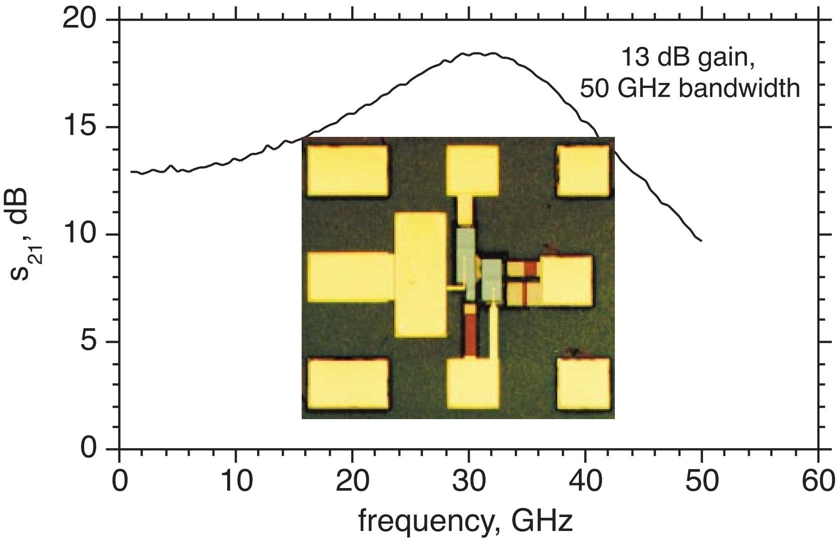

Fig. 4 Resistive feedback amplifier, forward gain and photograph

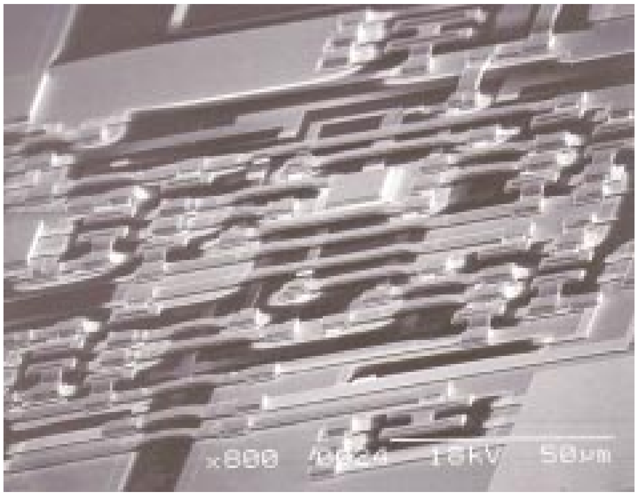

Fig. 5 80 GHz transferred substrate decision circuit - in development