Speeding oscillation of double heterojunction bipolar transistors

Researchers use graded quaternary gallium indium arsenide antimonide to improve electron transport from base to collector.

Researchers at ETH Zurich, Switzerland, claim the fastest quaternary-base double heterojunction bipolar transistor (DHBT) reported to date with maximum oscillation (f_{MAX}) greater than the cut-off (f_T) frequency, grown by metal-organic chemical vapor deposition (MOCVD) [Wei Quan et al, IEEE Electron Device Letters, published online 21 June 2018].

The quaternary base consisted of graded gallium indium arsenide antimonide (GaInAsSb). Adding indium to GaAsSb improves electron transport properties such as mobility and sheet resistance. GaAsSb's conduction band has two types of valley — one at zero wavevector (the Γ point) and one in the 'L' directions of the crystal structure. In GaAsSb, the L-valley is close in energy to the central Γ-valley. Electrons can be trapped in the L-valley, reducing performance.

The researchers comment: "Consideration of the DHBT higher bandstructure suggests the performance improvement mechanism is a reduction of the L-valley population in the GaInAsSb base and an associated easier collection into InP."

The team sees promise for the device in high-linearity high-efficiency amplification in sub-millimeter wavelength radio frequency integrated circuit applications.

MOCVD (Table 1) was carried out on 2-inch semi-insulating InP. Carbon (C) was used for p-doping of the base region, achieved through constant carbon tetrabromide precursor flux. The grading of the GaInAsSb composition resulted in variation of the uptake of carbon, decreasing with higher In-content, giving linear concentration grading between $3.1x10^{19}/cm^3$ and $8.1x10^{19}/cm^3$.

The device was designed with type-I alignment between the emitter and base and type-II alignment between the base and collector. The type-II alignment avoids blocking of electrons flowing into the collector. The alignment types I and II describe how the conduction and valence bands change at heterojunctions between different material compositions. In the type I alignments, the two bands change in opposite directions, while in type II the bands step in the same direction.

The DHBTs were fabricated in a process involving self-aligned triple mesas using the emitter and base contacts as etch masks. The emitter and base contacts consisted of titanium/platinum/gold and palladium/nickel/platinum/gold, respectively. The etching involved dry and wet processes. Atomic layer deposition of aluminium oxide was used for passivation of emitter sidewalls and extrinsic base surfaces.

Table 1. Epitaxial layer structure.

Emitter	$Ga_{0.25}In_{0.75}As$	Si: $3.8x10^{19}/cm^3$	5nm
Emitter	$Ga_{0.47}In_{0.53}As$ ---> $Ga_{0.25}In_{0.75}As$	Si: $3.8x10^{19}/cm^3$	10nm
Emitter	$Ga_{0.47}In_{0.53}As$	Si: $3.8x10^{19}/cm^3$	20nm
Emitter	InP	Si: $1.5x10^{19}/cm^3$	130nm
Emitter	InP	Si: $2.5x10^{16}/cm^3$	5nm
Emitter	$Ga_{0.20}In_{0.80}P$ ---> InP	Si: $2.5x10^{16}/cm^3$	10nm
Emitter	$Ga_{0.20}In_{0.80}P$	Si: $2.5x10^{16}/cm^3$	5nm
Base	$Ga_{0.83}In_{0.17}As_{0.62}Sb_{0.38}$ ---> $Ga_{0.94}In_{0.06}As_{0.70}Sb_{0.30}$	C: $3.1x10^{19}/cm^3$ ---> $8.1x10^{19}/cm^3$	20nm
Collector	InP	Si: $9.1x10^{16}/cm^3$	125nm
Collector	InP	S: $2.8x10^{19}/cm^3$	50nm
Collector	$Ga_{0.47}In_{0.53}As$	Si: $3.0x10^{19}/cm^3$	20nm
Collector	InP	S: $2.8x10^{19}/cm^3$	300nm
Substrate	InP	Semi-insulating	350μm

The collector mesa was produced using wet etching. Undercutting of the collector mesa reduced extrinsic base-collector capacitance. Probe pads were produced by evaporation of metal and a low-temperature Teflon-based etch-back and planarization process. Teflon has a lower dielectric constant (1.9 versus 2.7) compared with more conventional benzocyclobutene (BCB) polymer, allowing higher speed signal transmission and switching by reducing parasitic capacitance.

The researchers tested a device with 0.3μmx3.5μm emitter area (A_E). The base and collector current idealities were 1.78 and 1.04, respectively. The peak common emitter current gain was 16. Plasma etch damage reduced the gain. Larger devices fabricated with just wet etching achieved gains up to 32. Common emitter breakdown occurred at 5.1V, when the collector current density was 1kA/cm^2 (0.01mA/μm^2). The offset voltage of 70mV is described as "very low".

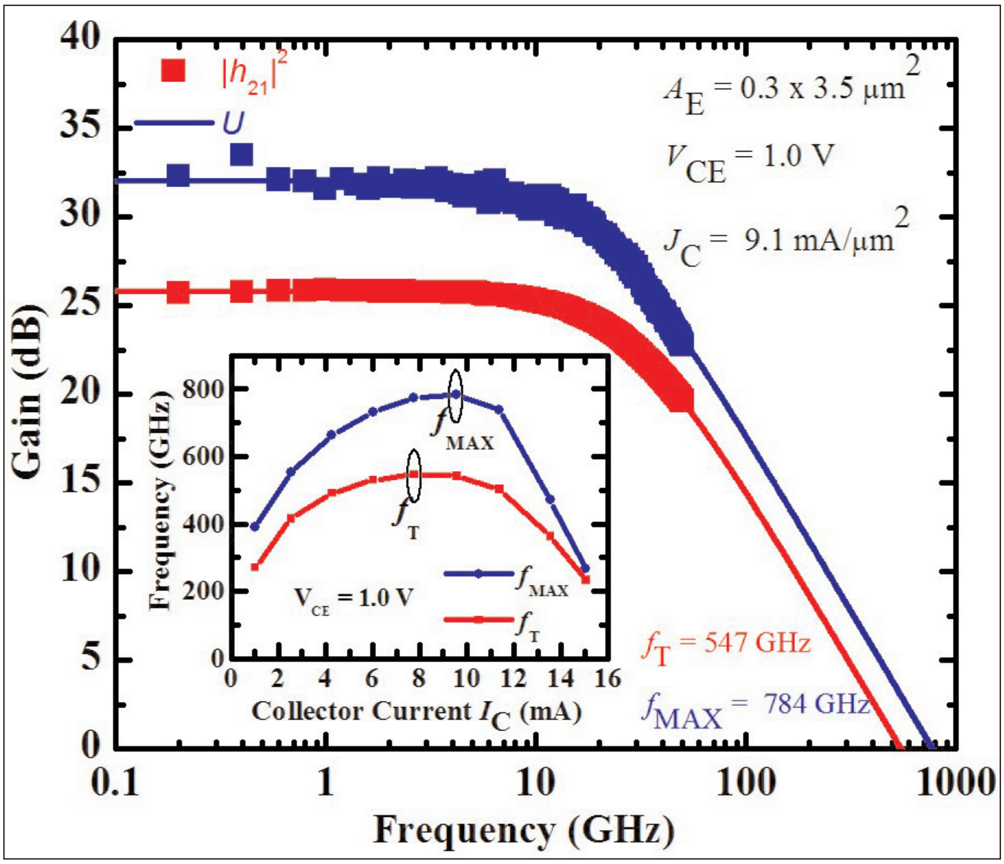

Figure 1. Short-circuit current gain ($|h21|^2$) and Mason's unilateral gain (U) measured between 0.2GHz and 50GHz. Inset dependence of f_T and f_{MAX} on collector current at 1.0V V_{CE}.

Radio frequency measurements up to 50GHz gave extrapolated maximum oscillation (f_{MAX}) and cut-off (f_T) frequencies of 784GHz and 547GHz, respectively (Figure 1). The collector–emitter voltage bias-point (V_{CE}) was 1.0V with the collector current (J_C) at 9.1mA/μm^2. Standard de-embedding gives 816GHz f_{MAX} and 552GHz f_T. Molecular beam epitaxy GaInAsSb-base devices have achieved f_T/f_{MAX} performance of 670GHz/185GHz. MOCVD graded-base DHBTs have clocked up 513GHz/637GHz.

The team reports: "The total base resistance extracted from RF measurements amounts to R_B = 25.3Ω with a contact contribution of 2.8Ω corresponding to a base contact resistance of 0.31Ω-μm^2. The f_{MAX} is therefore limited by the base sheet resistance in the present devices." ■

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