

Non-Linearity Characterization of Submicron Type-I InP/InGaAs/InP and Type-I/II AlInP/GaAsSb/InP DHBTs

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InP based single heterojunction bipolar transistors (SHBTs) have demonstrated high-speed transistor operation with current gain cutoff frequency (f_T) exceeding 850 GHz¹ via the use of a graded bandgap InGaAs base and collector. However, InP SHBTs suffer from low $BV_{CEO} = 1.65$ V. Mixed signal circuits require transistors exhibiting high linearity and high breakdown voltage to improve dynamic range. Foundries provide two types of InP based DHBTs to address the requirement of higher breakdown voltage, namely, Type I InP/InGaAs/InP DHBT and Type-II GaAsSb/InP DHBTs. Recently, a novel Type-I/II DHBT² with AlInP emitter and GaAsSb base layers has been developed which demonstrates higher gain, balanced $f_T / f_{MAX} > 400$ GHz and $BV_{CEO} > 4$ V. In this work, we have benchmarked the DC and RF linearity performance of submicron Type-I/II DHBTs made at UIUC against Type-I DHBTs obtained from two foundries.

Type I/II InP DHBT epitaxial wafers were grown and devices with emitter widths ranging from 0.3-0.5 μ m were fabricated at the UIUC microelectronics facility. The collector I-V family curves of two foundry-procured (A&B) Type-I DHBTs are characterized and compared to UIUC Type-I/II DHBTs (Fig. 1 (a) and (b)). Smaller knee voltage progression shown in the Type I/II DHBT indicates its suitability for linear amplification at lower bias voltage. The Type-I DHBT with a composite InGaAs and superlattice collector transition structure exhibits electron transport impedance resulting in current blocking at high current density. Fig. 2 illustrates the current gain compression shown in above two family curves: the UIUC device shows little compression, but both foundry Type-I devices suffer >35% β reduction in the forward-active region ($V_{CE}=1$ V). This is due to current blocking resulting from conduction band alignment at the base-collector junction. Both current gain compression and higher knee voltage contribute to nonlinear operation of the transistor. The RF data demonstrates that f_T (Fig. 3) and f_{MAX} roll off with higher current density (J_C) for both Type-I devices due to carrier blocking at B/C junction resulting in greater base transport delay. Since the third order harmonic is related to the 2nd derivative of f_T and f_{MAX} vs J_C , Type I/II DHBTs will achieve higher linearity than Type I DHBTs. The f_T and f_{MAX} roll off shows that the setback and superlattice layer in the collector of Type-I DHBTs is insufficient to resolve the current-blocking problem.

- 1 W. Snodgrass et. al., IEEE Int. Electron Devices Meeting, San Francisco, CA, December 11-13, 2006.
- 2 K. Cheng et. al., Applied Physics Letters, **98**, p. 242103, 2010

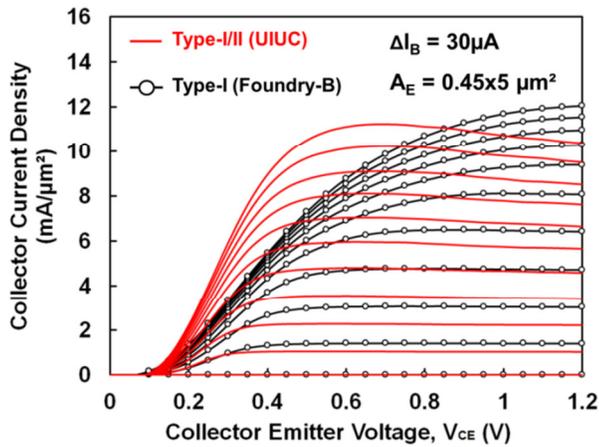


Fig. 1(a): Collector I-V of UIUC Type-I/II InP DHBT (red) and Foundry-B Type-I InP DHBT with $A_E = 0.45 \times 5 \mu\text{m}^2$. The foundry device exhibits considerable β compression due to current blocking at B/C junction despite the composite collector transition layer.

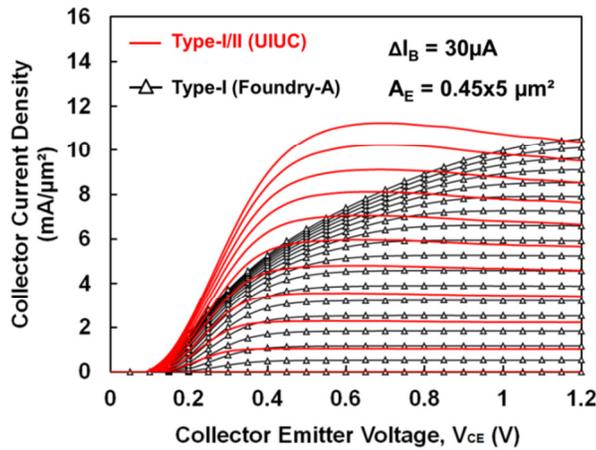


Fig. 1(b): Collector I-V of a Type-I/II InP DHBT (red) and Foundry-A Type-I InP DHBT with $A_E = 0.45 \times 5 \mu\text{m}^2$. The foundry device exhibits considerable β compression due to current blocking at B/C junction despite the composite collector transition layer.

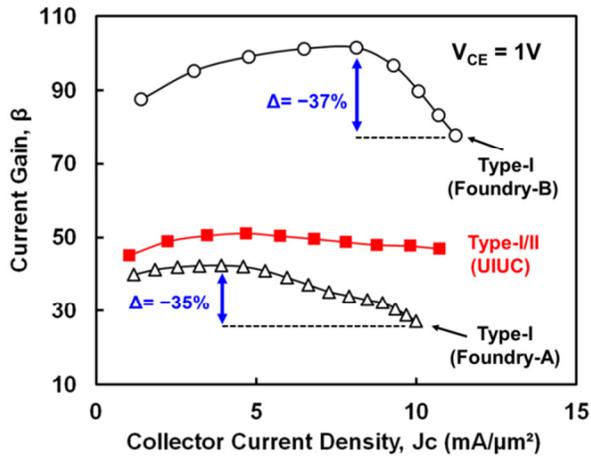


Fig. 2: Both Type-I InP DHBTs exhibit β compression with $>35\%$ drop in current gain at high current density. UIUC Type-I/II InP DHBT shows minimal β variation. Current gain compression is related to nonlinearity in device operation.

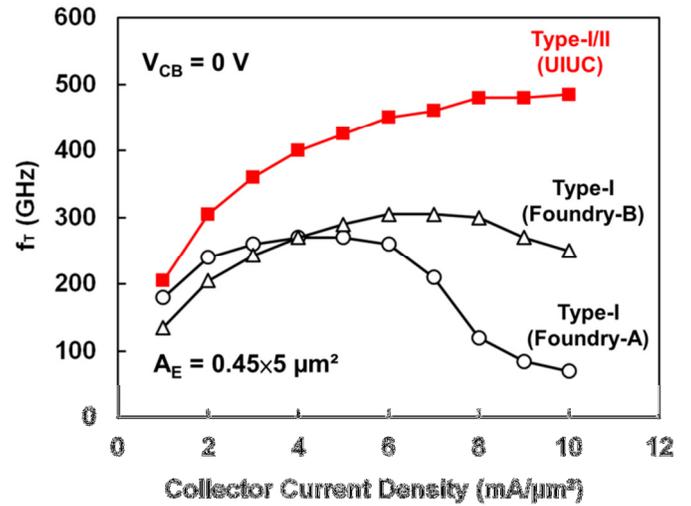


Fig. 3: Both Type-I devices show f_T roll-off behavior at $J_C > 5 \text{ mA}/\mu\text{m}^2$. The carrier transit time in the base is increased due to current blocking. The nonlinearity is related to 2nd derivative of f_T with respect to collector current density (J_C).