

Low-Voltage AlGaSb/InAs/AlGaSb PnP HBTs

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The InAs/AlSb/GaSb material system has a staggered band line-up with a large conduction band offset of 1.35eV and a small valence band offset of 0.1V, desirable for PnP HBTs capable of operating at very low voltages. The only previous attempt at realizing similar devices by Pekarik *et al.* produced transistors with low-collector current densities, high base currents, and current gain >1 at base-emitter voltages above 0.6V.¹ Pekarik reported a maximum beta of 5 at 1V and suggested that the excess base current was caused by recombination through defects at the InAs-AlSb interface. In the present work, we report on a significantly re-designed InAs/AlGaSb PnP transistor with improved low voltage operation, high collector current densities, and dc current gain approaching 50. The present device was grown on lattice-matched GaSb substrates with the active layer thickness of the device consisting of only 115 nm sandwiched between p-type GaSb emitter and collector contacts. The base is a 25 nm thick InAs layer that is silicon-doped for a base sheet charge of $5 \times 10^{12} \text{ cm}^{-2}$. The 30 nm thick emitter and 60 nm thick collector are mostly digitally graded AlGaSb layers that are not intentionally doped. There are 10nm AlSb spacers on either side of the base and the InAs-AlSb interfaces are forced “In-Sb like” after Pekarik.

Devices are fabricated in a conventional mesa HBT process using non-alloyed Ohmic contacts to the n-InAs and p-GaSb contact layers. The base sheet resistance is 250 Ohms/square. Gummel plots of a $15 \mu\text{m}^2$ HBT show excellent low-leakage characteristics. The low base leakage results in current gain at base-emitter voltages as low as 200mV and collector currents above 50 kA/cm^2 are obtained. The current gain peaks at 20 at 0.7V and then decreases by $\sim 30\%$ with higher hole-injection at 0.9V. The drop in current gain is almost certainly caused by space charge limited (SCL) transport in the collector at these high current densities, especially considering low hole velocity in the AlGaSb collector. A close inspection of the rate of increase of the collector and base currents in this regime indicates increased recombination in the base, consistent with our model of SCL transport. Space charge limited transport is verified by Gummel measurements at reverse biased collector-base junctions. These measurements show the peak current gain shifting to higher base-emitter voltage (higher collector current) with increasing collector-base reverse bias. An increase in the collector bias is accompanied by a base-collector leakage that is likely caused by Zener tunneling in the base-collector junction.

In comparison with Pekarik *et al.*, the observation of significantly lower base currents in our devices indicates that defects at the InAs-AlSb interface are not an inherent limitation of the InAs/AlGaSb HBT. An analysis of the hole transport and leakage characteristics will be presented along with a path to optimize the device for low-voltage operation, and possible integration with high performance InAs/AlSb HEMTs.

¹ Pekarik *et al.*, J. Vac. Sci. Technol. B 10,1032 (1992)

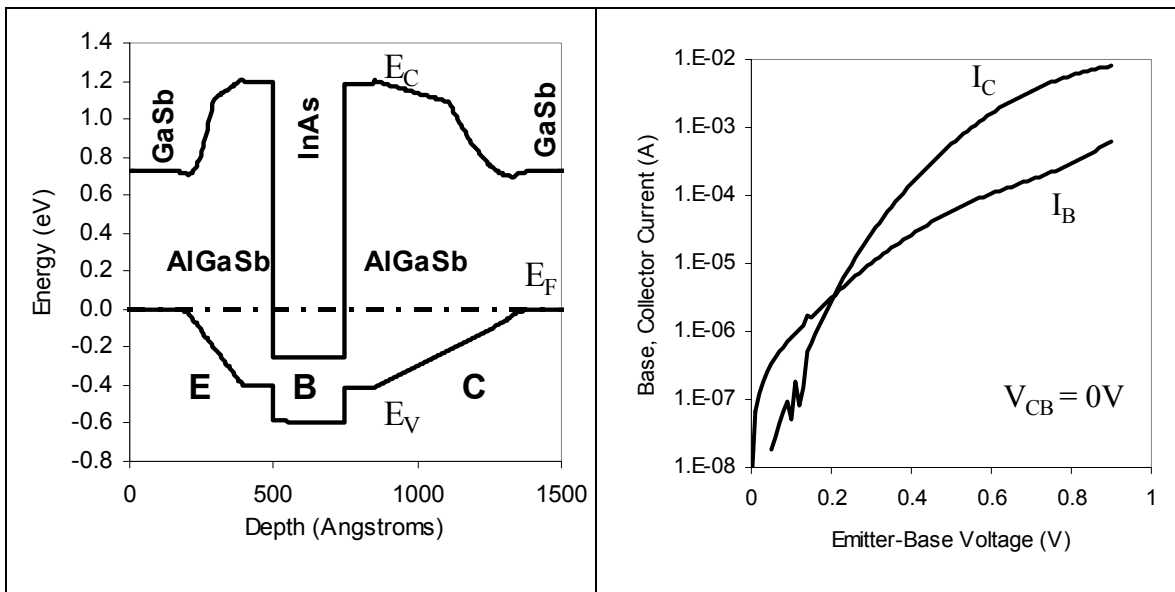


Fig. 1. Energy band diagram of an AlGaSb/InAs/AlGaSb HBT. The InAs base is doped at $5 \times 10^{12} \text{cm}^{-2}$. There are 10 nm AlSb spacers on either side of the base with the remainder of the emitter and collector digitally graded to p-type GaSb contacts

Fig. 2. Gummel plot of a $15 \mu\text{m}^2$ HBT. Current gain is obtained above 200mV and increases to a maximum of 20. The base current increases slightly above 0.8V due to increased recombination caused by space charge limited transport in the collector.

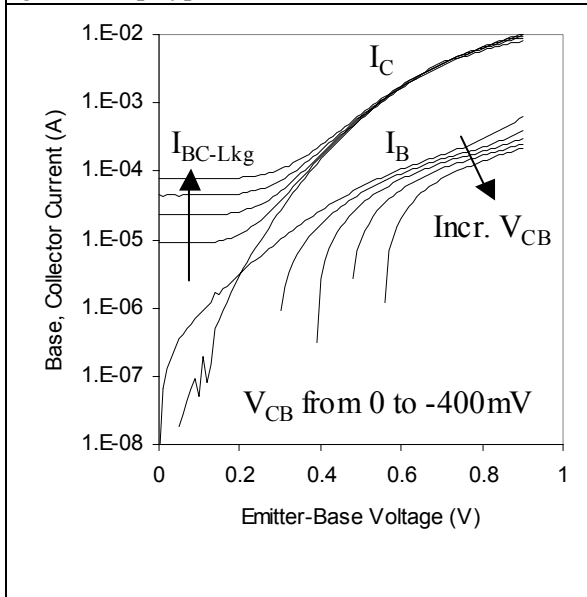


Fig. 3. Gummel plots at increasing collector voltage. The collector current increases slightly and base-collector leakage is observed with increasing B-C reverse bias. More importantly, beta increases due to reduced recombination in the base as the injected holes are collected by the increased field at the B-C junction.

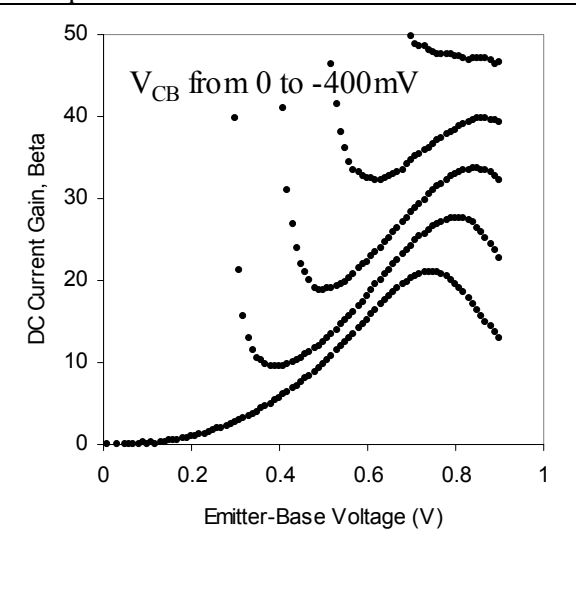


Fig. 4. Current gain for the Gummel data from Fig. 3. The maximum Beta increases above 45 at a B-C reverse bias of 400 mV and the critical current for peak gain is pushed to higher values. Such characteristics are consistent with space-charge limited transport in the collector (the so-called “Kirk-effect”).