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MBE Growth of Large Diameter InP-based Lattice-matched and Metamorphic HBTs

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InP-based single and double heterojunction transistors (SHBT and DHBT) with a heavily doped base are prime candidates for applications in new wireless and 40 Gb/s fiber-optic telecommunication products. The combination of superior electronic properties of InP, InGaAs, and InAlAs, heavily doped base layer, and precise control of alloy grading by molecular beam epitaxy (MBE) enable the realization of HBTs with f_t greater than 200 GHz. The development of a manufacturable and reliable 4" process will make InP-based HBTs highly competitive with traditional GaAs.

In this work, we focused our attention on Be- and C-doped InP-based HBTs grown lattice-matched on 4" InP (LM-HBTs) and on 4" GaAs substrates via metamorphic buffers (M-HBTs). Both SHBTs and DHBTs were grown with InP or InGaAs collectors and with InP or InAlAs emitters. The combination of material systems was chosen to optimize breakdown voltage and etch-stop properties for device processing. Uniformity data in terms of variation of doping, thickness, alloy composition and DC characteristics will be presented.

All epitaxial structures were grown on Varian GEN-II and EPI GEN-III MBE reactors using 4" SI InP and GaAs substrates. For base doping, a standard effusion cell was used for Be and a gas injector for C with CBr_4 as the precursor. LM-SHBT structures have a 500 Å InGaAs base layer doped at 4×10^{19} cm^{-3} and an InP emitter without a setback layer. LM-DHBT structures have a 500 Å, 4×10^{19} cm^{-3} InGaAs base, an InP collector and an InAlAs emitter layer. The digital grading at the B-E and B-C junctions was used to improve carrier injection and to suppress current blocking. High-resolution x-ray diffraction measurements indicate typical lattice mismatch of ≤500 ppm and maximum alloy composition variation of ~200 ppm across a 4" wafer. The typical layer thickness variation and base doping uniformity with both Be and C was ≤5%.

Material evaluation also consisted of DC measurements performed on large area devices with base-emitter junction dimensions of $120\times120\mu m^2$. LM-SHBTs displayed current gains of 52 and 40 for Be- and C-doped devices, respectively (Fig. 1a). We observe an increase in the turn-on voltage of 40 mV for the Be-doped devices due to slight Be diffusion towards the B-E junction. Further optimization of the growth process focused on suppression of Be diffusion and modification of the gas manifold and injector design to reduce CBr_4 transients. The change of both the growth procedure and hardware resulted in a decrease of the current gain difference for LM-DHBTs (gain 50 and 45 for Be and C doped devices, respectively) and a decrease of the turn-on voltage difference to 10 mV (Fig. 1b). The use of a thin InP collector layer (3000 Å) increased device collector-emitter breakdown voltage to 10 V. SIMS data indicates no Be diffusion for these LM-DHBT devices (Fig. 2).

The same approach was used for the growth of M-HBTs. Despite the formation of crosshatch patterns on the surface, large area devices with 1×10^{19} cm^{-3} base doping display high current gain that is within 10% of the reference LM-HBT devices (Fig. 3). Optimization of the grading scheme and growth parameters for the metamorphic buffer are currently underway to further minimize surface roughness and improve device characteristics.

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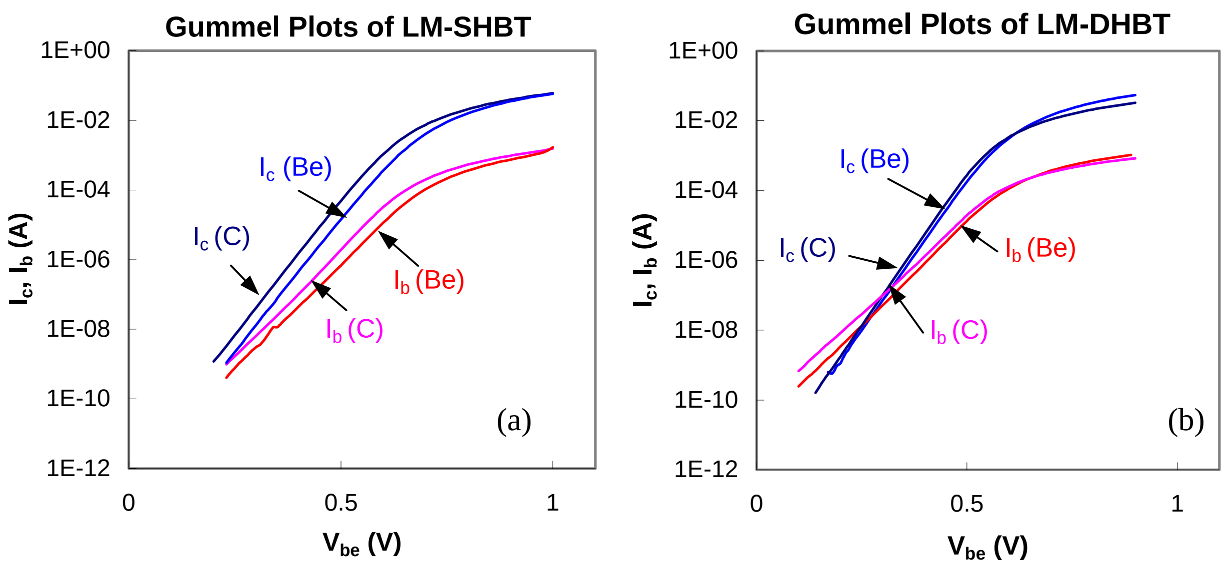

Figure 1. Gummel plots for large area devices: (a) LM-SHBT with base sheet resistance of 488 Ω (C-doped) and 550 Ω (Be-doped), respectively and (b) LM-DHBT with base sheet resistance of 563 Ω (C-doped) and 565 Ω (Be-doped), respectively.

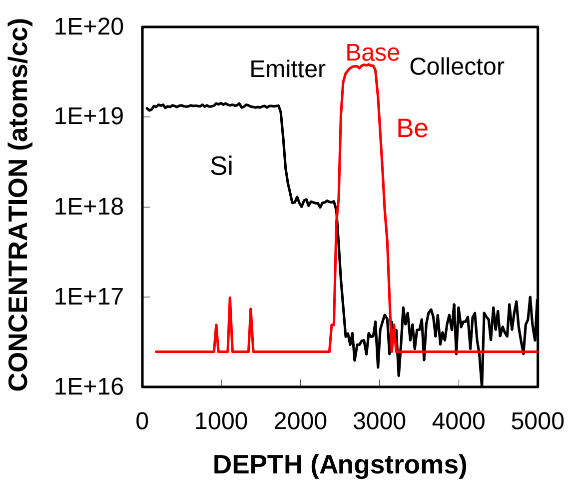

Figure 2. SIMS doping profile for a Be-doped LM-SHBT.

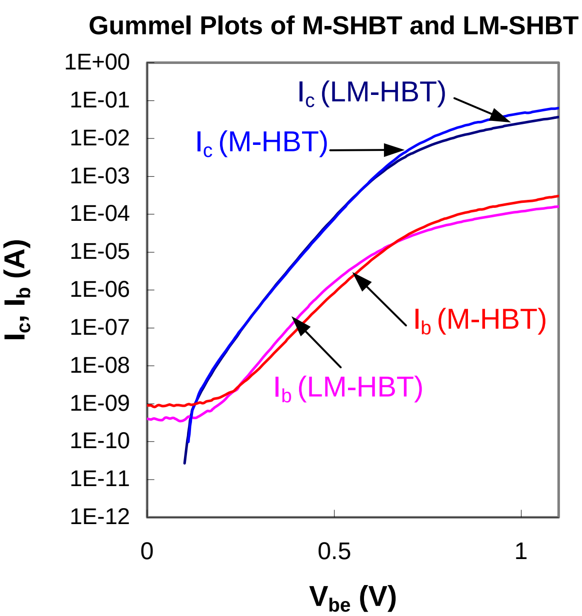

Figure 3. Gummel plots for large area devices. Base sheet resistance for the M-SHBT and LM-SHBT are 909 Ω and 985 Ω, respectively.