Measurement of Base Transit Time and Minority Electron Mobility in GaAsSb-Base InP DHBTs

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GaAsSb/InP Type-II DHBTs are used extensively in a variety of instrument products from mmWave network analyzers to high performance oscilloscopes. The underlying DHBT IC technology requires a favorable combination of high current gain and bandwidth, low turn-on voltage, and high breakdown voltage [1] which are controlled mostly by epitaxial design. To achieve even higher performance DHBT ICs, the epi design must be further optimized. In this work, optimization of lattice matched GaAsSb bases is discussed. RF data on discrete DHBT devices and a methodology for extracting base transit time and electron mobility in the p+GaAsSb base are presented. The results of this work advance the design of the base region in p+GaAsSb base InP DHBTs, and the experimental method presented here can also be used to characterize the base transit time and electron mobility of any bipolar transistor.

A lot of seven wafers ("Lot A") was grown and processed identically. The epi structures used in "Lot A" all had lattice matched, p-doped, GaAsSb bases, but the base thickness was varied from W_B = 250-750 Å. Small-signal microwave measurements were performed on each wafer, and the emitter-collector delay time $\tau_{EC} = 1/2\pi f_T$ was extracted from a single-pole approximation of $h_{21}(f)$ for each device operating at constant V_{CB} and multiple collector currents. Using a single-pole approximation of $h_{21}(f)$ of a small-signal T-model, the total delay time τ_{EC} is estimated as a sum of internal delay times $\tau_{EC} = \tau_T + (C_{JE} + C_{JC})\eta kT/qI_C$, with $\tau_T = \tau_B + \tau_C + (R_C+R_E)C_{JC}$. The delay time τ_T was extracted for each epi design by extrapolating τ_{EC} vs. $1/I_C$ to $1/I_C = 0$, as shown in Fig. 1 [2]. These delay times τ_T followed a quadratic relationship versus base thickness W_B, as shown in Fig. 2. This quadratic dependence can be understood because the delays τ_C and $(R_C+R_E)C_{JC}$ remain the same for all the wafers, but the base delay varies with base thickness as $\tau_B = W_B^2/2D_{nB} + W_B/v_{exit}$ [3]. The electron diffusion coefficient in the base D_n was then extracted from the RF data (see Fig. 2), producing a value for D_n of 61 cm^2/s. This electron diffusion coefficient together with the Einstein relation and our estimated junction temperature T_j were then used to calculate the minority electron mobility in the base, which gave a mobility value of μ_n =1970 $cm^2/(V\text{-}s)$. For comparison, the value quoted for p-InGaAs at the same doping value was about 1500 $cm^2/(V\text{-}s)$ [4].

A second lot ("Lot B") was grown and processed in the same way with a variety of base doping levels. All "Lot B" wafers were lattice matched GaAsSb with the same base thickness of 336 Å and with base doping values of 1.04, 1.30, and 1.60E20 cm^{-3}. The base transit times were extracted for each wafer (by finding t_T as before, and estimating the values of C_{JC}, R_C, R_E, and τ_C from microwave measurements), and the electron diffusion coefficients D_n were calculated. The plot in Fig. 3 of D_n versus base doping for these bases shows a significant decrease in D_n for doping levels Na above 0.6e20 cm-3 and approximately constant D_n value for higher values of N_a. This may be due to a strong dependence on doping concentration above 6E19 cm^{-3}, but growth reproducibility is also being investigated as a potential cause of this significant decrease.

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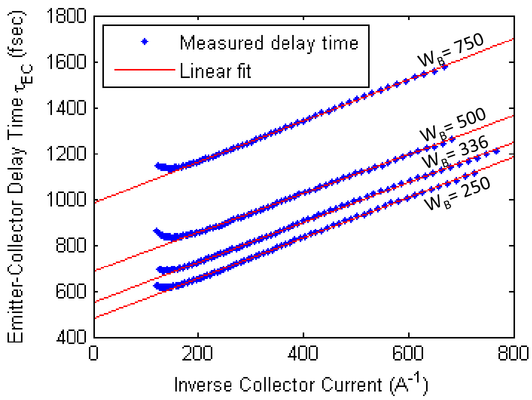

Fig. 1. Extrapolation of $\tau_{EC} = 1/2\pi f_T$ to determine the delay time τ_T according to the method in ref [2].

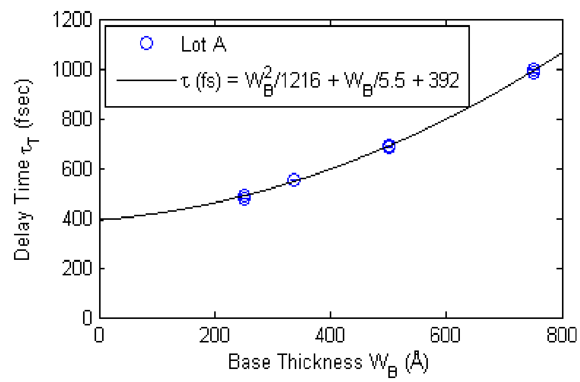

Fig. 2. Extrapolated delay time τ_T versus base thickness W_B, fitted to the quadratic function that is expected from refs [2] and [3].

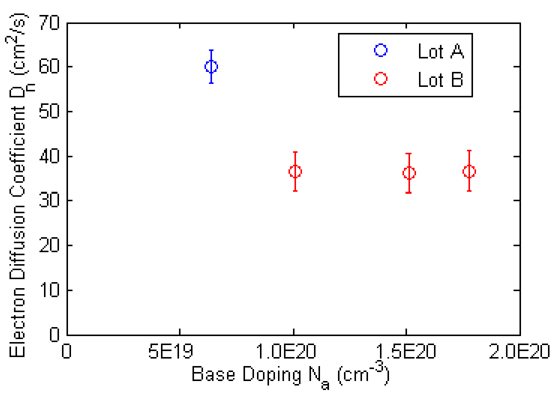

Fig. 3. Electron diffusion coefficient D_n versus base doping concentration for wafers in Lot A and Lot B