Verification of Effective Intrinsic Carrier Concentrations for Numerical Simulations of Gallium Arsenide Bipolar Transistors

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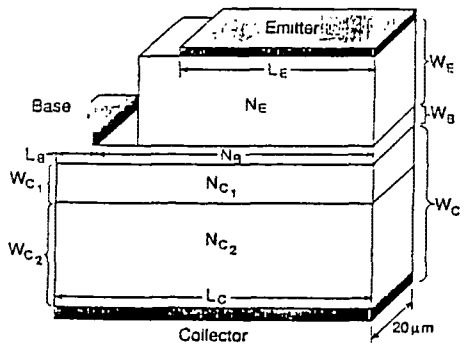
ABSTRACT

Using the best available physical models is essential for predictive numerical simulations of heterostructure GaAs bipolar transistors. Among the key input parameters of effective intrinsic carrier concentrations of n_{ie}, minority carrier mobilities, μ, and recombination lifetimes, τ, n_{ie} is the most critical parameter. Recent theoretical calculations of n_{ie} for GaAs at 300K have been verified experimentally for the first time by measurements on devices. These calculations are based on the quantum-mechanical formalism of Klauder[1] and give the dependences of n_{ie} on carrier and dopant densities for low level injection. The Klauder formalism is a multi-scattering theory and is valid for any screening radius. The new theoretical data for n_{ie} were implemented into a two-dimensional, drift-diffusion simulator for GaAs transistors. In order to compare predicted and measured DC common emitter gains, three npn GaAs homojunction bipolar transistors with different but heavily doped bases and emitters were fabricated by molecular beam epitaxy. The predicted gains of 8, 25, and 46 for these transistors agreed very well with their measured gains of 9, 22, and 42 at high current, respectively. Without using the new theoretical data for n_{ie} but setting n_{ie} equal every where to the intrinsic carrier concentration, n_i, the predicted gains became 4, 14, and 27, respectively. Sensitivity analyses on mobilities, lifetimes, and n_{ie} showed that physically correct n_{ie} values are very important for predictive simulations that contain no variational parameters. The other key quantities such as dopant density profiles and minority carrier mobilities and lifetimes were all measured by methods that do not depend on other use of lower level device models.

Figure 1 and Table I give the design parameters for the transistors. The measured input parameters for the numerical simulations of devices A, B, and C are $\tau = 0.1ns$, $\mu_p = 100cm^2/(V \cdot s)$ and $\mu_n = 2000, 1700, 1000cm^2/(V \cdot s)$, respectively. Figure 2 is the energy band diagram for Device C and shows the bandgap narrowing, ΔE_G, given by applying Klauder's formalism to GaAs. Figure 3 shows how the ratios (n_{ie}/n_i) vary with dopant density. We emphasize the significant quantitative difference between n-type and p-type GaAs. Figure 4 gives the DC common emitter gains as functions of the collector current. The $\odot$, $\times$,+ denote the measured gains for devices A, B and C, respectively. The solid curves are calculated from a two-dimensional simulator with n_{ie} from Fig.3 and the dashed curves are calculated with $n_{ie} = n_i$ everywhere. Previous empirical relations for ΔE_G used in most simulators neglect many body effects and do not distinguish between n-type and p-type GaAs.

1.J.R.Klauder, Ann.Phys. **14**, 43 (1961).



Those design parameters that are the same for all three devices A, B, and C are $L_B = 1.0\mu m$, $L_{BE} = 2.0\mu m$, $L_C = 8.0\mu m$, $L_D = 20.0\mu m$, $L_E = 5.0\mu m$, $W_B = 0.1\mu m$, $W_{C1} = 0.2\mu m$, $W_{C2} = 0.3\mu m$, and $N_E = 10^{18}\text{cm}^{-3}$.

	Device A	Device B	Device C
W_E	0.2 μm	0.45 μm	0.45 μm
N_B	10^{18} cm^{-3}	2×10^{18} cm^{-3}	10^{19} cm^{-3}
N_{C1}	2×10^{16} cm^{-3}	2×10^{17} cm^{-3}	2×10^{17} cm^{-3}
N_{C2}	5×10^{18} cm^{-3}	3×10^{18} cm^{-3}	3×10^{18} cm^{-3}

Figure 1

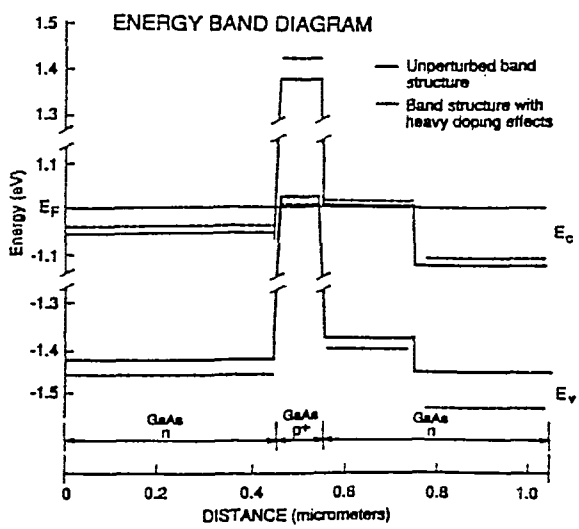


Figure 2

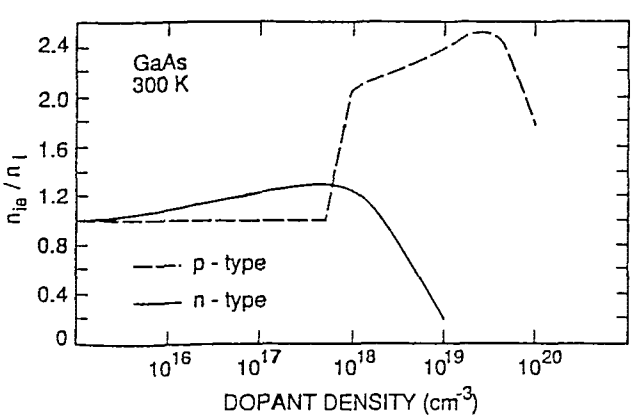


Figure 3

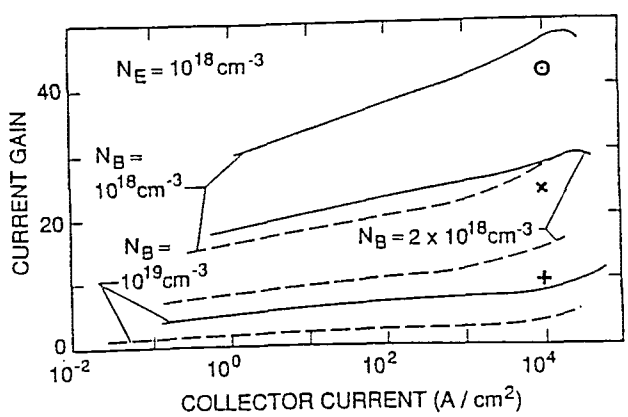


Figure 4