SIMULATION OF INFLUENCE OF HEAT REMOVAL ON POWER GAINS OF HETEROJUNCTION BIPOLAR TRANSISTORS

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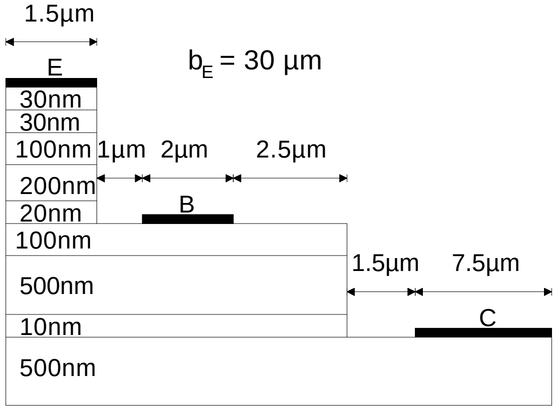
Abstract

The exact knowledge of the heat flow in heterojunction bipolar transistors (HBT) during power operation is an important key factor for the systematic improvement of power density, gain, power added efficiency and reliability. For an analysis of the influence of different thermal boundary conditions in HBT structures on the device performance, numerical simulations of HBT structures have been carried out.
For HBT modeling we used our 2D/3D program SIMBA [1,2], which is based on a self-consistent solution of a drift-diffusion model coupled with the heat flow equation to include non-uniform lattice temperatures. Thermal boundary conditions can be ideal thermal contacts, ideal thermal isolation and radiation thermal boundary conditions, which are determined by a surface thermal conductivity and a reference temperature.
Fig. 1 shows the basic GaInP/GaAs-HBT structure and the layer parameters used for the simulations. At the bottom of the structure an additional 20 µm thick undoped GaAs layer comprising a thermal conductivity of 20 W/cm^2K, which corresponds to a wafer thickness of 500 µm, was introduced. At the emitter contact we assumed a surface thermal conductivity of 5000 W/cm^2K and at base and collector contacts a 10 times smaller value. The thermal conductivity between the contacts was assumed to 50 W/cm^2K. The calculated temperature distribution at a high current density of $2{\cdot}10^5$ A/cm^2 (V_{CE} = 3V) is represented in Fig. 2. The temperature maximum of about 435 K is located in the collector area. At an operating current density of $2{\cdot}10^4$ A/cm^2 the temperature goes up to about 315 K. The corresponding cut-off frequencies f_{max} and f_t as a function of collector current density are shown in Fig. 3 (solid line). At a collector current density of about $4{\cdot}10^4$ A/cm^2 the cut-off frequencies drop significantly. This is due to base widening (Kirk effect) and increased self-heating. One approach to get rid of this effect is to increase the thermal conductivity from the emitter and base region towards the ambient. This can be accomplished by thermal shunts where the emitter metal interconnection overlaps the emitter sidewall and parts of the extrinsic base region. In this case base emitter short circuits are prevented by a suitable emitter sidewall passivation (e.g. Si_3N_4). The resulting efficiency for an assumed thermal conductivity of 5000 W/cm^2K in this region is also shown in Fig. 3 (dashed line). The maximum of cut-off frequencies can be obtained up to a current density of about $1{\cdot}10^5$ A/cm^2. In comparison the results for a narrower emitter with the same area but no thermal shunt structure is depicted.
For a verification of the thermal model experimental results of a conventional structure have been compared with simulation results. Fig. 4 shows the corresponding cut-off frequencies.

[1] R. Stenzel, W. Klix, R. Dittmann, C. Pigorsch, F. Schnieder: "Numerical simulation of III/V-semiconductor devices with SIMBA", Proc. of 8th GaAs Simulation Workshop, Duisburg 1994
[2] W. Klix, R. Dittmann, R. Stenzel: "Three-dimensional simulation of semiconductor devices", Lecture Notes in Computer Science 796, Springer-Verlag, 1994, pp. 99-104



Material	Thickness	Doping
InGaAs	30 nm	$1{\cdot}10^{19}$ cm^{-3}
InGaAs...GaAs	30 nm	$1{\cdot}10^{19}$ cm^{-3}
GaAs	100 nm	$4{\cdot}10^{18}$ cm^{-3}
GaAs	200 nm	$4{\cdot}10^{17}$ cm^{-3}
InGaP	20 nm	$1{\cdot}10^{17}$ cm^{-3}
GaAs	100 nm	$4{\cdot}10^{19}$ cm^{-3} (p)
GaAs	500 nm	$3{\cdot}10^{16}$ cm^{-3}
InGaP	10 nm	$4{\cdot}10^{18}$ cm^{-3}
GaAs	500 nm	$4{\cdot}10^{18}$ cm^{-3}

Fig. 1: HBT structure and layer parameters

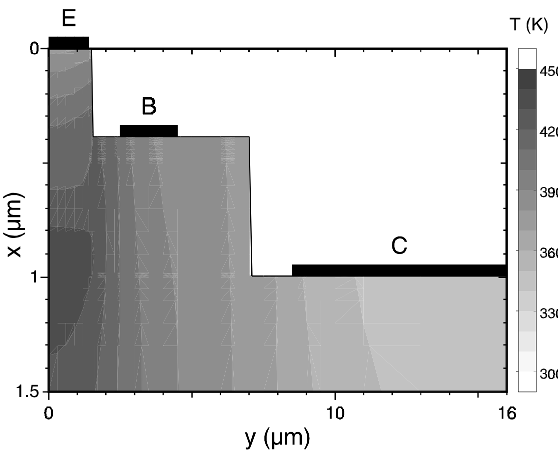


Fig. 2: Temperature distribution at V_{CE} = 3 V and $J_C = 2{\cdot}10^5$ A/cm^2

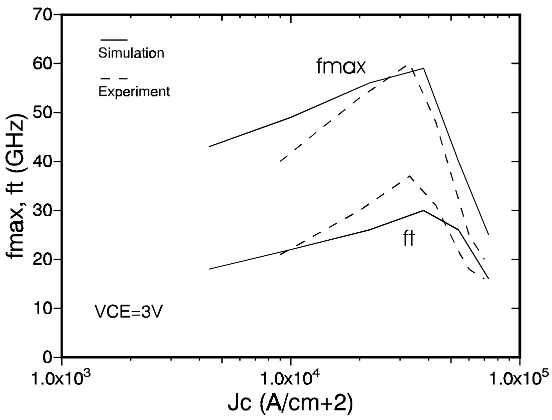


Fig. 4: Comparison of simulated (solid) and experimental (dashed) cut-off frequencies

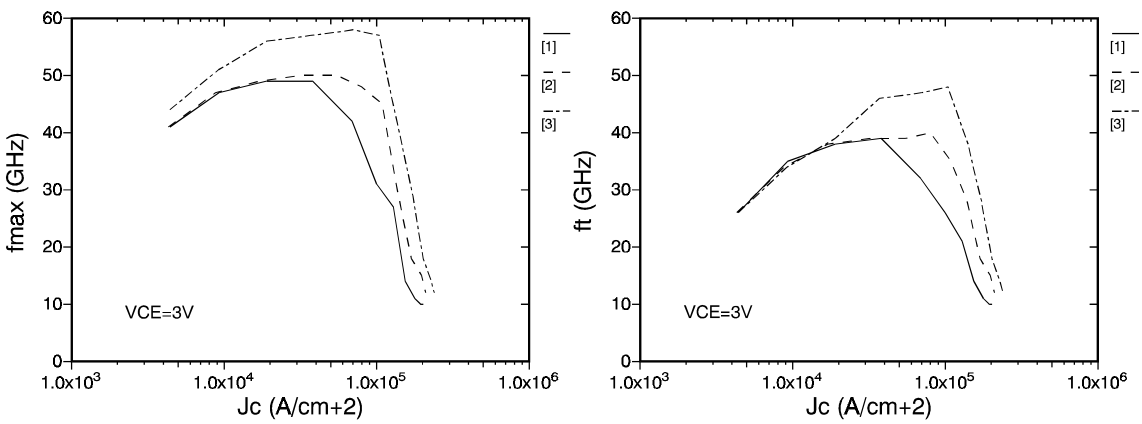


Fig. 3: f_{max} and f_t versus collector current density ([1]: basic structure, [2]: improved thermal surface conductivity between emitter and base contact, [3]: emitter area 2x45 µm^2)