# Simulation of Heterojunction Bipolar Transistors on Gallium-Arsenide

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Abstract

We demonstrate the results of two-dimensional hydrodynamic simulations of one-finger power Heterojunction Bipolar Transistors (HBTs) on GaAs. An overview of the physical models used and comparisons with experimental data are presented.

## 1. Introduction

Heterojunction Bipolar Transistors (HBTs) attract much industrial interest nowadays because of their capability to operate at high current densities [1]. AlGaAs/GaAs or InGaP/GaAs based devices are used for power applications in modern mobile telecommunication systems. Accurate simulations save expensive technological efforts to obtain significant improvements of the device performance. The two-dimensional device simulator MINIMOS-NT [2] is extended to deal with different complex materials and structures, such as binary and ternary semiconductor III-V alloys with arbitrary material composition profiles. Various important physical effects, such as band gap narrowing, surface recombination, and self heating, are taken into account.

## 2. The Physical Models

In previous work we emphasized on band gap narrowing as one of the crucial heavy-doping effects to be considered for bipolar devices [3]. We have developed a new physically-based analytical band gap narrowing model, applicable to compound semiconductors, which accounts for the semiconductor material, the dopant species, and the lattice temperature. As the minority carrier mobility is of considerable importance for bipolar transistors, a new universal low field mobility model has been implemented in MINIMOS-NT [4]. It is based on Monte-Carlo simulation results and distinguishes between majority and minority electron mobilities.
Energy transport equations are necessary to account for non-local effects, such as velocity overshoot [5]. In recent work a new model for the electron energy relaxation time has been presented [6]. It is based on Monte-Carlo simulation results and is applicable to all relevant diamond and zinc-blende structure semiconductors. The energy relaxation times are expressed as functions of the carrier and lattice temperatures and in the case of semiconductor alloys of the material composition.

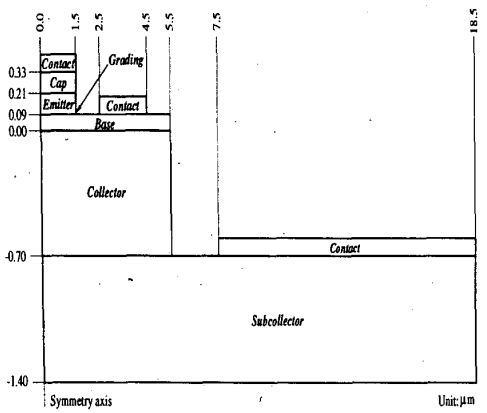


Figure 1: Simulated device structure

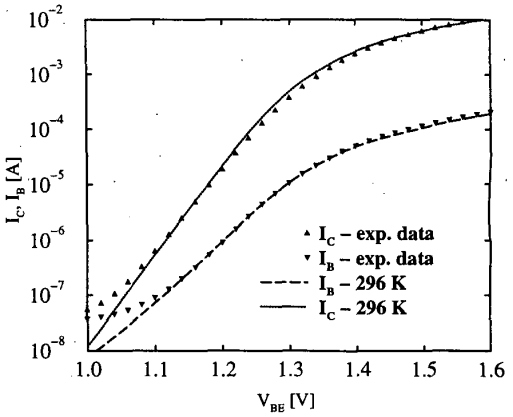


Figure 2: Forward Gummel plots at $V_{CB} = 0$ V

## 3. Heterointerfaces and Self-heating

In particular the electrical behavior of AlGaAs/GaAs and InGaP/GaAs one-finger power HBTs with emitter area of 90 $\mu m^2$ have been studied at several ambient temperatures. Typical values for the devices under consideration range from 300 K up to 380 K [7]. The device structure is shown in Fig. 1. Considering the nature of the simulated devices (including graded and abrupt heterojunctions) and the high electron temperatures observed at maximum bias (above 2500 K - see Fig. 5) we use sophisticated thermionic-field emission interface models [8] in conjunction with the hydrodynamic transport model.
To account for self-heating effects the lattice heat flow equation is solved self-consistently with the energy transport equations (system of six partial differential equations). The thermal conductivity and the specific heat are expressed as functions of the lattice temperature and in the case of semiconductor alloys of the material composition.

## 4. Simulation Results

In Fig. 2 we present the simulated forward Gummel plot for an AlGaAs/GaAs HBT at 296 K compared to experimental data. We achieve good agreement at moderate and high voltages, typical for operating of this kind of devices. The measured leakage currents at $V_{BE} \leq 1$ V still cannot be reproduced by simulation, regardless that several recombination mechanisms have been tried.
Encouraging results for a second device have also been achieved. The device structure is similar to that shown in Fig. 1, just the graded AlGaAs layer has been replaced by an InGaP ledge and the base doping has been increased. In Fig. 3 we include the simulated Gummel plot at 376 K to demonstrate our ability to reproduce correctly the thermal device behavior. In Fig. 4 the temperature dependence of the current gain is shown. The results verify our models and therefore are a good prerequisite for simulation of self-heating effects. For that purpose, an additional, substrate thermal contact has been introduced. A measured value of about 400 K/W for the thermal resistance has been used [1]. The resulting lattice temperature distribution over the device at $V_{CE} = V_{BE} = 1.6$ V is shown in Fig. 6. The heat generated at the heterojunctions flows out of the device in the direction of the substrate heat sink. In the opposite direction the heat cannot leave the device and therefore the emitter finger

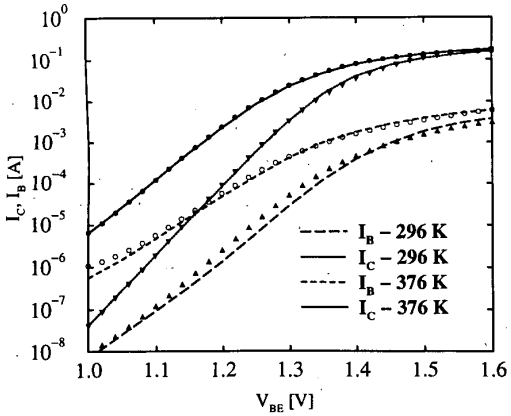


Figure 3: Forward Gummel plots at $V_{CB} = 0$ V

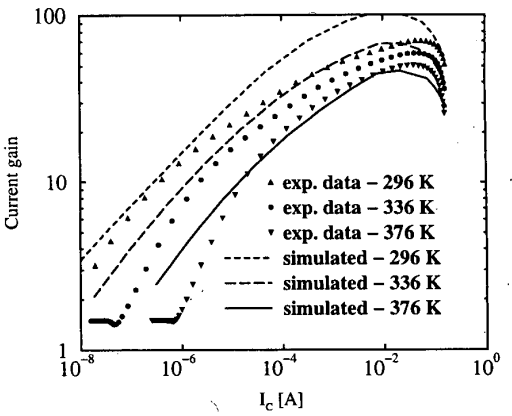


Figure 4: Temperature dependence of the current gain vs. $I_C$

is heated up significantly to more than 400 K. The simulation shown is of practical interest and demonstrates the need of using a thermal shunt at the emitter contact rather than reducing the substrate thickness.

## 5. Conclusion

In summary, we presented simulations of power HBTs on GaAs. Several sophisticated models were created and employed not only to get good agreement with experimental results, but to aid getting an insight and understanding of the real device and thus achieve better device performance.
Our further aim is to find an explanation for the leakage currents at low $V_{BE}$. It might come from the $Si_3N_4$ passivation, which has been simulated as an ideal dielectric, where only the Poisson's and the lattice heat flow equations have been solved.

## Acknowledgment

The authors acknowledge Dr. W. Kellner for his support of this work. V. Palankovski thanks Dr. T. Grasser for his work on MINIMOS-NT, R. Quay for proof-reading the paper, and both for valuable discussions.

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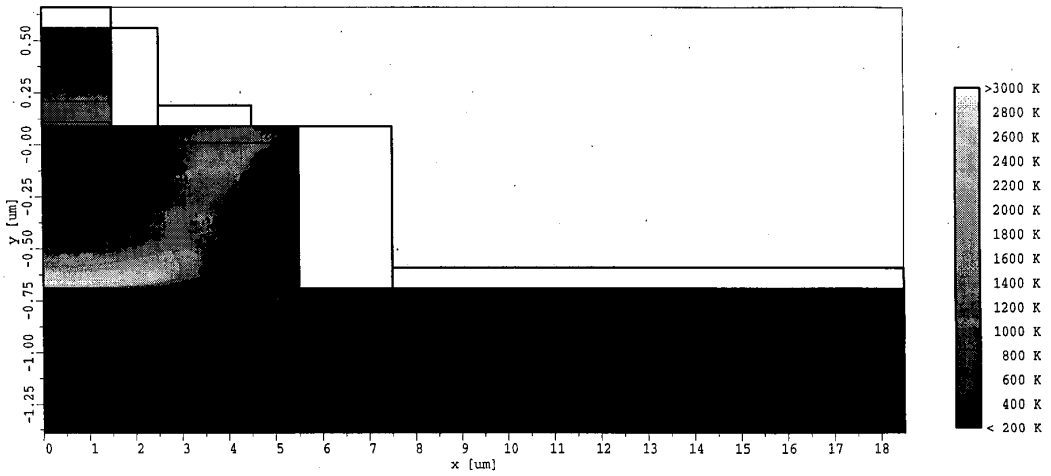


Figure 5: Electron temperature distribution at $V_{CE} = V_{BE} = 1.6$ V

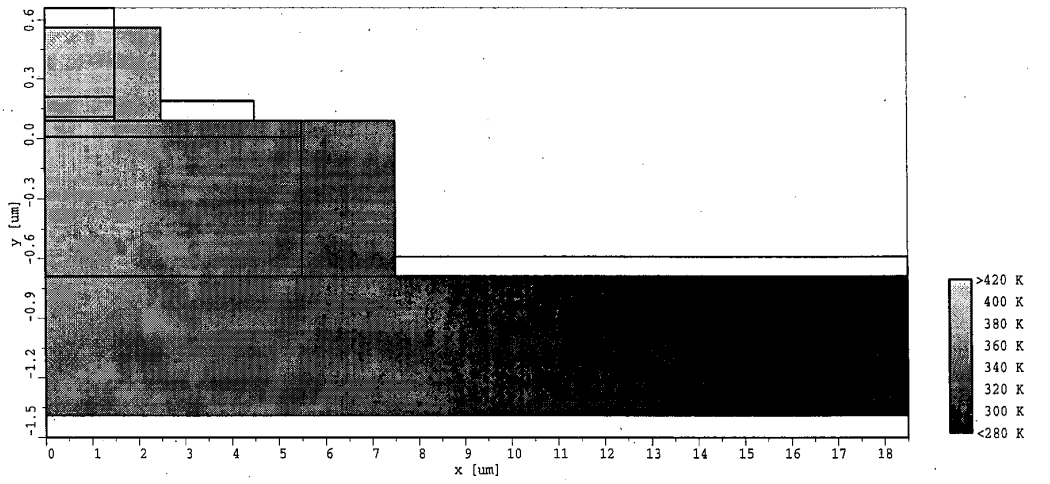


Figure 6: Lattice temperature distribution at $V_{CE} = V_{BE} = 1.6$ V. A substrate thermal contact has been added.