Numerical Modeling for Comparison of Emitter-Base Designs of InGaP/GaAs Heterojunction Bipolar Transistors

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ABSTRACT

In this paper, using physics based two-dimensional numerical simulator ATLAS, DC and AC performances of InGaP/GaAs heterojunction bipolar transistors, which have very similar cut-off frequency and maximum oscillation frequency, are evaluated. Numerical device modeling is used for comparison of emitter-base designs of InGaP/GaAs heterojunction bipolar transistors.

Keywords: InGaP/GaAs, heterojunction bipolar transistor, semiconductor device modeling, numerical modeling.

1 INTRODUCTION

Heterojunction bipolar transistors (HBTs) extend the advantages of silicon bipolar transistors to significantly higher frequencies. They are used in applications requiring high current capacities, high transconductance, high voltage handling capability, low noise and uniform threshold voltage [1]-[2]. The InGaP/GaAs HBT is an important investigation topic in power amplifiers [3]-[4], but the technology is also applicable to low noise amplifiers in the range of frequencies from 2 to 6 GHz. Reference [5] shows results of an LNA for WLAN applications at 5.3 GHz with 13 dB gain, noise figure of 2.1 dB and excellent linearity in terms of IIP3.

Numerical modeling of semiconductor devices allows to deep in the implications that the geometry and the characteristics of the materials have in the real operation of the device [6]-[7]. Several geometric implications of the InGaP/GaAs HBT design have been studied, theoretical and experimentally, in order to obtain better device performance [8]-[9]. In this work, the consequences of the design of the emitter pedestal in the electric DC and AC performance of InGaP/GaAs HBTs are studied using physics based two-dimensional numerical modeling TCAD tool, ATLAS [10].

2 DEVICES

Two heterojunction bipolar transistors are studied. Both devices are 1 emitter finger, two base contacts -1 μm length each one- and two collector contacts -4 μm length each one-, and they have the collector area of 18.6 × 20 μm^2 and the base pedestal area of 6.6 × 20 μm^2. Other dimensions of the device DEV-A are: spacing between emitter mesa and base contact, L_{BE}, is 1.3 μm, emitter pedestal area, A_{PE}, is 2 × 20 μm^2 and emitter contact area, A_E, is 1 × 20 μm^2. The particular dimensions of the device DEV-B are: spacing between emitter mesa and base contact, L_{BE}, is 1 μm, emitter pedestal area, A_{PE}, is 2.6 × 20 μm^2 and emitter contact area, A_E, is 2 × 20 μm^2. Figure 1 shows geometry of the device DEV-A.

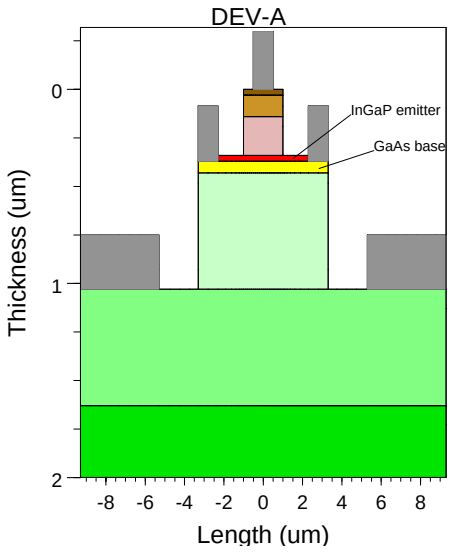

Figure 1: Geometry of the DEV-A, InGaP/GaAs HBT.

Doping profile of the InGaP/GaAs HBT transistors is in Table 1 and it is used for applications up to 10 GHz [11].

MATERIAL	THICKNESS(Å)	DOPING (cm^{-3})
n-InGaAs	300	1e19
n-GaAs	1100	1e19
n-GaAs	2000	2e17
n-InGaP	300	4.5e17
p-GaAs	**600**	**4e19**
n-GaAs	6000	1.5e16
n-GaAs	6000	3e18
Sust.-GaAs	-	-

Table 1: Doping profile of NPN InGaP/GaAs HBTs.

	GaAs	GaAs	InGaP	GaAs-p	GaAs	GaAs
Eg (eV)	1.42	1.42	1.84	1.42-0.07	1.42	1.42
χ (eV)	4.07	4.07	3.93	4.07	4.07	4.07
ε_r	13.2	13.2	12.5	13.2	13.2	13.2
Nc (10^{17} cm^{-3})	4.5	4.5	8.4	4.5	4.5	4.5
Nv (10^{19} cm^{-3})	1	1	1	1	1	1
μ_n($cm^2V^{-1}s^{-1}$)	1600	3000	850	1200	4000	2000
μ_p($cm^2V^{-1}s^{-1}$)	100	200	70	60	200	120
τ (10^{-9} s)	0.5	1	0.5	0.05	1	1

Table 2: Material parameters used in the simulation of the InGaP/GaAs HBTs.

In this study, it stays constant the total size of the device, the dimensions of the base mesa structure and the doping profile and it is only modified the layout of the emitter and base regions, see Fig. 2. The results show that it is possible keeping IC rules of design of the transistor layout and it does not changing the wafer area, optimize the heterojunction bipolar transistor design.

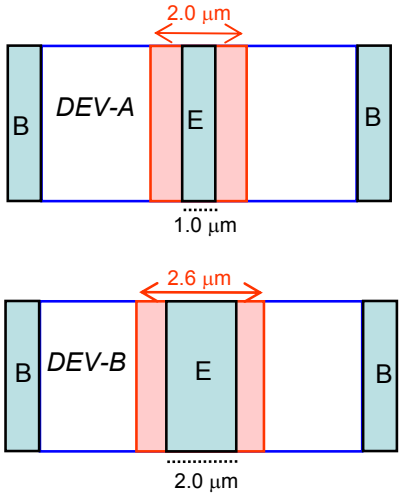

Figure 2: Emitter-base designs of the InGaP/GaAs HBTs.

3 MODELING

Numerical modeling of heterojunction bipolar transistors can help to understand the physical behavior of the device and optimize its design. In this work using physics based two-dimensional numerical modeling TCAD tool, ATLAS, emitter-base designs of InGaP/GaAs HBTs are studied. The model solves the Poisson and the electron and hole continuity equations assuming Anderson affinity-rule and band gap narrowing in the high doped base region [6]. Material parameters of HBTs used in the simulation are in Table 2. They were extracted from [12]. Figure 3 shows equilibrium energy band diagram for the InGaP/GaAs HBTs.

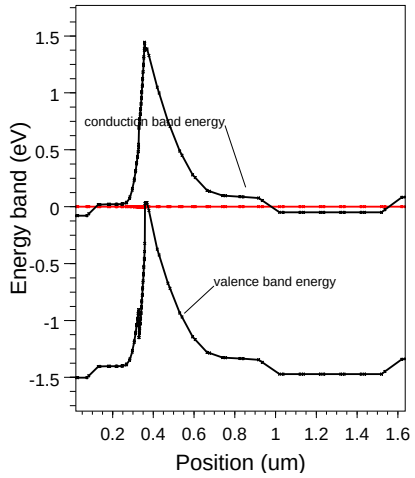

Figure 3: Equilibrium energy band of the InGaP/GaAs HBTs under the emitter contact.

4 DC AND AC RESULTS

Heterojunction bipolar transistors DC performance is illustrated by Figure 4 and Table 3. Forward gain current of the device DEV-A is higher than that of the device DEV-B. Values of $\beta_{F,max}$ of 160 and 100, respectively, are getting. Offset collector-emitter voltage, $V_{CE,off}$, of DEV-B is smaller than that of the device DEV-A due to the size difference among emitter area to collector area in the device DEV-B is smaller than that in the device DEV-A. Base-emitter on-voltages are also different, for example at the

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collector current of 1 nA, these are 0.92 V for device DEV-A and 0.9 V for device DEV-B.

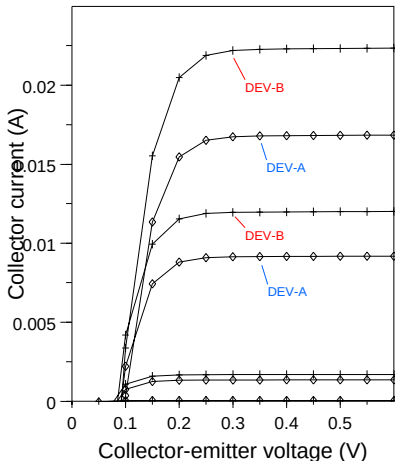

Figure 4: Ic(Vce) plots for devices DEV-A (rhombus marks) and DEV-B (plus marks).

	DEV-A	DEV-B	
$\beta_{F,max}$	160	100	
$V_{CE,offset}$	0.12	0.1	Ic@5mA
$V_{BE,on}$	0.92	0.9	Ic@1nA

Table 3: DC performance of the InGaP/GaAs HBTs.

Table 4 and figures 5 and 6 present AC performance of the HBTs, being I_C = 26 mA and V_{CE}= 2.5 V. Both HBTs have approximately f_T = 94 GHz and f_{max}= 84 GHz, estimated at the frequency of 2.5 GHz. Above of approximately 10 GHz, HBTs are unconditionally stables. But different AC performance is observed, for example, in the maximum transducer gain and the maximum stable gain.

2.5 GHz	DEV-A	DEV-B
K_{Stern}	0.15	0.20
h_{fe} (dB)	37.4	37.8
GU (dB)	33.5	33.7
G_{mT} (dB)	36.2	34.3
MSG (dB)	25.3	27.2
Input Loss (dB)	-1.34	-2.50
Output Loss (dB)	-1.28	-2.26
Forward Gain (dB)	24.5	26.8
Reverse Isolation(dB)	-26.2	-27.5

Table 4: AC performance of InGaP/GaAs HBTs at 2.5 GHz.

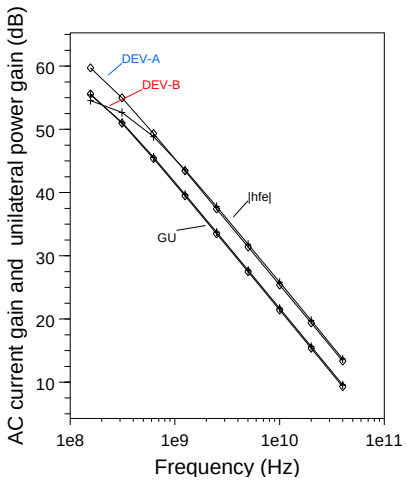

Figure 5: AC current gain, |hfe|, and Unilateral Power Gain, GU, as a function of the frequency, for devices DEV-A (rhombus marks) and DEV-B (plus marks).

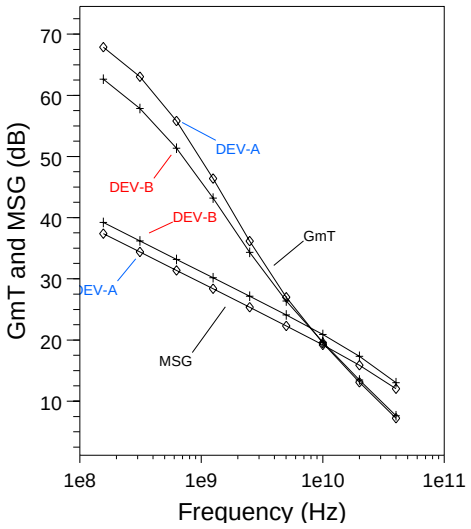

Figure 6: Maximum transducer power gain, G_{mT}, and maximum stable gain, MSG, as a function of the frequency for devices DEV-A (rhombus marks) and DEV-B (plus marks).

RF device performance at 2.5 GHz can be explained as follows. Susceptance of the device DEV-A is smaller than that in the device DEV-B since that DEV-A have emitter contact area smaller that device DEV-B, in consequence smaller capacity. Moreover, conductance of the DEV-A is also smaller than that in the device DEV-B because DEV-A has pedestal region area smaller and distance between electrodes larger that in the device DEV-B. Output admittance behavior is qualitatively similar that of the input admittance, although quantitatively less important due to the distance between the contacts of the collector and emitter.

In order to explain the RF gain versus the frequency performance of the HBTs observed in the figure 6, it is included the figure 7. This figure shows the forward gain, S_{21}, and the reverse isolation, S_{12}, as a function of the frequency. Note that below 4 or 5 GH, the value of S_{21} of the device DEV-B is higher than that in the device DEV-A and that above those frequencies S_{12} –reverse gain- of the device DEV-B is smaller than in the device DEV-B. The combined effect of these two parameters reverts in the maximum stable gain imposing this advantage by DEV-B design in front of DEV-A design in the studied frequencies range.

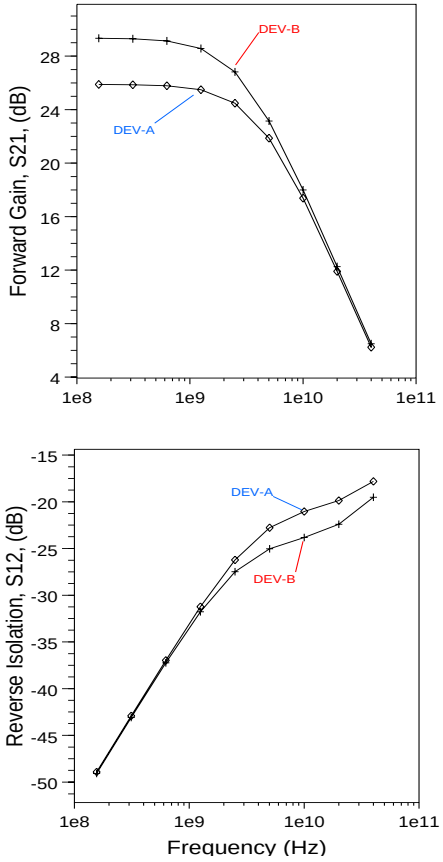

Figure 7: Forward gain, S_{21}(dB), and reverse isolation, S_{12}(dB), for devices DEV-A (rhombus marks) and DEV-B (plus marks) as a function of the frequency.

ACKNOWLEDGMENT

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