DC, LARGE-SIGNAL AND AC EQUIVALENT CIRCUITS OF A HIGH PERFORMANCE GaAs-HBT

Juan Miguel López-González, Pau Garcias-Salvà, Lluis Prat Viñas

Grup de Dispositius Semiconductors, Departament d´Enginyeria Electrònica
Universitat Politècnica de Calalunya
jmlopezg@eel.upc.es

RESUMEN

En este trabajo se deducen los valores de los componentes de los circuitos equivalentes DC, *Transient* y AC de SPICE correspondientes a un HBT real de GaAs partiendo de su geometría y las características físicas de los materiales que lo forman. A continuación se comparan los resultados obtenidos de la simulación con resultados experimentales de algunas figuras de mérito del dispositivo.

1. INTRODUCTION

From the late 1980s to the present, several major aerospace companies have developed advanced GaAs-based heterostructure technologies, including HEMT and HBT technology. GaAs HBT technology offers the high transconductance, high power density and power-added efficiency, and excellent threshold matching characteristics of a bipolar transistor while providing frequency and breakdown characteristics superior to advanced Si and SiGe BJT and HBT technologies [1]. The GaAs HBT has been the technology of choice for current cellular handset power amplifiers applications. In fact, GaAs HBT power amplifiers account for as much as 30 percent of the GaAs power amplifier IC market, and this number is growing rapidly.

HBT equivalent circuits constitute an active area of research because of their interest in high-speed electronic-circuit applications. The SPICE Gummel-Poon (SGP) model is still the only BJT model widely available and used for IC design, although recently, new BJT and HBT models as the VBIC95 have been published [2].

In this paper, the parameters of the different equivalent circuits (DC, AC and Transient) of the SPICE bipolar transistor model are obtained for a real GaAs-HBT by making use of a compact model of the semiconductor device. The input of the device model are the physical properties of the semiconductor materials and the geometry of the device. Then, using proper boundary conditions for heterojunctions, the I-V characteristics is obtained and, finally, the values of the parameters of the bipolar transistor SPICE model are calculated for each component in the different equivalent circuits. The procedure has been implemented with MATLAB. As a final application, we use the obtained SPICE data to calculate some figures of merit of the sample device (such as current gain, maximum frequency of oscillation and power gain) and we compare them with the measured data.

2. HBT STRUCTURE

The HBT modeled in this work was fabricated by TRW Inc. and extensive experimental results of the HBT were taken from the literature in order to compare our model with them [3].
Table 1 shows the doping profile of the 3x10 μm^2 GaAs HBT.

Region	Al composition	Thickness (Å)	Doping (cm^{-3})
Emitter	0	750	(n+) $7x10^{18}$
	0-0.3	300	(n) $5x10^{17}$
	0.3	1200	(n) $5x10^{17}$
	0.3-0	300	(n) $5x10^{17}$
Base	0	1500	(p+) $1x10^{19}$
Collector	0	7000	(n-) $7.5x10^{15}$
Subcollector	0	6000	(n+) $5x10^{18}$
Substrate	0	25000	Undoped

Table 1. *AlGaAs/GaAs HBT structure*.

The material properties shown in Table 2 have been taken into account to obtain the energy band structure.

	Emit.	**Graded Emitter**	**Base**	**Collec.**	**Subc.**
Doping	$7x10^{18}$	n-$5x10^{17}$	p-10^{19}	7.510^{15}	$5x10^{18}$
Al	0.3	x	0	0	0
$\mu_n(cm^2/Vs)$	2044	2044	2065	6642	1943
$\mu_p(cm^2/Vs)$	143	143	101	359	99
$\tau_n(s)$	10^{-9}	10^{-9}	$9x10^{-10}$	10^{-9}	10^{-9}
$\tau_p(s)$	10^{-9}	10^{-9}	$9x10^{-10}$	10^{-9}	10^{-9}
ε_r	12.6	13.1-3.12x	13.1	13.1	13.1
χ(V)	3.74	4.07-1.1x	4.07	4.07	4.07
E_g(eV)	1.7981	1.424+1.247x	1.424	1.424	1.424
m_{de}	0.0919	0.067+0.083x	0.067	0.067	0.067
m_{dh}	0.573	0.48+0.31x	0.48	0.48	0.48
V_{sat}(cm/s)	$8x10^6$	$8x10^6$	$8x10^6$	$8x10^6$	$8x10^6$
E_{ru}(kV/cm)	435	435	330	330	330
K(W/cm°C	0.12	0.12	0.46	0.46	0.46

Table 2. *Material properties(symbols have their usual meaning).*

3. HBT PHYSICAL MODEL

The physical model of the device takes into account Lundstrom´s boundary conditions for heterojunctions [4] and the recombination in the base and in the base-emitter space charge region [5].
The DC I-V characteristics of the 3x10 μm^2 AlGaAs/GaAs HBT described in Section 2 were obtained calculating the collector (I_C) and base (I_B) currents corresponding to steady-state solutions under various bias conditions. The simulated forward-bias Gummel plot is shown in Fig. 1.

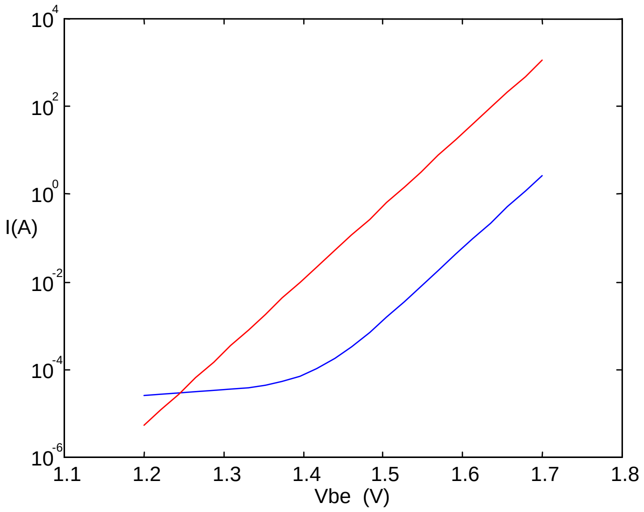

Figure 1. *Simulated I_C and I_B vs. V_{BE} characteristics.*

4. HBT SPICE EQUIVALENT CIRCUITS

The Ebers-Moll and Gummel-Poon large-signal models have been used, in order to obtain some of the SPICE parameters. Other SPICE parameters have been extracted by physical relationships. The SPICE parameters of the DC, Transient and AC equivalent circuits of this AlGaAs/GaAs HBT are shown in this section.

A detailed explanation about the DC, Transient and AC bipolar transistor SPICE models can be found in any SPICE manual or, for example, in [6]. The results here presented correspond to a V_{CE}=2.5 V and V_{BE}=1.36 V bias.

4.1. DC SPICE

Table 3 shows the calculated values for the parameters in the bipolar transistor DC-SPICE equivalent circuit. Using this model a DC current gain of 54 is obtained. The experimental result was β=50 for a similar bias.

R_b (Ω)	R_c (Ω)	R_e (Ω)	I_{cc} (mA)	I_{be} (mA)	I_{bc} (mA)	I_{re} (mA)	I_{rc} (mA)
28.9	28.5	1	2.2	0.005	0	0.04	0

Table 3. *Parameter values in the DC-SPICE circuit.*

4.2. Transient SPICE

Table 4 shows the calculated values for the parameters in the bipolar transistor large-signal SPICE equivalent circuit.

C_{JE} (fF)	C_{JCI} (fF)	C_{JCX} (fF)	C_{DE} (fF)	C_{DC} (fF)	τ_F (ps)	τ_R (ps)
82	1.7	3.4	177	0	2	2

Table 4. *Parameter values in the Transient-SPICE circuit.*

4.3. AC SPICE

Table 5 shows the calculated values for the parameters in the bipolar transistor AC SPICE equivalent circuit.

r_o kΩ	r_π kΩ	g_μ mA/V	g_m mA/V
549	2.5	0	86.5

Table 5. *Parameter values in the AC-SPICE circuit.*

5. COMPARISON WITH MEASURED RESULTS

Experimental values of parameters of the AlGaAs/GaAs HBT are compared in Table 6 with the simulated results obtained using the SPICE equivalent circuits. The differences between the experimental and simulated results in the high frequency performance are due to the parasitic elements that have not been included in the simulation.

	β	**f_{max}**	**G**	
Measured	50 (Ic=1mA)	40GHz (Ic=3mA)	10dB (Ic=4mA, f=12GHz)	
Simulated (Ic=2.2mA)	54	121GHz	30dB f=12GHz	8dB f=30GHz

Table 6. *Performance of the AlGaAs/GaAs HBT.*

ACKNOWLEDGMENT

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6. REFERENCES

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