The Impact of Base Current or Voltage Biasing On Characterization and Modeling of HBTs

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Abstract

The impact of base current or voltage biasing on HBT device characterization and modeling is explored experimentally and through the use of advanced HBT models for an example InGaP/GaAs HBT device. The important influences of the measurements with base voltage source are identified by showing the model performances of the device. The devices was used in this study a wafer-level (1.6 x 30um) InGaP/GaAs HBT modeled with several advance HBT models such as Curtice, FBH, and Mextram.

1. Introduction

Hetero-junction bipolar transistors (HBTs) are bipolar junction transistors that consist of two different semiconductor junction layers. Examples include InGaP and SiGe. HBTs provide many advantages over conventional silicon bipolar junction transistors (BJTs) such as larger current gain and higher cutoff frequencies. As a result, HBTs are widely used for digital and analog microwave applications. For designers of RF circuits, it is imperative to use reliable large signal models that are developed from measurements under various bias conditions of the device for accurate predictions of the circuit performance. Traditionally, a large signal model of HBTs can be extracted by using dc I-V and multi-biased S-parameter measurements. And the model performances are verified with 50Ω power sweep, intermodulation, and load pull measurements. Since bipolar transistors are primarily a current controlled active device in contrast to the voltage controlled field effect transistors (FETs), it is logical to parameterize measurement and modeling approaches using constant base-current biasing. However, device modeling engineers can easily extract inappropriate or incomplete model parameters if only constant base current measurements are used. The most important parameters are thermal resistance R_{th}, emitter resistance R_e, and forward thermal activation energy gap E_g, which in particular can be extracted incorrectly if the modeling process is performed without considering dc-IVs with constant base voltages. There are various methods of extraction R_{th} [1], [2], [3] and R_e [4], [5], but little research has been reported for the extraction method of E_g which has large influence on dc-IV model performances with constant base voltages.

2. The effect of a thermal resistance

Many of the parameters in a HBT model are functions of the device junction temperature, which depends on power dissipation of the device. The junction temperature can be calculated based on thermal resistance in the thermal model circuit, which plays a significant role in DC and large signal model

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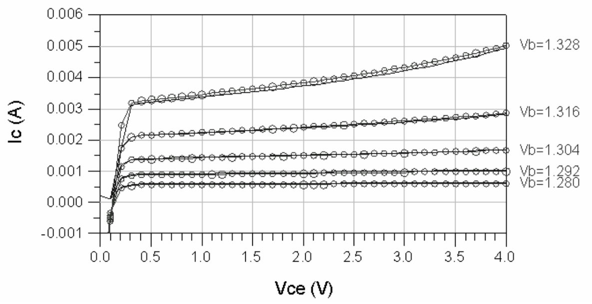
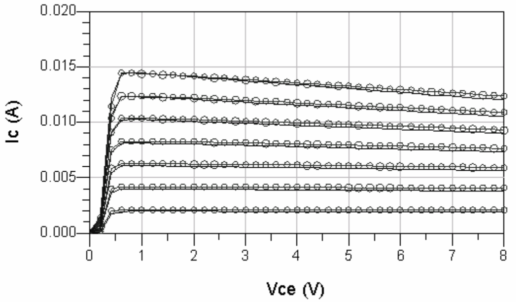
performance. Especially, correct modeling of self-heating is especially critical for III-V HBTs, like AlGaAs and InGAP HBTs, due to the large thermal resistivity of these materials.

Two major results from the temperature rise due to self-heating of HBTs are the decrease in the emitter junction built-in potential and the increase in the reverse hole injection from the base-emitter junction [6]. Due to the reason, the collector current increases under the constant base-emitter voltage V_{BE} biasing and decreases with the constant base current I_B biasing as shown in Figure 1.



(a) Ic vs. Vce with applied V_{BE}

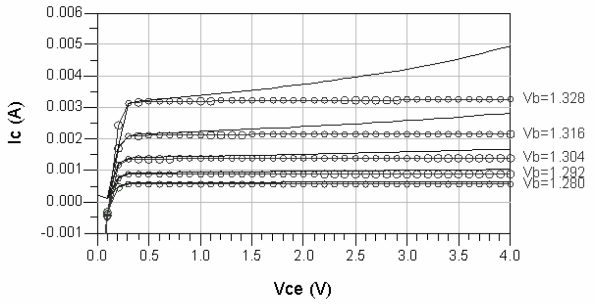


(b) Ic vs. Vce with applied I_B

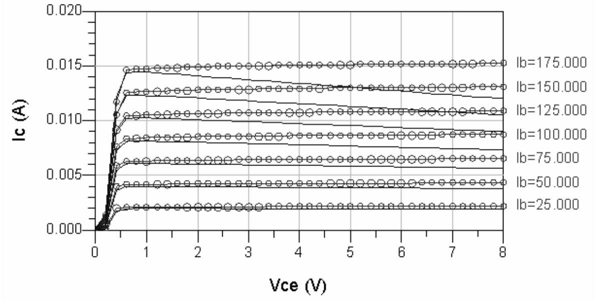
Figure 1 Comparison of modeled (-o- line) and measured (solid line) with self-heating effect properly modeled.

Figure 1 and Figure 2 show two cases of DC-IV characteristic with and without considering self-heating effect. As shown in Figure 2, without electro-thermal modeling the model is not able to predict the device characteristics which show significant self-heating effects. Therefore the correct parameter value of thermal resistance is the most important procedure in HBT modeling.

The reliable value of thermal resistance can be extracted by using one of several methods (e.g. [1], [2], [3]).



(a) Ic vs. Vce with applied V_{BE}



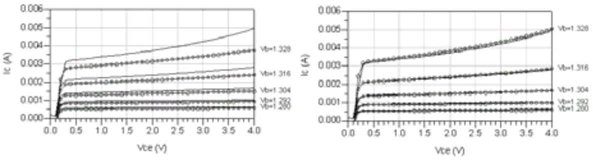
(b) Ic vs. Vce with applied I_B

Figure 2 Comparison of modeled (-o- line) and measured (solid line) without considering self-heating effect.

Most methods of thermal resistant extraction are using to calculate P_{diss} from the static IV or pulse IV measurement with constant base current biasing. However, our experience shows that without using measurements with constant base voltage, the parameter values of emitter resistance R_e and thermal related energy band-gap E_g can be extracted incorrectly. This is because these parameters affect the IV modeling performance with constant base voltages, but do not have much influence on IV performance with constant base currents.

3. The effect of the parameters *Re* and *Eg*

The emitter resistor, R_e which is physically located between the internal Emitter and external emitter pin, can be generally extracted by using "flyback" method. It measures the open collector voltage that is proportional to the Base current through this Emitter resistor. If the parameter R_e is correctly extracted, the collector current level agrees well in the IV model performance with constant base voltage. Figure 3 show the variation of the DC model performance with incorrect and correct R_e value.



(a) $R_e = 3\Omega$ ***(Incorrect)*** **(b)** $R_e = 1.6\Omega$ ***(correct)***

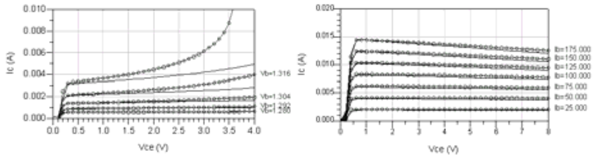
Figure 3 The IV model performances with the incorrect and the correct R_e value.

Table 1 shows the parameters for the thermal related forward active energy voltage in the various HBT models. The models such as Curtice Modified Gummel [7], FBH [8], and Mextram [9] were fully extracted for the device, 1.6x30um InGaP/GaAs HBT. The parameters of thermal resistance, R_{th} and emitter resistance, R_e were directly extracted from the measurements using appropriated methods. Thus these three models have the same value of R_e and R_{th}. Each model uses different name of the parameter and the thermal model functions should not be the same.

HBT Model	Parameter	Parameter name	The extracted value
Curtice	E_g	Energy gap for forward saturation current	1.65
FBH	V_g	Forward thermal active energy	1.69
Mextram	V_{gb}	Band-gap voltage of the base	1.62

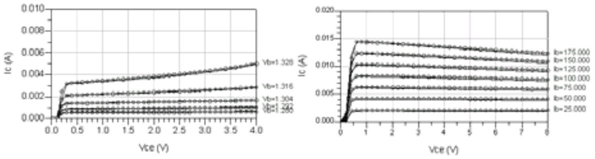
Table 1 The parameter information of the thermal related forward active energy voltage

A detailed analysis of the thermal model functions is the out of the scope in this research. This paper shows how an inaccurate value of the thermal related forward active energy voltage causes error model performances with constant base voltages. As shown in Table 1 the thermal related forward active parameters are around 1.65 for all the models. For simplicity, the extracted Curtice model is used to demonstrate the effects of an incorrect value of the parameter E_g affect into the DC model performance. Figures 4 and 5 show how the parameter E_g strongly influences the constant base voltage but not the constant base current behavior.



(a) IV vs. base voltages (b) IV vs. base currents

Figure 4 The model performance with the incorrect value of $E_g = 1.9$



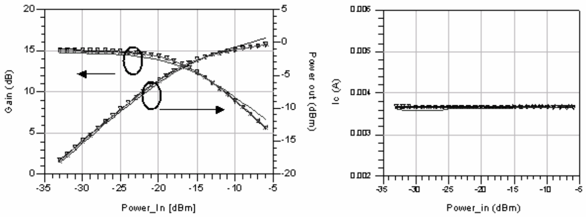
(a) IV vs. base voltages (b) IV vs. base currents

Figure 5 The model performance with the correct value of $E_g = 1.65$

It is hard to determine without using the DC measurement with constant base voltages, if the thermal model parameters are correctly extracted. Even though the model has correct parameter values for thermal resistance and emitter resistance. Thus the voltage source measurements are required for the correct thermal modeling of HBTs.

4. The Validation of the model performances

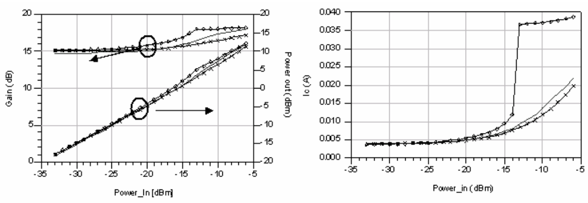
In this section, two cases of extracted model performances for the large signal model are shown in Figure 1 and Figure 2. The 1st model is extracted by using measurements with only a base current source and the 2nd model is extracted by using measurements with both base current source and base voltage source. The measurement and simulation are performed with RF signal frequency, 3.5GHz and the bias condition on the base is either Ib=44uA or Vb=1.32V for Vce=5V, and Ic=3.6mA.



(a) gain and power out (b) dc collector current

Figure 6 50Ω load power sweep simulation (-◊- the 1st model and -x- the 2nd model) and measurement (solid line) with a constant base current, Ib=44uA

Both models agree well for the power sweep with a constant base current as shown in Figure 6, but the 1st model is not able to predict the non-linear behavior of the power sweep with using a constant base voltage source as shown in Figure 7. However, the 2nd model is working well with both cases of power sweep measurements, because the 2nd model parameters used both base current and base voltage biased I-V measurements, which proved to improve the thermal modeling. Note that convergence problems were also observed initially for the 1st model simulated higher powers under constant base voltage biasing.



(a) gain and power out ***(b) dc collector current***

Figure 7 50Ω load power sweep simulation (-◊- the 1st model and -x- the 2nd model) and measurement (solid line) with a constant base voltage, Vb=1.32 V

5. Conclusion

The importance of correct HBT thermal modeling is briefly discussed in this paper in the context of base current and voltage biasing. One of the most important parameters is the thermal related forward active energy gap, which can be extracted and verified by using base voltage source measurements. Thus, it is emphasized that measurements with constant base voltages are also required to obtain the correct thermal model parameters, and proper model power compression behavior under both types of base DC bias setups.

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Equipment lists of the HBT characteristics

1. HP 8510 VNA, Anritsu 37397C lightning VNA (S-parameter measurements)
2. HP 4142 (DC measurements)
3. TEMPTRONIC TP03000 (Ambient temperature controller)
4. Cascade probe station (wafer measurements)
5. HP ESG-D4000A Digital Signal Generator, Maury ATS system, Keithley 2010 DC power source, Anritsu ML2438 power meter (50Ω power sweep measurements, source and load pull measurements, etc.)