

Electrical modeling of a New Super-Gain BJT dedicated to an innovative 600V AC switch

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Abstract – This paper deals with the electrical modeling of the super-gain BJT developed in GREMAN laboratory. As power bipolar component, its modeling is based on the Gummel-Poon model which is widely accepted and used by researchers as well as circuit simulators such as PSPICE. Model parameters are extracted from device characterization data. The characterization methods of respective parameter category are presented as well as the data processing method. The validation of the extracted model parameters will be done by comparing the SPICE simulation results with experimental ones under the same condition. The first comparison result proves a good coherence between simulation and experimentation.

Key Words — Modeling, super-gain BJT, Gummel-Poon, Characterization, parameter extraction.

1. INTRODUCTION

In the development of modern power electronics, new power switch has always been a priority and “hot spot” for both industries and researchers. The applications such as intelligent grid and smart buildings require the replacement of conventional mechanical and electromechanical switches by innovative performing power electronic devices. In this context, the GREMAN laboratory has designed and manufactured a super-gain ($h_{FE} > 220$) Gate Associated Bipolar Junction Transistor. In order to fully explore the potential of this device, an innovative 600V AC switch solution has been proposed, named as “TBBS” (Transistor Based Bidirectional Switch). The concept of the super-gain BJT and its physical structure is presented in Fig.1. The thin ($1.5 \mu\text{m}$) and lightly doped ($[Dop_B] > 1.10^{16} \text{at.cm}^{-3}$) base makes the DC current gain of super-gain BJT very important in both forward-biased mode (h_{FE}) and reverse-biased mode (h_{FC}). This result gives birth to our innovative AC switch TBBS which is composed of two super-gain BJTs in anti-serial (see Fig.2). The static mode characterization of the TBBS, which shows us their promising and encouraging electrical characteristics on conduction power dissipation, has been described in [1].

In order to be able to integrate this new AC switch into applications and to better understand the impact of its physical structure on its electrical behavior, a reliable and robust SPICE model should be created and this must pass through the electrical modeling for an elementary super-gain BJT. In this paper the electrical modeling of this super-gain BJT will be presented for the first time.

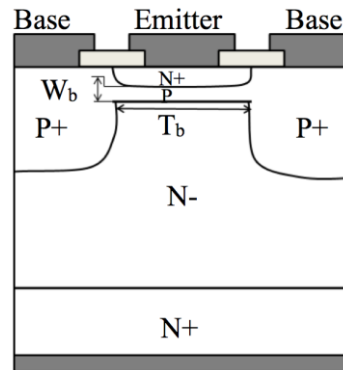


Fig. 1 Cross-sectional view of the super-gain BJT

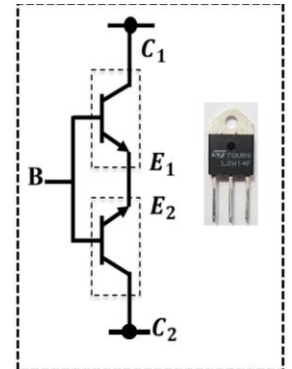


Fig. 2 Representative diagram of TBBS: two super-gain BJTs in anti-serial

2. ELECTRICAL MODELING OF SUPER-GAIN BJT

A simulation model of the super-gain BJT should be established, thus the widely used SPICE model Gummel-Poon has been chosen for their modeling. The modeling procedure including electrical characterization and model parameter extraction is mainly based on the method described in [2]. There are over 30 parameters implemented in Gummel-Poon model and they are divided into four categories: capacitance parameters, parasitic ohmic resistor parameters, DC parameters and transit parameters. The parameter extraction procedure follows the same order as the increase dependence of respective step with the former ones.

2.1. Electrical characterization and parameter extraction

In order to minimize the parasitic capacitance of packaging and the parasitic resistance of bonding, all of the electrical characterizations for parameter extraction have been done on wafer with probing tester under controlled temperature (300K) at the CERTEM platform of GREMAN laboratory.

2.1.1. Characterization bench

The characterization bench is presented as Fig.3, it is composed of several equipment: Probing tester allows us to access to the contact of a single chip; Impedance analyzer Ailgent 4294A performs the CV measurement (capacitance versus voltage) of every junction for capacitance parameter extraction; Tracer Tektronix 370A is used here to obtain DC curves under different text conditions for resistance and DC parameter extractions.

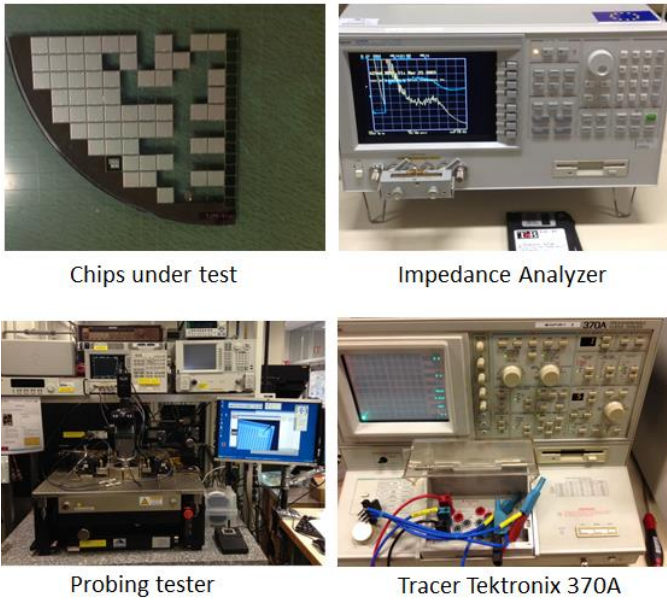


Fig. 3 Characterization bench and components under test

2.1.2. Data processing and parameter extraction

The measured data should be carefully selected for parameter extraction. For example the extraction of Base-Emitter leakage emission coefficient (N_E) should be done with low V_{BE} data and the Forward beta hi current roll-off (I_{KF}) should be extracted under high current. The wrong choice of data range could lead to unreasonable parameter value. Another important extraction technique is the application of the 'Loss function'. This function reflects the error between estimated and true value for an instance of data, seeking for the minimized error could help the parameter estimation. The extraction of I_{KF} is taken here as an example of this technique.

I_{KF} is extracted from the equation (1):

$$E = \sum_{i=1}^N \left\{ \frac{I_{Bi}}{I_{Ci}} \times \frac{1 - \frac{I_{Ci}}{I_{KF}} - \frac{V_{BCi}}{V_{AF}} - \frac{V_{BC}}{V_{AR}}}{\frac{1}{B_F} + \frac{I_{SE}}{I_S} \times \exp\left\{\frac{V_{BEi}}{V_T} \left[\frac{1}{N_E} - \frac{1}{N_F}\right]\right\}} \right\}^2 \quad (1)$$

Here in this equation, 'E' stands for total error and it is the loss function which has I_{KF} as its only variable. This function is solved for a best I_{KF} by iteration. The evolution of the total error in terms of I_{KF} is demonstrated as Fig.4. As shown in the figure above, the I_{KF} is determined when the total error is minimized. Many other model parameters are extracted by using the same technique.

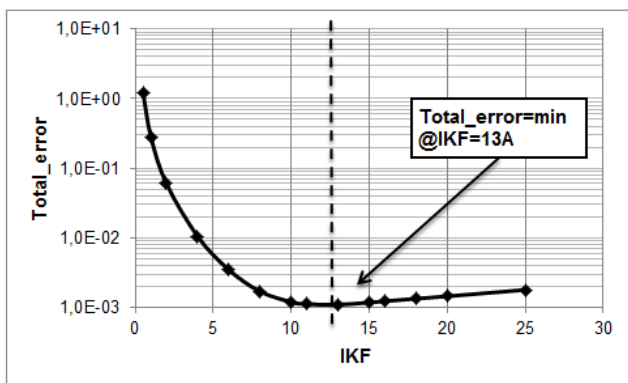


Fig. 4 Extraction of $I_{KF}=13A$, when the Total_error of the loss function are minimized

3. RESULTS AND CONCLUSIONS

After complete the model parameter extraction procedure, the reliability and robustness of the extracted parameters are verified by comparing the simulation results of the established model with the experimental ones. More precisely, here the output curve of the super-gain BJT and its Gummel curve are traced and compared with measured curves as presented respectively in Fig.5 and Fig.6.

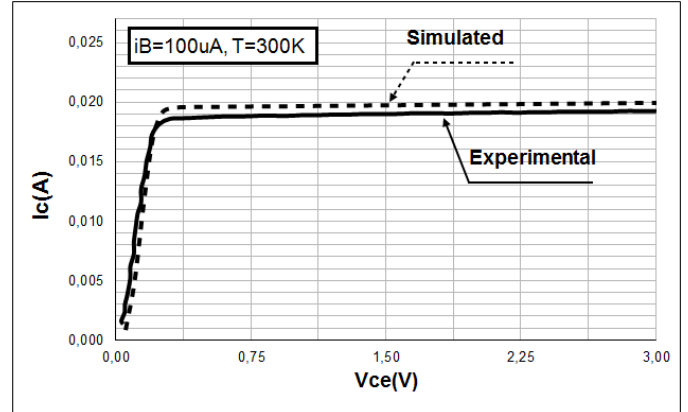


Fig. 5 Comparison of the simulated output curve and the experimental curve under the same base current level ($100\mu A$) and operating temperature (300K)

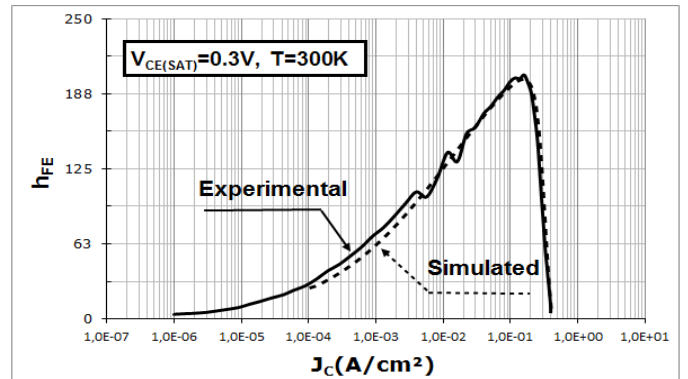


Fig. 6 Comparison of the simulated Gummel curve and the experimental curve under the same Collector-Emetter saturation voltage $V_{CE(SAT)}=0.3V$ and operating temperature (300K)

These two curves prove good coherence between obtained electrical model and the real component, which also confirm the reliability of our electrical characterization and parameter extraction procedure. The Gummel-Poon model of the super-gain BJT has been established and this will conduct us to the modeling of the 600V AC switch TBBS.

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5. REFERENCES

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