The Study of InGaP/GaAs HBT for Ruggedness Characteristics

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Abstract

DC SOA (Safe Operation Area) with forced base current (Ib-input) is commonly taken as an indication to predict the RF ruggedness characteristic of HBT device. However in practical power amplifier circuit design, it involves a ballasting resistor at base terminal with voltage bias (Vb-input). In this paper, Ib-input and Vb-input SOA are taken into consideration to further analyze RF ruggedness test result with various DC current gain (beta) and base ballasting resistors(Rb). The results show the high beta device has worse SOA and RF ruggedness performance. Besides, using the FOM of the ratio of Rb/beta can predict the Vb-input SOA.

INTRODUCTION

InGaP/GaAs HBT has been widely used in PA design for cellular handset and WLAN because of its high linearity and high efficiency. While the PA is operating at a high power density, the device may fail due to the high antenna load mismatch. Therefore, the ruggedness characteristic is one of the most important factors of the HBT device for cellular application. At the device level, DC SOA is an easy and quick method to investigate and predict the device robustness before the RF ruggedness test. Generally, the Ib-input SOA is commonly taken as an indication to judge the device robustness. However, in practical application, HBT device is driven by a base voltage via a base ballasting resistor instead of directly inputting base current.

In this paper, we analyze two kinds of SOA (Ib-input and Vb-input) using devices with different beta values and base ballasting resistors. Finally, the RF ruggedness test is discussed to compare with the DC SOA.

DEVICE FEATURES

The test device is an InGaP/GaAs HBT with the emitter size of 3μmX40μmX3 fingers which was fabricated by a conventional collector design. In this work, two HBTs with beta versions (75 and 140) were designed by adjusting the thickness of the base epitaxial layer are compared for the study of SOA and RF ruggedness test.

DEVICE PERFORMANCE

I. THE ANALYSIS OF SOA

Both Vb and Ib input SOA and the design of Rb are discussed in this section. In order to investigate the SOA mechanism, the two dimensional Technology Computer-Aided Design (TCAD) tool was employed. For the TCAD simulation of HBT, the basic model includes: 1.) concentration dependent analytic mobility, 2.) field dependent mobility, 3.) concentration-dependent Schockey-Read-Hall, 4.) Auger recombination, and 5.) bandgap narrowing. 6.) The thermal effects are also considered in the simulations with thermodynamic model. The thermal contact is set on the backside of the wafer.

1-1. IB-INPUT

Fig. 1(a) shows the Ib input I-V curves with two different betas of HBTs. Although the low and high beta HBTs show the same trend of the bend down phenomenon of collector current, the high beta HBT shows worse breakdown voltage.

In order to investigate the early breakdown phenomenon of the high beta HBT, the TCAD simulation was introduced. In Fig.2 (a), TCAD simulation shows the collector current for both high and low beta HBTs at current density of 10 kA/ cm^2. The bend down phenomenon, which is due to self heating is observed [1]. Fig.2 (b) further shows the center emitter current of the HBT device. The high beta HBT shows higher center emitter current with 5V of Vce. To further investigate it, Fig2(c) shows the center emitter current versus junction temperature which is increased with Vce increasing. This plot clearly demonstrates that the high beta HBT shows serious self heating. The device temperature after thermal coupling showed in Fig.2 (d). The temperature of center finger of high beta HBT is obvious higher [2].

1-2. VB-INPUT

The Vb-input SOA under the same base ballasting resistor (150 ohm) is shown in the Fig.1 (b). The failure mechanism is similar to Ib-input SOA. However, the main difference between two Vb input and Ib input SOA is that, the Vb-input IV has severe thermal run away effect. This depends on the selection of Rb value. Under the proper selection of Rb value, the unstable thermal run away effect can be minimized. Fig.3 shows the Vb-input SOA with a different beta and Rb. The result indicates that to keep the same ratio of base ballasting resistor to beta (Rb/beta) the HBT could result in an almost identical SOA behavior because of similar self heating and impact-ionization.

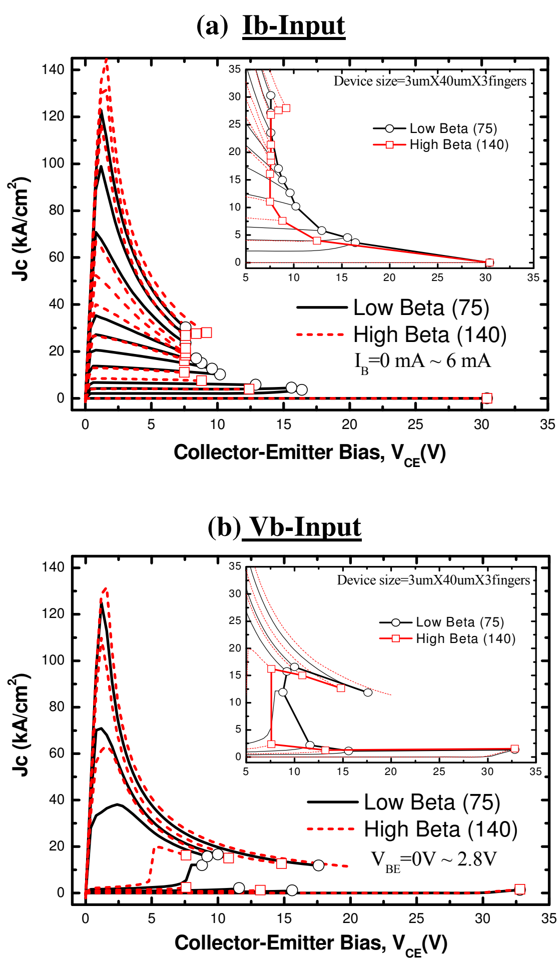

Fig.1. Comparison of IV curve and SOA between different beta values which is 75 and 140 with (a) forcing Ib input, (b) forcing Vb input and base ballasting resistance is 150 ohm.

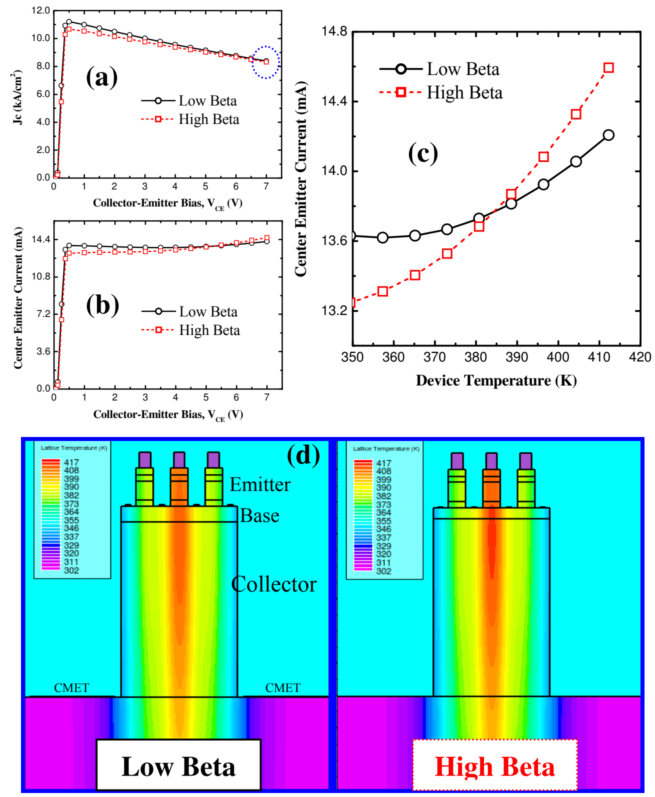

Fig.2. The simulation results of different beta devices : (a) collector current density vs. collector voltage, (b) center emitter current vs. collector voltage, (c) center emitter current vs. device temperature, (d) lattice temperature at Vce of 7V which is circled on (a).

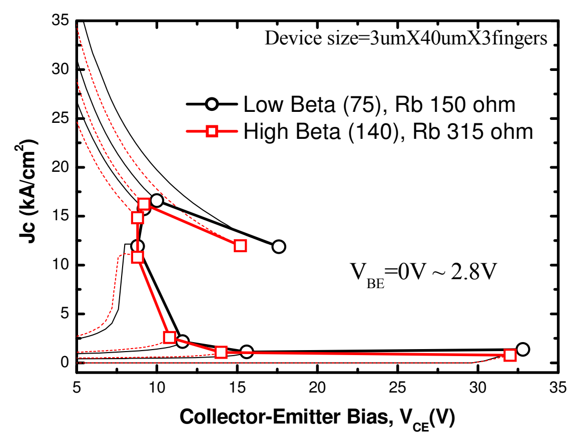

Fig.3. Comparison of Vb-input SOA between normal beta with Rb of 150 ohm and high beta with Rb of 315 ohm

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1-3. INTRODUCE DIFFERENT METHOLOGY

The Fig.4 (a) demonstrates a traditional method (Method1) to characterize Vb input SOA under relatively lower current density in this paper. This traditional method is to sweep Vce at a fixed Vbe. To further understand the correlation between SOA and RF ruggedness, an alternative measurement method (Method2) which focuses on higher current density is shown in Fig.4 (b). The Fig.4 (b) is to sweep Vbe at a fixed Vce. For the comparison of SOA, these two methods are identical below a collector current density of 12 kA/cm^2 which shown in Fig.4 (c). However, the Method1 can't detect the SOA boundary at low Vce since the collector current is too high and already reaches the upper limitation of the measurement set up.

To understand the Vb input SOA between two different beta values with two different base ballasting resistors, we plot Fig.5 by the method 2. The Kirk effect induced breakdown (KIB) is addressed to explain the failure mechanism at high current and low voltage region. [3]

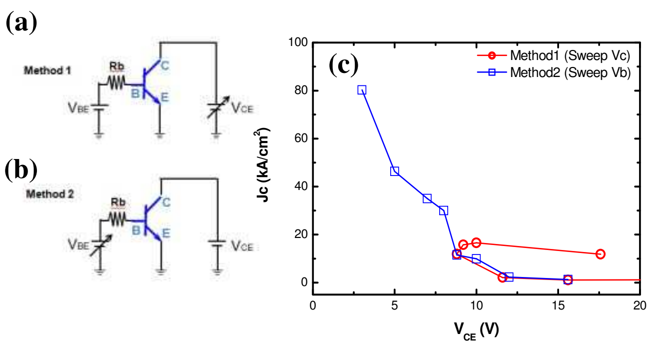

Fig.4. Schematic of (a) method1 which fixed the Vbe to sweep Vce, (b) method2 which fixed the Vce to sweep Vbe. (c) Comparison of SOA with constant Vb input between two methods.

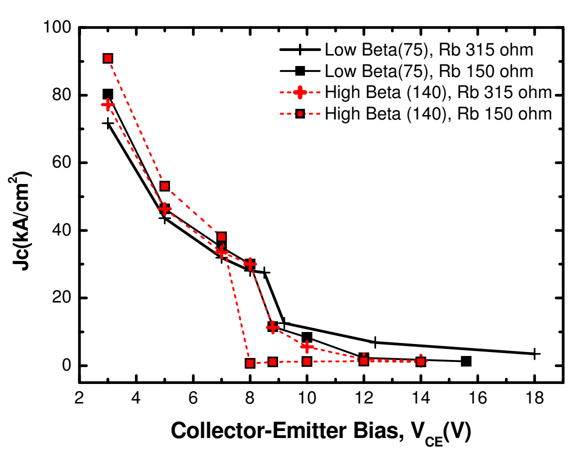

Fig.5. Comparison of Vb-input SOA between two different beta values with base ballasting resistance of 150 ohm

II. RF RUGGEDNESS TEST

2-1. LOAD LINE DECRIPTION

There are two types of load line behavior of RF ruggedness simulation as shown in Fig6. In the first one, VSWR was fixed at 10:1 for 360 degrees to increase Vce with the constant input power. The shape of the load line keeps the same and extends to higher voltage. The second one is to increase input power, and the shape of load line seems to extend to higher voltage and higher current region simultaneously.

2-2. THE MEASUREMENT RESULTS

In Table I~ Table III, we test the ruggedness of HBTs with different betas and the same Rb of 150 ohm. There are three different ruggedness test approaches, including: 1.Increasing input power at Vce=3.4V shown in Table I; 2. Increasing input power at Vce=5V shown in Table II; 3.Increasing Vce with a small constant input power shown in Table III. The ruggedness test results of the three approaches agree with the trend of Vb-input SOA at high voltage region and indicate the SOA in this region is more critical than the other region.

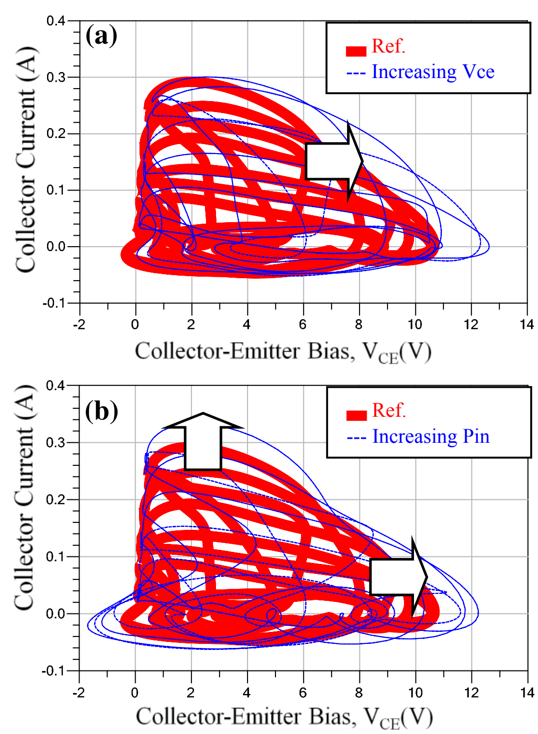

Fig.6. The Simulation of Load Line: (a) increasing Vce with a constant power, (b) increasing input power

TABLE I

Ruggedness test results under VSWR 10:1 at 1.95 GHz for different beta. The bias condition was 3.4V and collector quiescent current was 6.4 mA.

Pin (dBm)	15	18	21	24	27	28
Low Beta	Passed	Passed	Passed	Passed	Passed	Passed
High Beta	Passed	Passed	Passed	Passed	Passed	Passed

TABLE II

Ruggedness test results under VSWR 10:1 at 1.95 GHz for different beta. The bias condition was 5V and collector quiescent current was 6.4 mA.

Pin (dBm)	5	6	7	8
Low Beta	Passed	Passed	Passed	Failed
High Beta	Failed			

TABLE III

Ruggedness test results under VSWR 10:1 at 1.95 GHz for different beta.

VCE	4V	4.5V	5V	5.5V	6V	6.5V
Low Beta	Passed	Passed	Passed	Passed	Passed	Failed
High Beta	Passed	Passed	Passed	Passed	Failed	

TABLE IV

Ruggedness test results under VSWR 10:1 at 0.9 GHz with the constant output power of 21.5 dBm for different beta and base ballasting resistor

VCE		3.6V	5V	5.5V	6V	6.5V	7V	7.5V
Low Beta	Rb150 ohm	O	O	O	O	O	X	
	Rb315 ohm	O	O	O	O	O	O	X
High Beta	Rb150 ohm	O	X					
	Rb315 ohm	X						

O: Passed
X: Failed

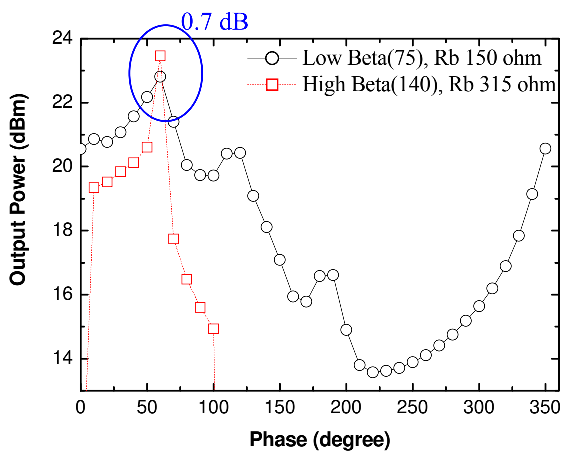

Fig.7. All phase rotation for the different device with same Rb/Beta ratio at 3.6V.

In Table IV, we test ruggedness of the HBT with different beta and different Rb. The test condition is at collector current of 2.7 kA/cm^2 under a constant power of 21.5 dBm and gradually increasing V_{CE} from 3.6V to device burn out.

Table IV shows the HBT with high beta failed earlier than that with lower beta. This agrees with the trend of Vb input SOA at higher Vce region. However, the comparison between low beta HBT with low Rb and high beta HBT with high Rb (keeping the ratio of Beta/Rb is the same) didn't agree the trend of Vb-input SOA. Fig.7 shows that the high beta HBT with high Rb has 0.7dB higher maximum output power during the 360 degree all phase rotation. The higher output power might be due to the mismatched impedance under the phase rotation.

Although the ruggedness of the high beta HBT is worse than that of normal beta HBT, WIN foundry has developed a superior high beta (140) HBT technology. It shows comparable ruggedness performance to the current normal beta (75) HBT as shown in Table V and also has better RF power performance.

TABLE V

Ruggedness test results under VSWR 10:1 at Vce of 5.

Pin (dBm)	15	16	17	18	19	20	21	22	23	24
Current normal(75) beta technology	O	O	O	O	O	O	O	O	O	X
Current high beta(140) technology	O	O	O	O	O	O	O	O	O	X

At 0.9 GHz

Pout=P1dB (Pin 15) Pout=Saturated Power (Pin 21)

CONCLUSIONS

In conclusion, the Vb-input SOA shows the same trend to the Ib-input SOA. The HBT with high beta value has a worse SOA below 15 kA/cm^2 is due to severe thermal coupling effect and correlates to poor RF ruggedness performance. In this study, the Vb-input SOA measurement successfully agrees with the trend of Rb/beta ratio. However, the ruggedness test can't be predicted by Rb/beta ratio. We suspect that is because of the unexpected higher returned output power caused by the impedance of the VSWR turner dominates the ruggedness failure beyond the SOA, and also the difference of thermal behavior between DC SOA and the ruggedness test should be considered simultaneously.

For the future work, it's interesting to investigate the pulsed SOA and load line to further clarify how the thermal effect and load impedance, respectively, will impact ruggedness results.

ACKNOWLEDGEMENTS

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ACRONYMS

HBT: Heterojunction Bipolar Transistor
SOA: Save Operating Area
VSWR: Voltage Standing Wave Ratio