The Maximum Operating Region in SiGe HBTs for RF Power Amplifiers

Akira Inoue, Shigenori Nakatsuka*, Ryo Hattori and Yoshio Matsuda

High Frequency and Optical Semiconductor Division, Mitsubishi Electric Corporation
4-1 Mizuhara, Itami City, Hyogo Pref. 664-8641, Japan
*Miyoshi Electronics Corporation, 306 Higashisakeya cho, Miyoshi City, Hiroshima 728-8511, Japan

Abstract — **Microwave waveforms of SiGe HBTs have been directly measured. The maximum operating region has been experimentally investigated by sweeping the load lines and power of the input signal. The device is found to operate beyond the conventional BVceo, while GaAs HBTs cannot survive at that voltage. The conventional BVceo is found to limit the average Vc of the maximum load lines, but has no influence on the peak voltage. Another BVceo measured with a voltage generator is proposed to represent the avalanche breakdown instead of the conventional one.**

I. Introduction

Recently, SiGe HBTs are going to be used in power amplifiers for mobile communication handsets. The device tends to be used at the high voltage of charging battery and standing waves from mismatched antennas. As the breakdown voltage of the SiGe HBT is relatively lower than that of the GaAs HBT, the maximum operating region of the SiGe HBT is definitely required for the design of the power amplifier. Recent SiGe power amplifiers can operate at a high collector voltage near the breakdown voltage [1-3]. Some of them can even survive at the high VSWR condition [3]. On the other hand, GaAs HBT amplifiers can operate at nearly one-third of the breakdown voltage [4].

Failure mechanisms and thermal instability in GaAs and SiGe HBTs were studied under DC conditions. However, these thermal condition and electric fields are completely different from the real microwave operation of the device, since physical time constants are not considered in the DC operation. To overcome this problem, the operating limits in a GaAs HBT were investigated by the direct measurement of the microwave waveforms [5]. However, no direct waveform measurement in SiGe HBTs near the operating limits has been reported.

In this study, the real current and voltage waveforms of SiGe HBTs at 0.9GHz have been directly measured. By sweeping load lines and input power Pin, the maximum operating region has been experimentally investigated. The relation between the conventional BVceo and microwave limits are also discussed.

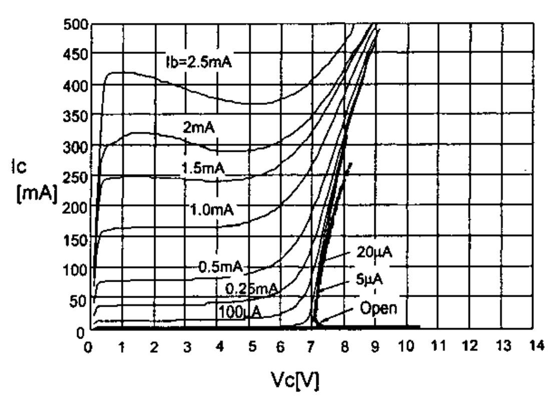

Fig.1 IV characteristics of the SiGe HBT with a constant Ib.

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II. Measurement

A SiGe high power HBT is measured in the common-emitter configuration. The emitter area is $2x30um^2$ x 240-fingers. Figure 1 shows the measured DC-IV characteristics of the HBT with a constant Ib. The bold line in the figure denotes the collector current measured by a current generator with opened base. The conventional BVceo is 7.0V.

In order to investigate the maximum operating region at the microwave frequency, the incident and reflected waves at the base and collector terminals are measured using a microwave transition analyzer up to 18GHz. The current and voltage waveforms at the transistor are calculated from the full-two-port calibration data [6]. The input and output matchings are adjusted to getting the proper load lines using automated tuners. The microwave waveforms at the pads of the device are calculated using the measured S-parameters of the test fixture.

To find the maximum collector voltage (Vc) with each collector current (Ic), we gradually increased the Vc while maintaining the Ic by Vb adjustment. The load contours were measured until the HBT reached its operating limits. These measurements were performed for several Ic and Pin values. The source and load impedances were fixed during these measurements.

III. Results

With the small Pin of 12.0dBm, we performed the waveform measurement procedure described in the previous section. Figure 2 shows all the load lines just before reaching its operating limits. Therefore, these lines represent the maximum operating region of the device with this specific input power, source and load impedances.

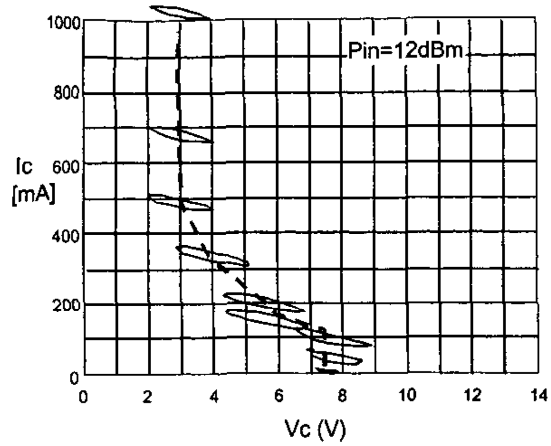

Fig.2 Measured maximum load lines with the Pin of 12.0dBm and the average Ic Vc of the load lines (dotted line).

An increase in the Vc beyond these lines results in two modes. One is a runaway of the collector current in the high collector current region over 100mA, and the other is an unstable operation in the low Ic region, where the average base current decreases to negative. The SiGe HBT can survive at this negative base current operation, while the GaAs HBT rushes into burnout. However, it is unstable and goes to burnout at a higher collector voltage. We defined this limit at the Vc where Ib becomes negative.

The dotted line in the figure denotes the average Vc and Ic at the maximum load lines. In the low Ic region under 100mA, the average Vc is almost same as the BVceo. Furthermore, the peak voltage exceeds the breakdown voltage. This is different from the GaAs HBT, in which the peak voltage cannot go over the BVceo.

As the base bias is supplied by a constant voltage source, these limits at a small RF power are supposed to be related to the DC limits with constant base voltage. Figure 3 shows the IV characteristics with a constant Vb condition. The dotted line denotes the average Ic Vc of the maximum load lines in Fig.2. The dotted line shows good agreement with the values of thermal runaway in the DC IV curve. Therefore, the average Vc and Ic of the load lines dominate the limits with the Pin of 12dBm.

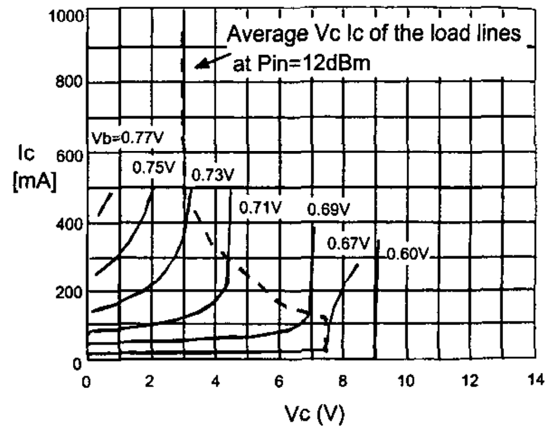

Fig.3 IV characteristics with a constant Vb (solid line) and the average Vc Ic of the maximum load lines at the Pin of 12.0dBm (dotted line).

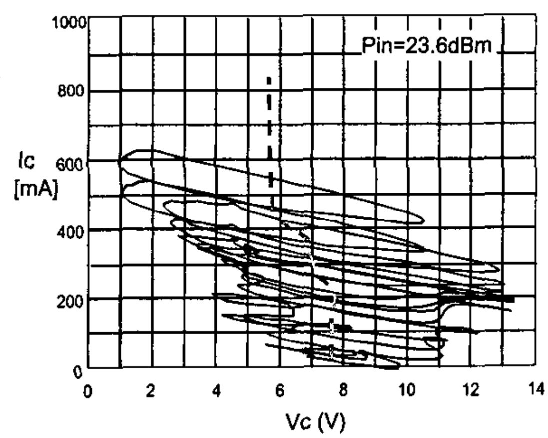

Fig.4 Measured maximum load lines with the Pin of 23.6dBm and the average Ic Vc of the lines (dotted line).

In order to confirm this explanation, the same measurement with larger input power Pin's of 18dBm and 23.6dBm were performed. Figure 4 shows the measured load lines with the Pin of 23.6dBm. The peak collector voltage goes far beyond the BVceo, while the average Vc still remains at 7.5V. The peak and average collector voltages are summarized in Fig.5. The solid lines are the envelope of the peak Vc of all the maximum load lines. The dotted lines show the average Vc Ic values of the load lines. The gray lines denote the IV characteristics in Fig.3. In the high Ic region, the average Vc increases with larger Pin. This means that the SiGe HBT can also operate beyond the DC thermal limit with a large Pin. This phenomena is similar to that of the GaAs HBT. However, the average Vc is restricted by the BVceo, because its bias cannot be set over the BVceo due to the thermal runaway.

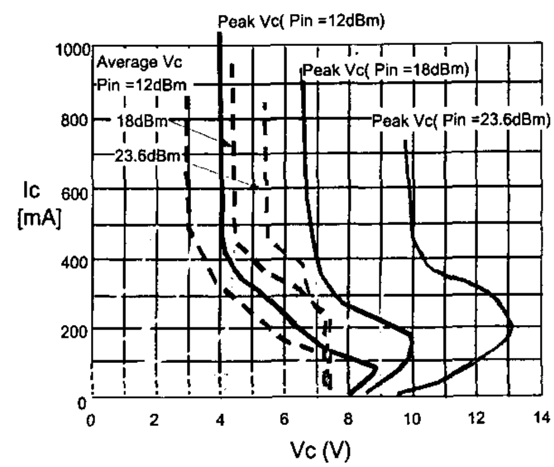

Fig.5 The envelope of the peak and average Vc of the maximum load lines with Pin values of 12, 18 and 23.6dBm.

As for the peak Vc, most of them exceed the BVceo. The peak Vc at a Pin of 23.6dBm reaches 13.1V. For this SiGe HBT, the BVceo has no influence on the peak Vc. This is different from the GaAs HBT.

This difference is explained as follows. Usually, the BVceo is measured using a current generator. As shown in the bold line in Fig.1, the peak voltage of 10.8V was observed before Vc goes into the conventional BVceo with a larger Ic. This means that an avalanche breakdown occurs around 10.8V. Also, the following impact ionization induces thermal runaway which reduces Vc to 7V. Thus, this BVceo of 7.0V shows its thermal limits, not the avalanche breakdown. Generally, the avalanche breakdown is considered to affect the peak voltage because its time constant is very fast. On the contrary, the thermal runaway has no influence on the microwave operation due to its slow time constant.

Based on this explanation, the conventional BVceo is not adequate to represent the peak voltage limit from the avalanche breakdown. We then measured BVceo with a voltage generator by sweeping the Vc, because no reduction in the Vc occurs after the avalanche breakdown. With this method, the BVceo of 13.0V is obtained. This agrees with the peak voltage of the measured load lines around 200mA at the Pin of 23.6dBm.

IV. CONCLUSIONS

The load and source waveforms of the SiGe HBT at 0.9GHz have been directly measured using a microwave waveform measurement system. The maximum operating region has been experimentally examined. Under a small input power operation, the average Vc Ic of the maximum load lines are determined by the DC thermal runaway condition. With a large input power, the HBT is found to operate beyond the DC limit of thermal runaway similar to the GaAs HBT. The device is also found to operate beyond the conventional BVceo where the GaAs HBT cannot survive. The conventional BVceo is considered to show the thermal limits, not the avalanche breakdown that affects the peak voltage. Instead of the conventional BVceo, the BVceo measured with a voltage source is suitable for the peak voltage limit. These results contribute to the design of SiGe high power amplifiers.

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