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Pulsed Characteristics of Microwave SiGe Heterojunction Bipolar Transistors Operated at High Collector Voltages

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1. Introduction

For power applications, SiGe heterojunction bipolar transistors (HBTs) have proven their capabilities of handling high power densities in the K-band operations [1]. However, a challenge faced by SiGe-based technologies is providing sufficient high-voltage immunity without compromising power performance. In addition, when the transistors operate in very high power region, a significant self-heating effect may occur, and leads to gain collapse [2]. Hence, it is required to know the limitations due to avalanche breakdown and thermal effect for circuit designs at high collector voltages. In this paper, we study the pulsed characteristics of SiGe HBTs at high collector voltages.

2. Experiments

Multi-finger SiGe HBTs were measured on wafer with Cascade microwave probes. Pulsed characterization was performed using the Agilent 85124A pulsed modeling system. Typical duration of the pulses was 1μs to 100μs with a period of 1ms. These values allow the devices to cool down sufficiently between pulses.

3. Results and Discussion

Fig. 1 displays the pulsed profile of a SiGe HBT with 10μs pulse width. We compare the pulsed characteristics of a transistor sampled at different delays (t_p). Fig. 2 shows the output characteristics of a transistor measured at constant base current (I_B). At t_p=1μs, when the collector voltage (V_{CE}) approaches the breakdown voltage, the collector current (I_C) increases rapidly with V_{CE}. However, with increasing $t_{p,}$ the roll-up of I_C decreases. For longer t_p and DC measurement, I_C will even decrease with V_{CE} at high V_{CE} and high I_B operation. It indicates that the current gain collapse effect has taken place. In collapse region, the device power is entirely dissipated in one finger and junction temperature increases rapidly, so the current gain decreases dramatically [2]. For pulsed measurement with short delay, the self-heating effect has been suppressed, so the current gain collapse can be eliminated.

Fig. 3 shows the output characteristics of a transistor at constant base voltage (V_{BE}). For long t_p, the current gain collapse is not distinctive easily from the avalanche breakdown. However, from the measured I_B at a constant V_{BE} operation, we can identify the gain collapse effect. In Fig. 4, as V_{CE} approaches breakdown voltage, the base current decreases with V_{CE} at t_p=1μs due to the generation of avalanche current. When t_p increases to 2μs, the base current reversal is no longer observable. For longer t_p, I_B increases dramatically at high V_{CE}, indicating the occurrence of gain collapse.

From above discussions, it was known that the pulsed measurement can separate the avalanche breakdown and gain collapse effect, making device modeling more easily. For modeling the gain collapse effect, the multi-finger HBT can be viewed as consisting of several identical sub-HBTs [2]. For modeling the avalanche current, we extract the avalanche multiplication factor (M-1) from I_B at a fixed V_{BE} bias [3]. As shown in Fig. 5, as V_{BE} increases to 790mV, the DC measurement gives wrong M-1 values due to self-heating effect. With pulsed measurement, the M-1 is consistent to that with DC measurement at low V_{BE}. At V_{BE}=830mV, M-1 is lower than that at low V_{BE} due to the decrease of junction peak field under high injection current.

For modeling the high-frequency characteristics of HBTs in high voltage region, we measured the S-parameters of devices. The calculated cutoff frequencies (f_T) from S-parameters are shown in Fig. 6. It was observed that f_T values under pulsed mode are higher than that under DC mode due to less thermal effect. At V_{CE}=6V, where the device operation has entered the collapse region, the device under pulsed mode still has good high-frequency performance, but the device under DC mode has been destructed during S-parameters measurement.

4. Conclusions

In this paper, we found the current gain collapse due to self-heating effect can be eliminated by using pulsed measurement with short delay. Hence the avalanche breakdown and gain collapse effect can be modeled separately. Besides, for device operated at pulsed mode, the device is not destructed when V_{CE} exceeds the collapse loci, and has good high-frequency performance. It indicated that the working range of HBTs can be extended under pulsed mode operation.

References

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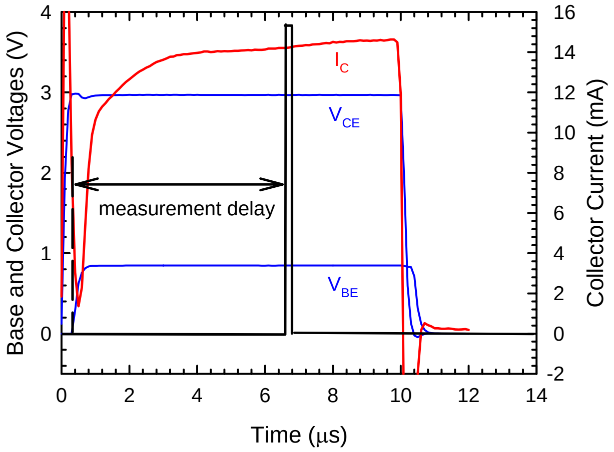

Fig. 1 Base voltage, collector voltage and collector current pulse shapes of a SiGe HBT.

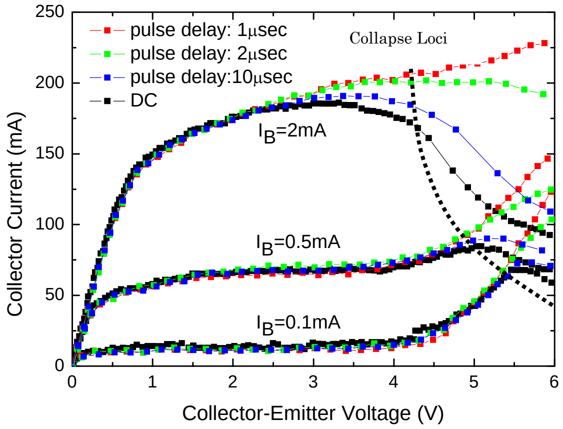

Fig. 2 Output I-V characteristics of a SiGe HBT at constant I_B with different pulsed measurement delays. I-V curves with DC measurement are also shown for comparison.

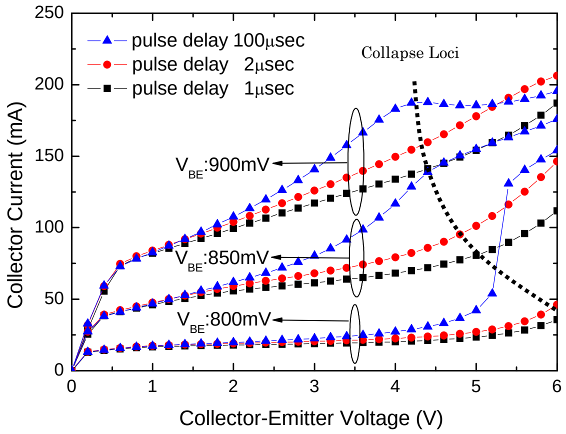

Fig. 3 Output I-V characteristics of a SiGe HBT at three different V_{BE} with different pulsed measurement delays.

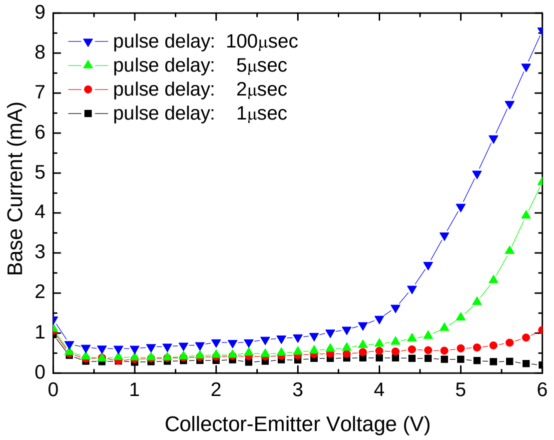

Fig. 4 Base current as a function of collector voltage at constant V_{BE}=900mV with different pulsed measurement delays.

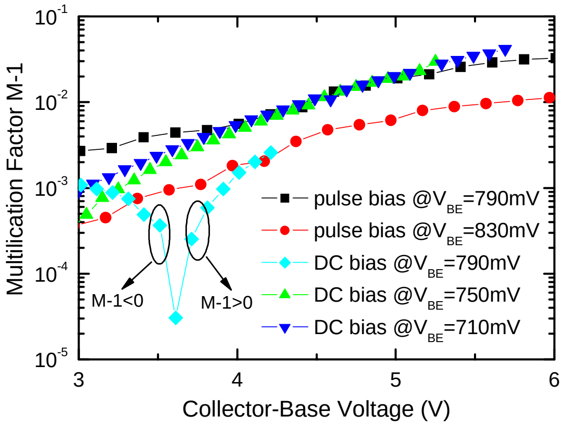

Fig. 5 The extracted M-1 from DC and pulsed measurements at different V_{BE}.

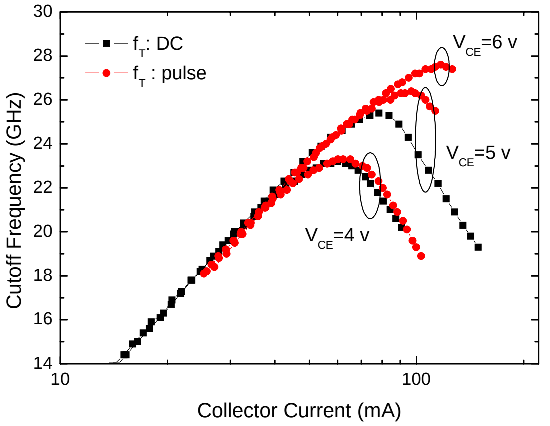

Fig. 6 Measured cutoff frequency as a function of collector current under DC and pulsed mode operations.