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Hot carrier effect on a single SiGe HBT's EMI response

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ABSTRACT

This paper describes the rectification responses exhibited by two kinds of SiGe HBTs when electromagnetic interference (EMI) is injected at the base of the transistor. The variation of the EMI induced DC offset after hot carrier stress is also studied. The experimental results show that the EMI response of a single SiGe HBT is different from that of a Si BJT. With interference present, the DC current gain increases at low base-emitter (BE) bias and decreases at larger V_{BE} values. The absence of AC crowding induced DC crowding along with the base recombination current accounts for the increase of current gain. The base-width effect and the high-injection effect tend to decrease the gain in presence of interference. The simulation results show that the Gummel–Poon model is able to quantitatively model the EMI response of a SiGe HBT.

1. Introduction

The reliability of SiGe HBTs has been widely investigated to fulfill its potential as an enabling component for extreme environment electronics [1]. Existing research concerning the radiation effect and hot carrier effect mainly focused on the degradation of DC and AC characteristics [2–8] and the noise performance [9–11]. Nowadays, as the electromagnetic environment deteriorates continuously and the manufacturers of integrated circuits tend to integrate more devices in a constrained volume, the electromagnetic compatibility (EMC) of electronic systems is receiving increasingly more attention [12]. Investigators have found that the electromagnetic emission and susceptibility of an integrated circuit may degrade after radiation and hot carrier stress, which raised a key issue to be solved to guarantee the EMC of an electronic equipment over its whole lifetime [13]. Li et al. [14] reported normal performance of a phase locked loop (PLL) device after accelerated life tests, nevertheless the electromagnetic susceptibility (EMS) of the voltage controlled oscillator degraded significantly, increasing the failure risk of the whole module. The change of EMS is ascribed to the variation of MOS transistors' response to EMI after the hot carrier damage, which was verified by the same authors later [15]. Aside from MOS transistors, the EMI response of a BJT is also reported to be affected by the ionizing radiation damage [16,17] and hot carrier damage [18]. Experimental results performed by Doridant et al. showed that the output voltage under EMI will change after radiation and sometimes the variation direction reversed. The change depends on the bias set-up on the base terminal [16,17]. They considered this phenomenon as a consequence of the decrease of low frequency input impedance h_{ie} (which is defined as dV_{be}/dI_B). Later, Xiong et al. [18] investigated the hot carrier effect on a single Si BJT's EMI response and provided some theoretical interpretation by taking advantage of a widely accepted model.

One of the effects of EMI on a bipolar transistor is to induce a shift in the quiescent operating point [19], which is also called DC shift. On ordinary Si BJTs, the DC shift includes a shift of the base current, the collector current (if any) and a reduction of the dc current gain [19–21]. Generally the base current increases under EMI, the collector current may increase, decrease or remain constant, depending on the base bias resistance. In the case that the base current is held constant, a reduction in the base-emitter (BE) voltage will decrease as a result of the injected interference signal [21].

Up to now the response of SiGe HBTs to EMI has not been reported. We may intuitively consider that the EMI response of SiGe HBTs is similar to that of ordinary Si BJTs, but it needs to be verified. In this work we investigated the EMI induced DC shift in a single SiGe HBT and the change after hot carrier damage. The experimental results showed that some difference exists between the EMI response of SiGe HBTs and Si BJTs.

2. Experimental setup

Two kinds of SiGe HBTs were utilized in the experiments. One is fabricated by the Institute of Microelectronics, Tsinghua University. The other is a commercial SiGe HBT-BFP740. The Tsinghua SiGe HBT features an f_T of 7 GHz and a BV_{CEO} of above 12 V; BFP740 has a peak f_T of around 45 GHz and a BV_{CEO} of 4.5 V. The schematic cross-section of the Tsinghua SiGe HBT is shown in reference [22].The Tsinghua SiGe HBT was mounted in SOT23 plastic package and BFP740 was mounted in SOT343 plastic package. The two SiGe HBTs were placed on FR4 substrate and biased as a common emitter amplifier during the EMI test. The EMI test circuit is shown in Fig. 1(a). The bias tees were comprised of onboard capacitors and inductors to reduce measurement noise. A capacitor was added between the base and emitter to mitigate oscillation

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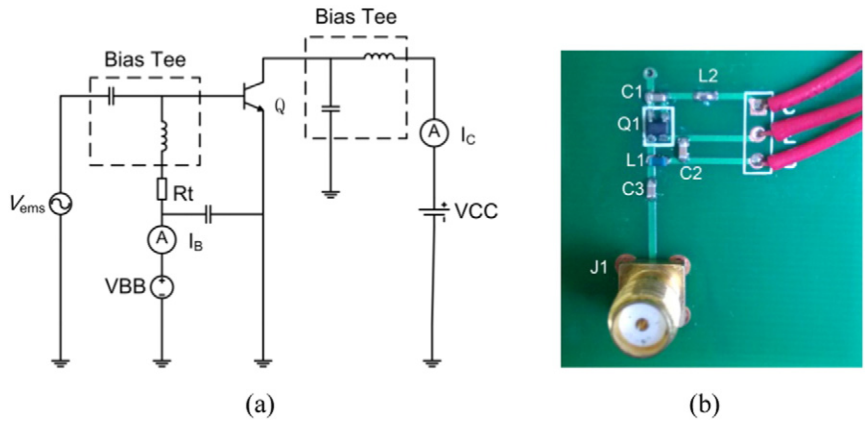

Fig. 1. EMI test setup for a transistor.

during the measurement. A photograph of the test board for BFP740 is shown in Fig. 1(b).

In the experiment, the collector was biased by a voltage source Vcc = 2 V. The base was either biased by a voltage source, sometimes along with a bias resistance, or by a current source. The base voltage or current could be varied to achieve a preselected collector current, which is called the quiescent operating point. Then the interference signal (continuous sine wave) was injected to the base of the transistor and the DC base current (or voltage) and collector current are measured. In this work, the base bias resistance was 0, 200 kΩ or 510 kΩ. The hot carrier stress was carried out by applying a reverse biased BE voltage, with the collector open. For the Tsinghua SiGe HBT and BFP740, the stress bias was 2.7 V and 3.65 V respectively. The stress was interpreted at 200 s, 500 s, 1000 s and 3000 s and the EMI response was evaluated. The electrical stress, the DC force and measurement were performed by a 4200-SCS semiconductor characterization system.

3. Experimental results

3.1. EMI effect on the dc characteristics of SiGe HBTs

Shown in Fig. 2 is the Gummel plot of the two SiGe HBTs with and without EMI. P_{in} means the power set on the AC signal generator. All the EMI tests in this work were performed with the same P_{in}. From Fig. 2 it could be seen that the base current and collector current increases when the AC interference signal is injected. Fig. 3 shows the effect of EMI on the DC current gain. It could be seen that in presence of EMI, the current gain increases at low BE bias and decreases at high BE voltages. This behavior is different from that of a Si BJT. It has been reported that the current gain of a Si BJT generally decreases as a result of EMI [20,21].

3.2. Hot carrier effect on the Gummel plot

Fig. 4 shows the forward-mode Gummel characteristics of the two SiGe HBTs measured at different cumulative stress times. After hot carrier stress, the base current increases with increasing stress time and the collector current remains unchanged. The increase of base current is due to the increased recombination velocity in the BE space charge region. When the BE junction is reversed biased, the valence electrons in the p-base would tunnel to conduction band of the n ± emitter, leaving behind some holes. These holes then transport under the electric field in the BE space charge region (pointing from the n ± emitter to the p-base) and gain energy [23,24]. Some holes would reach the Si/SiO_2 interface at the emitter periphery and generate interface traps. The interface traps act as generation/recombination (G/R) centers, leading to an increase of the recombination component of the base current [25].

3.3. Hot carrier effect on the EMI response

3.3.1. Assessment indicators of the DC offsets

In this paper the EMI response was investigated with the base supply resistance Rt being 0, 200 kΩ, 510 kΩ and infinite (constant base current). During the EMI tests, if the base bias was supplied by a voltage source along with a supply resistance, the DC base current and the DC collector current were measured. If the base was terminated in a current source, the voltage across the BE junction, and the collector current were measured. After hot carrier stress, the base supply voltage or

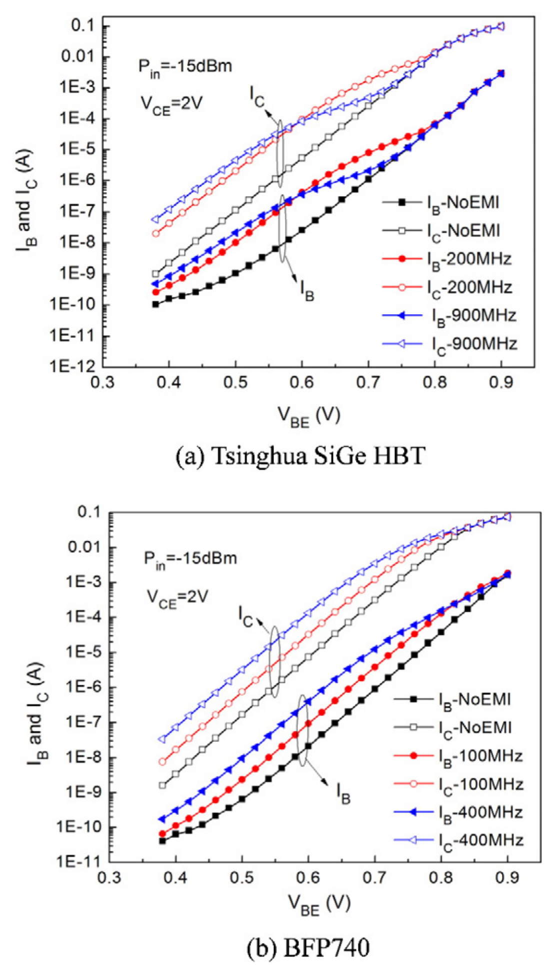

Fig. 2. EMI effect on the Gummel characteristics of the two kinds of SiGe HBTs.