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The Impact of Mixed-mode Electrical Stress on High-Frequency and RF Power Characteristics of SiGe HBTs

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1. Introduction

Due to the high electric field at p-n junctions caused by the high doping levels of SiGe HBTs, the hot-carrier (HC) reliability has become a major concern for such advanced devices used in commercial products [1]. Recently, a new HC degradation mechanism was reported in real product application [2], which was termed as a “mixed-mode” stress. It occurs when a high collector current density and a high collector-base voltage are imposed simultaneously on the device. It is very interesting because this stress condition is approaching to the operations of a bipolar-power amplifier, in which the active devices are working as a controlled current source. In this paper, we investigate the degradations of high-frequency and RF power characteristics of SiGe HBTs with different bias conditions after mixed-mode electrical stress.

2. Experiments

Multi-finger Si/SiGe HBTs were fabricated with a high-voltage 0.18 μm BiCMOS process. The emitter width of the 4-finger-stripe device is 1 μm, and the length is 32 μm. The electrical stress was carried out by applying a high collector current density J_C=2mA/μm^2 and a high collector-base voltage V_{CB}=3.7V simultaneously with a final stressing time up to 1500 seconds at room temperature. The RF power characteristics were measured using the load-pull system at 2.4GHz, while the source and load impedances were tuned for maximum output power.

3. Results and Discussion

Fig. 1 shows the typical Gummel plot of a SiGe HBT measured under mixed-mode stress with different stressing times. The value of base leakage current (I_B) increases significantly with the stressing time in forward Gummel plot. In addition, unlike the conventional emitter-base reverse-bias stress, which does not create any I_B leakage in the reverse-mode operation of SiGe HBT, the mixed-mode stress creates an excess I_B leakage current component in reverse Gummel plot, as indicated in the inset of Fig. 1 [3].

Fig. 2 shows RF figures-of-merit of a SiGe HBT before and after stresses. The cutoff frequency (f_T) shows an unnoticeable change after stressing in lower bias region. In higher bias region, the increase of f_T is due to the decreasing emitter resistance R_E after electrical stress. These observations are different from those under emitter-base reverse-bias stress [4], where the cutoff frequency decreased at high currents after stress. The maximum oscillation frequency (f_{max}) decreases after stress is due to the increasing base resistance (R_B) (see Table I).

As well as the high-frequency characteristics, the RF power characteristics are also affected by the electrical stress. As shown in Fig. 3, when the collector current was kept to a constant value, we observed a slight change on output power and power gain. However, the power-added efficiency (PAE) increases after electrical stress because of the reducing R_E. When the measurement was performed under a constant base-current, the power performances degraded after electrical stress (see Fig. 4). The comparisons of linear power gain measured with a constant collector-current and a constant base-current before and after stresses are shown in Fig. 5 and Fig. 6, respectively. The change of linear power gain in Fig. 6 is due to the decreasing collector current after electrical stress when the base current was kept to a constant. Fig. 7 presents the linearity of a SiGe HBT under a constant base-current measurement before and after stresses. The third order inter-modulation power (IM3) increases after stress and then results in a degradation of OIP3 and IIP3. However, under a constant collector-current measurement, it shows an unnoticed change after electrical stressing, which is similar to the observation under emitter-base reverse-bias stress [4].

4. Conclusions

We have discussed the “mixed-mode” electrical stress effect on RF power characteristics of SiGe HBTs. After stress, the hot carriers will be induced to degrade the RF power performance. By comparing stress effects at various bias conditions, we observe that the performance degradation under constant collector-current measurement is much smaller than that under constant base-current measurement. Hence, it is suggested that SiGe HBTs can be operated more robust to electrical stress under a constant collector current.

References

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[2] G. Zhang et al., IEEE Trans. Electron Devices **49** (2002) 2151.
[3] J.D. Cressler et al., IEEE TDMR **4** (2004) 222.
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Table I. The extracted electrical parameters for a SiGe HBT before and after stress.

Parameters	Before stressing	After stressing
C_{BE} (pF)	1.13	1.16
C_{BC} (pF)	0.16	0.16
R_C (Ω)	2.03	6.04
R_B (Ω)	21.7	48.2
R_E (Ω)	1.4	1.2
Ideality factor (n_C)	0.99	1.03
Ideality factor (n_B)	1.01	1.74
Current gain (β)	181	97

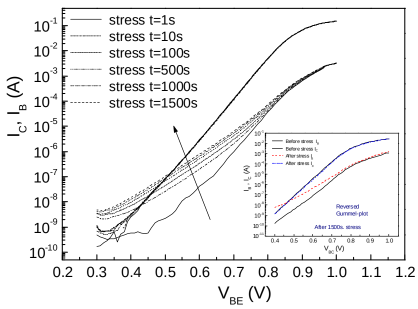

Fig. 1. DC characteristics of a SiGe HBT measured after HC stress.

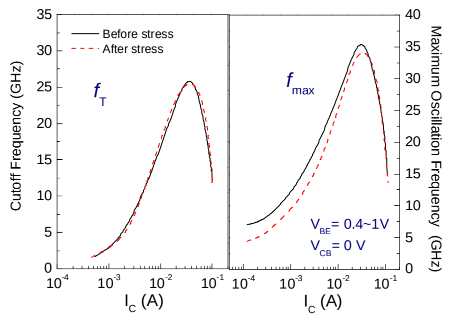

Fig. 2. Electrical stress effect on RF FOM: f_T and f_{max}.

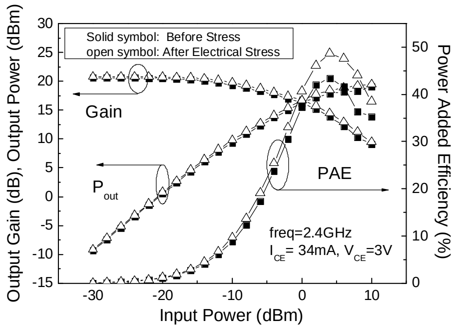

Fig. 3. Output power, power gain and PAE measured at a constant collector-current before and after HC stresses.

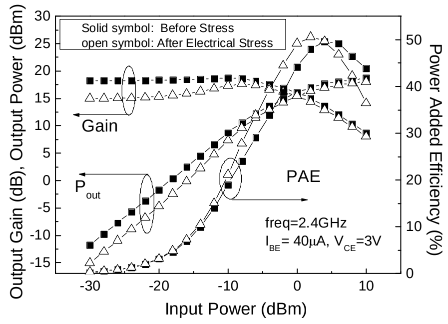

Fig. 4. Output power, power gain and PAE measured at a constant base-current before and after HC stresses.

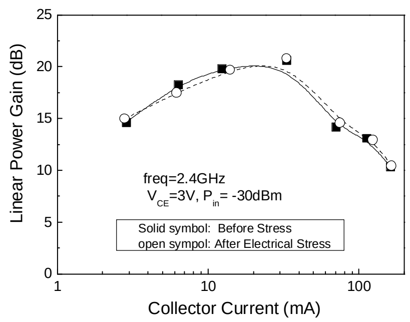

Fig. 5. Linear power gain as a function of collector current before and after stresses.

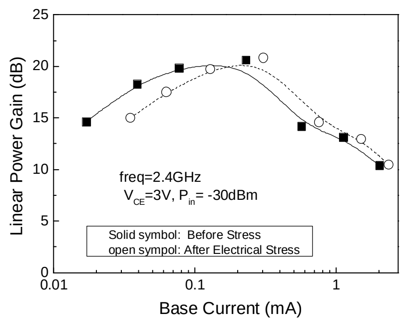

Fig. 6. Linear power gain as a function of base current before and after stress.

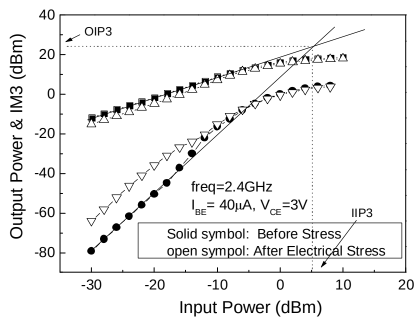

Fig. 7. HC stress effect on RF linearity at 2.4GHz with a constant base-current measurement.