RF Pulse I-V Based Avalanche Measurement in High Speed SiGe HBTs

Jun Pan and Guofu Niu
Alabama Microelectronics Science and Technology Center
Electrical and Computer Engineering Department
200 Broun Hall, Auburn University, Auburn, AL 36849

INTRODUCTION

Avalanche multiplication has become increasingly important in scaled SiGe HBTs due to increasingly high current density. In conventional avalanche factor ($M-1$) measurement, the base current (I_B) difference between a high V_{CB} and $V_{CB} = 0$ for a fixed V_{BE} gives the avalanche current. This, however, gives negative (and hence unphysical) $M-1$ at high currents when a DC I-V analyzer (e.g. HP4155) is used, because of self-heating, which makes I_B increase at high V_{CB}.

We recently proposed a substrate current based technique that enables $M-1$ measurement at high currents [1]. That technique, however, relies on the existence of the N+/P substrate junction, and a substrate contact placed close to the device under test, which is not always available. An example is SiGe HBTs on SOI, which have no substrate-collector junction at all. Another issue is that the device temperature is changing as one changes V_{CB}, which is not a true reflection of the situation found in a RF amplifier.

MEASUREMENT METHOD

We present $M-1$ measurement using a RF Dynamic I-V Analyzer (DIVA) from Accent Optical Technologies [2]. Very short (100 ns in our case) current or voltage pulses are applied to device terminals, as shown in Fig. 1. The key difference from conventional DC I-V is that all of the time dependent phenomena have no chance to reach steady state, including self-heating. The dynamic I-V is important for devices controlled by fast moving voltages, e.g. transistors in RF power amplifiers. The reference level can be chosen as the biasing point of interest.

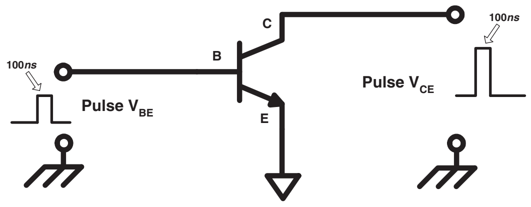

Figure 1

Illustration of the dynamic I(V) measurement technique.

For a given V_{BE}, a V_{CE} pulse is applied. The reference level of V_{BE} is set to be identical to the V_{BE} in question, which helps minimizing instrumentation error. The reference V_{CE} is set to 0 V intentionally to minimize steady-state self-heating for easier data analysis as $I_C = 0$ at $V_{CE} = 0$ V. Such a choice of reference levels is not necessarily the case in a practical circuit, and we can certainly set V_{CE} to the biasing V_{CE}. The resulting $M-1$ will be different because of DC steady state temperature difference. As the pulse duration is much shorter than the thermal time constant, the device temperature does not change for each pulsing. The base current difference between V_{CB}=0 V and the V_{CB} of interest gives the avalanche current, which can then be converted to $M-1$ [3].

RESULTS

The utility of the proposed method is demonstrated using SiGe HBTs with 120 GHz peak f_T. Fig. 2 shows the $M-1$ versus V_{CB} measured at V_{BE}=0.84, 1.0 and and 1.04 V. The collector current densities are approximately 0.5, 5 and 9 mA/μm^2. A current density of 7 mA/μm^2 is necessary to realize peak f_T. When a 4155 DC I-V Analyzer is used, the resulting $M-1$ is negative for the two higher V_{BE} values, due to self-heating. An even bigger problem is that the mutual interaction between self-heating and avalanche can easily cause thermal runaway and permanent damage to the devices for relatively higher but practical V_{BE} values. This precludes direct measurement of avalanche under RF excitations.

The $M-1$ results are close to but not identical to those obtained using the substrate current technique. Part of the difference is that the device temperature varies strongly with V_{CB} and V_{BE} in the substrate current based measurement. In the RF I-V measurements used here, the device operating temperature is the same for a fixed V_{BE}. The difference in temperature between different V_{BE} values is minimized by choosing $V_{CE} = 0$ V. At low V_{BE}, however, accurate $M-1$ measurement can only be done using conventional DC I-V measurement (e.g. 4155), as the resolution of RF pulsed I-V systems is not as good (resolution for fixed V_{BE} pulse is only a few mV). The conventional technique is valid at low V_{BE}, as self-heating is negligible.

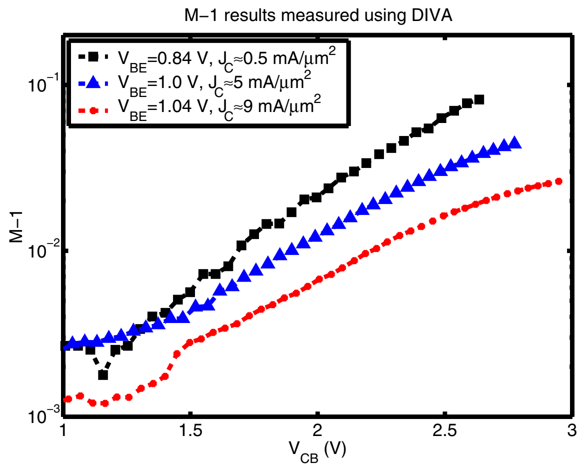

Figure 2

$M-1$ versus V_{CB} measured using the proposed RF pulse I-V method.

REFERENCES

1. J. Pan, G. Niu, J. Tang, S. Yun, A. J. Joseph and D. L. Harame, IEEE Electron Device Letters., **24**, 736 (2003).
2. DIVA 225HR, Accent Optical Technologies, 2003.
3. G. Niu, J. D. Cressler, S. Zhang, U. Gogineni, and D. C. Ahlgren, IEEE Trans. Electron Devices,**46**, 1007 (1999).