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

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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.

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 1.04 V. The collector current densities are approximately 0.5, 5, and 9 mA/µm². A current density of 7 mA/µm² 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_CE pulse is only a few mV). The conventional technique is valid at low V_BE, as self-heating is negligible.

REFERENCES