Avalanche Considerations in SiGe HBT Scaling

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SiGe HBT devices have increased in speed from the initial devices at f_T = 50GHz to recent announcements of performance in the range of 300GHz [1]. Figure 1 illustrates this with a comparison of f_T values between generations of HBT device, resulting from vertical and lateral scaling of the device. Fundamental to the increased f_T performance is an increase in collector concentration, which results in both higher current densities through the device and higher electric fields in the collector-base space-charge region of the device. The higher electric fields result in collector current avalanche multiplication, the effect of which is only now being explored because such trends result in greater avalanche in high-speed device operation. Thus we compare in this paper, for the first time, avalanche data on a variety of HBT devices, from f_T = 50 GHz to 265GHz, and discuss the trends and issues related to scaling of the SiGe HBT.

Figure 2 shows that for an f_T=210GHz technology with BV_{CEO} =1.7V [2], performance degrades very little with operating voltages at twice the BV_{CEO} value. Thus the limits are governed by other effects, such as addressed by Rickelt [3], Zhang [4], and Freeman [5].

Figure 3 shows M-1 characteristics for a range of device technologies. Taking cuts through this data at V_{CB} = 1.5V and at M-1 = 0.01 (where a current gain of 100 would result in base current reversal) results in the comparisons shown in Figure 4. Such measures are substantially less ambiguous as a measure of a device compared to BV_{CEO}, since BV_{CEO} involves the DC current gain and M-1 does not. Note that M-1 increases linearly with increasing f_T, and because the voltage is logorithmically related to M-1 (as observed in Figure 3), the voltage for a given M-1 is substantially insensitive to V_{CB} with higher performance. This suggests that the avalanche-related limits will remain similar above f_T > 100GHz.

Figure 5 illustrates the complex interactions of the avalanche current with the base resistance R_B. Such effects are well described in Rickelt [3]. With avalanche current exiting the base, the common-base device biased with fixed I_E and increasing V_{CB} first experiences a decrease in external V_{BE} and then a "pinch-in" where the current is concentrated within the center of the device. This pinch-in is apparent in a sudden drop in the measured V_{BE}. A comparison of measured V_{BE} characteristics is shown in Figure 6. Of particular note in Figure 6 is that the technologies do not monotonically scale in the external V_{BE} pinch-in voltage with increasing M-1. This is because, as observed in Figure 4, the M-1 does not grow substantially between certain technologies (e.g. 120 vs. 195GHz), yet the base resistance is substantially reduced between these technologies (which is done to enhance f_{MAX} performance). Explaining the case of the 265GHz device, base resistance is once again high relative to the 195 and 210 GHz devices. This dependence on base resistance points to the requirement that, in order to maintain a needed operating voltage, R_B should be reduced commensurate with the increased M-1 associated with the higher collector concentration. Conversely, if significant R_B improvements are made together with f_T improvements, one may expect an increase in maximum operating voltage.

[1] Rieh et al, IEDM 2002
[2] Jagannathan et. al., EDL March 2002
[3] M. Rickelt and H.M. Rein, BCTM 1999 p54
[4] Zhang et. al., BCTM 2002
[5] Freeman et. al, TED to be published

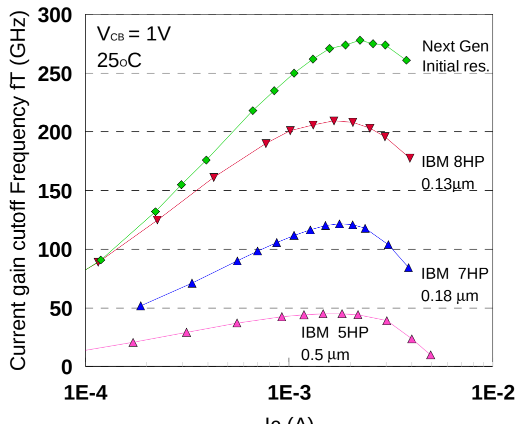

Figure 1: f_T curves by generation.

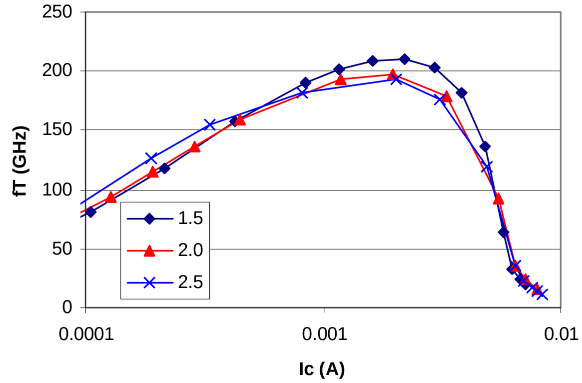

Figure 2: f_T performance in avalanche, at V_{CB} values listed in legend. V_{CE} values range from 2.4 to 3.4V for peak f_T, compared to BV_{CEO}=1.8V. Emitter size is 0.12x1.0µm^2.

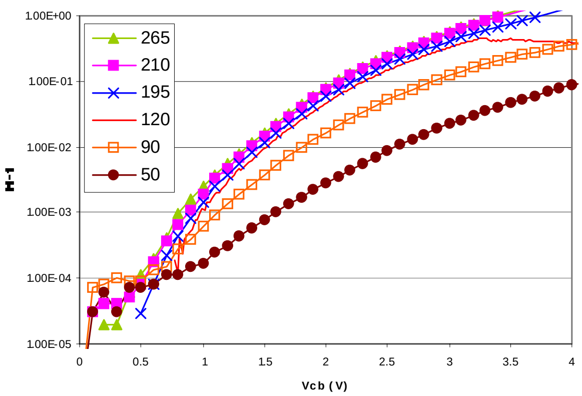

Figure 3: M-1 for different SiGe HBTs. Legend lists measured peak f_T values.

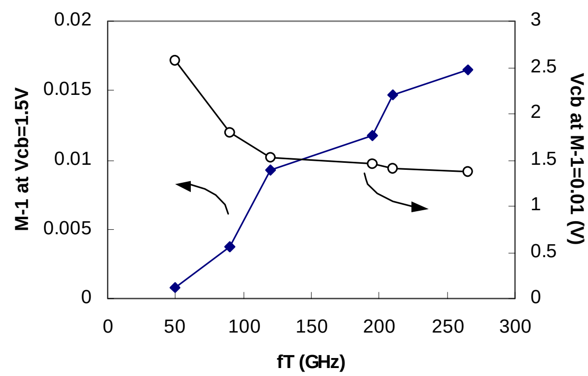

Figure 4: M-1 and voltage extracted from data in Figure 3 vs. measured peak f_T.

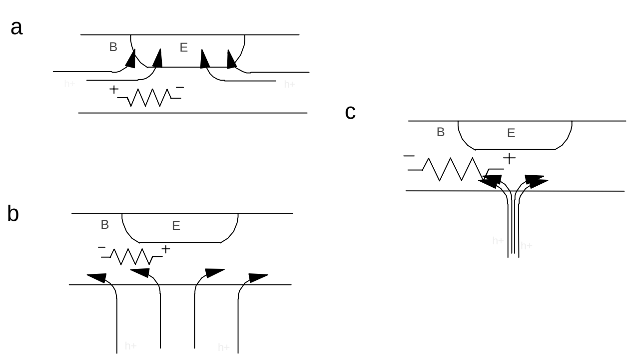

Figure 5: Avalanche effect on device operation. (a) low V_{CB} (b) moderate avalanche and (c) "pinch-in" resulting from high voltage drop across base resistance.

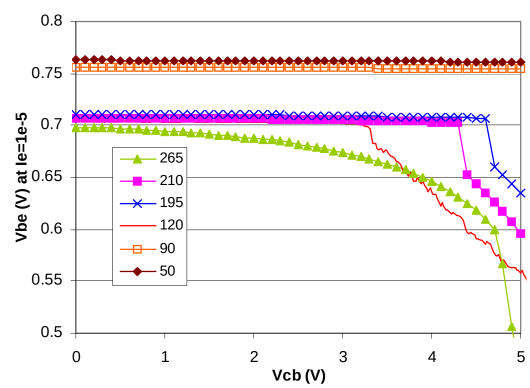

Figure 6: Measured V_{BE} vs. V_{CB} for fixed I_E = 10^{-5}A. Reverse base current is apparent in the voltage drop across the base resistance, exhibited as a drop in V_{BE}