Chapter 4

Geometrical Effect on Model Parameters

For IC applications, especially for VLSI, bipolar transistor must be reduced in size to meet the high-speed high-density requirement. As the technology is scaled down, the effect of this scaling on both device and circuit performance must be studied. In this chapter, we extracted the equivalent circuit elements of SiGe HBTs, based on the modeling method in chapter 2. The model parameter variation with different geometries has been studied. The testing devices were biased at $V_{BE} = 0.83V$ and V_{CE} = 3 V.

4.1 Scaling Effect of Emitter Length

The extracted model parameters of SiGe HBTs with different emitter lengths are listed in Table 4-1. Emitter width of these 3-fingers devices is 0.24μm. The extrinsic resistances R_c, R_{bx} and R_e decrease with increasing emitter length, while the extrinsic capacitances C_{bep} and C_{bcx} increase linearly. As shown in Table I, the substrate-collector capacitance C_{sub} and bulk capacitance C_{bk} increase with increasing emitter length, but the substrate resistance R_{bk} decreases with increasing emitter length. The length dependences of substrate network parameters are redrawn in Fig. 4-1. The C_{sub} and C_{bk} are almost a linear function of emitter length. In general, the value of the substrate network capacitance is proportional to the area. The schematic cross section of the SiGe HBT is shown in Fig. 4-2, the emitter length direct influences substrate area, hence the value of R_b,, C_{sub} and C_{bk} modulate with varying emitter length[24][25].

The intrinsic transconductance (g_m) can be written as $g_m = I_C / V_T$, it is clear that g_m is a linear function of collector current. Therefore, the g_m increases with increasing emitter length due to the increasing collector current. It should be noted that the g_m is not increased linearly with collector current due to self-heating effect. The self-heating effect is one of the major concerns in microwave circuit design employing HBTs. The excess phase delay (τ) is almost independent on the emitter length. The other intrinsic model parameters as listed in Table 4-1 have desired relation with emitter length (i.e. resistance decreases with increasing emitter length, while capacitance increases).

4.2 Scaling Effect of Emitter Width

Table 4-2 shows the extracted model parameters of SiGe HBTs with different emitter widths. Emitter length of the 3-finger devices is 8μm. The variation of extrinsic parameters and substrate network parameters with emitter width is similar to that with emitter length. In addition, the relations of most intrinsic parameters with emitter width are also similar to that with emitter length, except excess phase delay, intrinsic base-emitter capacitance and intrinsic base resistance.

Unlike emitter length, it is shown that the emitter width has strong influence on the excess phase delay, as indicated in Fig. 4-3. In Fig. 4-2, when the emitter width increases, the distance of electron flows from base to collector also increases. The excess phase delay also increase with the increasing emitter width. Fig. 4-4 shows the intrinsic base-emitter capacitance as a function of emitter width. Because the C_{bei} is almost equal to diffusion capacitance, the base transit time and base current are the most important values of C_{diff}. Hence, the C_{bei} will rise rapidly with emitter width. Fig. 4-5 shows the intrinsic base resistance as a function of emitter width. As indicated in Fig. 4-2, the intrinsic base resistance would be proportional to the emitter width. However, for devices with larger emitter width, the current crowding effect is more serious, making the increase of base resistance is compressed at larger emitter widths.

4.3 Scaling Effect of Emitter Finger Number

Table 4-3 shows the extracted model parameters of SiGe HBTs with different emitter finger number. The area of each finger is 0.24μm×8μm. The variation of extrinsic parameters and substrate network parameters with emitter finger is similar to that with emitter length and emitter width. So we conclude that the extrinsic parameters and substrate network parameter are dependent on the total emitter area. Finally, we find that the relation of the intrinsic model parameters with emitter finger number is similar to that with emitter width beside intrinsic base resistance. Fig. 4-6 shows the R_{bi} versus emitter finger number. The intrinsic base resistance is linear reduction with emitter finger number. It is due to the R_{bi} of multi-finger structure is similar to the resistance in parallel.

4.4 Cell Number Effect

The cell number structure is shown in Fig. 4-7, and there are three emitter fingers in each cell. The collector current is sum of the current of all fingers in cells. Table 4-4 shows the extracted model parameters of SiGe HBTs with different cell number. The extrinsic parameters with cell number are similar to that with emitter length, emitter width and emitter finger, but the multi-cell structure is parallel for each cell. So the extrinsic resistances reduce with increasing cell number and extrinsic capacitances increase with increasing cell number. On the other hand, the substrate parameters are direct relation with the total emitter area, hence the variation of R_b,, C_{sub} and C_{bk} with cell number is similar to that with emitter length, emitter width and emitter finger number. The intrinsic resistances and capacitances are similar to extrinsic resistances and capacitances. The intrinsic transconductance is dependent on the collector current, so the value of g_m arises with increasing cell number. Besides, the excess phase delay is independent on cell number. The excess time is almost a constant value with increasing cell number. It is due to the single base width not varying with the cell number. Table 4-4 shows the extracted model parameters of SiGe HBTs with different cell number.

4.5 Geometrical Effect of Collector and Substrate

Fig. 4-8(a)-(d) shows the collector and substrate layouts. They are Ring Collector - Ring Substrate(RC-RS), Strip Collector - Ring Substrate(SC-RS), Strip Collector - Strip Substrate(SC-SS) and Ring Collector – Strip Collector(RC-SC), respectively. Fig.4-9 shows the C_{sub} versus V_{CE}. Because “Ring” is centrical structure, the value of C_{sub} is relation between the contact of collector and substrate. The C_{sub} of RC-RS is larger than SC-RS, SC-SS and RC-SC. The substrate capacitance in RC-RS configuration is largest due to the parasitic capacitance between metal and metal. Besides, the C_{sub} reduces with increasing V_{CE}, it is due to the increasing reverse bias at C-S. The C_{bk} is independent of layouts of collector and substrate, shown in Fig. 4-10. Fig. 4-11 shows the R_{bk} of RC-RS is largest, because the bulk resistance is parallel connection. Fig. 4-12(a) and (b) show the structure of Ring Collector – Parallel Ring Substrate(RC-PRS) and Ring Collector – Outer Ring Substrate(RC-ORS) respectively. The C_{sub} versus V_{CE} is shown in Fig. 4-13. The C_{sub} of RC-PRS is larger than RC-ORS, because the C_{sub} of RC-PRS has larger parasitic capacitance. On the other hand, the C_{bk} and R_{bk} are also independent of layout configuration, shown in Fig. 4-14 and 4-15 respectively.

	R_{cx}(Ω)	R_{bx}(Ω)	R_{ex}(Ω)	C_{bep}(fF)	C_{bcx}(fF)	C_{sub}(fF)	R_{bk}(Ω)	C_{bk}(fF)
8(μm)	4.24	2.43	1.74	23.0	37.4	23.6	161.5	23.9
16(μm)	3.91	2.26	1.68	41.2	63.9	26.4	144.8	35.1
32(μm)	3.62	2.03	1.59	93.6	140.3	33.1	123.3	56.9
48(μm)	3.07	1.70	1.58	126.1	221.7	39.3	107.5	74.3

(a)

	C_{bei}(fF)	C_{bci}(fF)	G_m(ms)	τ (psec)	R_{bi}(Ω)	R_π(kΩ)
8(μm)	423.6	4.538	53.6	2.123	16.51	1.463
16(μm)	517.2	5.923	56.8	2.096	15.63	1.341
32(μm)	562.9	9.169	72.6	2.118	13.59	1.165
48(μm)	728.3	13.022	93.3	2.082	9.27	0.959

(b)

Table 4-1 Bias at V_{BE}=0.83V, V_{CE}=3V (a) Extrinsic and substrate parameters extracted (b) Intrinsic parameters extracted with emitter length variation

	Rcx(Ω)	Rbx(Ω)	Rex(Ω)	Cbep(fF)	Cbcx(fF)	Csub(fF)	Rbk(Ω)	Cbk(fF)
0.24(μm)	4.24	2.43	1.74	23.0	37.4	23.6	161.5	23.9
0.34(μm)	3.97	2.31	1.63	29.4	58.3	27.9	144.7	33.1
0.5(μm)	3.72	2.27	1.49	43.7	73.6	34.5	138.2	54.3
1.0(μm)	3.21	1.76	1.36	86.1x	143.7	44.8	118.3	81.7

(a)

	Cbei(fF)	Cbci(fF)	Gm(ms)	τ (psec)	Rbi(Ω)	Rπ(kΩ)
0.24(μm)	423.6	4.538	53.6	2.123	16.51	1.463
0.34(μm)	447.2	6.072	58.7	2.197	21.4	1.379
0.5(μm)	589.3	8.193	73.2	2.230	27.3	1.211
1.0(μm)	1946.5	12.627	98.6	4.018	35.9	0.978

(b)

Table 4-2 Bias at V_{BE}=0.83V, V_{CE}=3V (a) Extrinsic and substrate parameters extracted (b) Intrinsic parameters extracted with emitter width variation

	$R_{cx}(\Omega)$	$R_{bx}(\Omega)$	$R_{ex}(\Omega)$	C_{bep}(fF)	C_{bcx}(fF)	C_{sub}(fF)	$R_{bk}(\Omega)$	C_{bk}(fF)
1	4.56	2.71	1.83	21.9	29.3	19.6	214.8	16.5
2	4.37	2.66	1.81	22.4	32.2	21.4	191.1	19.6
3	4.24	2.43	1.74	23.0	37.4	23.6	161.5	23.9
4	4.03	2.37	1.67	24.6	36.8	25.3	142.7	28.1

(a)

	C_{bei}(fF)	C_{bci}(fF)	G_m(ms)	τ (psec)	$R_{bi}(\Omega)$	R_{π} (kΩ)
1	316.3	3.882	46.9	1.832	42.73	1.837
2	368.9	4.291	51.8	1.927	22.17	1.621
3	423.6	4.538	53.6	2.123	16.51	1.463
4	471.4	5.058	58.4	4.892	9.84	1.193

(b)

Table 4-3 Bias at V_{BE}=0.83V, V_{CE}=3V (a) Extrinsic and substrate parameters extracted (b) Intrinsic parameters extracted with emitter finger number variation

	R_{cx}(Ω)	R_{bx}(Ω)	R_{ex}(Ω)	C_{bep}(fF)	C_{bcx}(fF)	C_{sub}(fF)	R_{bk}(Ω)	C_{bk}(fF)
2	3.37	1.87	1.02	56	71	51.8	112.8	34.3
3	2.75	1.69	0.93	84	107	80.4	79.9	54.7
4	2.39	1.51	0.84	139	155	119.3	40.5	78.1

	C_{bei}(fF)	C_{bci}(fF)	G_m(ms)	τ (psec)	R_{bi}(Ω)	R_π(kΩ)
2	638.4	13.38	82.4	2.076	13.372	1.238
3	927.1	19.56	96.1	20.89	11.319	1.096
4	1336.5	27.71	110.6	2.081	9.941	0.834

Table 4-4 Bias at V_{BE}=0.83V, V_{CE}=3V (a) Extrinsic and substrate parameters extracted (b) Intrinsic parameters extracted with cell number variation