
Contents

Preface	ix
1 Introduction	1
1.1 History of device simulation	8
1.2 History of process simulation	10
1.3 Evolution of TCAD	12
1.4 Process flow integration	13
1.5 TCAD and compact model	15
1.6 Parameter extraction	17
1.7 Statistical process control and yield analysis	18
1.8 Virtual wafer fabrication	19
1.9 Optimisation	20
1.10 TCAD for nanoelectronics	20
1.11 Interconnect	23
1.12 Summary	23
References	25
2 IC technology and TCAD tools	31
2.1 Process simulation	32
2.1.1 Oxidation	33
2.1.2 Ion implantation	33
2.1.3 Diffusion	34
2.1.4 Lithography	35
2.1.5 Etching	37
2.1.6 Metallisation	37
2.2 Plasma processing	40
2.3 Chemical mechanical polishing	43
2.4 Synopsys TCAD Tools	44
2.5 SILVACO: TCAD simulation suite	46
2.5.1 ATHENA	47
2.5.2 ATLAS	47

2.6	Process-to-device simulation using SILVACO	48
2.6.1	Device generation	49
2.6.2	Device simulation	50
2.7	Simulation example: strained-Si MOSFET	54
2.8	Summary	56
	References	58
3	Diffusion and oxidation of SiGe/SiGeC films	63
3.1	Boron out-diffusion	63
3.2	Diffusion: B in strained-SiGe	65
3.3	Diffusion: P and As in strained-SiGe	70
3.4	Dopant diffusion in SiGeC	75
3.5	Oxidation: SiGe/SiGeC films	79
3.5.1	Oxidation kinetics	80
3.5.2	Plasma oxidation of SiGe films	84
3.6	Summary	88
	References	89
4	Strain-engineered MOSFETs	97
4.1	Scaling issues	100
4.2	Mobility-enhanced substrate engineering	102
4.2.1	Orientation-dependent mobility engineering	104
4.2.2	Mobility enhancement by process-induced stress	106
4.2.3	Mobility enhancement by substrate-induced strain	111
4.3	Channel engineering	117
4.4	Gate engineering	120
4.5	Strained-engineered CMOS technology	127
4.6	Layout engineering	132
4.7	Strain-engineered MOSFETs: simulation	136
4.8	Summary	143
	References	143
5	SOI MOSFETs	153
5.1	Fabrication of SOI wafers	154
5.2	SOI devices	158
5.2.1	Partially depleted SOI transistors	160
5.2.2	Fully depleted SOI transistors	162
5.3	Double-gate MOSFET	163
5.4	TCAD simulation of SOI devices	165
5.5	Simulation using MASTAR	168
5.6	Strained-Si MOSFETs on SOI	171
5.6.1	Simulation of SSGOI MOSFETs	173
5.6.2	MC simulation of sSOI MOSFETs	180
5.7	Modelling of multi-gate SOI devices	184
5.8	Summary	188
	References	189

6	Heterostructure bipolar transistors	195
6.1	The first SiGe transistor	199
6.2	Issues related to heterostructure	200
6.3	SiGe materials	204
6.3.1	UHVCVD growth of SiGe films	206
6.4	Physics of SiGe HBTs	208
6.5	Figures of merit of SiGe HBTs	211
6.6	Simulation of SiGe HBTs	213
6.7	Transit time in SiGe HBTs	219
6.8	SiGe HBTs at low temperature	220
6.9	Summary	224
	References	227
7	SiGe/SiGeC HBT technology	233
7.1	SiGe-BiCMOS technology	238
7.2	IBM SiGe-BiCMOS technology	240
7.2.1	Base-during-gate process	240
7.2.2	Base-after-gate process	243
7.3	SiGe HBTs on SOI	245
7.4	Complementary SiGe HBT technology	247
7.5	SiGeC HBT technology	249
7.6	TCAD: SiGe/SiGeC BiCMOS process	254
7.7	Summary	259
	References	260
8	MOSFET: compact models	267
8.1	Charge-based MOSFET models	268
8.2	Surface-potential based MOSFET models	271
8.2.1	SP model	273
8.2.2	HiSIM	275
8.2.3	MOS model 11	275
8.2.4	EKV model	277
8.3	Model evaluation	279
8.4	Modelling of SOI MOSFETs	280
8.5	Modelling of heterostructure MOSFETs	281
8.6	RF MOS modelling	285
8.7	Large-signal MOSFET models	287
8.8	Summary	295
	References	295
9	HBT: compact models	301
9.1	Advanced models	304
9.2	VBIC model	305
9.3	MEXTRAM model	310
9.4	The HICUM model	312
9.5	Parameter extraction	314

9.6	Extraction algorithm	316
9.7	VBIC model implementation in SPICE	323
9.8	TRADICA	332
9.9	Scalable modelling: SiGe/SiGeC HBTs	333
9.10	Role of TCAD	339
9.11	Summary	341
	References	343
10	Design and simulation of high-speed devices	351
10.1	SiGe vs. GaAs HBTs	354
10.2	Device simulation	356
10.2.1	Device simulators	357
10.3	Material parameters	359
10.3.1	Bandgap and bandgap narrowing	361
10.3.2	Conduction band density of states	365
10.3.3	Valence band density of states	366
10.3.4	$Si_{1-x}Ge_x$ mobility	368
10.3.5	Saturation velocity	372
10.3.6	Generation and recombination	373
10.3.7	Impact ionisation	375
10.4	Simulation of III–V devices	376
10.5	Comparison of HBTs	384
10.6	RFMOS vs. HBTs	390
10.7	Summary	394
	References	397
11	Passive components	409
11.1	Inductor	411
11.1.1	Inductor model description	414
11.1.2	Quality factor	417
11.2	Parameter extraction	418
11.3	Inductor simulation	421
11.3.1	ASITIC	423
11.4	Active inductors	425
11.5	Capacitors	427
11.6	Varactor	429
11.7	Resistor	430
11.8	Interconnects	431
11.9	Summary	434
	References	434
	Index	439