

Contents

Foreword	V
Preface	VI
Overview of symbols	XVII
List of physical constants	XXI
Contents	XXIII
1 Basic Principles	1
1.1 Introduction	1
1.2 The field-effect principle	2
1.3 The inversion-layer MOS-transistor	5
1.3.1 The Metal-Oxide-Semiconductor (MOS) capacitor	11
1.3.2 The inversion-layer MOS transistor	15
1.4 Derivation of simple MOS formulas	24
1.5 The back-bias effect (back-gate effect, body effect)	28
1.6 Factors which characterise the behaviour of the MOS tran- sistor	32
1.7 Different types of MOS transistors	33
1.8 Parasitic MOS transistors	35
1.9 MOS transistor symbols	37
1.10 Capacitances in MOS structures	39
1.11 Conclusions	50
1.12 References	51
1.13 Exercises	52

2	Physical and geometrical effects on the behaviour of the MOS transistor	57
2.1	Introduction	57
2.2	Temperature effects	58
2.3	Carrier-mobility degradation	59
2.4	Channel-length modulation and static-drain feedback	62
	2.4.1 Channel-length modulation	62
	2.4.2 Static-drain feedback (Drain-induced barrier lowering)	65
2.5	Small-channel effects	66
	2.5.1 Short-channel effect	66
	2.5.2 Narrow-channel effect	68
	2.5.3 Modelling of small-channel effects	69
2.6	Punch-through	71
2.7	Hot-carrier effect	72
	2.7.1 Introduction	72
	2.7.2 The electric field in MOS transistors	72
	2.7.3 Impact ionization	74
	2.7.4 Hot-carrier degradation	75
	2.7.5 Reducing the maximum electric field in a MOS transistor	78
2.8	Weak-inversion behaviour of the MOS transistor	82
2.9	Conclusions	84
2.10	References	85
2.11	Exercises	87
3	Fabrication of MOS devices	89
3.1	Introduction	89
3.2	Photolithography in MOS processes	91
3.3	Etching	97
3.4	Oxidation	98
3.5	Deposition	100
3.6	Diffusion and ion implantation	102
3.7	Basic MOS technologies	104
	3.7.1 The basic silicon-gate nMOS process	104
	3.7.2 The basic Complementary MOS (CMOS) process	107
	3.7.3 Types of CMOS processes	114
3.8	Testing, yield and packaging	120

3.8.1	Testing	120
3.8.2	Yield	124
3.8.3	Packaging	129
3.9	Quality and reliability	140
3.9.1	Quality	140
3.9.2	Reliability	140
3.10	Conclusions	142
3.11	References	143
3.12	Exercises	145
4	nMOS circuits	147
4.1	Introduction	147
4.2	Electrical design of nMOS circuits	148
4.2.1	Introduction	148
4.2.2	The DC behaviour	149
4.2.3	The transient response	158
4.2.4	Transforming a logic function into an nMOS transistor circuit	171
4.2.5	Summary of electrical design rules	174
4.3	Digital nMOS circuits	176
4.3.1	Introduction	176
4.3.2	Static nMOS circuits	177
4.3.3	Dynamic nMOS circuits	182
4.4	Input and output circuits (buffers)	192
4.5	Layout-design of nMOS circuits	196
4.5.1	Introduction	196
4.5.2	Layout design rules	196
4.5.3	The 'stick' diagram	202
4.5.4	Guidelines for layout design	205
4.6	Conclusions	207
4.7	References	208
4.8	Exercises	209
5	CMOS circuits	213
5.1	Introduction	213
5.2	Electrical design of CMOS circuits	215
5.2.1	Introduction	215
5.2.2	The CMOS inverter	216
5.2.3	Latch-up	232
5.2.4	Points to note	235

5.3	Digital CMOS circuits	237
5.3.1	Introduction	237
5.3.2	Static CMOS circuits	237
5.3.3	Clocked CMOS circuits	243
5.3.4	Dynamic CMOS circuits	247
5.3.5	Other types of CMOS circuitry	251
5.3.6	Choosing a CMOS implementation	252
5.3.7	Clocking strategies	253
5.4	CMOS input, output (I/O) and protection circuits	254
5.4.1	CMOS input circuits	254
5.4.2	CMOS output buffers (drivers)	255
5.4.3	MOS IC protection circuits	257
5.5	Layout design of CMOS circuits	264
5.6	Conclusions	271
5.7	References	272
5.8	Exercises	274
6	Special circuits, devices and technologies	277
6.1	Introduction	277
6.2	Charge-coupled devices (CCDs)	278
6.2.1	Introduction	278
6.2.2	Basic SCCD operation	278
6.2.3	Buried-channel CCDs (BCCDs)	282
6.2.4	Comparison of BCCDs and SCCDs	283
6.2.5	Applications	283
6.3	Power MOSFET transistors	285
6.3.1	Introduction	285
6.3.2	Technology and operation	287
6.3.3	Applications	288
6.4	BICMOS digital circuits	289
6.4.1	Introduction	289
6.4.2	BICMOS technology	289
6.4.3	BICMOS characteristics	291
6.4.4	BICMOS circuit performance	292
6.4.5	Future expectations and market trends	295
6.5	Conclusions	296
6.6	References	297
6.7	Exercises	299

7	Memories	301
7.1	Introduction	301
7.2	Serial memories	305
7.3	Random-access memories (RAM)	306
7.3.1	Introduction	306
7.3.2	Static RAMs (SRAM)	306
7.3.3	Dynamic RAMs (DRAM)	314
7.3.4	Error sensitivity	319
7.3.5	Redundancy	319
7.4	Read-Only Memories (ROM)	320
7.4.1	Introduction	320
7.4.2	ROM memory elements	320
7.5	Programmable read-only memories	324
7.5.1	Introduction	324
7.5.2	PROMs (programmable read-only memories)	324
7.5.3	EPROMs (erasable PROMs)	324
7.5.4	EEPROMs (electrically erasable PROMs)	325
7.5.5	NVRAM (non-volatile RAM)	327
7.5.6	BRAM (battery RAM)	328
7.5.7	Classification of the various memories	328
7.6	Conclusions	330
7.7	References	331
7.8	Exercises	332
8	Very Large Scale Integration (VLSI)	335
8.1	Introduction	335
8.2	Abstraction levels for VLSI	337
8.2.1	Introduction	337
8.2.2	System level	338
8.2.3	Functional level	339
8.2.4	RTL level	340
8.2.5	Logic-function level	343
8.2.6	Logic-gate level	343
8.2.7	Transistor level	344
8.2.8	Layout level	344
8.2.9	Conclusions	345
8.3	CAD tools for synthesis and verification	348
8.3.1	Introduction	348
8.3.2	System-level CAD tools	349
8.3.3	Functional-level CAD tools	349

8.3.4	RTL-level CAD tools	349
8.3.5	Logic-function level CAD tools	349
8.3.6	Logic-gate level CAD tools	350
8.3.7	Transistor-level CAD tools	350
8.3.8	Timing verification	352
8.3.9	Hybrid simulation	353
8.4	CAD tools for layout	354
8.4.1	Introduction	354
8.4.2	Conventional gate-array layout implementation	356
8.4.3	Standard-cell layout implementation	360
8.4.4	ROM and PLA layout implementations	361
8.4.5	Bit-slice layout implementation	364
8.4.6	Hierarchical layout implementation	365
8.4.7	Hand-crafted layout implementation	367
8.4.8	Memory layout implementation	368
8.4.9	The choice of a layout implementation form	370
8.5	Conclusions	373
8.6	References	375
8.7	Exercises	376
9	ASICs	377
9.1	Introduction	377
9.2	Customer motivation for the use of ASICs	379
9.3	Digital ASICs	381
9.4	Trends in the digital-CMOS ASIC market	384
9.4.1	The EPLD market	385
9.4.2	The Gate-Array market	386
9.4.3	The cell-based custom-design market	387
9.4.4	Conclusions	387
9.5	Technological developments	389
9.5.1	Introduction	389
9.5.2	General ASIC developments	389
9.5.3	Technological developments in the cell-based digital-CMOS ASIC sector	390
9.5.4	Technological developments in the gate-array digital-CMOS ASIC sector	391
9.5.5	Technological developments in the PLD digital-CMOS ASIC sector	395
9.5.6	Special approaches for fast prototyping	397

9.6	Potential ASIC design problems	399
9.7	Conclusions	400
9.8	References	401
9.9	Exercises	402
10	Effects of scaling on MOS transistors and MOS ICs	405
10.1	Introduction	405
10.2	Scaling effects on MOS transistor parameters and circuit performance	406
10.3	Consequences of increased power density due to scaling .	409
10.4	Conclusions	414
10.5	References	416
10.6	Exercises	417
	Index	418