

# Contents

<i>Foreword</i>	v
<i>Preface</i>	vii
<i>Definition of Symbols Used for Variables and Constants</i>	xvii
1. Semiconductor Device Physics	1
1.1 Band Structure Concept . . . . .	1
1.1.1 Energy Bands and Quasi Particles . . . . .	1
1.1.2 Effective Mass Approximation . . . . .	9
1.2 Carrier Density and Fermi Level in Semiconductors . . . . .	12
1.2.1 Impurities in Semiconductors . . . . .	12
1.2.2 Impurity Levels . . . . .	14
1.2.3 Number of Carriers under Thermal Equilibrium . . . . .	17
1.2.3.1 Carrier Density in Pure Semiconductors . . . . .	23
1.2.3.2 Carrier Density in Impure or Doped Semiconductors . . . . .	24
1.2.4 Fermi Level . . . . .	27
1.3 P-N Junction . . . . .	31
1.3.1 P-N Junction in Thermal Equilibrium . . . . .	33
1.3.2 P-N Junction with External Voltages . . . . .	40
1.4 Device Simulation . . . . .	45
1.4.1 Basic Equations . . . . .	45
1.4.2 Linearization and Discretization of Poisson Equation	51
1.4.3 Device Simulation of MOSFETs . . . . .	55

1.5 Summary of Equations and Symbols Presented in Chapter 1 for Semiconductor Device Physics . . . . .	60
<i>Bibliography</i>	75
2. Basic Compact Surface-Potential Model of the MOSFET	77
2.1 Compact Modeling Concept . . . . .	77
2.2 Device Structure Parameters of the MOSFET . . . . .	85
2.3 Surface Potentials . . . . .	87
2.4 Charge Densities . . . . .	96
2.5 Drain Current . . . . .	104
2.6 Summary of Equations and Model Parameters Presented in Chapter 2 for Basic Compact Surface-Potential Model of the MOSFET . . . . .	110
2.6.1 Section 2.2: Device Structure Parameters of the MOSFET . . . . .	110
2.6.2 Section 2.3: Surface Potentials . . . . .	110
2.6.3 Section 2.4: Charge Densities . . . . .	111
2.6.4 Section 2.5: Drain Current . . . . .	111
<i>Bibliography</i>	112
3. Advanced MOSFET Phenomena Modeling	117
3.1 Threshold Voltage Shift . . . . .	117
3.1.1 (I) Short-Channel Effects . . . . .	119
3.1.2 (II) Reverse-Short-Channel Effects . . . . .	125
3.2 Depletion Effect of the Poly-Si Gate . . . . .	145
3.3 Quantum-Mechanical Effects . . . . .	150
3.4 Mobility Model . . . . .	158
3.4.1 Low Field Mobility . . . . .	158
3.4.2 High Field Mobility . . . . .	163
3.5 Channel-Length Modulation . . . . .	164
3.6 Narrow-Channel Effects . . . . .	176
3.6.1 Threshold Voltage Shift . . . . .	177
3.6.2 Mobility Modification due to a Narrow Gate . . . . .	179
3.6.3 Leakage Current due to STI Technology . . . . .	181
3.6.4 Small-Geometry Effects . . . . .	185

3.7	Effects of the Length of the Diffused Source/Drain Contacts in Shallow-Trench Isolation (STI) Technologies . . . . .	188
3.8	Temperature Dependences . . . . .	190
3.9	Conservation of Symmetry at $V_{ds} = 0$ . . . . .	195
3.10	Harmonic Distortions . . . . .	198
3.11	Summary of Equations and Model Parameters Appearing in Chapter 3 for Advanced MOSFET Phenomena Modeling	206
3.11.1	Section 3.1: Threshold Voltage Shift . . . . .	206
3.11.2	Section 3.2: Depletion Effect of the Poly-Silicon Gate . . . . .	208
3.11.3	Section 3.3: Quatum-Mechanical Effects . . . . .	208
3.11.4	Section 3.4: Mobility Model . . . . .	209
3.11.5	Section 3.5: Channel-Length Modulation . . . . .	210
3.11.6	Section 3.6: Narrow-Channel Effects . . . . .	211
3.11.7	Section 3.7: Effect of the Source/Drain Diffusion Length for Shallow-Trench Isolation (STI) Technologies . . . . .	213
3.11.8	Section 3.8: Temperature Dependences . . . . .	214
	<i>Bibliography</i>	215
4.	Capacitances	223
4.1	Intrinsic Capacitances . . . . .	223
4.2	Overlap Capacitances . . . . .	228
4.3	Longitudinal (Lateral) -Field-Induced Capacitance . . . . .	236
4.4	Fringing Capacitance . . . . .	239
4.5	Summary of Equations and Model Parameters Appearing in Chapter 4 for Capacitances . . . . .	241
	<i>Bibliography</i>	242
5.	Leakage Currents and Junction Diode	245
5.1	Leakage Currents . . . . .	245
5.1.1	Substrate Current . . . . .	245
5.1.2	Gate Current . . . . .	248
5.1.3	GIDL (Gate-Induced Drain Leakage) Current . . . . .	251
5.2	Bulk/Source and Bulk/Drain Junction Models . . . . .	254
5.2.1	Junction Current . . . . .	254

5.2.2	Junction Capacitance . . . . .	260
5.3	Summary of Equations and Model Parameters Appeared in Chapter 5 for Leakage Currents and Junction Diode . .	264
5.3.1	Section 5.1: Leakage Currents . . . . .	264
5.3.2	Section 5.2: Junction Diode . . . . .	265
<i>Bibliography</i>		266
6.	Modeling of Phenomena Important for RF Applications	269
6.1	Noise Models . . . . .	269
6.1.1	<i>1/f</i> Noise Model . . . . .	270
6.1.2	Thermal Noise Model . . . . .	277
6.1.3	Induced Gate and Cross-Correlation Noise Model .	281
6.2	Non-Quasi-Static (NQS) Model . . . . .	290
6.2.1	Time-Domain Analysis . . . . .	291
6.2.2	Frequency-Domain Analysis . . . . .	301
6.3	External MOS Transistor Resistances . . . . .	310
6.3.1	Source/Drain Resistances . . . . .	310
6.3.2	Gate Resistance . . . . .	311
6.4	Summary of Equations and Model Parameters Appeared in Chapter 6 for Modeling of Phenomena Important for RF Applications . . . . .	312
6.4.1	Section 6.1: Noise Models . . . . .	312
6.4.2	Section 6.2: Non-Quasi-Static (NQS) Model . . .	313
6.4.3	Section 6.3: External MOS Transistor Resistances	313
<i>Bibliography</i>		314
7.	Summary of HiSIM’s Model Equations, Parameters, and Parameter-Extraction Method	319
7.1	Model Equations of HiSIM . . . . .	319
7.1.1	Physical Quantities . . . . .	319
7.1.2	MOSFET Size . . . . .	320
7.1.3	Temperature Dependence . . . . .	321
7.1.4	Substrate Impurity Concentration $N_{\text{sub}}$ . . . .	322
7.1.5	Threshold Voltage Shift $\Delta V_{\text{th}}$ . . . . .	322
7.1.6	Mobility Model . . . . .	324
7.1.7	Drain Current $I_{\text{ds}}$ . . . . .	325

7.1.8	Channel-Length Modulation . . . . .	325
7.1.9	Shallow-Trench-Isolation (STI) Effect . . . . .	326
7.1.10	Capacitances . . . . .	327
7.1.11	Leakage Currents . . . . .	328
7.1.12	Noise . . . . .	328
7.1.13	Non-Quasi-Static (NQS) Effects . . . . .	329
7.1.14	Parasitic Resistances . . . . .	329
7.2	Model Flags and Exclusion of Modeled Effects . . . . .	331
7.2.1	Parameter setting for Exclusion of Certain Model Parts . . . . .	331
7.2.2	Flags for Setting Model Options . . . . .	331
7.3	Model Parameters and their Meaning . . . . .	333
7.4	Default Values of the Model Parameter . . . . .	338
7.5	Parameter Extraction Method . . . . .	343
<i>Bibliography</i>		348
<i>Index</i>		349