

Contents

1. Introduction	1
<hr/>	
Part I: Semiconductor Physics	5
<hr/>	
2. Semiconductors	7
2.1 Crystal Structure	7
2.2 Energy Bands	8
2.3 Intrinsic Semiconductors	11
2.4 Extrinsic Semiconductors	14
2.5 Carrier Transport in Semiconductors	16
2.5.1 Drift	17
2.5.2 Diffusion	17
2.5.3 Magnetic Field Effects	19
2.6 Carrier Generation and Recombination in Semiconductors	21
2.6.1 Thermal Generation of Charge Carriers	21
2.6.2 Generation of Charge Carriers by Electromagnetic Radiation	22
2.6.3 Generation by Charged Particles	23
2.6.4 Shape of a Radiation-Generated Charge Cloud	25
2.6.5 Multiplication Processes	26
2.6.6 Recombination	28
2.6.7 Charge-Carrier Lifetime	29
2.6.8 Carrier Lifetime in Indirect Semiconductors	31
2.7 Simultaneous Treatment of Carrier Generation and Transport	34
2.8 Summary and Discussion	37
3. Basic Semiconductor Structures	39
3.1 The p–n Diode Junction	39
3.1.1 A p–n Diode in Thermal Equilibrium	39
3.1.2 A p–n Diode with Application of an External Voltage .	43
3.1.3 A p–n Diode Under Irradiation with Light	46
3.1.4 Capacitance–Voltage Characteristics	49
3.1.5 Breakdown Under Strong Reverse Bias	51
3.2 Metal–Semiconductor Contact	56

	3.2.1	Current–Voltage Characteristics	58
	3.2.2	Ohmic Contact	59
3.3		Metal–Insulator–Semiconductor Structure	59
	3.3.1	Thermal Equilibrium Condition	61
	3.3.2	The Si–SiO ₂ MOS Structure	68
	3.3.3	Capacitance–Voltage Characteristics	69
	3.3.4	Nonequilibrium and a Return to Equilibrium	70
3.4		The n ⁺ -n or p ⁺ -p Structures	72
3.5		Summary and Discussion	73

Part II: Semiconductor Detectors
77

4.		Semiconductors as Detectors	79
4.1		The Properties of Intrinsic Semiconductor Materials	79
4.2		Properties of Extrinsic Semiconductor Materials	83
	4.2.1	Doping of Semiconductors	84
	4.2.2	Bulk Defects	86
	4.2.3	Effects on Material Properties	88
4.3		Insulators and Metals	88
	4.3.1	Insulator Properties	89
	4.3.2	Semiconductor Surface Defects	89
	4.3.3	Metal Properties	90
4.4		Choice of Detector Material	91
	4.4.1	Interaction of Radiation with Semiconductors	91
	4.4.2	Charge Collection and Measurement Precision	92
5.		Detectors for Energy and Radiation-Level Measurement	95
5.1		Unbiased Diode	95
5.2		Reverse-Biased Diode	100
	5.2.1	Charge Collection and Measurement	102
	5.2.2	Surface Barrier Detectors	105
	5.2.3	p–n Junction Detectors	106
5.3		Summary	107
6.		Detectors for Position and Energy Measurement	109
6.1		Resistive Charge Division	109
6.2		Diode Strip Detectors	110
	6.2.1	Readout Methods	112
	6.2.2	Charge Collection and Measurement Accuracy	114
	6.2.3	Choice of Geometrical Parameters	115
6.3		Strip Detectors with Double-Sided Readout	116
6.4		Strip Detectors with Integrated Capacitive Readout Coupling	120
6.5		Drift Detectors	125

6.5.1	Linear Drift Devices	127
6.5.2	Matrix Drift Devices	132
6.5.3	Radial Drift Devices	133
6.5.4	Single-Sided Structured Devices	134
6.5.5	Readout of Drift Devices and Measurement Precision ..	136
6.6	Charge Coupled Devices as Detectors	137
6.6.1	Three-Phase “Conventional” MOS CCDs	138
6.6.2	Linear and Matrix CCDs	140
6.6.3	Charge Collection and Charge Transport	140
6.6.4	Signal Readout	143
6.6.5	Other Types of MOS CCDs	144
6.6.6	Fully Depleted p–n CCDs	144
6.7	Summary	151
7.	The Electronics of the Readout Function	153
7.1	Operating Principles of Transistors	153
7.1.1	Bipolar Transistors	153
7.1.2	Junction Field Effect Transistors	160
7.1.3	Metal–Oxide–Semiconductor Field Effect Transistors .	165
7.1.4	Threshold Behavior of Unipolar Transistors	175
7.1.5	The Different Types of JFETs and MOSFETs	178
7.2	Noise Sources	180
7.2.1	Thermal Noise	180
7.2.2	Low-Frequency Voltage Noise	181
7.2.3	Shot Noise	181
7.2.4	Noise in Transistors	182
7.3	The Measurement of Charge	190
7.3.1	The Charge-Sensitive Amplifier	190
7.3.2	Noise in a Charge-Sensitive Amplifier	191
7.3.3	Filtering and Shaping	192
7.4	Basic Electronic Circuits	195
7.4.1	Current Sources and Mirrors	196
7.4.2	Inverters	197
7.4.3	Source Followers	200
7.4.4	Cascode Amplifiers	201
7.4.5	Differential Amplifiers	202
7.5	Integrated Circuit Technologies	202
7.5.1	NMOS Technologies	203
7.5.2	CMOS Technologies	205
7.5.3	Bipolar Technologies	206
7.5.4	SOI Technologies	206
7.5.5	Mixed Technologies	207
7.6	Integrated Circuits for Strip Detectors	207
7.7	Integrated Circuits for Pixel Detectors	210
7.8	Noise in Strip Detectors – Front-End Systems	211
7.8.1	Biasing Circuits	212

7.8.2	Noise in Biasing Circuits	216
7.8.3	Noise Correlations	222
7.9	Summary	225
8.	The Integration of Detectors and Their Electronics	229
8.1	Hybrid Systems of Detectors and Their Electronics	229
8.1.1	Strip Detectors	229
8.1.2	Pixel Detectors	231
8.2	Detector-Technology-Compatible Electronics	233
9.	Detectors with Intrinsic Amplification	239
9.1	Avalanche Diode	239
9.2	Depleted Field Effect Transistor Structure	243
9.2.1	Depleted p-Channel MOS Field Effect Transistor (DEPMOSFET)	244
9.2.2	Electrical Properties and Device Schematics	247
9.2.3	Other Types of DEPFET Structures	251
9.2.4	DEPFET Properties and Applications	253
9.3	DEPFET Pixel Detectors	254
9.3.1	DEPFET Pixel Detector with Random Access Readout	254
9.3.2	DEPFET Pixel Detector for Continuous Operation ...	255
9.3.3	Hybrid DEPFET Pixel Detector	257
9.3.4	DEPFET Pixel Detector with Three-Dimensional Analog Memory	258
10.	Detector Technology	259
10.1	Production of Detector Substrates	259
10.2	Processing Sequence in Planar Technology	260
10.2.1	Photolithographic Structuring	261
10.2.2	Chemical Etching	261
10.2.3	Doping	262
10.2.4	Oxidation	263
10.2.5	Deposition from the Gas Phase	263
10.2.6	Metal Deposition	264
10.2.7	Thermal Treatments	264
10.2.8	Passivation	265
10.3	Technology Simulation	266
11.	Device Stability and Radiation Hardness	267
11.1	Electrical Breakdown and Protection	267
11.1.1	Breakdown Protection in Diode Strip Detectors	268
11.1.2	Breakdown Protection of the Detector Rim	273
11.2	Radiation Damage in Semiconductors	275
11.2.1	The Formation of Primary Lattice Defects	276

11.2.2	Formation and Properties of Stable Defects	277
11.2.3	Electrical Properties of Defect Complexes	279
11.2.4	Effects of Defects on Detector Properties	288
11.2.5	Annealing of Radiation Damage	296
11.2.6	Reverse Annealing	300
11.2.7	Parameterization of Radiation Damage for Low-Flux Irradiation	301
11.3	Radiation Damage in the Surface Region	301
11.3.1	Oxide Damage	302
11.3.2	Nonuniformity in Bulk Damage Near the Surface	303
11.4	Radiation Damage in Detectors	303
11.5	Radiation Damage in Electronics	307
11.6	Radiation Hardening Techniques	309
11.7	Summary	310
12.	Device Simulation	313
12.1	Mathematical Formulation	313
12.1.1	Poisson and Continuity Equations	314
12.1.2	Deep-Level Defects in Stationary Situations	315
12.1.3	Quasi-Fermi Levels	317
12.2	Numerical Solution of Stationary Situations	319
12.2.1	Linearization of the Problem	320
12.2.2	The Finite Difference Method	322
12.2.3	Example of a Stationary Problem	327
12.3	Simulation of Time-Dependent Situations	330
<hr/>		
Part III: Reference Material		333
<hr/>		
Appendix A: Frequently Used Symbols		335
Appendix B: Physical Constants		339
References		341
	Books and Reviews	341
	Articles	342
Index		349