

Contents

1	General Features and Fundamental Concepts	1
	1.1 Introduction	1
	1.2 Range Distributions	2
	1.3 Lattice Disorder	3
	1.4 Atomic and Planar Densities	5
	1.5 Energy and Particles	6
	1.6 The Bohr Velocity and Radius	8
	Suggested Reading	9
	Problems	9
2	Particle Interactions	11
	2.1 Introduction	11
	2.2 Interatomic Forces	11
	2.3 Short- and Long-Range Interatomic Forces	12
	2.4 Interatomic Forces in Solids	13
	2.5 Energetic Collisions of Atoms and Ions and the Screened Coulomb Potential	15
	2.6 Screening Functions	16
	2.7 Screening Length	18
	References	20
	Suggested Reading	20
	Problems	21
3	Dynamics of Binary Elastic Collisions	23
	3.1 Introduction	23
	3.2 Classical Scattering Theory	24
	3.3 Kinematics of Elastic Collisions	25
	3.4 Center-of-Mass Coordinates	27
	3.5 Motion Under a Central Force	30
	3.5.1 Energy Conservation in a Central Force	31
	3.5.2 Angular Orbital Momentum and the Impact Parameters	32
	3.6 Distance of Closest Approach	34
	References	35
	Suggested Reading	35
	Problems	35

4	Cross-Section	37
	4.1 Introduction	37
	4.2 Scattering Cross-Section	37
	4.3 Energy-Transfer Cross-Section	42
	4.4 Approximation to the Energy-Transfer Cross-Section	45
	References	47
	Suggested Reading	47
	Problems	47
5	Ion Stopping	49
	5.1 Introduction	49
	5.2 The Energy-Loss Process	50
	5.3 Nuclear Stopping	51
	5.4 ZBL Nuclear Stopping Cross-Section	54
	5.5 Electronic Stopping	56
	5.5.1 High-Energy Electronic Energy Loss	57
	5.5.2 Low-Energy Electronic Energy Loss	58
	5.6 Stopping Calculations Using SRIM	60
	References	60
	Suggested Reading	60
	Problems	61
6	Ion Range and Range Distribution	63
	6.1 Range Concepts	63
	6.2 Range Distributions	65
	6.3 Calculations	67
	6.3.1 Range Approximations	67
	6.3.2 Projected Range	68
	6.3.3 Range Straggling	70
	6.3.4 Polyatomic Targets	71
	6.4 Range Distributions from SRIM	72
	References	74
	Suggested Reading	75
	Problems	75
7	Displacements and Radiation Damage	77
	7.1 Introduction	77
	7.2 Radiation Damage and Displacement Energy	77
	7.3 Displacements Produced by a Primary Knock-on	79
	7.4 Primary Knock-on Atom Damage Energy	82
	7.5 Ion Damage Energy	83
	7.6 Damage Production Rate and DPA	85
	7.7 Replacement Collision Sequences	86
	7.8 Spikes	86
	7.8.1 Mean Free Path and the Displacement Spike	86
	7.8.2 Thermal Spike	87

7.9	Damage Distribution from SRIM.....	89
	References	91
	Suggested Reading	91
	Problems.....	91
8	Channeling.....	93
	8.1 Introduction	93
	8.2 General Principles	96
	8.3 The Maximum Range, R_{\max}	99
	8.4 Dechanneling by Defects	100
	References	105
	Problems.....	106
9	Doping, Diffusion and Defects in Ion-Implanted Si	107
	9.1 Junctions and Transistors	107
	9.1.1 Bipolar Transistors.....	109
	9.1.2 Metal-Oxide-Semiconductor Field-Effect Transistors	110
	9.1.3 Complementary Metal Oxide Semiconductor Devices	112
	9.2 Defects	114
	9.2.1 Point Defects	114
	9.2.2 Native Defects and Shallow Dopants	114
	9.2.3 Deep Level Centers	115
	9.2.4 Line Defects	116
	9.2.5 Planar Defects	117
	9.2.6 Volume Defects.....	117
	9.3 Fick's First and Second Law of Diffusion	118
	9.3.1 Diffusion Coefficient	119
	9.3.2 Diffusion of Doping Atoms into Si.....	119
	9.4 Diffusion Mechanisms	119
	9.4.1 Interstitial Mechanism.....	121
	9.4.2 Substitutional or Vacancy Mechanism	121
	9.4.3 Interstitial-Substitutional Mechanism	121
	9.4.4 Interstitialcy and the Kick-Out Mechanism.....	122
	9.5 Transient Enhanced Diffusion of Boron	122
	9.6 Irradiation-Enhanced Diffusion.....	124
	References	125
	Problems.....	126
10	Crystallization and Regrowth of Amorphous Si	127
	10.1 Introduction	127
	10.2 Epitaxial Growth of Implanted Amorphous Si	129
	10.3 Ion Beam-Induced Enhanced Crystallization.....	137
	10.4 Laser Annealing of Si.....	140
	References	141
	Problems.....	142

11	Si Slicing and Layer Transfer: Ion-Cut	143
	11.1 Introduction.....	143
	11.2 Formation of SOI by the Ion-Cut Process	144
	11.3 The Silicon–Hydrogen System	145
	11.4 The Mechanisms Behind the Ion-Cut Process.....	149
	11.4.1 The Ion-Cut Depth	149
	11.4.2 Microstructure of the Implantation Zone.....	153
	References.....	157
12	Surface Erosion During Implantation: Sputtering	159
	12.1 Introduction.....	159
	12.2 Sputtering of Single-Element Targets	159
	12.3 Ion Implantation and the Steady State Concentration	162
	12.4 Sputtering of Alloys and Compounds.....	164
	12.4.1 Preferential Sputtering	165
	12.4.2 Compositional Changes	166
	12.4.3 Composition Depth Profiles.....	168
	12.5 High-Dose Ion Implantation	169
	12.6 Concentrations of Implanted Species	171
	12.6.1 Si Implanted with 45 keV Pt Ions.....	171
	12.6.2 Pt Implanted with 45 keV Si Ions.....	172
	12.6.3 PtSi Implanted with Si	172
	12.7 Concentrations in High-Dose Ion Implantation.....	173
	12.8 Computer Simulation.....	175
	References.....	176
	Suggested Reading.....	176
	Problems.....	177
13	Ion-Induced Atomic Intermixing at the Interface: Ion Beam Mixing	179
	13.1 Introduction.....	179
	13.2 Ballistic Mixing	182
	13.2.1 Recoil Mixing	183
	13.2.2 Cascade Mixing	185
	13.3 Thermodynamic Effects in Ion Mixing	187
	References.....	191
	Suggested Reading.....	191
	Problems.....	192
14	Application of Ion Implantation Techniques in CMOS Fabrication	193
	14.1 Introduction.....	193
	14.2 Issues During Device Scaling	193
	14.2.1 Short-Channel Effects.....	195
	14.2.2 Hot-Electron Effect.....	197
	14.2.3 Latchup	198
	14.3 Ion Implantation in Advanced CMOS Device Fabrication	199
	14.3.1 Retrograde Well Implant	202

14.3.2	Punch-Through Stop Implant.....	203
14.3.3	Threshold Adjust Implant	203
14.3.4	Source and Drain Implant	205
14.3.5	Halo Implant	206
14.3.6	Gate Implant.....	207
14.4	Issues of Ion Implantation During Device Scaling	207
14.4.1	Space Charge Effects	207
14.4.2	Energy Contamination	208
14.4.3	Beam Shadowing Effect	208
14.5	The Role of Ion Implantations in Device Fabrications.....	208
	References	209
	Suggested Reading.....	210
	Problems.....	210
15	Ion implantation in CMOS Technology: Machine Challenges	213
15.1	Introduction.....	213
15.2	Implanters used in CMOS Processing	214
15.2.1	Beamline Architectures.....	215
15.2.2	Other Subsystems.....	221
15.3	Low Energy Productivity: Beam Transport.....	223
15.3.1	Space Charge Neutralization.....	224
15.3.2	Decel Implantation.....	224
15.3.3	Molecular Implantation.....	226
15.4	Low Energy Productivity: Beam Utilization	226
15.4.1	Beam Utilization	227
15.4.2	Implanters Commercialized in the Past 35 Years.....	230
15.5	Angle Control.....	232
15.5.1	Impact of Beam Steering Errors on Device Performance.....	232
15.5.2	Impact of Endstation Design and Beam Scan Mechanism.....	234
15.6	Conclusions and the Future of Ion Implantation in Semiconductors	236
	References	237
	Appendix A: Table of the Elements.....	239
	Appendix B: Physical Constants, Conversions, and Useful Combinations	255
	Index.....	257