

## Contents

<b>Preface</b>	xiii
<b>1 Introduction</b>	1
1.1 Early research	1
1.2 Basic concepts of amorphous semiconductors	3
1.2.1 Atomic structure	4
1.2.2 Chemical bonding, the $8-N$ rule and defect reactions	7
1.2.3 Electronic structure	9
1.2.4 Electronic properties	11
1.2.5 Localization, the mobility edge and conduction	13
<b>2 Growth and structure of amorphous silicon</b>	18
2.1 Growth of a-Si:H	18
2.1.1 The morphology of film growth	20
2.1.2 Growth mechanisms	29
2.2 The silicon bonding structure	34
2.2.1 Silicon–silicon atomic bonding	35
2.2.2 Intermediate range order, network voids and stress	36
2.2.3 Network vibrations	40
2.3 The hydrogen bonding structure	44
2.3.1 Silicon–hydrogen bonds	44
2.3.2 The hydrogen local order	48
2.3.3 Hydrogen diffusion, evolution and rehydrogenation	51
2.3.4 The role of hydrogen in the growth of a-Si:H	58
2.3.5 Hydrogen in amorphous and crystalline silicon	60
<b>3 The electronic density of states</b>	62
3.1 The conduction and valence bands	63
3.1.1 Measurements of the conduction and valence band density of states	66

viii	<i>Contents</i>	
3.2	<b>The band tails</b>	70
3.2.1	Dispersive trapping in a band tail	72
3.2.2	The band tail density of states distribution	81
3.3	<b>Optical band-to-band transitions</b>	83
3.3.1	The Urbach edge	88
3.3.2	Thermal and static disorder	91
4	<b>Defects and their electronic states</b>	95
4.1	Defects in amorphous semiconductors	95
4.1.1	Lattice relaxation at defects	97
4.1.2	Correlation energies	99
4.1.3	Valence alternation pairs – the example of selenium	102
4.2	Experimental measurements of defects	104
4.2.1	Electron spin resonance (ESR)	104
4.2.2	ESR hyperfine interactions	109
4.2.3	Defect level spectroscopy – thermal emission energies	114
4.2.4	Defect level spectroscopy – optical transition energies	123
4.2.5	Summary	129
4.3	Defect Models	130
5	<b>Substitutional doping</b>	135
5.1	Growth and structure of doped a-Si:H	138
5.2	The electronic effects of doping	142
5.2.1	Defects induced by doping	145
5.2.2	Shallow electronic states	147
5.2.3	The doping efficiency	155
5.2.4	Compensated a-Si:H	158
5.3	The doping mechanism	160
5.3.1	Discussion of the doping model	165
6	<b>Defect reactions, thermal equilibrium and metastability</b>	169
6.1	Evidence of structural equilibration	171
6.2	Thermal equilibrium models	179
6.2.1	Theory of chemical equilibrium	179
6.2.2	Defect and dopant equilibrium with discrete formation energies	181
6.2.3	Distributions of formation energies – the weak bond model	185
6.2.4	The role of the band tails and deposition conditions	190

<i>Contents</i>		ix
6.2.5	Doping dependence of gap state energies	194
6.2.6	Compensated a-Si:H	195
6.2.7	Defect and dopant pairing	196
6.2.8	The dopant distribution coefficient and equilibrium growth	199
6.3	Kinetics of structural relaxation and equilibrium	202
6.3.1	Stretched exponential relaxation	203
6.3.2	The hydrogen glass model	209
6.4	Metastability	211
6.4.1	Light-induced defects	213
6.4.2	Other metastable phenomena	220
7	<b>Electronic transport</b>	224
7.1	Measurements of dc conductivity	227
7.1.1	Doped a-Si:H above the equilibration temperature	230
7.1.2	Doped a-Si:H below the equilibration temperature	232
7.1.3	Undoped a-Si:H	234
7.2	Carrier mobility	237
7.3	Thermopower and Hall effect	242
7.3.1	The Hall effect	245
7.4	Theories of electronic conduction	247
7.4.1	Early models of extended state conduction	249
7.4.2	Scaling theory	254
7.4.3	Inelastic scattering and phonon effects	258
7.4.4	Hopping conductivity	262
7.4.5	Potential fluctuations and percolation	266
7.4.6	Conduction mechanisms in a-Si:H	271
8	<b>The recombination of excess carriers</b>	276
8.1	Thermalization and recombination mechanisms	277
8.1.1	Radiative recombination	278
8.1.2	Electron–phonon interactions	279
8.1.3	Thermalization and non-radiative transitions	281
8.1.4	Geminate electron–hole pairs	284
8.2	Carrier thermalization	288
8.2.1	Thermalization in extended states	288
8.2.2	Thermalization in localized states	291
8.3	Band tail recombination	292
8.3.1	Photoluminescence	293
8.3.2	Luminescence spectra	294
8.3.3	Recombination kinetics	297

x	<i>Contents</i>	
	8.3.4	Geminate and non-geminate recombination 300
	8.3.5	Thermal quenching of luminescence 302
	8.3.6	Auger and surface recombination 305
8.4	Recombination at defects 307	
	8.4.1	Low temperature non-radiative tunneling 308
	8.4.2	High temperature trapping at defects 311
	8.4.3	Radiative recombination at defects 314
8.5	Photoconductivity 315	
9	<b>Contacts, interfaces and multilayers</b> 321	
9.1	Metallic contacts 321	
	9.1.1	Models of the Schottky barrier 321
	9.1.2	Electrical transport across the barrier 325
	9.1.3	Measurement of depletion layers 328
	9.1.4	Material dependence of the Schottky barrier 330
9.2	Surfaces 334	
	9.2.1	Oxidation and surface states 334
	9.2.2	Gases adsorbed on the surface 338
9.3	Interfaces with dielectrics and semiconductors 340	
	9.3.1	Band offsets 342
	9.3.2	Electronic properties 344
9.4	Multilayers 348	
	9.4.1	Recombination in compositional multilayers 348
	9.4.2	Quantum confinement of electronic states 350
	9.4.3	Quantum confinement of phonons 356
	9.4.4	Doping multilayers 359
10	<b>Amorphous silicon device technology</b> 363	
10.1	Light sensors 363	
	10.1.1	p-i-n sensors 364
	10.1.2	Response to illumination 366
	10.1.3	Electrical characteristics 369
10.2	Thin film transistors (TFTs) 372	
	10.2.1	TFT electrical characteristics 374
	10.2.2	Other TFT structures 378
10.3	Other devices 378	
	10.3.1	Light emitting diodes (LEDs) 378
	10.3.2	Memory switching devices 380
10.4	Applications of amorphous silicon devices 383	
	10.4.1	Solar cells 383
	10.4.2	Active matrix arrays 391
	10.4.3	Photoreceptors 396

<i>Contents</i>	xi
10.4.4 Vidicon	399
10.4.5 High energy radiation imaging	399
10.4.6 Position sensors	403
<b>References</b>	404
<b>Index</b>	413