

Contents

1	Introduction	1
2	Scaling, Power Consumption, and Mobility Enhancement Techniques	5
2.1	Power Scaling	5
2.2	Strain Engineering.....	6
2.3	Global Strain Techniques and Substrate Engineering	8
2.4	Local Stress Techniques	10
2.5	Advanced Stress Techniques.....	12
2.6	Hybrid Orientation Technology and Alternative Channel Materials.	14
	References.....	16
3	Strain and Stress	23
3.1	Strain Definition	23
3.2	Stress.....	25
3.3	Relation Between Strain and Stress Tensor in Silicon and Germanium	27
3.4	Strain and Stress Tensors: Examples	28
3.4.1	Uniform All-Around Compression	28
3.4.2	Biaxial Strain Resulting From Epitaxial Growth.....	29
3.4.3	Uniaxial Stress	32
	References.....	34
4	Basic Properties of the Silicon Lattice	35
4.1	Crystal Structure of Silicon and Germanium	35
4.2	Reciprocal Lattice and First Brillouin Zone	39
4.3	Particle in a Periodic Potential.....	41
	References.....	44
5	Band Structure of Relaxed Silicon	45
5.1	Conduction and Valence Bands.....	45
5.2	First-Principle Band Structure Calculations	46
5.3	Pseudopotential Band Structure Calculations.....	49
5.4	Semi-Empirical Tight Binding Method	56

5.5	Comparison Between Different Numerical Methods	58
	References	61
6	Perturbative Methods for Band Structure Calculations in Silicon	63
6.1	The k-p Method for a Non-Degenerate Band	63
6.2	Effective Mass Theory for Non-Degenerate Bands	64
6.2.1	Electron Effective Mass in Relaxed Silicon	66
6.2.2	Approximations for the Conduction Band Dispersion at Higher Energies	67
6.3	Valence Band	70
6.3.1	Spin-Orbit Coupling in the Valence Band	72
6.3.2	Dispersion of the Valence Band in Silicon	75
6.3.3	Luttinger Parameters	76
	References	80
7	Strain Effects on the Silicon Crystal Structure	83
7.1	Strain-Induced Symmetry Reduction of Silicon Crystal Lattice	83
7.1.1	O_h Symmetry	83
7.1.2	D_{4h} Symmetry	84
7.1.3	D_{3d} Symmetry	85
7.1.4	D_{2h} Symmetry	85
7.1.5	C_{2h} Symmetry	86
7.2	Internal Strain Parameter	86
7.3	Strain and Symmetry of the Brillouin Zone	88
	References	90
8	Strain Effects on the Silicon Band Structure	91
8.1	Linear Deformation Potential Theory	91
8.1.1	Conduction Band	91
8.1.2	Valence Band	93
8.1.3	Stress-Induced Band Splitting of the Valence Bands	94
8.2	Inclusion of Strain into Perturbative Band Structure Calculations ...	97
8.3	Empirical Pseudopotential Method with Strain	102
	References	103
9	Strain Effects on the Conduction Band of Silicon	105
9.1	Limitation of the Effective Mass Approximation for the Conduction Band of Silicon	105
9.2	The Two-Band k-p Model	107
9.2.1	Valley Shift Due to Shear Strain	108
9.2.2	Stress-Dependent Transversal Effective Masses	111
9.2.3	Dependence on Strain of the Longitudinal Effective Mass	112
9.2.4	Stress and Non-Parabolicity	115

9.2.5	Comparison of the Two-Band $\mathbf{k}\cdot\mathbf{p}$ Model with Strain to the Empirical Pseudo-Potential Calculations.....	118
References	120
10	Electron Subbands in Silicon in the Effective Mass Approximation	123
10.1	Arbitrary Substrate Orientation	123
10.2	Substrate Orientation (001)	126
10.3	Substrate Orientation (110)	127
10.4	Substrate Orientation (111)	128
References	129
11	Electron Subbands in Thin Silicon Films	131
11.1	Numerical Methods for Subband Structure Calculations.....	131
11.2	“Linear Combination of Bulk Bands” Method.....	132
11.3	Unprimed Subbands in (001) Films: Analytical Consideration	137
11.3.1	Dispersion Relations from an Auxiliary Tight-Binding Model	141
11.4	Strain-Induced Valley Splitting	144
11.4.1	Small Strain Values	144
11.4.2	High Values of Shear Strain	144
11.4.3	Numerical Solutions	145
11.5	Effective Mass of the Unprimed Subbands	147
11.6	Valley Splitting in Magnetic Field and Point Contacts	152
11.6.1	Valley Splitting in Magnetic Fields	154
11.6.2	Valley Splitting in a Point Contact	154
11.7	Primed Subbands in Ultra-Thin (001) Silicon Films	155
11.7.1	Effective Mass of Primed Subbands	156
11.8	Substrate Orientations Different from (001)	157
11.8.1	Rotation of the Hamiltonian	158
11.8.2	Thin (110) Oriented Silicon Films	159
11.9	Appendix	162
11.9.1	Re-Expressing X_1 as a Function of X_2	162
11.9.2	Expressing the Dispersion Equations in Terms of $X_1 \pm X_2$	164
References	165
12	Demands of Transport Modeling in Advanced MOSFETs	169
12.1	TCAD Tools: Technological Motivation and General Outlook	169
12.1.1	Brief History of TCAD Transport Modeling	171
12.1.2	Transport Modeling: Formulation of the Problem	172
12.2	Semi-Classical Transport	173
12.2.1	From Drift-Diffusion to Higher Moments Equations	174
12.2.2	Model Verification	178
12.3	Mobility in Strained Silicon	182
12.3.1	Mobility and Piezoresistance.....	183

12.3.2	Compact Mobility Modeling	184
12.3.3	Monte Carlo Methods for Transport Calculations	187
12.4	Mixed Quantum-Semi-Classical Description and Quantum Corrections in Current Transport Models	192
12.4.1	Subband Monte Carlo and Degeneracy Effects	195
12.4.2	Simulation Results for Mobilities in Single- and Double-Gate FETs	200
12.4.3	Electron Mobility Enhancement in FETs with Ultra-Thin Silicon Body	206
12.4.4	Stress-Induced Mobility and Drive Current Enhancement	207
12.5	Quantum Transport Models	208
12.5.1	Ballistic Transport and Tunneling	209
12.5.2	Quantum Transport Models with Scattering	216
12.5.3	Non-Equilibrium Green's Function Method	222
12.5.4	Conclusion and Trends	226
	References	228
	Author Index	239
	Subject Index	251



<http://www.springer.com/978-3-7091-0381-4>

Strain-Induced Effects in Advanced MOSFETs

Sverdlov, V.

2011, XIV, 252 p., Hardcover

ISBN: 978-3-7091-0381-4