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
9.2.5 Comparison of the Two-Band k·p Model with Strain to the Empirical Pseudo-Potential Calculations

References

10 Electron Subbands in Silicon in the Effective Mass Approximation

10.1 Arbitrary Substrate Orientation

10.2 Substrate Orientation (001)

10.3 Substrate Orientation (110)

10.4 Substrate Orientation (111)

References

11 Electron Subbands in Thin Silicon Films

11.1 Numerical Methods for Subband Structure Calculations

11.2 “Linear Combination of Bulk Bands” Method

11.3 Unprimed Subbands in (001) Films: Analytical Consideration

11.3.1 Dispersion Relations from an Auxiliary Tight-Binding Model

11.4 Strain-Induced Valley Splitting

11.4.1 Small Strain Values

11.4.2 High Values of Shear Strain

11.4.3 Numerical Solutions

11.5 Effective Mass of the Unprimed Subbands

11.6 Valley Splitting in Magnetic Field and Point Contacts

11.7 Primed Subbands in Ultra-Thin (001) Silicon Films

11.8 Substrate Orientations Different from (001)

11.8.1 Rotation of the Hamiltonian

11.8.2 Thin (110) Oriented Silicon Films

11.9 Appendix

11.9.1 Re-Expressing $X_1$ as a Function of $X_2$

11.9.2 Expressing the Dispersion Equations in Terms of $X_1 \pm X_2$

References

12 Demands of Transport Modeling in Advanced MOSFETs

12.1 TCAD Tools: Technological Motivation and General Outlook

12.1.1 Brief History of TCAD Transport Modeling

12.1.2 Transport Modeling: Formulation of the Problem

12.2 Semi-Classical Transport

12.2.1 From Drift-Diffusion to Higher Moments Equations

12.2.2 Model Verification

12.3 Mobility in Strained Silicon

12.3.1 Mobility and Piezoresistance
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
Strain-Induced Effects in Advanced MOSFETs
Sverdlov, V.
2011, XIV, 252 p. 101 illus., Hardcover
ISBN: 978-3-7091-0381-4