

Table of Contents

Preface	xi
Annie BAUDRANT	
Chapter 1. Silicon and Silicon Carbide Oxidation	1
Jean-Jacques GANEM and Isabelle TRIMAILLE	
1.1. Introduction.	1
1.2. Overview of the various oxidation techniques	3
1.2.1. General information	3
1.2.2. Most frequently used methods in the semiconductor industry.	4
1.2.3. Other methods.	8
1.3. Some physical properties of silica	17
1.3.1. The silica structure	17
1.3.2. Three useful parameters of silica.	21
1.3.3. Transport properties in silica	22
1.4. Equations of atomic transport during oxidation	28
1.4.1. Transport equations in the general case.	29
1.4.2. First approximation: $C(x)$ varies slowly with the depth x	30
1.4.3. Second approximation: $\varepsilon(x)$ varies slowly with the depth x	33
1.4.4. Applications of the transport equations to thermal and anodic oxidation	34
1.5. Is it possible to identify the transport mechanisms taking place during oxidation?	35
1.5.1. Identification using isotopic labeling techniques	35
1.5.2. Important results for the thermal oxidation of silicon under dry O_2	41
1.5.3. Important results for wet thermal oxidation	45

1.5.4. Conclusions on the atomic transport mechanisms during silicon thermal oxidation	45
1.5.5. Experimental results and conclusions on the transport mechanisms during the anodic oxidation of silicon.	46
1.5.6. Important experimental results from dry SiC thermal oxidation	47
1.6. Transport equations in the case of thermal oxidation	48
1.6.1. General information on flux and on growth kinetics	48
1.6.2. Flux calculation for neutral mobile species.	49
1.6.3. Flux calculation for ion mobile species	49
1.7. Deal and Grove theory of thermal oxidation	53
1.7.1. Flux calculation	53
1.7.2. Growth kinetics equations.	57
1.7.3. Remarks on the fluctuations of the oxidation constants k_p and k_L	59
1.7.4. Determination of the oxidation parameters from experimental results	59
1.7.5. Confrontation of the Deal and Grove theory with experimental results	61
1.7.6. Conclusions on the Deal and Grove theory.	66
1.8. Theory of thermal oxidation under water vapor of silicon	67
1.8.1. Concentration profiles expected for H_2O	67
1.8.2. Concentration profiles expected for the OH groups.	68
1.8.3. Concentration profiles expected for H_2	68
1.8.4. Concentration profiles expected for H.	69
1.8.5. Comparison of the expected and the experimental profiles	71
1.8.6. Wolters theory.	71
1.9. Kinetics of growth in O_2 for oxide films < 30 nm	72
1.9.1. Introduction	72
1.9.2. Oxidation models of thin films	78
1.9.3. Case of ultra-thin films (< 5 nm).	80
1.9.4. On line simulator	80
1.9.5. Kinetics and models of SiC oxidation.	81
1.10. Fluctuations of the oxidation constants under experimental conditions	84
1.10.1. Role of the pressure.	84
1.10.2. Role of the temperature	85
1.10.3. Role of the crystal direction	88
1.10.4. Role of doping.	91
1.11. Conclusion	92
1.12. Bibliography	92

Chapter 2. Ion Implantation	103
Jean-Jacques GROB	
2.1. Introduction.	103
2.2. Ion implanters	105
2.2.1. General description.	105
2.2.2. Ion sources.	106
2.2.3. Mass analysis and beam optics	107
2.2.4. Current measurement.	108
2.2.5. Production throughput, temperature control and charge effects.	109
2.3. Ion range	111
2.3.1. Binary collision and stopping power	111
2.3.2. Profile of the implanted ions	115
2.3.3. Backscattering, surface sputter and channeling	119
2.3.4. Implantation through a mask	122
2.4. Creation and healing of the defects	124
2.4.1. Primary collision and cascade	124
2.4.2. Point defects	127
2.4.3. Accumulation of damages, amorphization	128
2.4.4. Damage healing and dopant activation	132
2.5. Applications in traditional technologies and new tendencies.	136
2.5.1. Common implantations	137
2.5.2. Other applications and new tendencies	140
2.6. Conclusion	147
2.7. Bibliography	147
Chapter 3. Dopant Diffusion: Modeling and Technological Challenges	155
Daniel MATHIOT	
3.1. Introduction.	155
3.2. Diffusion in solids	157
3.2.1. General information	157
3.2.2. Elementary mechanisms.	163
3.2.3. Semiconductor specificities	172
3.3. Dopant diffusion in single-crystal silicon	176
3.3.1. Predeposition methods.	176
3.3.2. Main experimental observations	178
3.3.3. Modeling.	184
3.4. Examples of associated engineering problems	191
3.4.1. Redistribution of the implanted dopants: transient enhanced diffusion	191
3.4.2. Engineering of ultra-thin junctions.	193
3.4.3. Reverse short channel effect	195

3.5. Dopant diffusion in germanium	196
3.5.1. Thermal diffusion process	197
3.5.2. Implanted dopants and junctions engineering	199
3.6. Conclusion	201
3.7. Bibliography	201
Chapter 4. Epitaxy of Strained Si/Si_{1-x}Ge_x Heterostructures	209
Jean-Michel HARTMANN	
4.1. Introduction.	209
4.1.1. General introduction	209
4.1.2. Chemical vapor deposition from the beginning	210
4.1.3. The Epi Centura epitaxy tool	216
4.1.4. Some general concepts of epitaxy	219
4.2. Engineering of the pMOSFET transistor channel using pseudomorphic SiGe layers	222
4.2.1. Introduction	222
4.2.2. Growth kinetics of Si and SiGe in chlorinated chemistry	224
4.2.3. Transposition on patterned substrates	229
4.2.4. pMOS transistors incorporating SiGe layers	231
4.3. Engineering of the nMOSFET transistor channel using pseudomorphic Si _{1-y} C _y layers; SiGeC diffusion barriers	233
4.3.1. Introduction	233
4.3.2. Incorporation of C in Si and SiGe	235
4.3.3. Si/Si _{1-y} C _y /Si stacks for nMOS transistors	238
4.3.4. nMOS transistors incorporating Si _{1-y} C _y layers or SiGeC diffusion barriers	241
4.4. Epitaxy of Si raised sources and drains on ultra-thin SOI substrates	243
4.4.1. Introduction	243
4.4.2. Problems encountered on ultra-thin SOI substrates	245
4.4.3. Method developed in response	246
4.5. Epitaxy of recessed and raised SiGe:B sources and drains on ultra-thin SOI and SON substrates	248
4.5.1. Introduction	248
4.5.2. Growth kinetics and boron doping of SiGe in chlorinated chemistry	249
4.5.3. Recessed and raised SiGe:B sources and drains on FD-SOI and SON substrates	251
4.6. Virtual SiGe substrates: fabrication of sSOI substrates and of dual c-Ge / t-Si channels	253
4.6.1. Introduction	253
4.6.2. Growth and structural properties of virtual SiGe substrates	255

4.6.3. Growth and structural properties of tensily-strained Si layers on SiGe virtual substrates	262
4.6.4. Fabrication of sSOI and XsSOI substrates & transport properties	267
4.6.5. c-Ge/t-Si dual channels on Si _{0.5} Ge _{0.5} virtual substrates	271
4.7. Thin or thick layers of pure Ge on Si for nano and opto-electronics	275
4.7.1. Introduction	275
4.7.2. Structural properties of thick layers of Ge on Si (001) and of GeOI	276
4.7.3. Optical and transport properties of thick Ge layers on Si (001) and of GeOI substrates	283
4.7.4. Structural and optical properties of Ge islands on Si (001)	288
4.8. Devices based on sacrificial layers of SiGe	292
4.8.1. Introduction	292
4.8.2. Selective HCl etching of SiGe selectively compared to Si.	293
4.8.3. Localized SOI devices and SON	297
4.8.4. Devices based on multi-wires and on multi-channels.	301
4.9. Conclusions and prospects	311
4.9.1. General conclusion	311
4.9.2. Prospects	313
4.10. Bibliography	317
List of Authors	333
Index	335