
SEMICONDUCTOR MATERIAL AND DEVICE CHARACTERIZATION

DIETER K. SCHRODER

Arizona State University
Tempe, Arizona



A WILEY-INTERSCIENCE PUBLICATION

John Wiley & Sons, Inc.

NEW YORK / CHICHESTER / BRISBANE / TORONTO / SINGAPORE

CONTENTS

INTRODUCTION	xiii
1 RESISTIVITY	1
1.1 Introduction, 1	
1.2 The Four-Point Probe, 2	
1.3 Resistivity Profiling, 21	
1.4 Contactless Methods, 27	
1.5 Conductivity Type, 30	
1.6 Strengths and Weaknesses, 32	
Appendix 1.1 Resistivity as a Function of Doping Concentration, 34	
References, 35	
2 CARRIER AND DOPING CONCENTRATION	41
2.1 Introduction, 41	
2.2 Capacitance Measurements, 41	
2.3 Current-Voltage Measurements, 58	
2.4 Measurement Circuits, 62	
2.5 Measurement Errors and Precautions, 64	
2.6 Hall Effect, 73	
2.7 Optical Techniques, 77	
2.8 Secondary Ion Mass Spectrometry, 85	

- 2.9 Strengths and Weaknesses, 87
References, 89

3 CONTACT RESISTANCE AND SCHOTTKY BARRIER HEIGHT 99

- 3.1 Introduction, 99
- 3.2 Metal-Semiconductor Contacts, 100
- 3.3 Contact Resistance, 104
- 3.4 Measurement Techniques, 109
- 3.5 Schottky Barrier Height, 130
- 3.6 Strengths and Weaknesses, 137
 - Appendix 3.1 Alloys for Contacts to Semiconductor Materials, 139
 - References, 139

4. SERIES RESISTANCE, CHANNEL LENGTH, THRESHOLD VOLTAGE 147

- 4.1 Introduction, 147
- 4.2 *PN* Junction Diodes, 147
- 4.3 Schottky Barrier Diodes, 151
- 4.4 Solar Cells, 154
- 4.5 Bipolar Junction Transistors, 161
- 4.6 MOSFET's, 169
- 4.7 MESFET's and MODFET's, 180
- 4.8 Threshold Voltage, 183
- 4.9 Strengths and Weaknesses, 186
 - Appendix 4.1 Schottky Diode Current-Voltage Equation, 186
 - References, 188

5 MOBILITY 194

- 5.1 Introduction, 194
- 5.2 Conductivity Mobility, 195
- 5.3 Hall Effect and Mobility, 195
- 5.4 Magnetoresistance Mobility, 216
- 5.5 Time-of-Flight Drift Mobility, 219
- 5.6 MOSFET Mobility, 226
- 5.7 Strengths and Weaknesses, 231
 - Appendix 5.1 Semiconductor Mobilities, 232
 - References, 236

6	OXIDE AND INTERFACE TRAPPED CHARGE	244
6.1	Introduction, 244	
6.2	Fixed, Oxide Trapped, and Mobile Charge, 246	
6.3	Interface Trapped Charge, 267	
6.4	Strengths and Weaknesses, 285	
	Appendix 6.1 Capacitance Measurement Techniques, 286	
	References, 288	
7	DEEP-LEVEL IMPURITIES	297
7.1	Introduction, 297	
7.2	Generation-Recombination Statistics, 297	
7.3	Capacitance Measurements, 304	
7.4	Current Measurements, 315	
7.5	Charge Measurements, 319	
7.6	Deep-Level Transient Spectroscopy, 319	
7.7	Thermally Stimulated Capacitance and Current, 339	
7.8	Strengths and Weaknesses, 340	
	Appendix 7.1 Activation Energy, Capture Cross Section, 341	
	Appendix 7.2 Time Constant Extraction, 342	
	Appendix 7.3 Arrhenius Plots for Si and GaAs, 344	
	References, 348	
8	CARRIER LIFETIME	359
8.1	Introduction, 359	
8.2	Recombination Lifetime/Surface Recombination Velocity, 360	
8.3	Generation Lifetime/Surface Generation Velocity, 365	
8.4	Recombination Lifetime—Optical Measurement Techniques, 367	
8.5	Recombination Lifetime—Electrical Measurement Techniques, 394	
8.6	Generation Lifetime, 411	
8.7	Strengths and Weaknesses, 424	
	Appendix 8.1 Optical Excitation, 424	
	Appendix 8.2 Electrical Excitation, 434	
	References, 435	

9 OPTICAL CHARACTERIZATION	448
9.1 Introduction, 448	
9.2 Optical Microscopy, 448	
9.3 Ellipsometry, 459	
9.4 Transmission, 466	
9.5 Reflection, 476	
9.6 Line Width, 485	
9.7 Photoluminescence, 490	
9.8 Raman Spectroscopy, 494	
Appendix 9.1 Transmission Equations, 497	
Appendix 9.2 Absorption Coefficients and Refractive Indices for Selected Semiconductors, 499	
References, 500	
10 CHEMICAL AND PHYSICAL CHARACTERIZATION	507
10.1 Introduction, 507	
10.2 Electron Beam Techniques, 509	
10.3 Ion Beam Techniques, 538	
10.4 X-Ray and Gamma-Ray Techniques, 551	
Appendix 10.1 Selected Features of Some Analytical Methods, 564	
Appendix 10.2 Sensitivity, Depth, and Spot Size of Analytical Methods, 565	
References, 565	
APPENDIX A LIST OF SYMBOLS	577
APPENDIX B ABBREVIATIONS AND ACRONYMS	583
INDEX	587