

Contents

Preface ix

Acknowledgments xi

Biography xii

1 Graphene for Silicon Optoelectronics 1

1.1 Introduction 1

1.2 Optical Absorption 2

1.3 Emergence of Graphene in Silicon Optoelectronics 3

1.4 Photodetection in Graphene 4

1.4.1 Performance Metrics 5

1.4.2 Photovoltaic Effect 5

1.4.3 Photoemission in Graphene Schottky Junctions 6

1.4.4 Thermionic Emission in Graphene-based Interfaces 7

1.4.5 Hot Electron-based Photodetection 9

1.4.5.1 Photothermoelectric Effect (PTE) 10

1.4.5.2 Photobolometric Effect (PBE) 12

1.4.5.3 Photothermionic (PTI) Effect 13

1.4.5.4 Photogating Effect 13

1.4.6 Infrared Modulators 16

1.4.7 Photovoltaic Devices 16

1.5 Outlook 17

References 18

2 Growth and Transfer of Graphene for Silicon Optoelectronics 21

2.1 Introduction 21

2.2 Growth of Graphene 21

2.2.1 Growth Dynamics of CVD Gr and Choice of Substrate 22

2.2.2 Growth on Metallic Substrates 24

2.2.3 Direct Growth on Dielectric Substrates 26

2.2.4 Direct Growth on Semiconductor Substrates 29

2.2.5 Large-scale CVD Growth of Graphene 31

2.3 Dielectric Deposition on Graphene 33

2.4 Graphene Transfer Methods 35

2.5	Fabrication of Solution-processed Graphene and Integration with Silicon	38
2.6	Graphene Transfer on Flexible Silicon	39
2.7	Graphene Integration with Silicon in CMOS Process	40
2.8	Challenges and Future Prospectives	41
	References	42
3	Physics of Graphene/Silicon Junctions	47
3.1	Introduction	47
3.2	Physics of Schottky Junction	48
3.3	Measurement of Schottky Barrier Height	53
3.3.1	Capacitance Voltage Measurement	53
3.3.2	Current–Voltage Measurement	54
3.3.3	Photoelectric Measurement	55
3.3.4	Thermionic Emission Measurements	55
3.4	2D Materials and Schottky Junctions	58
3.5	Challenges and Future Prospective	61
	References	63
4	Graphene/Silicon Junction for High-performance Photodetectors	65
4.1	Introduction	65
4.2	Ultraviolet Photodetectors	65
4.3	Visible to Near-infrared Photodetector	68
4.4	Broadband Photodetectors	71
4.5	Hybrid Gr/Si Photodetectors	75
4.6	Challenges and Perspectives	80
	References	81
5	Graphene/Silicon Solar Energy Harvesting Devices	85
5.1	Introduction	85
5.2	Photovoltaic Mechanism and Performance Parameters of Graphene/Silicon Solar Cells	86
5.3	Theoretical Efficiency Limits of Graphene Silicon Solar Cells	88
5.4	Optimization of Graphene/Silicon Solar Cells	89
5.4.1	Doping of Graphene	89
5.4.2	Light Trapping in Silicon	92
5.4.3	Antireflection Coating	94
5.4.4	Interface Engineering	97
5.4.5	Surface Passivation	100
5.5	Challenges and Perspectives	101
	References	102
6	Graphene Silicon-integrated Waveguide Devices	107
6.1	Introduction	107
6.2	Hybrid Waveguide Photodetector	111
6.3	Hybrid Waveguide Modulator	114
6.3.1	Electro-optical Modulator	115
6.3.2	Thermo-optic Modulator	117

6.4	Challenges and Prospectives	117
	References	118
7	Graphene for Silicon Image Sensor	121
7.1	Introduction	121
7.2	Quantum Dot-based Infrared Graphene Image Sensor	123
7.3	Graphene Thermopile Image Sensor	124
7.4	Graphene THz Image Sensor	125
7.5	Curved Image Sensor Array	126
7.6	Neural Network Image Sensors	127
7.7	Graphene Charge-coupled Device Image Sensor	128
7.8	Graphene-based Position-sensitive Detector	132
7.9	Challenges and Perspectives	136
	References	137
8	System Integration with Graphene for Silicon Optoelectronics	141
8.1	Introduction	141
8.2	Graphene Silicon Flip Chips	142
8.3	Graphene Silicon Heterogeneous Integration	145
8.4	Graphene Silicon Monolithic Integration for Optoelectronics Applications	147
8.5	Challenges and Prospective	150
	References	152
9	Graphene for Silicon Optoelectronic Synaptic Devices	153
9.1	Introduction	153
9.2	Silicon Neurons	154
9.3	Synaptic Devices	156
9.4	Silicon Optoelectronic Synaptic Devices	157
9.5	ORAM Synaptic Devices	159
9.6	Graphene for Silicon Synaptic Devices	159
9.7	Synaptic Phototransistor	160
9.8	Broadband, Low-power Optoelectronic Synaptic Devices	163
9.9	Challenges and Prospects	164
	References	167
10	Challenges and Prospects of Graphene–Silicon Optoelectronics	169
10.1	Emergence of Wafer-scale Systems	169
10.2	Wafer-scale Synthesis and Foundry Process	169
10.3	Scalable Transfer and Quality Metrics	171
10.4	Scaling Laws and Hot-electron Effects	172
10.5	Optical Modulators	173
10.6	Infrared Photodetectors	174
10.7	Neuromorphic Optoelectronics	176
	References	176
	Index	177