

H. Schneider H.C. Liu

Quantum Well Infrared Photodetectors

Physics and Applications

With 153 Figures and 8 Tables



Springer

Contents

1	Introduction	1
----------	---------------------	----------

Part I Physics

2	Basics of Infrared Detection	5
2.1	Blackbody Radiation	5
2.2	Signal, Noise, and Noise-Equivalent Power	7
2.3	Detectivity and Noise-Equivalent Temperature Difference	10

3	Semiconductor Quantum Wells and Intersubband Transitions	13
3.1	Quantum Wells	13
3.2	Intersubband Transitions	13
3.3	Intersubband Transition: More Details	18
3.3.1	Basic Formulae	18
3.3.2	Calculations for a Symmetric Quantum Well	21
3.3.3	Transfer-Matrix Method	27
3.4	Corrections to the Intersubband Energy and Lineshape	29
3.4.1	Coulomb Interaction	29
3.4.2	Many-Particle Effects	31
3.4.3	Further Interactions	34
3.4.4	Band Nonparabolicity	36
3.5	Intersubband Relaxation and Carrier Capture	39
3.5.1	Electron-Phonon Interaction	40
3.5.2	Electron-Impurity and Electron-Electron Scattering	41

4	Photoconductive QWIP	45
4.1	Dark Current	45
4.1.1	Simple Models	45
4.1.2	Self-Consistent and Numerical Models	55

4.2	Photocurrent	57
4.2.1	Photoconductive Gain	57
4.2.2	Detector Responsivity	64
4.3	Detector Performance	65
4.3.1	Detector Noise	65
4.3.2	Detectivity and Blip Condition	67
4.4	Design of an Optimized Detector	72
4.5	THz QWIPs	75
4.5.1	Design Considerations	76
4.5.2	Experimental and Discussion	77
5	Photovoltaic QWIP	83
5.1	General Concept	83
5.2	The Four-Zone QWIP	85
5.2.1	Transport Mechanism and Device Structure	85
5.2.2	Responsivity and Dark Current	88
5.2.3	Noise	89
5.2.4	Detectivity	92
5.2.5	Time Dependence	93
5.2.6	Theoretical Performance of Low-Noise QWIPs	94
6	Optical Coupling	97
6.1	Simple Experimental Geometries	97
6.2	Gratings for Focal Plane Arrays	100
6.3	Strong Coupling in Waveguides, Polaritons, and Vacuum-Field Rabi Splitting	104
7	Miscellaneous Effects	107
7.1	Intersubband Absorption Saturation	107
7.2	Nonlinear Transport and Optical Effects	109
7.2.1	Extrinsic (Photoconductive) Nonlinearity	109
7.2.2	Negative Differential Photoconductivity and Electric Field Domains	115
7.2.3	Intrinsic Nonlinearity	121
7.3	Asymmetry Caused by Dopant Segregation	123
7.4	Coherent Photocurrent	125
7.4.1	Coherent Control by Optical Fields	125
7.4.2	Coherent Control Through Potential Offsets	128
7.5	Impact Ionization and Avalanche Multiplication	131
7.6	Radiation Hardness	135
8	Related Structures and Devices	139
8.1	High Absorption QWIPs	139
8.1.1	Absorption Measurements	139
8.1.2	Detector Characteristics	141

8.2	Multicolor QWIPs	144
8.2.1	Voltage Switched Multicolor QWIP	146
8.2.2	Voltage Tuned Multicolor QWIP	149
8.3	Interband and Intersubband Dual-band Detectors	151
8.3.1	Using the Same Quantum Well	151
8.3.2	Stacked QWIP and PIN	158
8.4	Integrated QWIP-LED	161
8.5	Quantum Dot Infrared Photodetector	163
8.5.1	Anticipated Advantages and Current Status	165
8.5.2	Areas for Improvement	170
8.6	Single Well and Blocked Miniband QWIPs	170
8.7	Transistors and Monolithic Integration	172

Part II Applications

9	Thermal Imaging	175
9.1	Signal, Noise, and Noise-Equivalent Temperature Difference ...	175
9.1.1	Signal Detection	175
9.1.2	Detector Noise	177
9.1.3	System Noise	178
9.1.4	Thermal Resolution	179
9.1.5	Fixed-Pattern Noise and NETD of an Array	181
9.1.6	Modulation Transfer Function	183
9.2	QWIP Cameras	185
9.2.1	Fabrication of QWIP FPAs	185
9.2.2	System Integration	187
9.2.3	Camera Performance	188
9.3	MWIR/LWIR Dual-Band QWIP FPA	190
9.3.1	Detector Concept	191
9.3.2	Array Fabrication and FPA Layout	193
9.3.3	Properties of Dual-Band QWIP Test Devices	194
9.3.4	System Integration and Dual-Band QWIP FPA Performance	195
9.4	Opportunities for QWIP FPAs in Thermal Imaging	196
9.5	Alternative Architecture and New Functionality of QWIP FPAs	199
10	Dynamics, Ultrafast, and Heterodyne	203
10.1	Dynamic Processes in QWIPs	203
10.1.1	Quantum Well Recharging	204
10.1.2	Picosecond Photocurrent	208
10.2	High Frequency and Heterodyne QWIPs	213
10.2.1	Microwave Rectification	213
10.2.2	Heterodyne Detection	216

10.3 Two-Photon QWIP	220
10.3.1 Equidistant Three-Level System for Quadratic Detection	220
10.3.2 Autocorrelation of Subpicosecond Optical Pulses	223
10.3.3 Externally Switchable Quadratic and Linear Response ..	225
11 Conclusions and outlook	229
References	231
Index	247