Contents

1 Introduction 1

2 IR Detector Performance Criteria 5
- 2.1 Photon Detectors 5
  - 2.1.1 IR detector operating temperature 5
  - 2.1.2 IR detector sensitivity 7
- 2.2 Thermal Detectors 9

3 IR Detector Materials: A Technology Comparison 13
- 3.1 Intrinsic Direct Bandgap Semiconductor 13
- 3.2 Extrinsic Semiconductor 16
- 3.3 Quantum Well IR Photodetectors (QWIPs) 18
- 3.4 Silicon Schottky Barrier Detectors 23
- 3.5 High-Temperature Superconductor 26
- 3.6 Conclusions 27

4 Intrinsic Direct Bandgap Semiconductors 31
- 4.1 Minority Carrier Lifetime 32
  - 4.1.1 Radiative recombination 32
  - 4.1.2 Auger recombination 33
  - 4.1.3 Shockley–Read recombination 34
- 4.2 Diode Dark Current Models 34
- 4.3 Binary Compounds 35
  - 4.3.1 Indium antimonide: InSb 35
- 4.4 Ternary Alloys 37
  - 4.4.1 Mercury cadmium telluride: $Hg_{1-x}Cd_xTe$ 37
- 4.5 $Pb_{1-x}Sn_xTe$ 42
  - 4.5.1 Minority carrier lifetime 43
  - 4.5.2 Dark currents 44
- 4.6 Type III Superlattices 45
  - 4.6.1 Superlattice bandstructure 45
  - 4.6.2 Band offsets and strain 47
  - 4.6.3 Interdiffusion in HgTe/CdTe superlattices 48
  - 4.6.4 Misfit dislocations 48
  - 4.6.5 Absorption coefficient 49

4.6.6 Effective mass 51
4.6.7 Minority carrier lifetime 52
4.7 Type II Superlattices 53
4.7.1 Minority carrier lifetime 54
4.8 Direct Bandgap Materials: Conclusions 57
4.8.1 HgCdTe 57
4.8.2 InSb 57
4.8.3 PbSnTe 58
4.8.4 Type III superlattices 59
4.8.5 Type II superlattices 59
4.8.6 Final thoughts 59

5 HgCdTe: Material of Choice for Tactical Systems 61
5.1 HgCdTe Material Properties 61
5.1.1 Material growth 61
5.1.2 HgCdTe annealing 65
5.1.3 HgCdTe properties 67
5.2 HgCdTe Device Architectures 75
5.2.1 DLHJ architecture 76
5.2.2 Bump-bonded ion implant architecture 77
5.2.3 Vertically integrated photodiode (VIP and HDVIP) architectures 77
5.3 ROIC Requirements 81
5.3.1 Detector performance: Modeling 82
5.3.2 Dark current in HgCdTe diodes 82
5.3.3 1/f noise 87
5.4 Detector Performance 89
5.5 HgCdTe: Conclusions 91

6 Uncooled Detection 93
6.1 Thermal Detection 93
6.2 Photon Detection 95
6.2.1 HOT detector theory 95
6.2.2 HOT detector data 101
6.2.3 HOT detector contacts 103
6.2.4 HOT detector options 103
6.3 Uncooled Photon vs. Thermal Detection Limits 105
6.4 Uncooled Detection: Conclusions 107

7 HgCdTe Electron Avalanche Photodiodes (EAPDs) 109
7.1 McIntyre's Avalanche Photodiode Model 110
7.2 Physics of HgCdTe EAPDs 112
7.2.1 High-energy scattering rates 113
7.2.2 Electron impact ionization rate in HgCdTe 115

7.3 Empirical Model for Electron Avalanche Gain in HgCdTe 121
7.4 Room-Temperature HgCdTe APD Performance 129
7.5 Monte Carlo Modeling 131
7.6 Conclusions 133

8 Future HgCdTe Developments 135
8.1 Dark Current Model 135
8.1.1 N-side 136
8.1.2 P-side 137
8.2 The Separate Absorption and Detection Diode Structure 139
8.3 Multicolor and Multispectral FPAs 141
8.4 High-Density FPAs 143
8.5 Low Background Operation 143
8.5.1 LWIR 14 μm at 40 K 143
8.5.2 Low background operation at a cutoff of 25 μm 144
8.6 Higher Operating Temperatures 145
8.6.1 High-gain APDs 147
8.7 Conclusion 148

Epilogue 149

Appendix A: Mathcad Program for HgCdTe Diode Dark Current Modeling 151

References 165

About the Author 169

Index 171