

Uncooled Infrared Imaging Arrays and Systems

**SEMICONDUCTORS
AND SEMIMETALS**

Volume 47

Volume Editors

PAUL W. KRUSE

INFRARED SOLUTIONS, INC.
MINNEAPOLIS, MINNESOTA

DAVID D. SKATRUD

DEPARTMENT OF THE ARMY
PHYSICS DIVISION
ARMY RESEARCH OFFICE
RESEARCH TRIANGLE PARK
NORTH CAROLINA



ACADEMIC PRESS

*San Diego London Boston
New York Sydney Tokyo Toronto*

Contents

LIST OF CONTRIBUTORS	xi
PREFACE	xiii

Chapter 1 Historical Overview

Rudolph G. Buser and Michael F. Tompsett

I. Introduction	1
II. History of Electronic Materials Research for Uncooled Imagers	6
1. Ferroelectric-Pyroelectric Materials	6
2. Resistive Materials	8
III. Uncooled Imaging Arrays Using Silicon Read-Out	9
1. Ferroelectric-Pyroelectric Arrays	9
2. Resistive Bolometric Arrays	11
IV. Future	12
References	14

Chapter 2 Principles of Uncooled Infrared Focal Plane Arrays

Paul W. Kruse

I. Importance of the Thermal Isolation Structure	17
II. Principal Thermal Detection Mechanisms	23
1. Resistive Bolometers	23
2. Pyroelectric Detectors and Ferroelectric Bolometers	25
3. Thermoelectric Detectors	29
III. Fundamental Limits	31
1. Temperature Fluctuation Noise Limit	31
2. Background Fluctuation Noise Limit	33
IV. Discussion	37
References and Bibliography	40

Chapter 3 Monolithic Silicon Microbolometer Arrays

R. A. Wood

I. Background	45
II. Responsivity of Microbolometers	47
1. Microbolometer Model	47
2. Resistance Changes in Microbolometer Materials	51
3. Microbolometer Heat Balance Equation	56
4. Solutions of the Heat Balance Equation	57
5. Heat Balance with No Applied Bias	57
6. Heat Balance with Applied Bias	59
7. Calculations of V-I Curves	61
8. Load Line	64
9. Low-Frequency Noise in Microbolometer with Applied Bias	68
10. Microbolometer Responsivity with Pulsed Bias or Large Radiation Signals	70
11. Numerical Calculation of Microbolometer Performance	71
III. Noise in Bolometers	75
1. Bolometer Resistance Noise	75
2. Noise from Bias Resistors	79
3. Thermal Conductance Noise	80
4. Radiation Noise	81
5. Total Electrical Noise	83
6. Preamplifier Noise	85
IV. Microbolometer Signal-to-Noise	86
1. Noise Equivalent Power (NEP)	86
2. Noise Equivalent Temperature Difference (NETD)	86
3. Detectivity	87
4. Comparison with the Ideal Bolometer	89
5. Johnson Noise Approximation	91
V. Electric Read-Out Circuits for Two-Dimensional Microbolometer Arrays	91
VI. Offset Compensation Schemes	95
VII. Gain Correction	97
VIII. Modulation Transfer Function (MTF)	98
IX. Microbolometer Physical Design, Fabrication, and Packaging	98
1. One-Level Microbolometers	100
2. Two-Level Microbolometers	102
3. Packaging	109
X. Practical Camera Development	116
References	119

Chapter 4 Hybrid Pyroelectric–Ferroelectric Bolometer Arrays

Charles M. Hanson

I. Introduction	123
II. Principles of Pyroelectric Detectors	124
1. Pyroelectricity and Ferroelectric Materials	124
2. Modes of Operation	139
3. Signal and Noise	144
III. Practical Considerations and Designs	154

I. Ferroelectric Material Selection	154
2. Thermal Isolation	156
3. Modulation Transfer Function (MTF)	158
4. Read-out Electronics	159
5. System Electronics	161
6. Choppers	162
IV. Systems Implementations	169
References	173

Chapter 5 Monolithic Pyroelectric Bolometer Arrays

Dennis L. Polla and Jun R. Choi

I. Introduction	175
II. Detector Design Methodology	176
1. Materials Processing	178
2. Materials Characterization	181
3. Thermal Isolation Structures	183
4. Micromachined Sensor Process Design	184
5. Integrated Circuits	186
III. Process Design	187
IV. Silicon-Based Integrated Pyroelectric Detector Arrays	189
1. Cell Structure	190
2. Circuit Operation	191
3. Silicon-Based PbTiO ₃ Array Performance	195
V. Gallium Arsenide-Based Integrated Pyroelectric Detectors	197
VI. Summary	199
References	200

Chapter 6 Thermoelectric Uncooled Infrared Focal Plane Arrays

Nobukazu Teranishi

I. Introduction	203
II. Thermopile Infrared Detector	204
1. Mechanism for Uncooled Infrared Detector	204
2. Comparison Among Uncooled Infrared Detector Schemes	205
3. The Seebeck Effect	206
4. Various Thermopile Infrared Detectors	209
III. A 128 × 128 Pixel Thermopile Infrared Focal Plane Array	210
1. Polysilicon Thermopile Infrared Detector	210
2. Characteristics of a Thermopile Infrared Detector	211
3. Signal Read-Out Circuit	211
4. Charge-Coupled Device Scanner	213
5. Package	214
6. Performance	215
7. Future Improvements	217
IV. Summary	217
References	218