Operating Parameter Optimization of Single color and Four-Color Spatially Separated QWIP Focal Plane Array


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ABSTRACT

Four-Color spatially separated QWIP Focal Plane Array (FPA) presents very unique challenges to characterize and optimize. In ideal single color QWIP FPA, bias and integration time are independently controllable parameters. Hence, a single color FPA is easily characterize and optimized. Unfortunately, the read out integrated circuit (ROIC) that is used for a four-color demonstration is not designed to simultaneously operate with four different color detectors that exhibit different responsivity and dark currents. Even though all detectors are specifically designed to operate at the same bias, the four-color QWIP FPA still exhibits different offsets. Therefore, in a background limited operation of the four-color FPA, the longest wavelength detector dictates the highest operating temperature while the most responsive detector with large dark current dictates the longest integration time without saturating the ROIC well capacity. Since the bias and integration time are the same for all four detectors, the most responsive detector with large dark current limits the upper bound of the dynamic range, and the least responsive detector with smaller dark current limits lower bound, e.g., 300 K background. Hence, bias and integration times are adjusted to optimize the operation of spatially separated four-color QWIP FPA at a given background condition. This paper will report on the characterization of spatially separated four-color QWIP FPA and LWIR QWIP camera. Optimization of operating parameters for each color and the best optimized operating parameters for all four-color operating simultaneously will be discussed.
Introduction

• Multispectral Applications
  – Environmental monitoring (Urban Dynamics, Pollution, etc)
  – Metrology (Weather prediction, etc.)
  – Global Change Monitoring (Global Warming, Deforestation, etc.)
  – Mapping (topography, land use, civil engineering)
  – Military Surveillance and Reconnaissance
    • Better Target Discrimination, contrast, detection of suppressed target signature, etc
  – Agriculture (Soil Moisture, Crop Condition, etc.)
  – Planetary Exploration (Thermal mapping of Mars)

• Objectives
  – Design and Fabricate 4-band QWIP FPA using a single color design 640 x 512 Format ROIC
  – Design compromise is to spatially separate each color (4x128)V x 640H
  – 4 band, covers 3 - 15.4 μm
  – Overcome Processing Difficulty
  – Characterize and Optimize operation
    • Same Bias and Integration Time
  – Scheme for NUC
  – Display Four Different Color Intensity Images.
Well depth and Width determine the allowed energy states in the quantum well.

Only Photons with energy equal to the difference of the first excited and ground state are absorbed.

Tunability (Peak Position and bandwidth)
Bound to Quasi-Bound
Single Color FPA Fabrication and Characterization

FPA Test Electronics

Dewar

Camera Head → PC → Monitor

Best Operating Parameter
- Bias ~ 1 V
- Integration time ~ 16 msec
- FPA Temperature ~ 65 K

Lowest NEDT Achieves by Maximizing $T_{\text{int}}$ at fixed Bias without saturation.
Four-Band FPA Fabrication

- 4-bands: 128x640 pixels/band
  - 3-5 mm, 8-10 mm, 10-12 mm, 14-15.4 mm
- Readout: Indigo 9803, DI, 11E6 e-
  - Single Color ROIC
- QWIP detectors design to operate with similar Bias, Integration Time, and Temperature
- Different Offset and Gain
  - MWIR lowest dark Current
- Exhibit Different Intensity
  - Nonuniform display intensity
- Different Thermal and Spatial Resolution
- Longest Wavelength defines the operating Temperature
- Single and Two Point Correction
- Not simple to optimize

Multiple stack detectors
- Separated by heavily doped contact layer
- Response at different wavelength
- Only single wavelength is active in each band
- Unused detectors are shorted
- Complicated Processing
**Four-Color Characterization**

Uncorrected Image (27 C BB)  

Band 1  
MWIR  

Band 2  
8-10 μm  

Band 3  
10-12 μm  

Band 4  
14-15.4 μm  

Soldering Iron  

4.1 V  

Voltage Swing  

1.6 V  

Pixel Number  

NEDT Optimization  
1) Set ROIC internal gain set to minimum  
2) Blackbody at Maximum Scene Temperature  
3) Adjust Vdet_com  
4) Adjust Integration Time  
5) Maximize Dynamic Range
Four-Color Characterization

NEDT MWIR

NEDT 8-10 um

NEDT 14-15.5 um

NEDT 10-12 um

Band | NEDT (mK)
--- | ---
MWIR | 31.7
8-10 um | 55.4
10-12 um | 13.3
14-15.4 um | 26.1

- Vdet_Com = 5 V, Tint = 3 msec, T_operating = 45 K
- NEDT very Sensitive to changes in Bias and integration time
Four-Color Characterization

Detectivity MWIR

Detectivity 8-10 um

Detectivity 10-12 um

Detectivity 14-15.5 um

<table>
<thead>
<tr>
<th>Band</th>
<th>$D^*$ (cm Hz$^{-5}$/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MWIR</td>
<td>2.30E+10</td>
</tr>
<tr>
<td>8-10 um</td>
<td>2.27E+09</td>
</tr>
<tr>
<td>10-12 um</td>
<td>8.00E+09</td>
</tr>
<tr>
<td>14-15.4 um</td>
<td>4.88E+09</td>
</tr>
</tbody>
</table>
Four-Color Image Correction

Intensity Correction

- Different Offsets affects display intensity
- ROIC internal gain set to minimum, small bias, and longest integration time
- Four Parallel ADC, each dedicated to one color
- For Each Band, Gain and offset independently adjusted at the ADC.
- Two Point or one-point correction is easily applied for each ROI of 128 x 640.

Four Band FPA
Single Output

<table>
<thead>
<tr>
<th>ADC 1</th>
<th>3-5 μm</th>
<th>1:128 x 1:640</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADC 2</td>
<td>8.5-10 μm</td>
<td>129:256 x 1:640</td>
</tr>
<tr>
<td>ADC 3</td>
<td>10-12 μm</td>
<td>257:384 x 1:640</td>
</tr>
<tr>
<td>ADC 4</td>
<td>14-15.4 μm,</td>
<td>385:512 x 1:640</td>
</tr>
</tbody>
</table>

3-5 pm
8.5-10 pm
10-12 pm
14-15.4 pm,
Summary and Conclusion

- Demonstrated four color QWIP FPA using ROIC designed for single color
- Lesson learn
  - Single color is not difficult
  - Difficult to compensate due to different dark currents and responsivity.
    - Gratings, injection efficiency, integration capacitance, bias, etc.
  - Need to correct for in-band nonuniformity and global nonuniformity
  - Global Nonuniformity corrected by four parallel ADC assign to each color, In-band correction by ROI NUC correction.
  - Dynamic range can suffer
- Suggestion
  - ROIC design for multicolor
  - Compensate through design of ROIC and QWIP detector arrays
  - Prefer either adjustable bias or integration time or both
  - Compensate through detector area (dark current and responsivity)
  - longer wavelength should have larger integration capacitance.