T2SLS Digital Focal Plane Arrays for Earth Remote Sensing Instruments

Sarat Gunapala, David Ting, Alexander Soibel, Arezou Khoshakhlagh, Sam Keo, Sir Rafol, Anita Fisher, Cory Hill, Brian Pepper, Edward Luong, and Jason Mumolo

Center for Infrared Photodetectors, NASA Jet Propulsion Laboratory, California Institute of Technology
Pasadena, California, USA

Kwong-Kit Choi
NASA Goddard Space Flight Center
Greenbelt, Maryland, USA

Arvind D'Souza and Christopher Masterjohn
DRS Network & Imaging Systems, Inc.
Cypress, California, USA

Sachidananda Babu and Parminder Ghuman
NASA Earth Science Technology Office
Greenbelt, Maryland, USA

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Outline

• High Operating Temperature Barrier Infrared Detectors (HOT-BIRDs) technology
  – Decrease detector dark current (i.e., reduce noise -> increase SNR)

• Resonator Pixel (RP) light coupling technology
  – Increase detector quantum efficiency (i.e., increase SNR)

• 3D-Digital read out integrated circuits (DROICs) technology
  – Increases the ROIC well depth (i.e., reduce noise -> increase SNR)
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• Digital RP-BIRD focal plane arrays
  – Increases SNR or increases operating temperature for same SNR
  – Reduce the Size, Weight, and Power (SWaP) factor of the Integrated Detector Dewar Cooler Assembly (IDDCA) -> Enables SmallSat applications
  – Digital RP-BIRD MWIR at 200K & LWIR at 100K for broadband imaging
  – SF-400: 2W, 100W, 3.8Kg whereas SF-070: 800mW, 40W, 0.85Kg
Barrier Infrared Detector Technology
MWIR InAs/InAsSb T2SLS High Operating Temperature Barrier IR Detector (HOT-BIRD)

- QE(4.3 µm, 150K) = 52% – No A/R coating
- $J_{\text{dark}}(-0.2V, 157K) = 9.6 \times 10^{-5} \text{ A/cm}^2$ ($\sim 4.5X \text{ Rule’07}$)
- 160K: NEDT 18.7 mK, Operability 99.7%
- 170K: NEDT 26.6 mK, Operability 99.6%
- FPA shows **significantly higher operating temperature than InSb**


LWIR T2SL Detectors & FPAs

- Developing T2SL-based LWIR detectors for NASA Sustainable Land Imaging Technology (SLI-T) Program
  - Unipolar barrier infrared detector architecture, T2SL absorber
    - High quality $\lambda_{\text{cutoff}} \sim 11.2 \, \mu$m T2SL absorber material
    - 240 ns minority carrier lifetime
    - $J_{\text{dark}}(60K) \sim 10^{-5} \, \text{A/cm}^2$; QE $\sim 37\%$ without A/R coating.
    - Very good FPA operabilities
- Also demonstrated $\lambda_{\text{cutoff}} \sim 12.6 \, \mu$m detectors/FPAs
Resonator Pixel Technology
Resonator-Pixel Technology

**Concept:**
- Diffract incident light at an angle larger than the critical angle of total internal reflection to achieve three-dimensional optical confinement.
- Use pixel active volume as a resonator to achieve coherent accumulation of light.

**Advantages:**
- Increases quantum efficiency
- Thin active layers (good for low carrier mobility)
- Low dark current (due to thin pixel)
- Free of anti-reflection coating
RP-BIRD, 6 μm Period

- (6, 4.0, 1.6)
- (6, 3.6, 2.0)
- (6, 3.6, 1.2)
QE Spectrum with n x n Rings

![Graph of QE Spectrum with n x n Rings](image)
ISC 0903 DA Layout #3 - Stripes

- Vertical arrangement
- 8 different designs for 40x256 stripes on the array
- Longest wavelength on the left

Decreasing wavelength
- 3x3 superpixel, pick out sub-frames with matlab
- Not as visceral as the stripes, but it’s a good option to see all pixels uniformly distributed
- Could mix a few of these in with the striped ones
- Would have entire images to compare instead of stripes
Micrograph of Detector Array

Superpixel
Micrograph of Detector Array with In Bumps

Indium Bumps
ISC 0903 based Detector Array Reticle Layout

Wafer layout – can mix and match FPA designs and process evaluation chips (PECs)

Four permutations on the grating layer
- Normal (no grating)
- Choi’s default
- 1x8 stripe (normal+7)
- 3x3 superpixel

Number of ISC 0903 detector arrays (DAs) on a 4” wafer
Digital Pixel Read Out Electronic Circuit (DROIC) Technology
Digital Read Out Integrated Circuits (DROICs)

Detector Array (HOT BIRD)  
Indium Bumps  
Read Out  
Read Out Int. Circuit (ROIC)

Analogue ROIC  
Digital ROIC

Analog current injection circuit and current-to-frequency converter

Case Study: Digital BIRD FPA for Land Imaging to Meet New Challenges (Imager)

- BIRD for improved detector dark current and QE performance over QWIP (i.e., 43K)
- Digital-pixel ROIC with large well depth enables much longer integration time to improve signal to noise ratio
  - Conventional ROIC well depth ~ few million e⁻’s
  - D-ROIC well depth can exceed 1 billion e⁻’s
- Can achieve 20 mK NEDT for 500 nm wide spectral band centered at 10 – 12.5 µm only with D-ROIC large well depth
Estimated MWIR Performance with DROICs

For Spectrometers

Center Wavelength 4.5 ± 0.01 μm
Operating Temperature 200 K

For Thermal Imagers

Wavelength Bandwidth 3.5-4.5 μm
Operating Temperature 200 K
Summary

- Recent advances in HOT Barrier IR Detector (BIRD) technology is a breakthrough
  - Elevated the FPA operating temperature, good uniformity & operability, and good manufacturability

- Resonator Pixel technology
  - Will increase quantum efficiency

- Digital ROIC is a breakthrough technology
  - Elevates operating temperature

- RP-BIRD DFPA elevates the operating temperature of FPAs
  - Lowers the SWaP factor
  - Enables the low cost Cubesats & Smallssats (for IR land imaging, Spectrometers, and sounders)
  - 200K for MWIR and 100K for LWIR for broadband land imaging

- This work is sponsored by NASA ESTO under ACT program
Backup Slides
Spectral Bandwidth 0.5 μm about 5 μm center

Smaller Fluctuation in NE\(\Delta T\) at longer integration time or deeper well than in shorter integration time or shallower well. For example, at \(10^9\) electrons well depth, NE\(\Delta T\) fluctuation \(\sim 17\) mK peak-to-peak and at \(2\times10^8\) electrons well depth, NE\(\Delta T\) fluctuation \(\sim 55\) mK peak-to-peak for \(\pm 1\) K variation about the operating temperature of 200 K.
Smaller Fluctuation in NE\Delta T at longer integration time or deeper well than in shorter integration time or shallower well. For example, at $10^7$ electrons well depth, NE\Delta T fluctuation < 30 mK peak-to-peak and at $1\times10^6$ electrons well depth, NE\Delta T fluctuation < 230 mK peak-to-peak for ± 1 K variation about the operating temperature of 150 K.