Virtual Research Presentation Conference

Barrier Infrared Detector Digital Focal Plane Arrays

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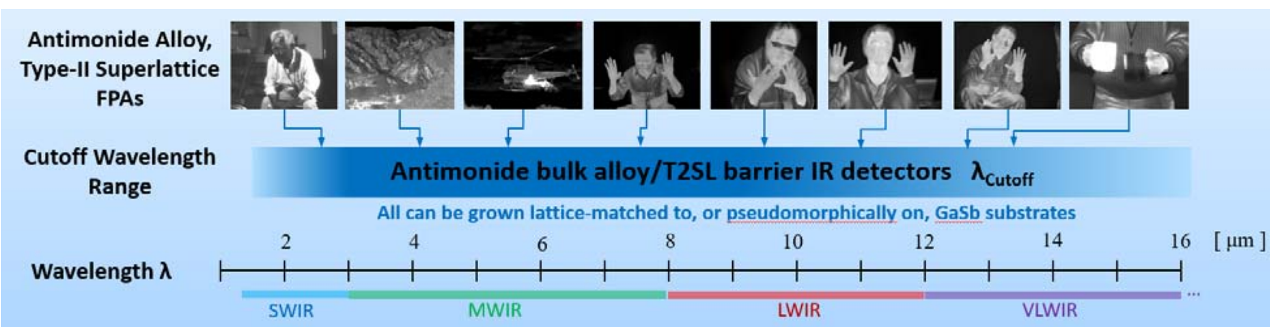
Tutorial Introduction

Abstract

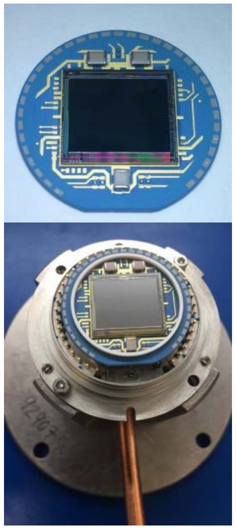
The goal of this project is to demonstrate digital focal plane array (FPA) using the JPL type-II superlattice (T2SL) barrier infrared detector (BIRD) technology. The T2SL BIRD offers continuously adjustable cutoff wavelength ranging from the short wavelength infrared (SWIR) to the very long wavelength infrared (VLWIR) using cost-effective, robust III-V semiconductors. In particular, the mid-wavelength infrared (MWIR) T2SL BIRD FPA has demonstrated a 40 – 50 K higher operating temperature advantage over the InSb FPA, a major incumbent technology. Digital FPA simplifies output electronics and reduces interference in signal chain. Digital FPA based on large-well-depth digital-pixel readout integrate circuit (ROIC) provides much higher dynamic range than a conventional FPA, leading to higher operating temperature, reducing cooler size, weight, and power (SWaP), thereby enabling long wavelength infrared (LWIR) instruments for CubeSat/SmallSat platforms. We will incorporate a LWIR digital FPA in an integrated dewar cooler assembly (IDCA), which will enable us to perform relevant tests to raise the technology readiness level (TRL) for future flight opportunities.



JPL barrier infrared detector (BIRD) focal plane arrays (FPAs) with cutoff wavelength ranging from 2.6 μm to 13.3 μm.

Problem Description

- Mid-wavelength infrared (MWIR) focal plane array (FPA)
  - **InSb** FPA excels in producibility and affordability. Currently accounts for >50% of the photodetector FPA market
  - HgCdTe (**MCT**) FPA can operate at significantly higher temperatures than InSb, but more costly.
  - **JPL** high operating temperature (**HOT**) barrier infrared detector (**BIRD**) combines InSb and MCT advantages.
  - HOT-BIRD operates at 40 – 50 K higher temperature than InSb. Poised to replace InSb for most applications.
  - HOT-BIRD FPA performance and cost-effectiveness enabled MWIR hyperspectral imaging instrument in the JPL CubeSat Infrared Atmospheric Sounder (CIRAS)
- Long-wavelength infrared (LWIR) FPA challenges to overcome
  - Type-II superlattice BIRD FPA capable of LWIR operation
  - LWIR FPA requires more cooling. **Higher LWIR FPA operating temperature** for reducing cooler size, weight, and power (Swap) is desirable, particularly for CubeSat/SmallSat platforms.
- Relevance to NASA and JPL
  - JPL BIRD technology current supports several NASA projects: LWIR FPA for Sustainable Land Imaging Technology (SLI-T) (ROSES), multiband LWIR imager for studying planetary volcanism (PICASSO), LWIR FPA for Earth Science applications (ACT), LWIR hyperspectral thermal imager (HyTI) for SmallSat platform (InVEST), and dual-band digital FPA for Sustainable Land Imaging Technology (SLI-T) (ROSES).
  - Responds to NASA Earth Science Surface Biology and Geology (hyperspectral imagery in the thermal IR), Greenhouse Gases (thermal IR sounders), and Planetary Boundary Layer (hyperspectral IR sounders).



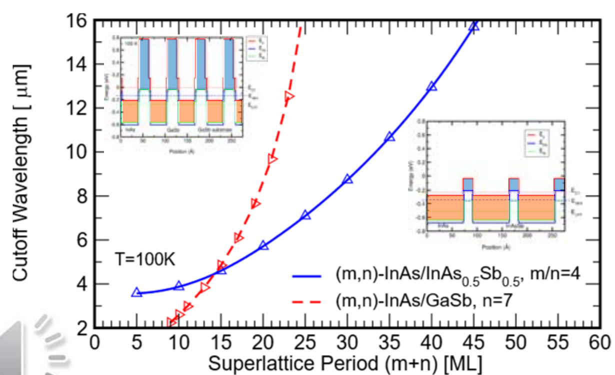
JPL mid-wavelength HOT-BIRD FPA, integrated with cryocooler, for the CubeSat Infrared Atmospheric Sounder (CIRAS)

Methodology

Three Key ingredients:

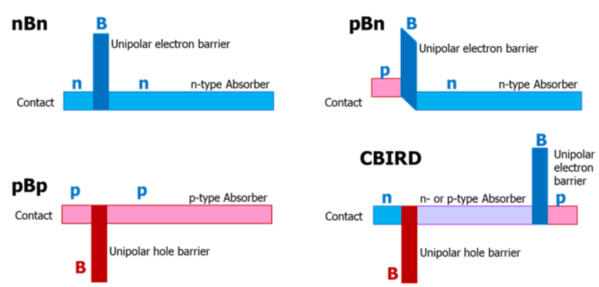
Type-II Superlattice Infrared Absorber

- Robust artificial semiconductor material with continuously adjustable cutoff wavelength
- Suppression of tunneling and Auger dark current



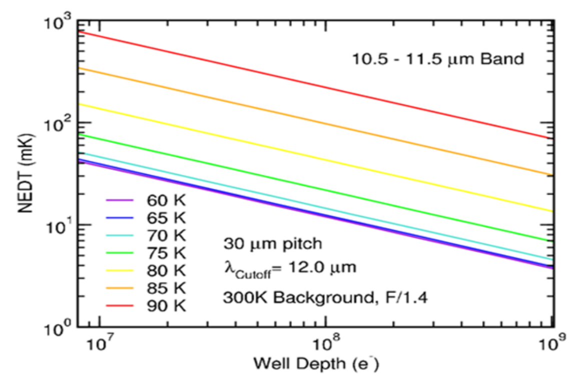
Unipolar Barrier Device Architecture

- Reduce generation-recombination (G-R) and surface leakage dark current (noise)
- Un-impeded photocurrent (signal)



Digital Readout Integrated Circuit

- Digital output reduces interference in signal chain
- Large well depth enables better sensitivity or higher operating temperature



Benefit of Barrier Infrared Detector & Digital ROIC

- Baseline: LandSat-8 Thermal IR Sensor (TIRS)
  - Long-wavelength quantum well infrared photodetector (QWIP) FPA, with conventional analog ROIC
    - QWIP FPAs operate at lower temperature than MCT. Chosen for uniformity and temporal stability.
- Barrier Infrared Detector (BIRD) & same analog ROIC: 20K advantage
  - Type-II superlattice BIRD has superior QE and dark current
- BIRD & digital-pixel ROIC: another 15K advantage
  - Digital-pixel ROIC provides significantly larger well depth, enabling longer integration time.

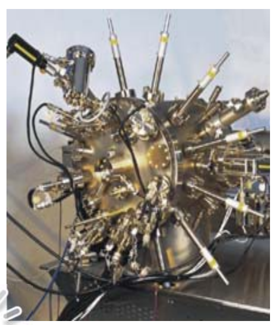
Detector / ROIC	QWIP / Analog ROIC	BIRD / Analog ROIC	BIRD / Digital ROIC
(Effective) Well Depth	11 Me^-	11 Me^-	426 Me^-
Operating Temperature	43 K	**63 K**	**78 K**
NEDT	45.3 mK	42.0 mK	38.4 mK

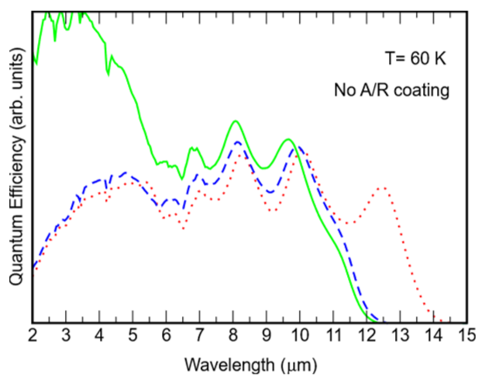
Radiometric calculation comparison of operating temperature needed to achieve ~ 40 mK NEDT in the 11.5-12.5 μm band, for F/1.64 optics, 300K background.

Results

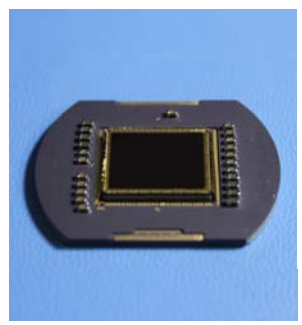
- **Detector material**: Designed, grew, and tested LWIR detector material with cutoff wavelengths from 11.5 μm to 13.5 μm. Multiple detector wafers grown by molecular beam epitaxy (MBE) are ready for use in FPA fabrication.
- **Digital FPA fabrication**: Completed FPA mask designs. Photolithography mask sets ready. FPA pilot run ongoing.
- **Digital FPA test setup**: Custom ceramic chip carrier and PC board to mount digital FPAs. Cryogenic digital-pixel FPA test dewar, optics, and electronics.
- **Significance**: Detector demonstrated spectral quantum efficiency suitable for targeted LWIR D-FPA applications.
- **Next steps**: (1) Complete fabrication of digital FPA. (2) Integrate digital FPA in a dewar-cooler assembly and test.

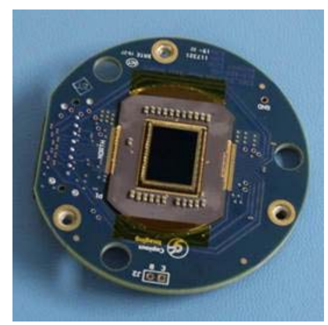
MBE grown LWIR detector material

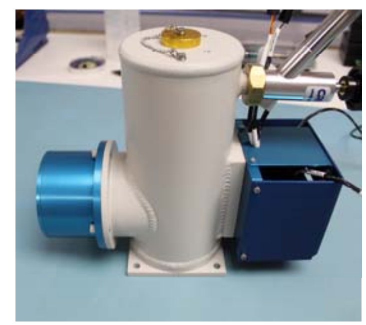




Digital FPA test setup







Publications and References

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