Jet Propulsion Laboratory
California Institute of Technology

T2SLS Digital Focal Plane Arrays for Earth Remote Sensing Instruments

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June 11, 2019

NASA Earth Science Technology Forum
Mountain View, California

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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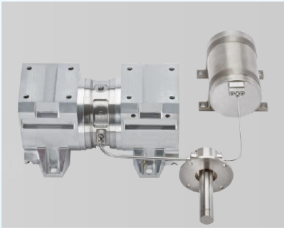
- 3D-Digital read out integrated circuits (DROICs) technology
  - Increases the ROIC well depth (i.e., reduce noise -> increase SNR)
- Digital RP-BIRD focal plane arrays
  - Increases SNR or increases operating temperature for same SNR
  - Reduce the Size, Weight, and Power (SWaP) factor of the Integrated 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

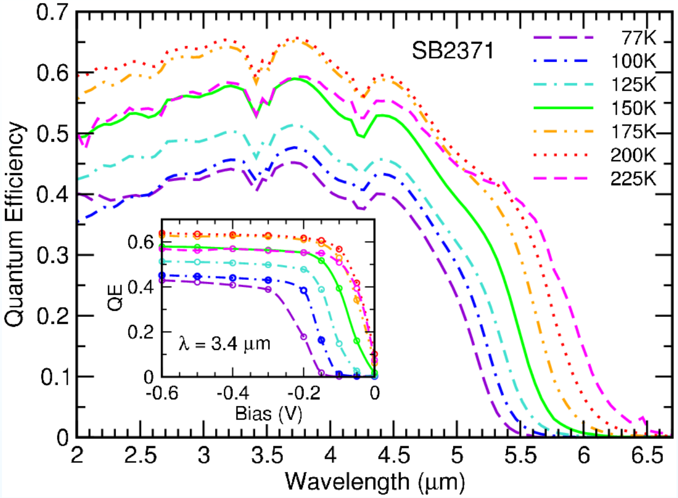


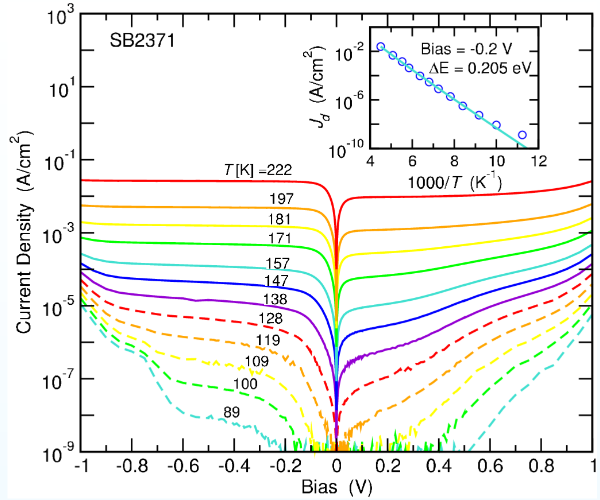
SF-400

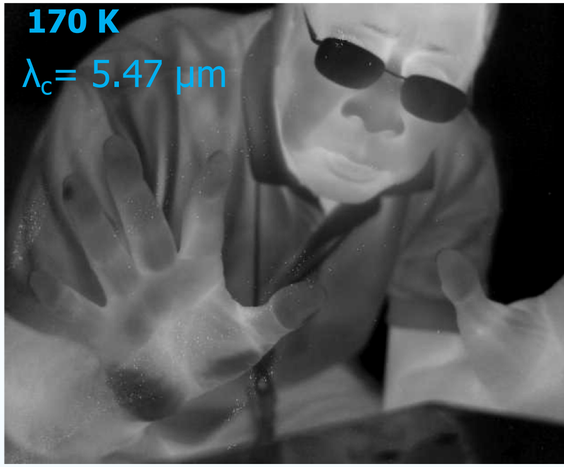
SF-070

Barrier Infrared Detector Technology

MWIR InAs/InAsSb T2SLS High Operating Temperature Barrier IR Detector (HOT-BIRD)





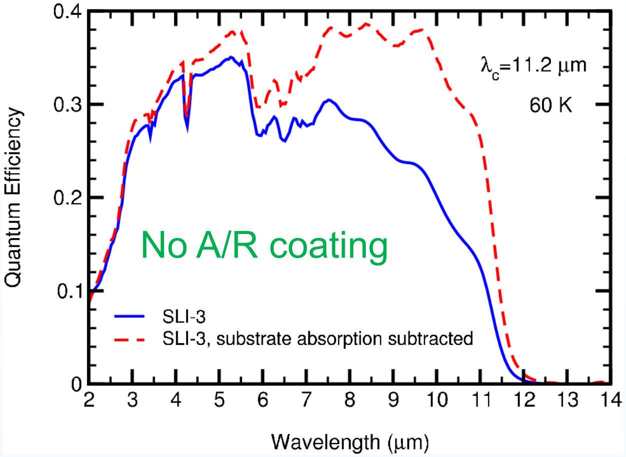


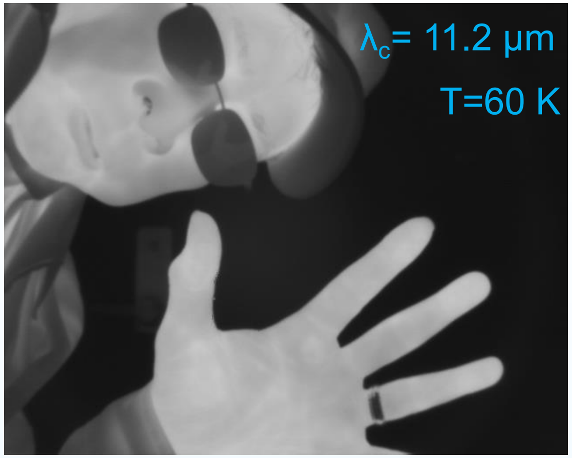
- QE(4.3 µm, 150K)=52% – No A/R coating
- J_{dark}(-0.2V, 157K)=9.6$\times 10^{-5}$ A/cm^2 (~4.5X Rule'07)
- 160K: NEDT 18.7 mK, Operability 99.7%
- 170K: NEDT 26.6 mK, Operability 99.6%
- FPA shows **significantly higher operating temperature than InSb**

"**B**arrier **I**nfra**R**ed **D**etectors", D. Z. Ting, A. Khoshakhlagh, A. Soibel, Cory J. Hill, and S. D. Gunapala, U. S. Patent No. 8,217,480 (2012)

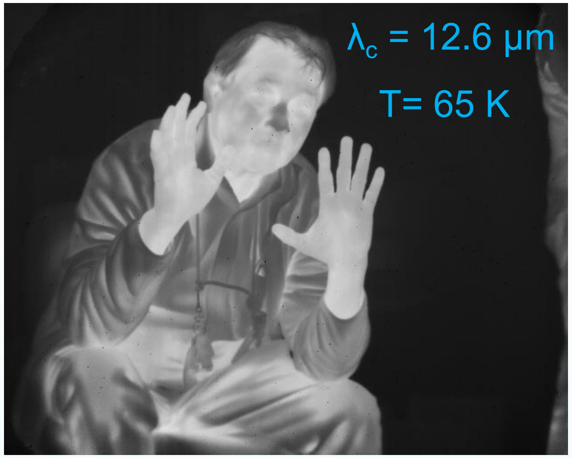
HOT-BIRD: "Mid-wavelength **h**igh **o**perating **t**emperature **b**arrier **i**nfra**r**ed **d**etector and focal plane array", D. Z. Ting, A. Soibel, A. Khoshakhlagh, S. B. Rafol, S. A. Keo, L. Höglund, A. M. Fisher, E. M. Luong, and S. D. Gunapala, *Appl. Phys. Lett.* **113** , 021101 (2018). doi: 10.1063/1.5033338

LWIR T2SL Detectors & FPAs





99.7% operability (17SLL03)



99.98% operability (18SLL03)

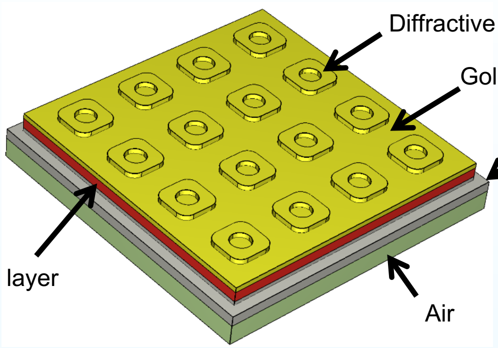
- Developing T2SL-based LWIR detectors for NASA Sustainable Land Imaging Technology (SLI-T) Program
- Unipolar barrier infrared detector architecture, T2SL absorber
  - High quality λ_{cutoff} ~ 11.2 μm T2SL absorber material
  - 240 ns minority carrier lifetime
  - $J_{dark}(60K) \sim 10^{-5}$ A/cm^2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

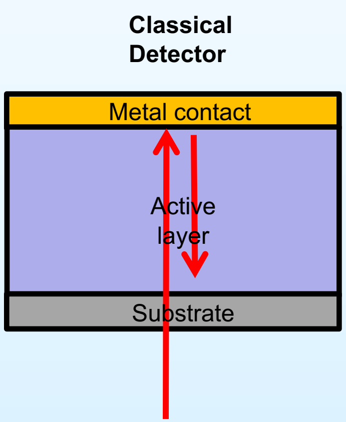
Resonator Pixel Technology

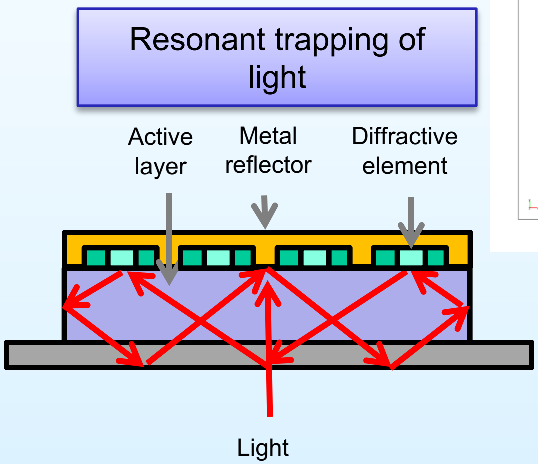
Resonator-Pixel Technology

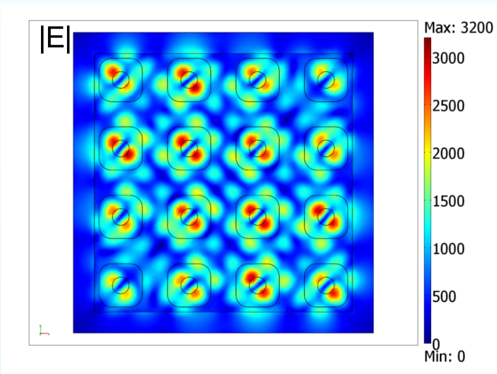
Concept:

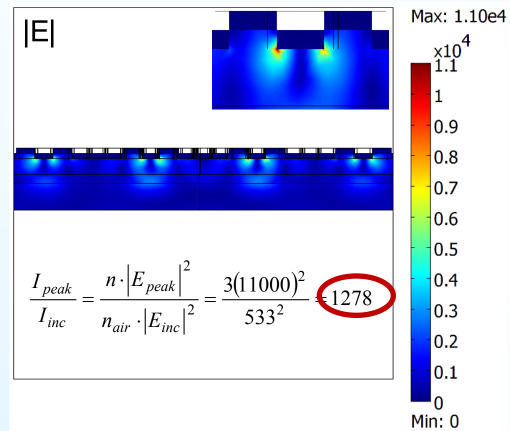
- Diffract incident light at an angle larger than the **critical angle** of total internal reflection to achieve three-dimensional optical confinement.
- Use pixel active volume as a resonator to achieve coherent accumulation of light.







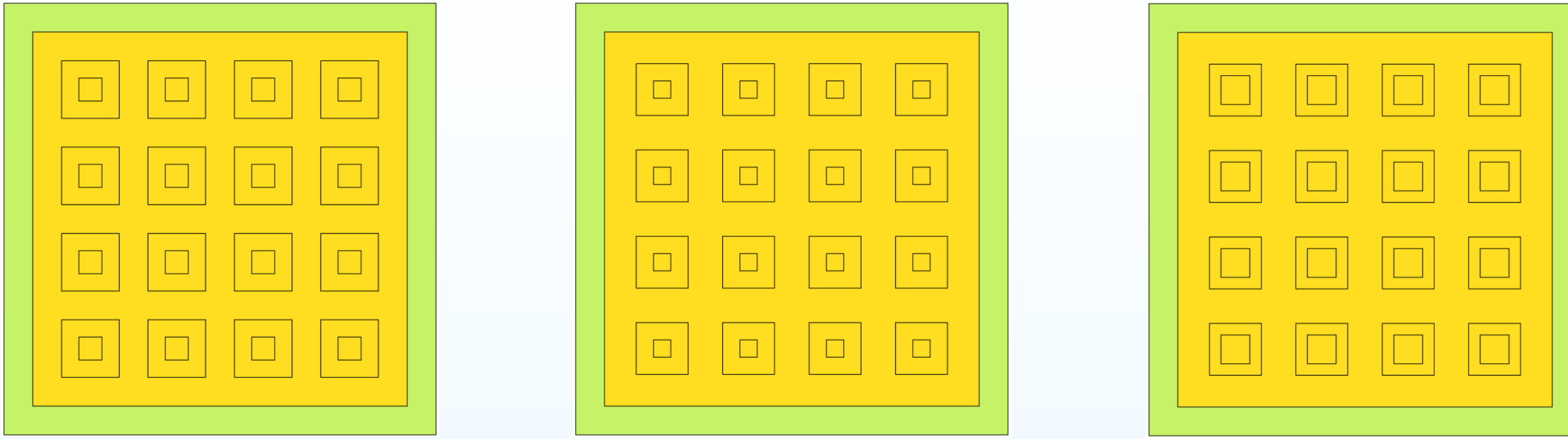


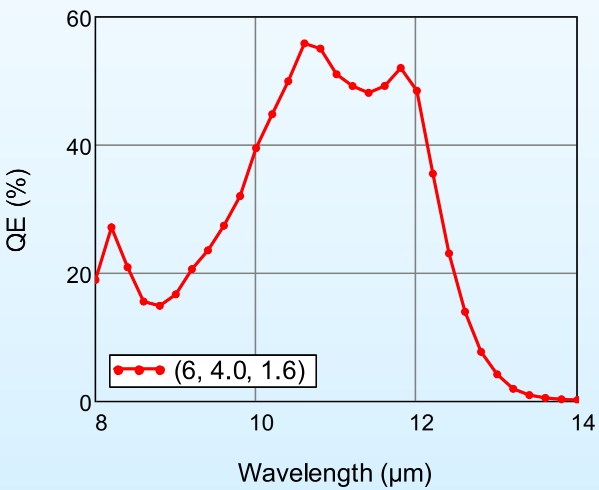


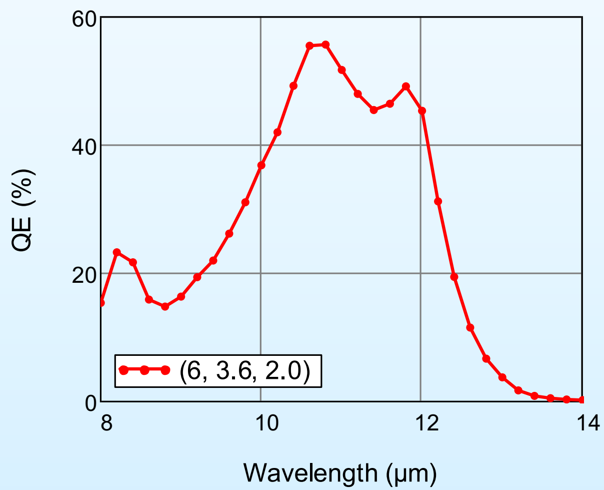
Advantages:

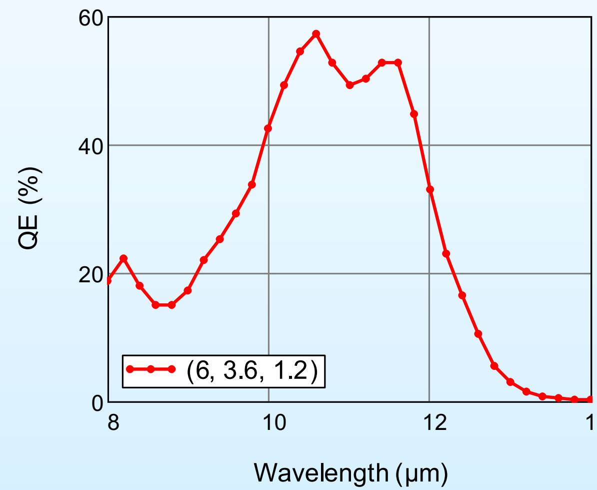
- Increases quantum efficiency
- Thin active layers (good for low carrier mobility)
- Low dark current (due to thin pixel)
- Free of anti-reflection coating

RP-BIRD, 6 μm Period

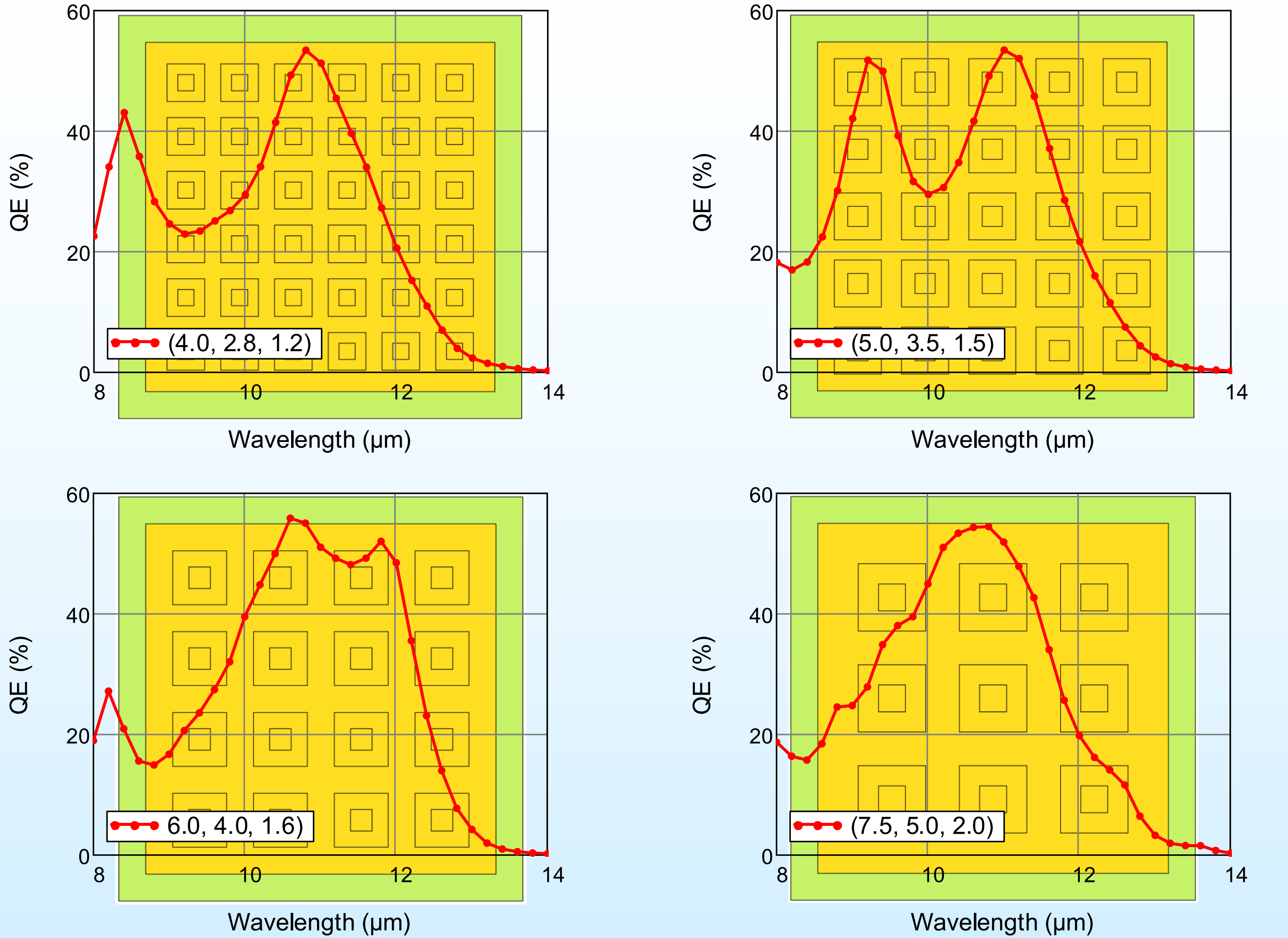








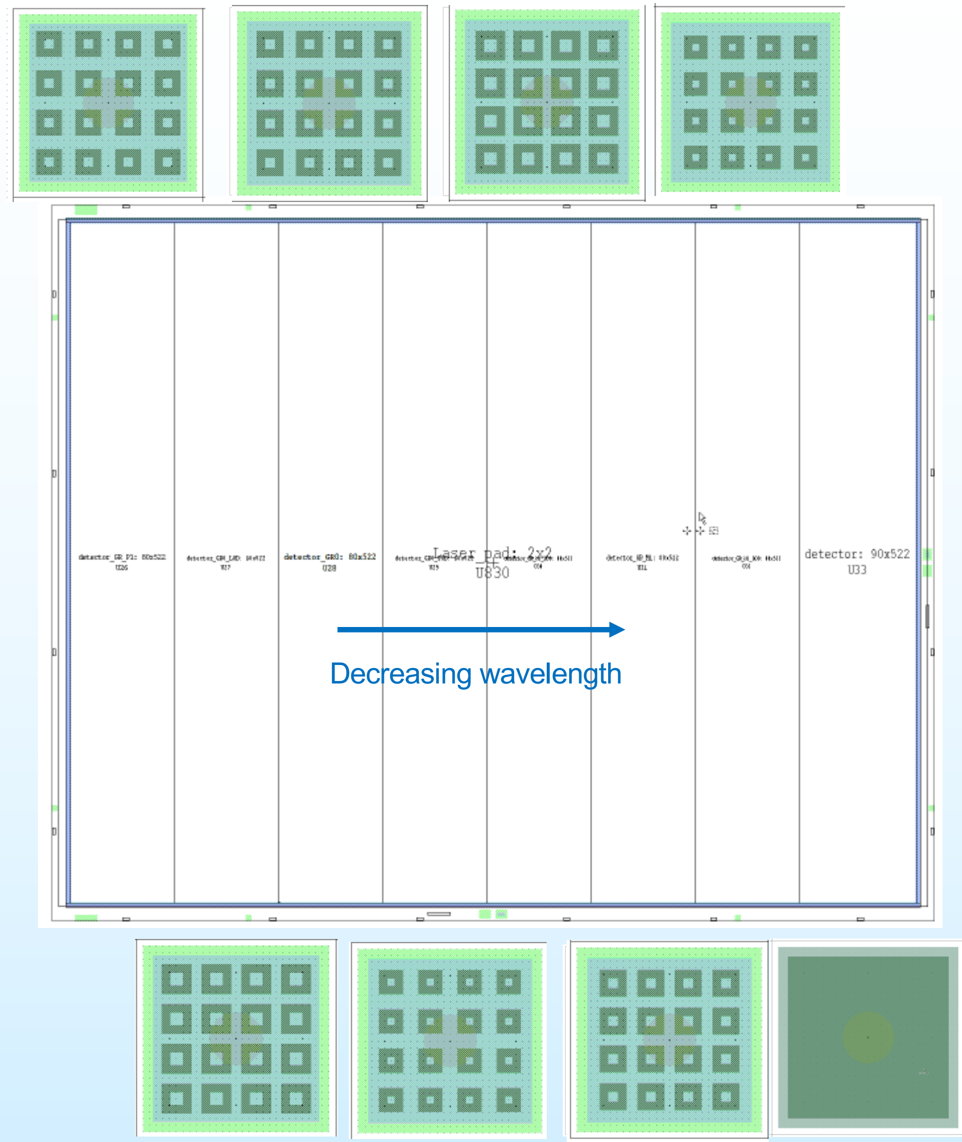
QE Spectrum with n x n Rings



ISC 0903 DA Layout #3 - Stripes

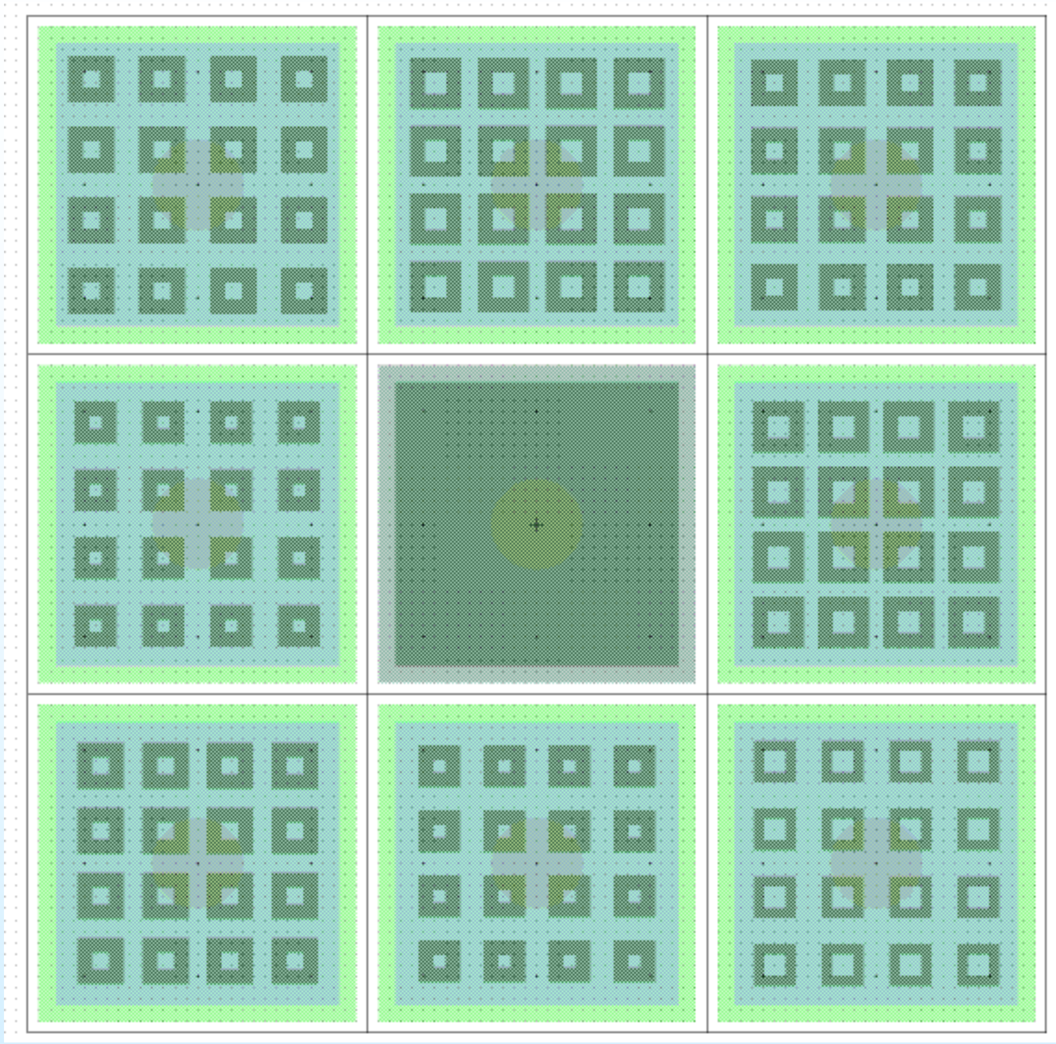
- Vertical arrangement
- 8 different designs for 40x256 stripes on the array

- Longest wavelength on the left

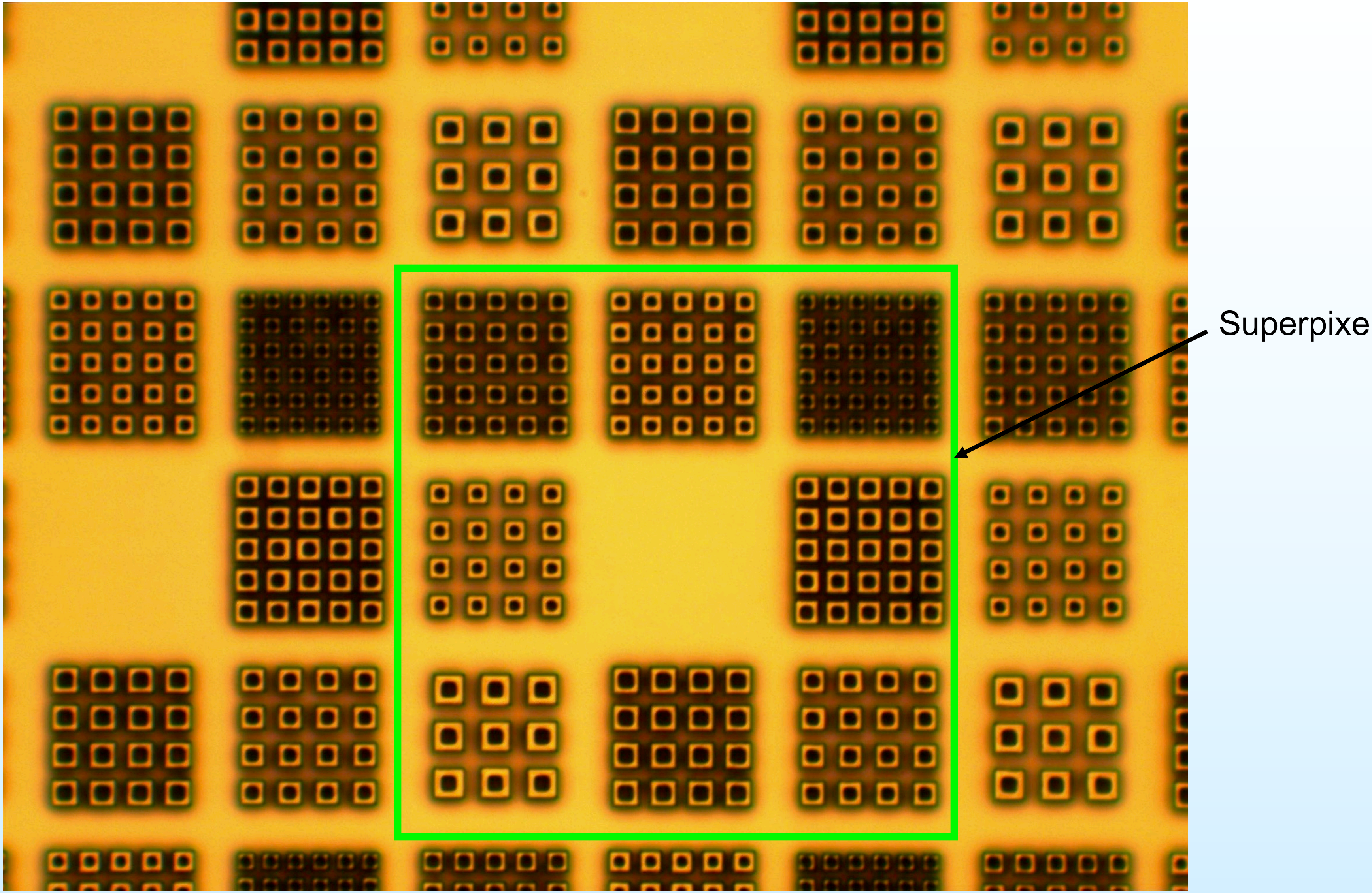


ISC 0903 FPA Layout #4 - Superpixel

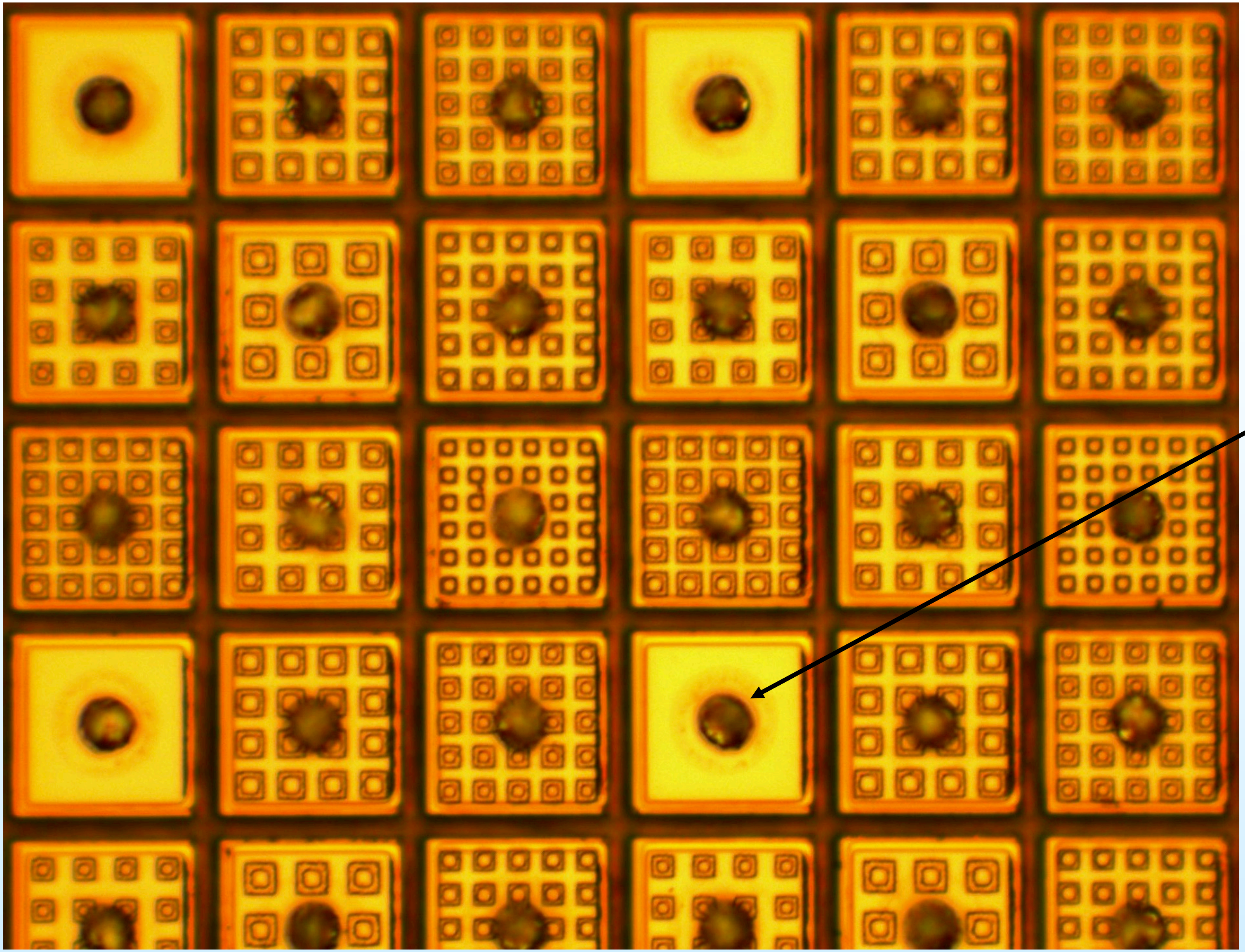
- 3x3 superpixel, pick out sub-frames with matlab
- Not as visceral as the stripes, but it's a good option to see all pixels uniformly distributed
- Could mix a few of these in with the striped ones
- Would have entire images to compare instead of stripes



Micrograph of Detector Array



Micrograph of Detector Array with In Bumps

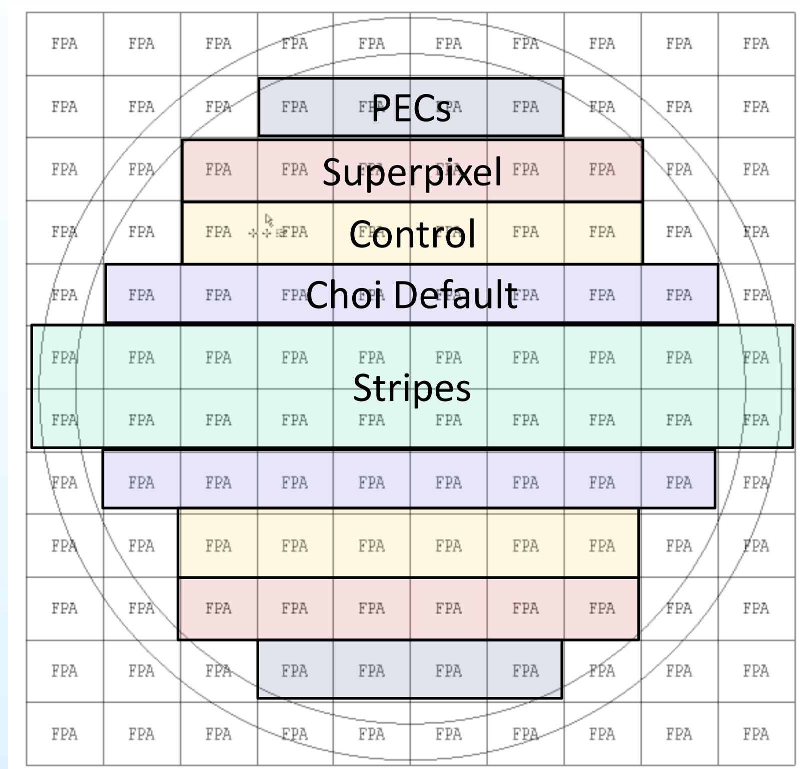


ISC 0903 based Detector Array Reticle Layout

Four permutations on the grating layer

- Normal (no grating)
- Choi's default
- 1x8 stripe (normal+7)
- 3x3 superpixel

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



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)

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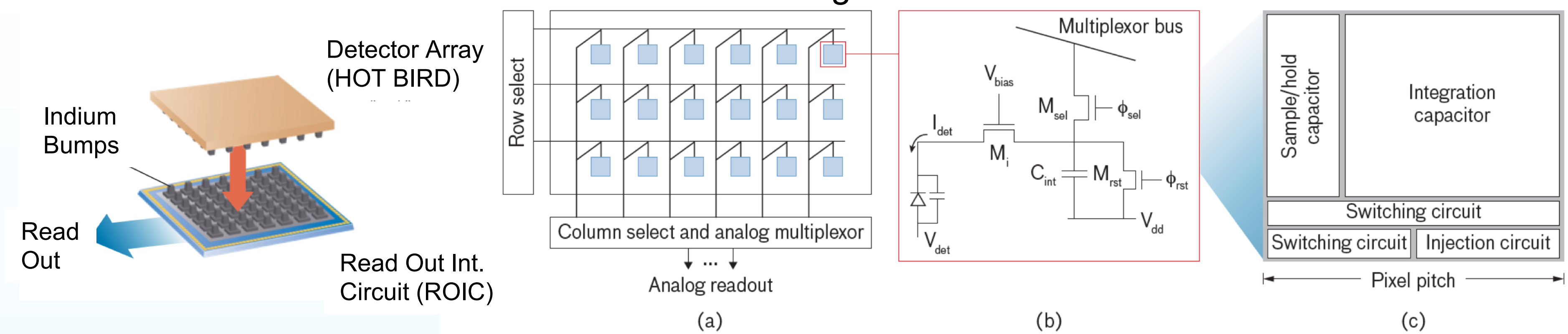
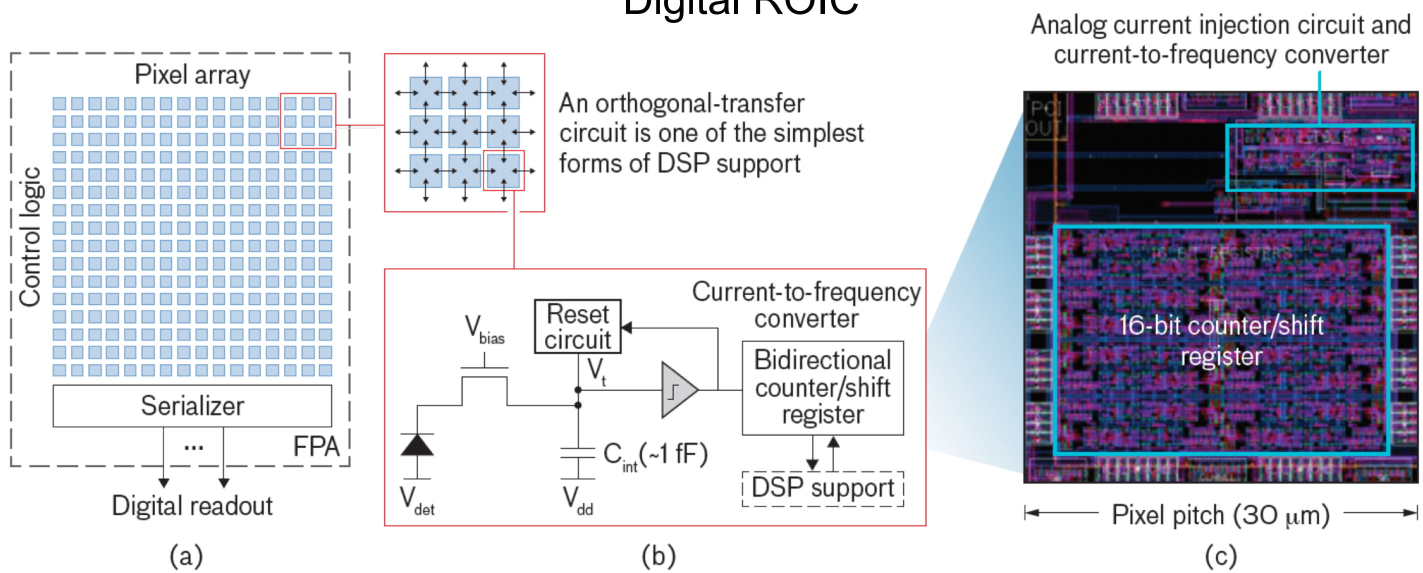
Analog ROIC



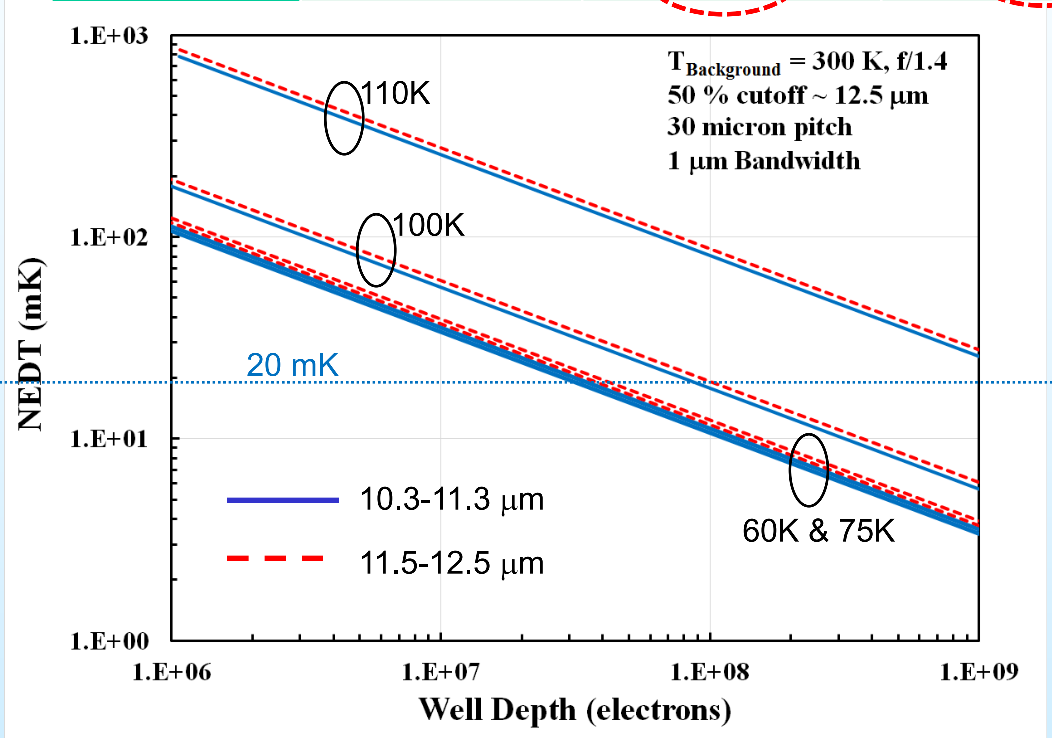
Digital ROIC



Ref: Kenneth I. Schultz, *et al.*, “Digital-Pixel Focal Plane Array Technology”, Lincoln Laboratory Journal, Vol. 20, Number 2 (2014).

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

ROIC	ISC-9803 AROIC	ISC-0905 AROIC	DRS 3D-DROIC	DRS 3D-DROIC	DRS 3D-DROIC
Binning	1×1	1×1	1×1	3×3	4×4
ROIC Format	640×512	640×512	2004×2008	668×668 (eff.)	501×502 (eff.)
Pixel Pitch	25 µm	30 µm	8 µm	24 µm (eff.)	32 µm (eff.)
Well Depth	11 Me$^-$	18 Me$^-$	173 Me$^-$	1,560 Me$^-$ (eff.)	2,780 Me$^-$ (eff.)

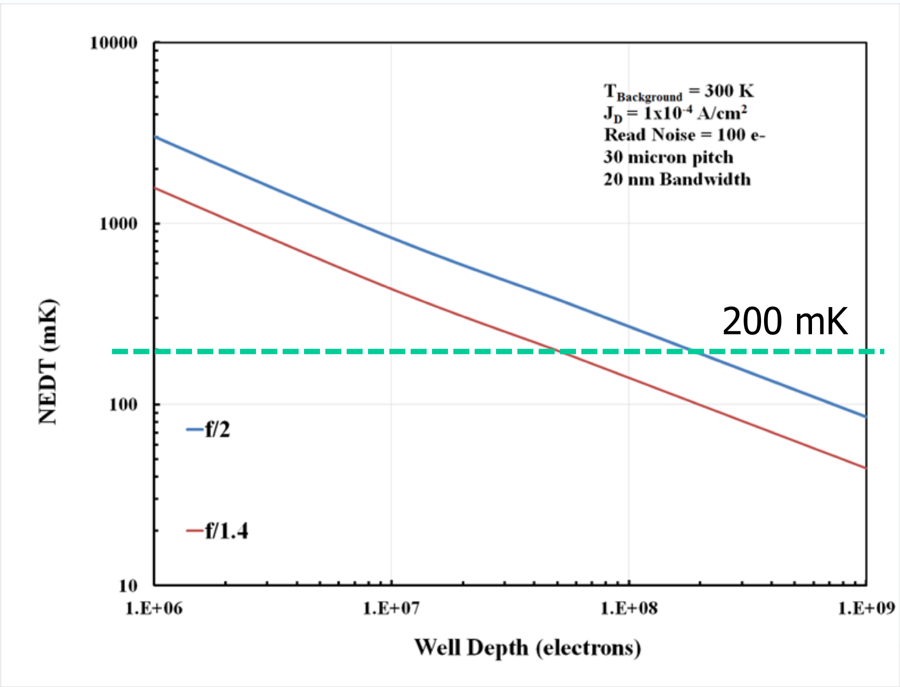


$$SNR_{Max} = \frac{Signal_{Max}}{Noise} = \sqrt{Well\ Depth_{Max}}$$

- 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

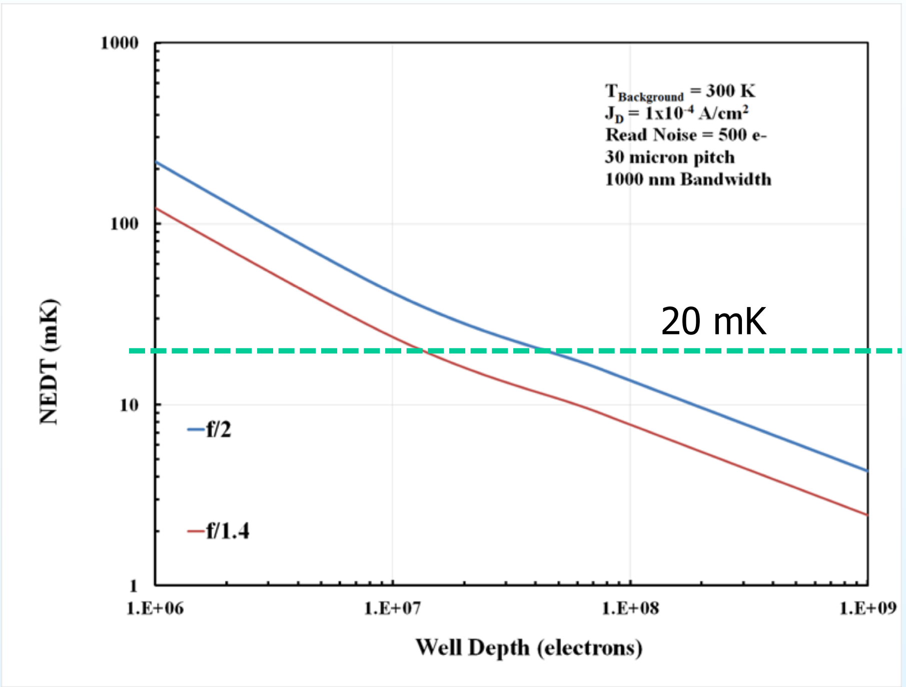
Estimated MWIR Performance with DROICs

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

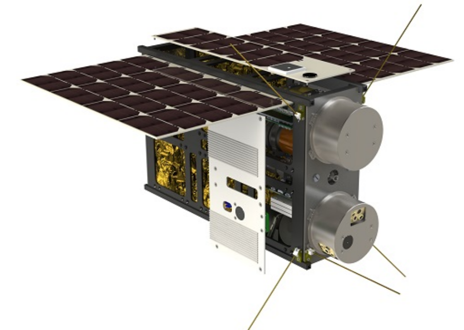
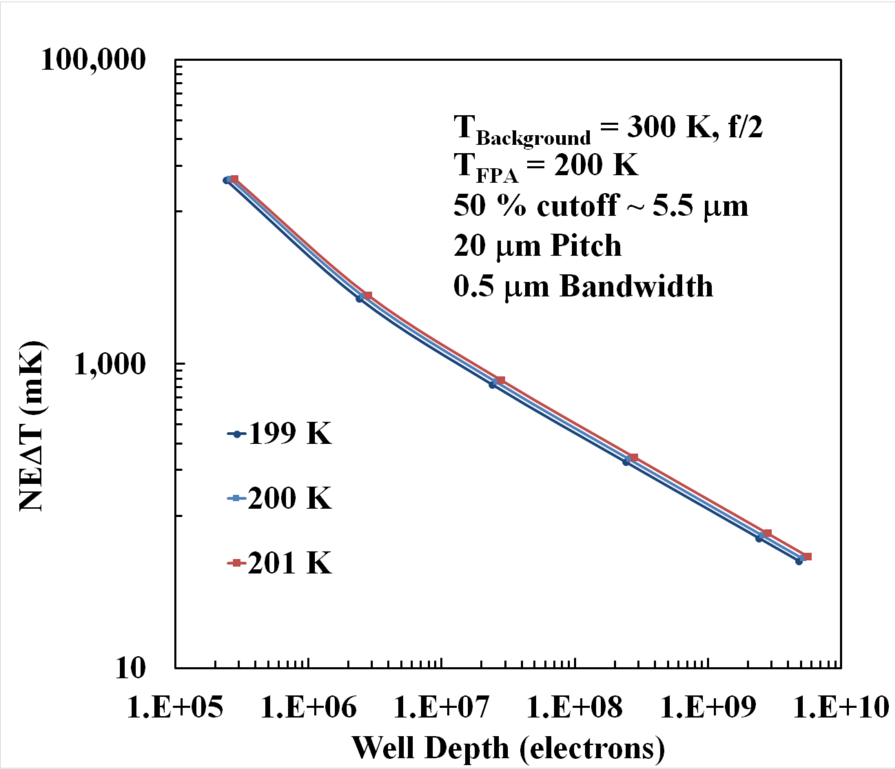


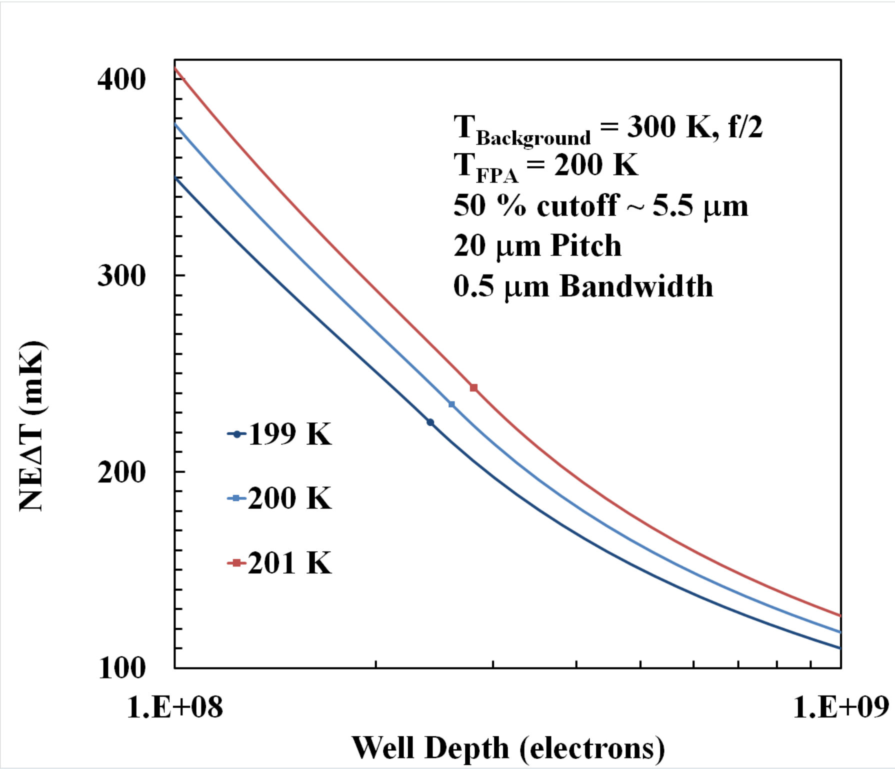
Image Credit: https://n-avionics.com/

- RP-BIRD DFPA elevates the operating temperature of FPAs
  - Lowers the SWaP factor
  - Enables the low cost Cubesats & Smallsats (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

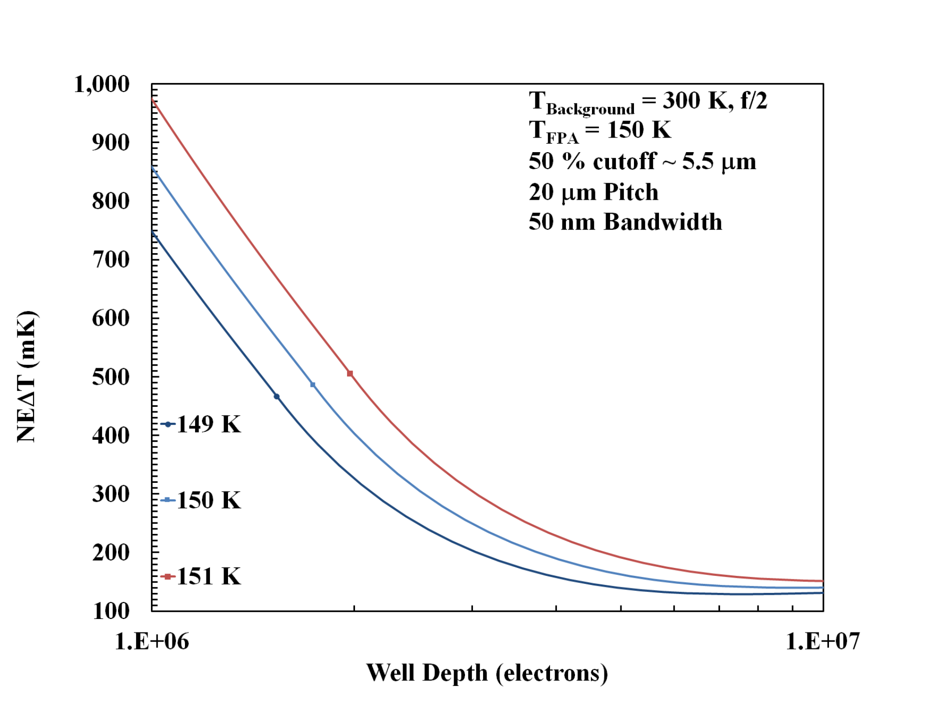
Spectral Bandwidth 0.5 μm about 5 μm center

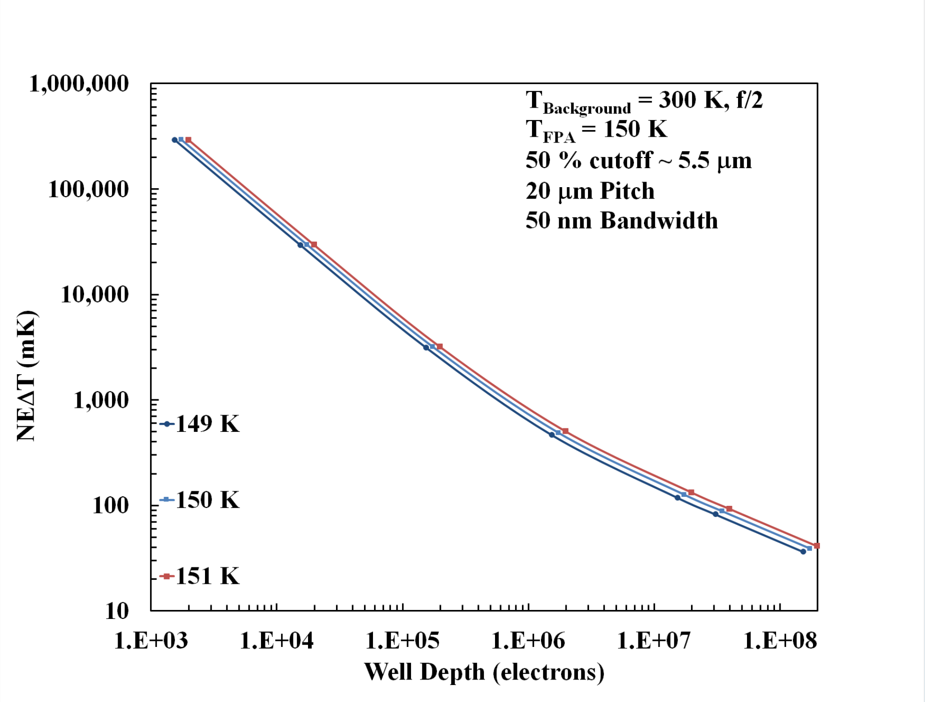




Smaller Fluctuation in NEΔT at longer integration time or deeper well than in shorter integration time or shallower well. For example, at 10^9 electrons well depth, NEΔT fluctuation ~ 17 mK peak-to-peak and at $2x10^8$ electrons well depth, NEΔT fluctuation ~ 55 mK peak-to-peak for ± 1 K variation about the operating temperature of 200 K.

Spectral Bandwidth 50 nm about 5 μm center





Smaller Fluctuation in NEΔT at longer integration time or deeper well than in shorter integration time or shallower well. For example, at 10^7 electrons well depth, NEΔT fluctuation< 30 mK peak-to-peak and at 1×10^6 electrons well depth, NEΔT fluctuation < 230 mK peak-to-peak for $\pm$ 1 K variation about the operating temperature of 150 K.