Development of Megapixel MWIR & LWIR QWIP Focal Planes Arrays & 320 x 256 Pixel Dualband QWIP Focal Plane Arrays

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SPONSOR: MDA & JPL/NASA

TEAM

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- Radiometric Calculations
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- Test Device and FPA Fabrication
  - John Liu
  - Sam Keo
  - Jason Mumolo
  - Jian Li
- ROIC
  - Jim Woolaway – FLIR Indigo
- FPA Hybridization
  - Craig Shott – FLIR Indigo
  - Diane Zalasar – FLIR Indigo
- Packaging and Mounting Detectors & FPAs
  - John Liu
  - Sam Keo
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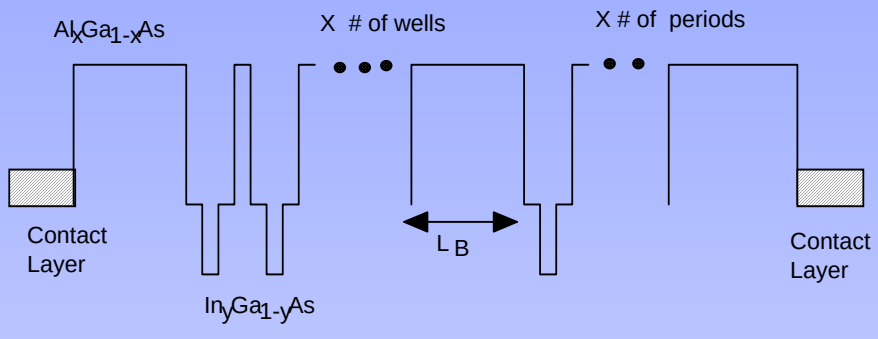
- Test Device Characterization
  - Sumith Bandara
  - Julianne Liu
  - Jason Mumolo
  - Joseph Thang
- Data Analysis
  - Sumith Bandara
  - Jason Mumolo
- FPA Characterization
  - Jason Mumolo
- Electronics
  - Mark Stegal - SEIR
- Camera Integration & Testing
  - Jason Mumolo
  - Joseph Thang

OUTLINE

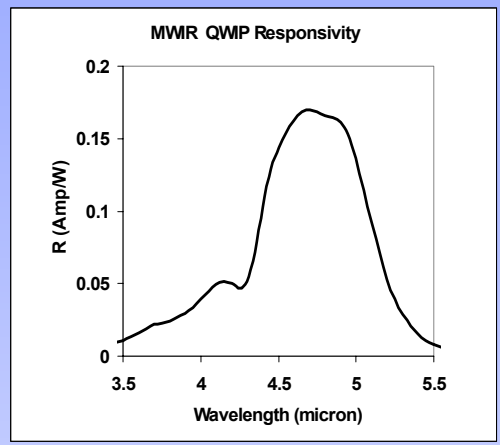
- 1K x 1K MWIR Focal Plane Array
- 1K x 1K LWIR Focal Plane Array
- 320 x 256 Dual-band FPA & Camera
- Summary

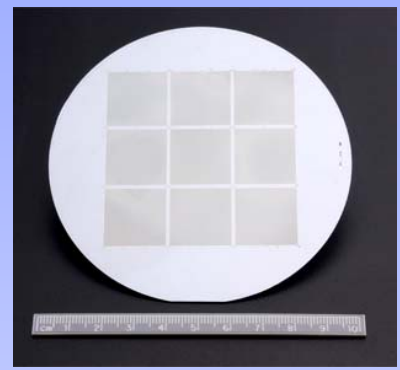
1024 x 1024 PIXEL MWIR CAMERA

BROADENED MWIR RESPONSE FOR SPECIFIC DOD APPLICATION



QWIP Device Structure





Nine 1024 x 1024 QWIP Focal Plane Arrays (FPAs) on 4-inch GaAs Wafer

- Increased the spectral coverage by utilizing a multi-coupled-quantum-well structure for tracking missiles during boost phase.
- Grown on 4-in GaAs wafers.

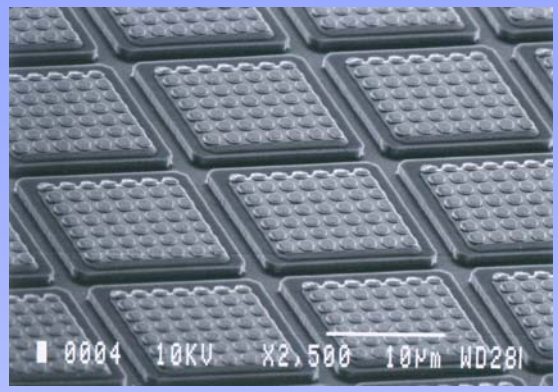
• S. V. Bandara, S. D. Gunapala, J. K. Liu, E. M. Luong, J. M. Mumolo, W. Hong, D. K. Sengupta, and M. J. McKelvey, "10-16 µm Broadband Quantum Well Infrared Photodetector", Appl. Phys. Lett. **72**, 2427 (1998).

* Sarath D. Gunapala, Sumith V. Bandara, John K. Liu, Sir B. Rafol, and Jason M. Mumolo, "640x512 Pixel Long-wavelength Infrared Narrowband, Multiband, and Broadband QWIP Focal Plane Arrays" IEEE Trans. Electron Devices, **50**, pp. 2353-2360, 2003.

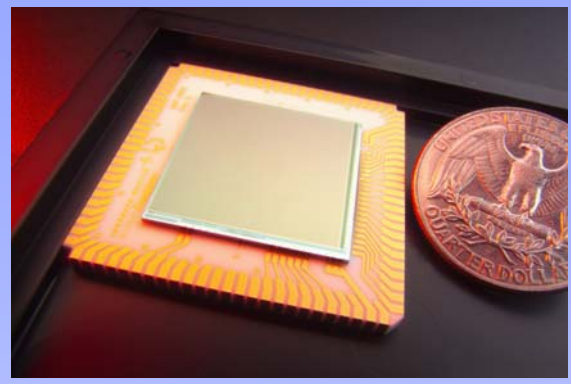
1024X1024 PIXEL QWIP FPA SPECIFICATIONS FOR THIS APPLICATION

SPECTRAL RANGE	- 4.4 - 5.1 μm
PIXEL PITCH	- 19.5 μm
PIXEL ACTIVE AREA	- 17.5 x 17.5 μm^2
ABSORPTION (peak) Q.E.	- 19%
GAIN	- 0.3
RESPONSIVITY	- 0.27 A/W
OPERATING TEMP.	- 80 - 110 K
FRAME RATE	- 30 Hz
NON-U (UNCORRECTED)	- 5.6%
NON-U (CORRECTED)	- 0.05%
OPERABILITY	- 99.98%
NEF*	- 2 X 10^{-16} W/cm^2
OPTICS	- f/2.3; 400 mm & f/2; 38 mm

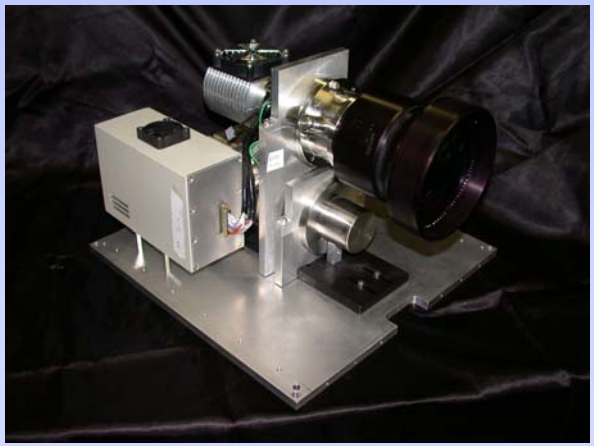
1024X1024 PIXEL MWIR QWIP FPA AND CAMERA DELIVERED TO THIS APPLICATION



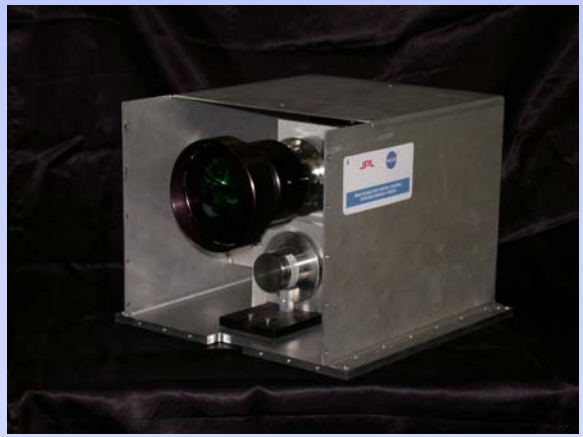
Detector pixel with light coupling gratings



1024 x 1024 pixel QWIP focal plane array



1Kx1K MWIR sensor engine

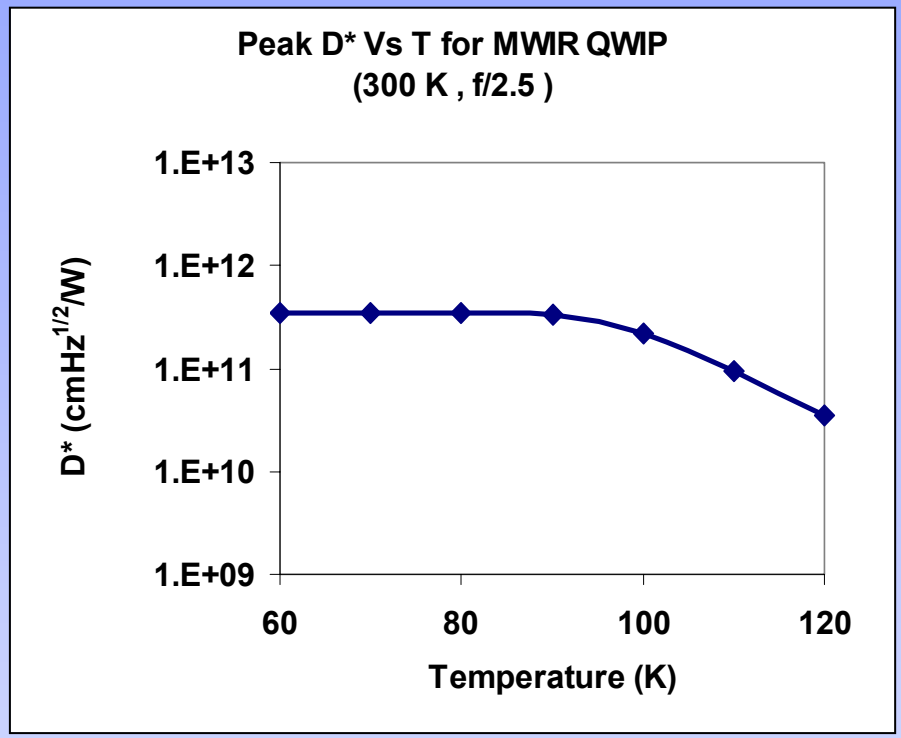


1Kx1K MWIR QWIP camera

1024 x 1024 PIXEL QWIP FPA IMAGERY

- NEΔT OF 19 mK WAS ACHIEVED.

DETECTIVITY AND NEF



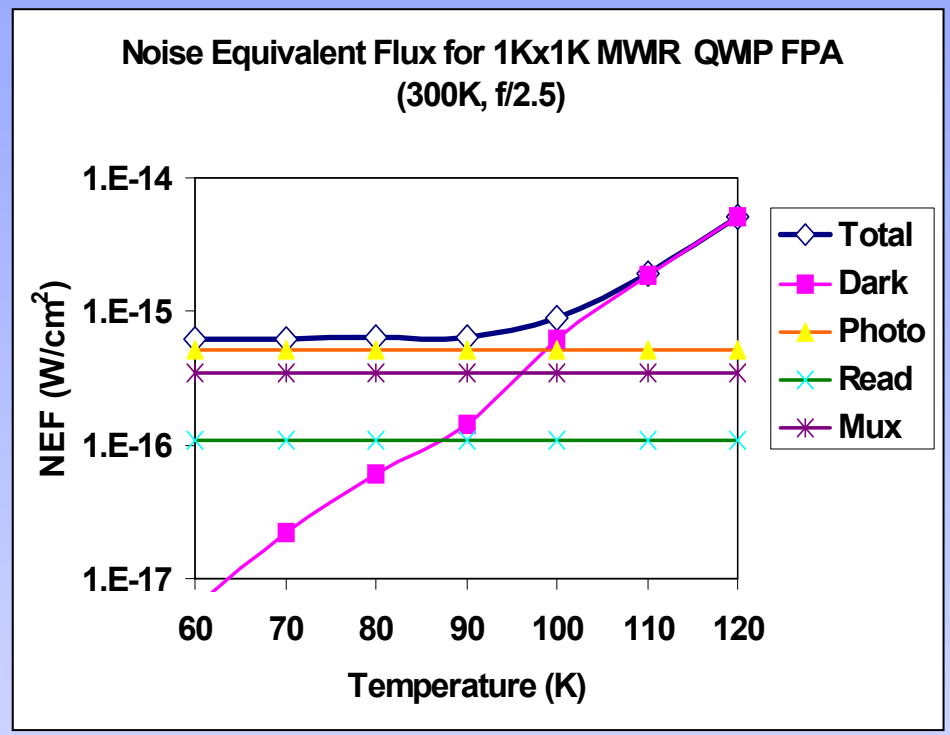
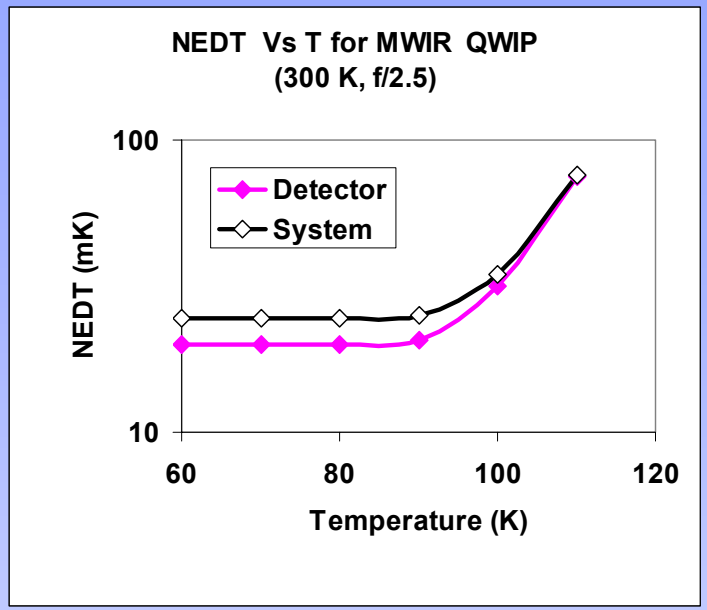
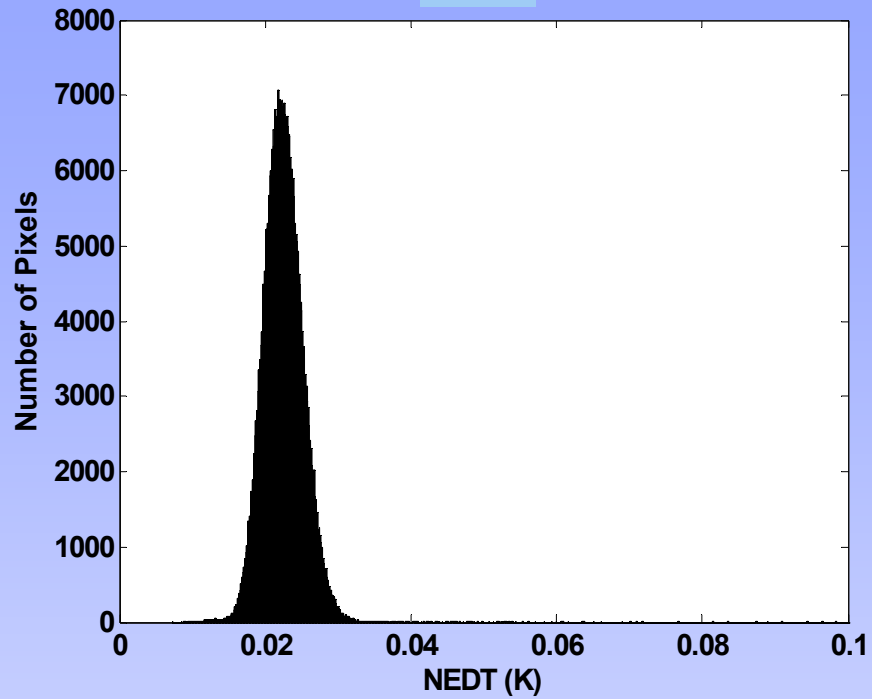


IMAGE OF THE EXIT SLIT OF MONOCHROMATOR

NORMALIZED SPECTRAL RESPONSE

NEΔT



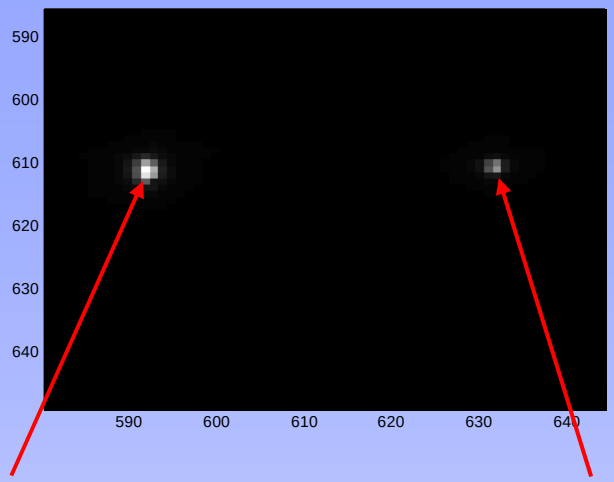


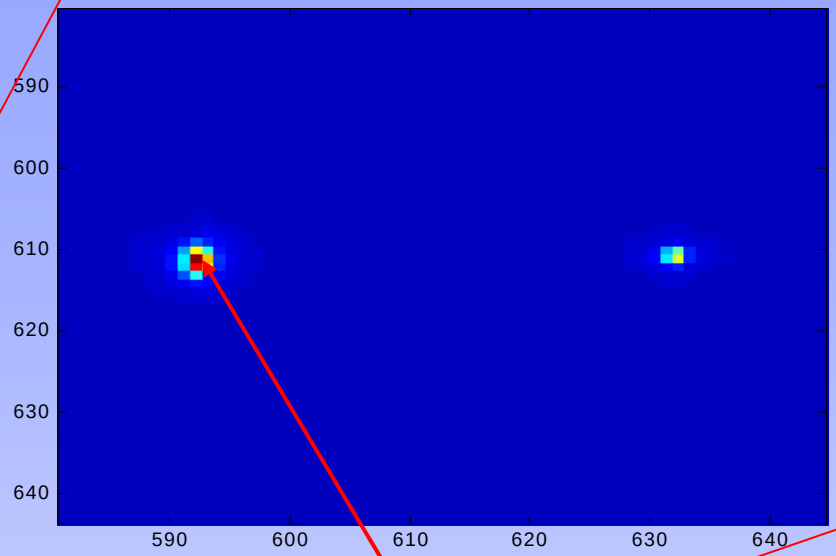
NOISE EQUIVALENT TEMPERATURE DIFFERENCE

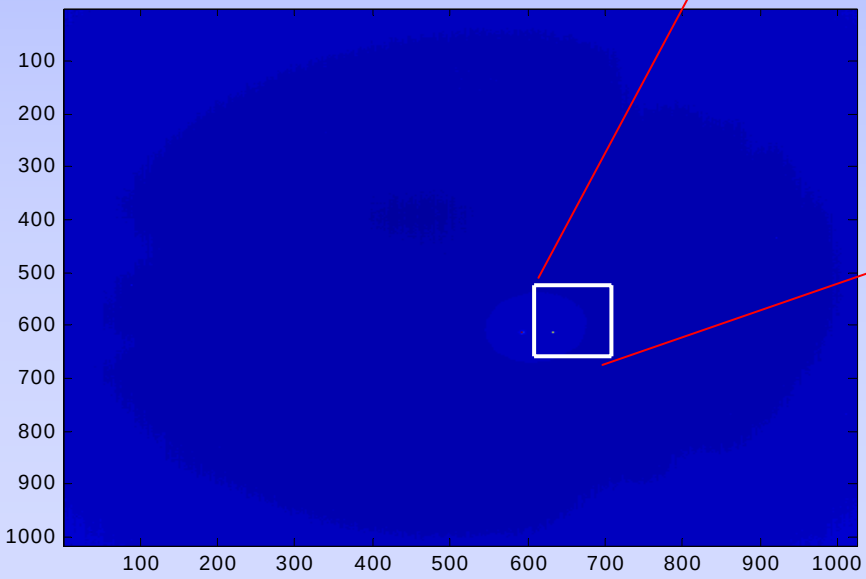
NOISE EQUIVALENT TEMPERATURE DIFFERENCE HISTOGRAM

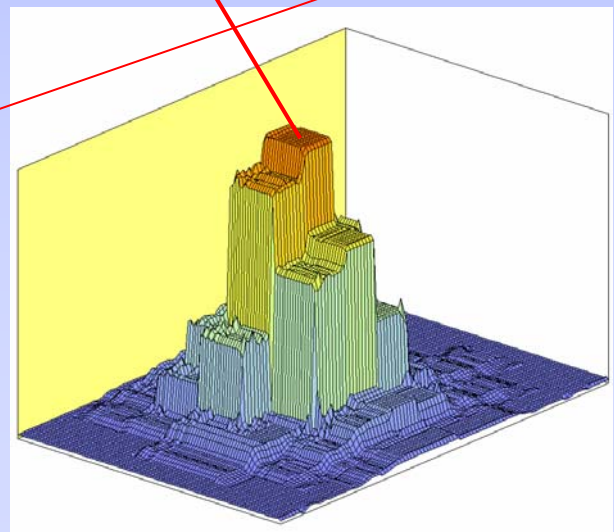
- NEΔT = 22 mK (= 19 mK if ADC noise is subtracted)
- Uniformity = 0.03%
- Operability = 99.5%

POINT SPREAD FUNCTION

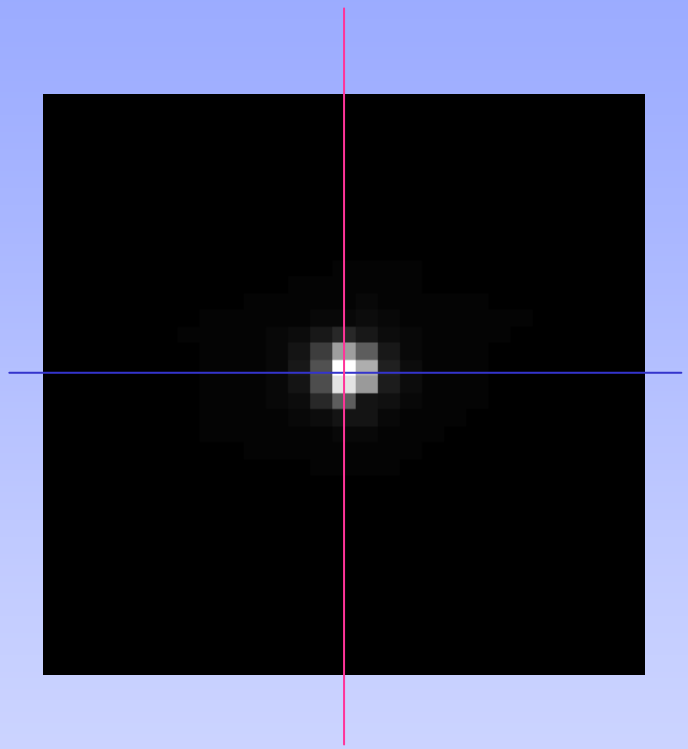




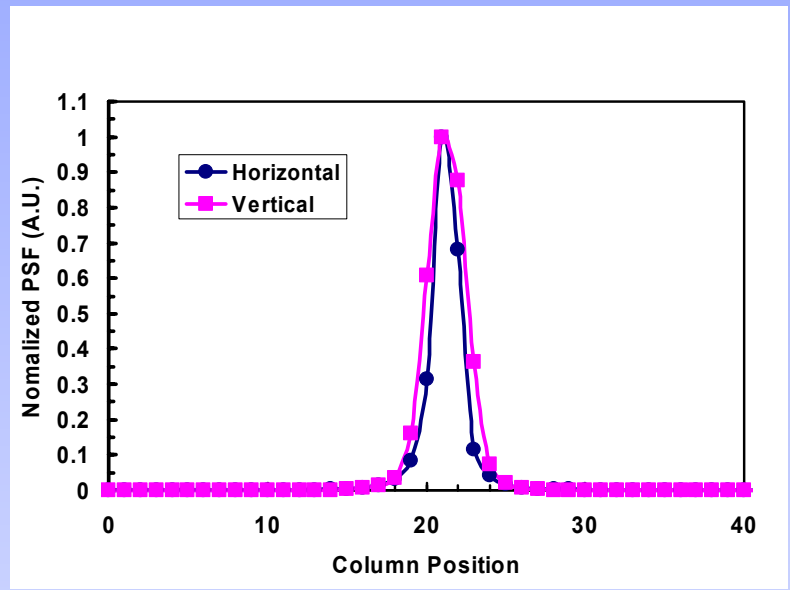




CROSS SECTION OF 3-D PSF



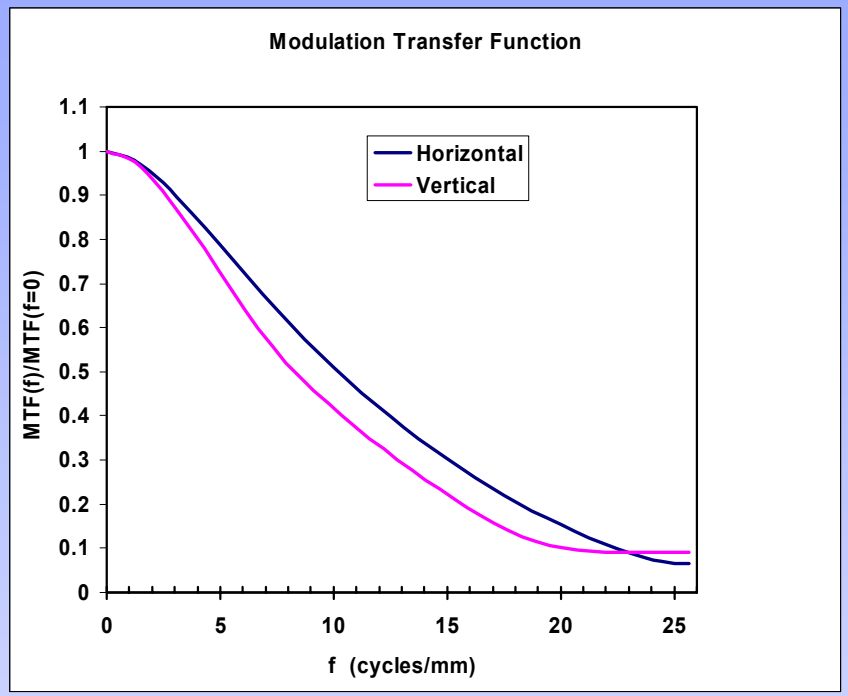
POINT SPREAD FUNCTION



POINT SPREAD FUNCTION

MODULATION TRANSFER FUNCTION

MTF WITHOUT LENS CORRECTION

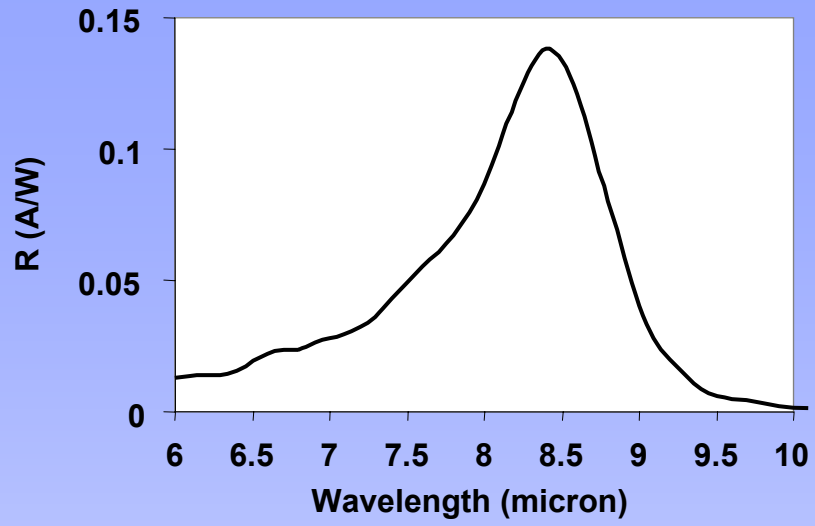


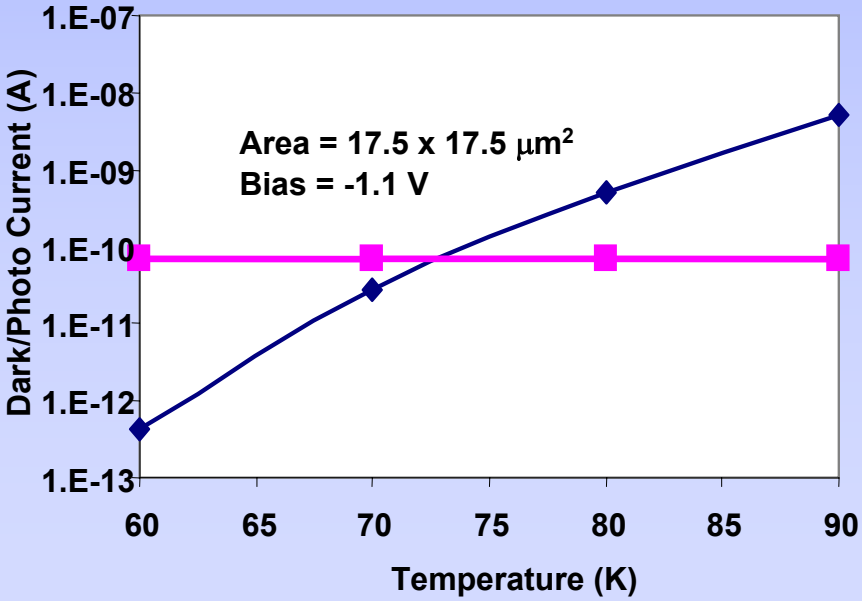
MTF of Lens	–	0.2
Pixel Pitch	–	19.5 µm
Nyquist Frequency	–	25.6 Cy/mm

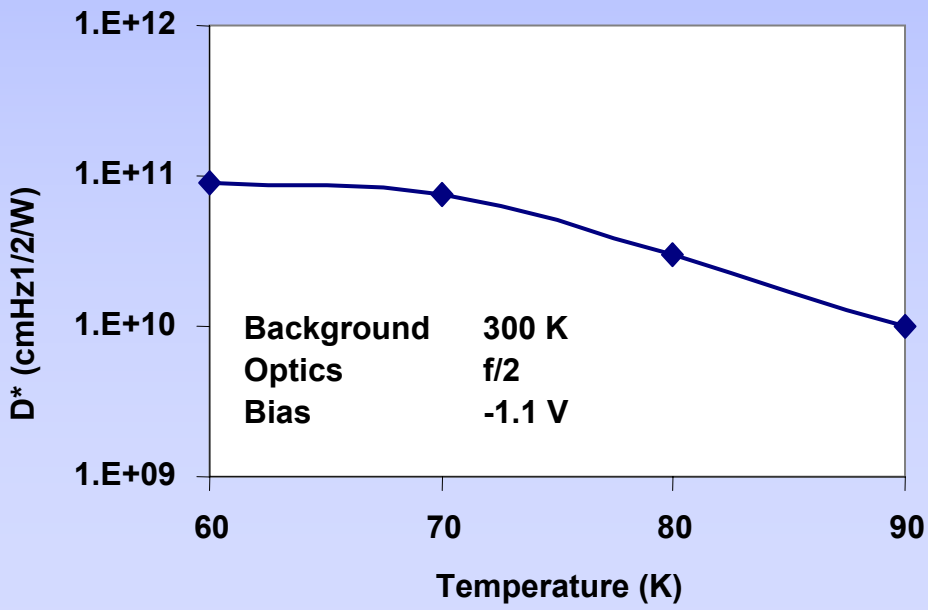
$$MTF_{system} = MTF_{framegraber} \times MTF_{cabling} \times MTF_{focalplane} \times MTF_{lens}$$
$$MTF_{framegraber} \times MTF_{cabling} \times MTF_{focalplane} = 0.5$$
$$MTF_{focalplane} > 0.5$$

1024 x 1024 PIXEL LWIR CAMERA

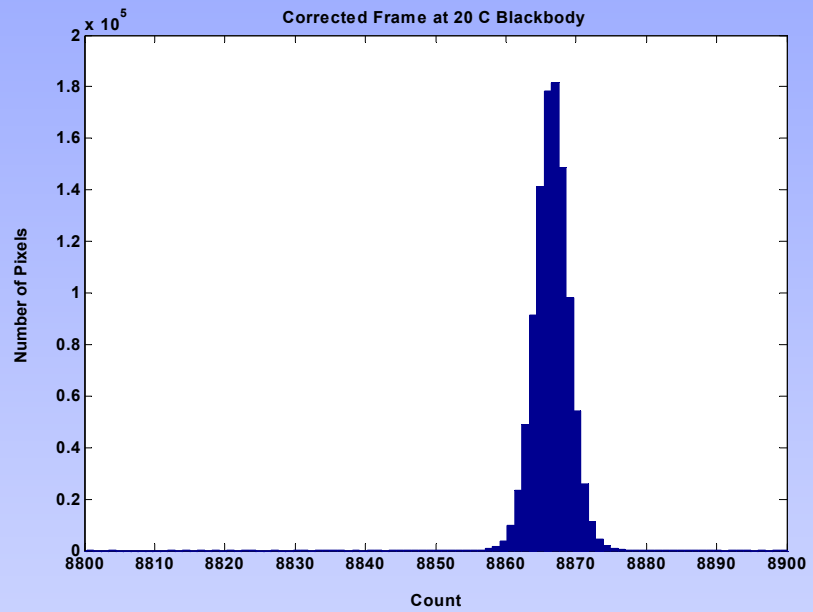
FIGURES OF MERIT







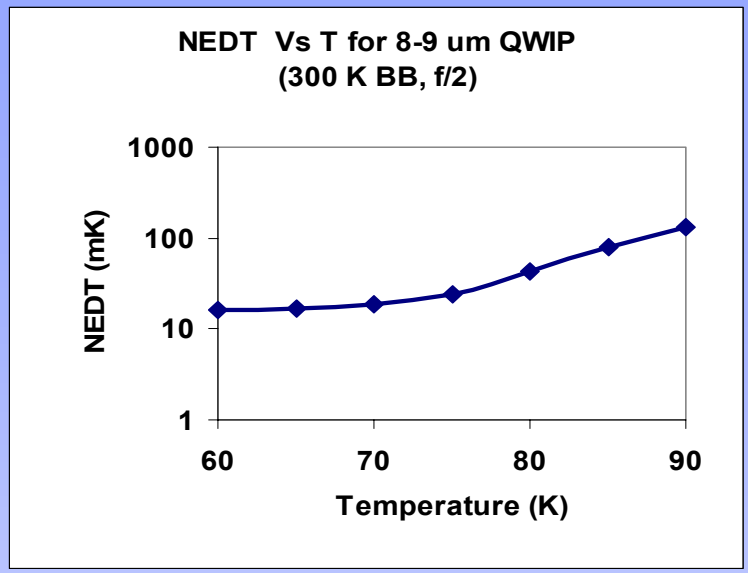
CORRECTED IMAGE



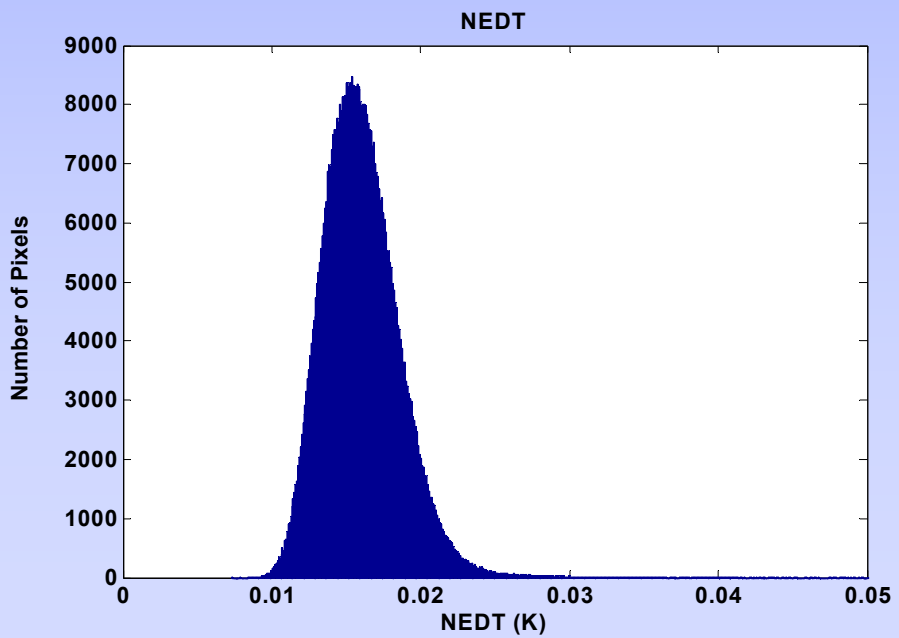
Nonuniformity ~ 0.8 %

Operability ~ 99.98%

NEΔT



NEΔT = 16
Window Transmission Assume 95 %
Detector Bias = 1 V,
Integration time = 29 msec,
Operating Temperature = 67 K



$$n_{sys}^2 = n_{Detector}^2 + n_{ADC}^2 + n_{MUX}^2$$

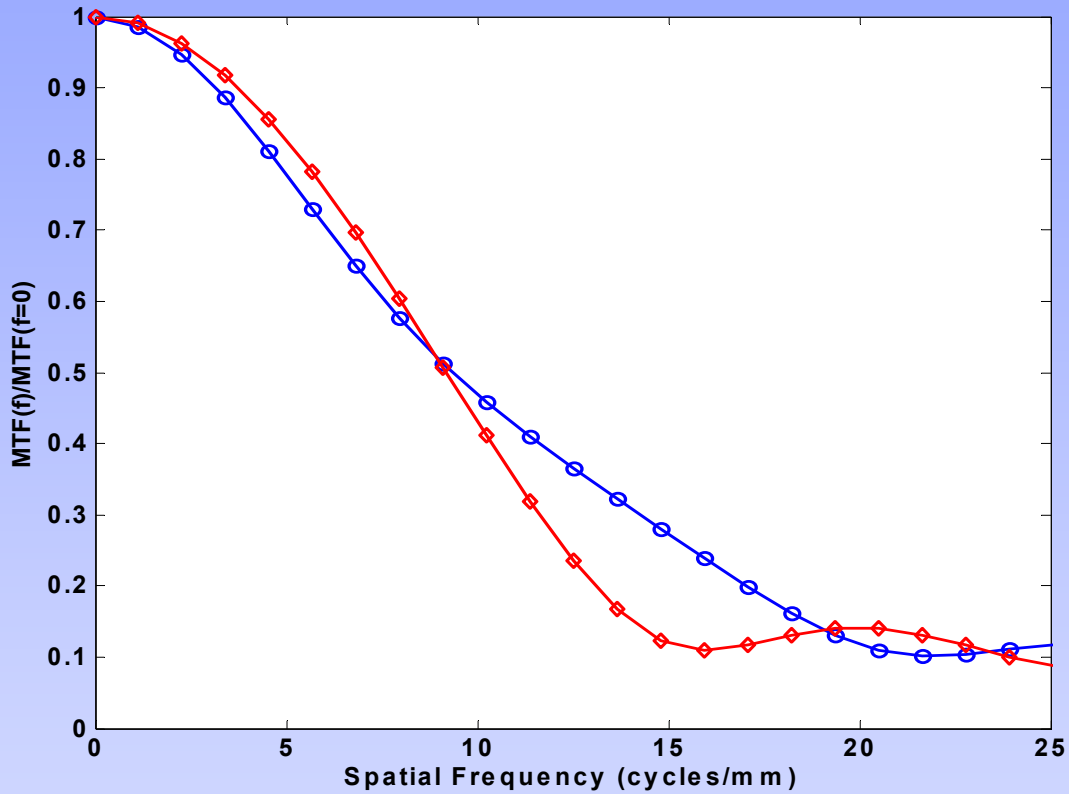
$$2.4^2 = n_{Detector}^2 + 0.8^2 + 1.0^2$$

$$n_{Detector} = 2.0$$

$$NEDT_{Detector} = 13\ mK$$

MODULATION TRANSFER FUNCTION

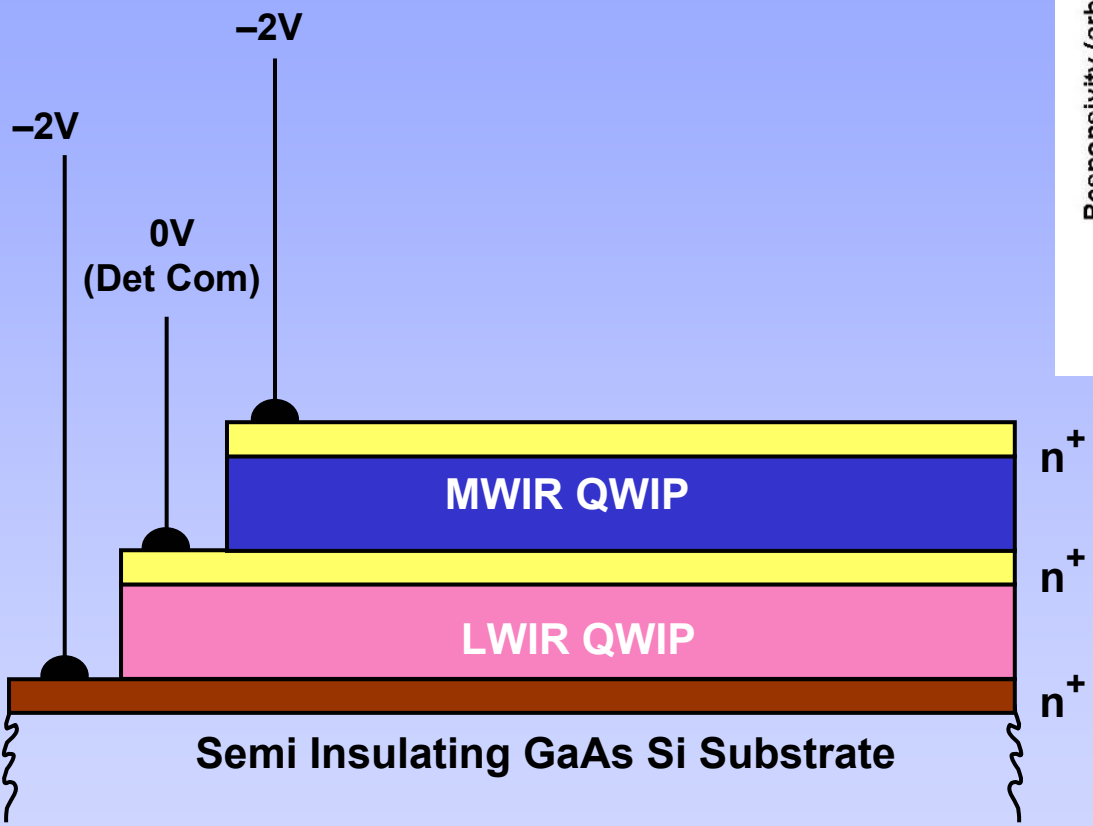
MTF Without Lens Correction

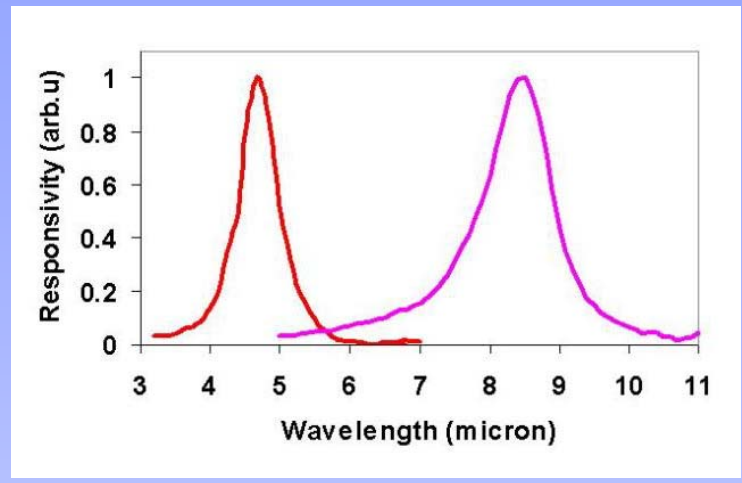


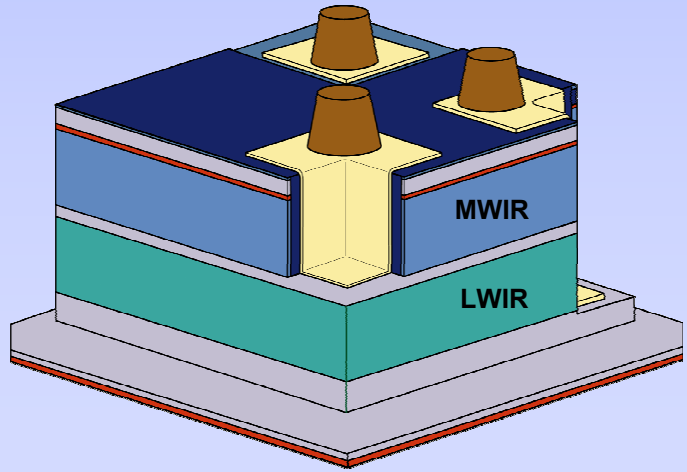
- Blue Horizontal MTF
- Red Vertical MTF
- Diffraction Limit at ~ 21 cyc/mm, f/# = 2.3
- Nyquist at ~ 25.6 cyc/mm
- $MTF_{focalplane} > 0.5$
- Frequency above 21 cyc/mm is not justified since it is beyond diffraction limit blurred circle.

PIXEL CO-REGISTERED SIMULTANEOUSLY READING DUALBAND (MWIR & LWIR) QWIP FPA

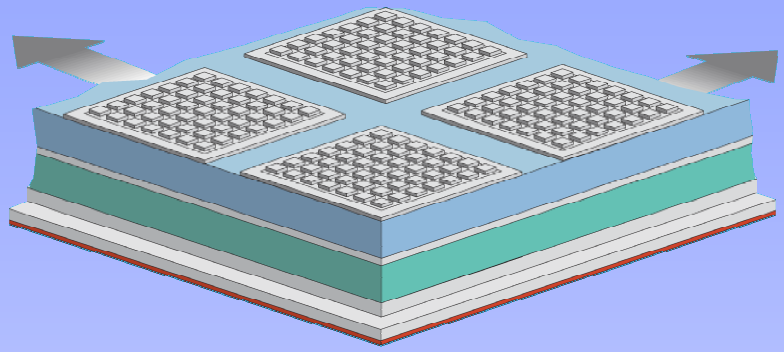
DUAL-BAND (MWIR & LWIR) DETECTOR



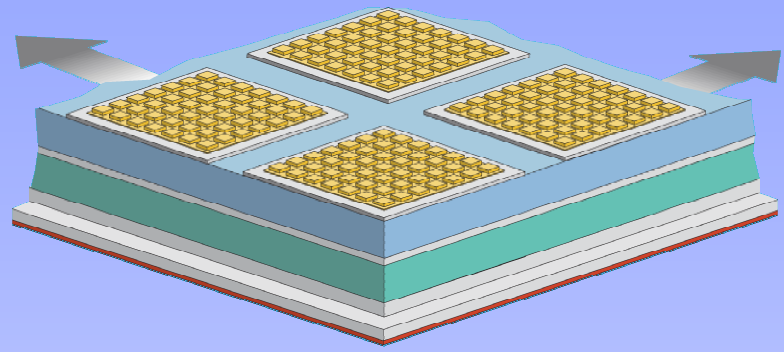




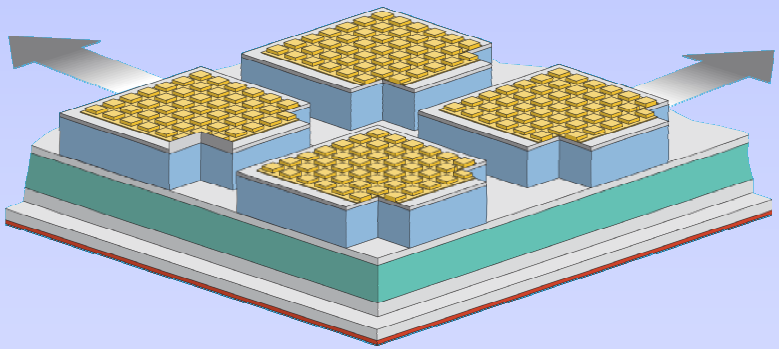
DUAL-BAND FPA FABRICATION PROCESS



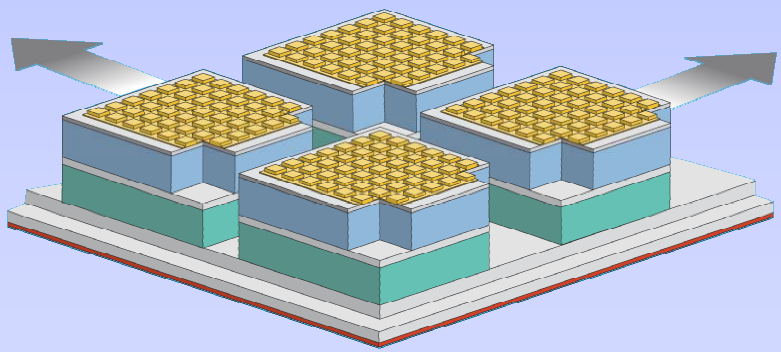
Grating Etch



Top Metal Deposit

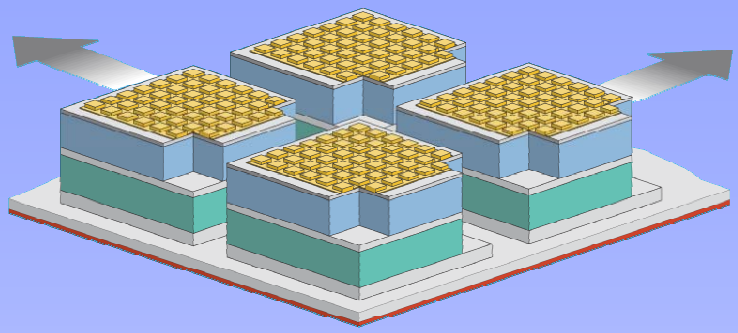


First Mesa Etch

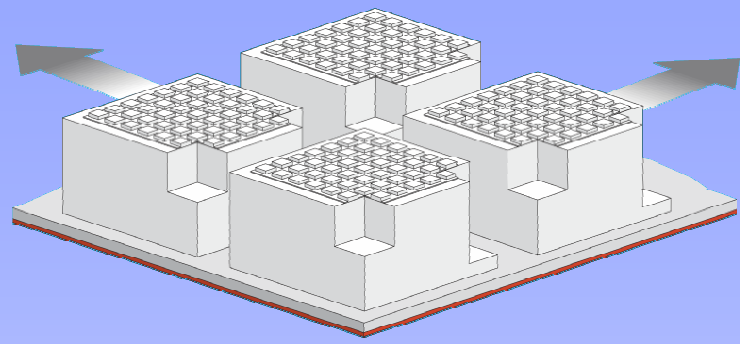


Second Mesa Etch

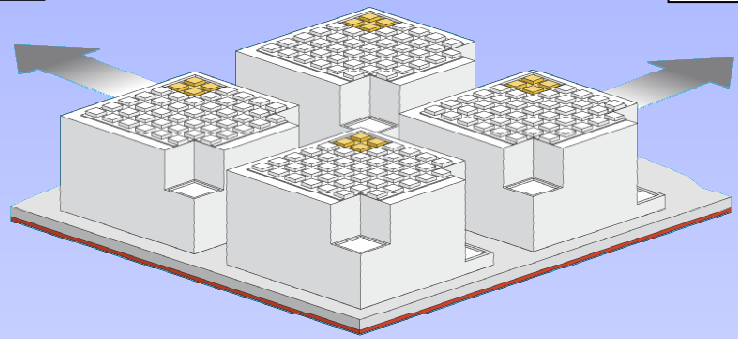
DUAL-BAND FPA FABRICATION PROCESS



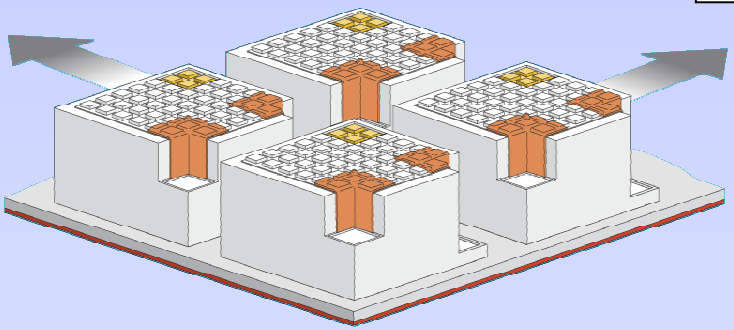
Isolation Etch



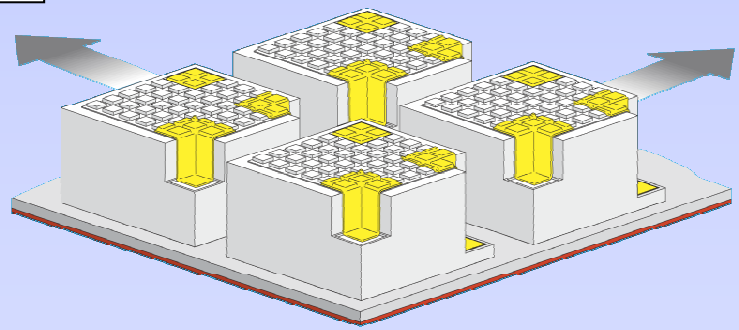
Deposit Insulation Layer



Window Opening

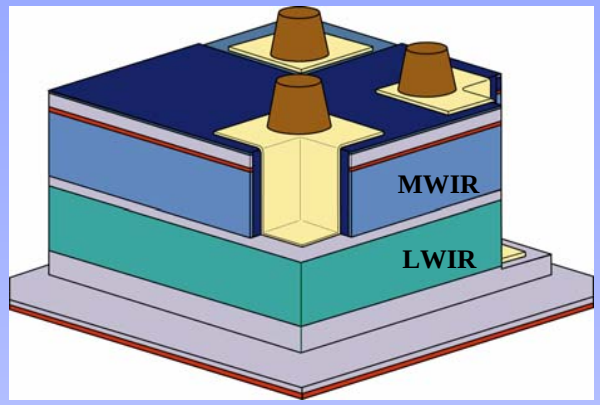


Adhesion Metal Deposit

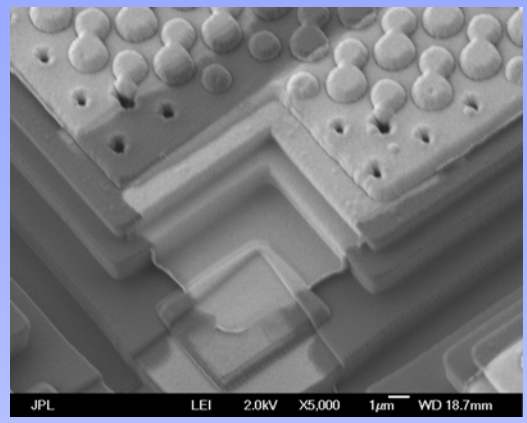


Final Metal Deposit

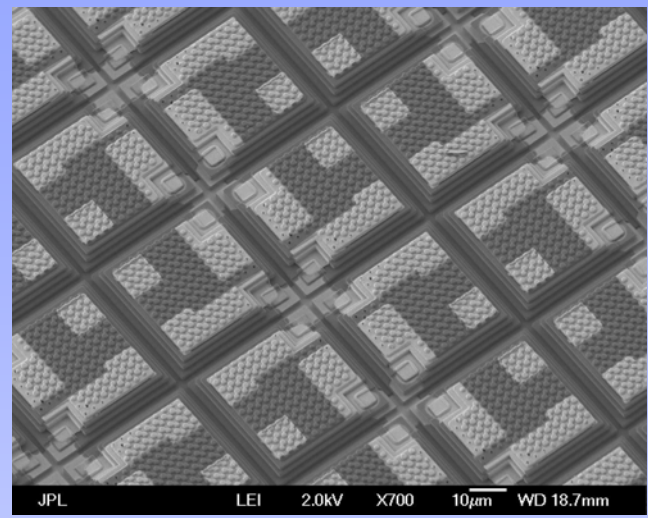
PIXEL CO-LOCATED SIMULTANEOUSLY READABLE DUALBAND QWIP FPA



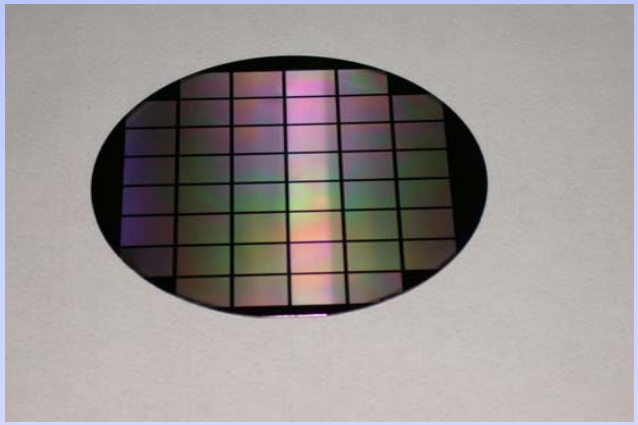
Dualband QWIP device structure



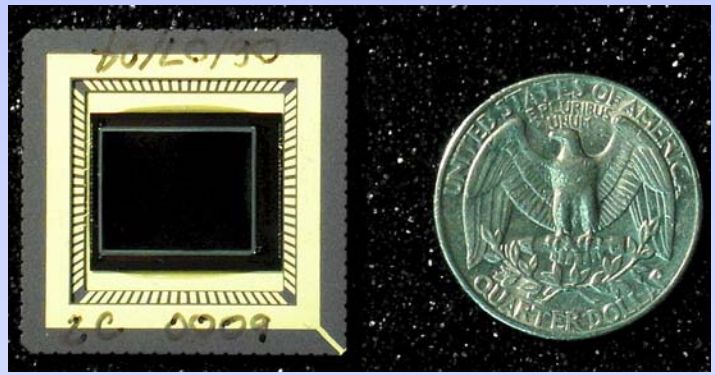
SEM of metal via connects



SEM of dualband QWIP array

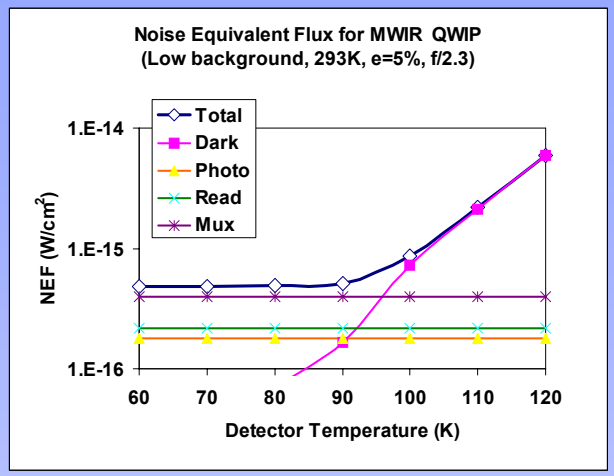


4-inch wafer with 48 detector dies

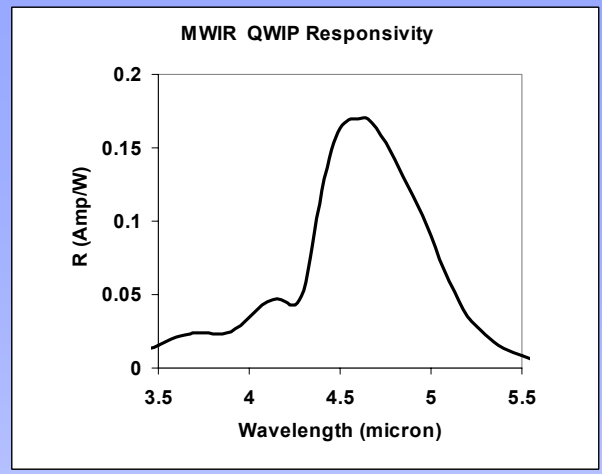


Dualband QWIP FPA HYBRID

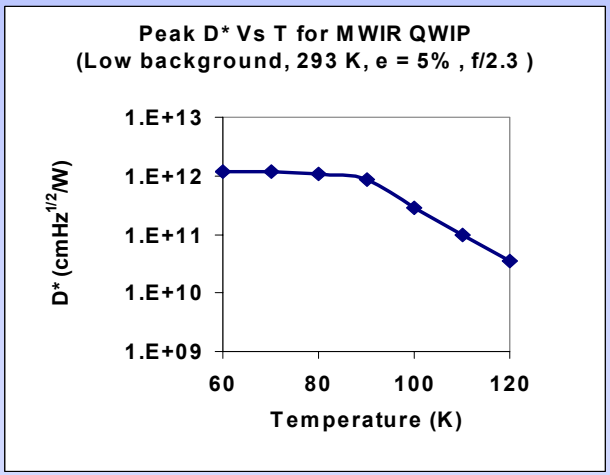
DUALBAND QWIP – MWIR LOW BACKGROUND



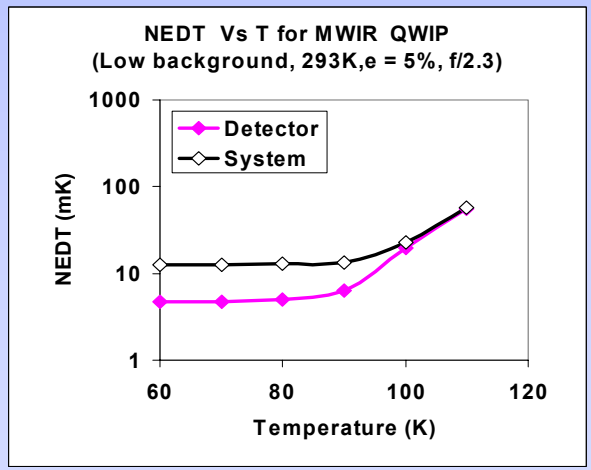
NEF



RESPONSIVITY

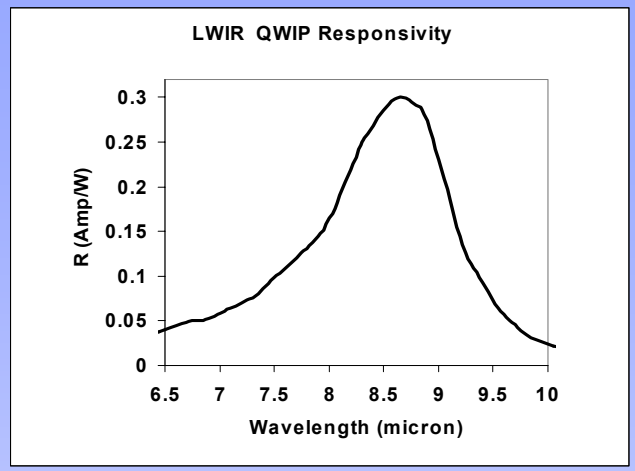


DETECTIVITY

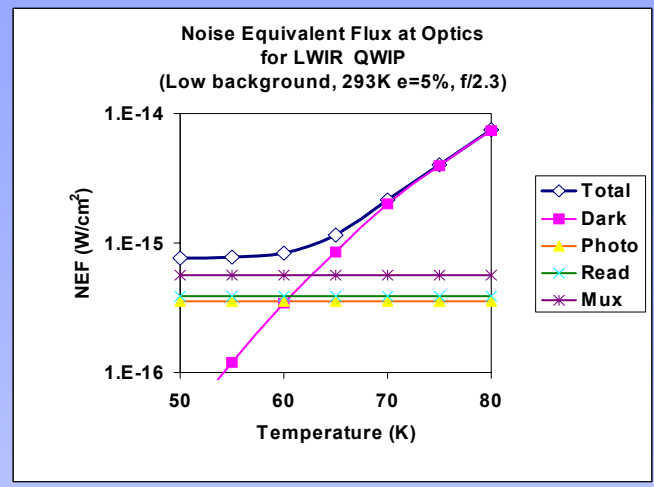


NEDT

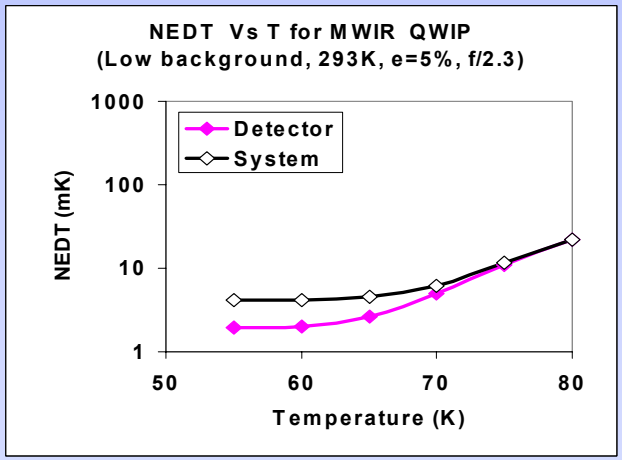
DUALBAND QWIP – LWIR LOW BACKGROUND



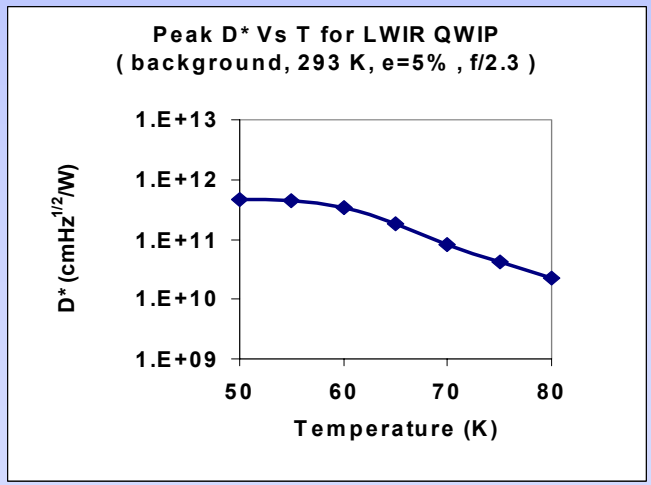
RESPONSIVITY



NEF

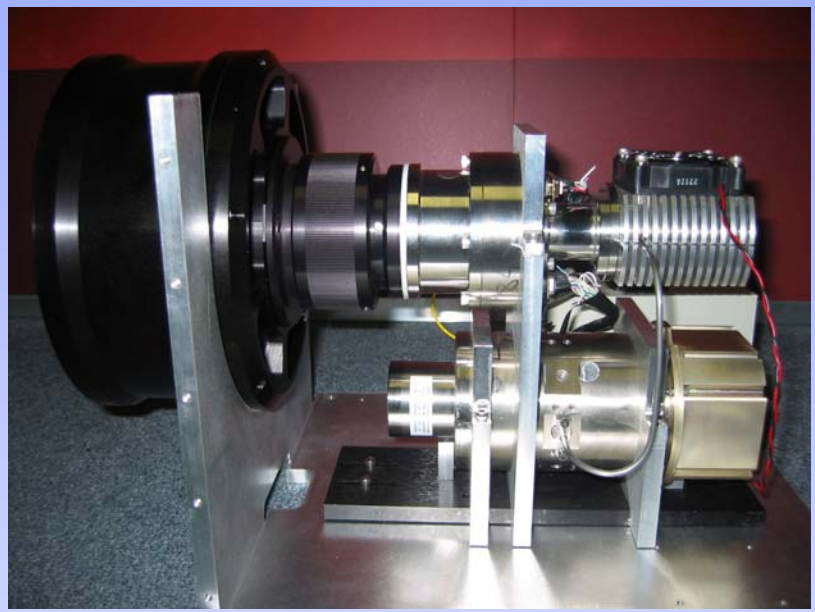


NEDT

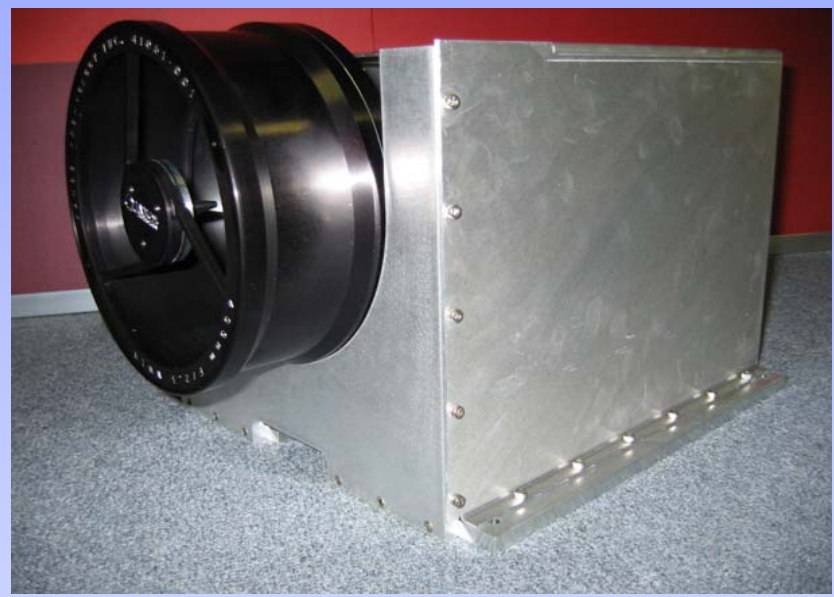


DETECTIVITY

320X256 PIXEL DUALBAND QWIP CAMERA DELIVERED TO THIS APPLICATION



Dualband sensor engine



320x256 pixel dualband QWIP camera

320X256 PIXEL DUALBAND QWIP SPECIFICATIONS

SPECTRAL RANGE **(MWIR)**	- 4.4- 5.1 μm (peak 4.7)
PIXEL PITCH	- 40 μm
FILL FACTOR	- 81%
ABSORPTION Q.E.	- 19%
PHOTOCONDUCTIVE GAIN	- 0.2
RESPONSIVITY	- 0.18 A/W
OPERATING TEMP.	- 65 K
NON-U (UNCORRECTED)	- 5%
NON-U (CORRECTED)	- 0.3%
OPERABILITY	- 98%
NEF*	- 7 X 10^{-16} W/cm^2
SPECTRAL RANGE **(LWIR)**	- 8 – 9.1 μm (peak 8.6)
FILL FACTOR	- 86%
PIXEL PITCH	- 40 μm
ABSORPTION Q.E.	- 15%
PHOTOCONDUCTIVE GAIN	- 0.3
RESPONSIVITY	- 0.3 A/W
BLIP TEMPERATURE	- 65 K
NON-U (UNCORRECTED)	- 5%
NON-U (CORRECTED)	- 0.4%
OPERABILITY	- 97.5%
NEF*	- 8 X 10^{-16} W/cm^2
FRAME RATE	- 30 Hz
OPTICS	- f/2.3; 400 mm & f/2 24 mm

DUALBAND QWIP MOVIE

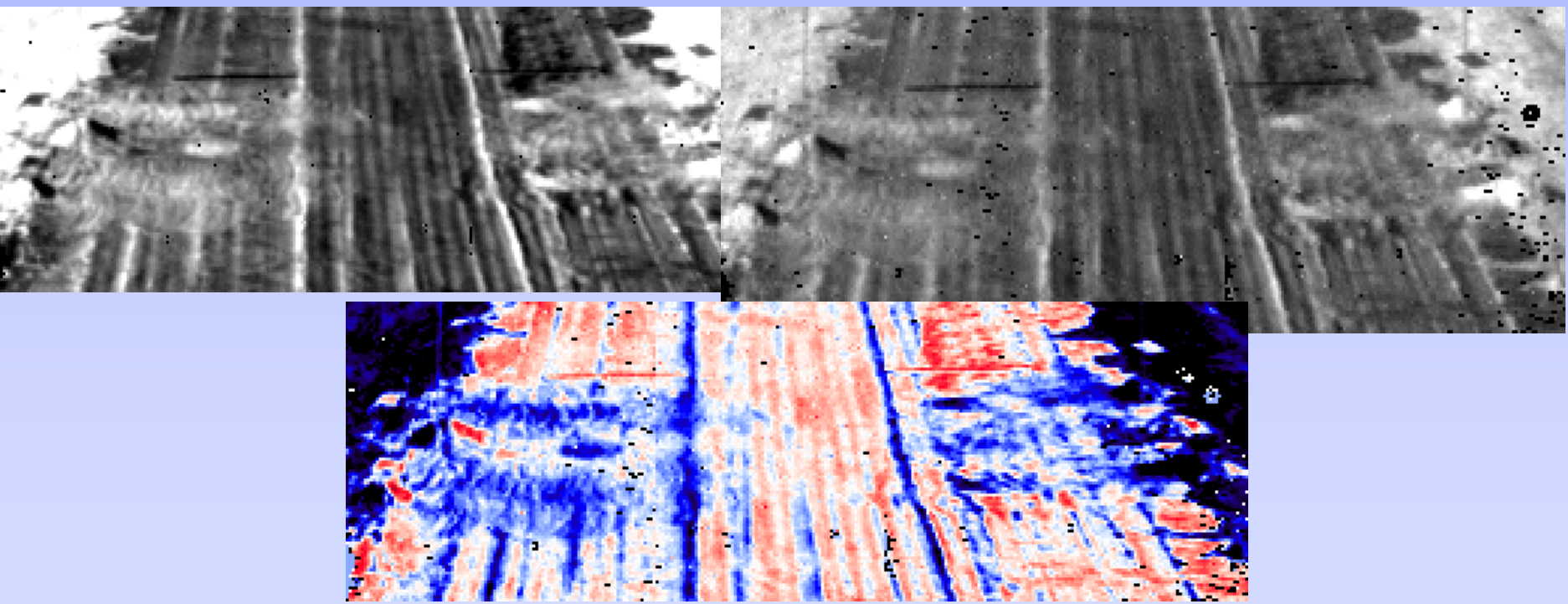
LWIR **MWIR**

Features to look for,
The cigarette lighter produce lots of hot CO2 gas. So, flare is broader MWIR due to CO2 emission, where as LWIR (8-9 microns) doesn't have any emission (just the heat).
The hot cigarette lighter flame produce so much MWIR signal, it reflects off from the lens and Jason's face.
The plastic piece Jason is holding is opaque in LWIR, but transparent in MWIR.

Format	- 320x256 pixels, dualband & pixel co-registered
Wavebands	- 4.4-5.1 & 8-9 μm
NEDT	- 22 & 24 mK for 300K background with f/2 optics
QE	- 19% & 15%
Photoconductive gain	- 0.2 & 0.3
Detectivity	- > $2x10^{11}$ & $1x10^{11}$Jones
Operating temp.	- 65 K
Fill factor	- > 81%

Mine Detection

- Mine Detection is a current issue that LWIR can answer
- QWIPs are a technology of choice.



1024 x 1024
Two-Color QWIP ROIC : ISC0501

1024 x 1024 PIXELS DUALBAND ROIC SPECIFICATION

ROIC PARAMETER	SPECIFICATION REQUIREMENT	COMMENTS
Array Configuration	1024 x 1024	Large-format
Pixel Size	30um x 30um	
Spectral Range	MWIR: 4.3-5.1um (Color A) LWIR: 8-9um (Color B)	Drives well capacity requirements
Input Polarity	Hole Collection	GaAs/AlGaAs QWIP detector
Input Configuration	Direct Injection (DI)	P-Channel Inputs
Input Clock Rise and Fall	CLK: 10ns rise/fall FSYNC, DATA: 10ns rise/fall	10% to 90%
Number of Outputs	8 Analog per color	Additional 1 reference output/Color Analog at 10MHz (8/Color+1Ref/Color=18 outputs total)
Output Modes	4, and 8 Analog per color	Common Output Mode for each color
Windowing	Row Only Windowing Minimum Window of 1 Rows	
Frame Rate (1024 x 1024)	60Hz (8 outputs per color)	ITR, IWR, Additional 1 reference output/color
Total Well Capacity	$\geq 17 \times 10^6$ carriers	Unit Cell Layout Limited, Goal of 20×10^6 carriers
Well Capacity Ratio	4:1 (LWIR:MWIR)	$\pm$ 10%, Repartition can be accomplished with 1-3 layer mask change
Noise	$\leq 420\ e^-_{RMS}$ at 3.4×10^6 e- $\leq 1250\ e^-_{RMS}$ at 13.6×10^6 e-	MWIR (Color A) LWIR (Color B)
Power	$\leq$ 600mW	8 Output Mode with No Output reference, Goal of $\leq$ 400mW

SUMMARY

- Demonstrated 1024x1024 pixel MWIR & LWIR focal plane arrays.
- Demonstrated 320x256 pixel MWIR/LWIR pixel collocated focal plane array.
- Increased QE from 19% to 36%. We will incorporate high QE material with dualband QWIPs.