Thales Long Wave QWIP Thermal Imagers

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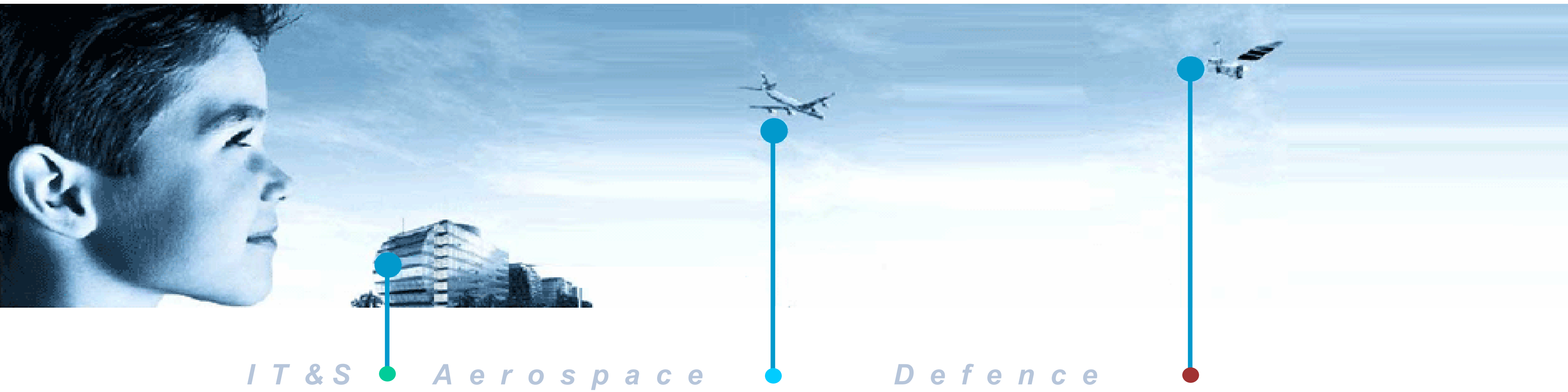
A. Manissadjian (Sofradir)

O. Cocle (Thales Optronique Fr) , R. Craig (Thales Optronics UK)



1) III-V lab presentation
2) How to set up a QWIP detector
3) QWIP Thermal imagers at Thales
   - Catherine MP and SIRIUS IDDCA
   - Catherine XP and VEGA IDDCA
4) Operating temperature

Conclusion

What is Alcatel Thales III-V Lab?

ALCATEL THALES

▶ Web site
3-5lab.fr

JV organization

Alcatel – Thales contract signed on July 1st, 2004

A common Laboratory of 100 R&D professionals

Performing industrial R&T on III-V technology

- Optoelectronic and microelectronic materials, devices and circuits
- From basic research to industrial development
- A capacity for prototyping and small scale production

For complementary Alcatel / Thales applications

- High bit rate Optical Fibre and Wireless Telecom
- Microwave and Optronic systems for Defence, Security and Space

Open to external customers

Two-site implantation

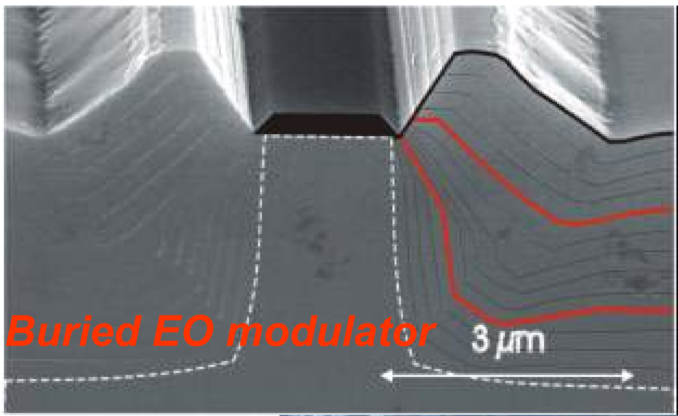
Thales Research and Technology
Palaiseau

Alcatel Research and Innovation
Marcoussis

III-V Semiconductors Epitaxy

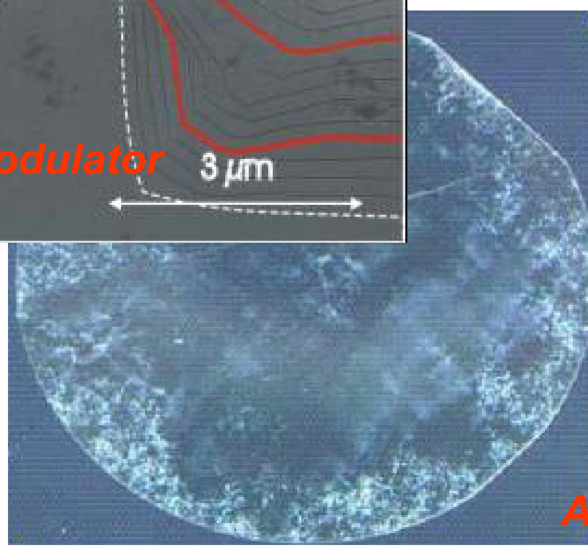
Epitaxial growth of III-V semiconductors

- Multi-wafers MBE, GS-MBE, MO-VPE reactors
- Complex hetero-structures based on GaAs, InP, SiC, GaSb… substrates



Buried EO modulator

GS-MBE reactor

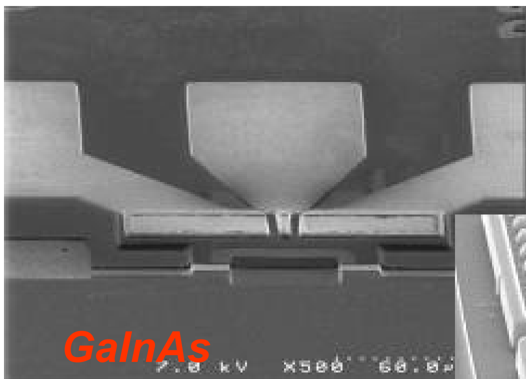


AlGaN/GaN HEMT on SiC substrates

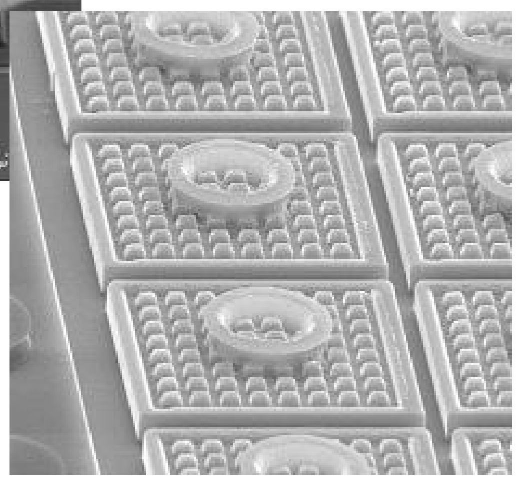
Clean-Room Device Processing

Clean room device processing

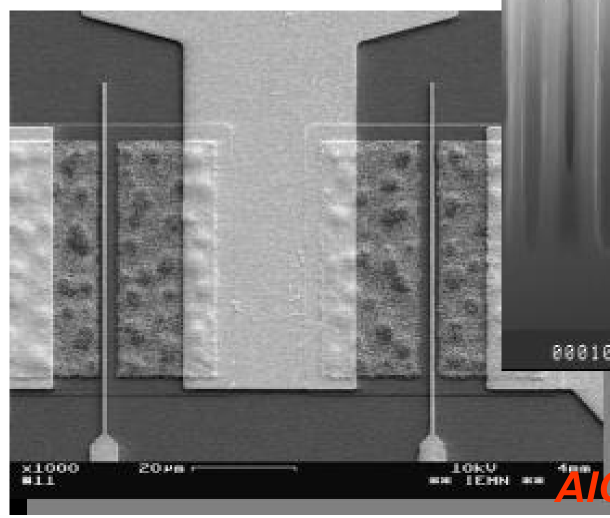
- Microelectronic technologies: lithography, metal and dielectric material deposition and etching, …
- Microwave and fast digital devices and circuits : InP HBTs, GaN HEMT, …
- Opto-electronic devices (lasers, modulators, photo-detectors, …)



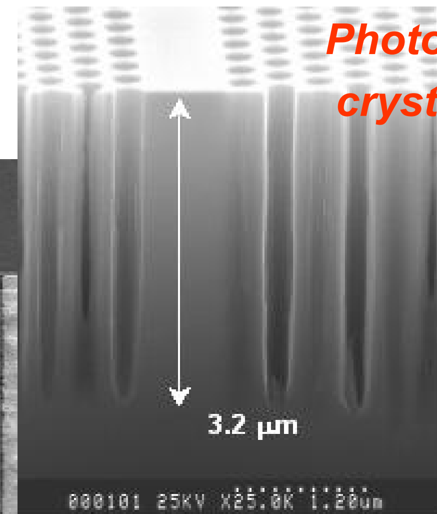
GaInAs photodiodes



QWIP FPA



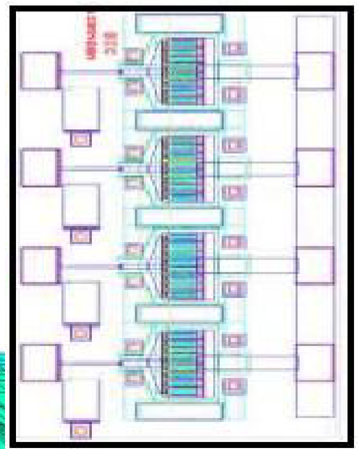
AlGaN/GaN HEMTs

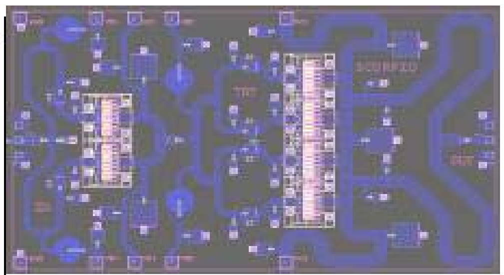


Photonic crystals

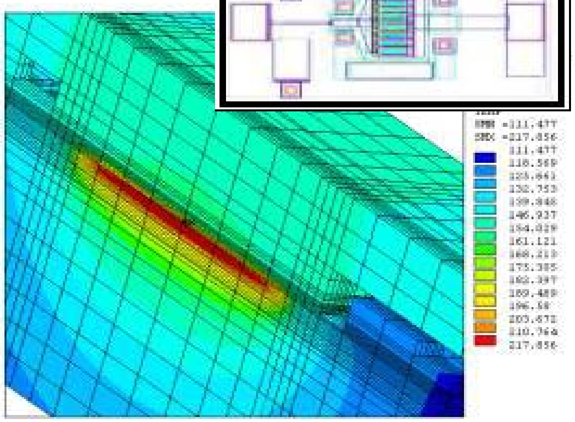
Measurement, simulation and design

- Physical modelling of microelectronic and optoelectronic devices
- Linear and non-linear equivalent circuits
- Microwave and fast digital circuit design and simulation

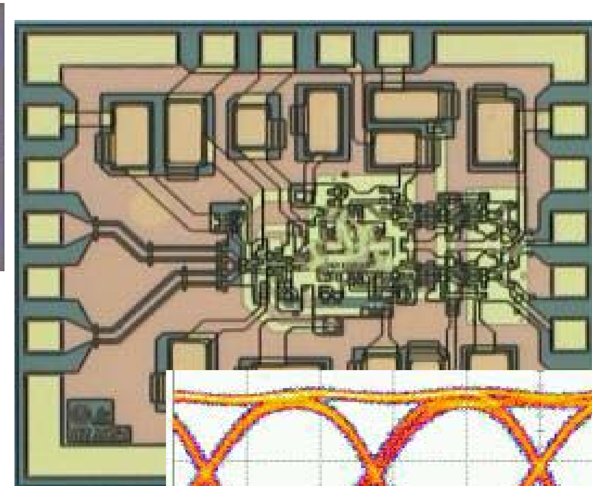




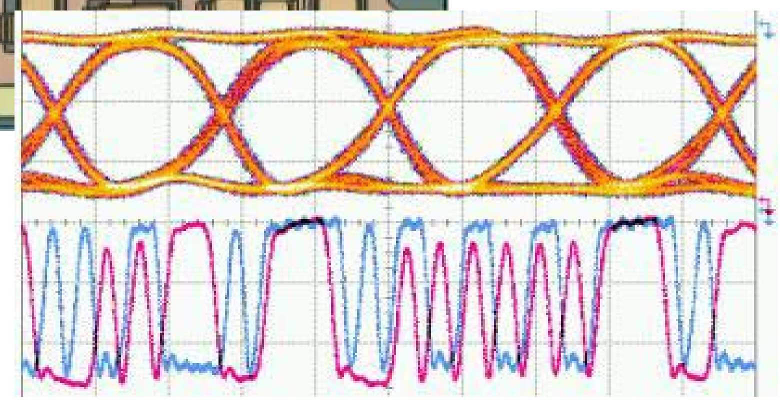
Power transistors and HPA MMIC design



Electro-thermal modelling

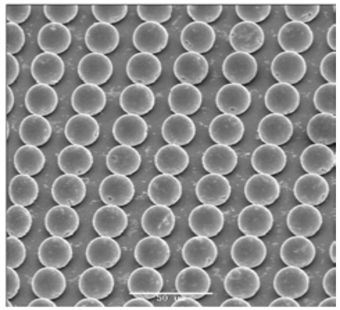


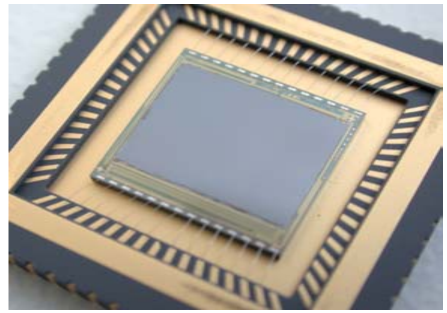
40Gb/s (and above) InP HBT ICs



Module and sub-system demonstrators

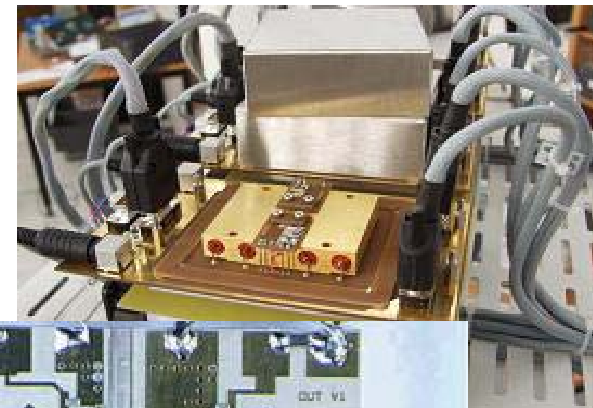
- Optoelectronic modules demonstrators (40Gb/s transceivers, …)
  Microwave amplifiers demonstrators
- Operational reliability evaluations





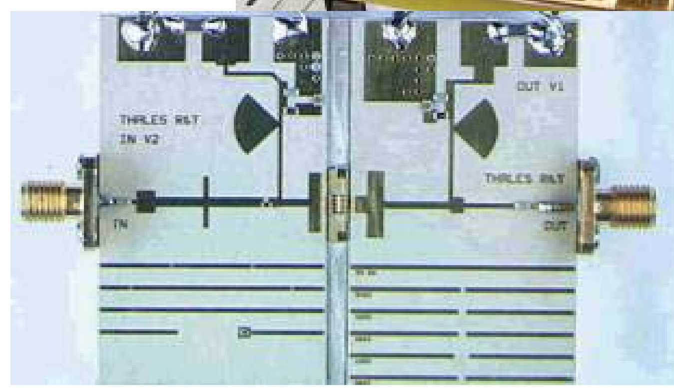
Hybridization & FPAs characterization

Reliability test bench



60GHz UTC photodiode

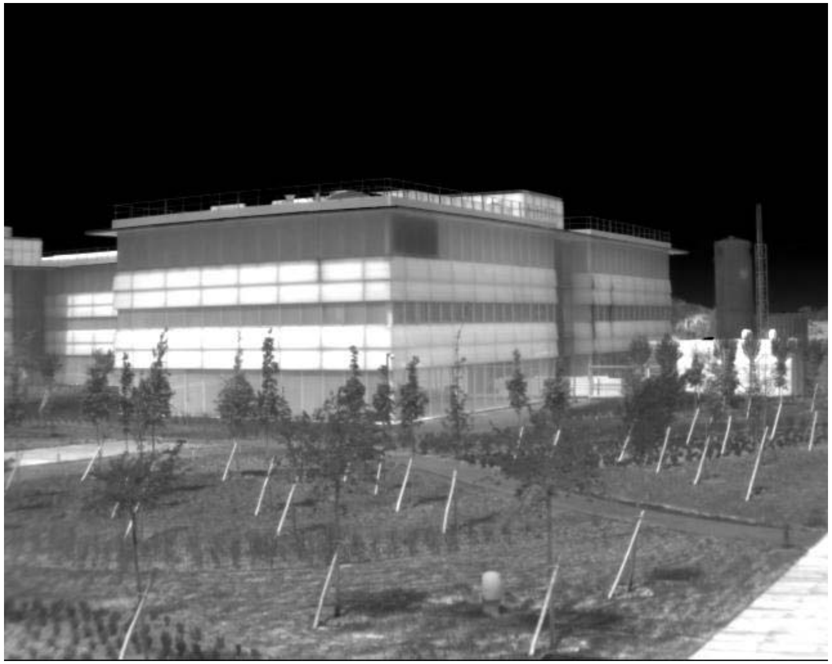
III-V lab
ALCATEL-THALES



18GHz direct modulation laser diode

30W S-band hybrid HPA

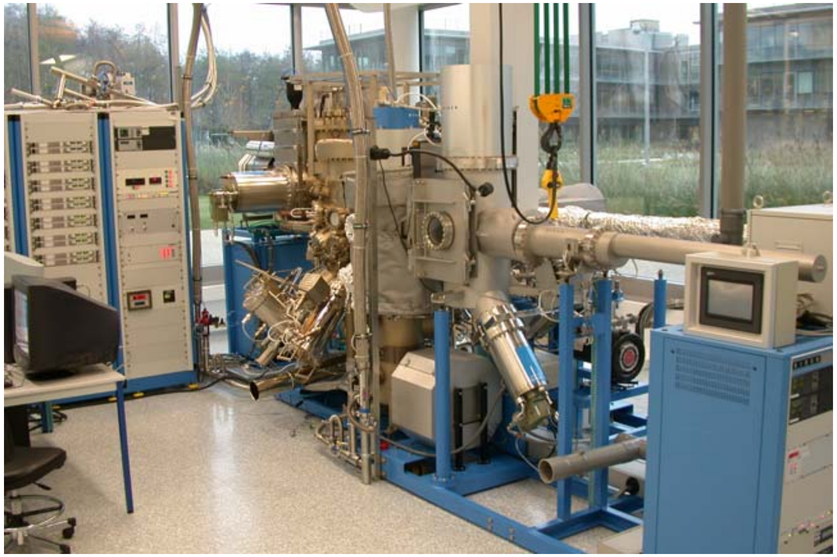
(640x512 QWIP Phoenix picture)



New front end for QWIP R&D and Production

250m² class 1000/100 dedicated clean room

- **Moving in July 2005**
- **Fully operational since March 2006**



New RIBER 49 MBE equipment

5x3 inch or 3x4 inch wafers per platen

Uniformity & Reproducibility fully compatible with QWIP production

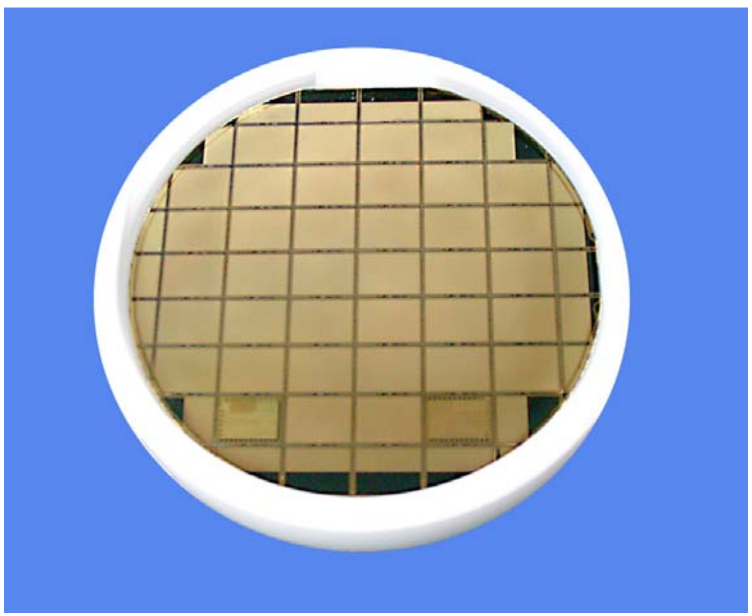
➔Faster Transfer to Epitaxial Layer Suppliers

SOFRADIR

TRT QWIP Product

384x288 ; pitch 25 µm

30 arrays on 3 inch wafer



VEGA-LW

Thales Optronique (France)

SOFRADIR

SIRIUS-LW

Thales Optronics (UK)

TRT QWIP Product

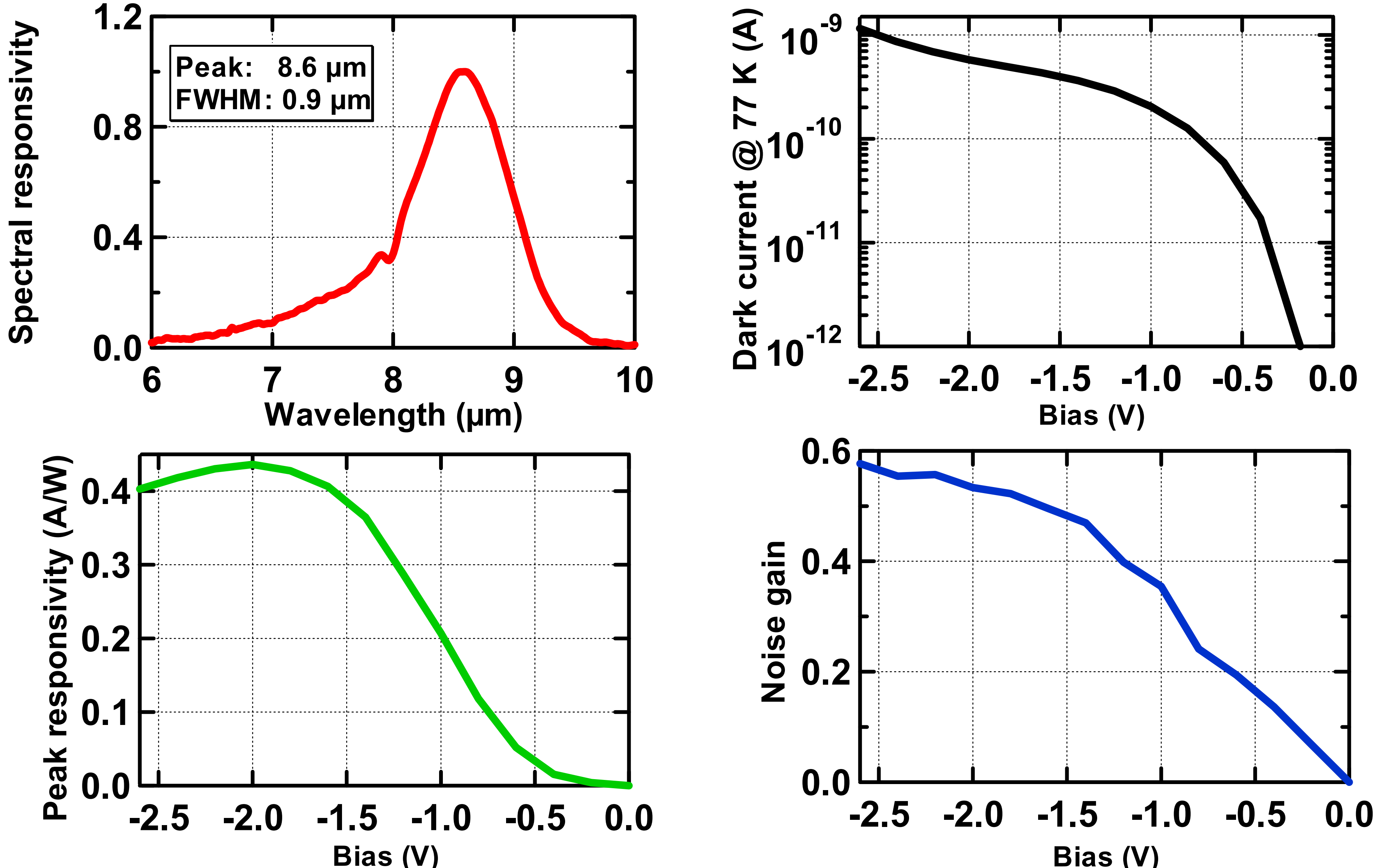
640x512 ; pitch 20 µm

16 arrays on 3 inch wafer

Test cell for E&O QWIP measurement

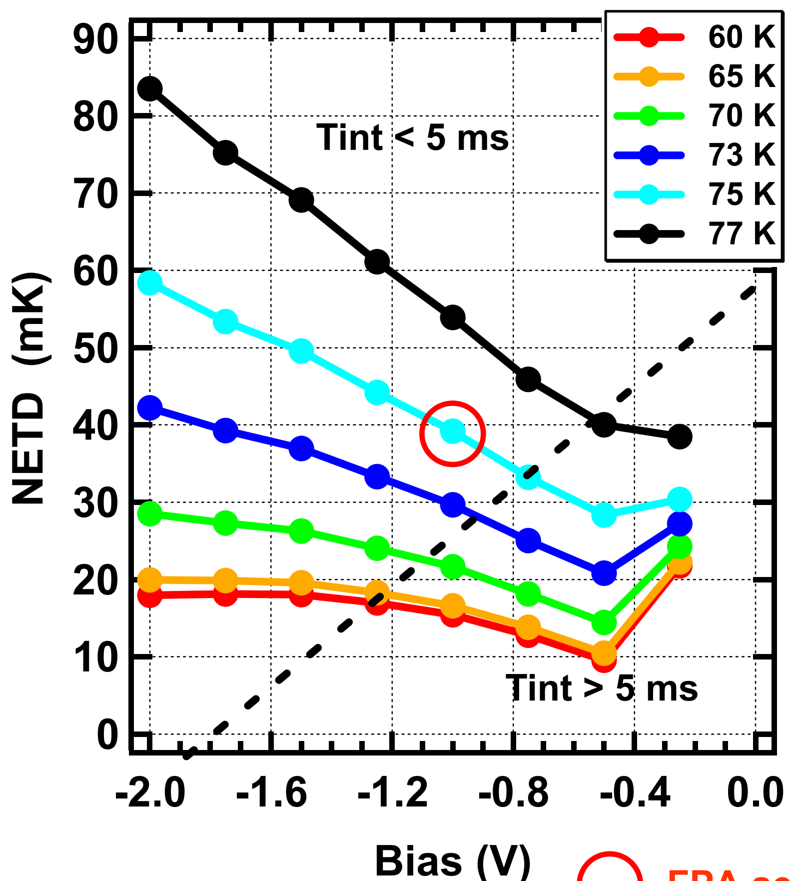
FPA Performance: E&O inputs

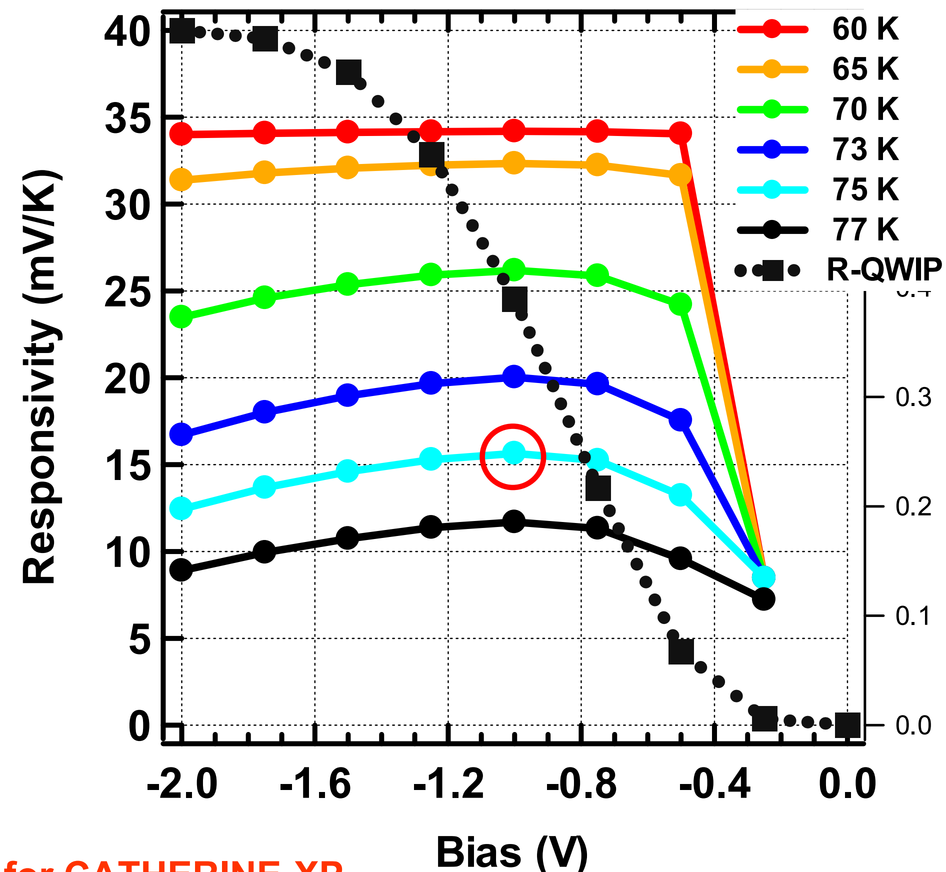
Intrinsic QWIP E&O Characteristics measured on a 23µm pixel



FPA Performance: Model outputs

ROIC: pitch 25µm ; C=18.5Me- ; gain=160nV/e- ; noise=160µV
Tbb=300K ; f/2.7 ; ΔT=+50K ; pixel 23.5µm





FPA set point for CATHERINE-XP

External Quantum Efficiency is definitively not a relevant parameter for QWIP

THALES

SIRIUS-LW-K548: 640×512 20µm pitch IDDCA

Compact dewar design

- small diameter feedthru ceramics (Ø40mm).
- 20 mm height cold shield
- aperture up to f/2.2 applications
- two 21-pin connectors electrical interface

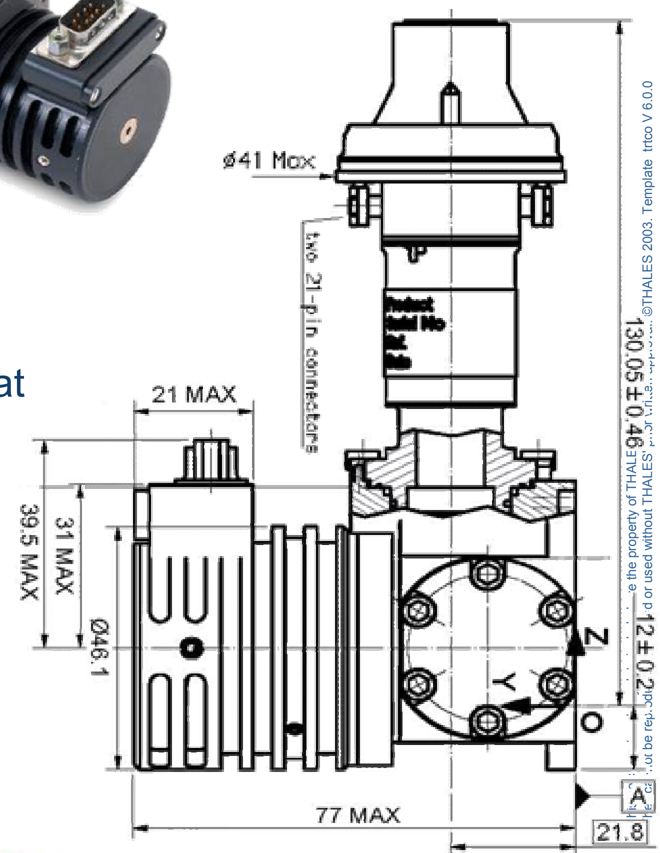
20µm pitch ROIC (Sofradir)

- four gains (10.3Me$^-$ = ×1, ×1.3, ×2, ×4)
- 1/2/4 outputs; IWR;
- **120Hz frame rate** enabling 2×2 microscanning for SXGA format (1280×1024)
- Image invert/revert/inverse; Random windowing
- Skimming mode

0.75W K548 by Ricor

Dimensions 142 mm height × 77 mm width

Total IDDCA weight < 0.65 kg (1.43 lb)



SIRIUS-LW-K548: E&O performance @ 73K

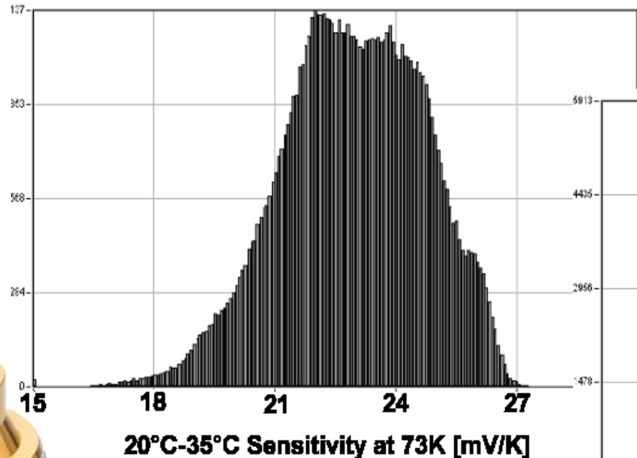
Tfpa =**73K**; f/2.2; gain 1 (10.3Me-); 120Hz; 20°C blackbody

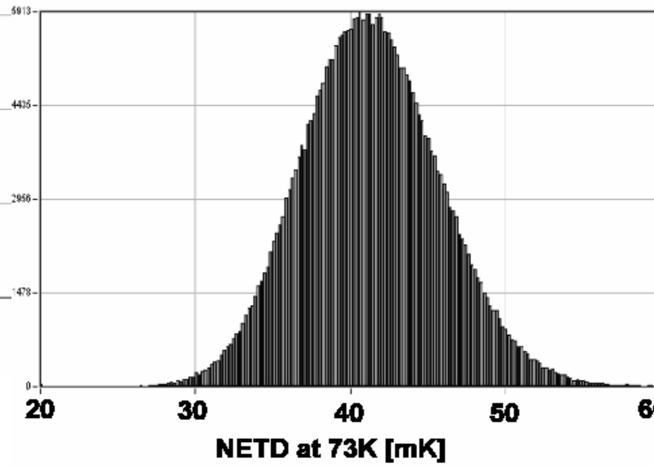
Ti = **4ms** for **+50K** instantaneous dynamic range

20-35°C Sensitivity: Mean = 23mV/K; σ = 8.5% **(No FOV correction)**

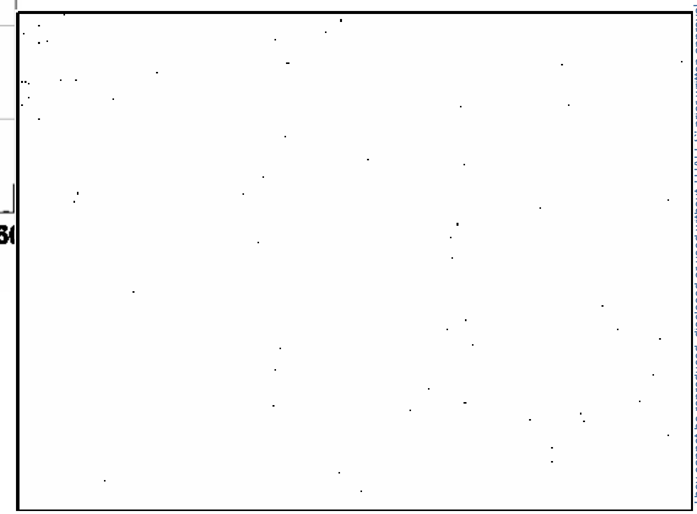
NETD : Mean = **41 mK**; σ = 10.9% (FOV corrected)

Operability = 99.9% **(NETD<2×mean); no cluster of size > 3 pixels**





Dead map pixels



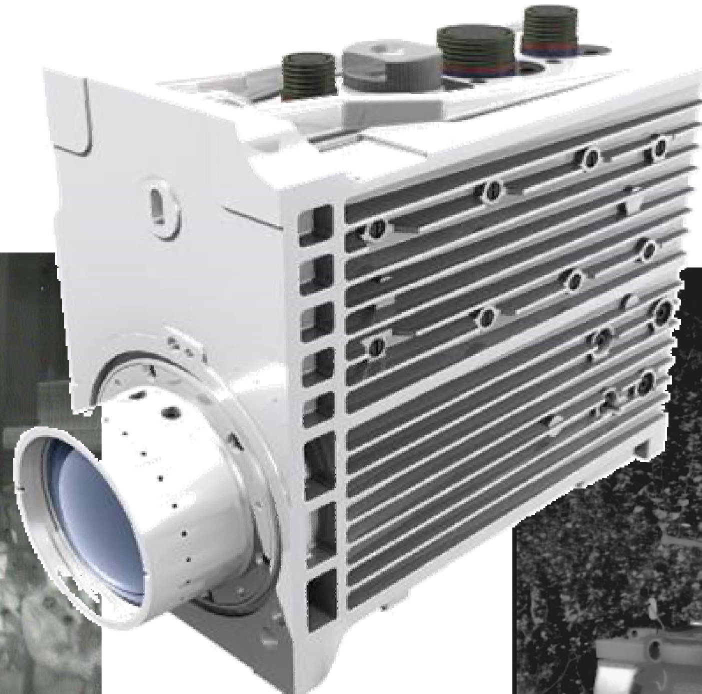
SOFRADIR

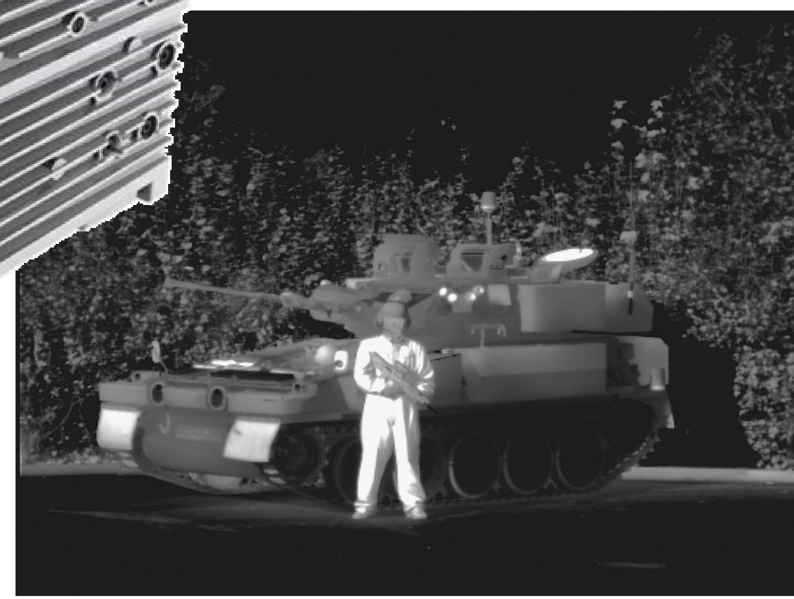
THALES

SIRIUS-LW-K548: ready for production

1st Prototypes in 2005 for CATHERINE-MP by Thales Optronics (TOL)

- affordable and production-ready alternative offered for fighting vehicles and tanks for future UK MOD programmes
- provides outstanding SXGA (1280×1024) format image quality with the use of microscan





Developed for Catherine-XP FLIR (Thales Optronique)

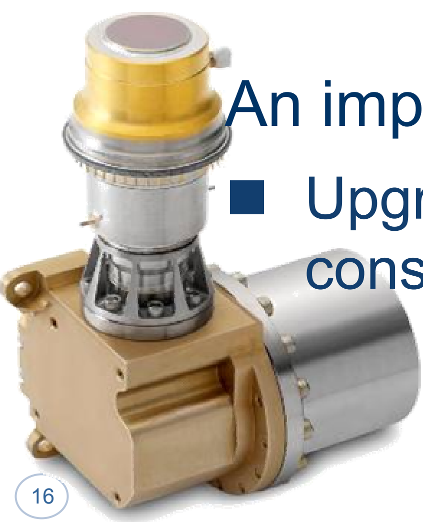
- Highly compact (3 kg)
- Power consumption and heat dissipation to be minimized

Working point around 75K

- satisfying tradeoff with NETD/detection range
- Lowest power consumption & thermal behavior

An improved RM4-7i microcooler **(Thales Cryogenics)**

- Upgrade of RM5-7i, with higher efficiency for lower power consumption (and heat dissipation)



VEGA-LW-RM4: 384×288 25µm pitch IDDCA

Latest dewar design

- small diameter feedthru ceramics (Ø32mm) for optimizing the compactness of the detector.
- cold shield up to 20 mm height
- aperture up f/2 applications

ISC0208 ROIC (Indigo)

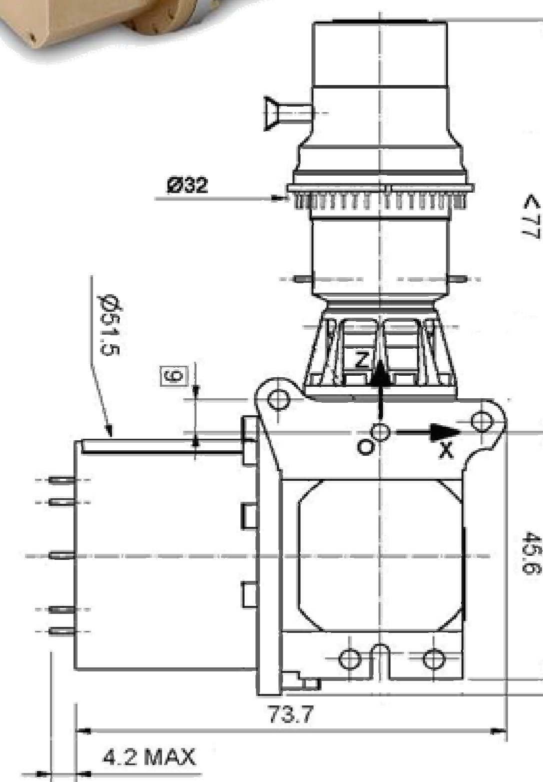
- four gains (18.5Me-, 13.9Me-, 9.2Me-, 4.6Me-)
- 1/2/4 outputs; IWR
- **>150Hz** frame rate enabling 2×2 microscanning for full TV CCIR format (768×575)

0.7W RM4-7i by Thales

- @ 20°C: CDT < 3 minutes; Preg < 9W_{ac}

Dimensions < 126 mm height × 73.7 mm width

Total IDDCA weight < 0.55 kg (1.21 lb)



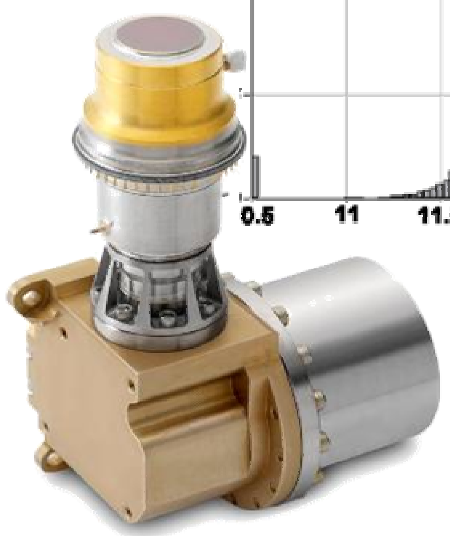
Tfpa =**75K**; f/2.68; gain 2 (13.9Me-); 120Hz; 20°C blackbody

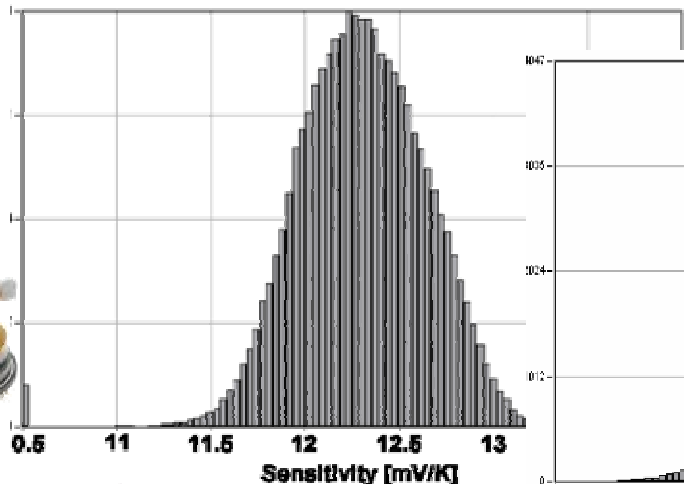
Ti = **4ms** for **+50K** instantaneous dynamic range

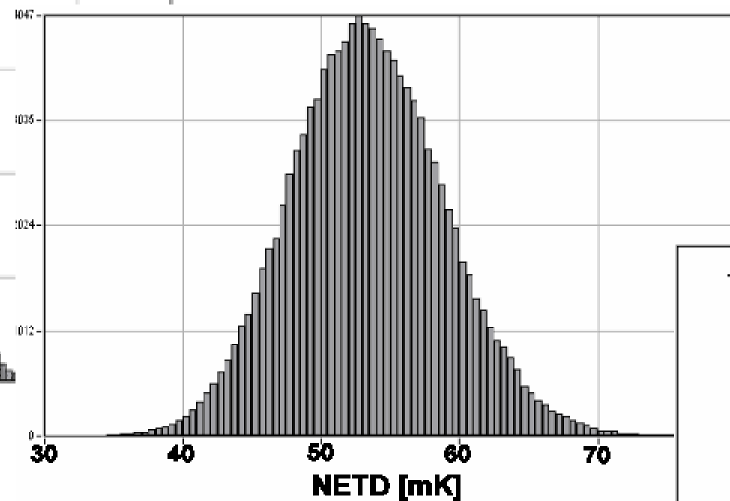
20-35°C Sensitivity: Mean = 12.3mV/K; σ = 3.51% **(No FOV correction)**

NETD : Mean = **54 mK**; σ = 10.5% (FOV corrected)

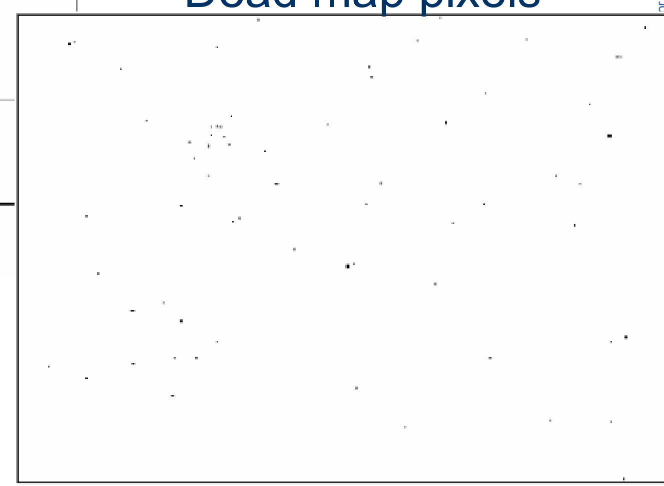
Operability = 99.9% **(NETD<2×mean)**





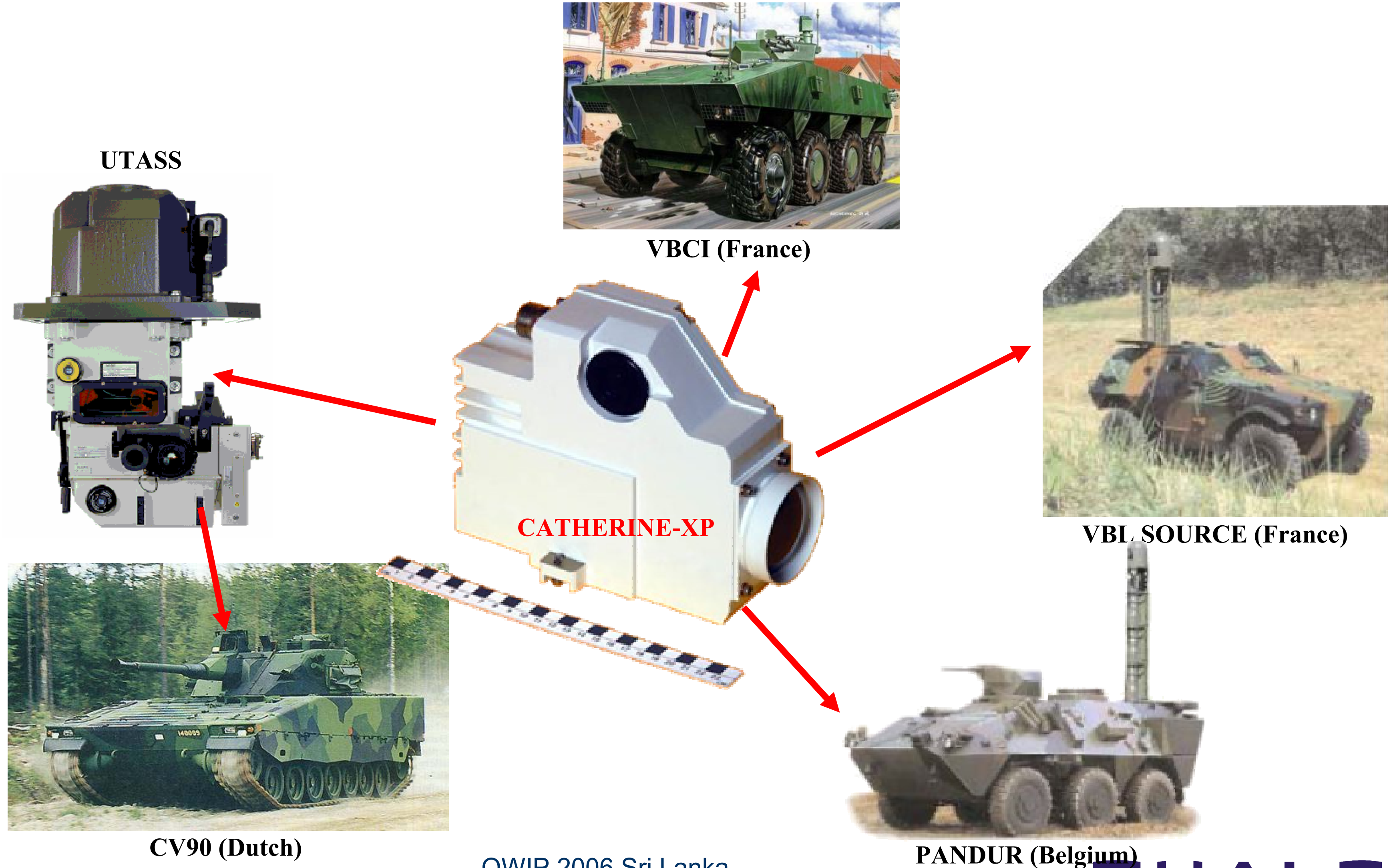


Dead map pixels



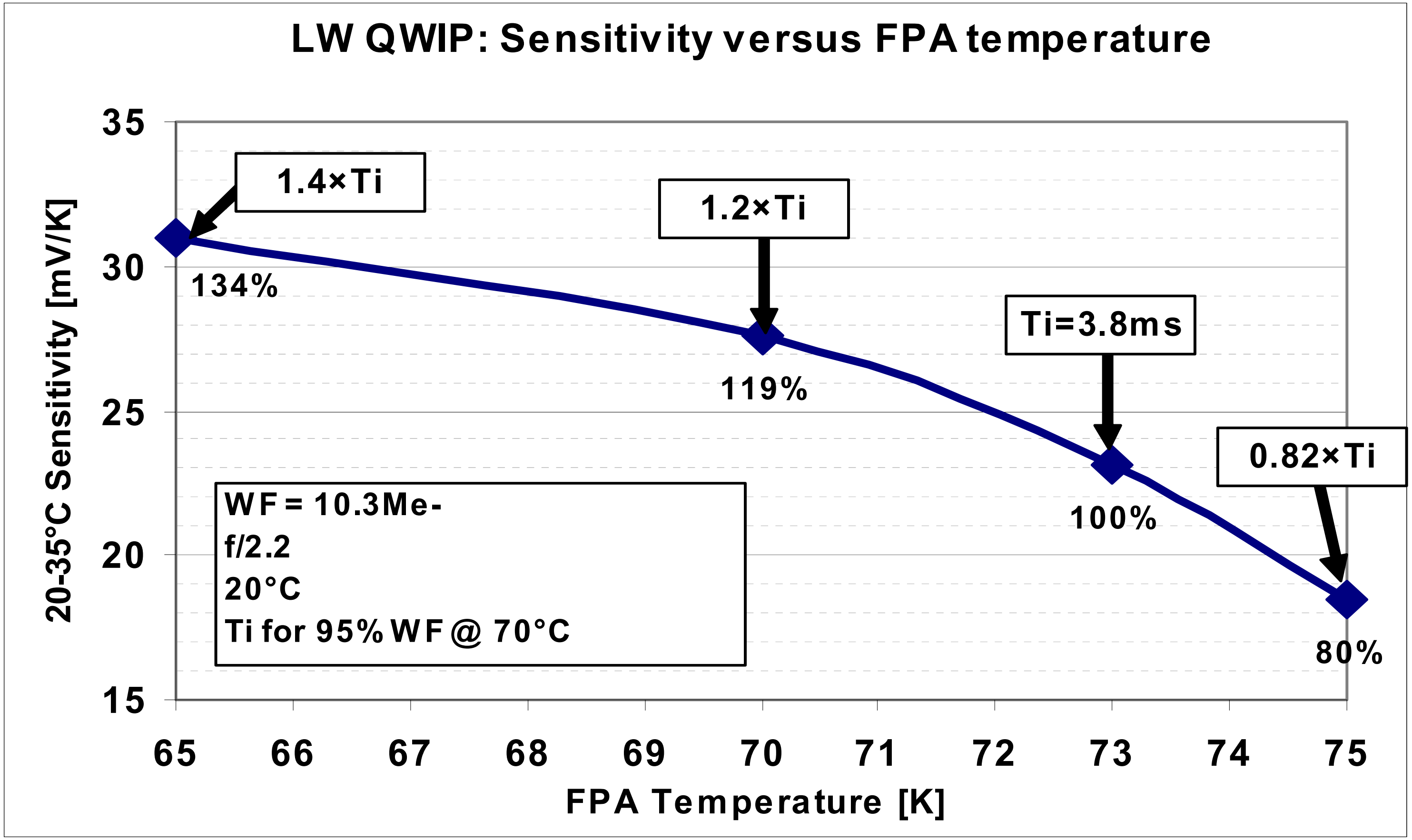
Full production since 2005 (150 VEGA-LW detectors within 15 months)

1000 cameras ordered, Business plan for up to 4000



LW QWIP performance vs T_{FPA} in IDDCA

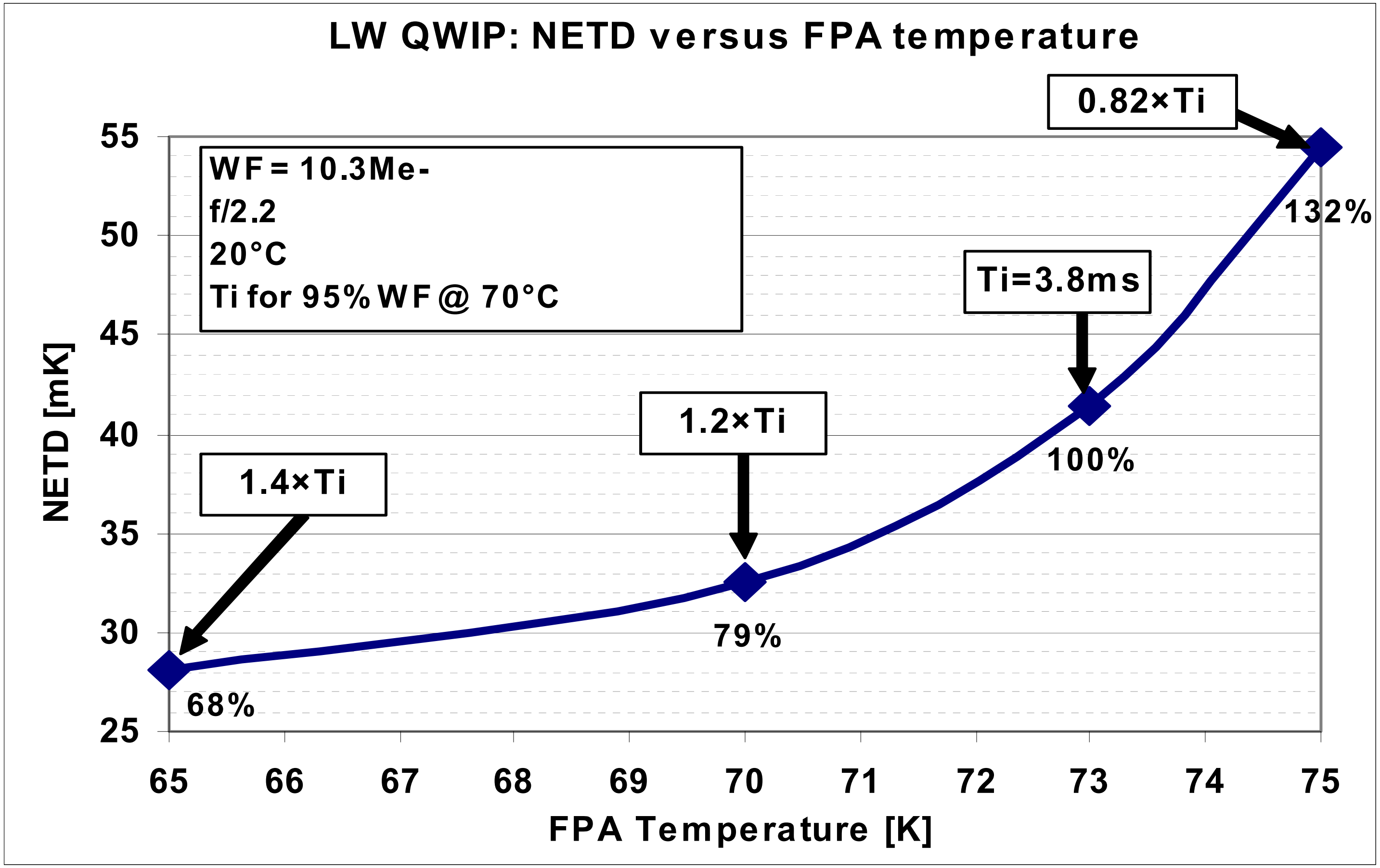
Ti adjusted for +50K instantaneous dynamic range



FPA sensitivity in mV/K is proportional to Ti

But intrinsic QWIP responsivity is independent on Temperature…………..!

LW QWIP performance vs T_{FPA} in IDDCA



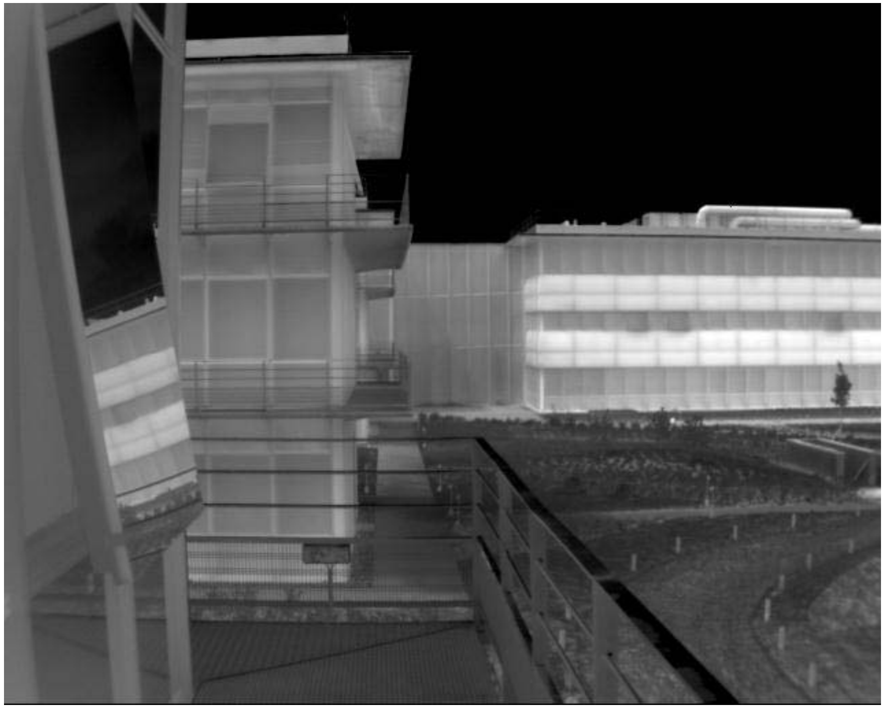
Ti adjusted for +50K instantaneous dynamic range

50-55mK @ 75K

40-45mK @ 73K

CONCLUSION

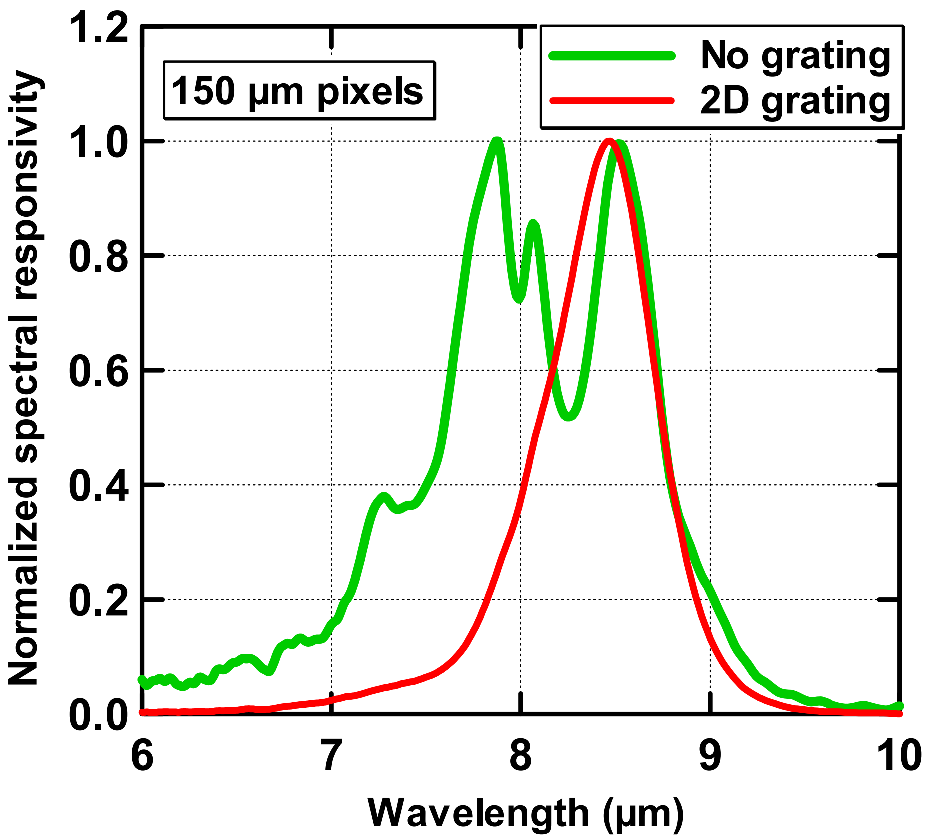
- •LWIR QWIPs : 75K and diffraction limited:
  - ❑NETD< 40mK
  - ❑Dynamic range > 100K
  - ❑Integration Time < 5ms
  - ❑>100Hz in full TV Format

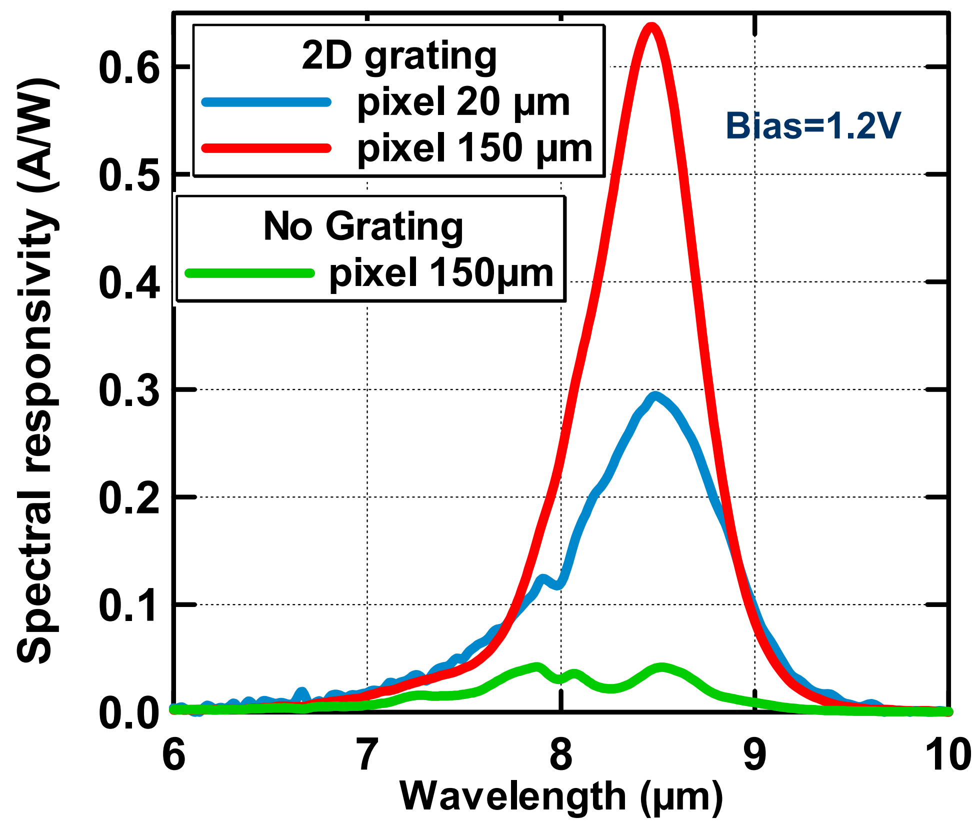


(640x512 QWIP Phoenix pictures)

- •New facilities for QWIP array production
- •Large format and small pitch in production (VEGA & SIRIUS by SOFRADIR)
- •R&D up to the FPA level to Extend QWIP Spectral Range (4µm-18µm)
- •QWIP are also Natural candidates for large format dual band / dual color FPAs

Influence of the Pixel Design on QWIP Performances



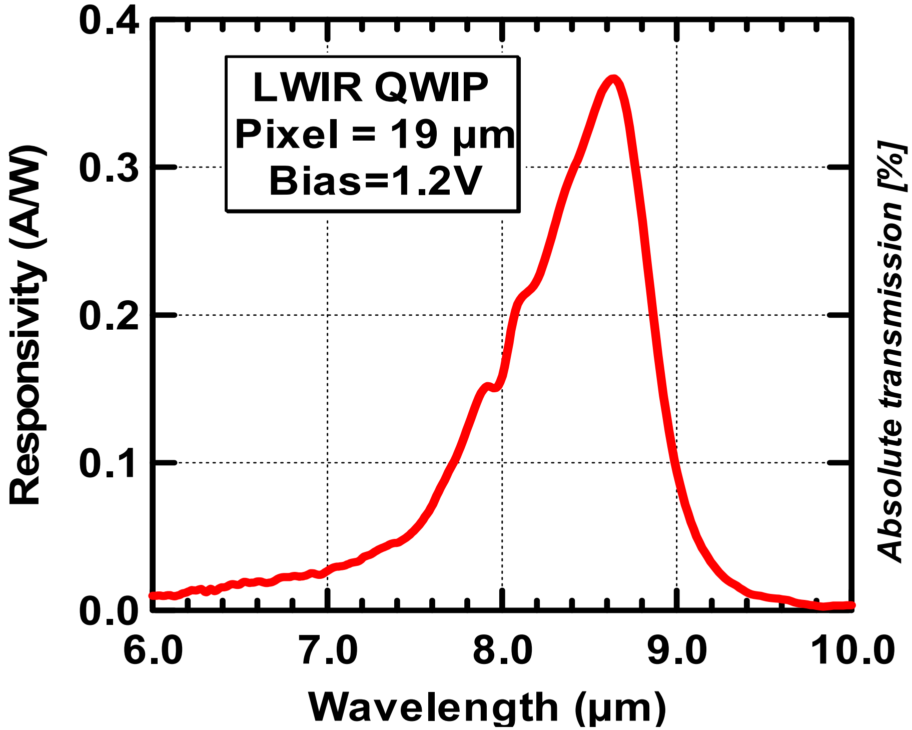


FWHM Wider
without
Optical coupling pattern

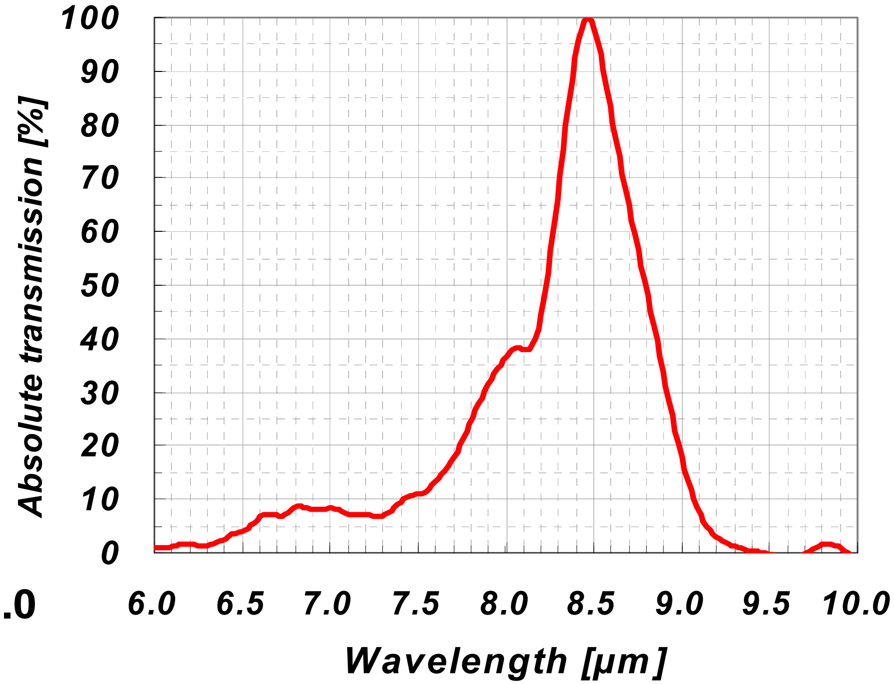
Peak Responsivity Higher
On Large Pixels
With Optical coupling pattern

Peak = 8.5µm **±0.1µm**

FWHM < 1.0µm

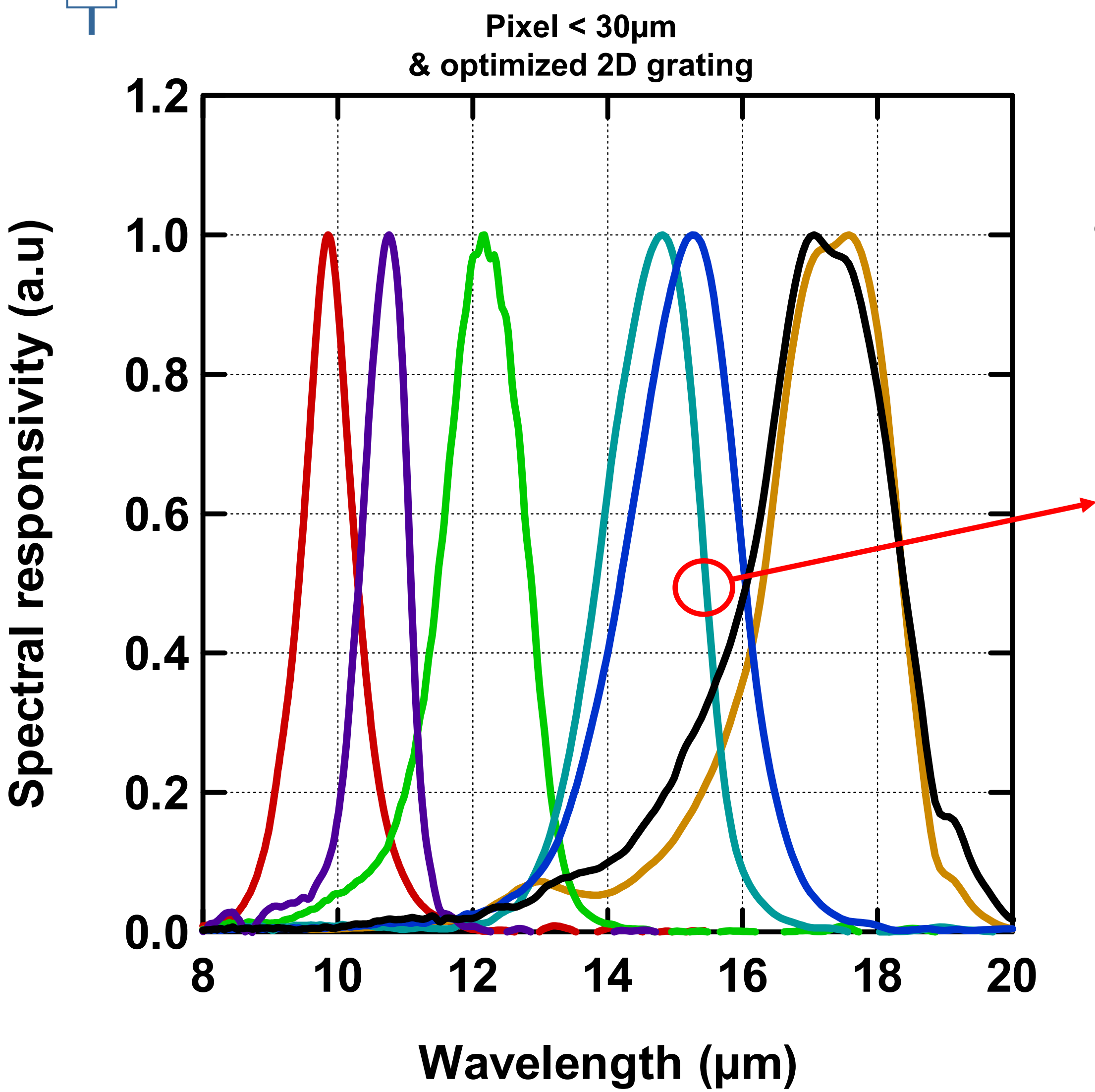


Measure on QWIP wafer, before thinning & AR coating



Measure on IDDCA, after thinning & AR coating & with IDDCA window

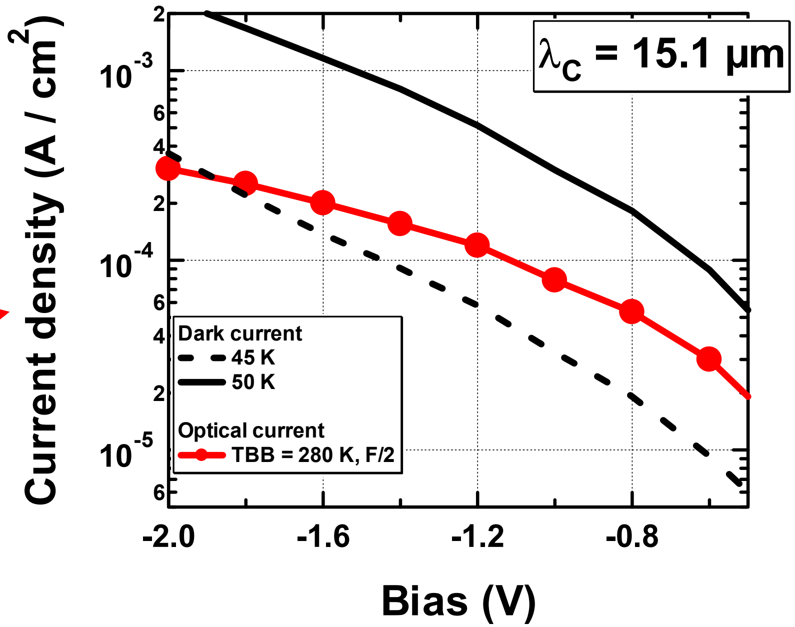
QWIPs cover the full LWIR spectrum



ROIC ISC0208 : 384x288 ; pitch 25µm

Tbb=280K; f/2 (diffraction limited)

dynamics = +30°C



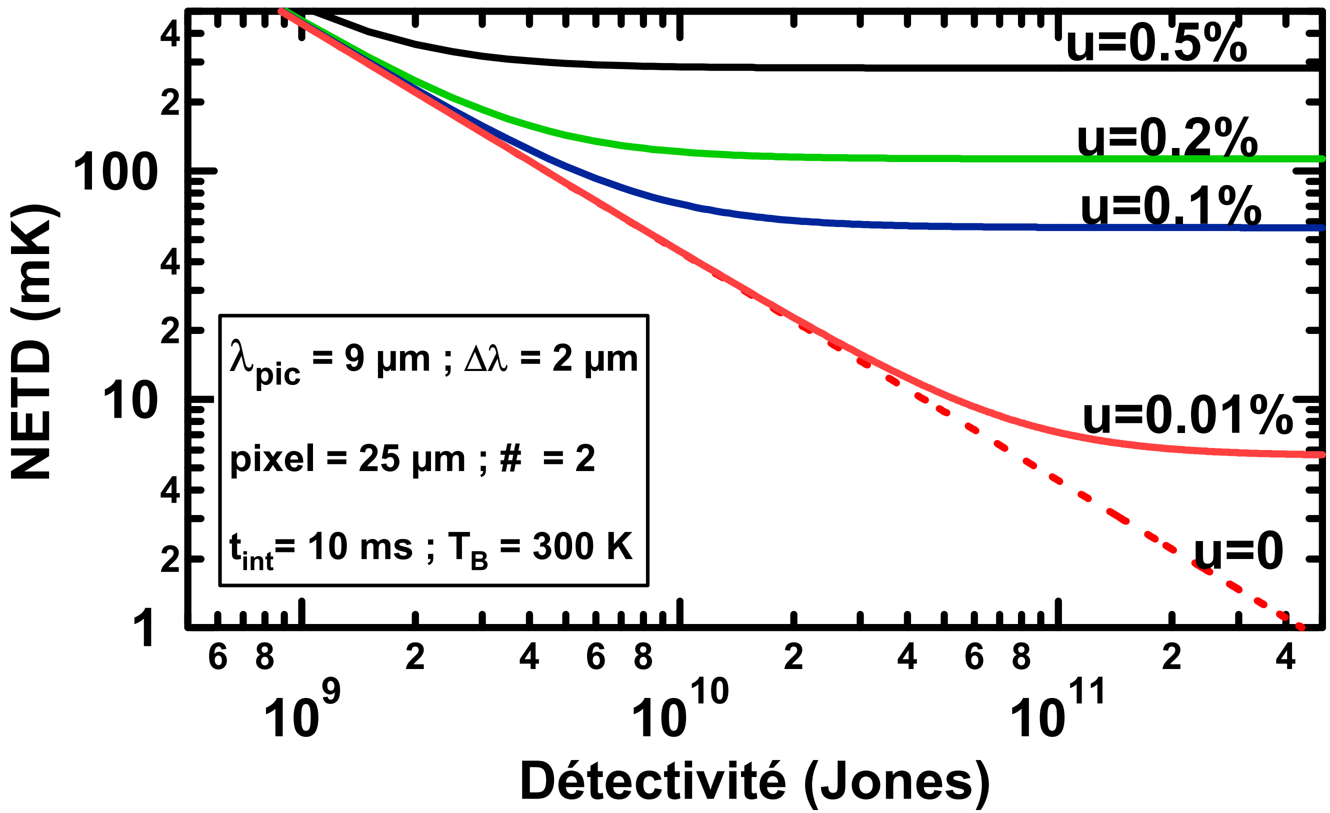
FPA performance modeling:

T_{det}=50K ; λ_c=15.1µm

NETD = 15 mK

Responsivity = 20 mV/K

Integration Time = 6 mS



Single Element :

Only D* is important

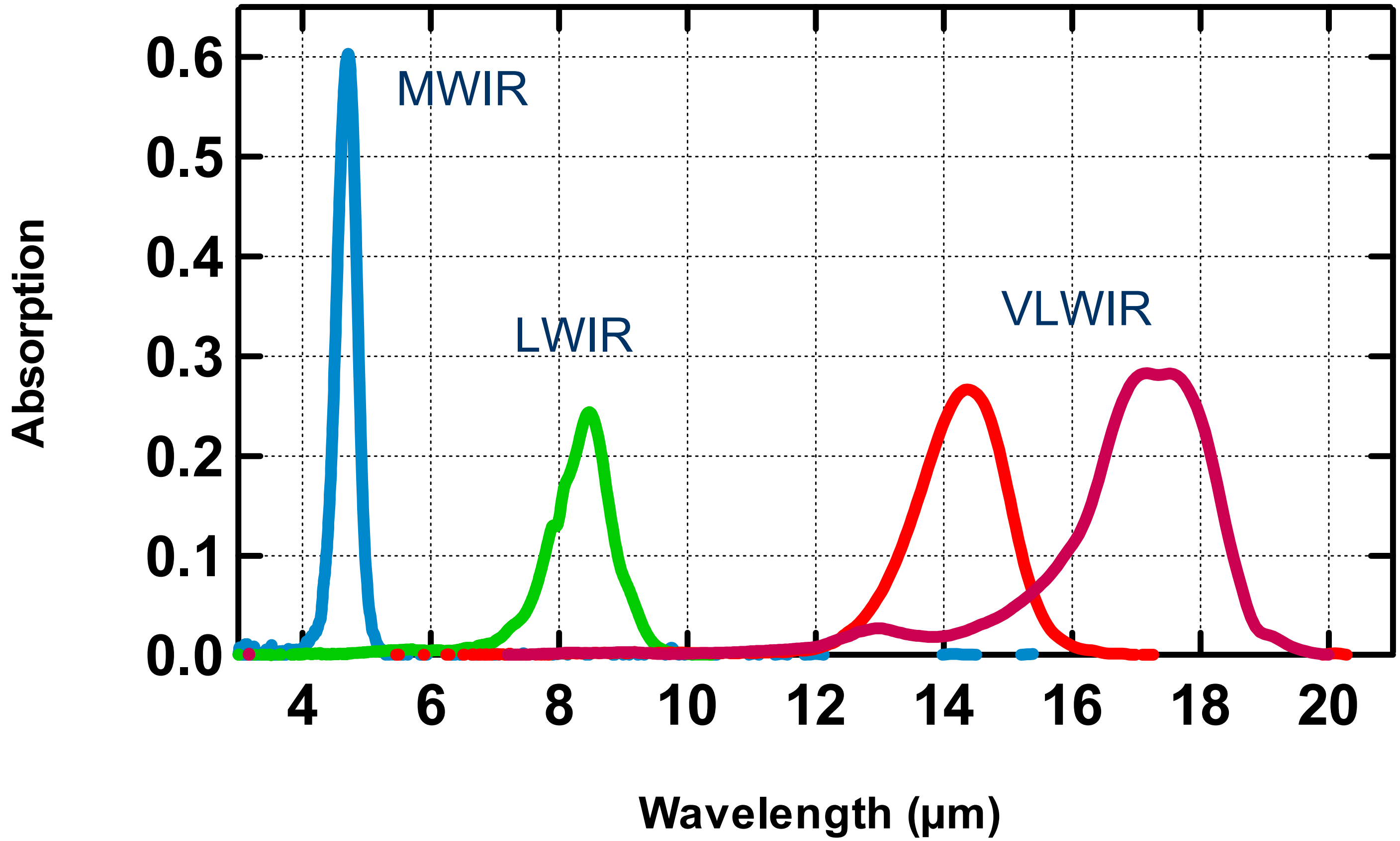
2D Arrays :

Uniformity = key factor

$$NETD\,(u, D^*) = \frac{P_B}{\frac{dP_B}{dT_B}} \times \sqrt{u^2 + \frac{1}{2t_{int}A} \times \frac{(1+4\#^2)^2}{D^{*2} \cdot P_B{}^2}}$$

Uniformity has to be preserved for each new QWIP quantum design or processing step

Internal quantum efficiency: Absorption



4 typical spectral absorption: α_{peak} > 25% indeed > 60% for MWIR

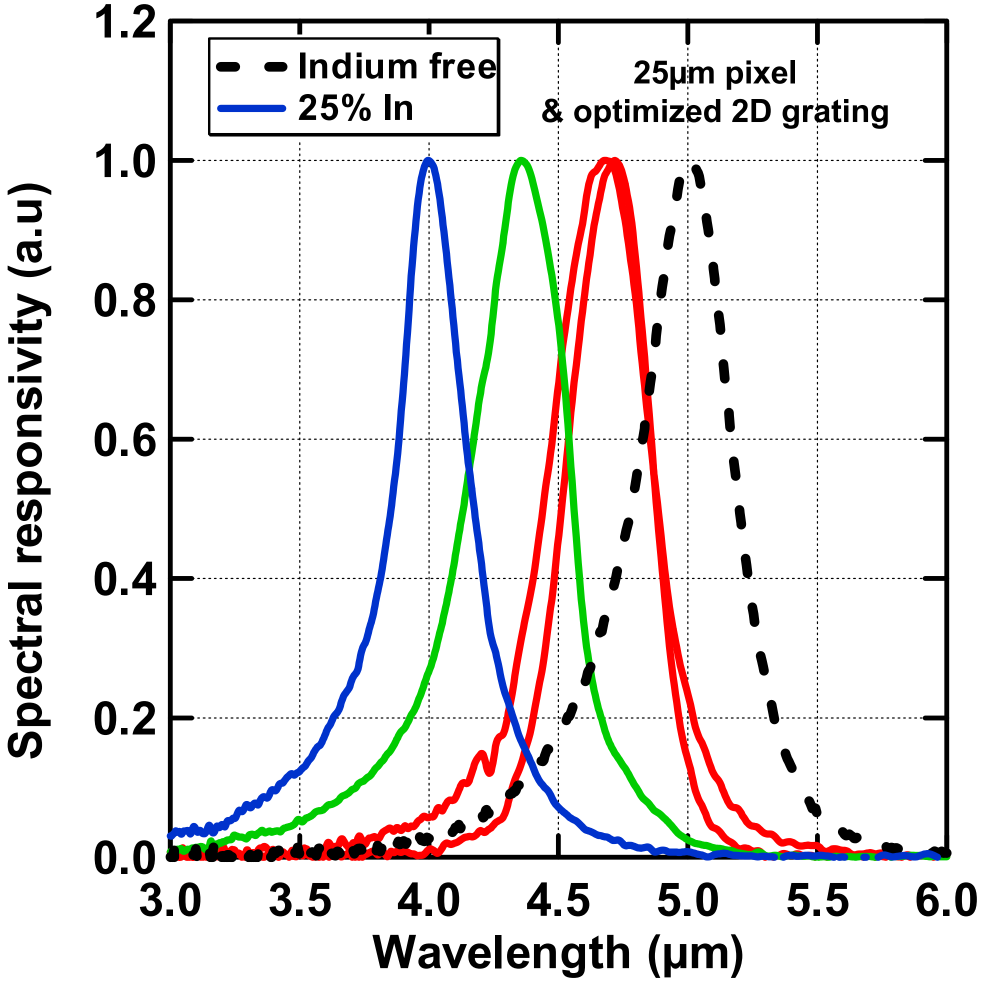
The Peak absorption can be adjusted (trade-off with operating Temperature)

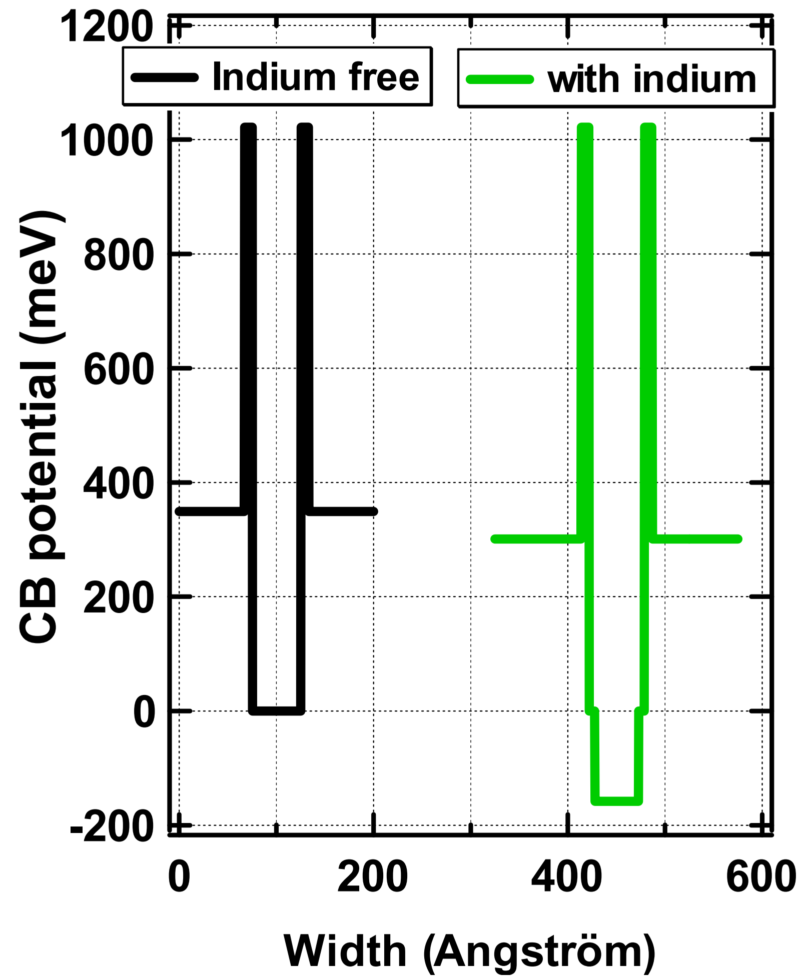
Uniformity, stability and affordability guaranteed from MWIR to VLWIR

QWIP nearly cover the MWIR spectrum…

…without exotic nor mismatched material

(IDDCA performance: Presentation 6206-14)





Spectral shapes suitable for dual color MWIR FPA

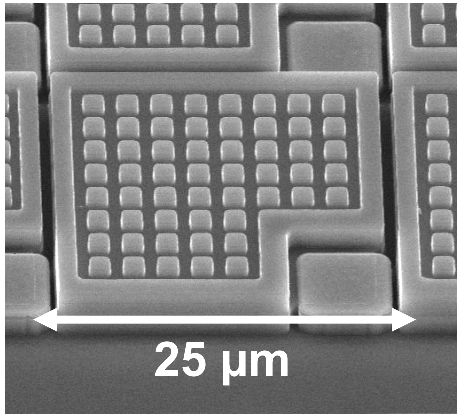
Dual-Band QWIP FPA demonstrated in 2005

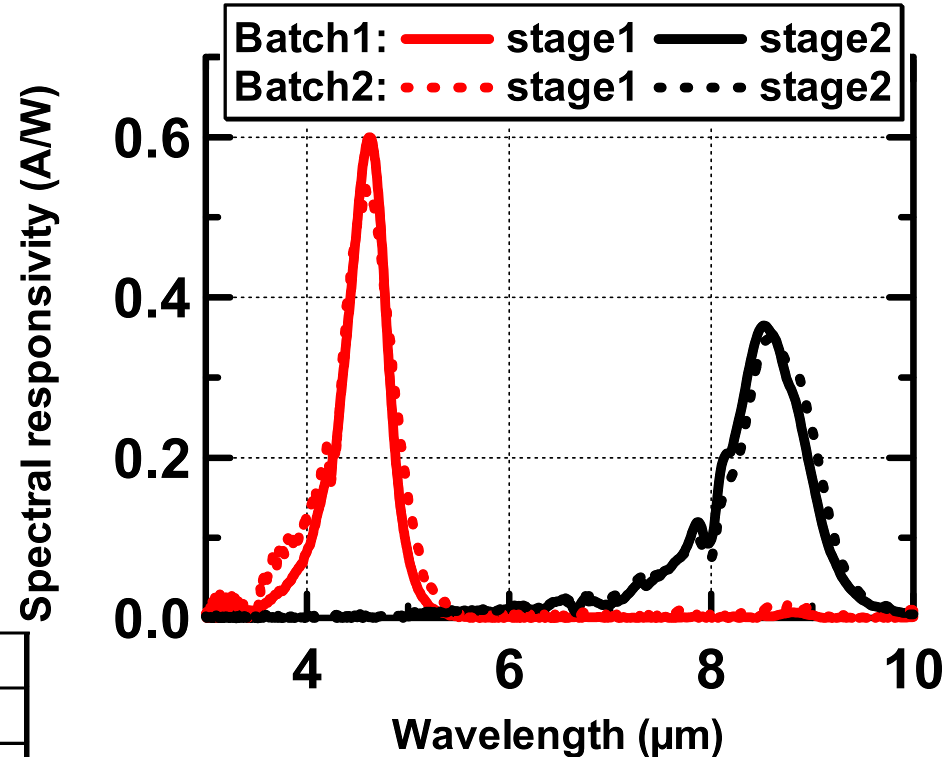
No Spectral Cross Talk

Even on small Pixels

Dual Band QWIP FPA:

- 256x256 pitch 25µm
- IWR mode
- 2 color subframe at 100Hz

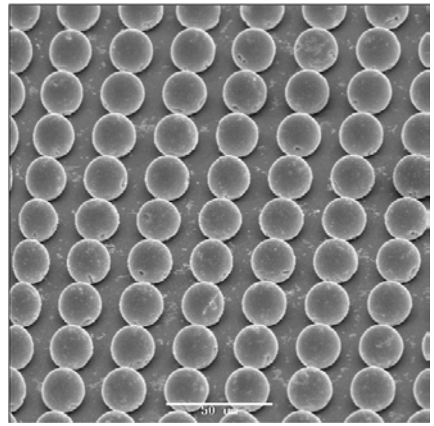




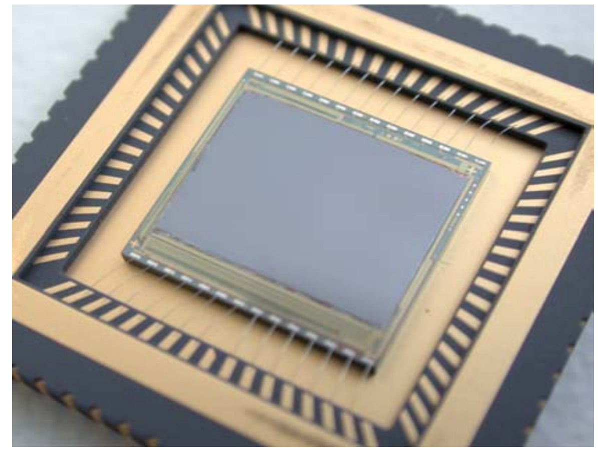
	MWIR band	LWIR band
Responsivity		
Mean responsivity	10.4 mV/K	13.9 mV/K
σ	8.5%	9.9%
operability at 1.5 x mean value	99.04%	99.04%
NETD		
Mean NETD	40 mK	39 mK
σ	17%	16%
operability at 2 x mean value	99.5%	99.9%

Sofradir & TRT are developing a MWIR / LWIR IDDCA based on a ISC0208 ROIC (384x288 pitch 25µm)

384x288 QWIP FPA
ISC0208 ROIC from ***Indigo***
Pitch 25µm



Indium Bump Array



Pulse Instrument system 7700

- **4 Preamplifiers**
- **14 bits A/D (bandwidth ≥ 30Mhz)**
- **8 clock drivers and 8 bias generators**
- **Easy pattern generation**

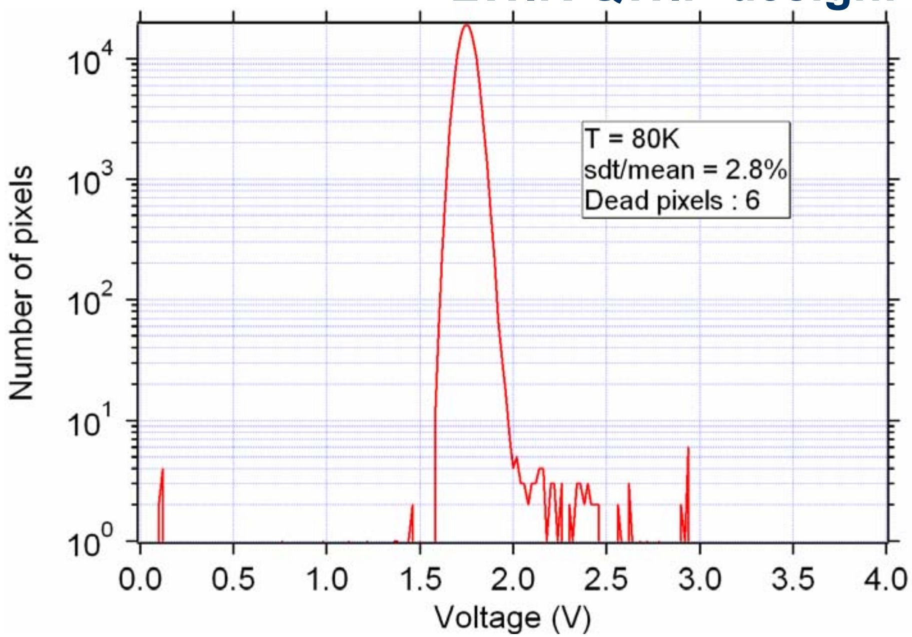
New building Block: hybridization

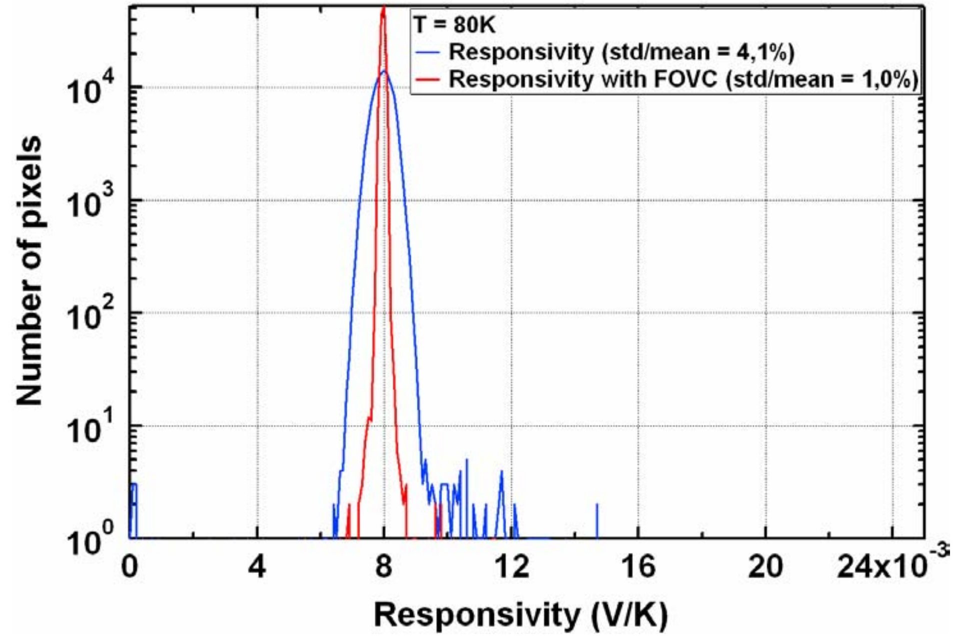
For Research & Development

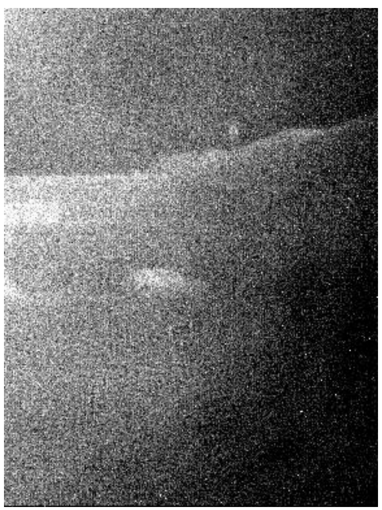
Tests in lab dewar (He or LN2)

In House FPA Capability (2/2)

LWIR QWIP design: λc = 9 µm ; 384x288, pitch 25 µm







- **6 non connected pixels**
- **9 saturated pixels**
- **No Cluster**

T=80K

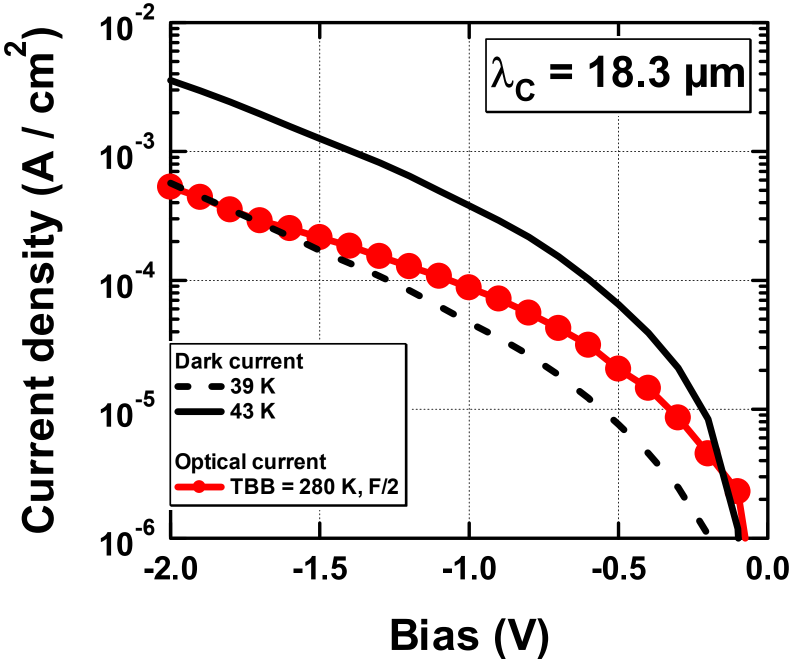
without & with 2 point correction

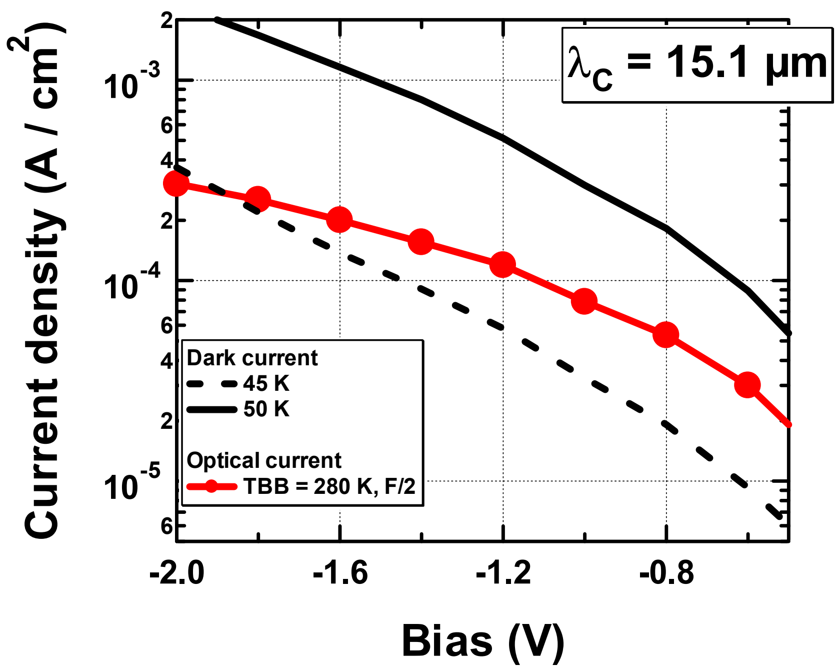
FPA expected performances in VLWIR

ROIC ISC0208 : 384x288 ; pitch 25µm

Tbb=280K; f/2 (diffraction limited)

dynamics = +30°C





T_{det}=40K ; λ_c=18.3µm

NETD = 22 mK

Responsivity = 16 mV/K

Integration Time = 8.5 mS

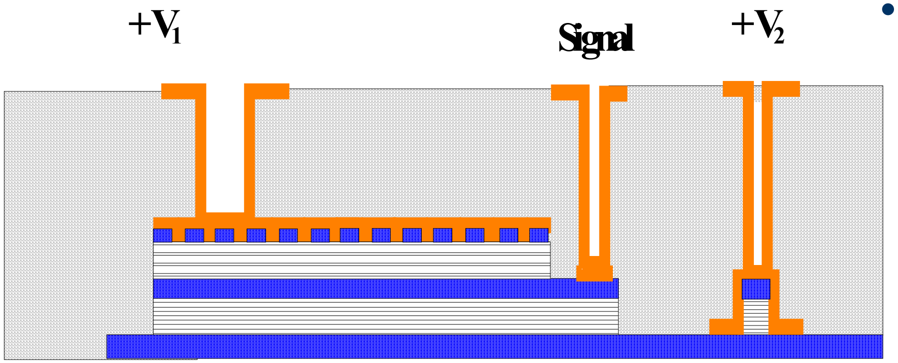
T_{det}=50K ; λ_c=15.1µm

NETD = 15 mK

Responsivity = 20 mV/K

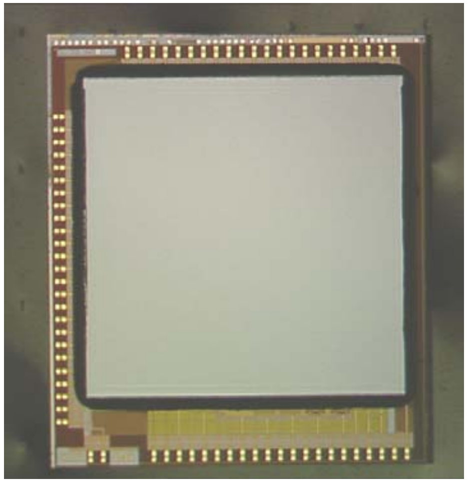
Integration Time = 6 mS

2 color (LW/LW or MW/LW) QWIP arrays



ROIC designed for:

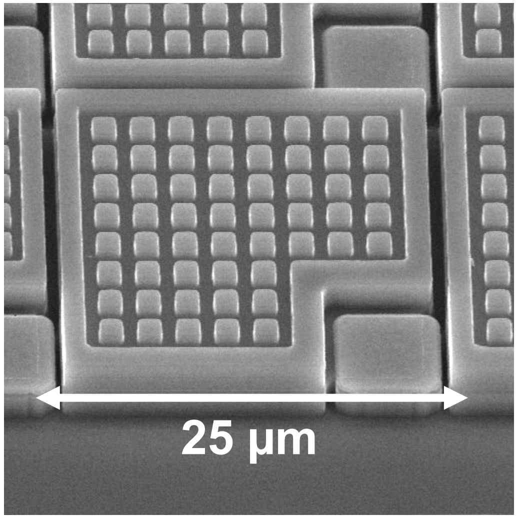
- 2 color subframe at 100Hz
- Optimized FPA temperature



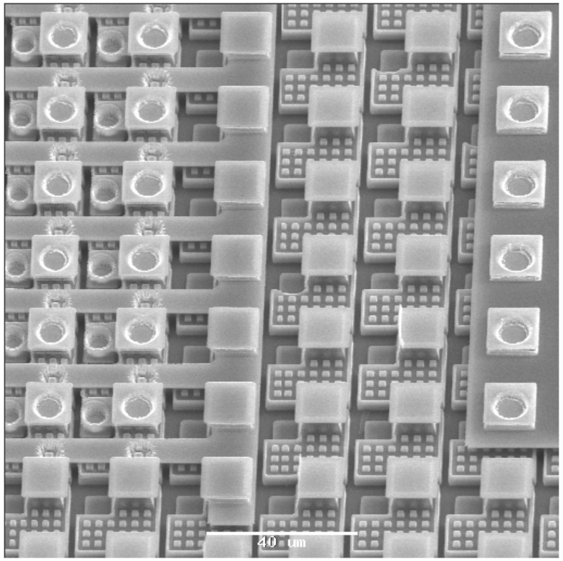
Dual color QWIP FPA

256x256 pitch 25µm

IWR mode



Spatial correlation

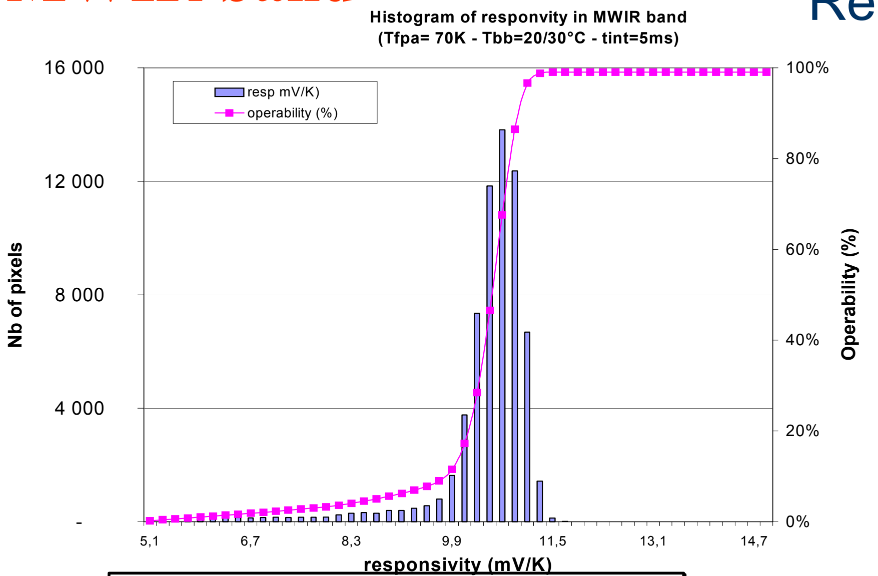


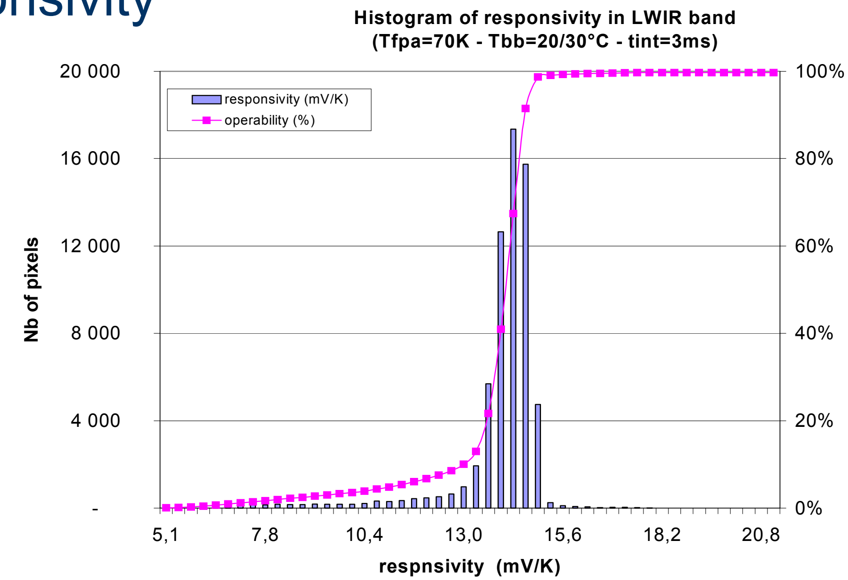
(details of a 2 color QWIP array)

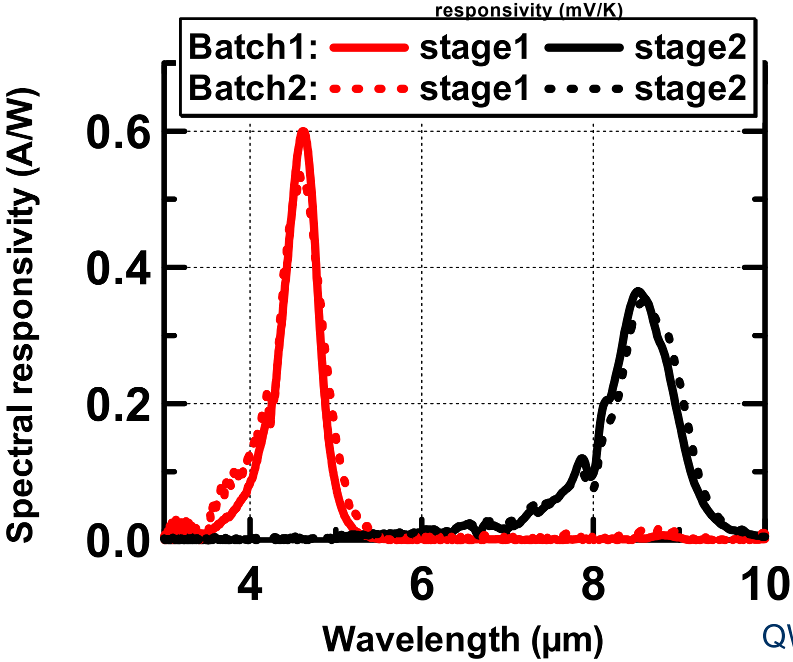
MWIR band

Responsivity

LWIR band





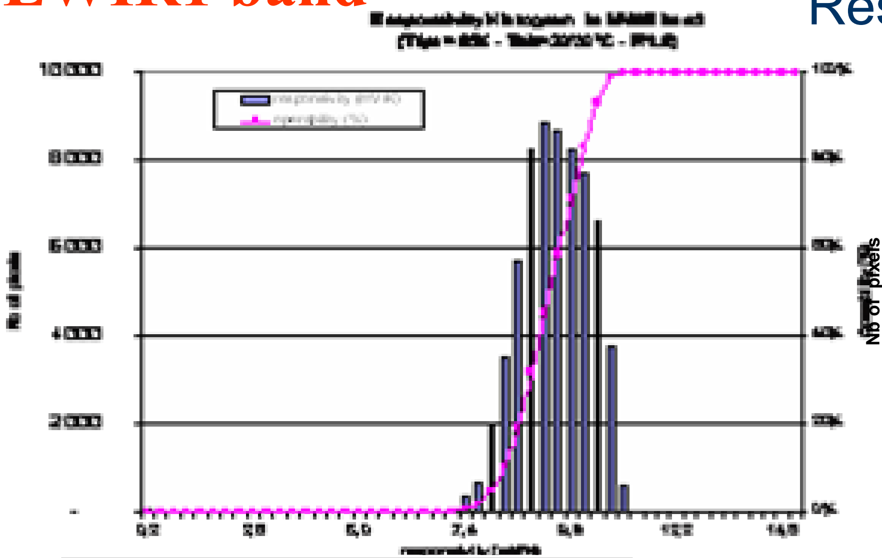


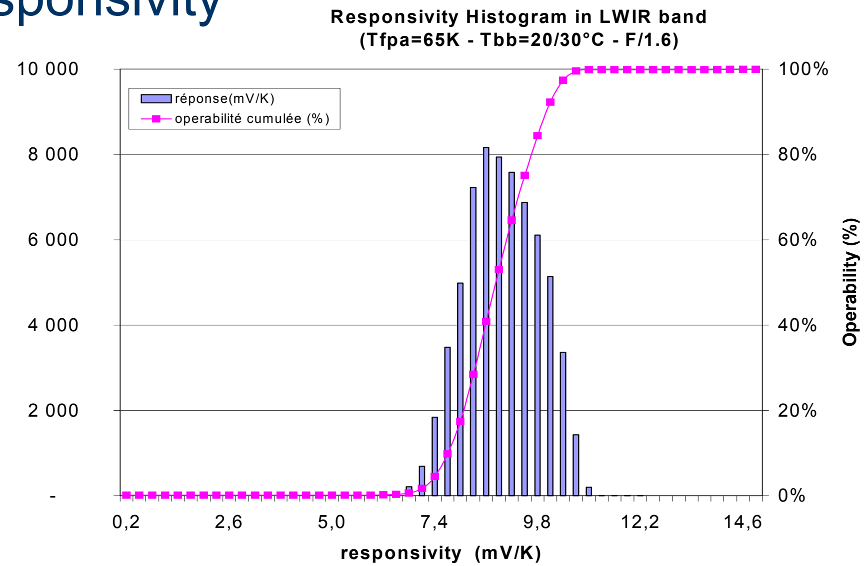
	MWIR band	LWIR band
Responsivity		
Mean responsivity	10.4 mV/K	13.9 mV/K
σ	8.5%	9.9%
operability at 1.5 x mean value	99.04%	99.04%
NETD		
Mean NETD	40 mK	39 mK
σ	17%	16%
operability at 2 x mean value	99.5%	99.9%

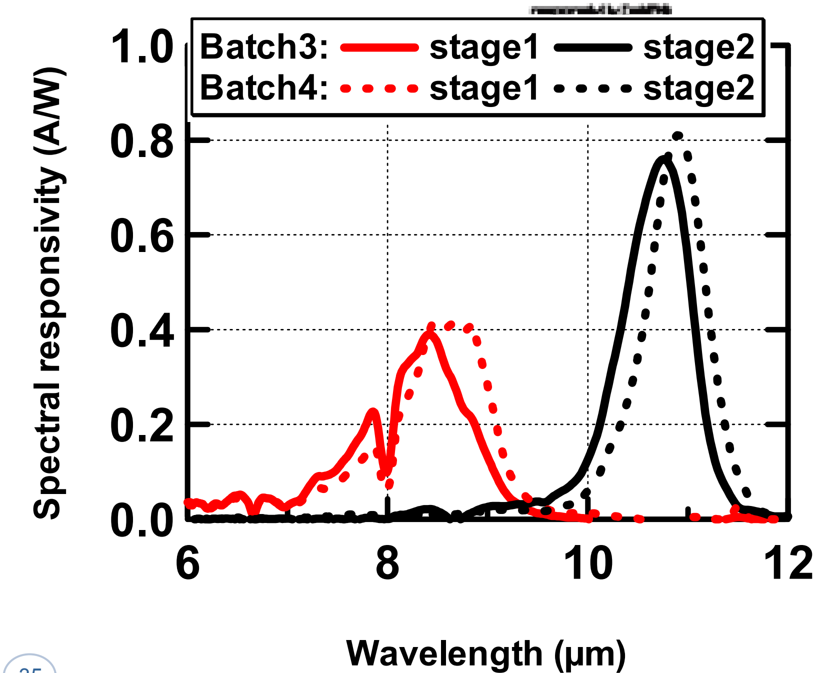
LWIR1 band

Responsivity

LWIR2 band

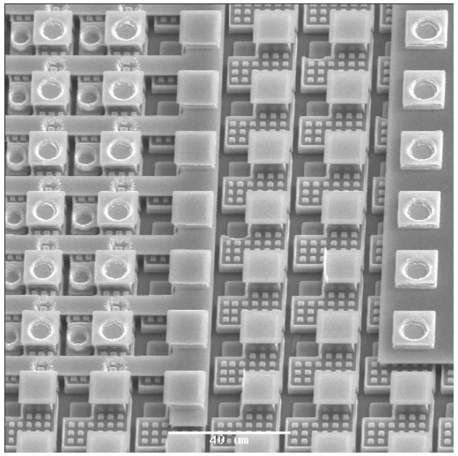






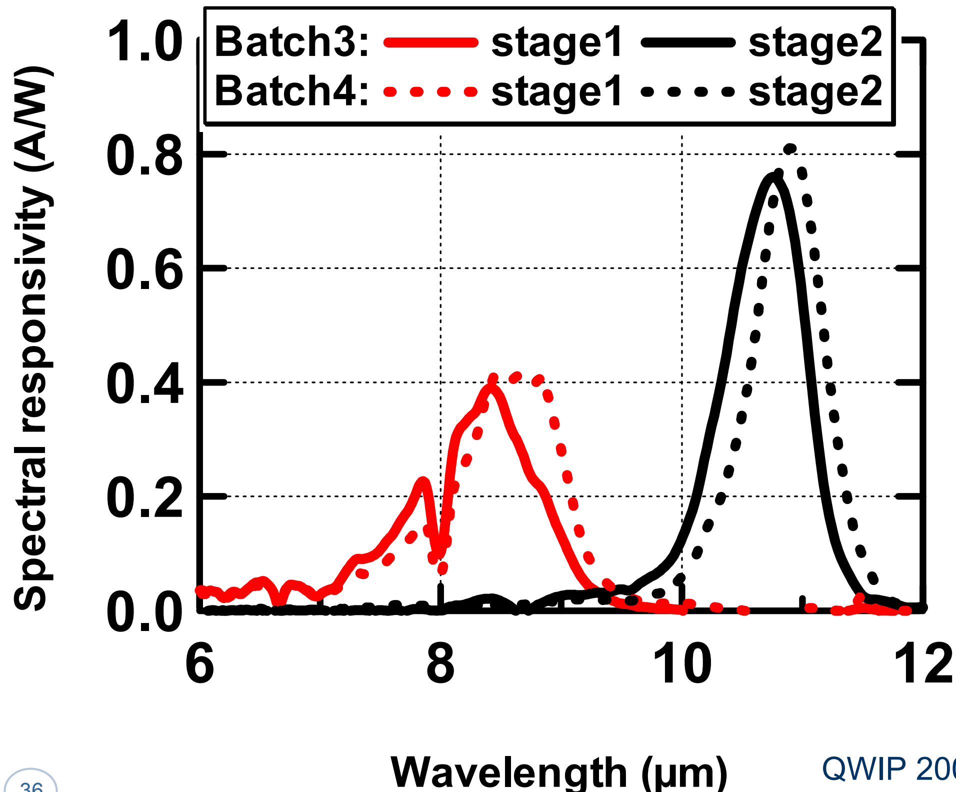
	LWIR1 band	LWIR2 band
Responsivity		
Mean responsivity	9.4 mV/K	8.9 mV/K
σ	7.6%	9.3%
operability at 1.5 x mean value	99.8%	99.8%
NETD		
Mean NETD	50 mK	59 mK
σ	15.9%	12.4%
operability at 2 x mean value	99.5%	99.4%

256² pitch 25µm Dual-Color LWIR FPA demonstrator



Dual Color QWIP FPA:

- 256x256 pitch 25µm
- IWR mode
- 2 color subframe at 100Hz



	LWIR1 band	LWIR2 band
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Mean responsivity	9.4 mV/K	8.9 mV/K
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operability at 1.5 x mean value	99.8%	99.8%
NETD		
Mean NETD	50 mK	59 mK
σ	15.9%	12.4%
operability at 2 x mean value	99.5%	99.4%

Negligeable Spectral Cross Talk

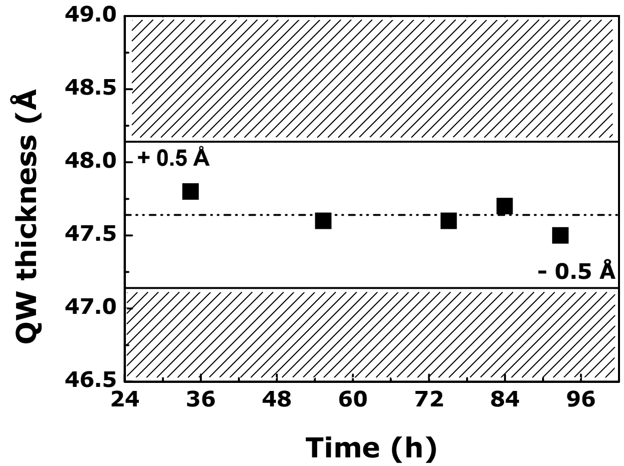
Even on small Pixels

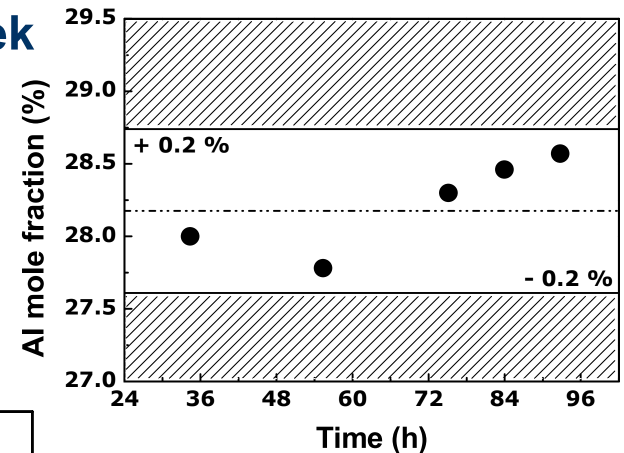
The Tool for R&D QWIP:

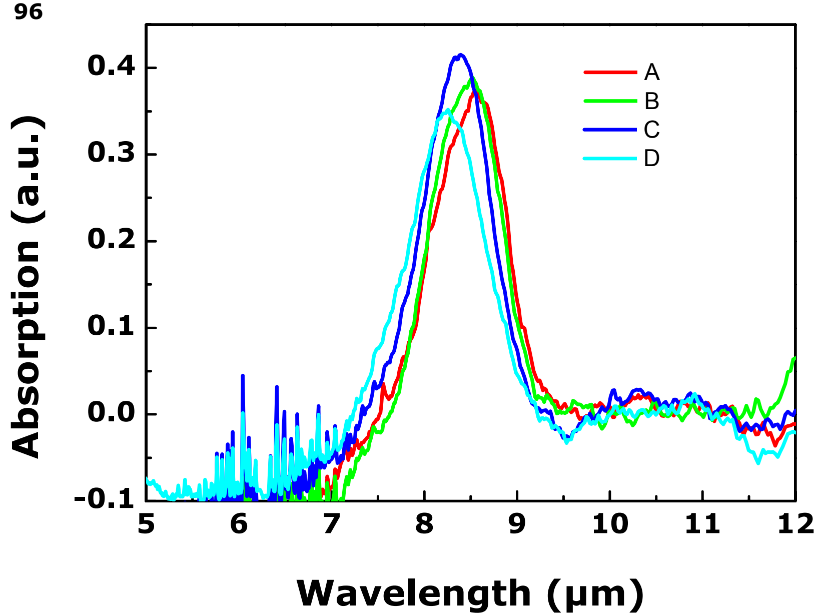
Uniformity

Reproducibility over a full week

5X3 inch wafers per platen







THALES