# T2SL technology for Mid-IR detectors

Linda Höglund

**Minerva Workshop**
**June, 30th**

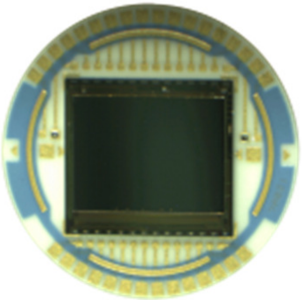
# Outline

- Introduction
- Tasks in MINERVA
- Starting point: MW detectors 320×256 on 30 µm pitch
- Technologies developed in MINERVA
- Triggered results in following projects

# IRnova

- Who are we?
  - IRnova is a Swedish high-tech company engaged in the development, manufacture and marketing of high-end cooled infrared detectors and related technology

- Detector technology
  - Quantum Well Infrared Photo detector (QWIP)
  - Type II Super Lattice detector (T2SL)



- Integrated Detector Cooler Assembly (IDCA)
  - Split/Integral Stirling cooler based
  - Small and light weight

- Design and Process
  - III/V material processing
  - Indium bumping and Flip-Chip

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- Introduction
- Tasks in MINERVA
  - Objectives
  - Partners and workflow
  - Challenges
- Starting point: MW detectors 320×256 on 30 µm pitch
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# Objectives

- Development of ROIC (readout integrated circuit), compatible with T2SL sensor
- Development of two T2SL imaging detectors for MWIR (1-5 µm) and LWIR (5-12 µm) and resolution of at least 640×512 on 15 µm pitch (max)
- Integration of T2SL on ROIC into detector module and further into camera

# Partners and workflow

| Xenics nv (WP leader) | IRnova AB |
|---|---|
| Readout circuit design and fabrication | T2SL imaging detectors development |
| | Hybridization and integration in IDCA |
| Camera development | |
| | |
| | |

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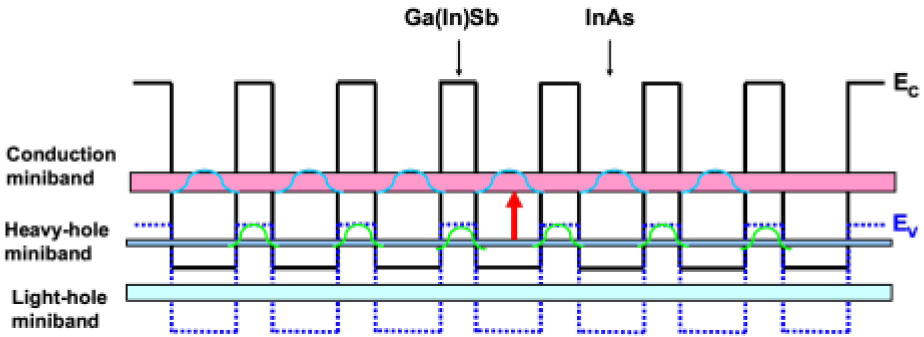
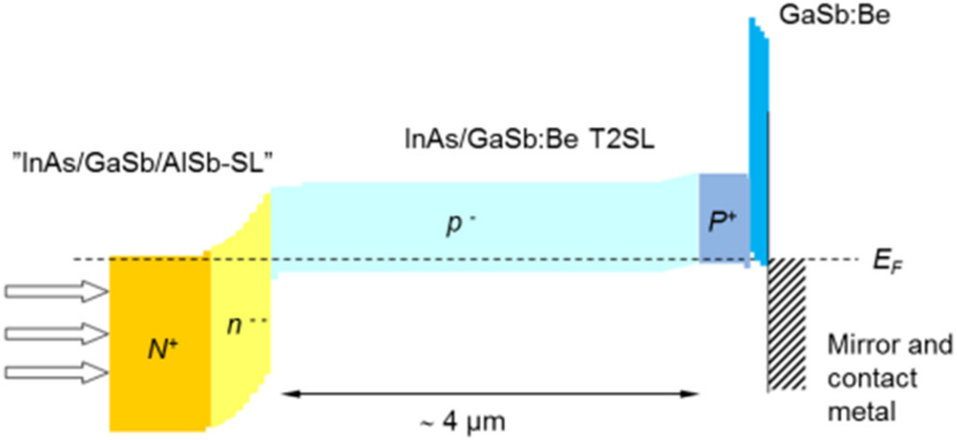
# Starting point: MWIR T2SL at IRnova



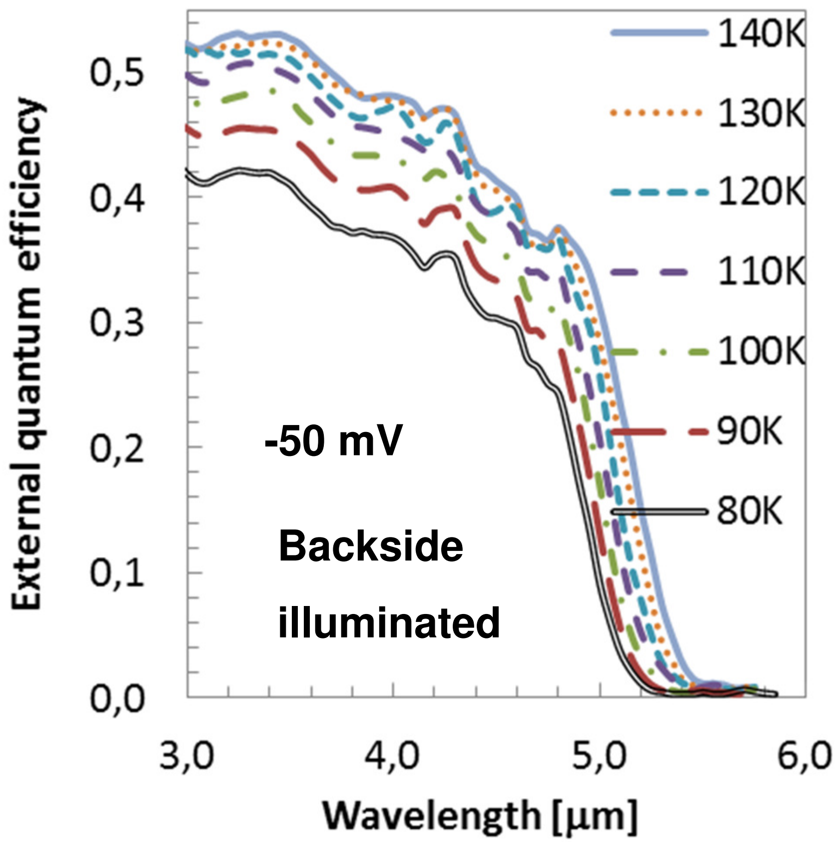



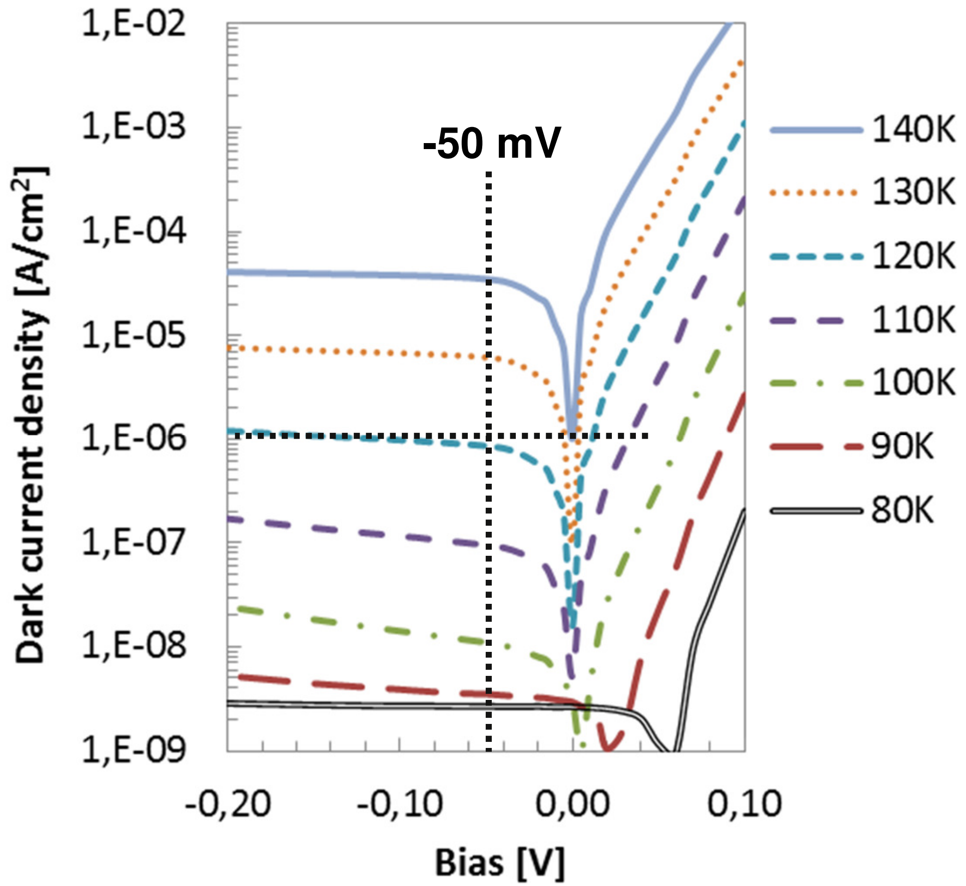

- The InAs/GaSb/AlSb material system is used to form superlattice materials with band gaps tailored for the infrared region
- Double heterostructure (DH) design with unipolar barriers used to block majority carriers while allowing unimpeded transport of minority carriers
- Reduction of Shockley-Read-Hall current and tunneling related dark current component with this design

# MW photodiode performance

Good performance for MWIR detectors:

- ~**40-50%** QE without AR-coating
- Dark current **≤ 1×10$^{-6}$ A/cm$^2$** obtained for **T < 120 K** at -50 mV operating bias



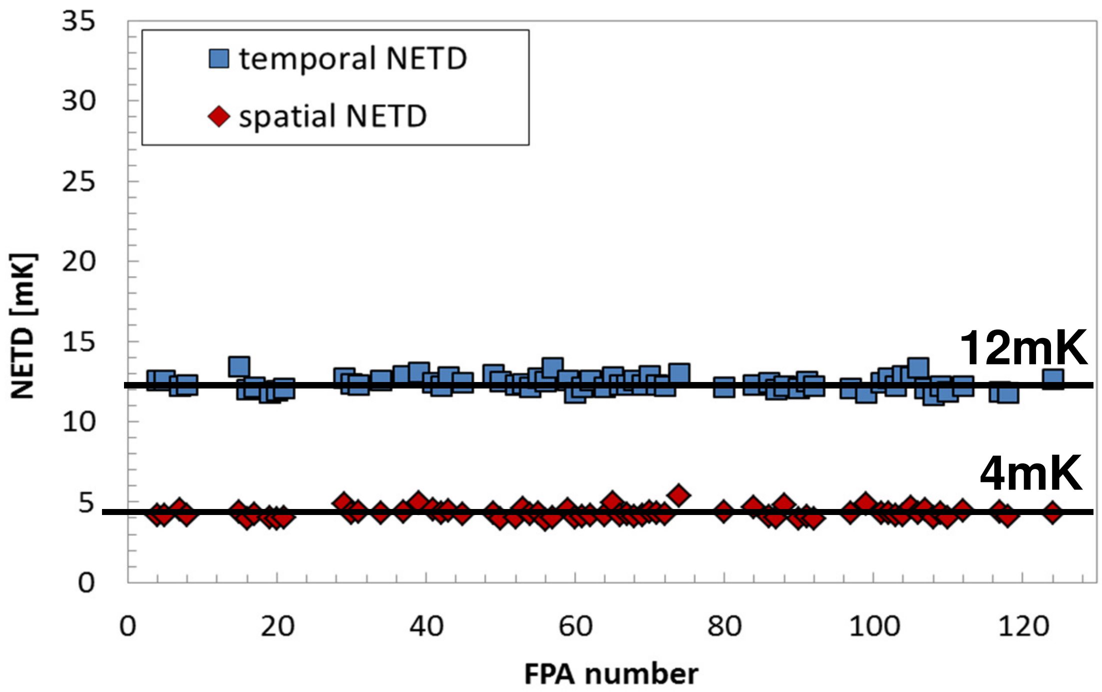
# MW FPA performance

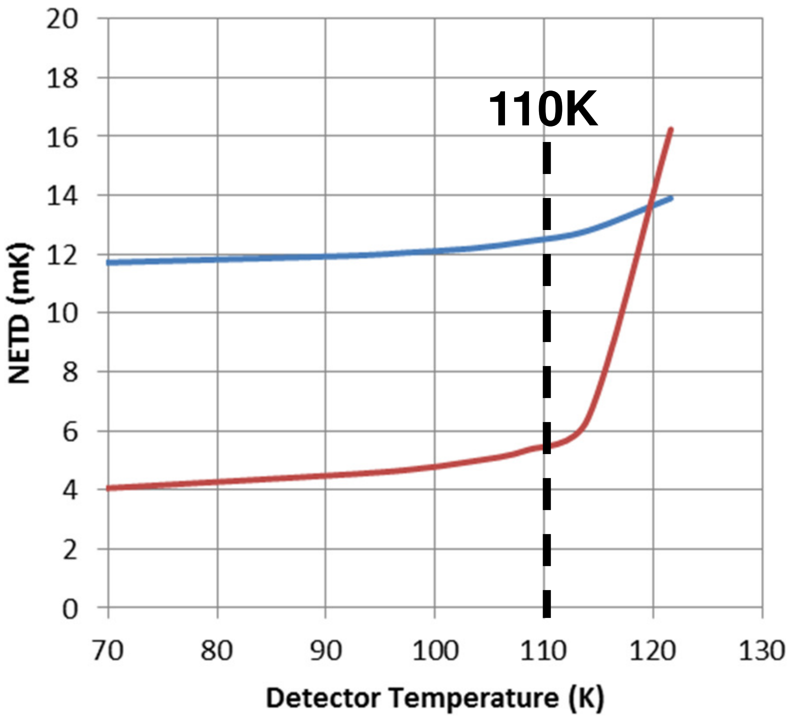
Figures of merit for evaluating FPA performance

- Temporal NETD* = standard deviation in time / response per Kelvin
- Spatial NETD* = standard deviation of pixel from its neighbors / response per Kelvin

** NETD – noise equivalent temperature difference*

- **F#2**
- **T= 85 K**
- **$\tau_{int}$ = 8 ms**
- **$T_{BB}$ = 30 °C**
- **ROIC: ISC9705**



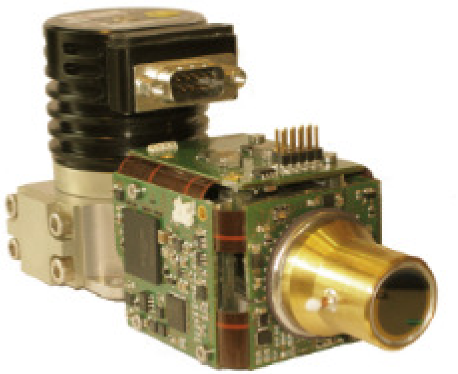



## Excellent image stability (measured on IDCA by ONERA, France)

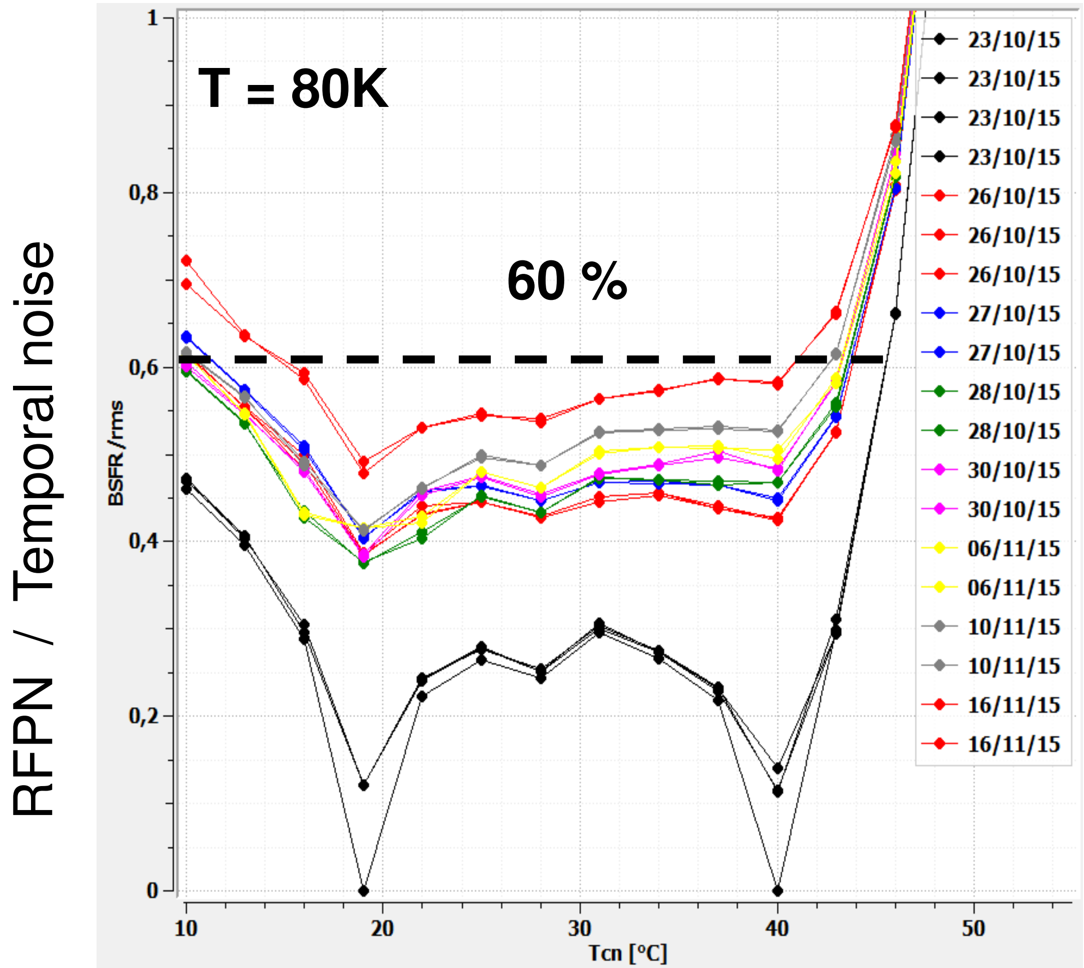
- **24 cooling downs**
- **> 3 weeks of testing**

- Excellent image stability:
  - Within the same cool-down
  - From one cool-down to the next one

- **RFPN < 60% temporal noise**



IRnova320ER-MW




- *RFPN=residual fixed pattern noise*
- *TN =temporal noise*

# Challenges

- MWIR – LWIR
  - Leakage currents, passivation, correct cut-off
  - Rule 07
  - Absorber length
  - Inverted structure
- Resolution and pitch
  - Trenches / passivation
  - Pixel size – hyb process
  - Array dimension – planarity/parallelism
- New ROIC
  - First attempt to design cooled ROIC for Xenics
  - Suitable for inverted structure

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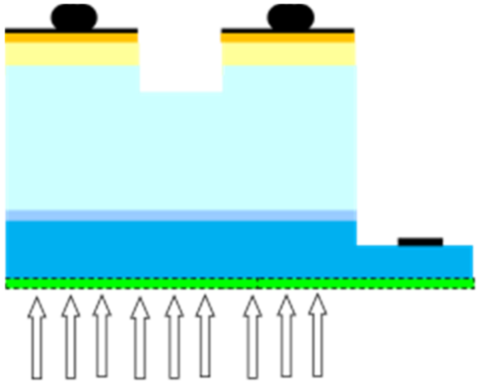
- Technologies developed in MINERVA
  - Design of MW structure for shallow etching → higher fill factor
  - LW inverted detector design
  - Processing scheme for 1280 × 1024 matrix
  - Passivation development
  - Development of flip chip bonding with small bumps
  - Design and manufacturing of IDCA
- Triggered results in following projects

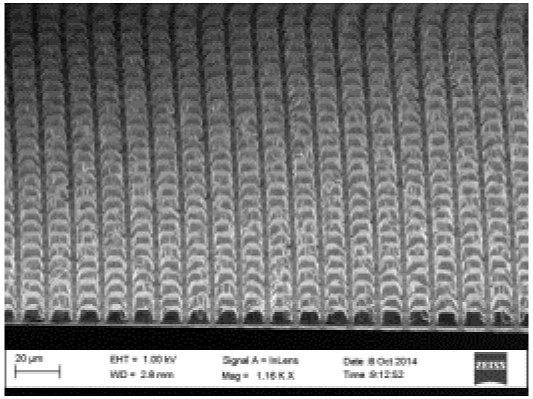
# Developed technologies

- Development of **1280×1024** FPA on **12 µm pitch**
- Detector design with **5.3** and **12 µm** cut-off wavelength
- Process development for large format and small pitch arrays
- Passivation development
- Development of hybridization with small bumps
- IDCA design and manufacturing

*IDCA designed for the large MW and LW arrays.*



*Design and fabrication of detector material*

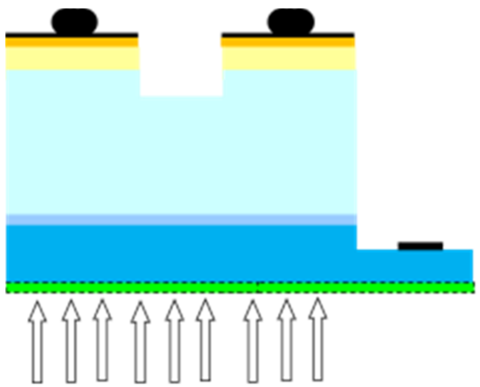


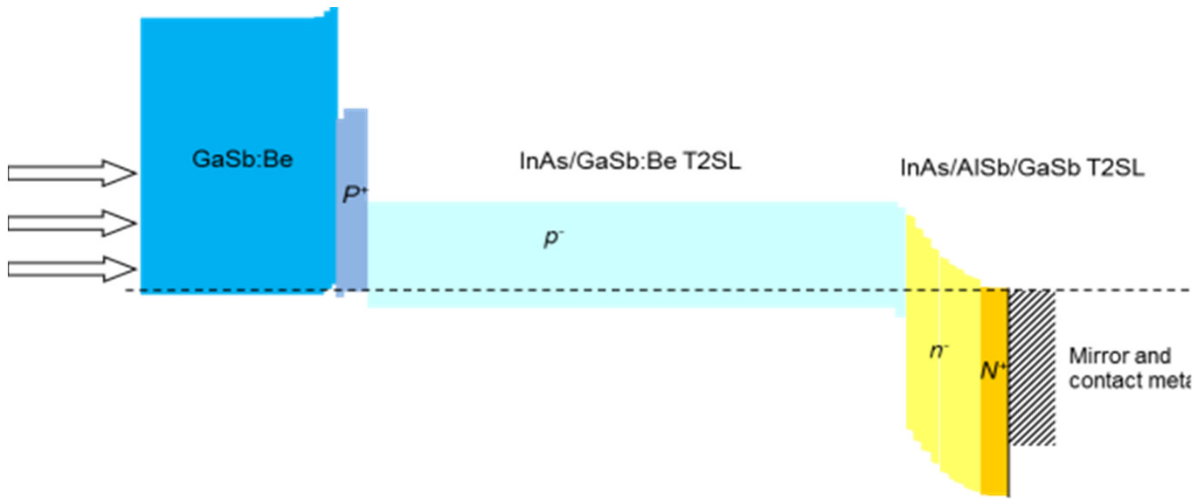
*Development of the hybridization process*

*1280×1024 MW FPA hybridized to Xenics ROIC*

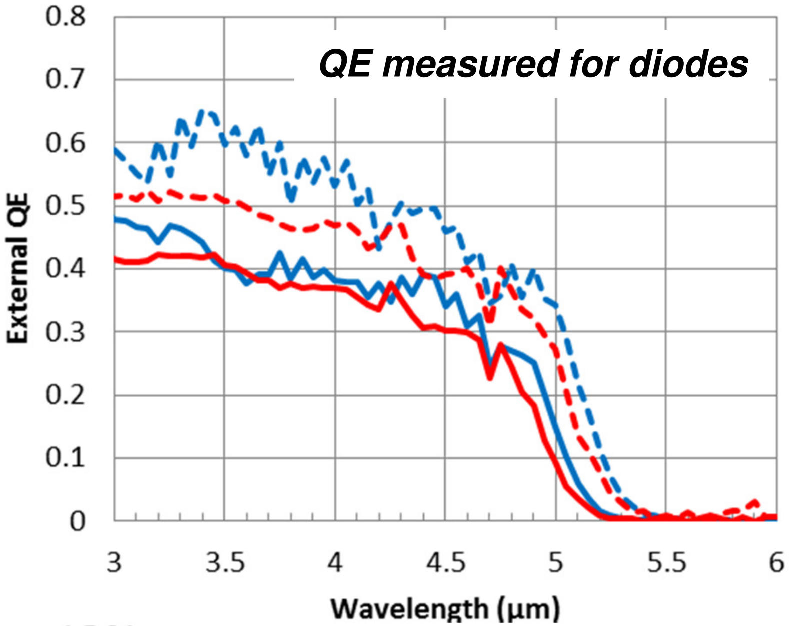
# Detector design

- MW and LW detector structures were designed with inverted structure compared to IRnova’s standard design
- *n*-on-*p* design enables shallow etching with 100% fill-factor
- By etching only into the barrier surface leakage could be prevented

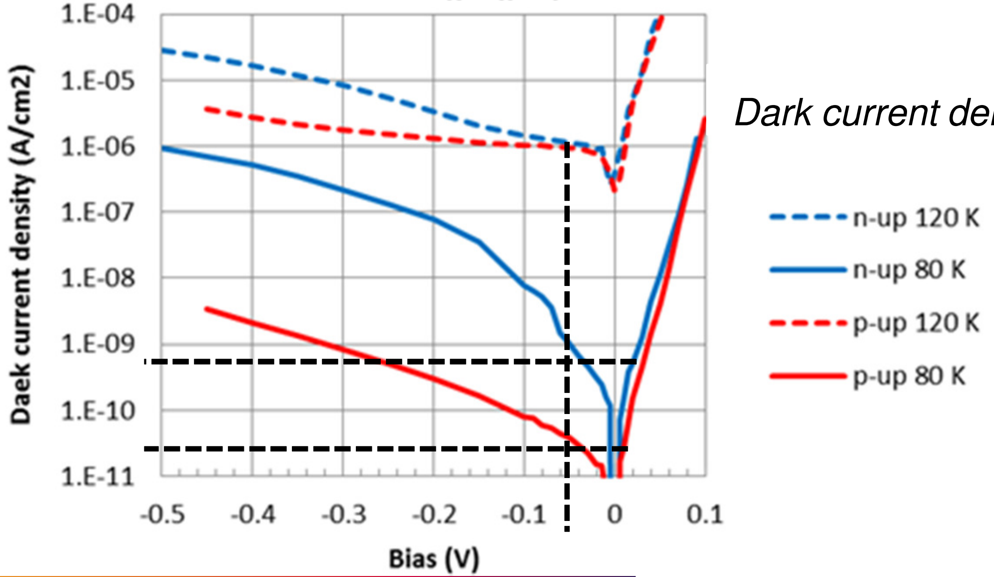




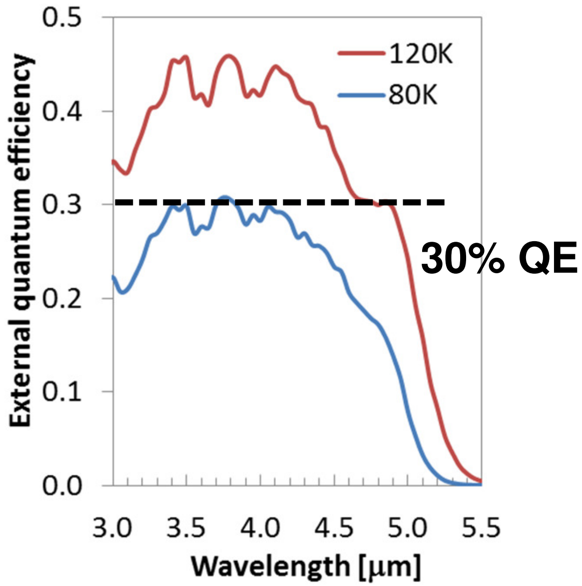
# MWIR detector (MINERVA)




- Target cut-off wavelength: 5.2 µm
- Diode results looked very promising:
  - Devices fully turned on at 0V
  - Dark current and QE comparable to the *p*-on-*n* structure
- 1280×1024 FPA:s fabricated and hybridized
- Testing not successful…




*Dark current density*

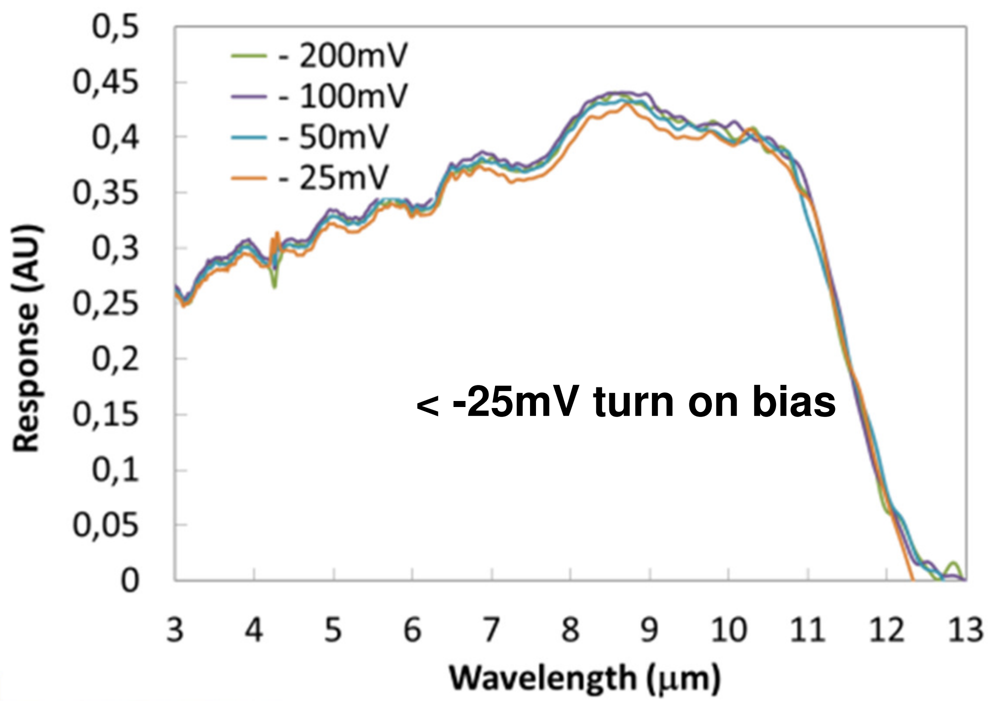



*QE measured on 12 µm pixels in array*

# LWIR detector (MINERVA)

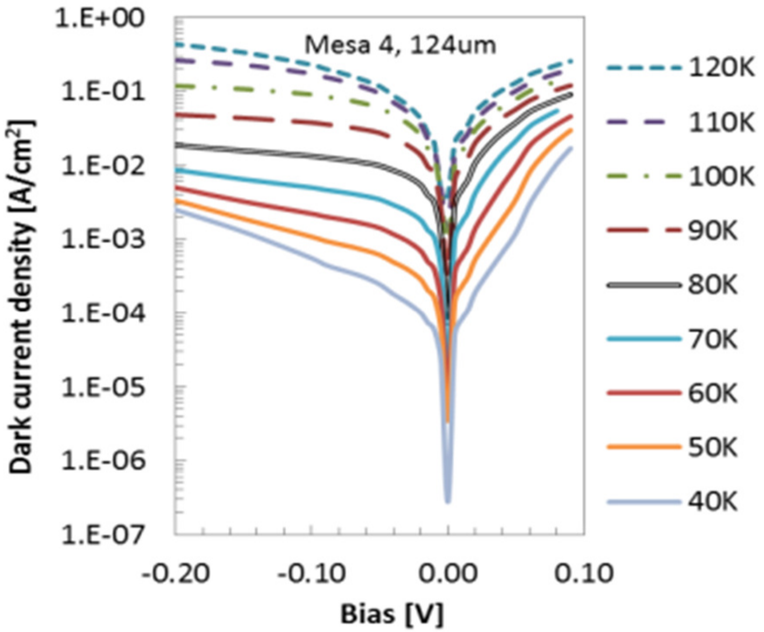
- Target cut-off wavelength: 12 µm
- Initial results looked very promising:
  - Low turn on bias of the response (< -25mV)
  - Dark current values only 3-4 times higher than Rule-07 for unpassivated devices

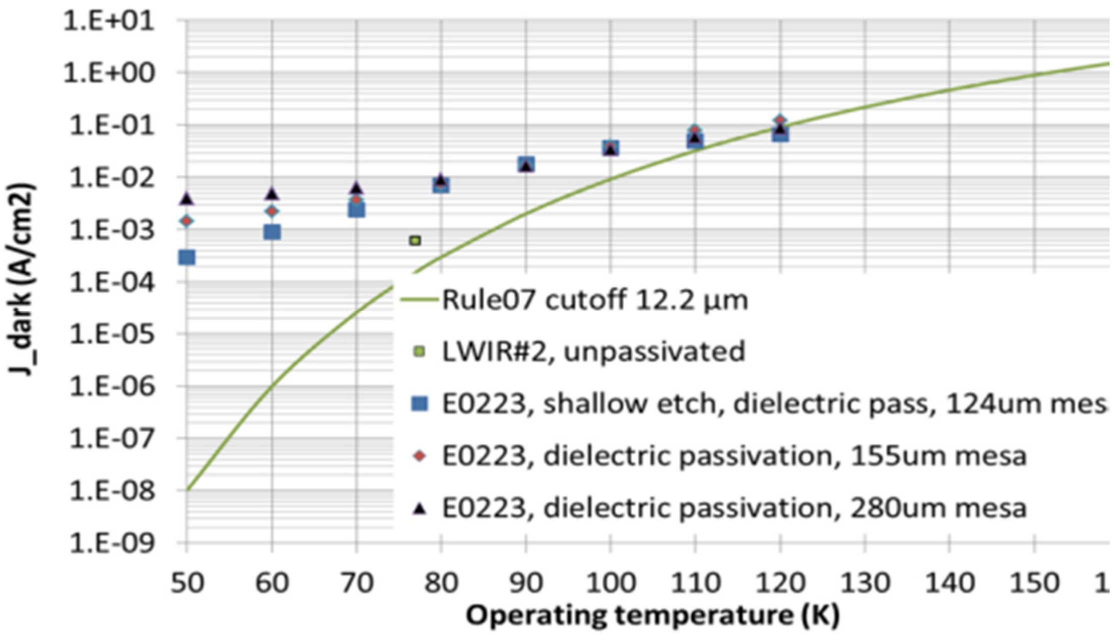
→ Proves that the design and material quality are good



# LWIR detector (MINERVA)

- The passivation was however not successful
- High dark current observed already for large mesas and got even worse for test FPAs with 12 µm pixels



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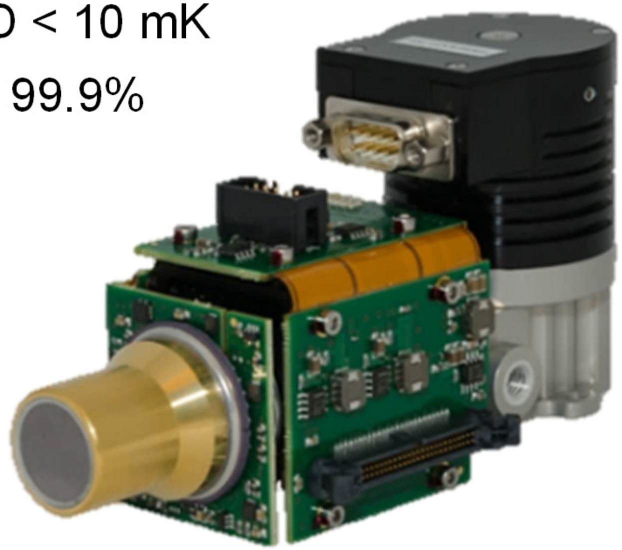
- Triggered results in following projects
  - Investment in Flip-chip bonder FC300
  - Development of 640 x 512 MW FPAs with 15 µm pitch
  - ESA project for LWIR / VLWIR detector development with same design
  - Dual color detector
  - Collaboration between Xenics and IRnova for ROIC + detector

# 2nd gen 640×512@15µm IDCA

Features of the second generation MW IDCA (launched 2017 Q1):

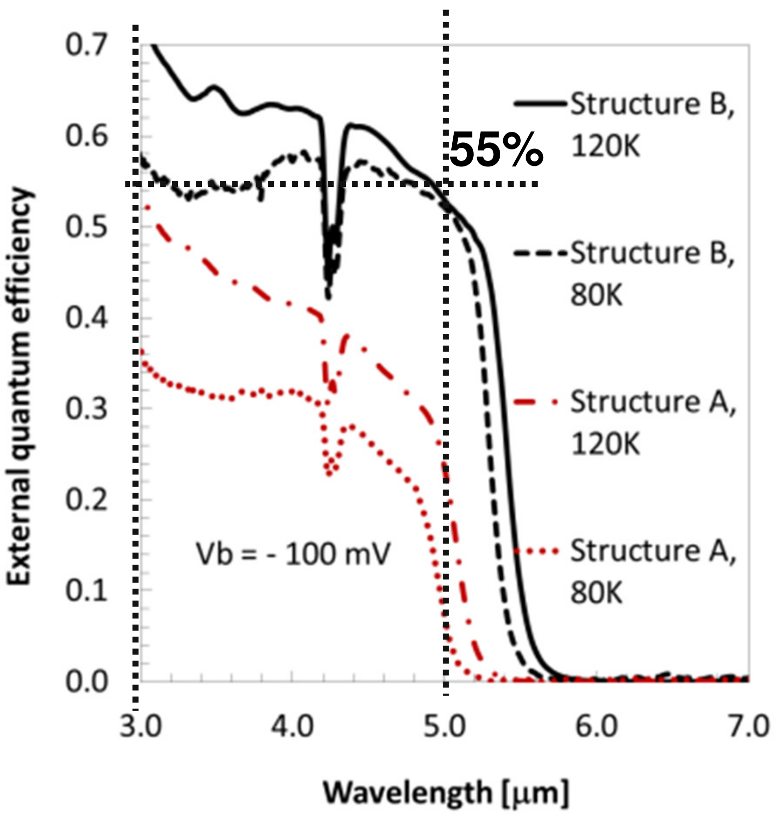
- Pitch 15 µm
- Resolution 640 × 512 pixels
- Operating temperature 85 K
- Integration time < 16 ms
- Temporal NETD < 20 mK at F/#4
- Spatial NETD < 10 mK
- Operability ≥ 99.9%

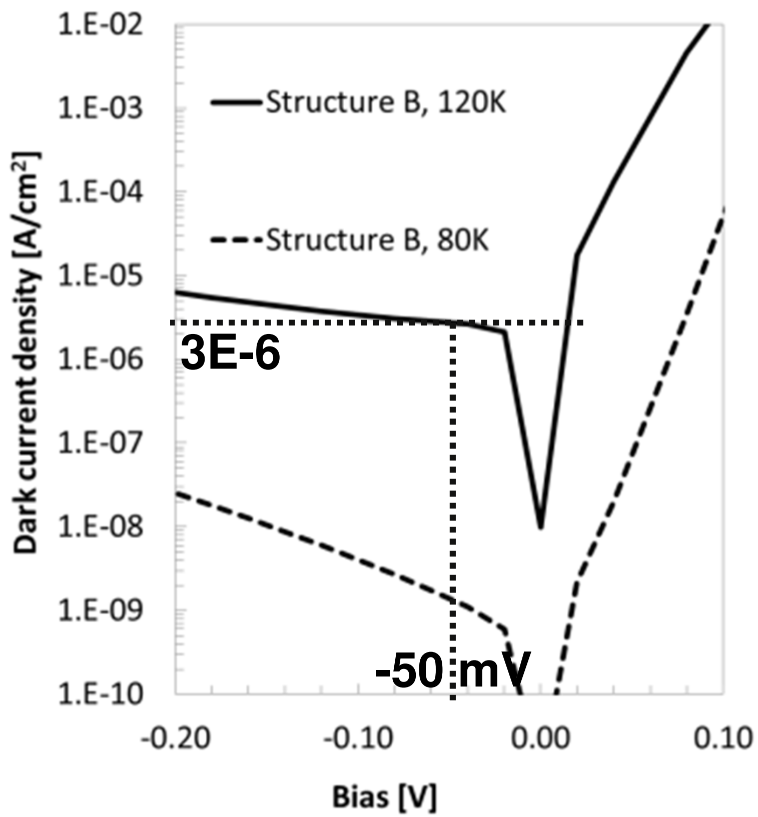


*IRnova640-MW*

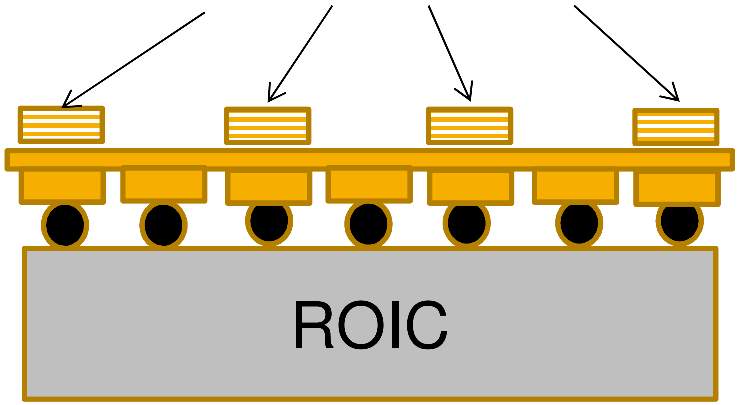
# 2nd gen MW diode performance

- 1st generation was optimized for gas detection in the 3 - 3.5 µm range
- Detector design now adjusted to cover the full 3 - 5 µm MW spectrum
- QE = 55-60 % in the entire MW range
- Dark current in the 3E-6 A/cm² range @ 120 K



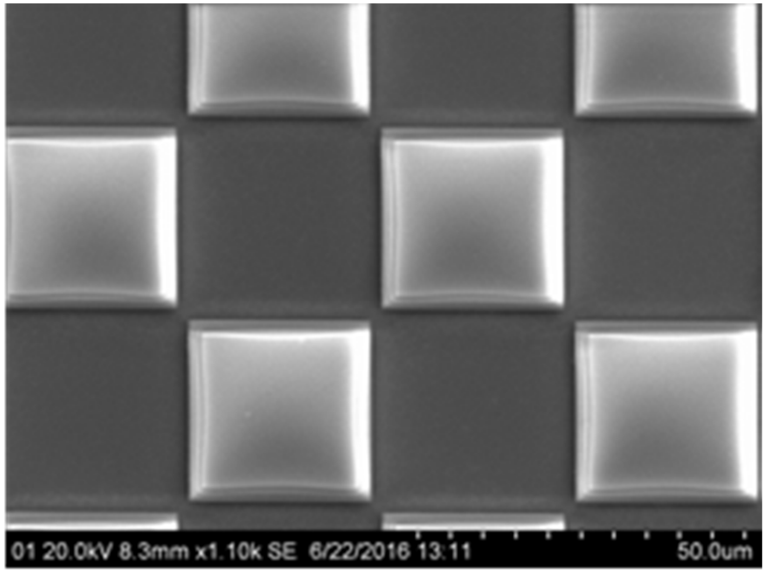



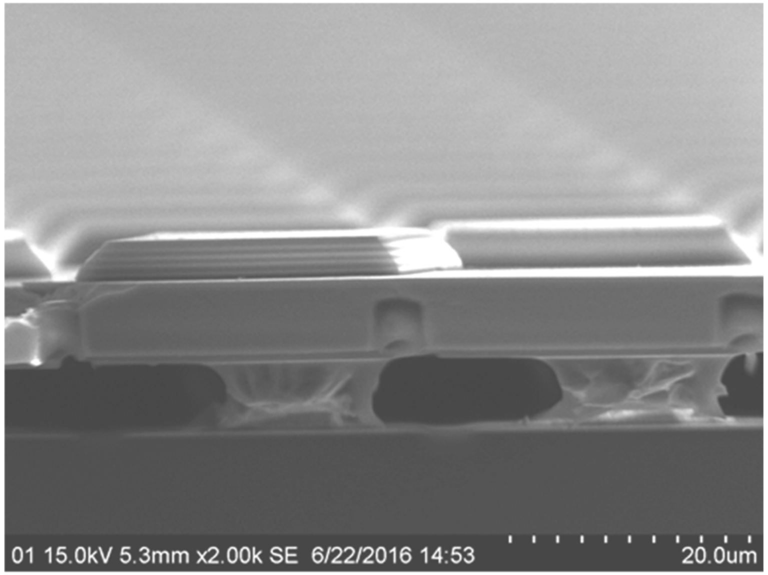
## Filters on every second pixel




- Dual color detection with pixel filters on every second pixel demonstrated
- A checker board filter is patterned on the backside of the FPA, well aligned with the FPA pixels

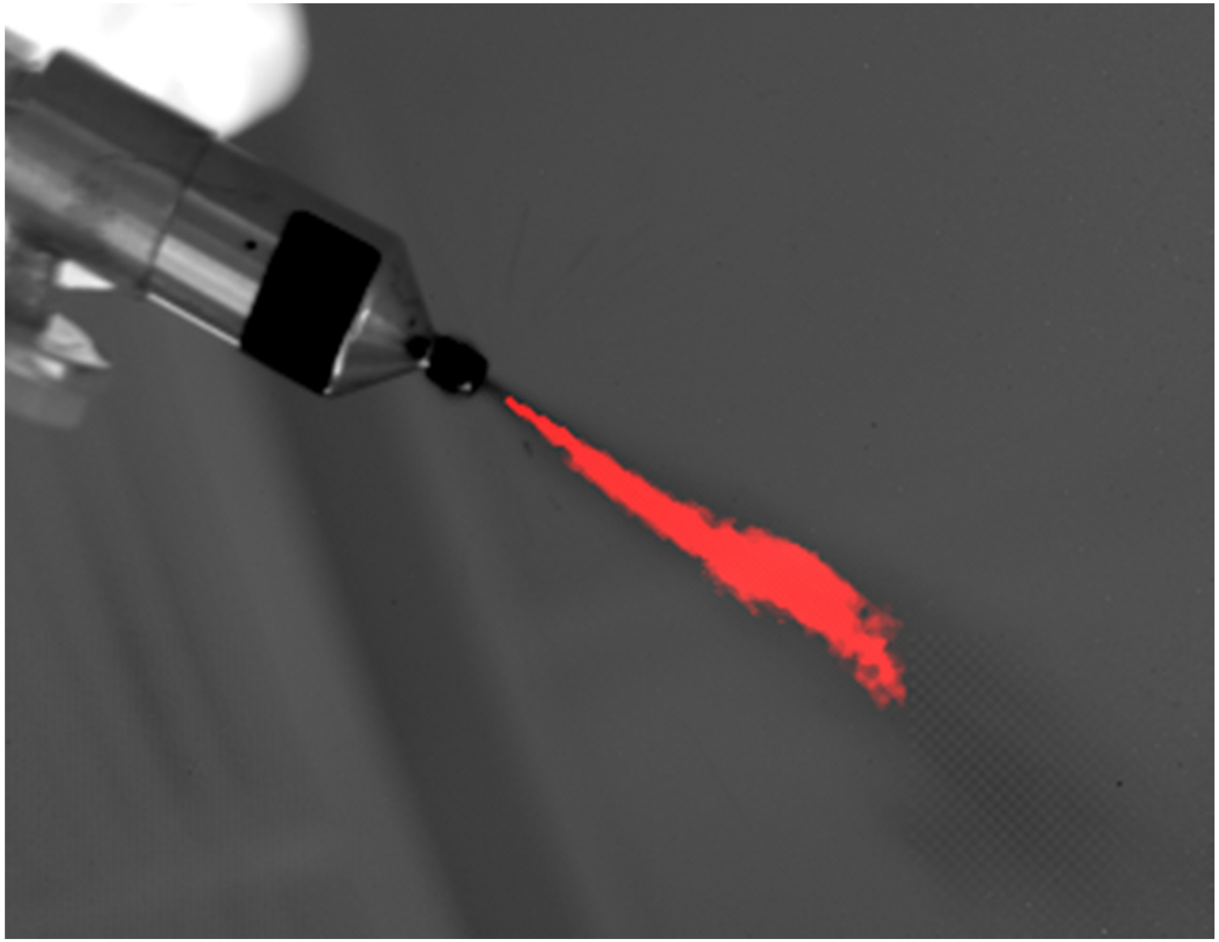
## SEM images of pixel filter on FPA backside



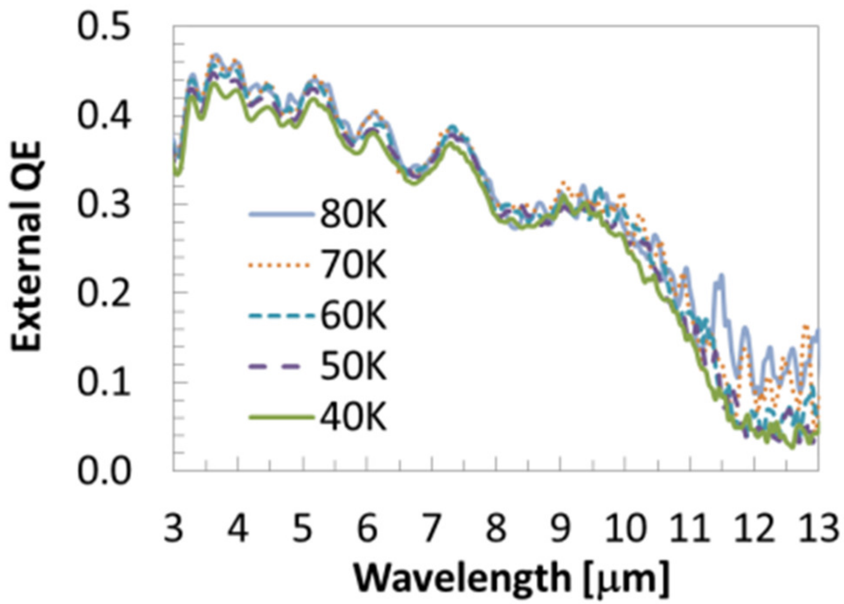
# Dual colour – FPA video

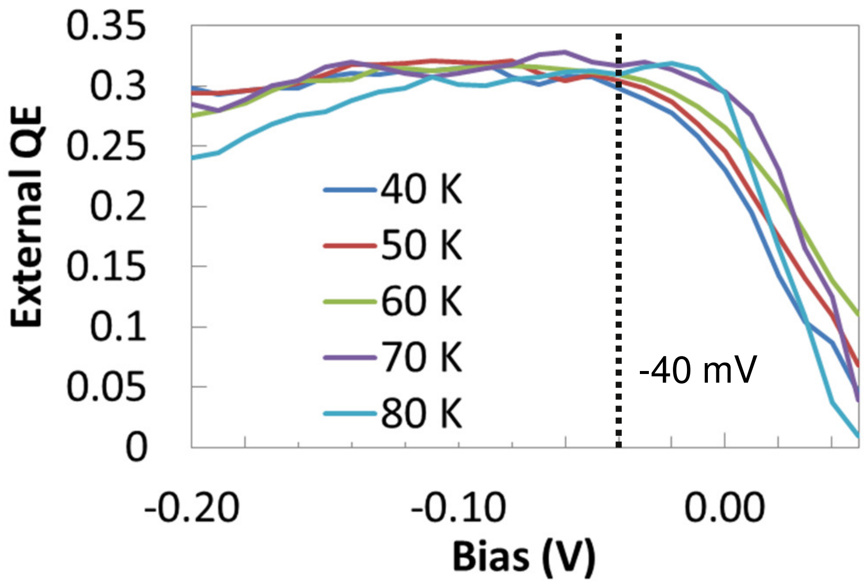
- Ability to distinguish gases demonstrated
- Algorithm used to highlight areas where gas is present
- Advantage is that the gas detection becomes automated and operator-independent



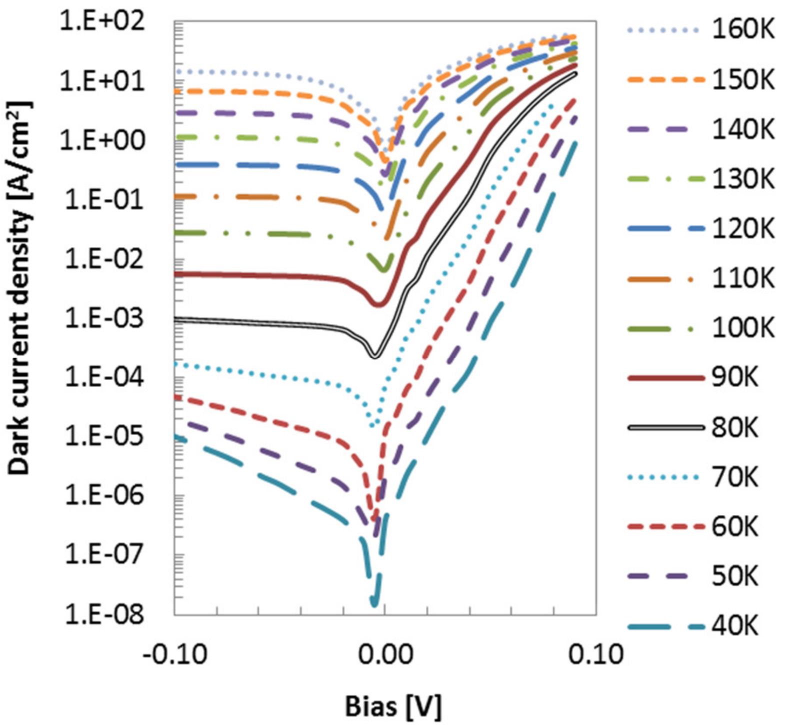
- **Target wavelengths:** 11.5 µm, 14.5 µm, 16.5 µm
- **Initial results, Quantum efficiency:**
  - QE ~ 30 % @ 10 µm (no AR-coating)
  - No temperature dependence of QE
  - Low turn-on bias of the QE

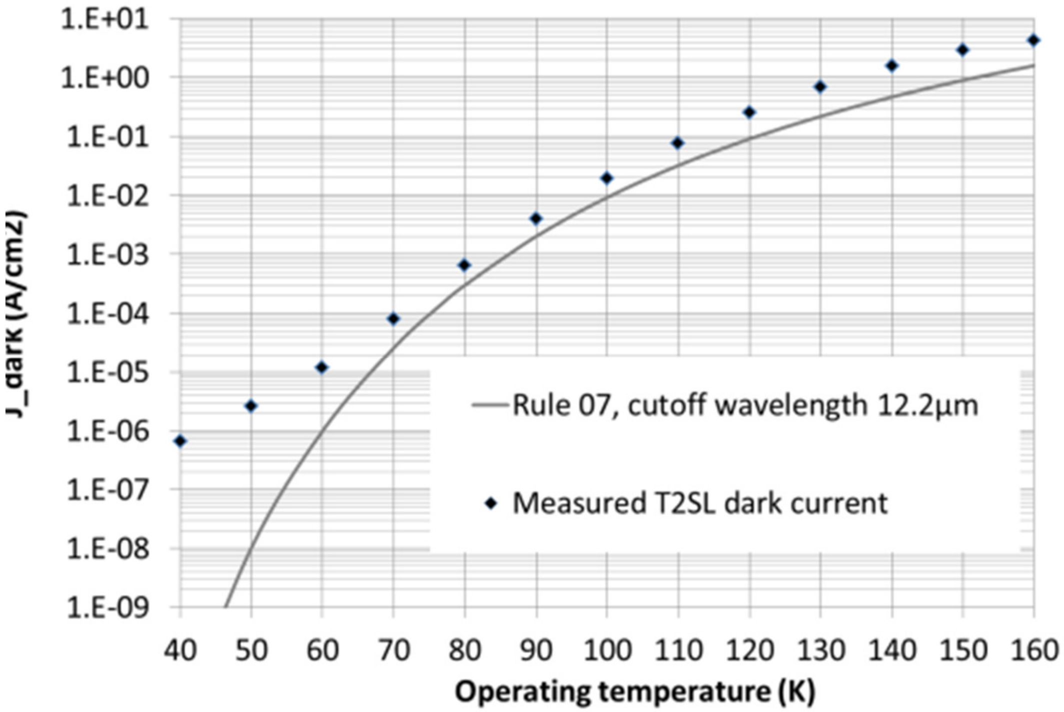
**Partners:**
IRnova
IES, University of Montpellier
Airbus defense and space (ADS)



- **Initial results, dark current:**
  - Dark current values only 2-3 times higher than Rule-07 @ T > 80K
  - At the operating bias (- 50 mV) dark current < 1E-4  A/cm² @ T = 70K

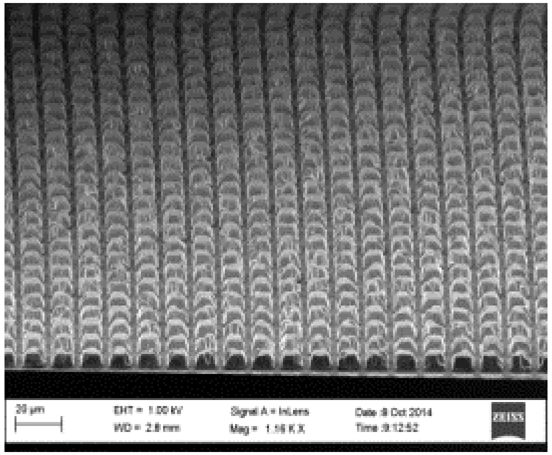


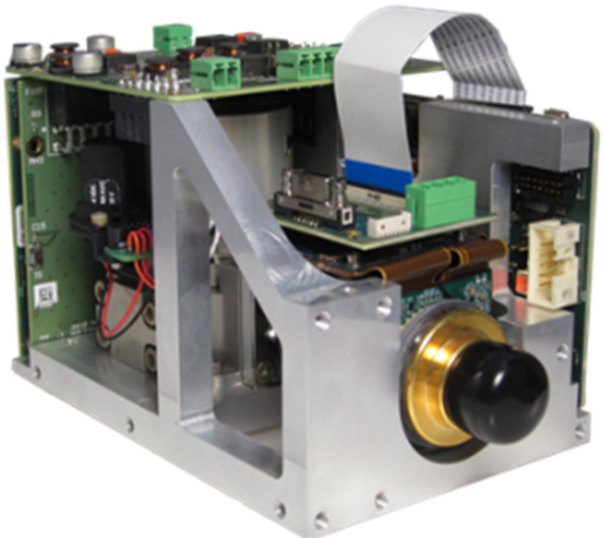

- **Next step:** Optimise dark current and QE towards the targets and then fabricate FPAs for benchmarking with MCT.

# Summary

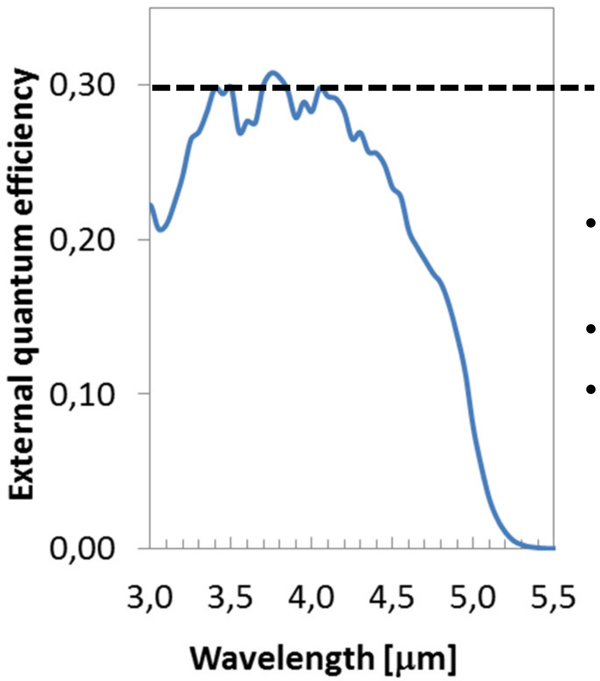
*1280 × 1024 MW FPA hybridized to Xenics ROIC*



*IDCA used for the MW array*



*XCO camera developed by Xenics*




- 30% QE measured at FPA level
- 12 µm pitch
- T = 77 K

# Acknowledgements


- IRnova staff, especially C.Asplund, R.Marcks von Würtemberg, A.Gamfeldt, H.Kataria, S.Smuk, E.Costard
- Xenics - R.M.Vinella, P.Merken

# Finally…

Join us at the QSIP conference next summer!!

June 17-21, 2018 in Stockholm, Sweden (www.qsip2018.com)

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