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THE FRENCH AEROSPACE LAB

Type-II superlattice (T2SL) detectors tutorial

Isabelle RIBET

ONERA – IR detector characterisation Lab

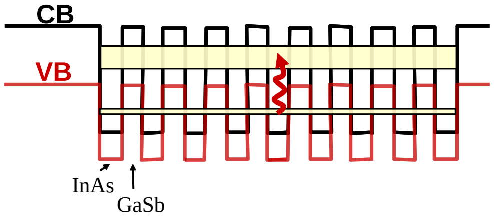
IR Detection Workshop – CNES – June 2023

Outline

- Back to basics of Type-II superlattice photodetectors
- (Some) scientific questions investigated in the last 20 years
- State-of-the-art
- Perspectives

Back to basics of type-II superlattice photodetectors

Periodic sequence of alternating III-V materials
→ optical transition between energy minibands
→cut-off wavelength λc adjusted from SWIR to VLWIR by varying the thickness and the composition of the layers

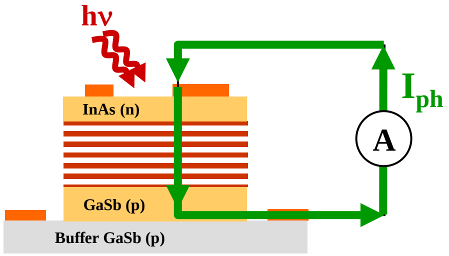


InAs/GaSb type-II superlattice

Theoretical work in the 70's
20 years ago, emerged as **potential competitor to well established infrared technologies** sur as MCT, InSb or QWIP

Potential advantages :
- Tunable wavelength, multiband possible
- Low dark current, High QE
- Good uniformity / NUC stability

Tremendous amount of academic work (on the periodic sequence as well as on the structure) **and technological work** (etching / passivation)



Principle of a T2SL PIN photodiode

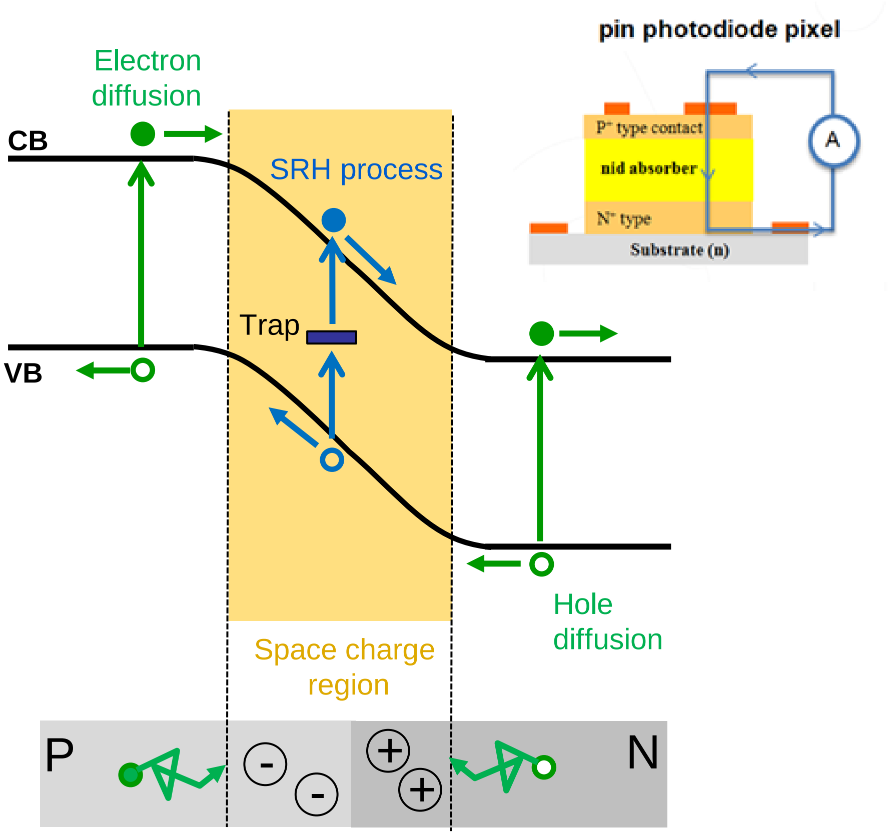
Outline

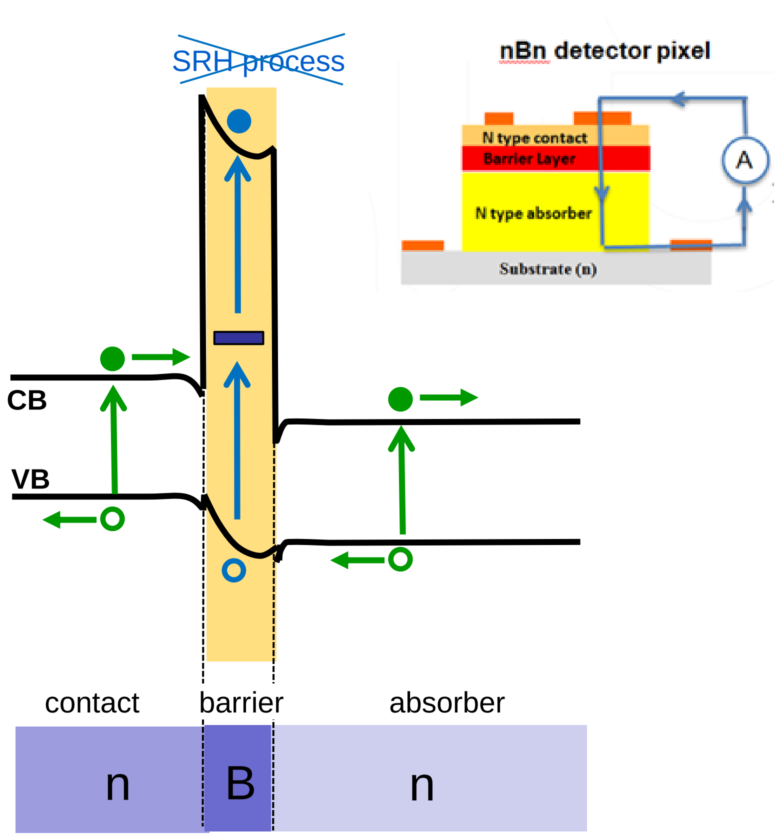
- Back to basics of Type-II superlattice photodetectors

- **(Some) scientific questions investigated in the last 20 years**
  - **Barrier detectors**
  - Ga-free superlattice

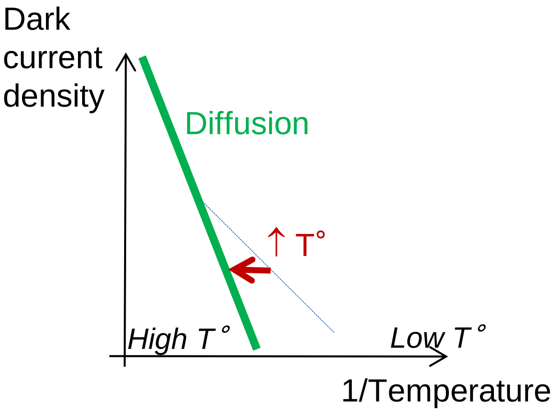
- State-of-the-art
- Perspectives

Dark current in PIN photodiodes and barrier detectors



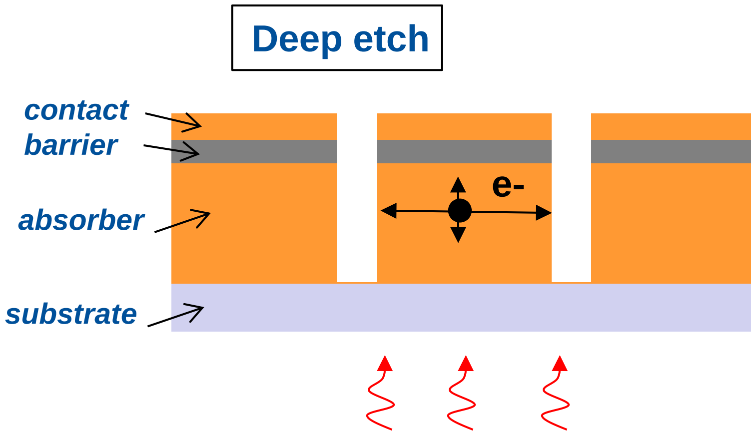


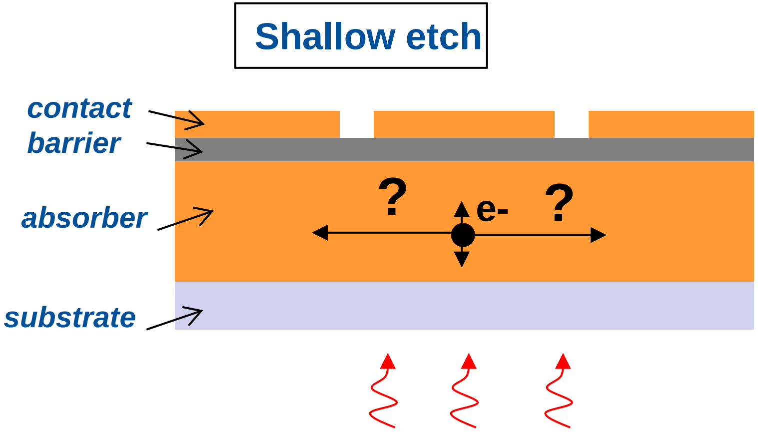
Advantages of barrier detectors



- ➢ Lower dark current → **higher operating temperature**
- ➢ **Allows shallow etch / potentially avoids passivation** → easier to fabricate

→ But the question of **MTF (modulation transfer function)** and crosstalk arises * for these **anisotropic** structures





* J. Nghiem *et al.*, « MTF measurements of a type-II superlattice infrared focal plane array sealed in a cryocooler ». *Optics express*, *26*(8), 11034-11045 (2018)

Ga-containing vs Ga-free T2SL

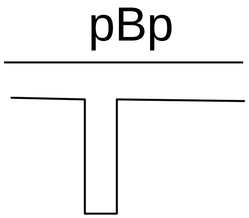
InAs/GaSb T2SL

- **Minority carrier lifetime** :

~ 100 ns in MW
~ few 10 ns in LW

- **P-type absorber**

→ mino = e-
→ Good transport (high mobility)



✓ **Suitable for MWIR, for LWIR**

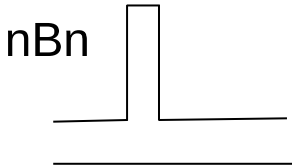
InAs/InAsSb T2SL « Ga-free »

- **Minority carrier lifetime** :

> 1 µs in MW
~ few 100 ns in LW

- **N-type absorber**

→ mino = holes
→ Penalises carrier transport (low mobility)



✓ **Suitable for MWIR, for LWIR ?**

- **Large periods** required for LWIR

→ Lower wavefunctions overlap
→ Penalised absorption (solutions proposed by JPL*)

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** Proc. Vol. 12107, Infrared Technology and Applications XLVIII; 121070O (2022)*

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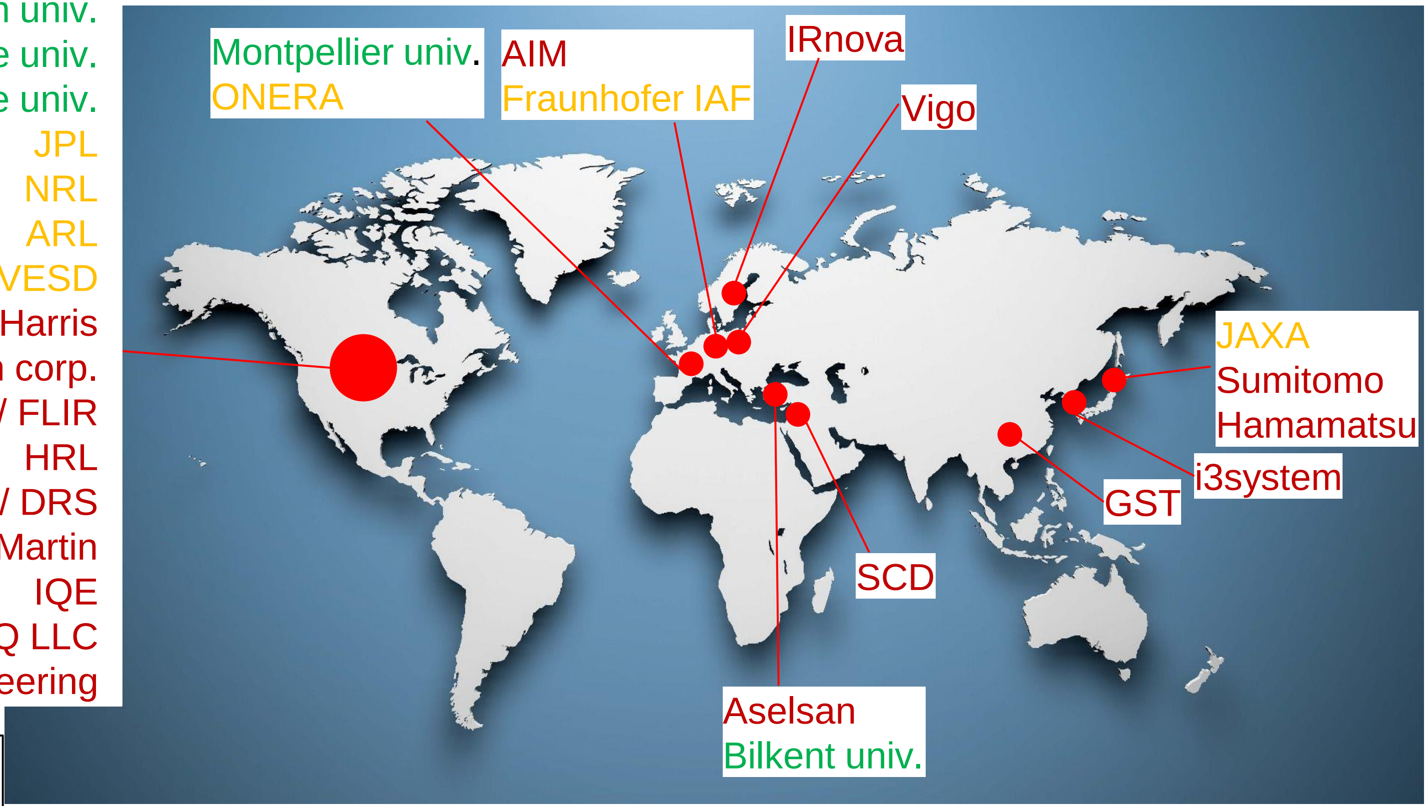
- Back to basics of Type-II superlattice photodetectors
- (Some) scientific questions investigated in the last 20 years
- **State-of-the-art**
- Perspectives

Main players

Northwestern univ.
Arizona state univ.
The Ohio state univ.
JPL
NRL
ARL
NVESD
L3 Harris
Raytheon corp.
Teledyne / FLIR
HRL
Leonardo / DRS
SBFP / Lockheed Martin
IQE
QmagiQ LLC
Attolo engineering



$ *VISTA program (Vital Infrared Sensor Technology Acceleration)*

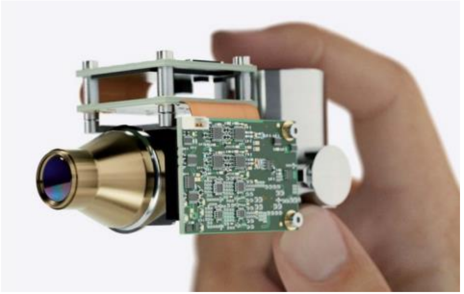
Significant achievements

(HOT)
MWIR

*High Operating Temperature (**HOT**) is crucial to meet Size, Weight And Power (**SWAP**) requirements*

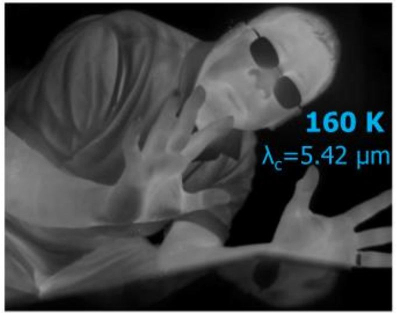
Oden MW (IRnova)
640x512,
15µm pitch
3.7-5.1 µm spectral range
Up to 150K

Source : irnova.se



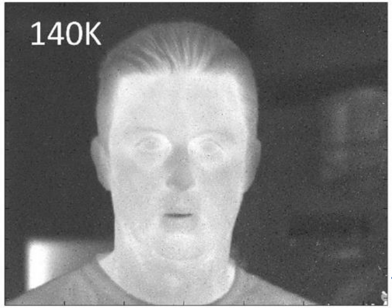
HOT BIRD FPA (JPL)
640x512,
24µm pitch
5.4µm cut-off wavelength
150K

Source : D. Ting, IEEE Photonics Journal, 10(6), 1-6 (2018)



HOT MWIR FPA (SCD)
640x512,
15µm pitch
5.5µm cut-off wavelength
150K

Source : APL 120, 060502 (2022)



Significant achievements

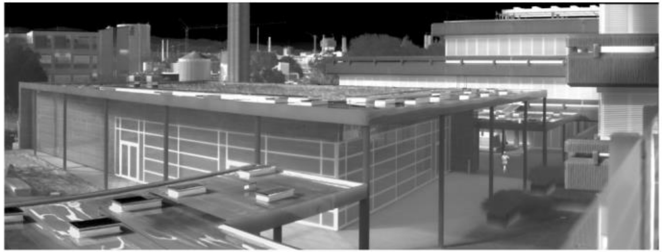
(HOT)
MWIR

LWIR

Pelican LW (SCD)
640x512,
15 µm pitch
9.3 µm cutoff wavelength
77K

Source : scd.co.il

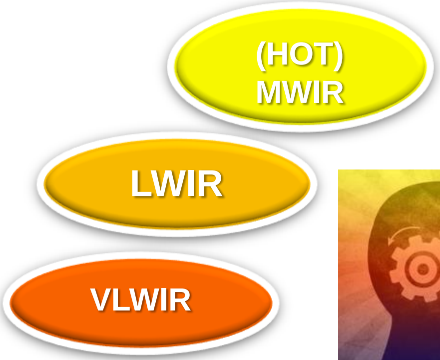
Fraunhofer-IAF
640x512,
15 µm pitch
10.3 µm cutoff wavelength
55 K



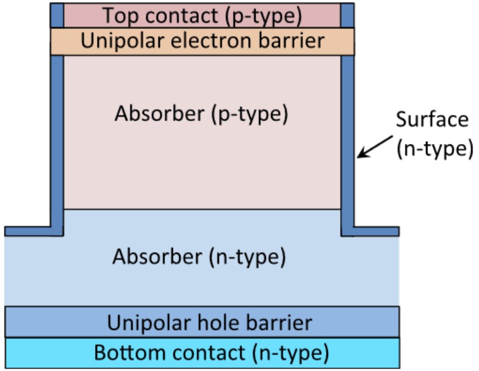
Source : Proc. Vol. 9819, Infrared Technology and Applications XLII; 98190X (2016)

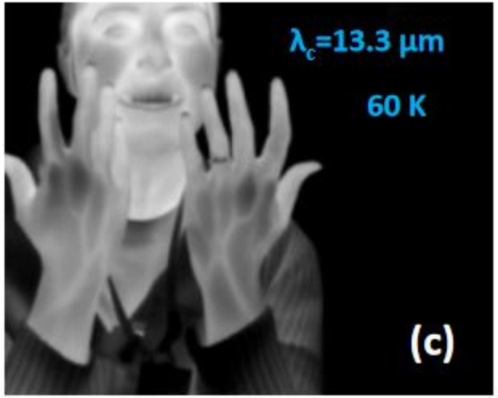
FLIR A6750 SLS
640x512,
10-11 µm cutoff wavelength
125 Hz full frame,
up to > 4 kHz in subwindow mode

Significant achievements



- **VLWIR FPA** (λc=13.3µm) **with pn-CBIRD architecture (JPL)**



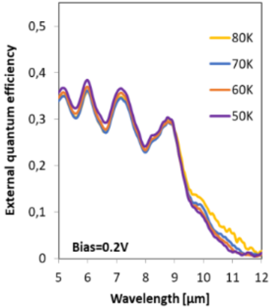


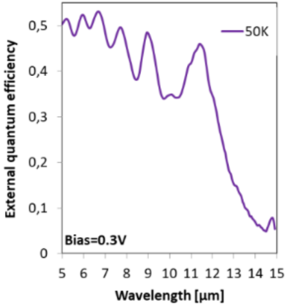
Source : Proc. Vol. 12107, Infrared Technology and Applications XLVIII; 121070O (2022)

- **Low Dark current VLWIR T2SL FPA for space applications**

IRnova | ies l'institut d'électronique | AIRBUS DEFENCE & SPACE

Project financed by ESA



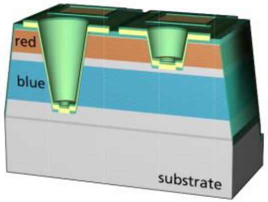


Source : Proc. SPIE 11741, Infrared Technology and Applications XLVII, 117410X (12 April 2021)

Significant achievements

Dual-color T2SL pixel (Fraunhofer-IAF)
MW-MW

Source : Proc. Vol. 9819, Infrared Technology and Applications XLII; 98190X (2016)



- (HOT) MWIR
- LWIR
- VLWIR
- Dualband

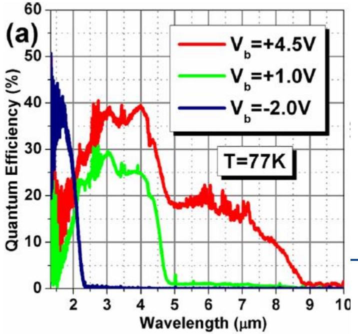
Dual band FPA (Raytheon)
1280x720, 12µm pitch dual band (MW/LW)

Source : www.sto.nato.int (9th NATO Military Sensing Symposium, 2017)

I3system
Dual-color MW/LW 640x512 FPA, 20µm pitch
Source : SPIE DCS 2023 (Orlando)

Multiband SW, MW, LW photodetector (CQD)

Razeghi, *Results in Optics*, 2, 100054.



Significant achievements

(HOT) MWIR

LWIR

VLWIR

Dualband

Small pixels

Large format

Raytheon
4kx4k, 10µm pitch
HOT MW FPA
Source : www.sto.nato.int (9th NATO Military Sensing Symposium, 2017)

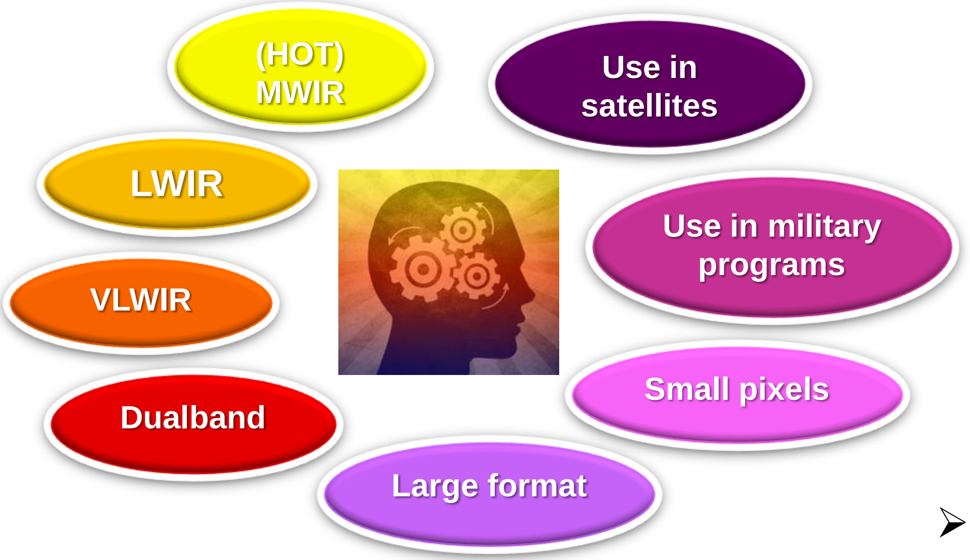
Aselsan :
MW 1280x1024 10µm pitch FPA
Source : SPIE DCS 2023 (Orlando)

Significant achievements

- (HOT) MWIR
- LWIR
- VLWIR
- Dualband
- Large format
- Small pixels
- Use in military programs

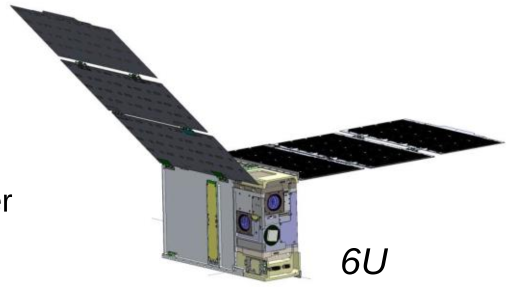
The first major military T2SL infrared program was awarded in the U.S. in 2018.

Significant achievements



- **CubeSat Hyperspectral Imaging Application**

CubeSat InfraRed Atmospheric Sounder (CIRAS)



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Requirements :
- Dark current <10^{-6} A/cm2
- Operating temperature > 110K

✓ JPL's **MW** Ga-free T2SL n-CBIRD FPA*

- **Land imaging with LW T2SL ?**

* *Proc. Vol. 12107, Infrared Technology and Applications XLVIII; 121070O (2022)*

Conclusion

- ✓ T2SL FPA commercially available in MWIR, LWIR
- ✓ Electro-optical performance :

Spectral domain	MWIR	LWIR	VLWIR
Operating T°	110-150 K	70-80 K	50-70 K
External quantum efficiency	60-70 %	50-60%	$\leq$ 50 %

- ✓ Production advantages include the "-ilities": operability, uniformity, stability, manufacturability, and affordability *

* V. Arounassalame et al., « Robust evaluation of long-term stability of an InAs/GaSb type II superlattice midwave infrared focal plane array », IEEE Transactions on Instrumentation and Measurement, 70, 1-8 (2020)

Unanswered questions / Perspectives

- **Radiation hardness** → see oral presentations of C. Bataillon and S. Bernhardt
- **Modulation transfer function *** → some results at SPIE DCS conference (Orlando, May 2023)
- **T2SL for e-SWIR spectral range** (cutoff wavelength in the 2-2.5µm range for machine vision, space applications…)
- **Work still in progress** (several starting/ongoing european projects, more results from VISTA expected)

* J. Nghiem et al., « MTF measurements of a type-II superlattice infrared focal plane array sealed in a cryocooler », *Optics express*, *26*(8), 11034-11045 (2018)

Thanks for your attention… Questions ?