Optical Functions Integrated onto Infrared Detectors

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1. Introduction

2. SWIR multispectral imager prototype

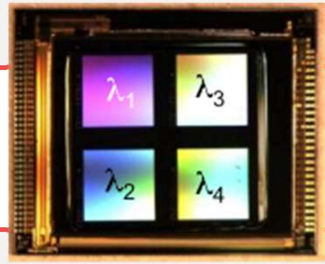
3. MW-MW detector

4. Conclusion

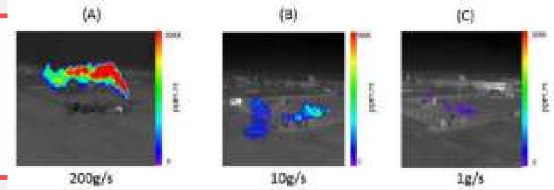
LYNRED IS LEADING SPECTRAL FILTERING on IR detectors

INTRODUCTION

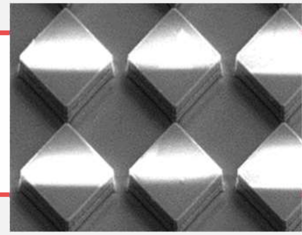
2014
- First 2x2 filters glued onto the FPA - MW



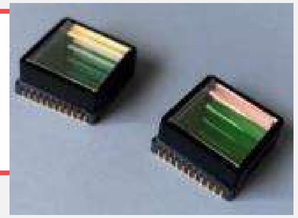
2018
- Integrated optics - LW



2021
- Demonstrator of a MW-MW pixel level filtering



2022
- Development of a SW multispectral imager prototype



SWIR multispectral imager prototype

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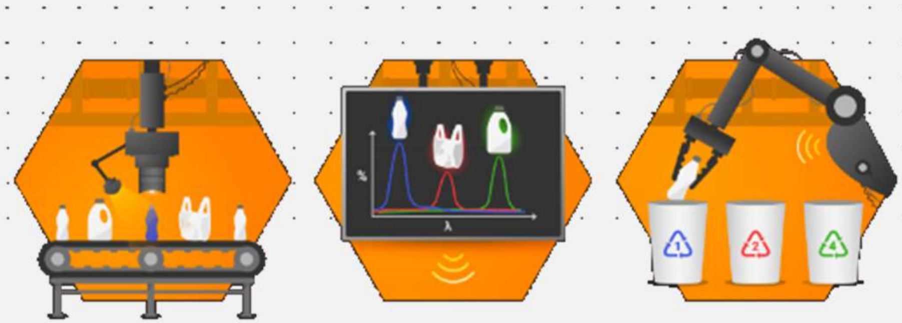
MULTISPECTRAL IMAGING in the SWIR

INTRODUCTION

Hyperspectral mapping of crop and soils for precision agriculture



Plastic waste sorting

SILIOS TECHNOLOGIES

THALES

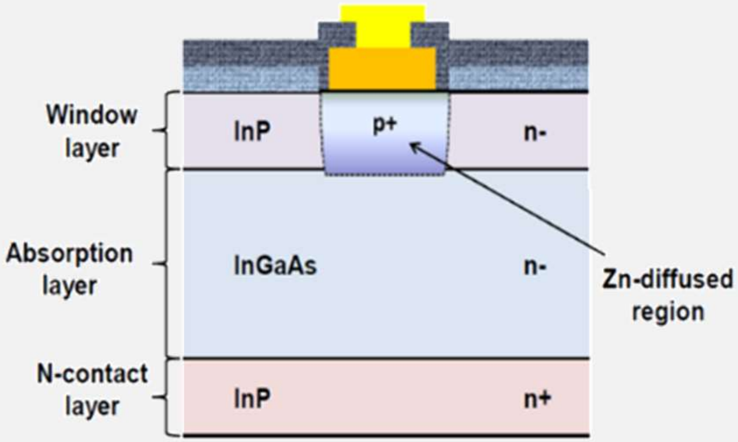
Prototype design

FPA
640x512
15µm pitch

Filters array
3x3 filters
From 1.0 up to 1.6µm

MULTISPECTRAL IMAGER

InGaAs LEGACY TECHNOLOGY



Keeping :

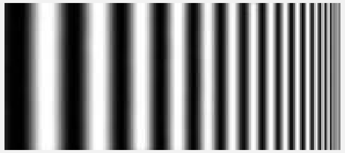
- A low dark current
- A high QE
- High MTF

MULTISPECTRAL IMAGER

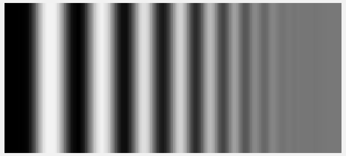
Modulation Transfer Function (MTF)

The MTF is the ability to distinguish the contrast as a function of spatial frequency

GOOD MTF



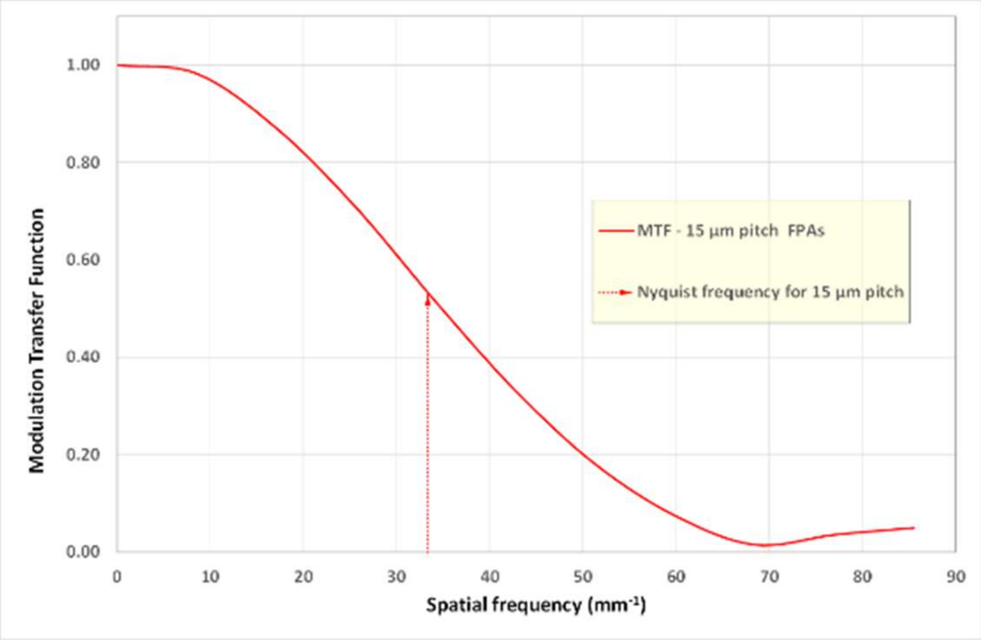
DEGRADED MTF



MULTISPECTRAL IMAGER

Modulation Transfer Function (MTF)

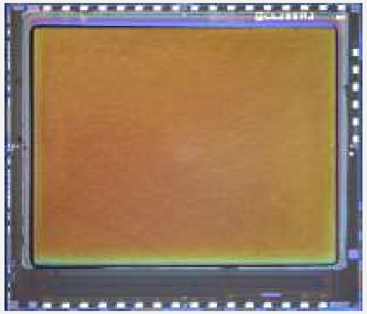
15µm PITCH FPA - SNAKE



- MTF > 0.5 @ Nyquist frequency → spatial Xtalk 1st neighbor ~6%

MULTISPECTRAL IMAGER

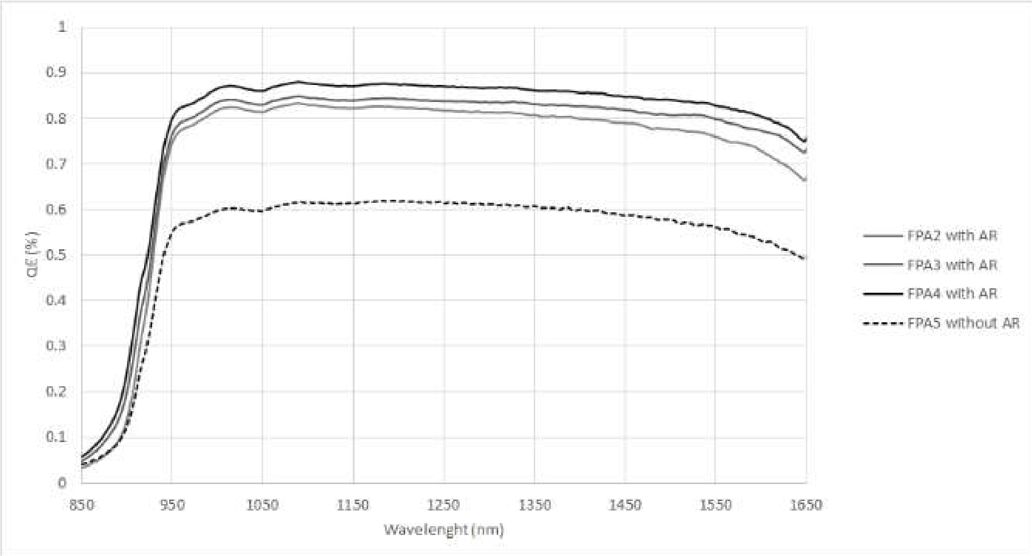
Quantum efficiency



A SNAKE FPA

With a specific thinning process

An antireflective coating



MULTISPECTRAL IMAGER

A HIGH QE IS DEMONSTRATED > 80%

MULTISPECTRAL IMAGER

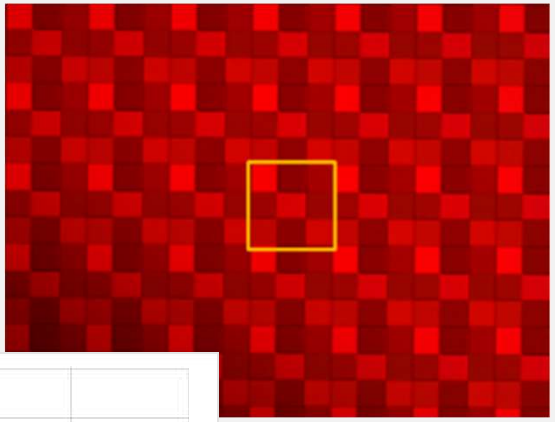
Filter design

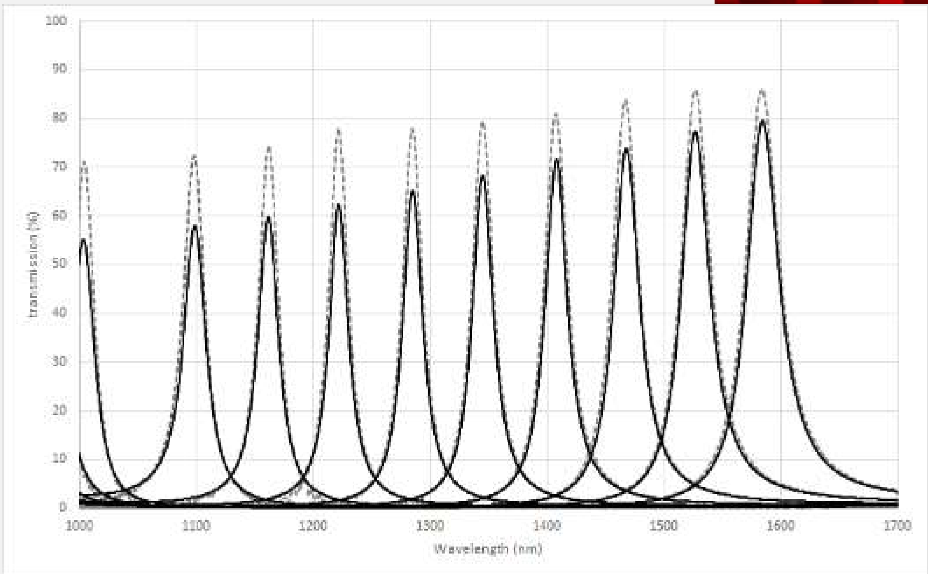
3x3 FILTERS

Ranging from 1.0µm up to 1.6µm

Distance between two filters = 15µm

The macro-pixels are repeated on the full FPA surface





FILTERS WITH A HIGH TRANSMISSION IN THE SWIR BAND

Electro-optical performances

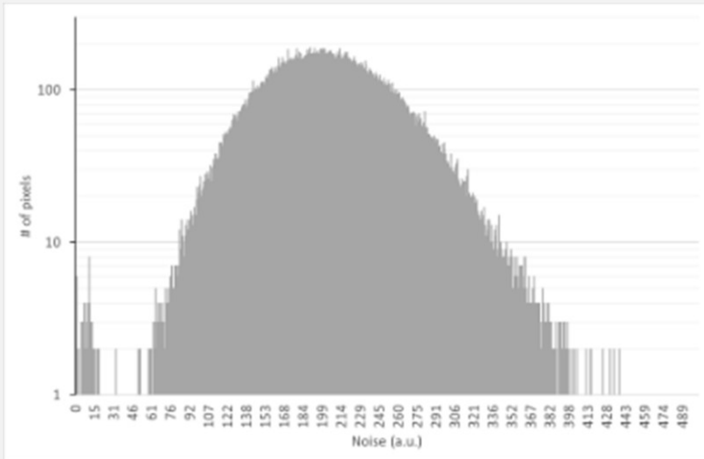
MULTISPECTRAL IMAGER

DC LEVEL in front of an homogeneous illumination

- A low dispersion of the DC level
- No additional hot spot
- Some interference are present due to a lack of parallelism

NOISE HISTOGRAM

- Still a gaussian shape even with filters
- No noise tail



Electro-optical performances

MULTISPECTRAL IMAGER

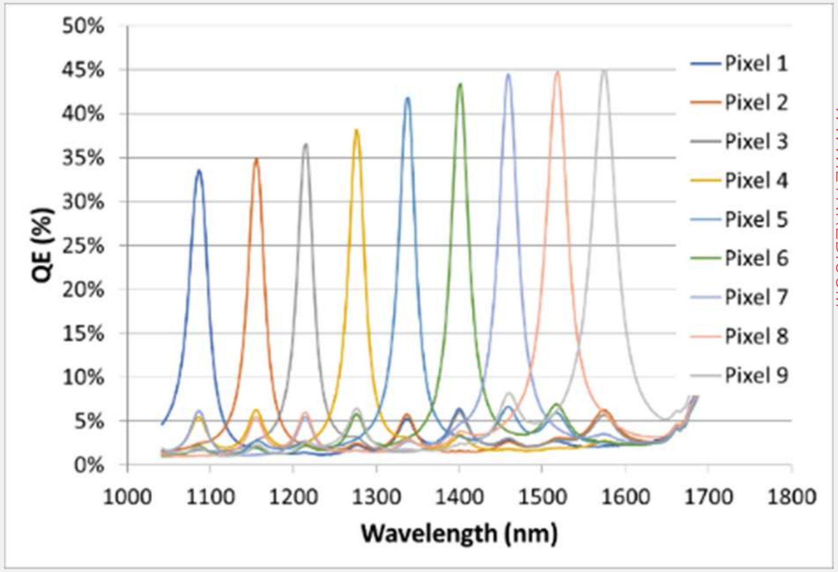
QUANTUM EFFICIENCY

In a collimated configuration

Wavelength position & FWHM are in good accordance with the transmission data

QE value is good but not as high as the filters transmission

This phenomenon is due to spectral crosstalk



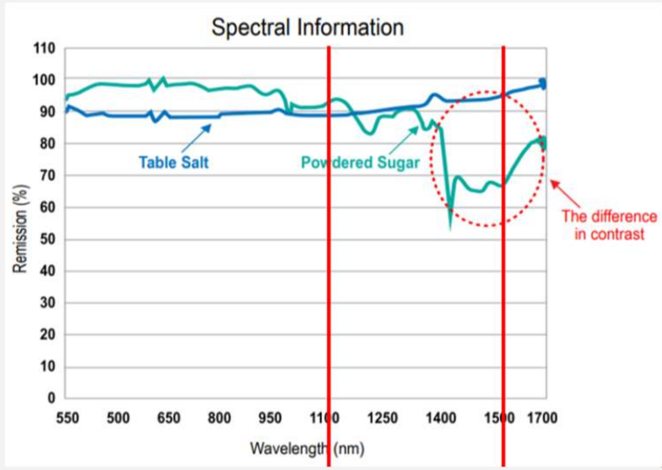
SILIOS TECHNOLOGIES

THALES

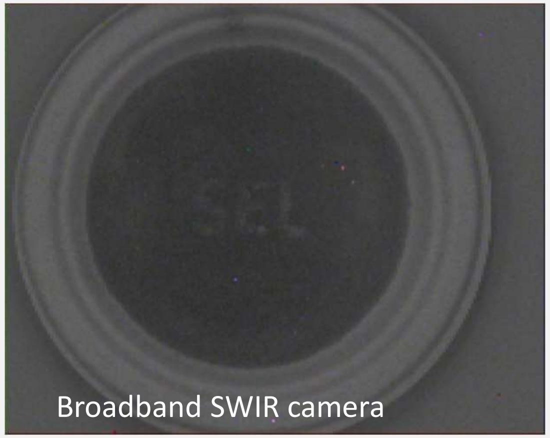
Applicative tests

How to discriminate salt and sugar?

@ 1500nm, optical properties of SALT are different from SUGAR



MULTISPECTRAL IMAGER


Broadband SWIR camera

→ LOW CONTRAST


Multispectral snapshot SWIR camera

→ HIGH CONTRAST

MW-MW infrared detector

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INTRODUCTION

MAIN APPLICATION OF THE DUAL COLOR INFRARED DETECTOR IN THE MW BAND

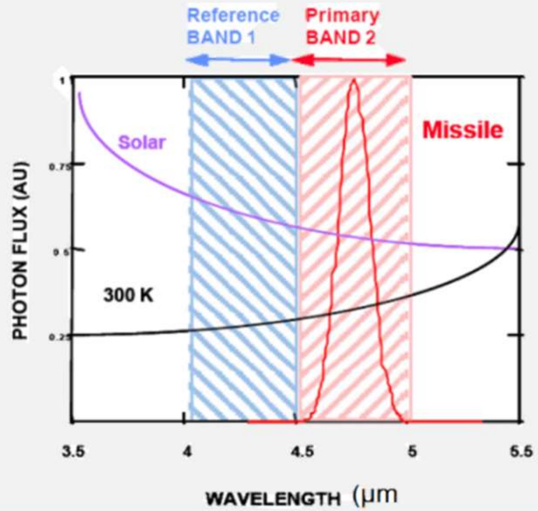
Missile Warning System (MWS)

Solar reflection on surfaces

DRAWBACK/LIMITATION

A high number of false alarms

Due to solar reflection on surfaces



Waterman, J. R., "Two Color IRFPAs for Navy Missile Warning," Night Operations Symposium, (2002).

MW- MW dual color approach allows

Giving a spectral information

Discriminating efficiently

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SAFRAN

OPTICAL CONFIGURATION

THE OPTICAL CONFIGURATION OF THE INTEGRATED DEWAR ASSOCIATED WITH A SPECIFIC FPA IS PATENTED BY LYNRED

2 PARTS

+ One FPA with a chessboard pattern of two optical functions.

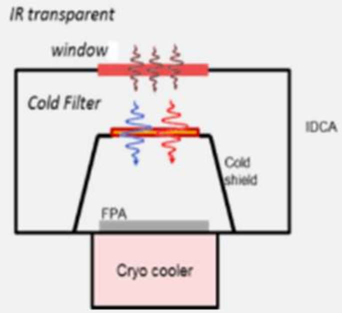
  ½ of the pixels : antireflective coating

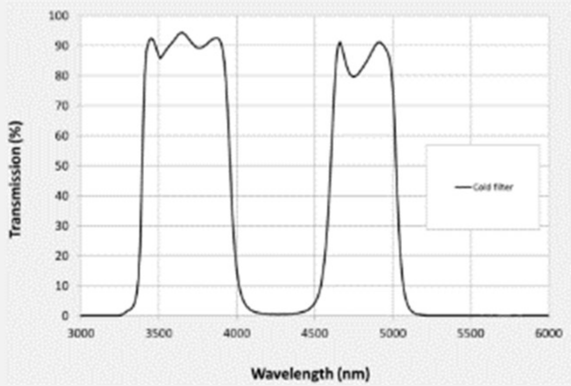
  ½ of the pixels : high pass filter

+ One Dewar

  Cold filter with 2 bands of transmission architecture with a simultaneous reading in both bands

OPTICAL APERTURE OF THE DEMONSTRATOR : F/3





OPTICAL CONFIGURATION

LYNRED

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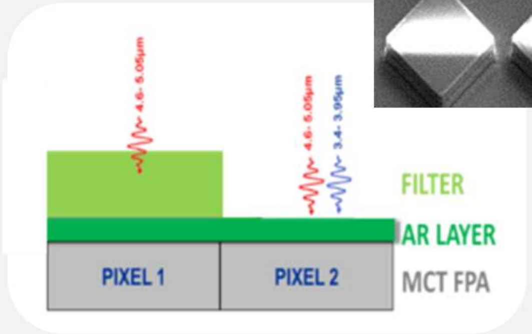
OPTICAL CONFIGURATION

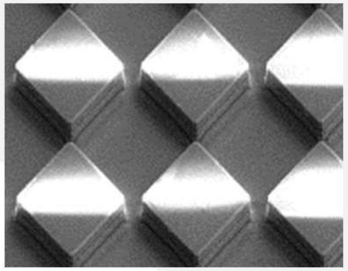
THE FPA DESIGN

2 optical functions performed onto the FPA

An antireflective coating in the entire MW band

A high pass filter in the red band





ANTIREFLECTIVE COATING

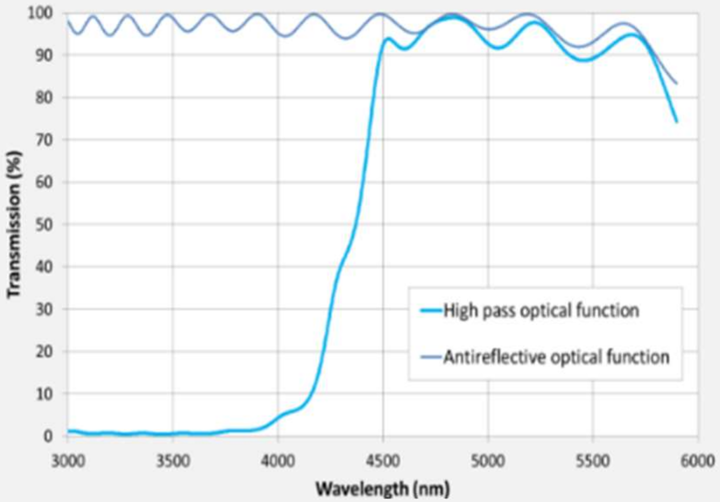
Integrated transmission of 97%

From 3.0µm up to 5.1µm

HIGH PASS FILTER :

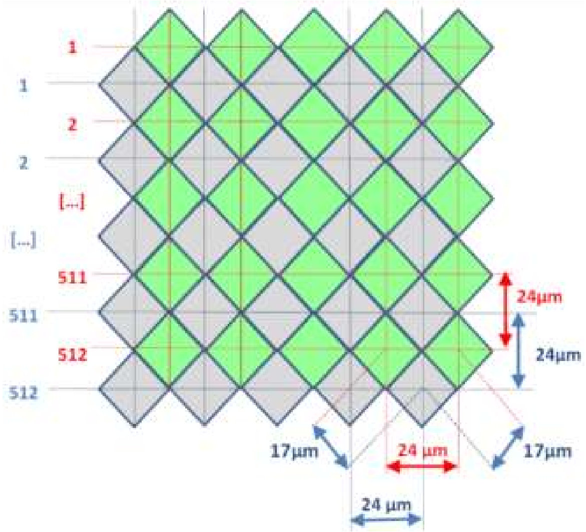
Integrated transmission of 95%

From 4.5µm to 5.1µm



OPTICAL CONFIGURATION

DEMONSTRATOR



Read-out integrated circuit (ROIC)

640x512, 24µm pitch with 2 sub-pixels

In a mono spectral config : 1280x512, 17µm pitch

Pixels in green ➤ pixels 1

Pixels in grey ➤ pixels 2

	ROIC Characteristics
Technology	CMOS 0.35µm
Format	1280x512
Pitch	17µm
Integration	Temporal coherence
Read out mode	IWR, ITR and DTI 2 analog outputs per band Frame rate: 90 Hz
Non-Linearity	< 1% (WF 10% to 90%)
Storage capacity	Pixel 1: 4.2 Me- Pixel 2: 6.6 Me-
Noise floor	160µv rms both bands
ROIC Dynamic	1.6V

DEMONSTRATOR

DETECTION CIRCUIT DESIGN

+ SUBSTRATE
  - Large mono-crystalline CdZnTe substrates
  - (111) oriented
  - A mastered Zn ratio to ensure a lattice match with the HgCdTe layer
+ EPI-LAYER
  - HgCdTe grown by liquid phase epitaxy
  - Our demonstrator **cut-off wavelength is 5.3µm at 80K**
+ ARRAY PROCESS
  - LYNRED's legacy n on p planar technology
  - Hg vacancies doped material in the absorbing layer
  - ion implantation : n-type doped region in HgCdTe

+ PLANAR TECHNOLOGY : AN IDEAL PASSIVATION OF THE HgCdTe SURFACE WITHOUT ANY DEFECTS
  → HIGH OPERABILITY AND HIGH STABILITY

+ A SPECIFIC DESIGN OF THE DIODE ARRAY HAS BEEN PERFORMED TO MAXIMIZE THE MTF IN ORDER TO MINIMIZE THE SPECTRAL CROSSTALK.

ELECTRO-OPTICAL PERFORMANCES

+ T_{FPA} = 80K

+ DC LEVELS CARTOGRAPHIES

  High homogeneity of the MPS process

+ NETD DISTRIBUTIONS OF THE SUB-ARRAYS = GAUSSIAN DISTRIBUTIONS

  NETD1 = 17.9mK - pixels 1

  NETD2 = 19.3mK - pixels 2

+ NETD1 < NETD2

  Response pixels 1 > Response pixels 2 despite the filters

  Attributed to a diffraction pattern of the MPS

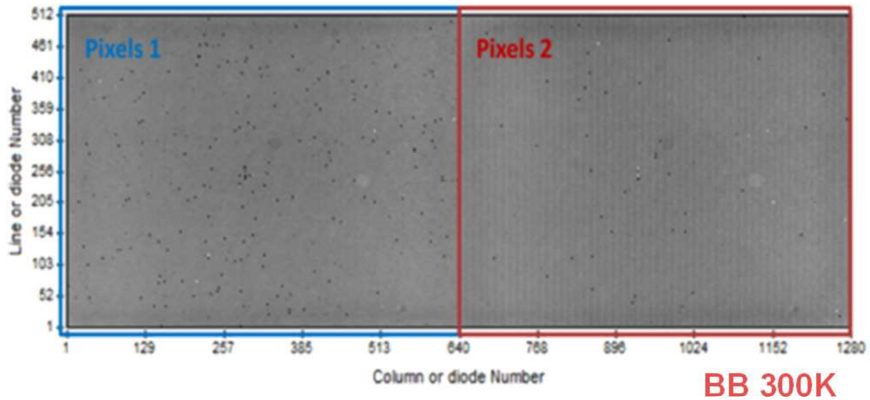
+ OPERABILITY

  Criteria : DC level +/- 30%, the RESP +/- 30%, NETD > 100mK

  99.6% for pixels 1

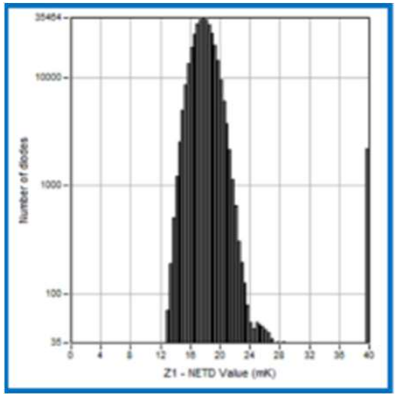
  99.9% for pixels 2

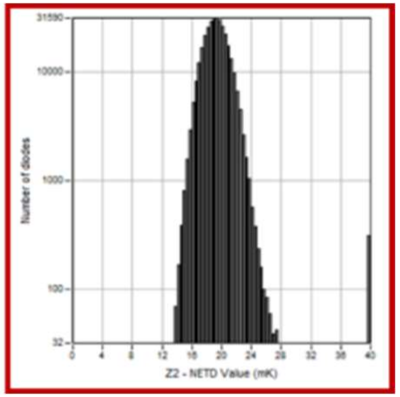
DC LEVELS



BB 300K

NETDs





ELECTRO-OPTICAL PERFORMANCES

+ AN ILLUSTRATION OF THE XTALK IN THE BAND [3.4; 3.95] µm
  Each pixel 1 can collect a fraction of the photogenerated carriers in the volume of its neighbor pixel 2.
  This fraction of signal is the crosstalk per pixel (δ)
  The total Xtalk = the sum of the 4 contributions of crosstalk δ

+ THE RATIO OF RESPONSIVITY :

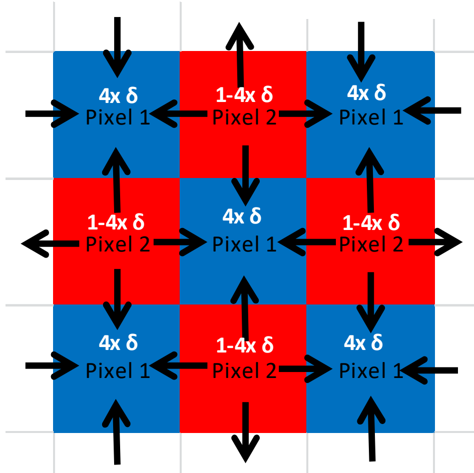
For a homogeneous illumination with a blue band filter

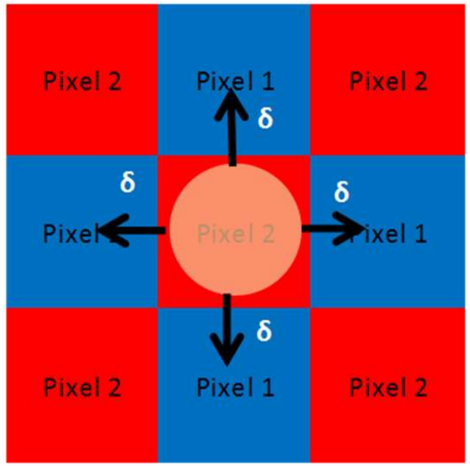
$$Ratio\ of\ responsivity = \frac{4\delta}{1-4\delta}$$

⇢ Xtalk per pixel δ = 7.7%

+ XTALK PER PIXEL = THE DIFFUSION OF CARRIERS (~6%) + THE DIFFRACTION PATTERN (~2%)

+ IN CASE THE TARGET AFFECTS ONLY ONE PIXEL : THE TOTAL XTALK IS ONLY ONE TIMES δ





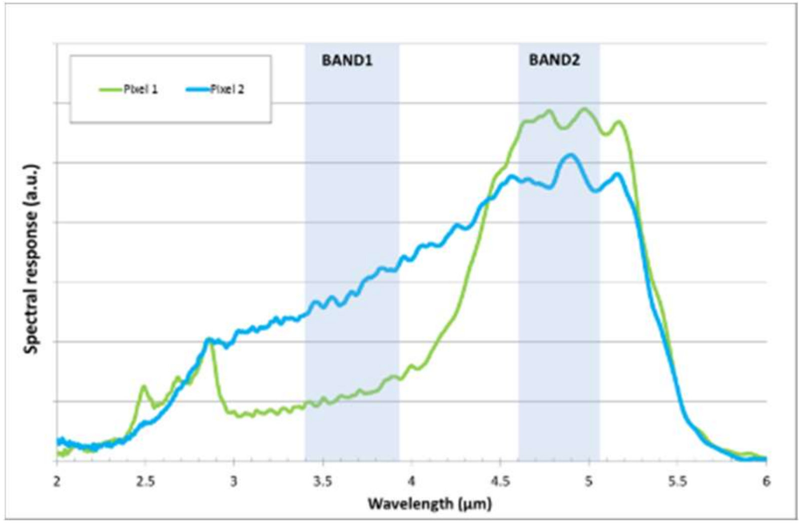
ELECTRO-OPTICAL PERFORMANCES

- A 2ND FOM FOR THE SPECTRAL PERFORMANCE : SPECTRAL RESPONSE
  - Homogeneous illumination due to the optical bench
  - In the MW red band (band 2) :
    - Response is ~ equal
    - In accordance with the performance in NETD

- THE RATIO OF RESPONSIVITY :

In blue band (band 1) : Response pixel 1 < Response pixel 2

Spectral function demonstrated



ELECTRO-OPTICAL PERFORMANCES

+ VALIDATE THE RELIABILITY OF THIS NEW TECHNOLOGICAL SOLUTION : AGEING TESTS
  - High temperature storage : 3 sequences of ageing
    - 6 days at 70°C
    - 8 days at 90°C
    - 20 days at 90°C
  - 2 FoMs :
    - Number of noise defects
    - NETD

+ RESULTS :
  - NETD is constant for both bands
  - No significant increase of defectivity is observed

+ CONCLUSION : we can assess this technological solution is reliable and stable

	Beginning of life	6 days at 70°C	8 days at 90°C	20 days at 90°C
NETD pixel 1	16.0mK	16.0mK	15.9mK	15.9mK
Defects pixel 1	0.09%	0.09%	0.10%	0.12%
NETD pixel 2	17.4mK	17.4mK	17.3mK	17.2mK
Defects pixel 2	0.09%	0.09%	0.08%	0.08%

Conclusion

SWIR MULTISPECTRAL IMAGER

- Development of a multispectral imager prototype
- FPA design : 640x512 15µm pitch
  3x3 optical filters from 1.0 up to 1.6µm
- Spectral function is demonstrated
- Evaluation by customers can be realized

MW-MW DETECTOR

- 2 optical functions, a high pass filter and an antireflective coating
- Very low NETD (below 20mK)
- Spectral crosstalk per pixel of 7.7%
- High operability (> 99.5%)