Thales Long Wave QWIP Thermal Imagers

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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

THALES Research & Technology
What is Alcatel Thales III-V Lab?

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

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Two-site implantation

Thales Research and Technology
Palaiseau

Alcatel Research and Innovation
Marcoussis
Epitaxial growth of III-V semiconductors

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

GS-MBE reactor

Buried EO modulator

AlGaN/GaN HEMT on SiC substrates
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, …)
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

40Gb/s (and above) InP HBT ICs

Electro-thermal modelling

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Modules and Demonstrators

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

- 60GHz UTC photodiode
- Hybridization & FPAs characterization
- 18GHz direct modulation laser diode
- Reliability test bench
- 30W S-band hybrid HPA
New Building & Facilities

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
TRT QWIP Product
384x288; pitch 25 µm
30 arrays on 3 inch wafer

VEGA-LW

Thales Optronique (France)

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TRT QWIP Product
640x512; pitch 20 µm
16 arrays on 3 inch wafer

Thales Optronics (UK)

Test cell for E&O QWIP measurement

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

Spectral responsivity

Peak: 8.6 µm
FWHM: 0.9 µm

Wavelength (µm)

Peak responsivity (A/W)

Dark current @ 77 K (A)

Bias (V)

Noise gain

Bias (V)
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

External Quantum Efficiency is definitively not a relevant parameter for QWIP

FPA set point for CATHERINE-XP

NETD  (mK)

Responsivity (mV/K)

Bias (V)

Tint < 5 ms

Tint > 5 ms

Bias (V)

60 K
65 K
70 K
73 K
75 K
77 K

60 K
65 K
70 K
73 K
75 K
77 K
R-QWIP

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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 ($10.3\mathrm{Me}^{-} = \times1, \times1.3, \times2, \times4$)
- 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; \( \sigma = 8.5\% \) (No FOV correction)
NETD : Mean = 41 mK; \( \sigma = 10.9\% \) (FOV corrected)
Operability = 99.9% (NETD<2×mean); no cluster of size > 3 pixels
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: 384x288 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 2x2 microscanning for full TV CCIR format (768x575)

0.7W RM4-7i by Thales
- @ 20°C: CDT < 3 minutes; Preg < 9Wac

Dimensions < 126 mm height x 73.7 mm width
Total IDDCA weight < 0.55 kg (1.21 lb)
VEGA-LW: E&O performance @ 75K

Tfpa = 75K; f/2.68; gain 2 (13.9 Me-); 120Hz; 20°C blackbody
Ti = 4 ms for +50K instantaneous dynamic range
20-35°C Sensitivity: Mean = 12.3 mV/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
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
• LWIR QWIPs: 75K and diffraction limited:
  - NETD < 40mK
  - Dynamic range > 100K
  - Integration Time < 5ms
  - >100Hz in full TV Format

• 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
LWIR QWIP spectral response

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

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QWIPs cover the full LWIR spectrum

Pixel < 30µm & optimized 2D grating

Wavelength (µm)

Spectral responsivity (a.u.)

Current density (A / cm²)

Bias (V)

Dark current
45 K
50 K
Optical current
TBB = 280 K, F/2 (diffraction limited)

λ_c = 15.1 µm

FPA performance modeling:
Tdet = 50K ; λ_c = 15.1µm
NETD = 15 mK
Responsivity = 20 mV/K
Integration Time = 6 mS

ROIC ISC0208 : 384x288 ; pitch 25µm
Tbb=280K; f/2 (diffraction limited)
dynamics = +30°C

TBB = 280 K, F/2
2-D Arrays: Uniformity is more important than D*

Single Element:
Only D* is important

2D Arrays:
Uniformity = key factor

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

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

\( \lambda_{\text{pic}} = 9 \mu m; \Delta \lambda = 2 \mu m \)

\( \text{pixel} = 25 \mu m; \# = 2 \)

\( t_{\text{int}} = 10 \text{ ms}; T_B = 300 \text{ K} \)

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Internal quantum efficiency: Absorption

4 typical spectral absorption: $\alpha_{\text{peak}} > 25\%$ 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

(Spectral shapes suitable for dual color MWIR FPA)

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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

<table>
<thead>
<tr>
<th></th>
<th>MWIR band</th>
<th>LWIR band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Responsivity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean responsivity</td>
<td>10.4 mV/K</td>
<td>13.9 mV/K</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>8.5%</td>
<td>9.9%</td>
</tr>
<tr>
<td>Operability at 1.5 x mean value</td>
<td>99.04%</td>
<td>99.04%</td>
</tr>
<tr>
<td>NETD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean NETD</td>
<td>40 mK</td>
<td>39 mK</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>17%</td>
<td>16%</td>
</tr>
<tr>
<td>Operability at 2 x mean value</td>
<td>99.5%</td>
<td>99.9%</td>
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</table>

Sofradir & TRT are developing a MWIR / LWIR IDDCA based on a ISC0208 ROIC (384x288 pitch 25µm)
In House FPA Capability (1/2)

Pulse Instrument system 7700
- 4 Preamplifiers
- 14 bits A/D (bandwidth ≥ 30Mhz)
- 8 clock drivers and 8 bias generators
- Easy pattern generation

384x288 QWIP FPA
ISC0208 ROIC from Indigo
Pitch 25µm

New building Block: hybridization
For Research & Development
Tests in lab dewar (He or LN2)
LWIR QWIP design: $\lambda_c = 9 \mu m$; 384x288, pitch 25 $\mu m$

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

$T = 80K$

without & with 2 point correction

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FPA expected performances in VLWIR

ROIC ISC0208 : 384x288 ; pitch 25µm

T\text{bb}=280K; f/2 (diffraction limited)

\text{dynamics} = +30^\circ\mathrm{C}

\begin{align*}
\lambda_c &= 18.3 \, \mu\text{m} \\
B_{\text{det}} &= 40\,\text{K} ; \lambda_c = 18.3\,\mu\text{m} \\
\text{NETD} &= 22 \, \text{mK} \\
\text{Responsivity} &= 16 \, \text{mV/K} \\
\text{Integration Time} &= 8.5 \, \text{mS}
\end{align*}

\begin{align*}
\lambda_c &= 15.1 \, \mu\text{m} \\
B_{\text{det}} &= 50\,\text{K} ; \lambda_c = 15.1\,\mu\text{m} \\
\text{NETD} &= 15 \, \text{mK} \\
\text{Responsivity} &= 20 \, \text{mV/K} \\
\text{Integration Time} &= 6 \, \text{mS}
\end{align*}
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)

QWIP 2006 Sri Lanka
**256² MWIR–LWIR FPA demonstrator**

### MWIR band

<table>
<thead>
<tr>
<th>Spectral responsivity (A/W)</th>
<th>Wavelength (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>5.1</td>
</tr>
<tr>
<td>0.4</td>
<td>6.7</td>
</tr>
<tr>
<td>0.2</td>
<td>8.3</td>
</tr>
<tr>
<td>0.0</td>
<td>10</td>
</tr>
</tbody>
</table>

**Histogram of responsivity in MWIR band**

(Tfpa= 70K - Tbb=20/30°C - tint=5ms)

- **Batch1:**
  - stage1
  - stage2
- **Batch2:**
  - stage1
  - stage2

### LWIR band

<table>
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<th>Wavelength (µm)</th>
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<tbody>
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**Histogram of responsivity in LWIR band**

(Tfpa=70K - Tbb=20/30°C - tint=3ms)

- **Batch1:**
  - stage1
  - stage2
- **Batch2:**
  - stage1
  - stage2

### Responsivity

**Mean responsivity**

- MWIR band: 10.4 mV/K
- LWIR band: 13.9 mV/K

**σ**

- MWIR band: 8.5%
- LWIR band: 9.9%

**Operability at 1.5 x mean value**

- MWIR band: 99.04%
- LWIR band: 99.04%

**NETD**

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<th>Mean NETD</th>
<th>σ</th>
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**Operability at 2 x mean value**

- MWIR band: 99.9%
- LWIR band: 99.9%
256² LWIR–LWIR FPA demonstrator

**LWIR1 band**

**Responsivity**

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<td>Mean responsivity</td>
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<tr>
<td>( \sigma )</td>
<td>7.6%</td>
<td>9.3%</td>
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<td>Operability at 1.5 x mean value</td>
<td>99.8%</td>
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**NETD**

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<tr>
<td>Mean NETD</td>
<td>50 mK</td>
<td>59 mK</td>
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<tr>
<td>( \sigma )</td>
<td>15.9%</td>
<td>12.4%</td>
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<td>Operability at 2 x mean value</td>
<td>99.5%</td>
<td>99.4%</td>
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256² pitch 25µm Dual-Color LWIR FPA demonstrator

Dual Color QWIP FPA:
• 256x256 pitch 25µm
• IWR mode
• 2 color subframe at 100Hz

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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

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