Low dark current 2D VLWIR MCT detectors
Contract ESTEC 4000107414/13/NL/SFe
Stefan Hanna, AIM, Heilbronn/Germany
• Motivation and approach for AIM LWIR/VLWIR MCT low dark current technologies

• MCT photodiode technologies and FPA design

• Electro-optical characterization results for p-on-n planar diode technology devices

• Electro-optical characterization results for n-on-p planar diode technology devices

• Results from accelerated life time testing

• Summary and outlook

• Satellite IR image data: Sentinel 3-SLSTR (SWIR-MWIR-LWIR-VLWIR), KOMPSAT 3A push-broom imager (MWIR)
Motivation

ESA fundamental TRP study “Low Dark Current 2D V LWIR MCT Detectors”

Topic: Infrared radiation detection in the 8-14.5\textmu m spectral range, spatially resolved using 2D pixel arrays

Why Mercury Cadmium Telluride (MCT)?

- Tunable IR sensitivity range
- Leading material for IR detection

For space applications on board of satellites:

- Astronomy applications: Need for low thermal detector dark current and low shot noise for observation of low photon flux scenes
- Earth observation missions: Reduction in cooling requirements for detectors (higher operating temperature for same dark current) relieves burden on satellite power bus

→ In general “low” operating temperature applications (20-60K) for (V)LWIR
→ Desire for “higher” operating temperatures (HOT)
## PLANAR MCT PHOTODIODE TECHNOLOGY

<table>
<thead>
<tr>
<th>Technology approach</th>
<th>p-on-n planar</th>
<th>n-on-p planar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector substrate</td>
<td>lattice-matched CdZnTe, vertical Bridgman-grown</td>
<td></td>
</tr>
<tr>
<td>Epitaxy method</td>
<td>liquid phase epitaxy, vertical dipping technique</td>
<td></td>
</tr>
<tr>
<td>Epitaxial layer</td>
<td>HgCdTe, Indium doped</td>
<td></td>
</tr>
<tr>
<td>Cut-off wavelength</td>
<td>11.0-12.9µm at 80K</td>
<td>11.0-12.5µm at 80K</td>
</tr>
<tr>
<td>PV-detector</td>
<td>ion implantation of Arsenic</td>
<td>Ion implantation of Boron</td>
</tr>
<tr>
<td>Read-out integrated circuit</td>
<td>AIM bi-polar off-the-shelf 0.35µm CMOS ROIC</td>
<td>AIM standard flip-chip technology</td>
</tr>
<tr>
<td>FPA hybridization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-processing</td>
<td>substrate thinning, ( \lambda/4 ) anti-reflective coating deposition</td>
<td></td>
</tr>
</tbody>
</table>

### Diagrams

**p-on-n**
- **p-contact metallization**
- **Passivation**
- **p⁺-MCT**
- **n⁻-LPE-MCT**
- **CdZnTe substrate**

**n-on-p**
- **n-contact metallization**
- **Passivation**
- **n⁻-LPE-MCT**
- **p-LPE-MCT**
- **CdZnTe substrate**
FPA Design for Study and Measurements

(512×320) pixels per half array at 20µm pixel pitch
= 10.2mm×6.4mm per half array (pv-chip #1, #2)

Testing of two technology variations under identical conditions possible!

Variations of technological parameters in the study

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Level 1</th>
<th>Level 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV diode technology</td>
<td>p-on-n</td>
<td>n-on-p</td>
</tr>
<tr>
<td>Indium doping levels</td>
<td>Level 1</td>
<td>Level 2</td>
</tr>
<tr>
<td>Cut-off wavelength</td>
<td>LWIR</td>
<td>VLWIR</td>
</tr>
</tbody>
</table>

major main technology variation and topic of this presentation
Dark current densities for AIM p-on-n planar LWIR /VLWIR MCT diodes are around and below ‘Rule 07’ benchmark.
**P-ON-N TECHNOLOGY: (V)LWIR MCT QE SPECTRA**

Good quantum efficiency for LWIR/VLWIR cut-off material even with simple anti-reflective coating and in conjunction with very low dark currents!
P-ON-N TECHNOLOGY: NETD HOMOGENEITY

half-well IC filling level, F/#2, 25°C BB, opt. BW [3µm, λ_co]

80K, 11.0µm cut-off

110K, 10.2µm cut-off

Excellent NETD homogeneity, narrow spread!
P-ON-N TECHNOLOGY: NETD OPERABILITY

Half-well IC filling level, F/#2, 25°C BB, opt. BW [3µm, λ_{co}]

Defective pixel criterion:
NETD not [0.5,2] x median NETD

The NETD remains below 30mK for operating temperatures up to 110K!
**P-ON-N TECHNOLOGY: THERMAL IMAGES**

**a**

<table>
<thead>
<tr>
<th>$T_{\text{op}}$</th>
<th>80K</th>
<th>100K</th>
<th>120K</th>
<th>130K</th>
<th>140K</th>
<th>150K</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_{\text{co}}$</td>
<td>11.0μm</td>
<td>10.4μm</td>
<td>9.9μm</td>
<td>9.7μm</td>
<td>9.4μm</td>
<td>9.2μm</td>
</tr>
</tbody>
</table>

**b**

Series a: Images **without** “bad pixel“ replacement  
Series b: Images **with** “bad pixel“ replacement

LWIR imaging up to 150K (160K) possible!
Dark current densities for n-on-p planar LWIR MCT diodes are smaller than predicted by ‘Rule 07’ by a factor ~3 at 80K. Compared to AIM Standard: $T_{op}$ increases by ~20K for the same dark current!
**N-ON-P Technology: (V)LWIR MCT QE Spectra**

Good quantum efficiency for LWIR/VLWIR cut-off material even with simple anti-reflective coating and in conjunction with very low dark currents!
N-ON-P TECHNOLOGY: NETD HOMOGENEITY

half-well IC filling level, F/#2, 25°C BB, opt. BW [3µm, λ_{co}]

50K, 12.2µm cut-off

100K, 10.5µm cut-off

Excellent NETD homogeneity, narrow spread!
N-ON-P Technology: NETD Operability

Half-well IC filling level, F/#2, 25°C BB, opt. BW [3μm, λ_{co}]

Defective pixel criterion:
NETD not [0.5,2] x median NETD

The NETD remains below 30mK and NETD defects below 0.45% for operating temperatures up to 100K!
N-ON-P TECHNOLOGY: THERMAL IMAGES

AIM

(a) 

$T_{op}$  
80K  100K  120K  

$\lambda_{co}$  
11.0\text{$\mu$m}  10.5\text{$\mu$m}  10.0\text{$\mu$m}  

(b) 

(all images 2-point-corrected and without “bad pixel“ replacement)
THERMAL STABILITY / ACCELERATED AGEING

P-ON-N AND N-ON-P TECHNOLOGIES:

FPA storage at 70°C / 80°C for 12 days

Thermal dark current and quantum efficiency are unchanged under standard operating conditions.
SUMMARY AND OUTLOOK

- Excellent, low dark currents around and below ‘Rule 07’ have been demonstrated for AIM LWIR/VLWIR MCT material in both p-on-n and n-on-p planar technology along with good QE performance
- Enhanced dark current performance at typical operating temperatures is achieved or standard performance at temperatures higher by ~20K
- Good homogeneity in NETD and low to moderate pixel defect figures were attained, thermal stability of dark current and QE was demonstrated
- Operation up to 150K for p-on-n and up to 120K for n-on-p was demonstrated
- A new LWIR low dark current study (pv-array and ROIC development) is currently in the post-TRR phase, with one focus on diminishing cluster defects (ESTEC contract 4000113065/15/NL/RA)
- Extension of new technologies to established LWIR and VLWIR products, introduction of new technologies into the MWIR (3-5µm)

THANK YOU FOR YOUR ATTENTION!
A European contribution to Earth & Climate Observation: Sentinel-3A
Launch Feb. 16th, 2016

Image data available online!

http://www.esa.int/spaceinimages/Images/2016/04/Thermal_signature_of_Namibian_coastline
Korean Earth-Observation Program: KOMPSAT-3A
Launch March 25th, 2015

3-5μm

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