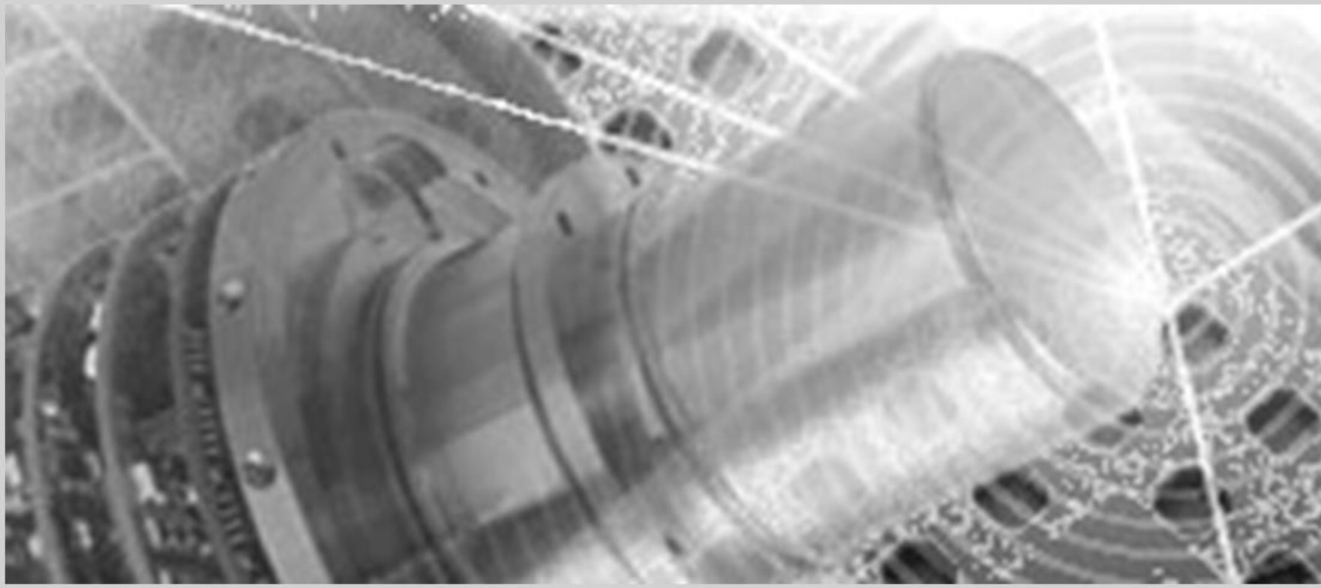
AIM INFRAROT-MODULE GmbH



Next generation IR technology for imaging applications

Rainer Breiter, Heinrich Figgemeier, Ingo Ruehlich

9th NATO Military Sensing Symposium
SENSORS & ELECTRONICS TECHNOLOGY (SET) PANEL
SET-241, Quebec City, Canada

■ OUTLINE

AIM

- **Introduction: IR technology development at AIM**
- **Multi-Color IR detectors**
- **Reduction of Size, Weight and Power (SWaP)**
- **SWIR Imaging**
- **Summary**

■ INTRODUCTION

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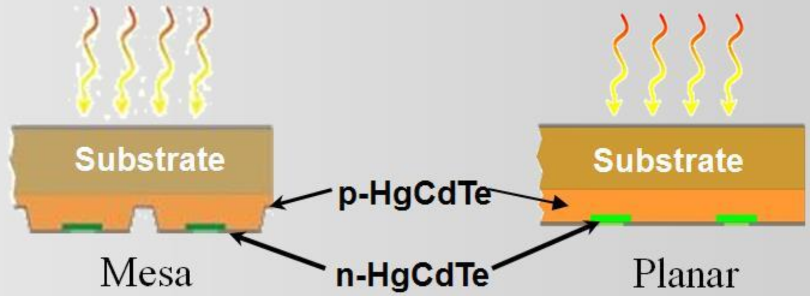
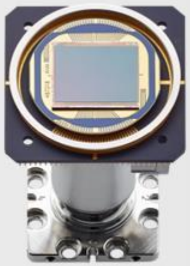
IR technology at AIM

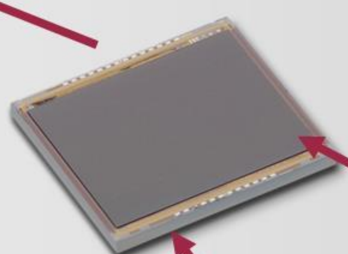
SWIR to VLWIR



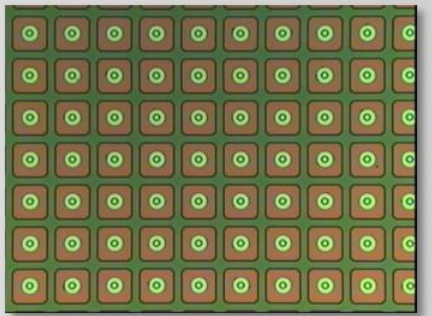
Cooler



Dewar



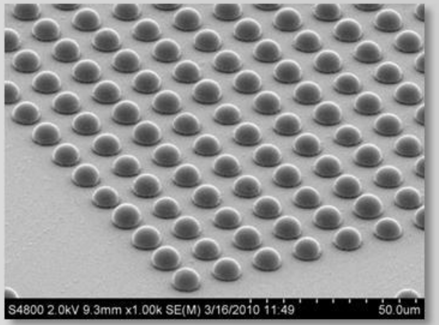
FPA



Array

- Epitaxy:
  LPE grown MCT on CZT
  or
  MBE grown MCT on GaAs
- Planar / Mesa process

40µm → 10µm Pitch
7.5µm ⌛



ROIC

- Reflow process
- Flip-chip by soldering

180nm Si CMOS

- Optical Interface
- Cooler Integration
- Proximity Electronics

Integrated Detector Cooler Assembly

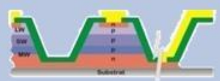
INTRODUCTION

AIM

IR technology development at AIM: MCT based IR detectors

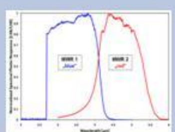
Next GEN

Dual-Band MWIR/LWIR



640x512 (✓)
1280x720 ⌛

Dual-Color MWIR/MWIR



320x256 ⌛
Temporal & Spatial Coincidence

High-Definition (MCT)

1280x1024 ✓ 1024x768 ✓
1280x720 ✓

Low SWaP
(Reduce Size, Weight and Power)

MWIR Detector Operating Temperature (HOT)

95K → 140K ✓ → 160K ✓ → 180K ⌛

Smaller Cooler

15W → 3W ✓ → < 2W ✓

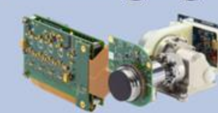
Smaller Pixel

24µm → 15µm ✓ → 12µm ✓ → 10µm ✓
↓ ⌛
7.5µm

SWIR
Shortwave Infrared

Hyperspectral Imaging

384x288 ✓
1024x256 ✓



eSWIR for Enhanced Vision

640x512 15µm ✓
640x512 10µm ⌛

Gated-Viewing (active)

640x512 15µm (✓)

MWIR/MWIR
Focal Plane Array Results

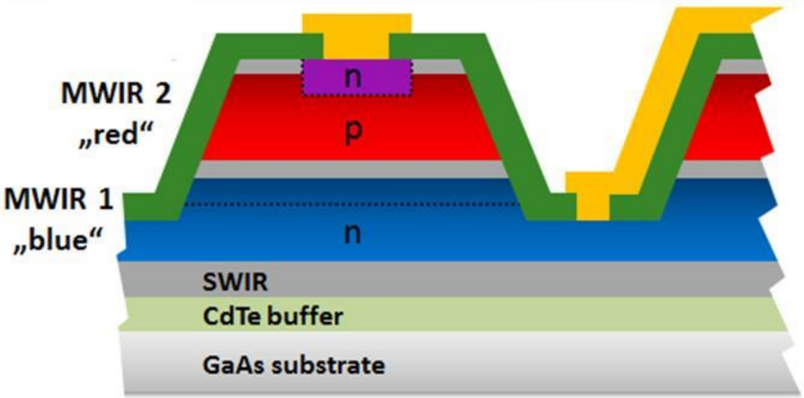
Compact, high resolution
MWIR Engine

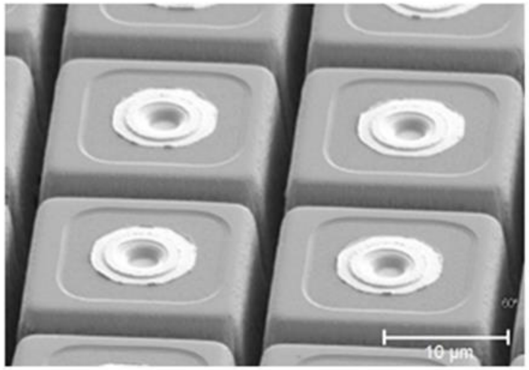
eSWIR (0.9µm – 2.5µm) Imaging
for Enhanced Vision
SWIR Modules for Active Imaging
with Gated Viewing

■ MULTI-COLOR IR DETECTORS

AIM

MBE MCT on GaAs: MWIR/MWIR Focal Plane Array results





- Design 640 x 512 pixel 20 µm pitch
- Backside-illuminated back-to-back diodes
- Mesa structure with one electrical contact per pixel
- MWIR 1 region doped with In during MBE growth
- P-N junction in MWIR 2 formed by Boron implantation
- Integration in Testdewar and operation with linear stirling cooler
- Cold shield F/2

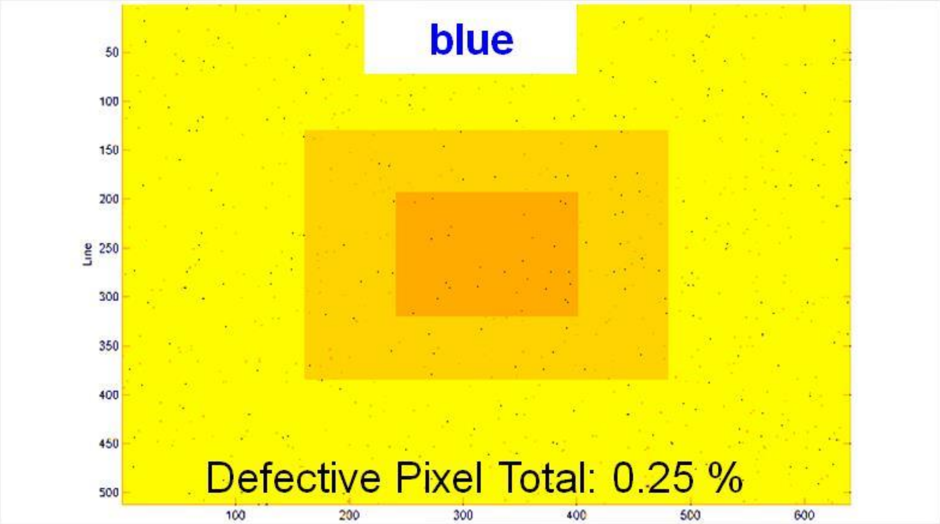
Multi-Color IR Detectors

AIM

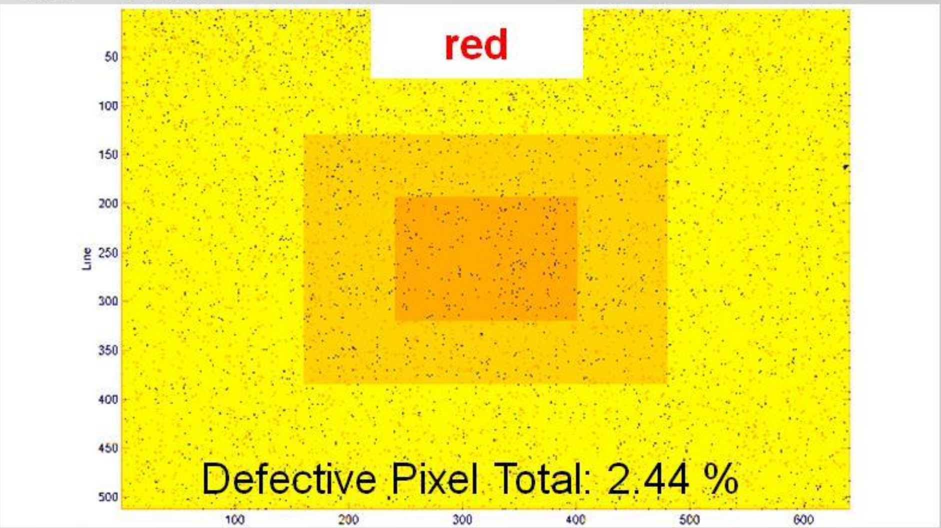
MBE MCT on GaAs: MWIR/MWIR Focal Plane Array results

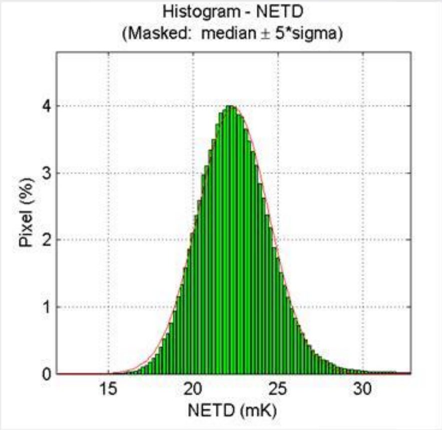
NETD and defective pixel evaluation, Top=80K

tint= 4 ms



tint= 1 ms

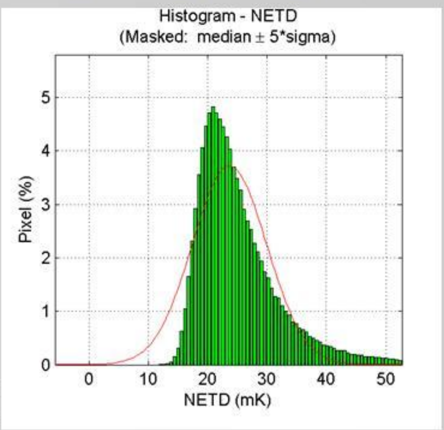




Defective criteria:
Gain <> [0.5,2]*mean
NETD <> [0,2]*mean
Noise <> [0,5]*median

NETD@300K= 22.5mK

NETD@300K= 25.0mK



MULTI-COLOR IR DETECTORS

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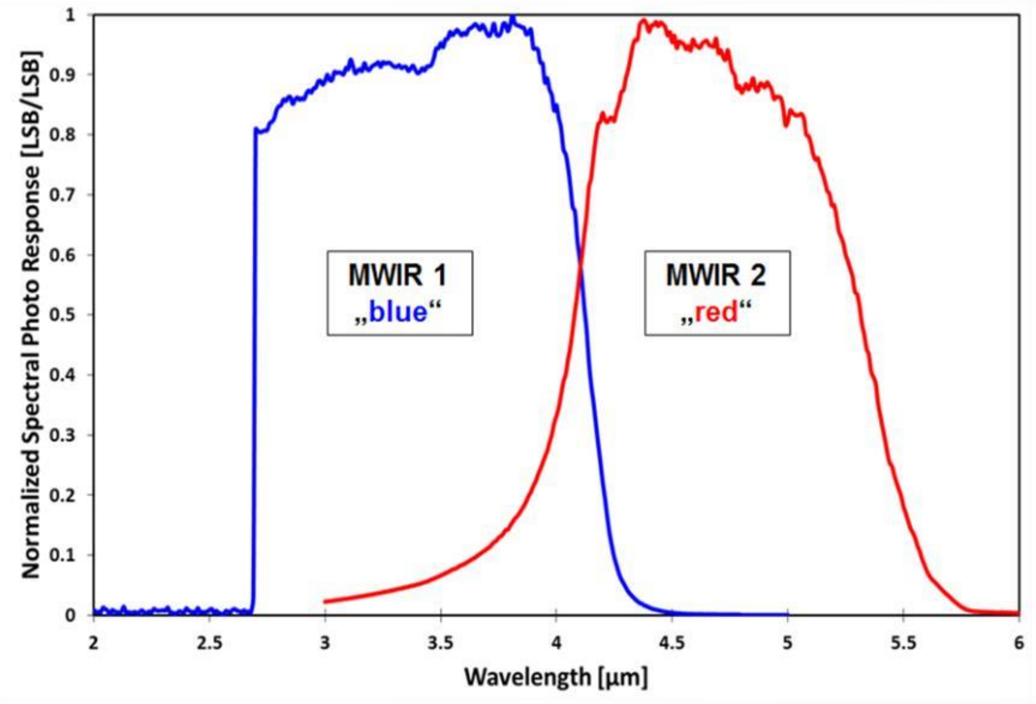
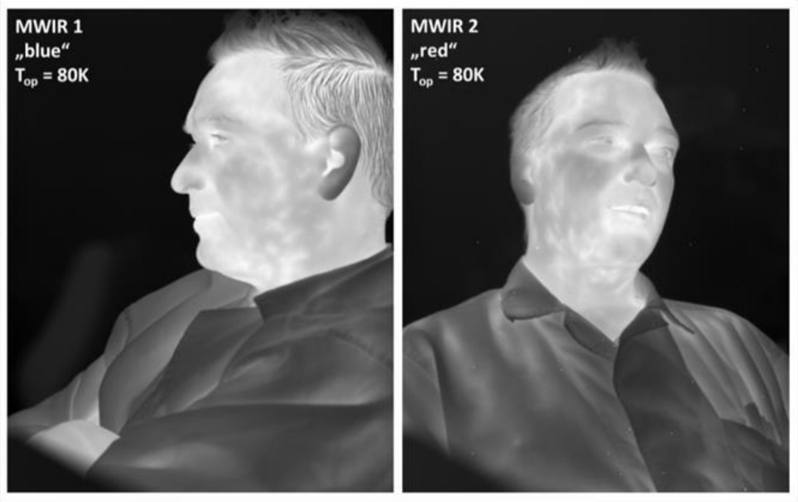
MBE MCT on GaAs: MWIR/MWIR Focal Plane Array results

Spectral Response @ 80K



Images @ 80K



blue: cut-off 4.13µm (50%)
red: cut-off 5.32µm (50%)

- MCT MBE MWIR/MWIR layers on GaAs successfully grown
- Low spectral crosstalk and QE >60% for blue and red color
- Design 320x256 in 30µm pitch with temporal and spatial coincidence in development

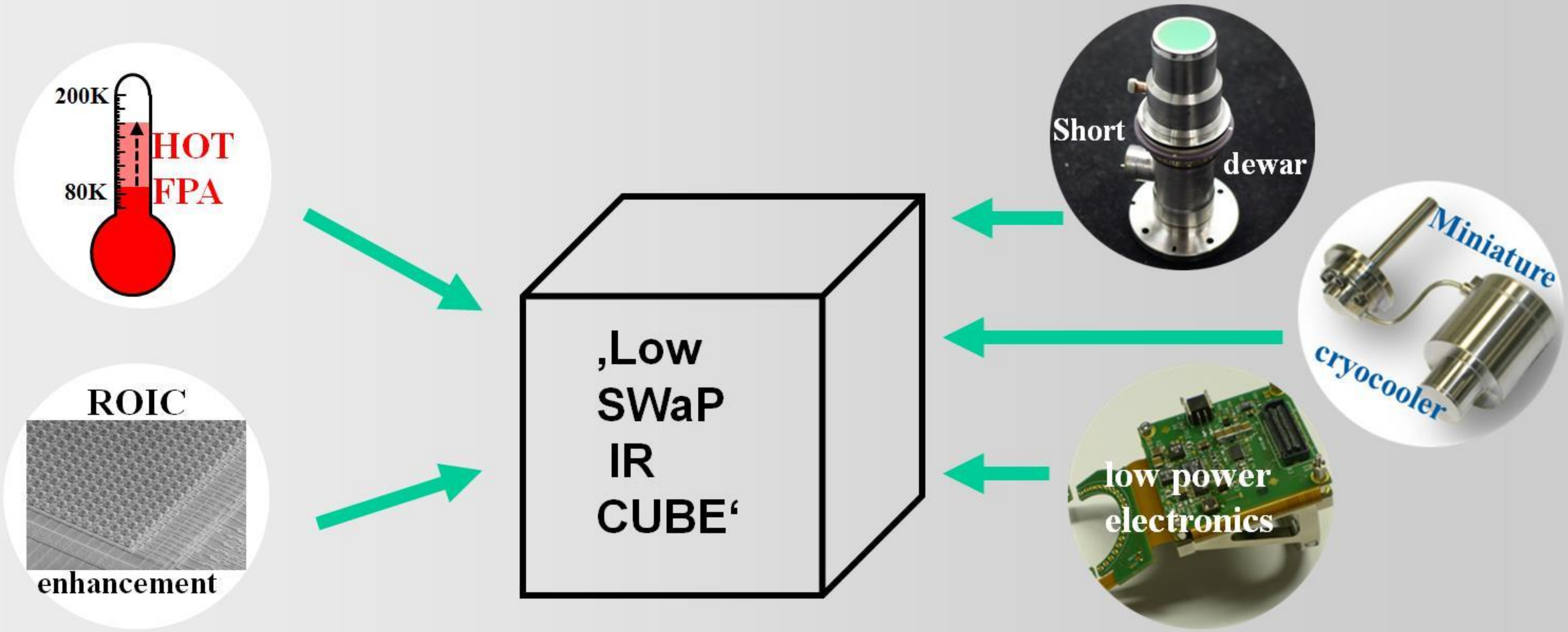
Reduction of Size, Weight and Power (SWaP)

AIM

Motivation: IR detector solution for …

- Applications with limited space, critical thermal management like small gimbals
- Handheld soldier thermal sights for observation and targeting
- Or any other application that requires low SWaP characteristics

⇒ Desire for high-performance IR-solutions in a small package



Reduction of Size, Weight and Power (SWaP)

AIM

HOT 1024x768, 10µm pitch FPA

Key design goals FPA

- HOT ~160K aimed
- High spatial resolution
- Small pixel pitch
- Preserve ~5µm cutoff wavelength

Challenges

- Reduction of dark current
- Preserve high e/o-performance
- High quantum efficiency
- In-bump technology / hybridization

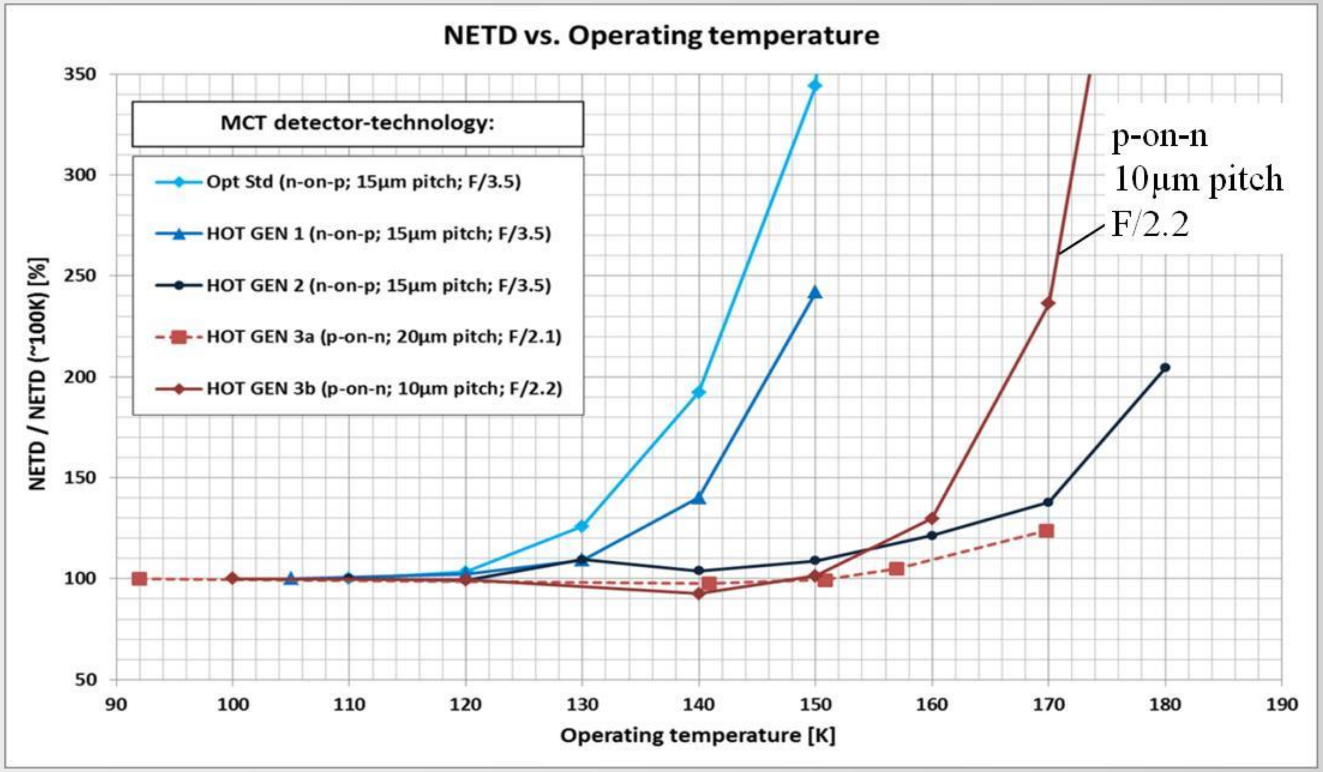
Realization

- Decision for 1024x768, 10µm format
- Planar p-on-n detector technology

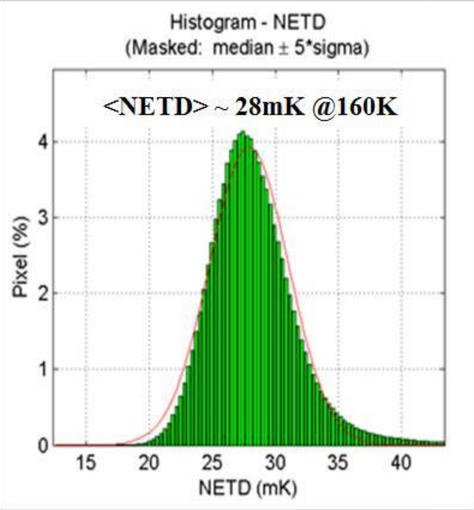
■ REDUCTION OF SIZE, WEIGHT AND POWER (SWAP) AIM

HOT FPAs, performance

<NETD> @300K, Integration time adjusted for ~50% well fill, λ_{cutoff}~5.2±0.1µm@80K



HOT 1024x768, 10µm pitch FPA



IR image @160K

(2-point NUC and BPR applied)

- ➢ Promising first p-on-n results in 10µm pixel pitch
- ➢ Further potential by optimizing passivation and doping level
- ➢ Limitation for HOT ≥ 160K is explained by consequences from rising dark current rather than from defective pixel level

■ Reduction of Size, Weight and Power (SWaP) AIM

Additional key components

Low Power ROIC

- Usage of 4 analog video outputs with optimized amplifiers
- Usage of internal DACs and current sources
- Set ‚nice to have'-features aside, focus on essential features

Short Dewar

- Usage of short 5mm coldfinger with wall thickness < 100µm
- Reduced heat load contribution of bond wires
- F/2.2 standard configuration
- Number of single parts is kept low → cost-efficient

Total length ~47mm
Weight only ~42g

Small, low power Microcooler

- Gap between rotary integral and split linear coolers in terms of power consumption is closing at HOT
- HOT linear cryocoolers have advantages of high lifetimes, low audible noise, low vibrational output

SX020 with 5mm micro CF
~$2W_{AC}$ @160K

■ Reduction of Size, Weight and Power (SWaP)

AIM

Compact, high resolution MWIR Engine

Design

- Detector-dewar assembly and cryocooler in parallel configuration
- Command&Control electronics and cooler drive electronics combined to on one printed board
- All subcomponents mounted on a common frame
- Mounting interfaces for assembling of IR-engine on system level and for installing of optics

Characteristics

- Small form factor (length x height x width):

60mm x 60mm x 50mm (2.36 x 2.36 x 1.97 inches)

- Light weight: ~0.37kg (~0.8lbs)
- Only one system interface connector
- Cool down time ~3min @ + 23°C (Top ~160K)
- Total input power only ~3.6W @160K (Basic functions)

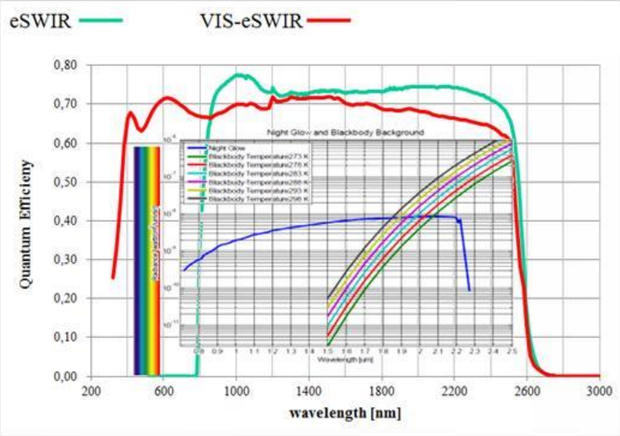
→ Differences in SWaP characteristics compared to uncooled IR-modules are getting small

SWIR IMAGING

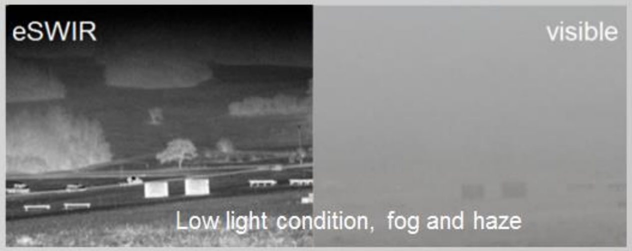
AIM

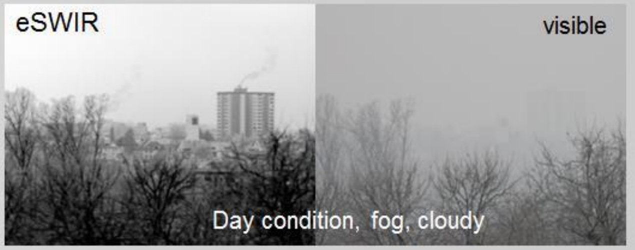
eSWIR (extended SWIR) for Enhanced Vision

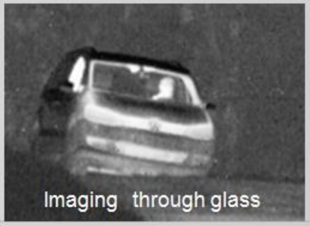
- MCT eSWIR Modules: 640x512
  - 15µm pitch
  - 10µm pitch (Low SWaP-C)
- Spectral response 0.9µm – 2.5µm (VIS option 0.4µm – 2.5µm)
- Combining reflective + thermal imaging in one sensor
- Full coverage of the nightglow spectrum
- Thermal target radiation in complete darkness
- „Out-of-band“ operation >2µm, not detectable with InGaAs



	Illumination: Bulb + Blackbody	Illumination: Blackbody	No illumination
eSWIR 0.9µm – 2.5µm			
SWIR 0.9µm – 1.8µm			







SWIR IMAGING

AIM

eSWIR 640x512 FPAs in 15µm and 10µm Pitch

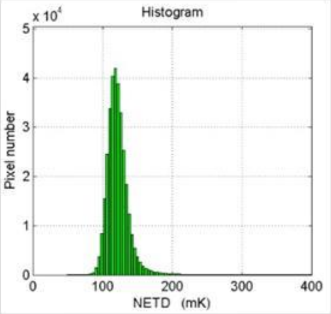
- MCT by Liquid-Phase-Epitaxy (LPE) on CdZnTe substrates (lattice-matched), n-on-p polarity
- Spectral range 0.9µm – 2.5µm
- Top >= 175K
- **640x512 15µm pitch => Integrated to Field Demonstater Camera**
  - QE 74% (average between 1µm and 2.4µm)
  - Dark current 1nA/cm² @ Top ~ 175K
  - Low Noise ROIC
    - 2 Gains: High Gain 125,000e-, Low Gain 1.800.000e-
    - ITR and IWR Snapshot, RS with CDS option
    - Selectable operation parameters from day condition (low gain, tint=48µs) to full darkness (high gain, tint=38.6ms)
  - IDCA with Microcooler and F/2 cold shield

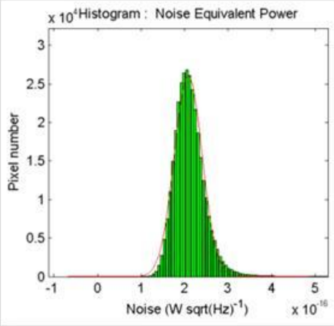
- **640x512 10µm pitch** => only 44% of the array size with 15µm pitch

- MCT by Molecular-Beam-Epitaxy (MBE) on 4“ GaAs substrates in development, currently an order of magnitude higher dark current at 175K

640x512 15µm
Top = 180K
RS with CDS, High Gain
tint=38.6ms

NETD@300K:
<NETD> ~ 119mK





NEP:
<NEP> ~ 2.1×10^{-16} W/Hz$^{1/2}$

SWIR IMAGING

AIM

Comparison of different sensor technologies (eSWIR 640x512 15µm pitch)

Field trials outside urban area, objects in 100m distance, forest in the background

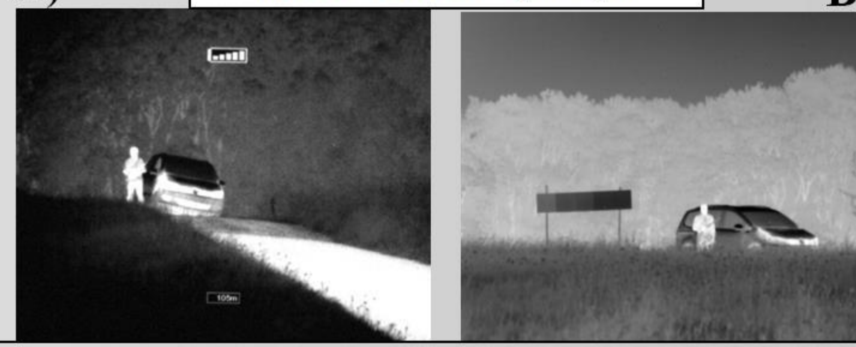
A) Overcast night

B) No clouds, almost full moon

A) eSWIR 0.9µm – 2.5µm B)

AIM eSWIR Sight, FOV 6°x4.9°, NETD@300K ~150mK

A) MWIR Thermal 3.4µm - 5µm B)



AIM HuntIR Mk2, FOV 6°x4.9°, NETD@300K ~30mK

A) SWIR 0.9µm – 1.8µm B)

AIM SWIR Sight, FOV 6°x4.9°

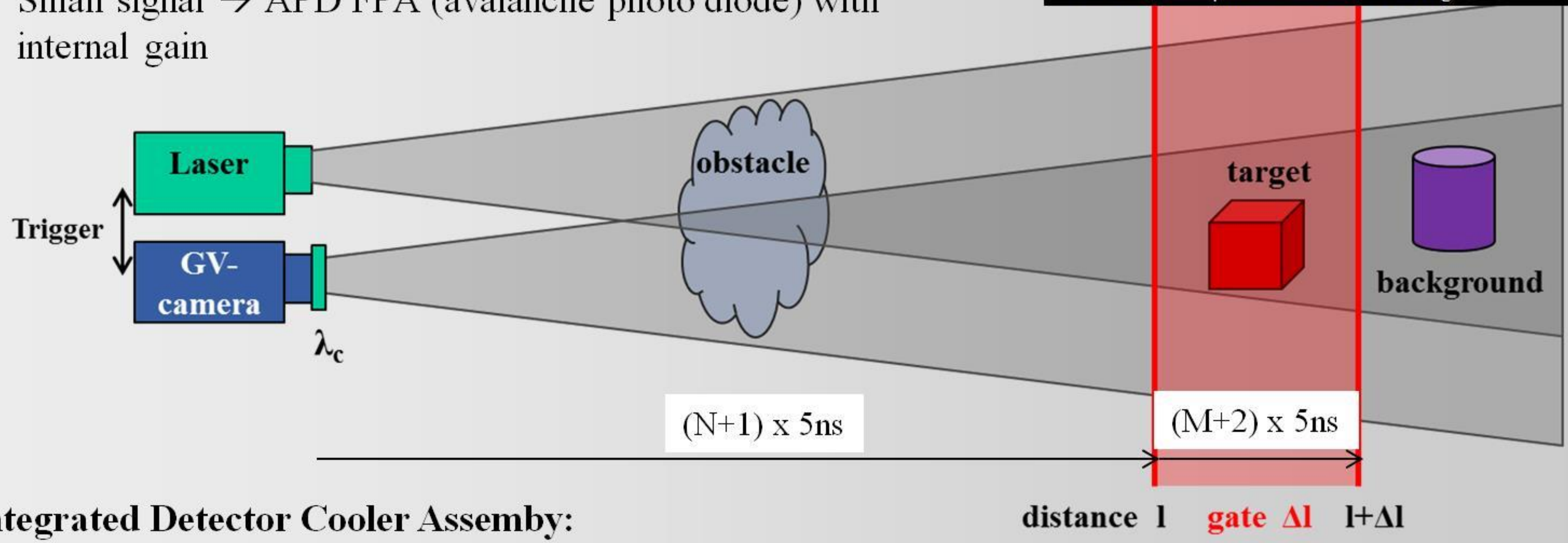
A) Image Intensifier recorded with camera, 0.4µm – 0.9µm B)

Hensoldt NSV600, Gen2 I², FOV 8°

SWIR IMAGING

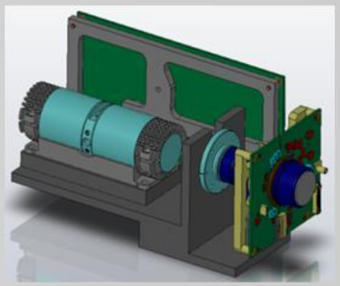
2D MCT SWIR Module for Gated Viewing

- Pulsed laser illuminator 1.5µm
- Fast-gating camera → ROIC with on-chip gating functionality
- Small signal → APD FPA (avalanche photo diode) with internal gain



Integrated Detector Cooler Assemby:

- Detector MCT n-on-p APD, 640x512 15µm, cut-off 2.5µm
- ROIC with internal PLL 200 MHz (5ns), operated by master clock
- Full frame rate max. 100Hz
- Programmable gate delay N and gate integration M in steps of 5ns
- Snapshot imaging mode, integrate then read



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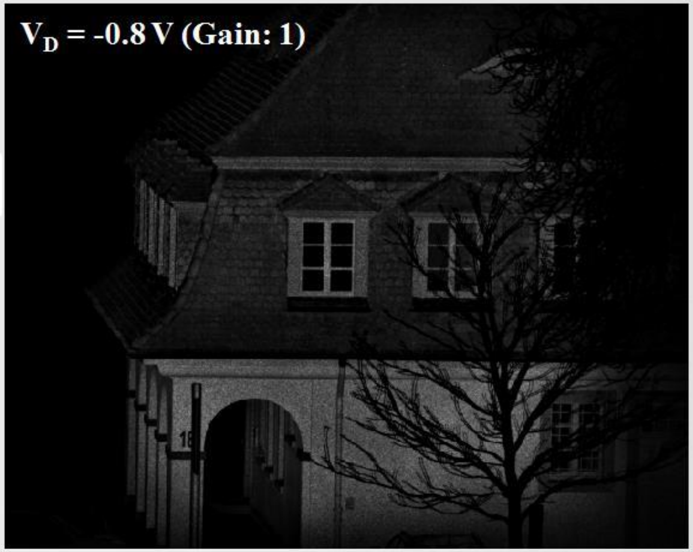
SWIR GV imaging results

100 m



MCT APD
Gain 1 ⇒ 2.3

E_{LASER} = 50 mJ
λ_{LASER} = 1.5 µm

Source: Benjamin Göhler, Peter Lutzmann, Simon Brunner, H. Bürsing, Fraunhofer IOSB, Ettlingen, Germany

Receiver optics f=90mm, F/2

228m → Range → 315m

Gating Function

E_{LASER} = 8mJ
~5ns pulse duration
λ_{LASER} = 1.57 µm
Gate time = 15ns
(≈ 2.3m range gate)
Gain = 1

SUMMARY

AIM

- **IR technology development at AIM**
  - MCT based IR technology from SWIR to VLWIR including Multi-Color Arrays
- **Multi-Color IR detectors**
  - MWIR/MWIR MBE grown MCT on GaAs demonstrated
  - Final MWIR/MWIR design with spatial & temporal coincidence
- **Reduction of Size, Weight and Power (SWaP)**
  - Compact, high resolution MWIR Engine
  - Key component HOT FPA with T_{op}=160K, 1024x768 10µm pitch
  - Low power ROIC, short Dewar, split linear Microcooler, low power electronics
- **SWIR Imaging**
  - eSWIR combining reflective + thermal imaging for Enhanced Vision
  - 2D SWIR Module for Active Imaging with Gated Viewing capability

ACKNOWLEDGEMENTS

AIM

The development activities presented here in were partially supported by the German MOD under different BAAINBw contracts.

This support is gratefully acknowledged.

THANK YOU FOR YOUR ATTENTION