Development of a Thermal Infrared Image Sensor (based on Microbolometers)

EPICTURE THIS WORKSHOP 2023

https://project-mantis.eu/#epicture

Wd **21 June 2023, 13:00 - 21:00**

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All slides are non-confidential and can be made available publicly.

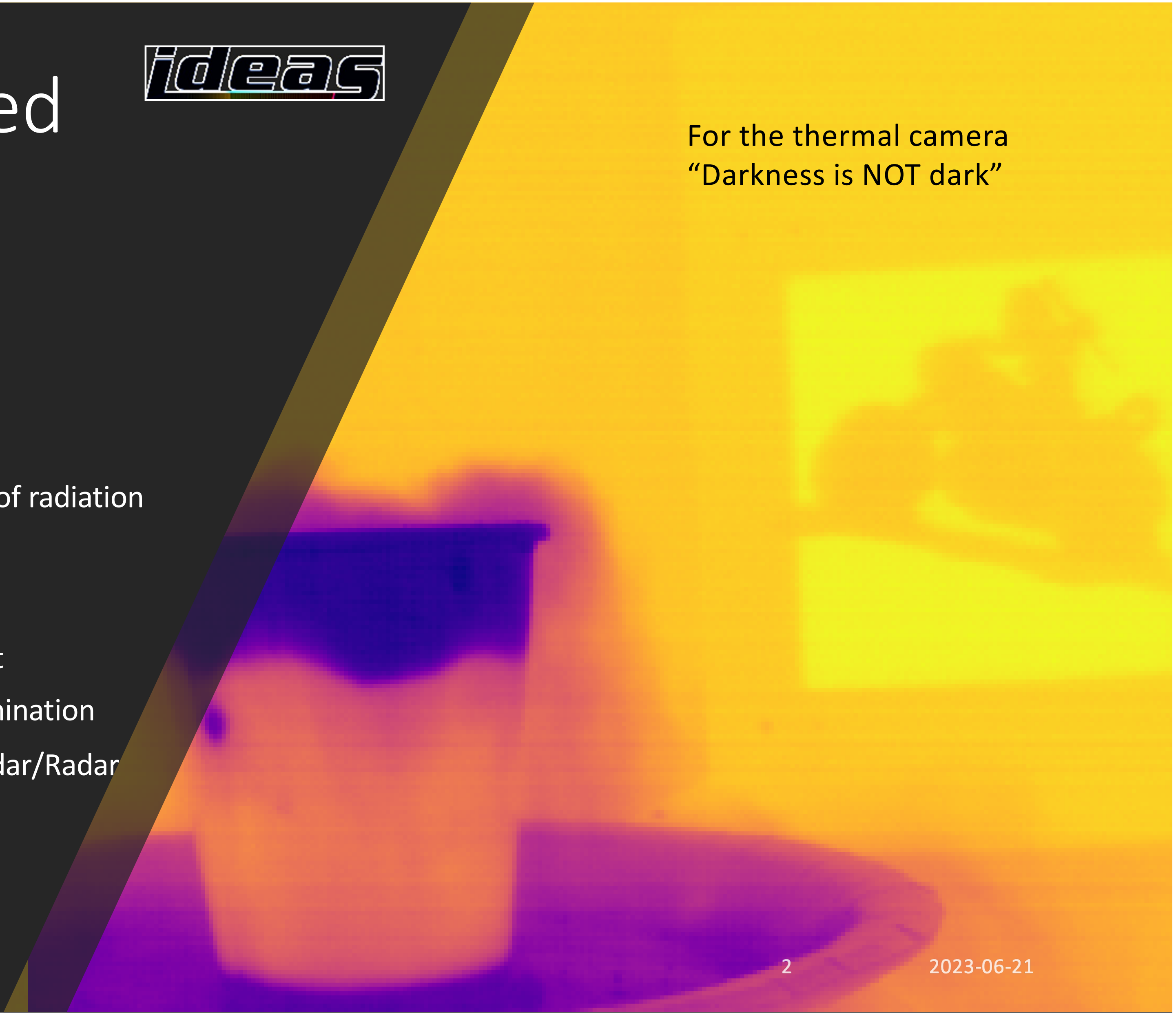
Thermal Infrared Imaging

Thermography
– images/video from radiated heat

Radiometry
– Surface temperature from intensity of radiation

Benefits of Thermal Infrared Imaging

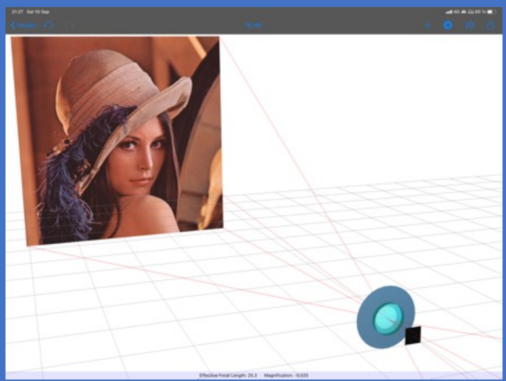
- See through smoke, vapor, fog, dust
- Day and night vision – without illumination
- Passive imaging method – unlike Lidar/Radar



For the thermal camera
“Darkness is NOT dark”

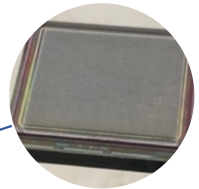
Components in Our Thermal Infrared Camera

Real world object…

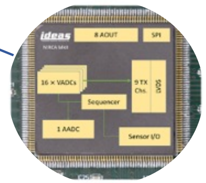


… emits thermal radiation which casts an image in the sensor

- Optics
- Shutter



- Sensor of MBA
- IDEAS SA2V12



- IDEAS Controller IC with ADCs

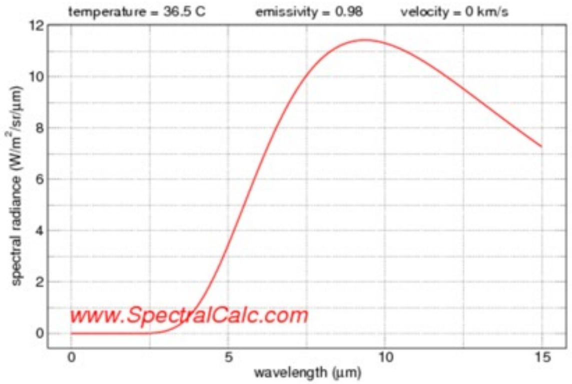
- SoC Module w/FPGA
- Image Pre-processing

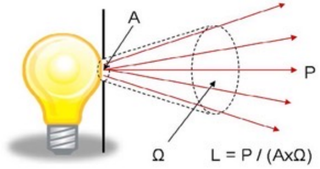
Video images…

… are read out by ICs and SoC Module with image pre-processing

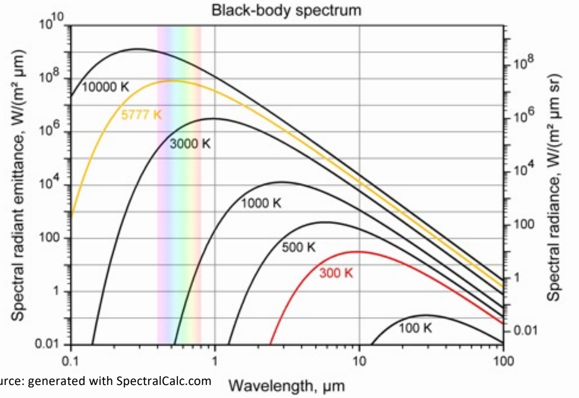
Emission and Absorption of Infrared Radiation

Radiation emitted from living human body (skin)

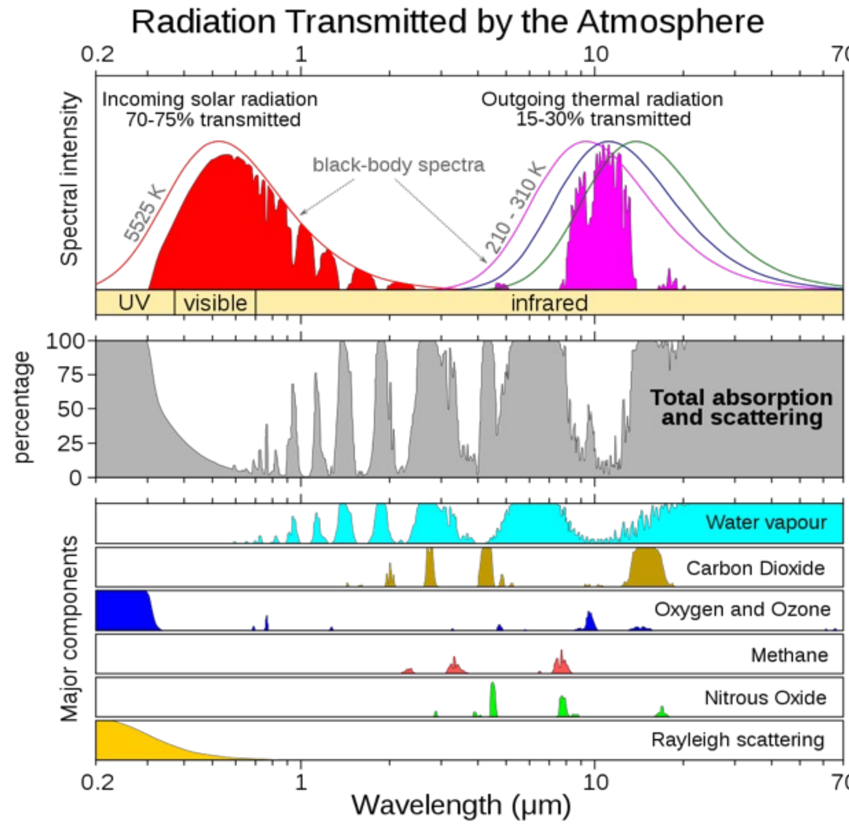




Source: Wikipedia



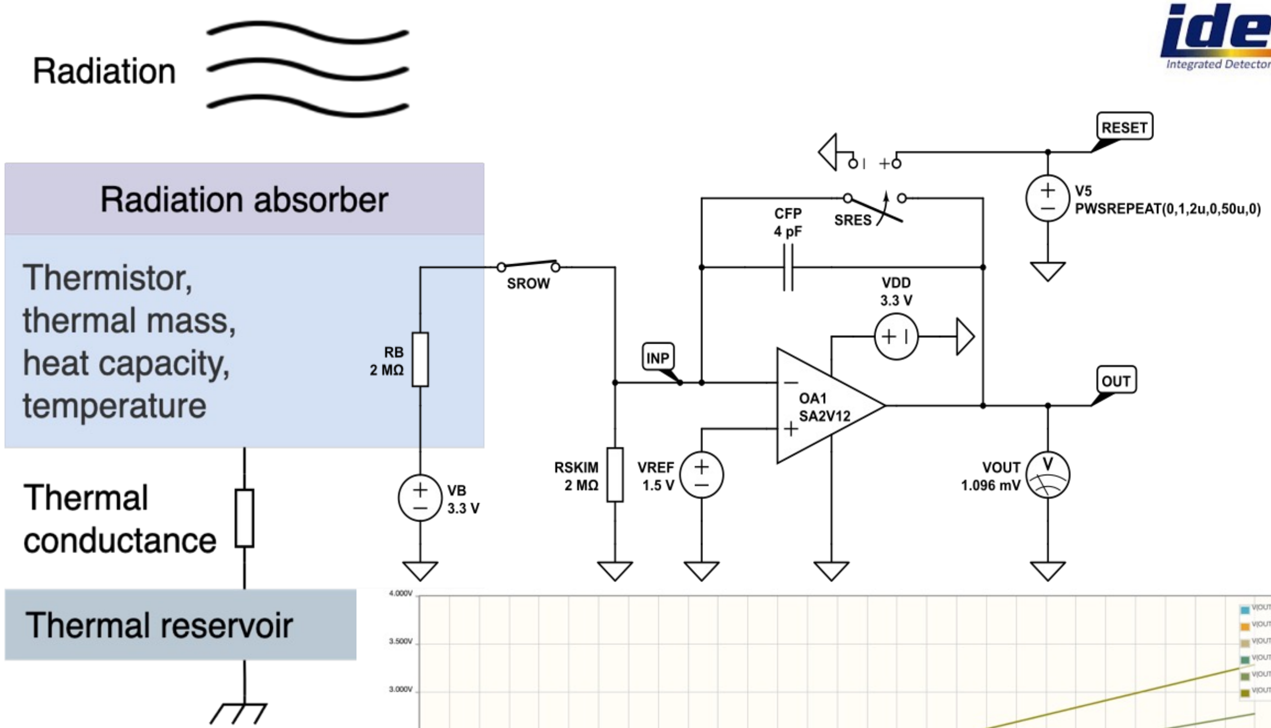
Source: generated with SpectralCalc.com

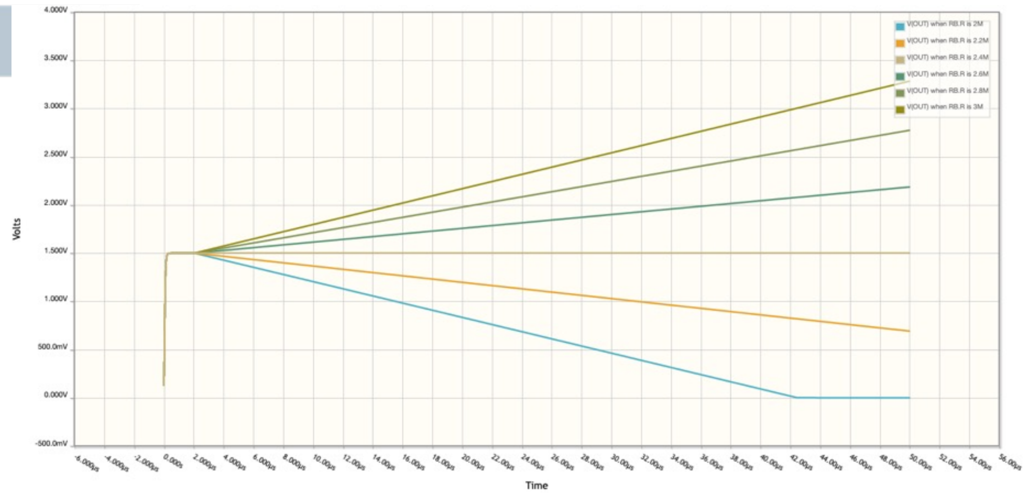


Objects emit radiation at Temperature and Emissivity

Water Vapor and Gases absorb Radiation

Principle of Microbolometer Electronic Readout

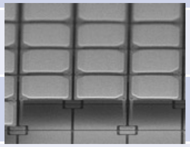
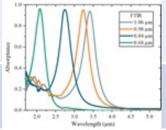
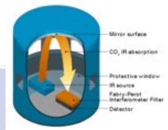
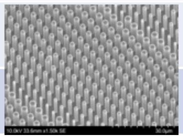
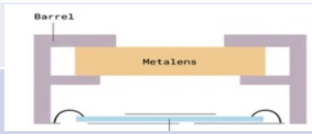




$$R_{\mathrm{B}} = \frac{V_{\mathrm{B}} - V_{\mathrm{REF}}}{\frac{V_{\mathrm{REF}}}{R_{\mathrm{SKIM}}} + \frac{[V_{\mathrm{OUT}}(t_2) - V_{\mathrm{OUT}}(t_1)] * C_{\mathrm{FP}}}{t_2 - t_1}}$$

Principle in www.circuitlab.com
Detailed design in CMOS using www.cadence.com tools

Overview of R&D Activities

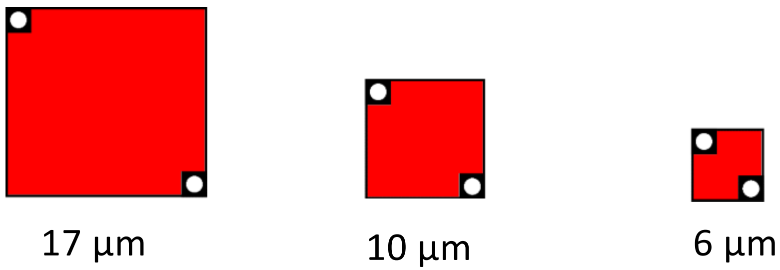
R&D and Technology Innovation	What it Enables
RD-1 - Microbolometer arrays	Room temperature operated 
  Vertical nanotubes	FF, smaller pixels, higher resolution 
Spectral absorbers	DOAS and T w/o ϵ
RD-2 - CMOS Readout ICs	Low SWaP and cost 
  In-pixel memory (SA2V12 ROIC)	Large temperature range
Controller IC with ADC (NIRCA ASIC)	Designed for analog MBA and FPA, i.e., MCT, InGaAs
RD-3 - Diffractive infrared optics in silicon	Low weight, flat lenses
 Meta-optics binary etching	
Grayscale lithography	

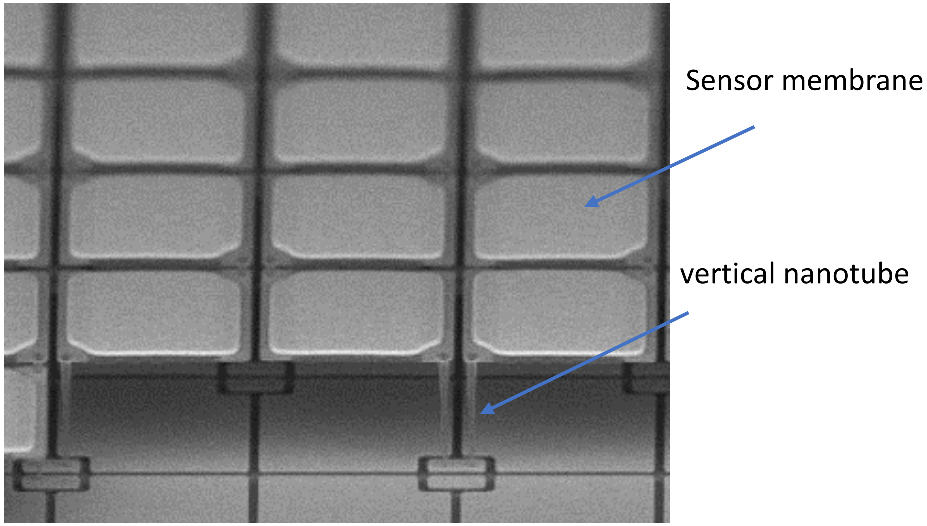
R&D-1

Uncooled Microbolometers

Nanotube technology*

- Scalable microbolometer technology up to 6µm pixel size
- Utilization of the largest possible area of the absorber layer





SEM-picture of the nanotube-microbolometers

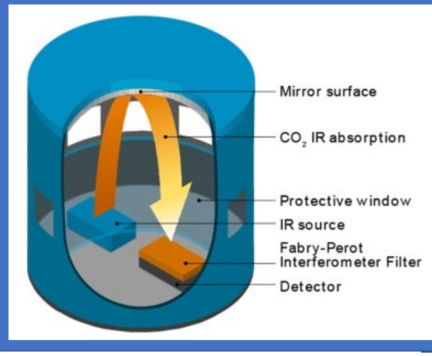
*Michel, M., et al., Proc. SPIE 11537, Electro-Optical and Infrared Systems: Technology and Applications XVII, 1153704 (2020).

R&D-1

Plasmonic Metal-Insulator-Metal (MIM) Absorber

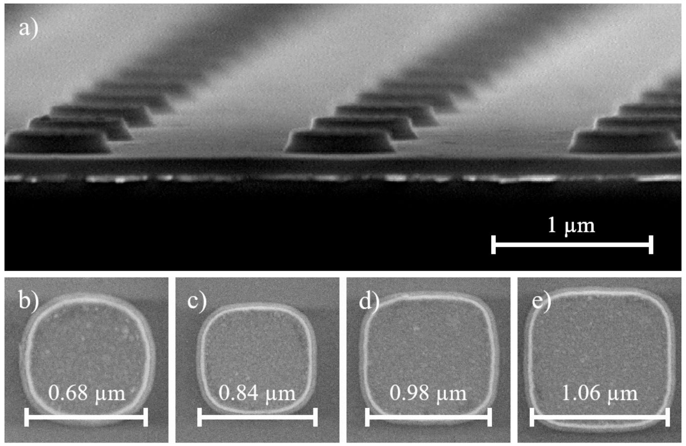
Can MIM absorbers replace Fabry Perot In gas detectors?

#DOAS – differential optical absorption spectroscopy

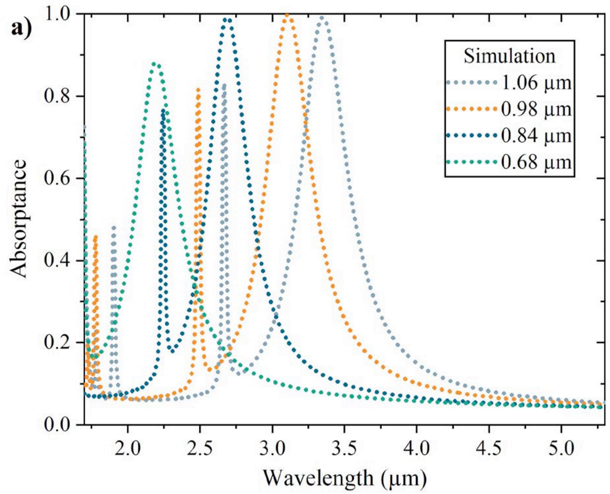


Selective absorption in MWIR

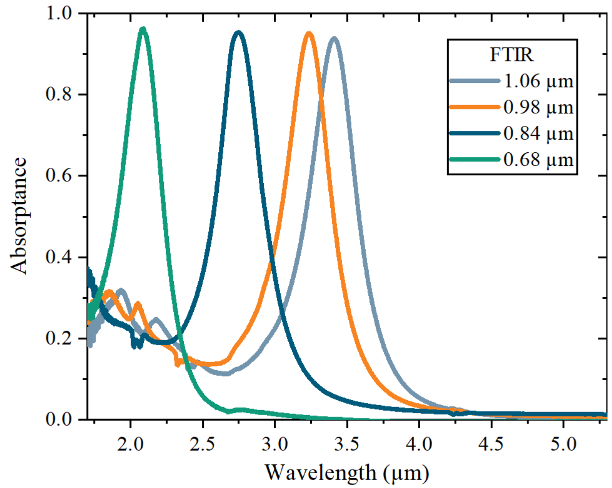
MIM test structure adaptable to Fraunhofer IMS's nanotube microbolometer **for multispectral imaging****



SEM-picture of fabricated MIM test structures



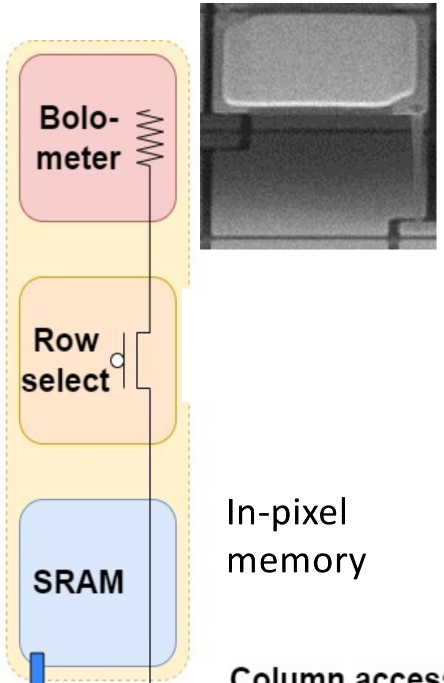
Simulation absorption spectra

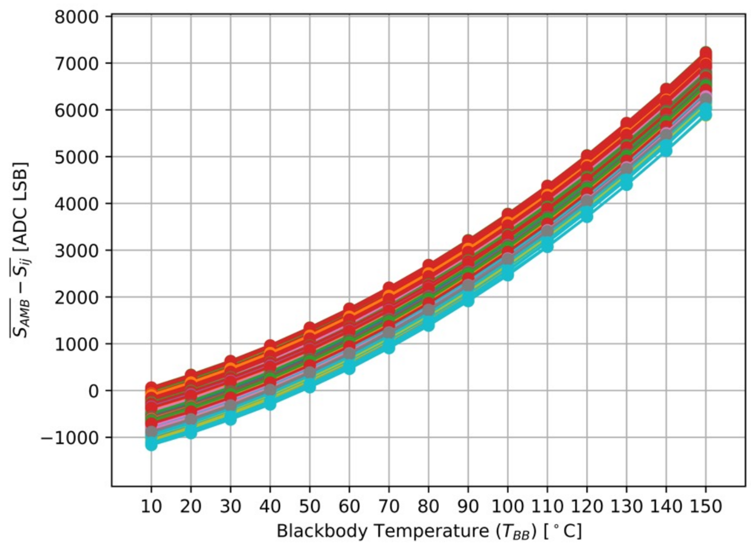


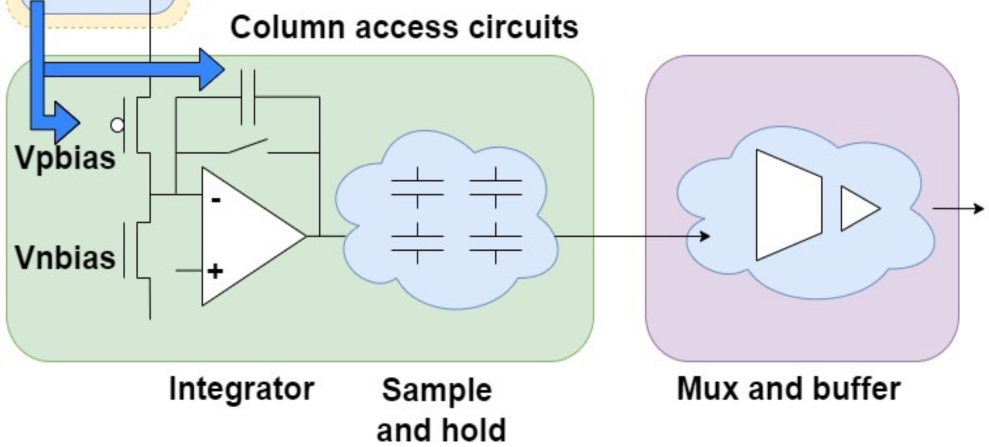
FTIR measurements of MIM test structures

Principle of Microbolometer Electronic Readout

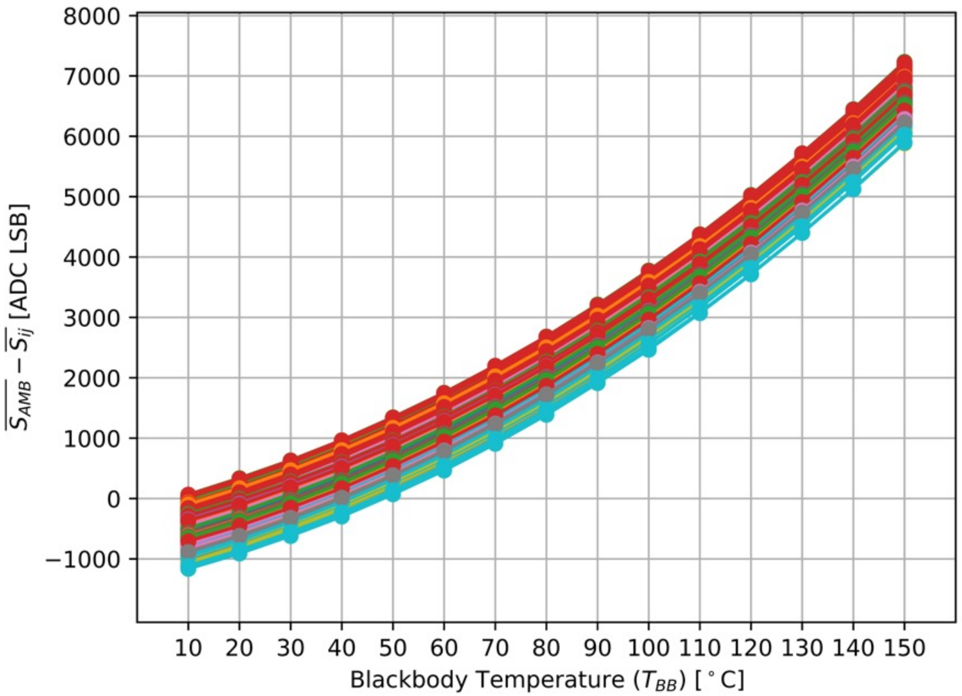
R&D-2







Responsivity (Preliminary Measurement with 17um MBA)



SITF – signal transfer function

$$\bar{S}(i,j,T)\ [\text{LSB}] \stackrel{\text{def}}{=} \frac{1}{200}\sum_{k=1}^{200} S_k(i,j,T)\ [\text{LSB}]$$

Responsivity

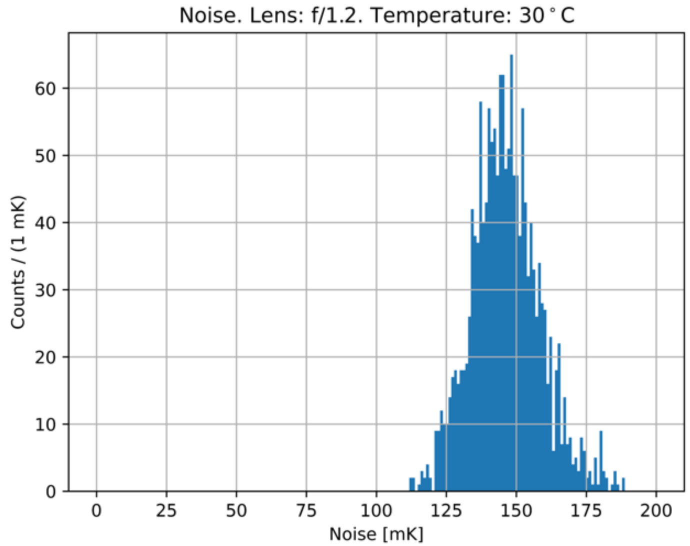
$$R(i,j,T)\left[\frac{\text{LSB}}{\text{K}}\right] \stackrel{\text{def}}{=} \frac{\partial P(i,j,T)\ [\text{LSB}]}{\partial T\ [\text{K}]}$$

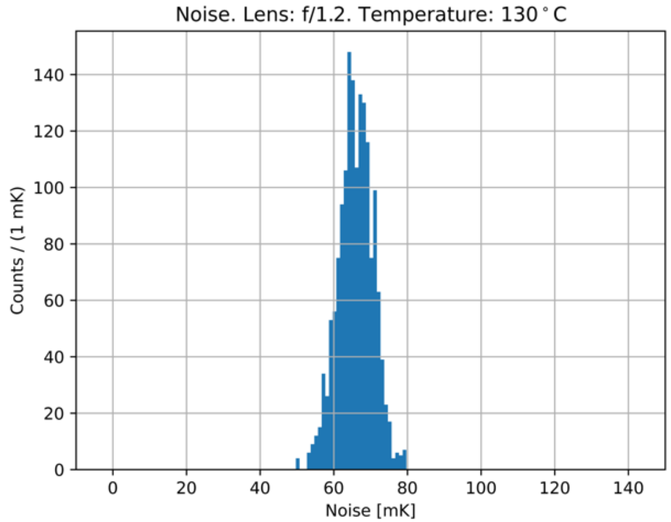
With $P(i,j,T)$ is polynomial fit to $\bar{S}(i,j,T)$.

Temperature range 0℃ up to 150 ℃, higher temperatures are possible

NETD – Noise Equivalent Temperature Difference

(Preliminary measurement with 17um MBA)





NETD – Noise Equivalent Temperature Difference

$$\mathrm{NETD}(i,j,T)[\mathrm{K}] \stackrel{\mathrm{def}}{=} \frac{\tilde{S}(i,j,T)\ [\mathrm{LSB}]}{R(i,j,T)\ [\frac{\mathrm{LSB}}{\mathrm{K}}]}$$

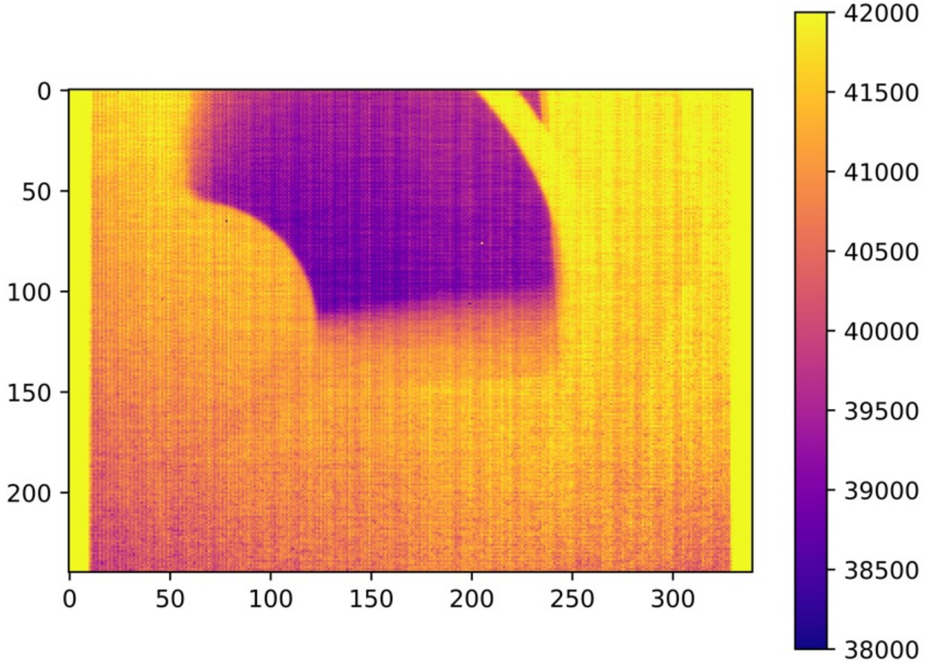
with

$$\tilde{S}(i,j,T)\ [\mathrm{LSB}] \stackrel{\mathrm{def}}{=} \sqrt{\frac{1}{200-1}\sum_{k=1}^{200}\left[S_k(i,j,T)\ [\mathrm{LSB}] - \bar{S}(i,j,T)\ [\mathrm{LSB}]\right]^2}$$

NETD at f/1.2 is 60mK to 170mK depending on temperature and other.

Blur from Thermal Time Constant

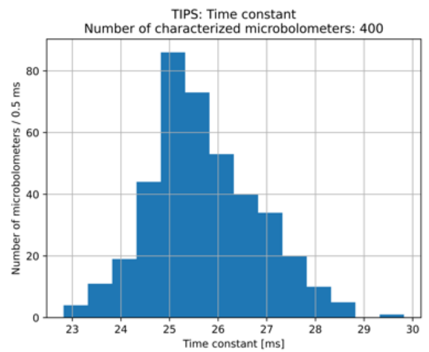
(Preliminary with 17um MBA)



Thermal time constant

$$\tau_{\text{th}} \stackrel{\text{def}}{=} \frac{\mathrm{C}_{\text{th}} \left[\frac{\mathrm{J}}{\mathrm{K}}\right]}{G \left[\frac{\mathrm{W}}{\mathrm{K}}\right]}$$

Heat capacity C_{th} and thermal conductance G $\left[\frac{\mathrm{W}}{\mathrm{K}}\right]$

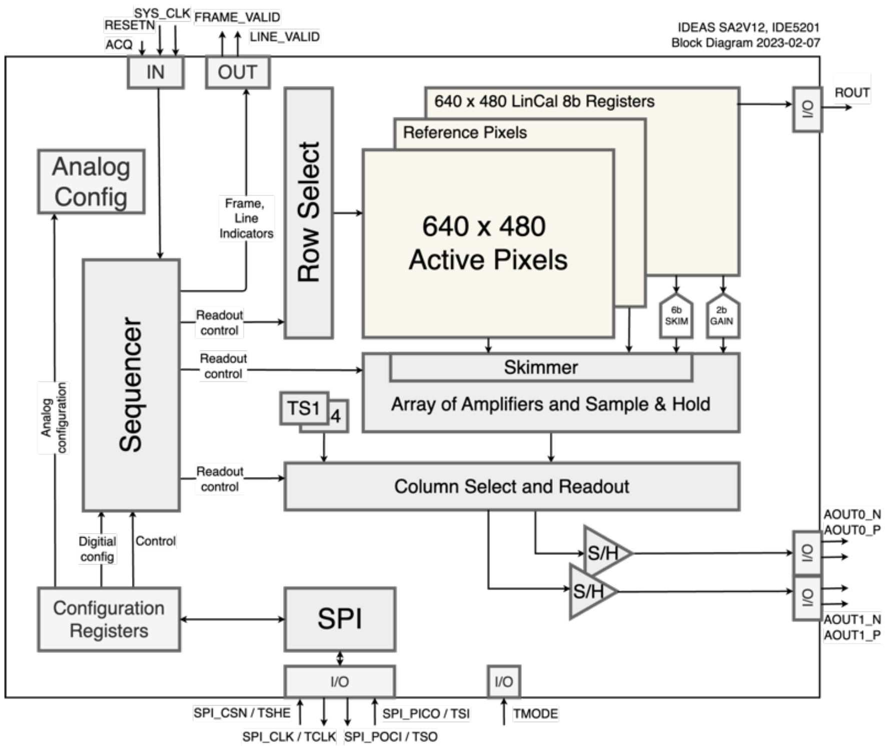


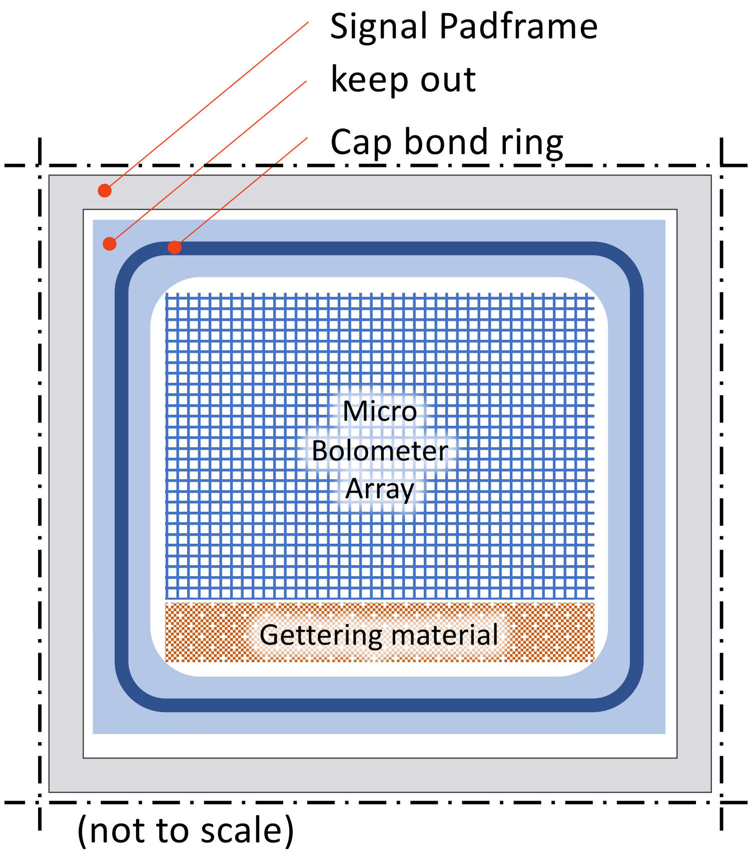
Preliminary: Thermal time constant of about 26ms (for these microbolometers)

R&D-2

SA2V12 ROIC for MBA

(2 Analog Out, VGA, 12µm Pixel Pitch)





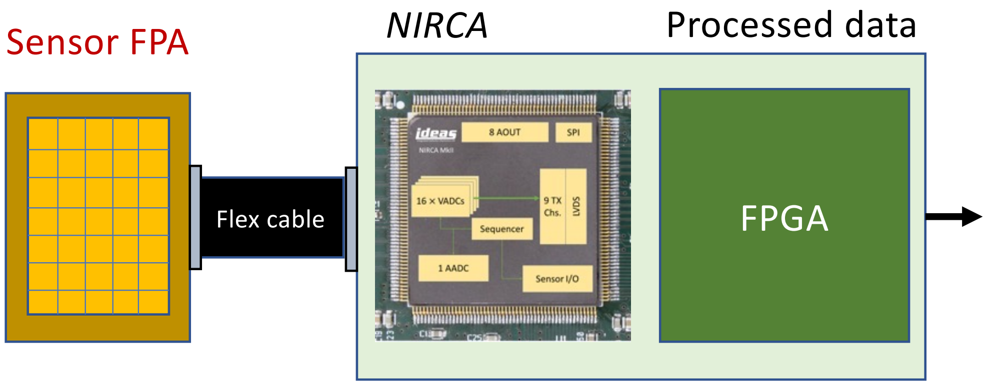
(not to scale)

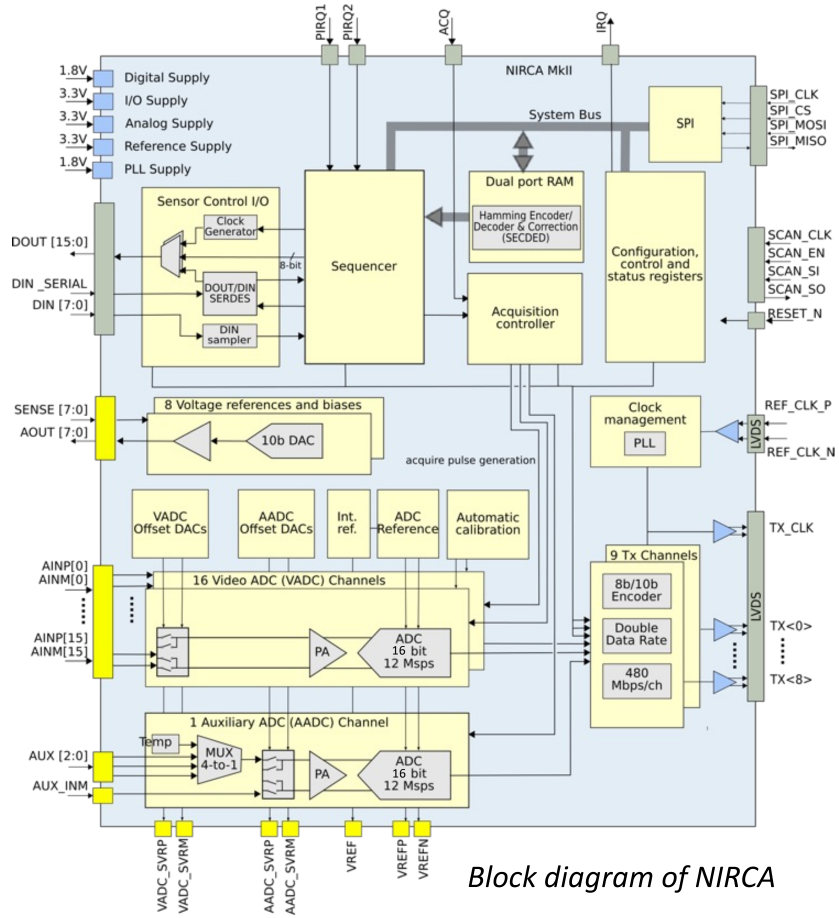
Block diagram of the ROIC, to be manufactured in CMOS.
The Microbolometer array will be fabricated directly on the ROIC.

R&D-2

NIRCA – Near Infrared Readout Controller ASIC

- 17 ADCs (16-bit each) with sample rate of 12 MSPS to digitize analog data
- Output DACs to bias references
- I/O interface with sensor



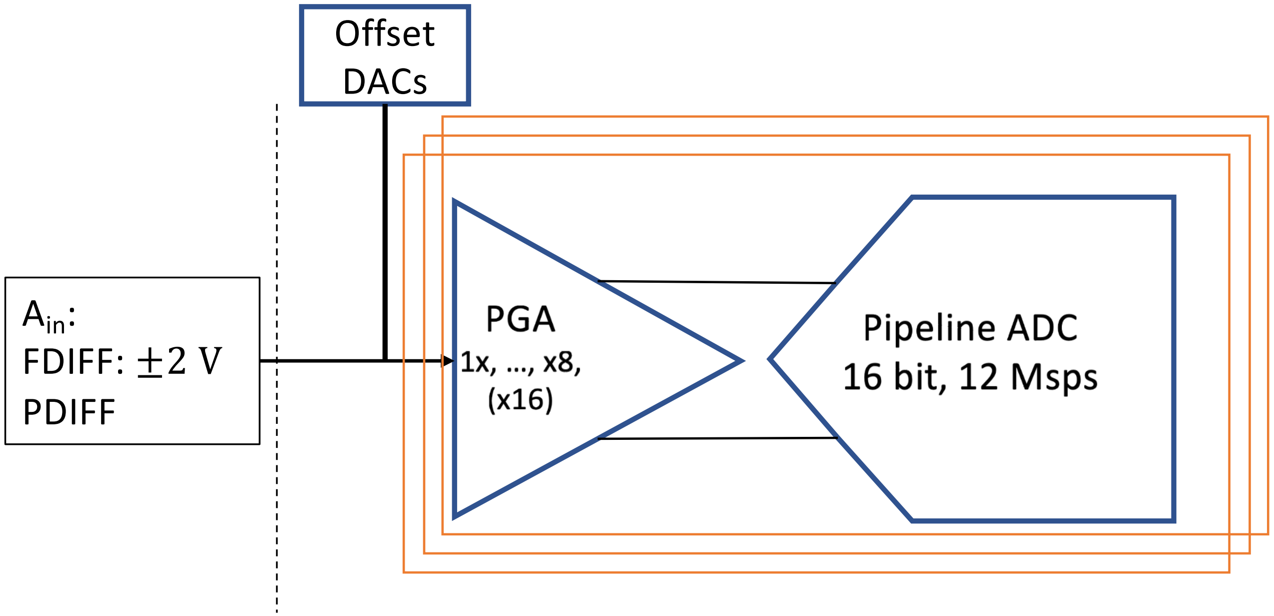


Block diagram of NIRCA

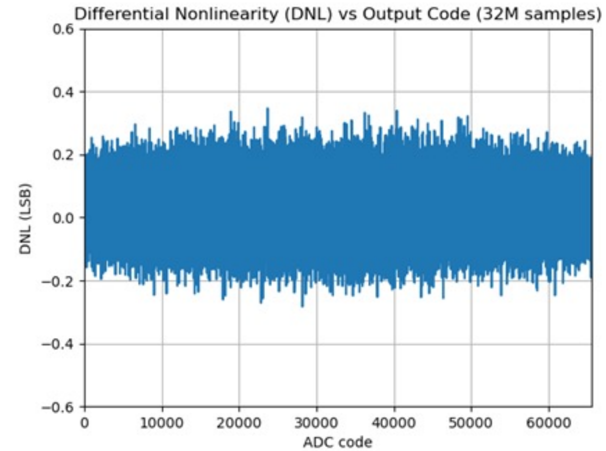
R&D-2

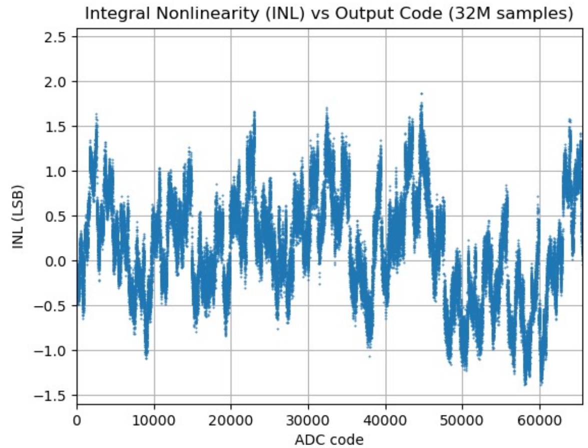
Integrated Detector Electronics AS

NIRCA A/D converters



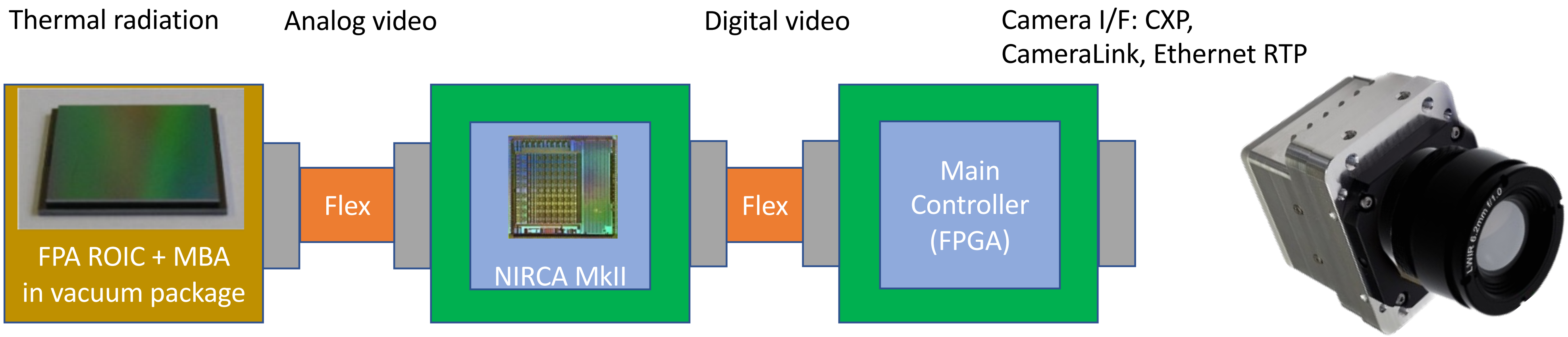
- 16 Video ADCs + 1 auxiliary ADC
- C_{in} = 7 pF





R&D-2

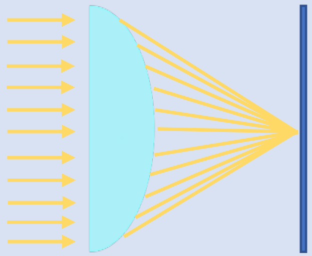
Thermal IR MBA + NIRCA + SoC Module

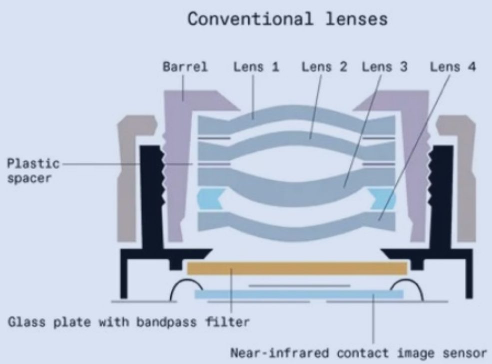


R&D-3

Optics for Thermal Infrared

Example Refractive Lens Assemblies

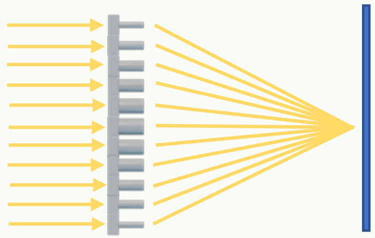


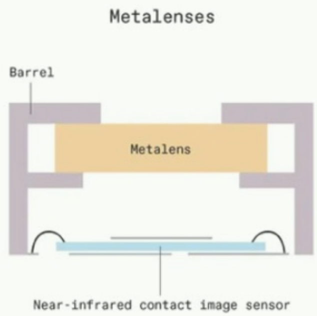


Refractive optics with lens assembly from

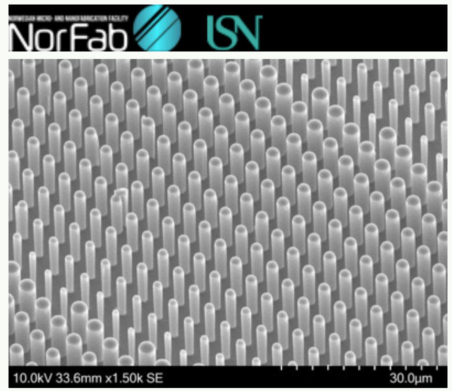
1. Chalcogenide GASIR®
2. Germanium
3. Fresnel mold

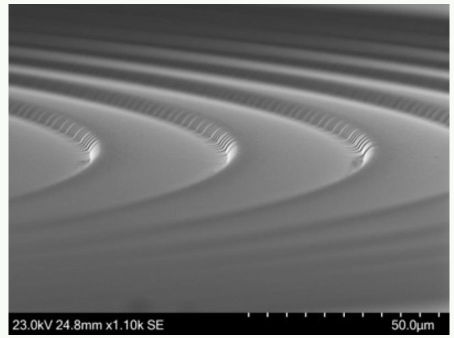
R&D with Metalens and Grayscale lithography





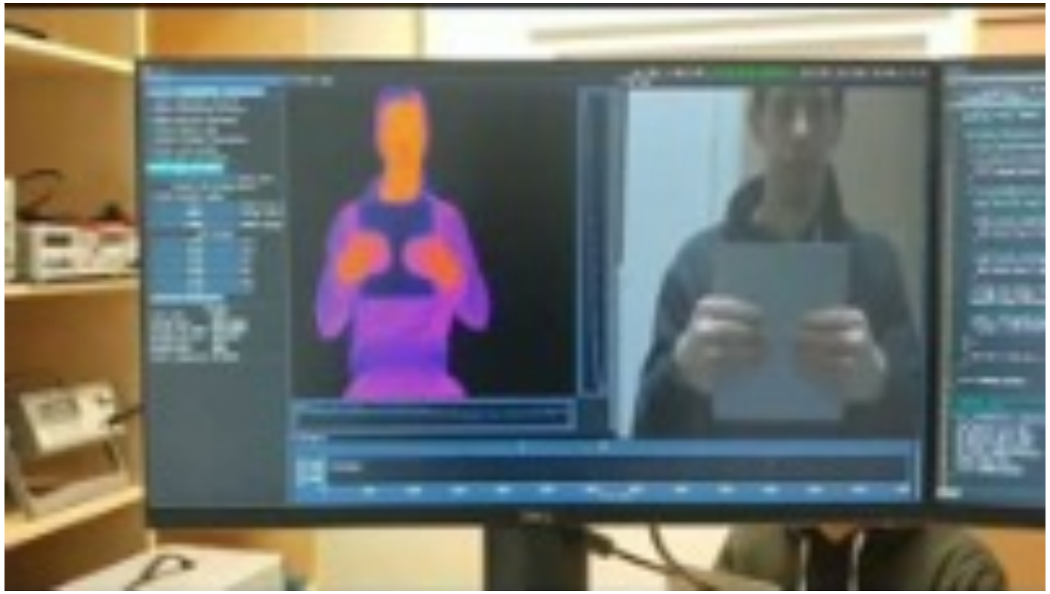
A single metalens [right] can replace a stack of traditional lenses [left], simplifying manufacturing and dramatically reducing the size of a lens package. METALENZ





Design and fabrication at NorFab/USN [Bouchouri and Akram] in collaboration with IDEAS.
Lens of f/2, Ø8mm, 10µm CWL monochrome, silicon pillars of 6.3µm height and 5µm pitch.

Demonstration of a Thermal Infrared Camera



Rihards Novickis, Edgars Lielamurs et al. at EDI, https://youtu.be/aXIDwRos-gI

click

Features

Sensor technology	Silicon MBA, 17µm QVGA, CSP
Data Interface	Ethernet
Lens	Umicore GASIR® IR, 7.5mm, f/1.2
Spectral range	Mid- and long wave infrared
Temperature FOV	0℃ to +400℃
NETD at f/1.0	47mK 120℃, 94mK at 30℃
Thermal time constant	25.7ms
Frame rate	30fps
Data acquisition system	Xilinx ZCU102 MPSoC
Operating temperature	-20℃ min, +60℃ max

Description

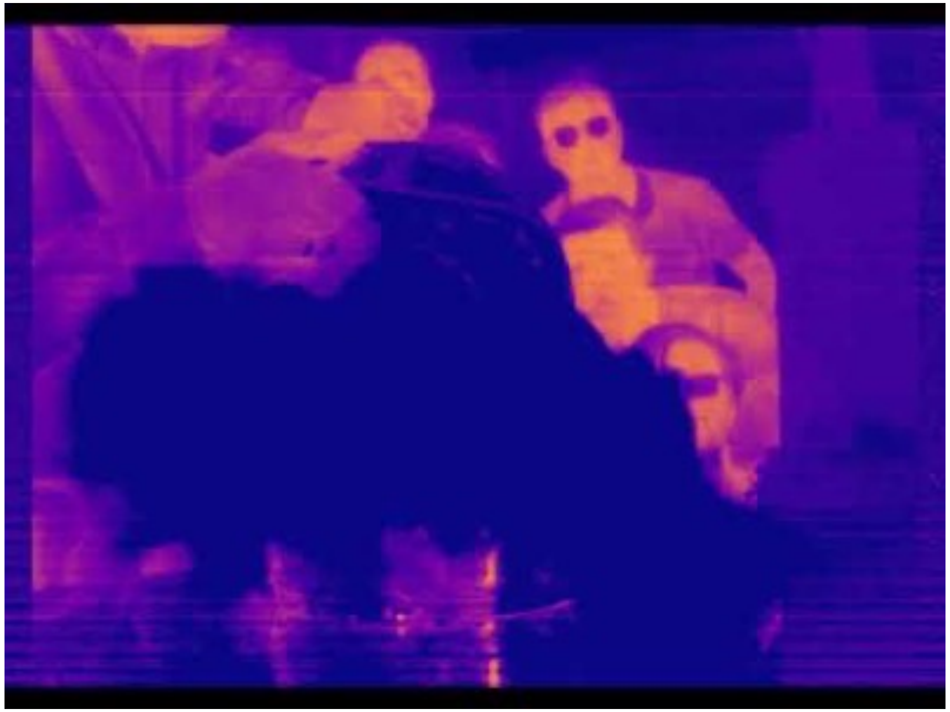
The TC-N1 camera system demonstrates video-rate thermal infrared (IR) imaging at 30fps with a focal plane array (FPA) based on silicon microbolometers (MBA). The IRFPA has 320 × 240 active pixels at 17-µm pixel pitch and has been fabricated in a standard CMOS process certified for automotive applications followed by MEMS process to realize microbolometers and a chip-scale vacuum-package (CSP). The camera is sensitive to thermal radiation (heat) over several hundreds of degrees Celsius with average noise of 94mK at +30℃ and 47mK at +120℃ (NETD, normalized to f/1.0). Details of the design must be customized and optimized for the intended applications.

Applications

The TC-N1 is a thermal infrared camera for the purpose of technology evaluation and demonstration. The technology is intended for camera manufacturers and system integrators. Possible applications are in thermography, security, and safety, automotive, firefighting and others.

Camera Demonstrator Tests

click



https://youtu.be/ir_NtIkv5is

IDEAS Ambition is to **supply Thermal Infrared Camera Modules** to OEMs

High-performance thermal infrared camera modules

MBA – Microbolometer Array, **uncooled and room-temperature operated**
TSense – Temperature Sensing and Radiometric
PxPy – Pixel in X and Y, VGA, such as SA2V12 and **higher resolution**
FOM – Figure of Merit, low NETD and short time constant

Enable OEMs to offer new solutions in thermography

MIM – Metal insulator metal, multi-spectral bands, https://doi.org/10.1117/12.2638111
SWaP – Size, weight, and power are low, e.g., metalens, Bouchouri et al. ELOS2022

Capability for customizations and increase sovereignty

- Non-US ITAR, made-in-Europe, European sovereignty

About IDEAS

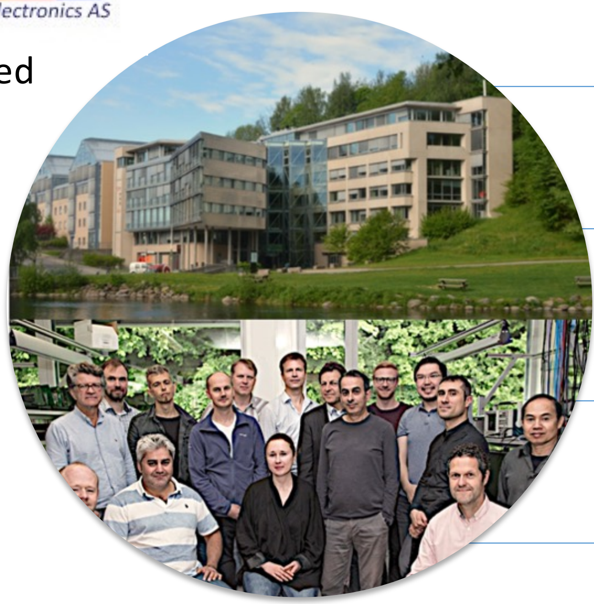
IDEAS is a Norwegian company (SME), located in Oslo, founded in 1992.

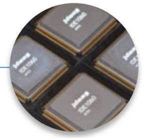
IDEAS **designs and supplies**

- Electronic **integrated circuits**,
- **Sensor components, systems, modules.**

Team of about 28 employees, with background in electronics, software, radiation physics and material science.

www.ideas.no





IC Designer/Supplier

Radiation Detectors

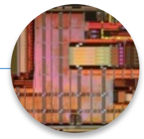


Image Sensors

Special Apps/Ops/Env

For 30 year, the company has been developing electro-optical systems for radiation detection and imaging.

We focus on **performance-defining and proprietary ROIC/ASICs and sensor components (semiconductors + MEMS).**

Our customers are in **scientific and emerging imaging technologies** with disruptive market potential.

Acknowledgements

Project	Program
NIRCA	ESA contracts + IDEAS, ~10 years
MINC	Eurostars Eureka Grant + IDEAS, 2016-2018, 3years
SPEKTIR	Eurostars Eureka Grant + IDEAS, 2020-2024, 4years
APPLAUSE UC2	ECSEL JU, H2020/NFR Grant + IDEAS, 2019-2022, 42months
MANTIS	IPN, NFR Grant + IDEAS, 3years
MANTIS Vision	Euripides Penta, IDEAS, 3years
AGRARSENSE	KDT JU, H2020/NFR Grant + IDEAS, 2023-2025, 3 years
CENSSS	SFI, NFR Grant + IDEAS