

Extending uncooled thermal imaging to multispectral absorption

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Outline

1. Introduction

- Fraunhofer IMS

2. Uncooled Thermal Imagers

- Components of an IRFPA
- Overview of Fraunhofer IMS's previous works
- Technology
- Recent Projects and Future Topics
 - MWIR spectral range
 - Combined MWIR / LWIR sensitivity
 - Multispectral imaging

3. Summary

Portfolio overview of Fraunhofer IMS

Introduction

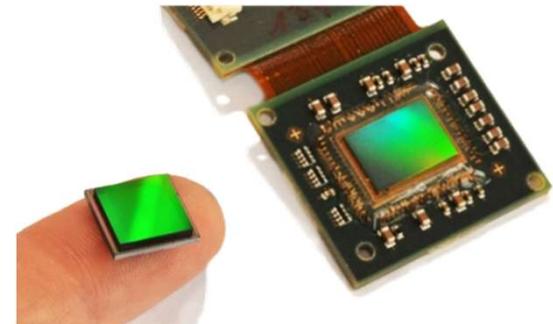
Fraunhofer Institute for Microelectronic Circuits and Systems

Infrastructure of Fraunhofer IMS:

- Cleanroom-Infrastructure based on 200 mm Silicon-Wafern
- 0.35 μm CMOS-Technology including Post-Processing
- Pilot-Production possible and modern test-equipment available
- Part of "Forschungsfabrik Mikroelektronik Deutschland" (FMD)
 - Largest cross-site R&D Cooperation for Micro- and Nanoelectronics in Europe

Core-Competences / -technologies of Fraunhofer IMS:

- Realized optical sensors: embedded CCD (CMOS TDI), LiDAR (BSI SPAD), uncooled IRFPA
- Embedded AI (e.g. Contactless measurement of vital signs)
- RISC-V with AI, DSP-acceleration, Krypto-Algorithmic



Uncooled Thermal Imagers

Uncooled IRFPAs as Thermal Detector

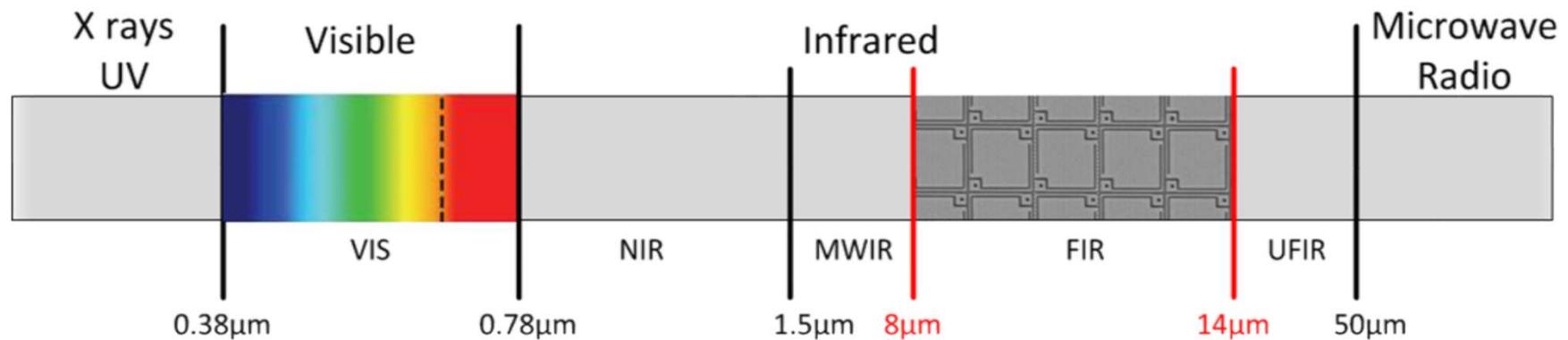
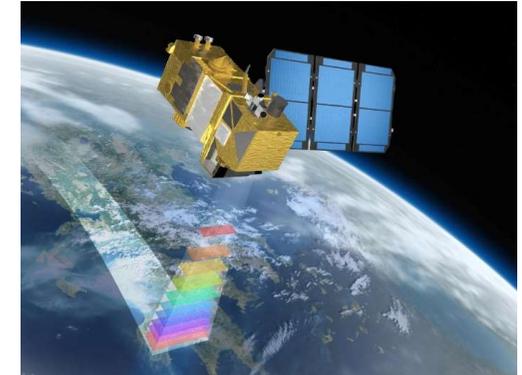
Thermal Detector for the LWIR regime

Motivation for uncooled IRFPAs:

- Detection / visualization of human thermal radiation in case of limited visibility conditions
 - Dark night, fog, smog, overexposure by background light...

Advantages of uncooled IRFPAs:

- IR as a passive technology does not require active illumination of the scenery as compared to VIS sensors
- Attractive trade-off in terms of costs versus thermal resolution



Uncooled Thermal Imagers

Components of an IRFPA

Thermal Detector for the LWIR regime

Microbolometer as IR sensing element:

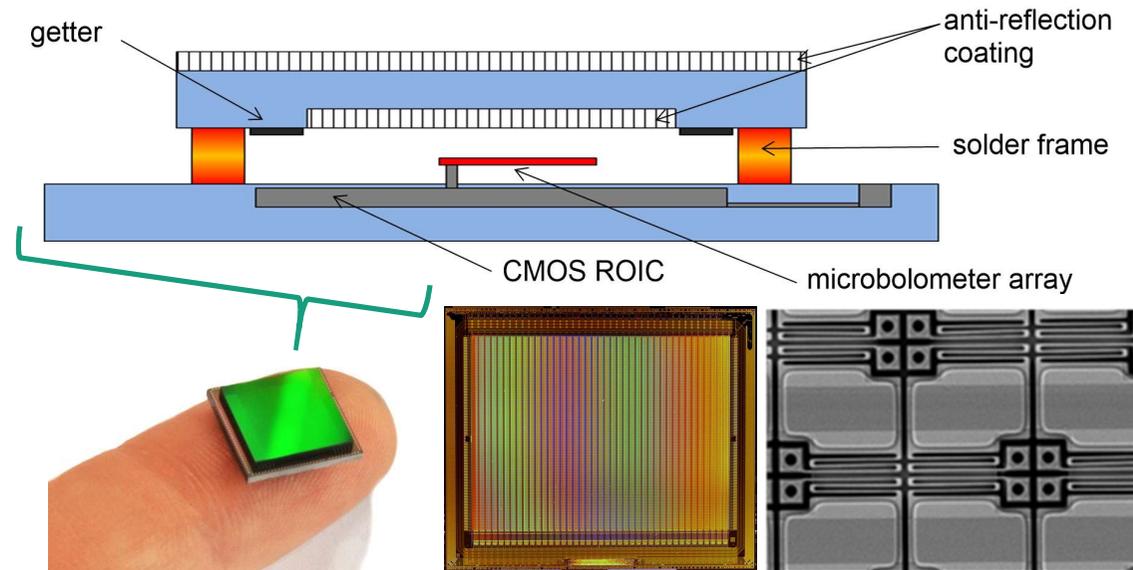
- Thermal detection principle:
 - Absorption membrane relying on $\lambda/4$ resonance
 - Amorphous Silicon (a-Si) as thermal sensing material
 - Thermal insulation achieved by lateral meander-like legs

Chip-scale package (CSP) as miniaturized vacuum package:

- Minimization of thermal losses by gas convection
- IR-entrance window including double-sided antireflection coating (ARC)
- Integrated gettering material for long-term stability

Fully digital 17 μm QVGA-IRFPA of Fraunhofer IMS:

- Digital readout electronics (ROIC)
 - Video signal with 16 Bit resolution
 - Large scene dynamic range ($T_{\text{scene}} > 300 \text{ K}$)
- Chip-on-board (CoB) solution for easy camera integration



Uncooled IRFPA composes of three main components

- CMOS ROIC
- Microbolometer array in a post CMOS technology
- Vacuum packaging

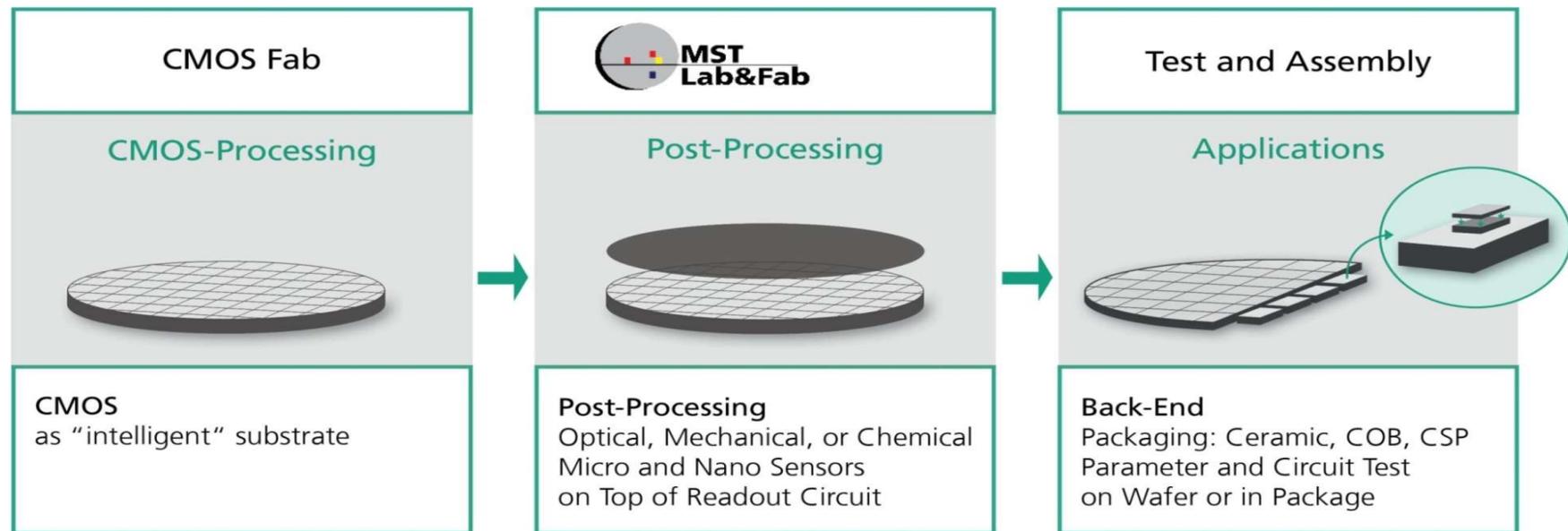
Uncooled Thermal Imagers

Fabrication Process of Uncooled IRFPAs

Thermal Detector for the LWIR regime

Simplified fabrication process of IMS IRFPAs

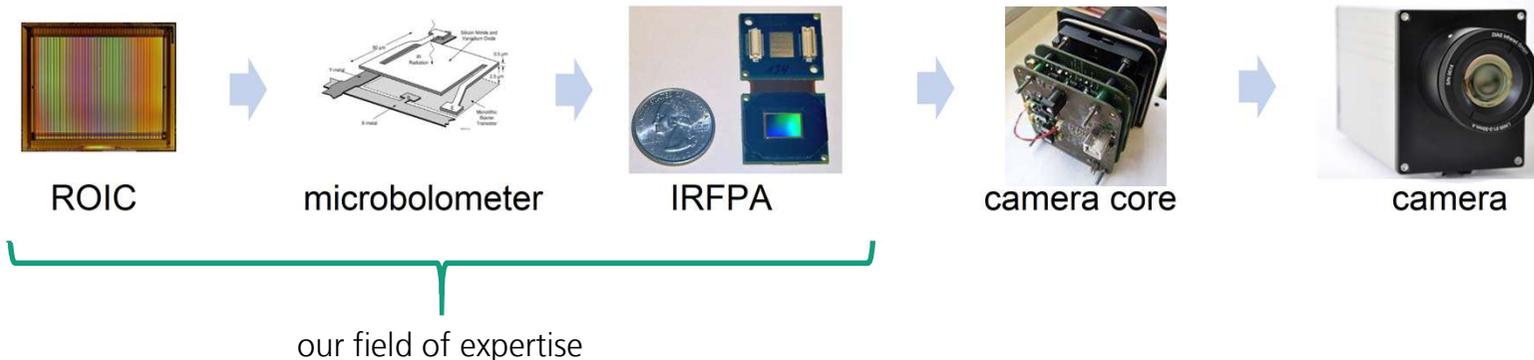
- Complete in-house fabrication on 200 mm wafers
 - ROIC: IMS 0.35 μm CMOS process or external foundry processes possible



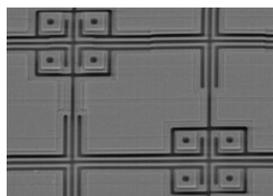
Uncooled Thermal Imagers

Overview of Fraunhofer IMS's previous works

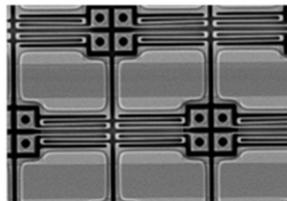
Process chain from microbolometer to camera



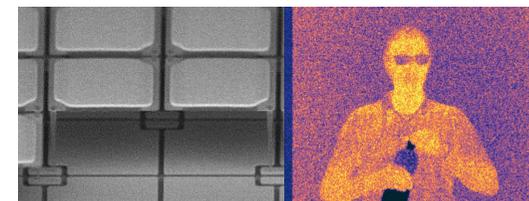
Timeline of Fraunhofer IMS's microbolometer developments



- 350 nm CMOS ROIC (25 μm pitch)
- 25 μm microbolometers



- 350 nm CMOS ROIC (17 μm pitch, QVGA)
- 17 μm microbolometers with CSP



- 180 nm (12 μm pitch) and 110 nm (8.5 μm pitch) on external CMOS ROIC
- Scalable nanotube microbolometers (pitch: 17 μm down to 6 μm realized)

Uncooled Thermal Imagers

Technology

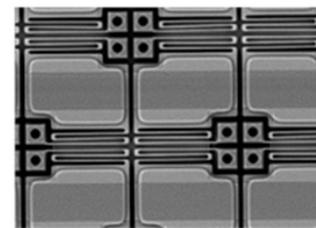
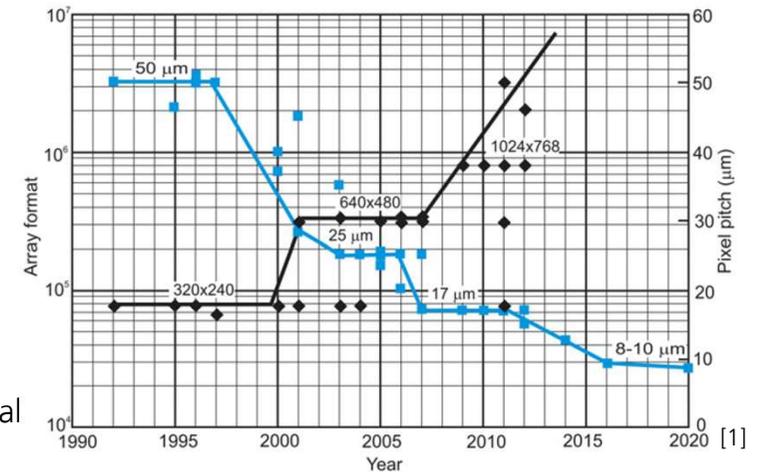
Use of uncooled IRFPAs for the LWIR regime

Microbolometer following the trend of VIS imagers

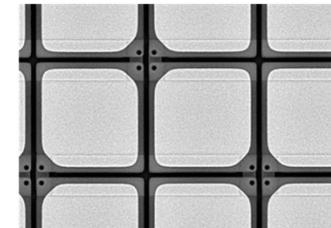
- Higher optical resolution → reduction of pixel pitch
- Higher thermal resolution → more sophisticated concepts for thermal insulation
- Scalable microbolometer based on vertical nanotubes as Fraunhofer IMS's contribution to tackle this challenge

Concept of Fraunhofer IMS's nanotube microbolometer

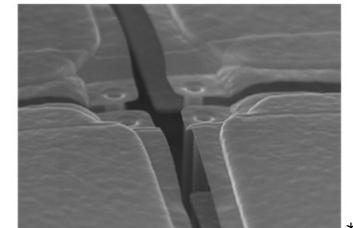
- State-of-the-art microbolometers rely on lateral meander-like legs to achieve sufficient thermal insulation
 - Area required for thermal insulation competes with area of absorption
 - Desired reduction of pixel pitch further reduces active area
- Scalable nanotube microbolometer decouple areas for thermal insulation and absorption by implementing vertical nanotubes underneath the sensing membrane
 - Maximization of area for absorption → increase of fill factor



17 µm microbolometers with lateral leg insulation



scalable microbolometers (17 µm – 6 µm) with vertical nanotube insulation



* Supported by WTD 81, TF Optronik

[1] A. Rogalski: Scaling infrared detectors – status and outlook. Rep. Prog. Phys. 85 (2022)

Uncooled Thermal Imagers

Recent Projects and Future Topics

Expansion of uncooled IRFPAs to MWIR spectral range

Motivation for uncooled MWIR IRFPAs

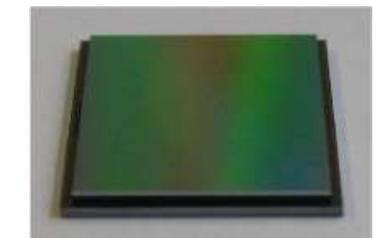
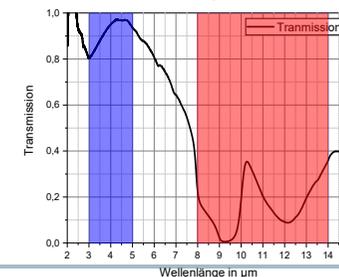
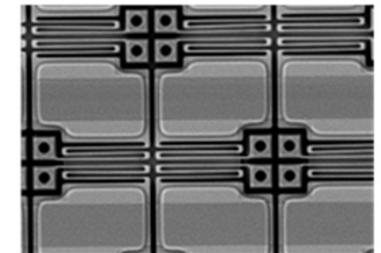
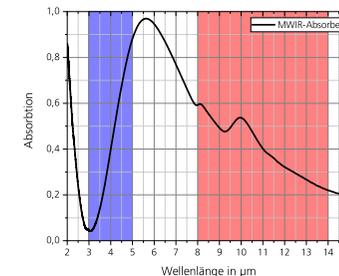
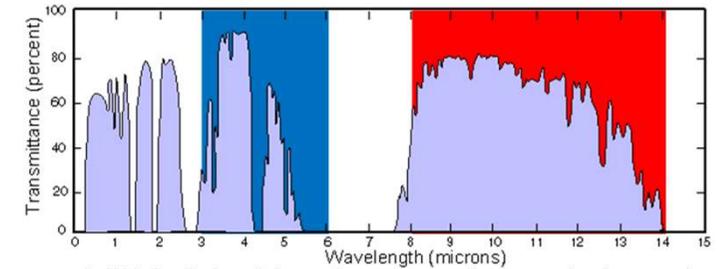
- State-of-the-art MWIR detectors based on cooled detectors
- Uncooled IRFPAs only for LWIR-range available
 - Typically: Integrated blocking filter for $\lambda < 8 \mu\text{m}$
- Applications of uncooled MWIR-IRFPA
 - Optimized spectral range for „hot“ sources
 - Visualization of gas leakage

New MWIR absorber structure (microbolometer)

- Development of a new MWIR-microbolometer structure
- First characterization results: Further shift of absorption peak required

New MWIR antireflection coating (chip-scale package)

- Adaption of ARC microstructures to MWIR spectral range
- First characterization results: Small shift of transmission peak required



Uncooled Thermal Imagers

Recent Projects and Future Topics

Expansion of uncooled IRFPAs to MWIR spectral range

Spectral measurement of MWIR- and LWIR-IRFPAs

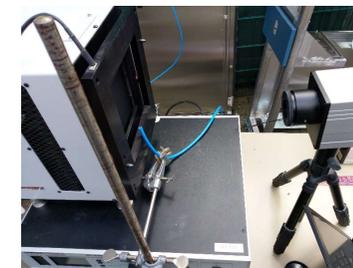
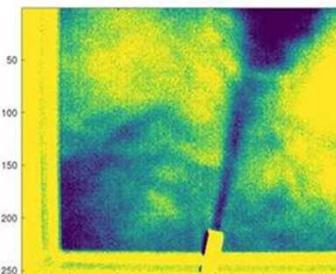
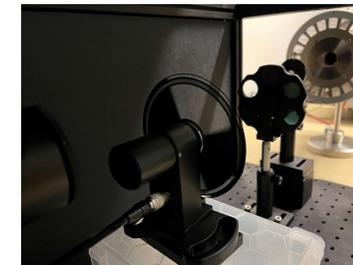
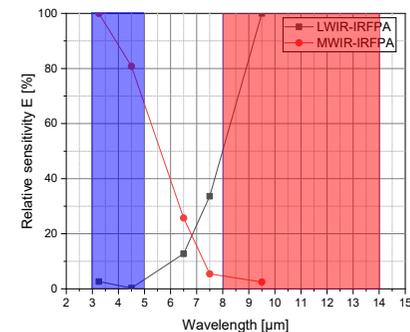
- Evaluation of spectral sensitivity by using a filter wheel and a high temperature black body source
- Additional shutter wheel for measurement of the thermal time constant

Measurements of gas leakage

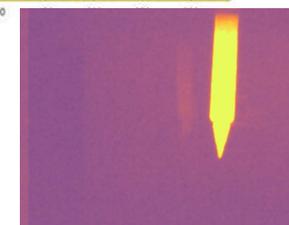
- MWIR-absorption lines for most technical gases
- Localization of gas leakages possible

Comparison MWIR- and LWIR-images

- Optimum for scenes at room temperature: LWIR-images
- Hot objects and detection of gas absorption lines: MWIR-images
- Materials with opacity in MWIR- or LWIR-range: combined MWIR- and LWIR-images



VIS image



MWIR image



LWIR image

Portfolio overview of Fraunhofer IMS

Uncooled IRFPAs as Thermal Detector

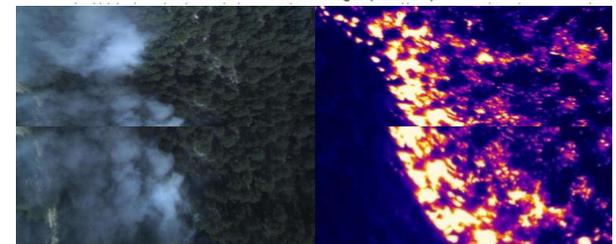
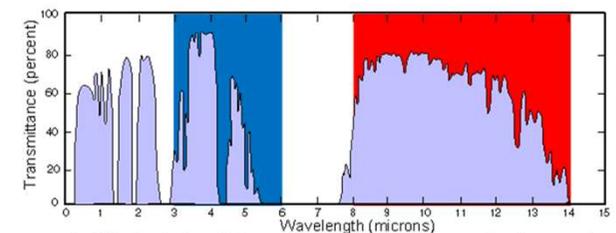
Uncooled IRFPAs with combined MWIR / LWIR sensitivity

Motivation for uncooled IRFPAs with combined MWIR / LWIR sensitivity:

- For now: uncooled thermal imaging within either LWIR or MWIR spectral regime
 - Corresponds to B/W images in VIS
- In the future: Uncooled thermal imaging uniting two absorption spectra
 - Corresponds to 2-color images in VIS
 - Allows for cost-effective detection without need of Stirling cooler

Advantages of uncooled IRFPAs with combined MWIR / LWIR sensitivity:

- Expansion of IR spectrum to MWIR allows for visualization of additional image information
- Use case scenario 1: Satellite-based early detection of wild fires
 - Wild fire detection from orbit highly depends on atmospheric transmission
 - Combining two spectral regimes allows for ground temperature reference
- Use case scenario 2: Detection of decoys
 - Decoys being mainly optimized for one spectral regime
 - More reliable detection by combining two spectral regimes



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Uncooled Thermal Imagers

Recent Projects and Future Topics

Multispectral imaging (3 – 8 μm) with uncooled microbolometers

Concept idea

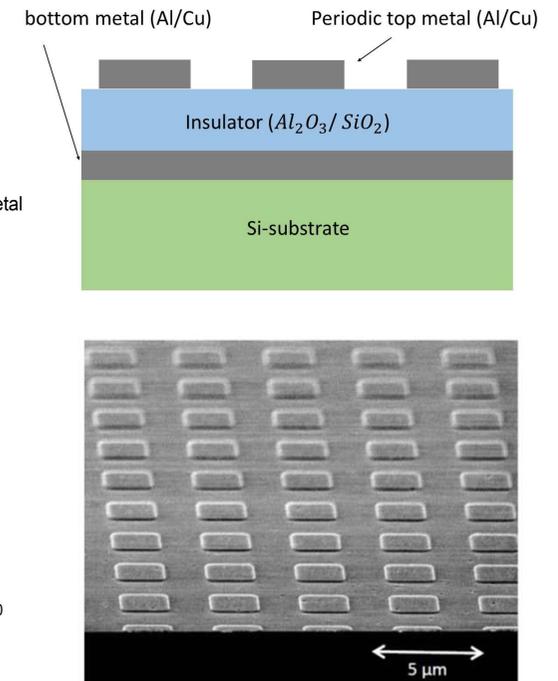
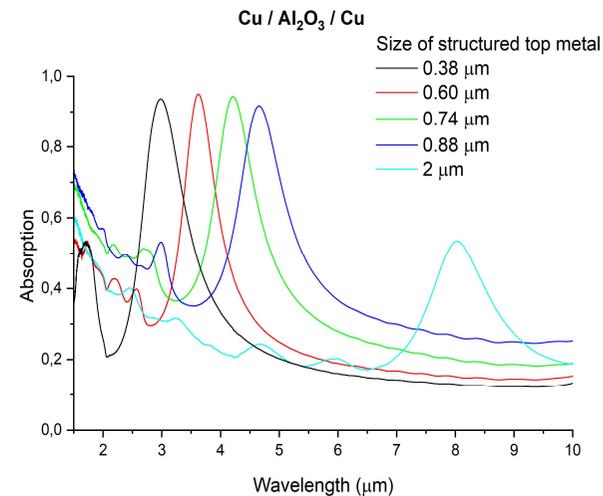
- Uncooled IR imaging based on spectral integration over complete LWIR or MWIR band (B/W images in VIS)
- Idea: Microbolometer with different spectral absorption behavior (multi-color images in VIS)

Metal-insulator-metal (MIM) absorbers

- Absorption based on resonance between the frequency of the incident photons and the collective oscillation frequency of conduction electrons in metallic structures
- Absorption wavelength can be tuned by material, shape and size of periodic top metal structures

MIM absorbers on microbolometers

- Different MIM layouts for different target wavelengths
- Periodic mosaic arrangement enables color filter array in IR analogously to Bayer pattern in VIS
- maximized fill factor of nanotube microbolometer technology highly suited for MIM integration



Uncooled Thermal Imagers

Summary

Extending uncooled thermal imaging to multispectral absorption

Key innovations of Fraunhofer IMS:

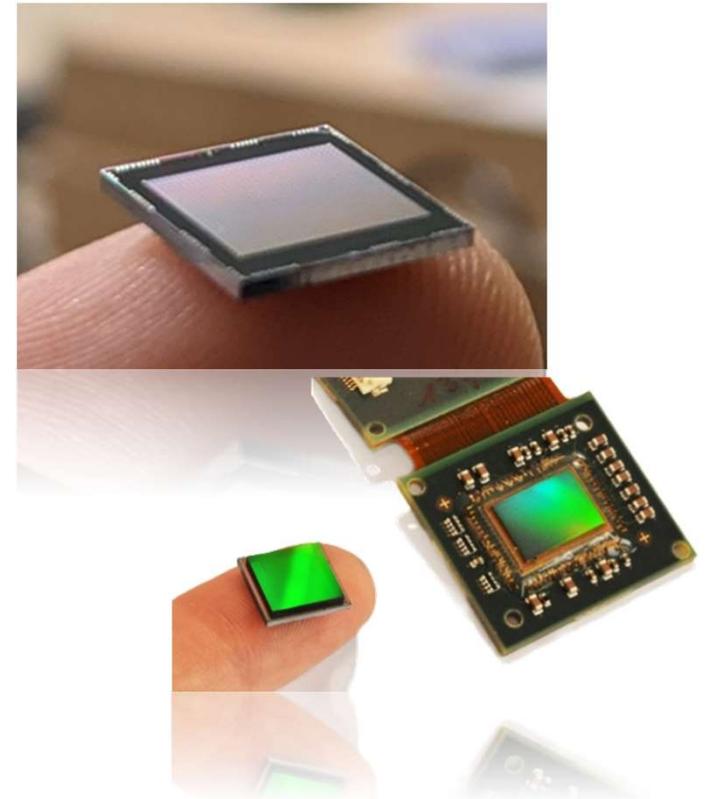
- Application-specific solutions for optical sensor systems
- Own cleanroom infrastructure for pilot fabrication and testing
 - Realization of non-standard technological processes

Technology examples of Fraunhofer IMS's IRFPAs:

- Digital IRFPAs as uncooled IR imager
- Visualization of LWIR or MWIR regime
- Approaches for combined MWIR / LWIR sensitivity
- Addition of multispectral imaging

Cooperation offer:

- Feasibility study, detector development, system integration, E/O-characterization
- Cooperation in ESA, HEU, EDF tenders



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