CMOS based VIS-IR Tunable Multiband Imaging Sensors & Systems using Quantum Dots

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(3) INAF, Osservatorio Astronomico di Brera, Merate (LC), Italy
(4) ANTARES S.c.a.r.l., Milan , Italy
(5) Compagnia Generale per lo Spazio S.p.A, Milan ,Italy
(6) Wegapixel, Barcelona, Spain

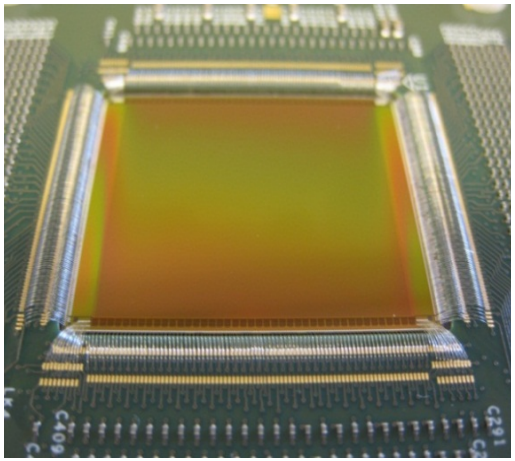
Wegapixel

wegapixel.com

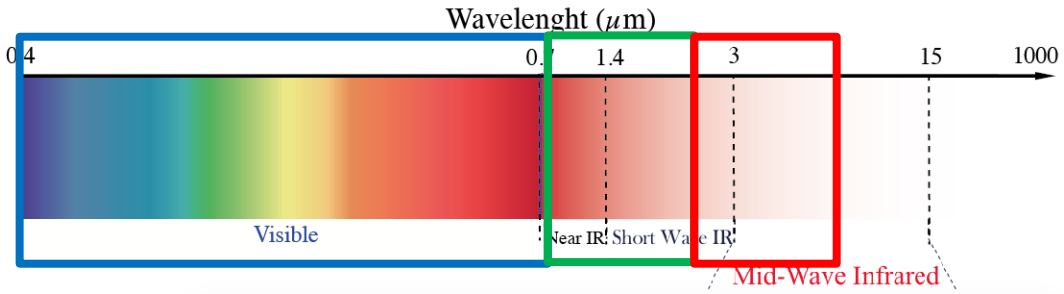
Start 2016

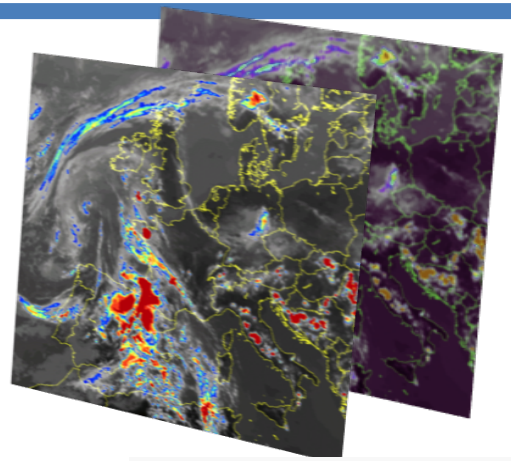
- One-stop shop for advanced custom CIS
- Solutions for and beyond visible light spectrum: IR, UV, X/γ-rays, including low energy X-rays as well as particles: $e^{\pm}$, p, α, β, n, …
- Monolithic and hybrid solutions
- Pixel size down to 1.2 µm and beyond 100 µm
- Pixel rate beyond Tpixel/sec
- Sensor size up to full 300 mm wafer

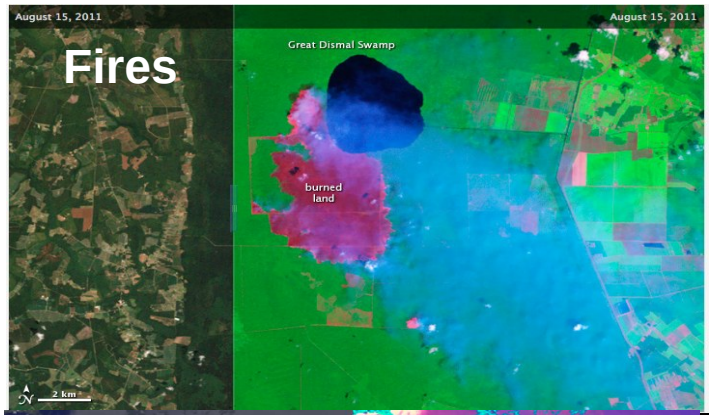
WEGA PIXEL



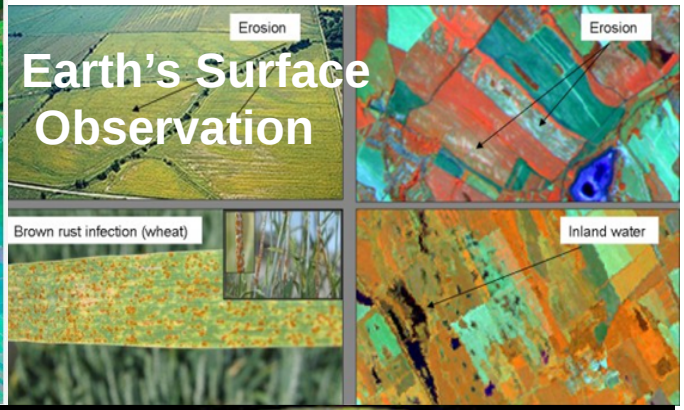
Multi-Spectral/band Imaging



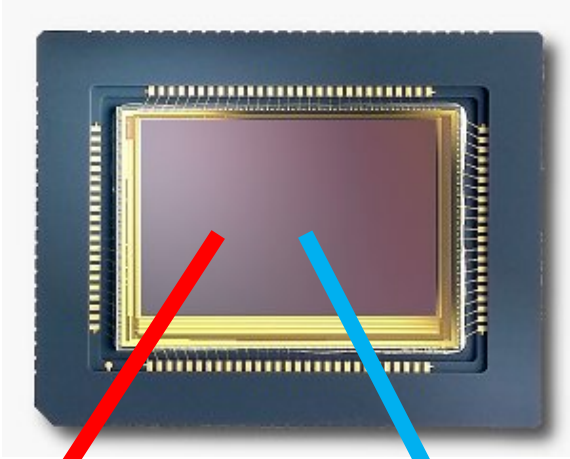


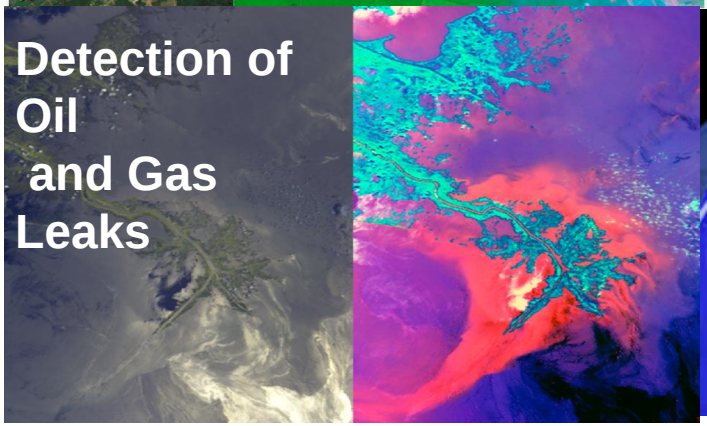


Fires

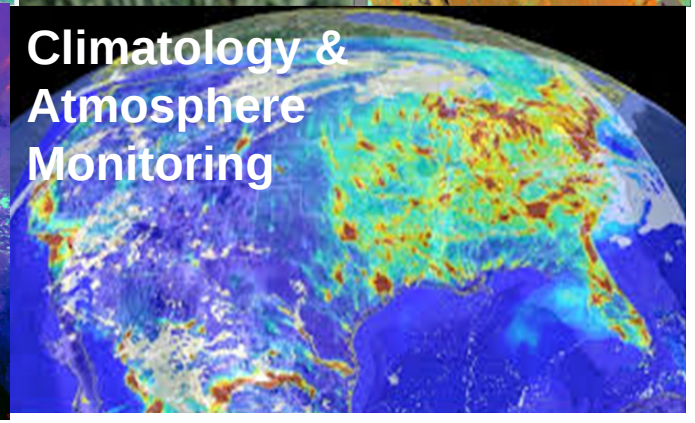


Earth's Surface Observation

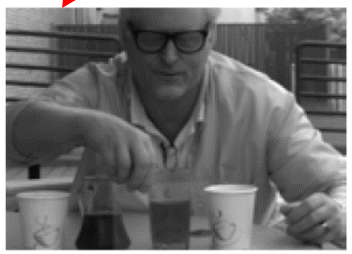




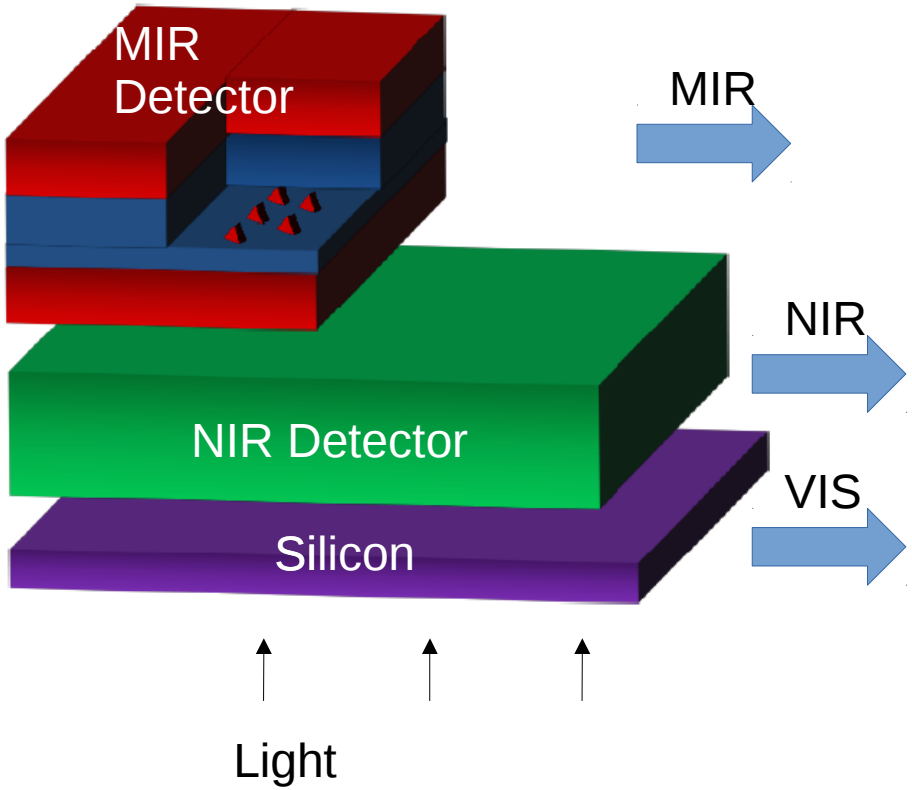
Detection of Oil and Gas Leaks



Climatology & Atmosphere Monitoring



The Multispectral Sensor Idea



Monolithic Integration on Silicon

- Reduced cost (Microelectronic Tech)
- Compatibility with CMOS IC
- Large area sensors

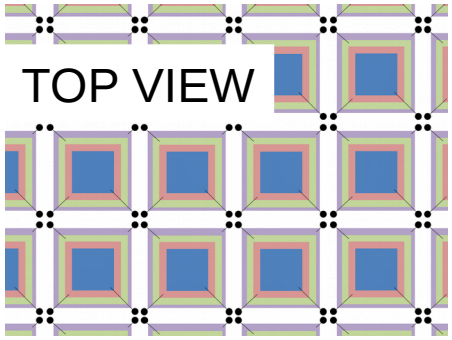
Photodetection in the 0.4-10 µm spectral window (VIS-NIR-MIR bands)

- Parallel acquisition of VIS-NIR-MIR channels
- Reduced complexity (no need for spectral filtering)
- Increased speed in image detection (1 GHz intrinsic limit)

n-i-n GaAs/AlGaAs QDIP
Spectral Window 2.5 - 10 µm

p-i-n photodiode Ge on Si
Spectral Window 1.0-1.7 µm

CMOS Si Detector
Spectral Window 0.4- 1.0 µm



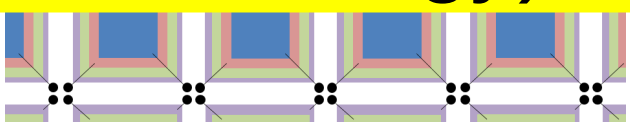
The Multispectral Sensor Idea

Monolithic Integration on Silicon

Cinzia Da Via Six Golden Rules

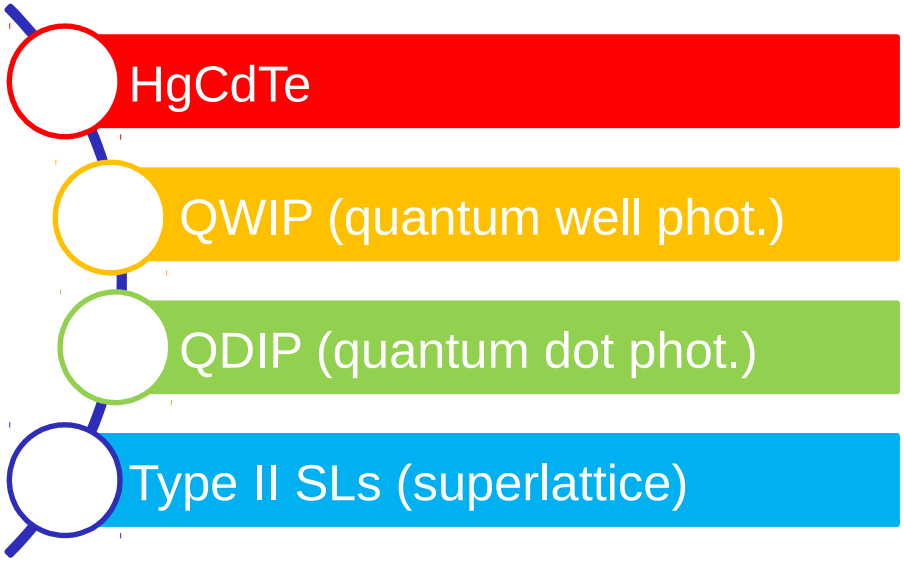
- ✔ULTRA FAST (1GHz limit)
- ✔ULTRA-PRECISE (High QE)
- ✔ULTRA-STRONG (Monolithic)
- ✔ULTRA-BIG (Full Wafer Sensor Possible)
- ✔ULTRA-CHEAP (CMOS based technology)
- ✔ULTRA-LIGHT (Thin Film Technology)

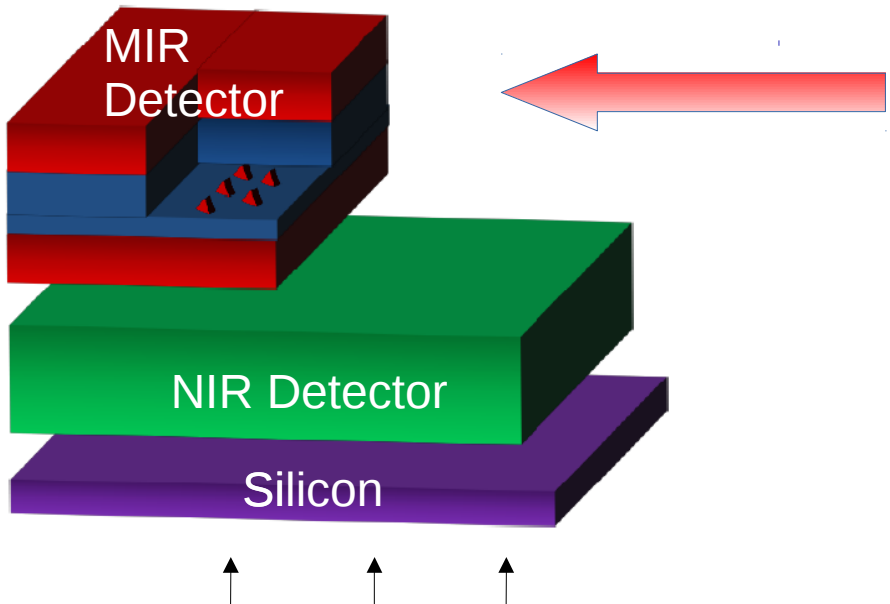
Spectral Window 0.4- 1.0 μm



The MIR photo-detectors

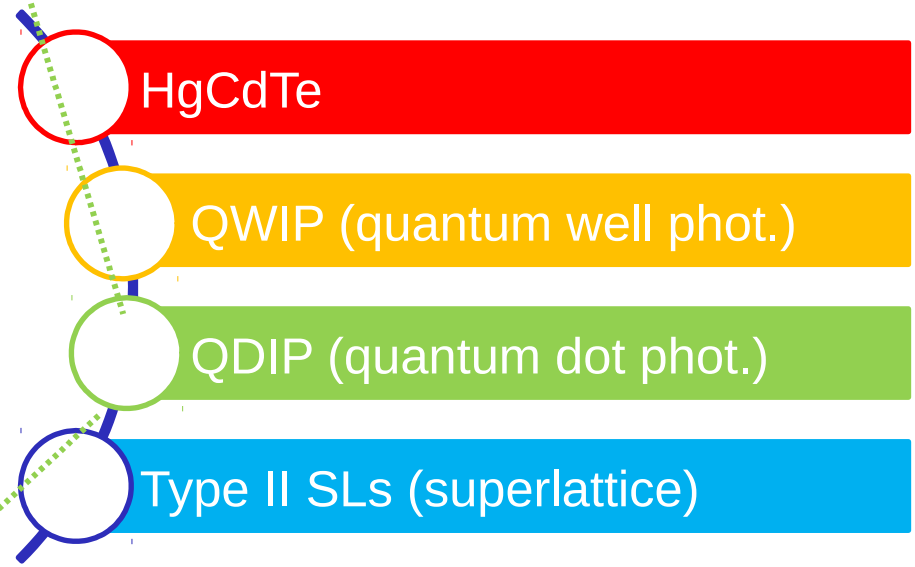
- Large area substrates
- High density of pixels
- Low production costs
- Uncooled (or Peltier) detection
- Multispectral imaging





The MIR photo-detectors: QDIP

- Low dark current due to lower thermal emission
- Possible high operating temperature (Peltier cooling -80°C)
- Multispectral
- Cheap substrates
- Silicon foundry compatible



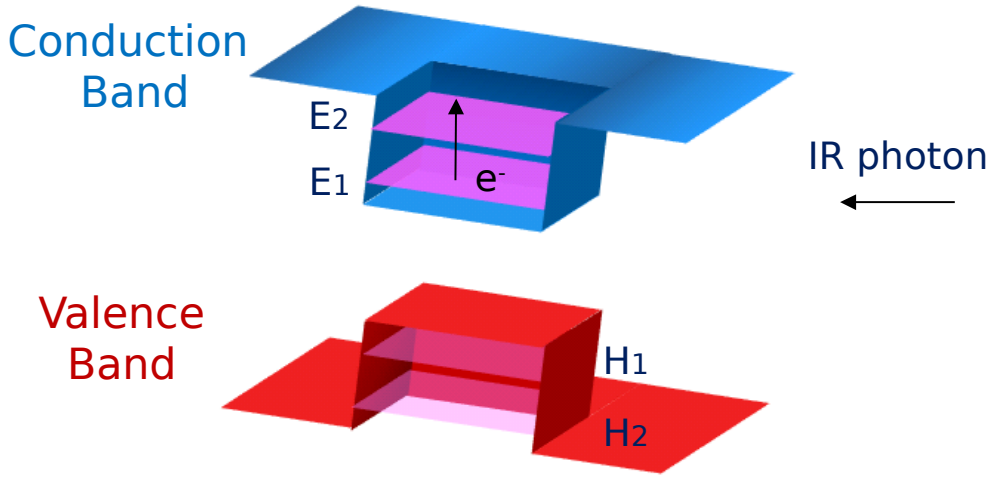
QDIP working principle

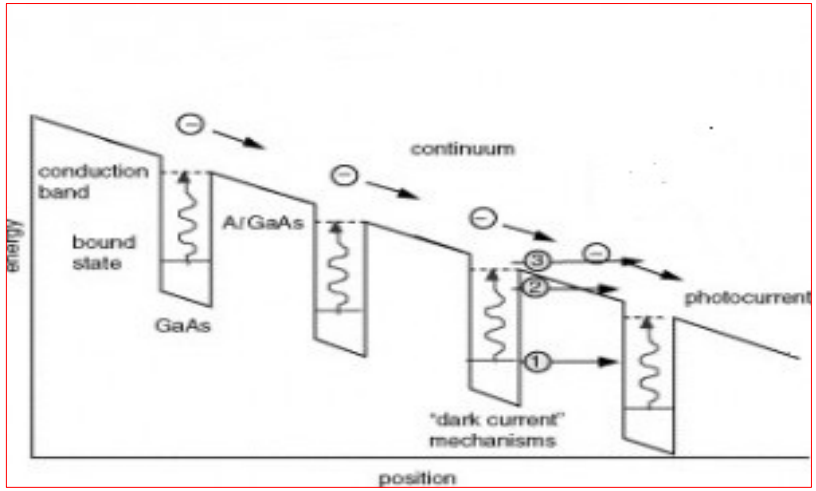
Defining energy levels
- 3D confinment locally change the energy diagram of the embedding matrix

IR absorption
- IR photons are absorbed in a doped QD (intersubband transitions)

Signal generation
- Electrons promoted by the transition are collected by a potential generating a photo-current

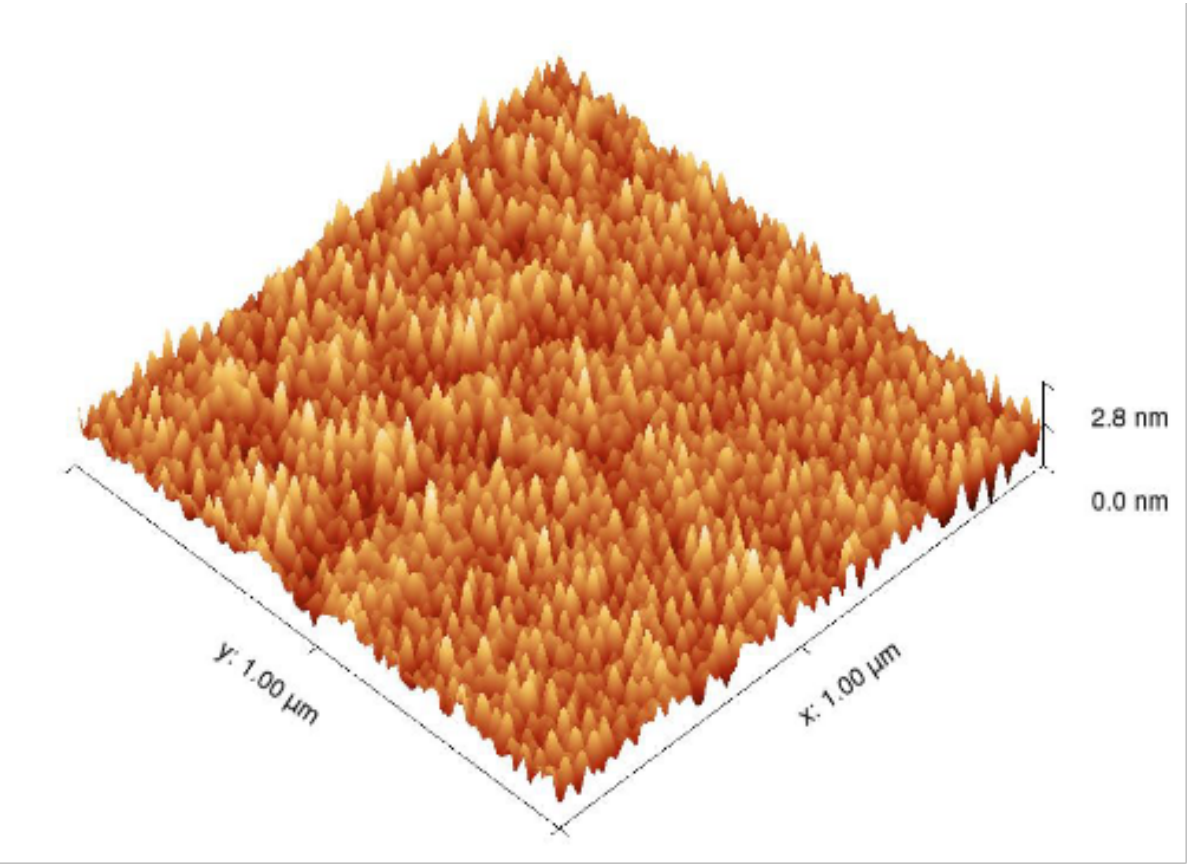
"Intersubband" absorption



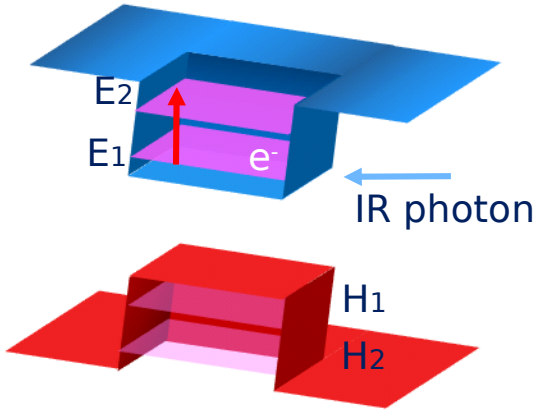


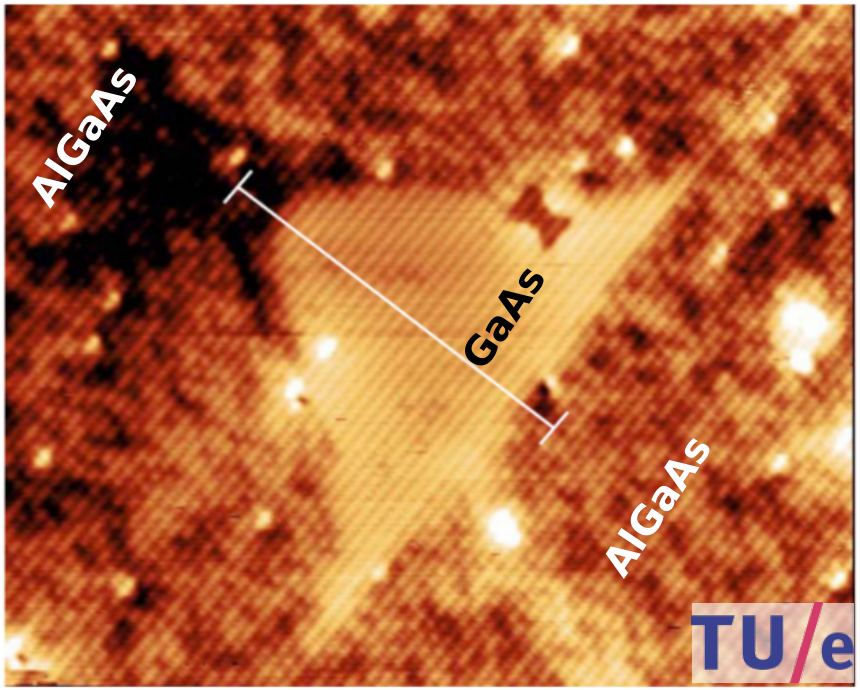
The GaAs/AlGaAs QDs

QD Density: 1000 μm^2



Interlevel absorption, 3D confinement

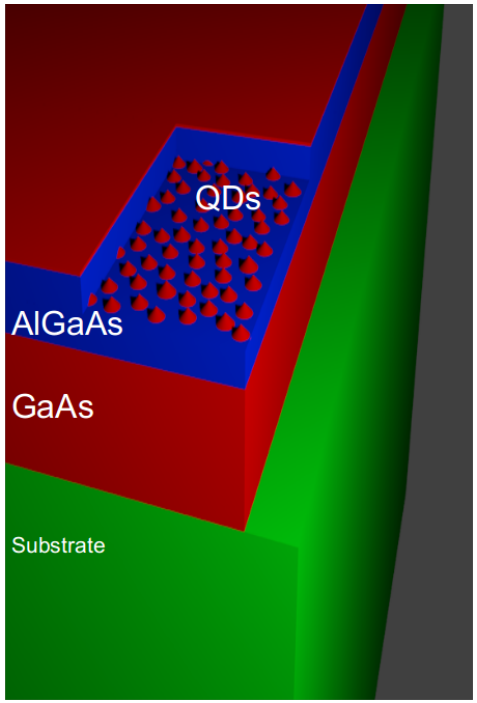


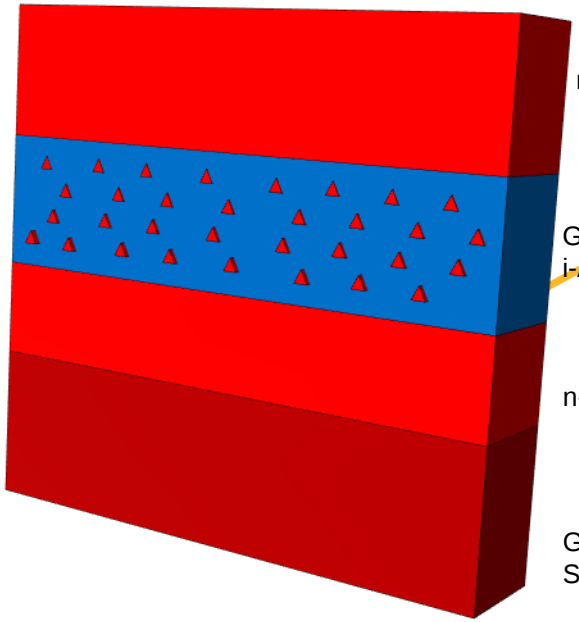


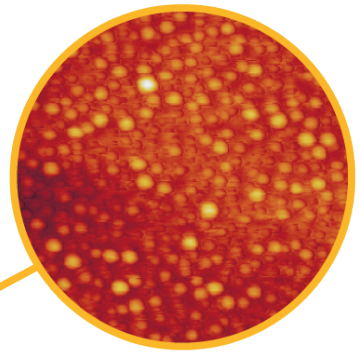
- ✓ Well developed fabrication technology
- ✓ Good uniformity over large area
- ✓ Extremely high density (1000 μm^2)

QD lateral size: 20 nm

The QDIP Device



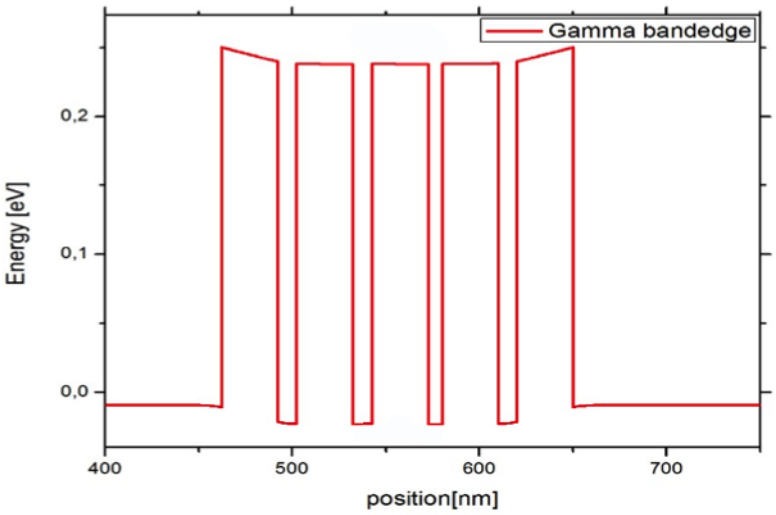


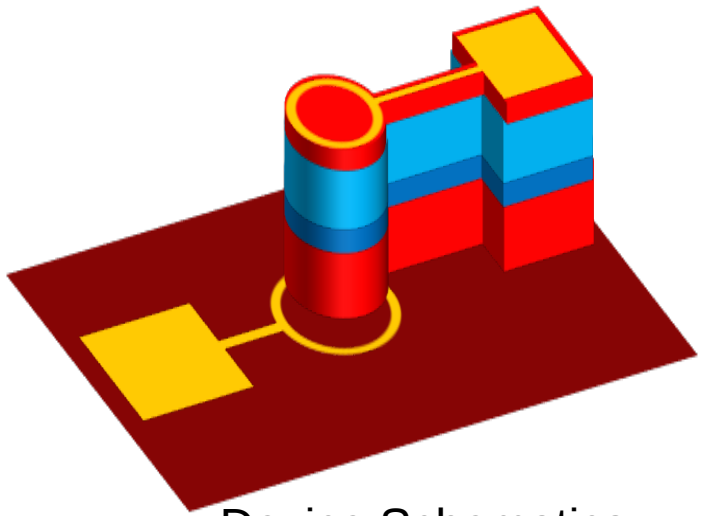


4 stacks of QD layers at 2*10^{11} cm^{-2}

AGGIUNGERE dark cur

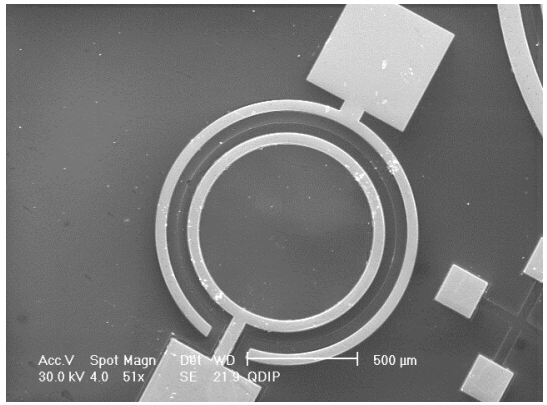
Band alignment for GaAs/AlGaAs QDIP





Device Schematics

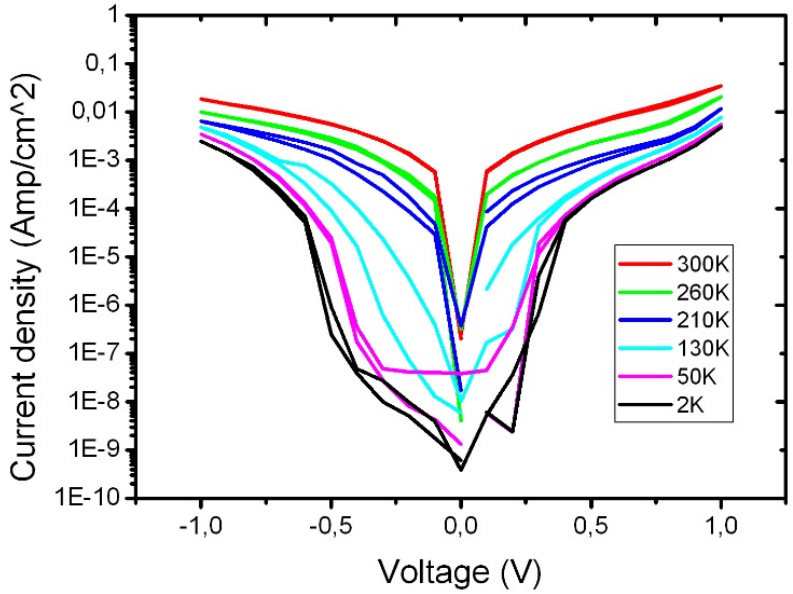
SEM top view



Infrared detection: FTIR measurement

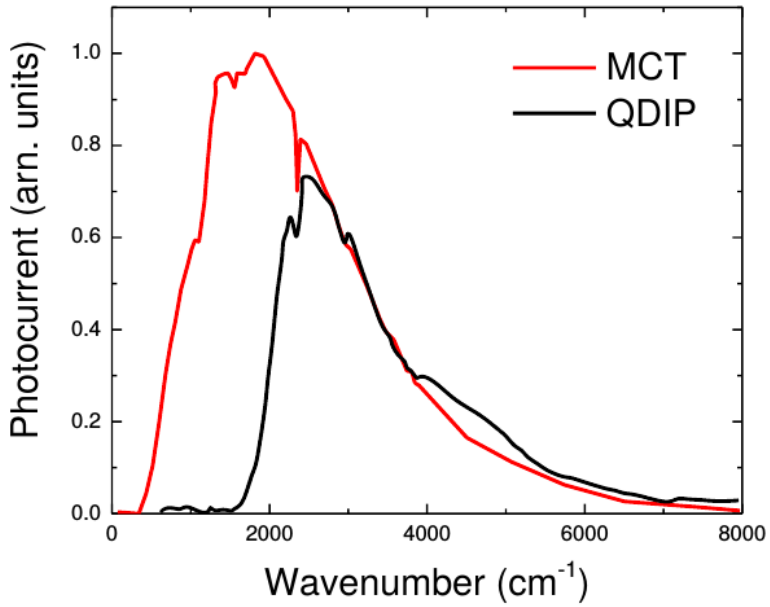
Low Dark Current

$I_{dark} \sim 10^{-9}$ A/cm^2 at low T (50K)



MIR Sensitivity

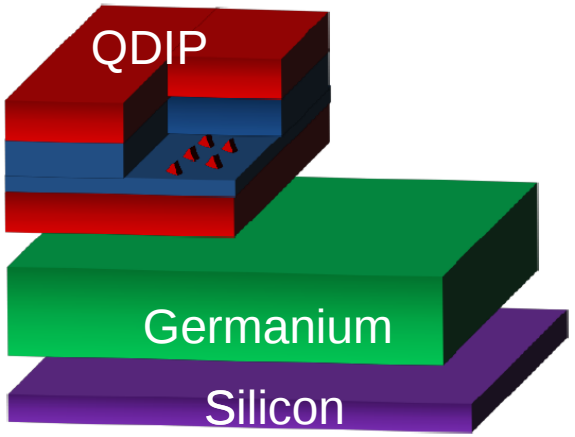
Signal to Noise ratio similar to MCT



*** In collaboration with Patrick Rauter , JKU (Linz, AU)**

Heterogeneous Monolithic Si Integration

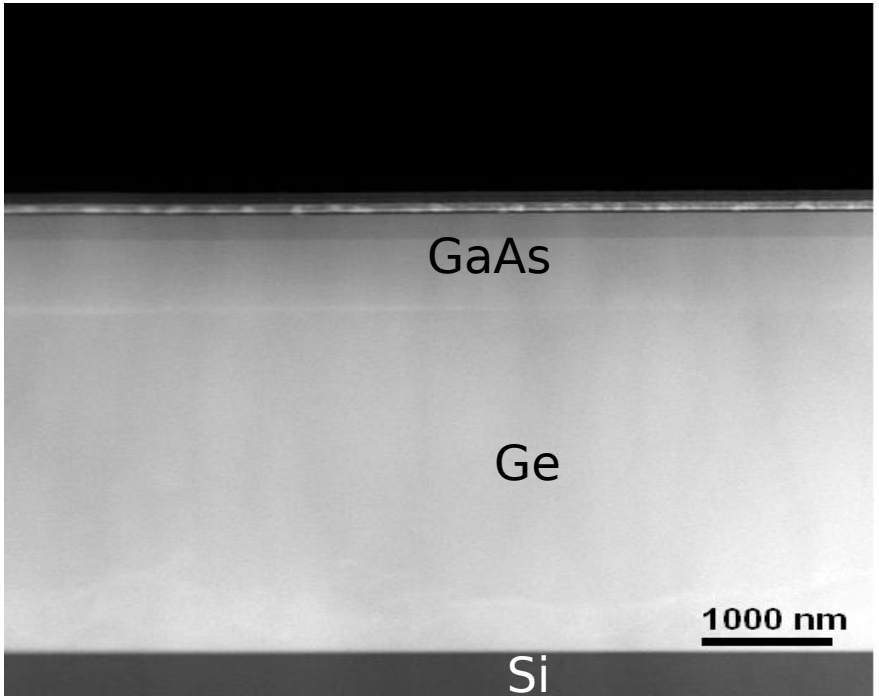
Lattice mismatch	⇒	Dislocations
Thermal expansion coefficient mismatch	⇒	Strain and thermal cracks
Growth of polar on non-polar	⇒	Anti phase domains



Growth of the Ge Virtual substrate by LEPECVD

- Thin relaxed Ge layer (< 3 μm)
- Low threading dislocations density (< 10^7 cm^{-2})
- Low surface roughness (RMS < 1nm)

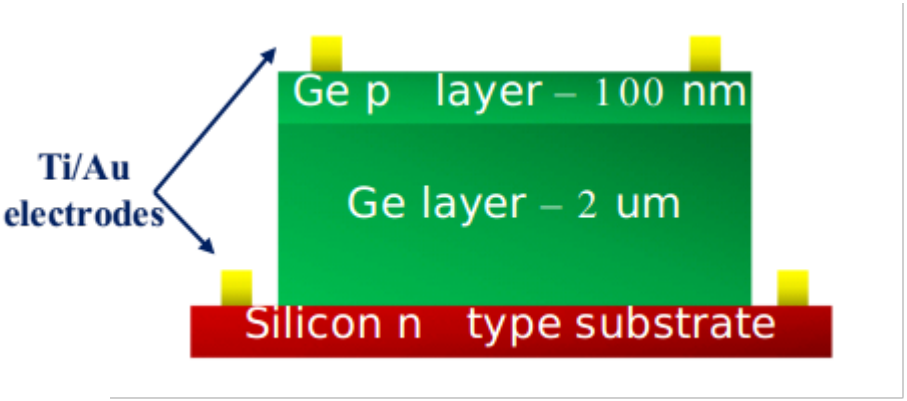
J.Osmond et al. Appl. Phys. Lett. **94** (20) 201106 (2009)

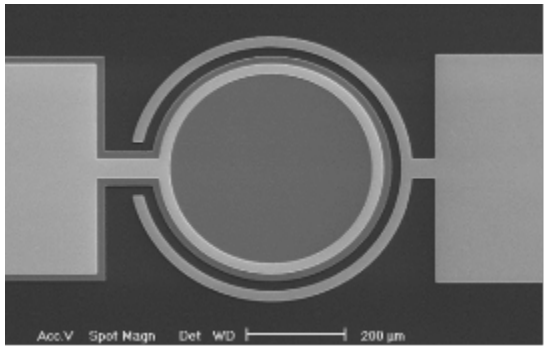


TEM image of GaAs on Ge VS – Courtesy of C. Frigeri IMEM Parma

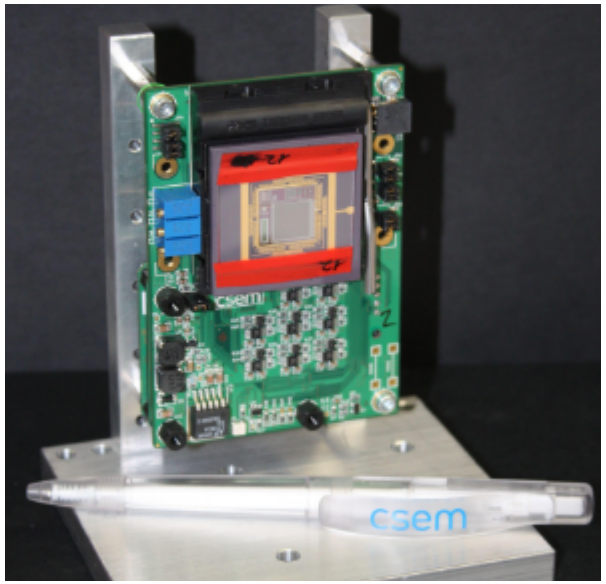
Ge/Si CMOS Compatible Detector

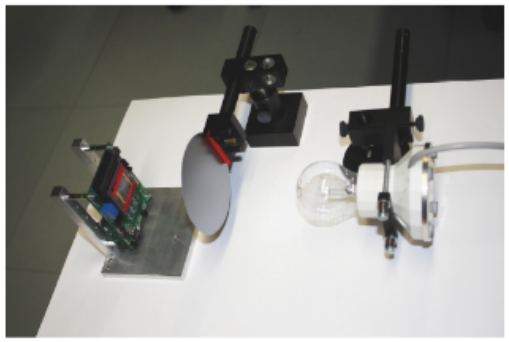
P-i-n photodiodes were fabricated by optical lithography and reactive ion etching

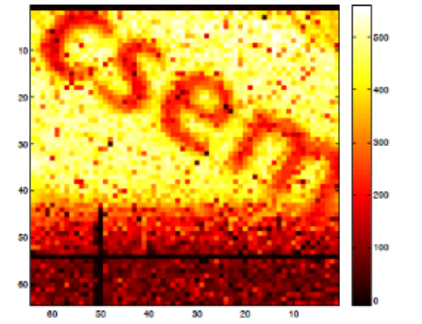




CMOS integrated Ge diode array







Good responsivity in the NIR – SWIR and low dark current density at room temperature

L-NESS / CSEM* collaboration

*CSEM SA - Centre Suisse d'Electronique et de Microtechnique

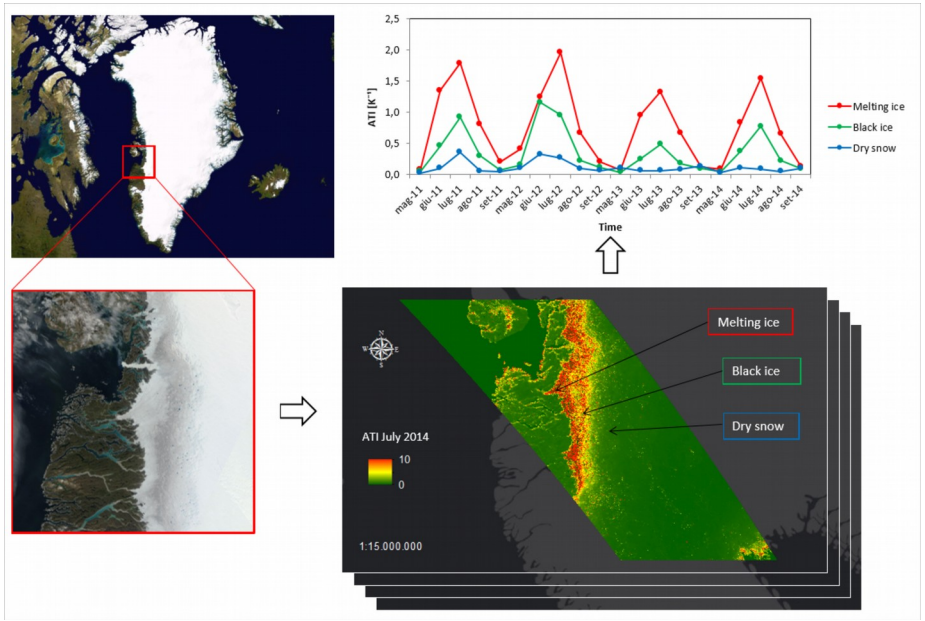
Conclusions & Perspectives

Where we are:

- Compressive Sampling in VIS - NIR ranges
- CMOS compatible Ge/Si integrated photodetector
- Low dark current – Low noise QDIP
- High quality compound semiconductors (GaAs/AlGaAs) on Ge/Si

Perspectives:

- Full Monolithic Integration of QDIP/Ge stack with Si based CMOS ROIC
- From one pixel MIS to Megapixel MIS (VIS-NIR-MIR)



Thank You for Your Attention.

We acknowledge support from: