

**EMBERION**

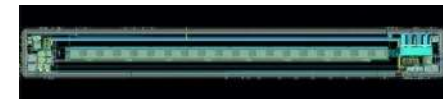
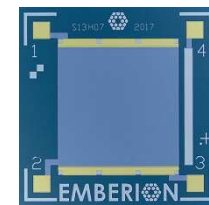
**Broaden your Vision**





# Emberion

- Develops and produces revolutionary **photo- and thermal detectors and imagers** for night vision, machine vision, spectroscopy, hyperspectral and X-ray imaging
- Spin-out from Nokia - June 2016
- A team of 22 top experts with **long experience in product development and applied research**
- Operating in **Cambridge UK**, and **Espoo Finland**
- Unique differentiation based on **graphene and nanomaterials & leading-edge integrated circuit design**



# Emberion Team

A team of 22 top experts representing a unique combination of skills and experience:

- Novel nanomaterials and CMOS integration
- Product creation and applied research
- Backgrounds in both SME and corporate environments

Working in two R&D hotspots:

- Nanomaterials and sensor development in Cambridge, UK
- Electronics and system development in Espoo, Finland

Efficiently networked to both research and production partners

- An active member of European Graphene Flagship program and a member with access to the Cambridge University Graphene Centre
- Established business relationship with selected CMOS foundries and key graphene suppliers

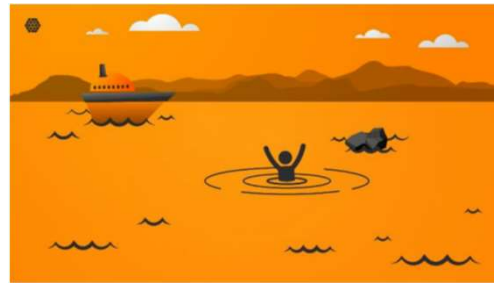


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# Applications and Customer Value



Portable spectrometers – possibility to identify or assess the chemical composition of a sample on site



Less expensive, portable surveillance cameras for challenging conditions – enhanced night vision



Complementing LIDAR detection of objects – machine vision to understand the context and road conditions



Accurate automated inspection and analysis of material and structural properties of products and materials



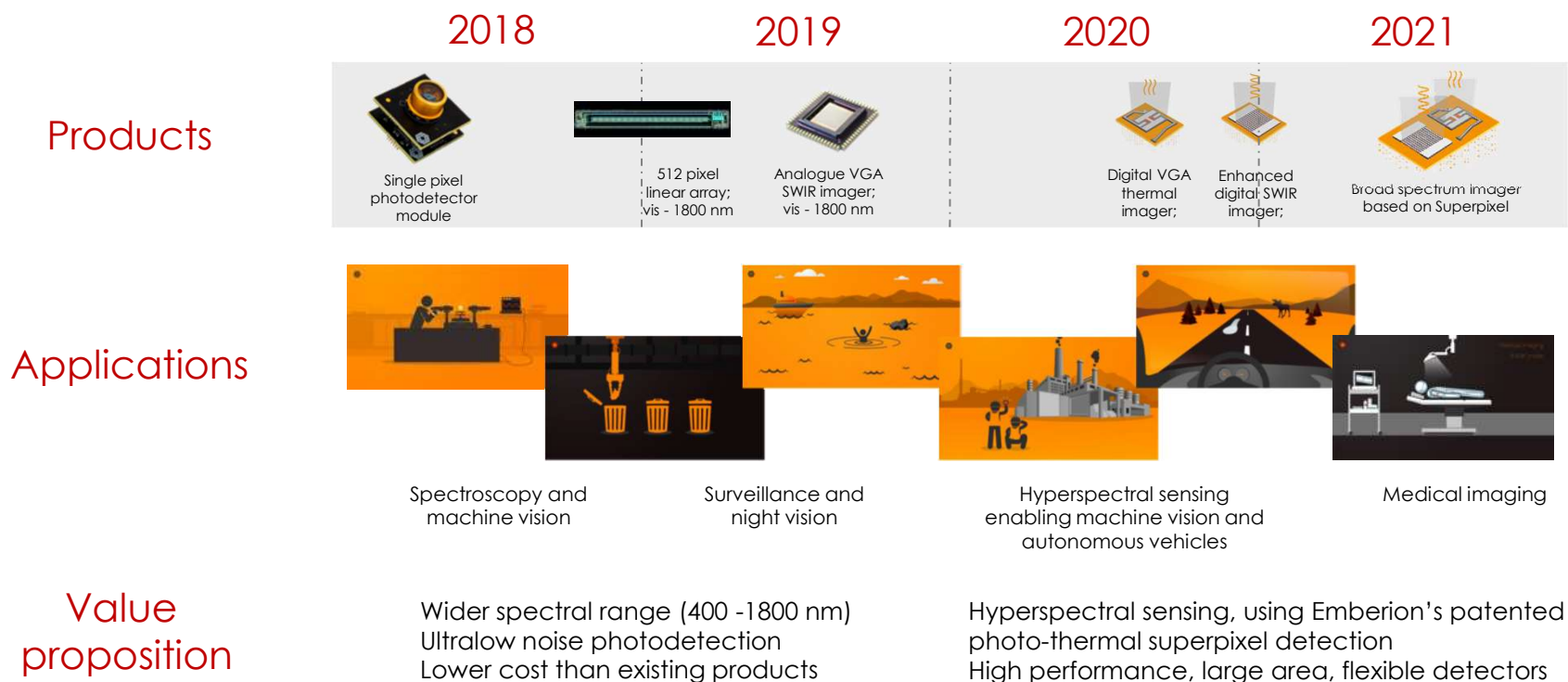
Cost efficient, high-quality hyperspectral imaging for environmentally sustainable production and supply chains



Flexible detectors for medical imaging – large-area, affordable X-ray detectors and wearable vis-IR sensors



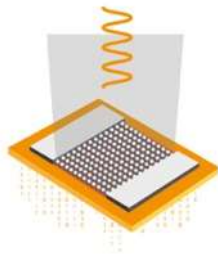
# Emberion Roadmap





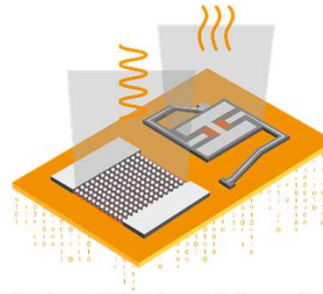
# Emberion's Technology

## VIS-SWIR photodetectors



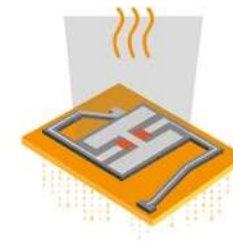
- Novel image sensors based on graphene and nanocrystalline photonic absorber
- Excellent noise performance (low NEP)
- Very wide spectral range (400 – 1800 nm)
- Large dynamic range
- Cost-efficient, semi-fabless manufacturing

## Superpixel detectors



- Superpixel architecture: integrated photo and thermal detector array
- Visible, NIR, SWIR, MWIR and LWIR imaging – using only one device
- Creates opportunities for hyperspectral machine vision applications

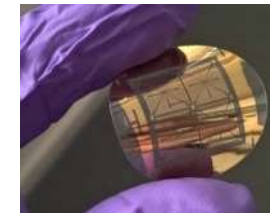
## Thermal detectors



- Low noise thermal imagers based on graphene and pyroelectric absorber
- Ultrasensitive measurement principle
- Uncooled operation
- Broad and tunable MWIR & LWIR spectral sensitivity (3 - 5  $\mu\text{m}$  & 7 - 14  $\mu\text{m}$ )

## Scalable platform for detector integration

- Low power, intelligent, digital output readout ICs
- Versatile platform to build various different sensors, using the same measurement principle
- Low cost integration on leading-edge CMOS foundry processes
- Possibility to integrate the same graphene technology also on flexible and/or large-area substrates



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# Lean, Semi-Fabless Manufacturing

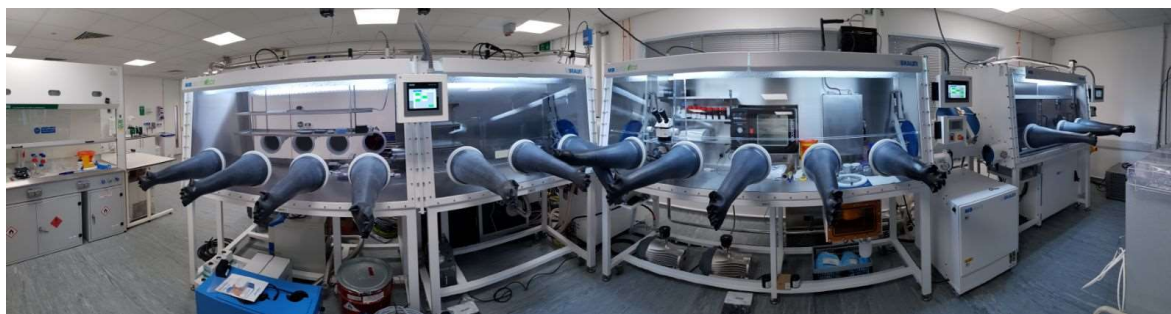


Emberion manages the whole manufacturing process through its captive know-how and concentrates own resources on the new value adding processes.

Overall system design by Emberion.

# Cambridge Pilot Manufacturing Line for Absorber Integration

- Class 100 cleanroom environment for lithography and graphene transfer
- Inert atmosphere fabrication facility for nanocrystalline material deposition and optical characterisation
- Inert atmosphere metallization via sputtering and evaporation
- Thin film encapsulation via attached ALD with load lock
  
- Capability of 500 imagers per month by 2019
- Functionalization of 5-10 CMOS wafers per week in 2020
- Scalable to volume of 200 imager module per day by 2022



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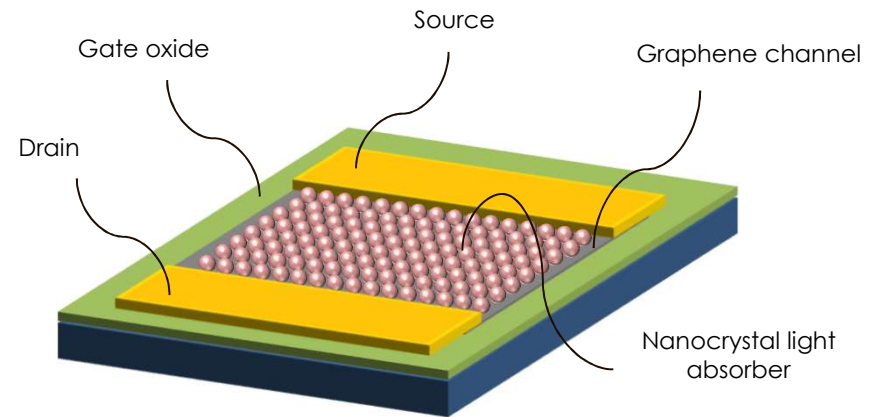
# VIS-SWIR photodetectors – technology and products



# VIS-SWIR detector

## Technology in brief

- Ultra-sensitive photo-detectors combining a GFET charge transducer with an efficient light absorbing layer of nanocrystals
- Visible light and NIR/SWIR-infrared (400-1800 nm) photodetectors: single pixel, linear and 2D array detectors
- Monolithically integrable on CMOS readout ICs

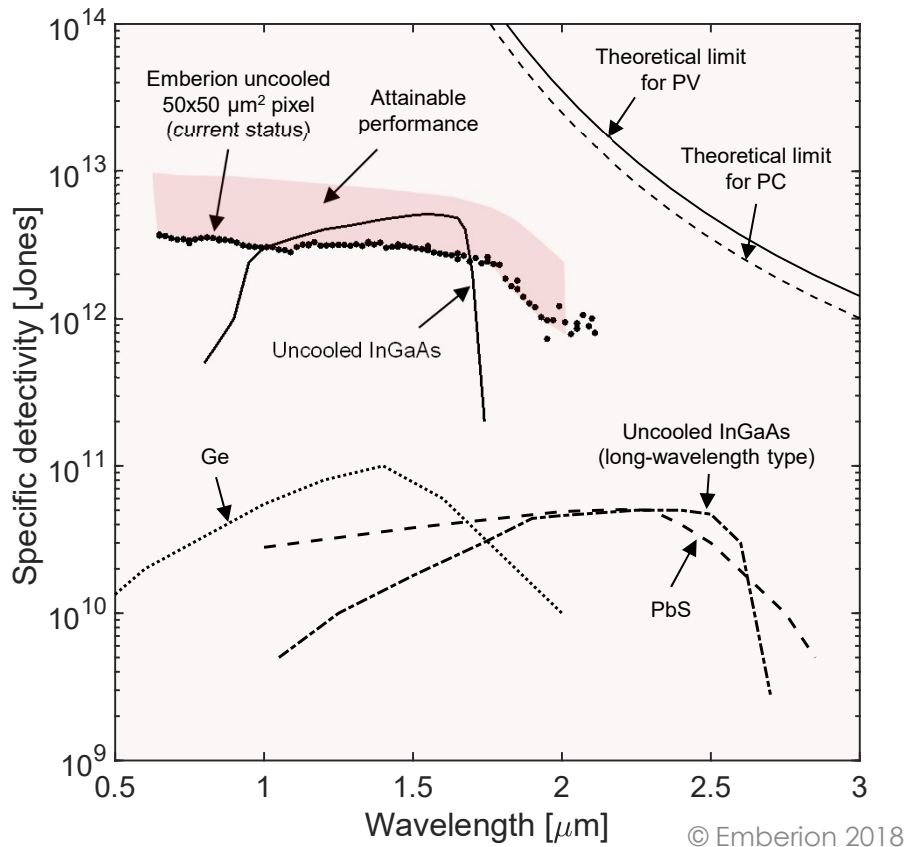


## Unique benefits

- Un-cooled
- Low noise (NEP, NEI)
- Large dynamic range
- Broad spectral range
- Scalable pixel size
- Cost efficient manufacturing



# Detectivity at 1/100 s Exposure



Our VIS-SWIR detectors are on par with uncooled InGaAs detectors in SWIR region and outperforming in VIS-NIR region

Dots present measured Specific detectivity ( $D^*$ ) performance

Red shading illustrates an attainable performance level which is a realistic near term R&D target for VGA image sensors of  $20 \times 20 \mu\text{m}^2$  pixel size

# Emberion Products



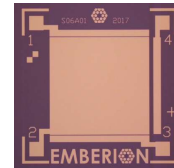
## Single pixel photodetector

- For gas and laser detection, optical power measurements, and for FPI, TLDS & FTIR spectrometry
- Digital module with signal processing available
- Available: summer 2018



## Linear array of 512 pixels

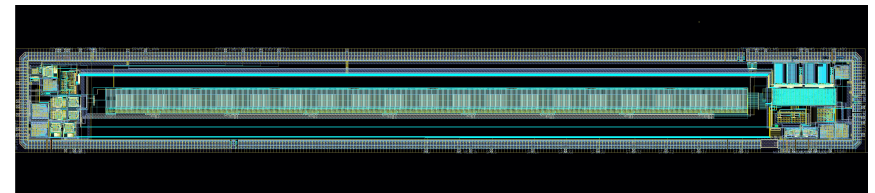
- For diffraction spectrometry, gas detection, line scan camera applications, medical diagnostics
- Single-chip digital photodetector array for vis-SWIR
- Available: early 2019



Emberion's single pixel photodetector, digital output module and the evaluation kit (i.e., a reference implementation).

## VGA sensor of 640 x 512 pixel

- For night and machine vision applications, hyperspectral imaging, and for medical imaging
- Single-chip analog imaging sensor for vis-SWIR
- Camera core reference implementation available
- Available: fall 2019



Final layout of Emberion's 512-pixel SWIR photodetector array product with high-speed digital output.



# VIS-SWIR single pixel detector

## Single pixel photodetector

- Analog output component, with a digital output module option
- Component in a TO-5 package, TO-8 with a built-in TEC available for evaluation purposes
- Pixel size tailorable to customer and application specific requirement
- Potential applications: gas and laser detection, optical power measurements and FT & FPI spectrometry
- Available: Summer 2018

### Technical Data

Spectral range:	0.4 - 1.8 $\mu\text{m}$
Active area:	$0.5 \times 0.5 \text{ mm}^2$
Package:	TO-5
Dynamic range:	120 dB
$\text{NEI}_{\text{RMS}} @\text{RT}$ :	$< 10^{-4} \text{ W/m}^2$
$D^* @\text{RT}$ :	$> 10^{10} \text{ Jones}$
Sampling rate:	max 100 Hz
Digital module I/O:	SPI with 1.8V



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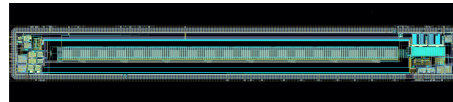




# VIS-SWIR linear array detector

## Linear array of $512 \times 1$ pixels

- **Digital output component**, detector array integrated monolithically on a tailor-made CMOS readout integrated circuit (ROIC)
- ROIC contains analog front-end, performs analog-to-digital conversion and provides digital data output
- A tailored package with an optional built-in thermo-electric cooling element for room temperature operation stabilization
- Also **available as a sensor module** with HW&SW implementation for pre-processing, thermal control, power management and a digital I/O
- Potential application: diffraction **spectrometry**, line scan imaging and machine vision
- Pixel size tailorable to customer and application specific requirement, primary option optimized for spectrometry applications
- Available: Early 2019



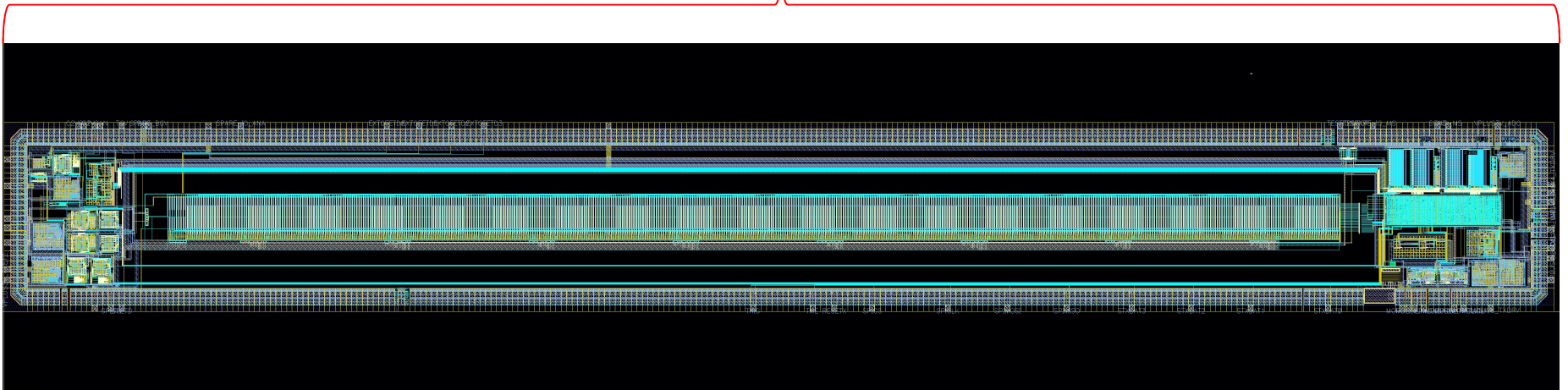
## Technical Data

Spectral range:	0.4 - 1.8 $\mu\text{m}$
Array size:	$512 \times 1$
Active area:	$25 \times 500 \mu\text{m}^2$
Package:	customized, metal or ceramic, 54 I/O pins
Dynamic range:	80 dB
NEI (30/100 fps @RT):	$2 \cdot 10^{-5} / 6 \cdot 10^{-5} \text{ W/m}^2$
$D^*$ (30/100 fps @RT):	$1 \cdot 10^{12} / 5 \cdot 10^{11}$ Jones
Frame rate:	max 100 fps
ADC resolution:	max 16 bits
Control interface:	SPI
Digital I/O:	LVDS or SLVS, with proprietary protocol

# Linear array ROIC layout



17.2 mm



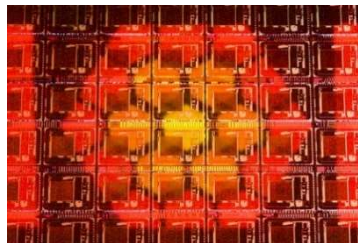
# VIS-SWIR VGA sensor



Preliminary specs

VGA sensor of  $640 \times 512$  pixel

- Analog output image sensor component, digital imaging module and camera core options
- Detector array integrated monolithically on a tailor-made CMOS readout integrated circuit (ROIC) which contains analog front-end and provides analog data output
- Imaging modules contains HW&SW implementation for analog-to-digital conversion, image pre-processing, thermal control, power management and a digital camera interface.
- Pixel design tailorable, primary option  $20 \times 20 \mu\text{m}^2$
- Potential applications: **hyperspectral imaging, night vision and machine vision**
- Available: Fall 2019



## Technical Data

Spectral range:	0.4 - 1.8 $\mu\text{m}$
Array size:	$640 \times 512$
Active area:	$20 \times 20 \mu\text{m}^2$
Array area:	$12.8 \times 10.24 \text{ cm}^2$
Package:	BGA or similar
Dynamic range:	80 dB
NEI (30/100 fps @RT):	$2 \cdot 10^{-4} / 5 \cdot 10^{-4} \text{ W/m}^2$
$D^*$ (30/100 fps @RT):	$2 \cdot 10^{12} / 7 \cdot 10^{11} \text{ Jones}$
Frame rate:	max 100 fps
Control interface:	SPI
Image sensor data I/O:	Muxed analog
Imaging module I/O:	CameraLink, GigE Vision, USB
Shutter mode:	Global electronic





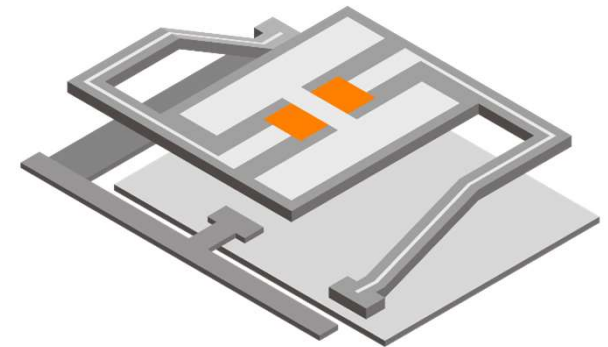
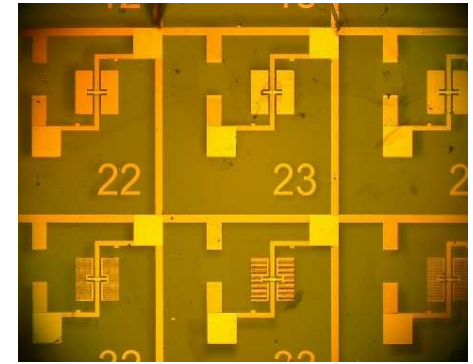
# Thermal detectors – technology and products



# Graphene-based thermal photodetector

## Pyroelectric bolometer with an ultrahigh TCR:

- Two-terminal device whose resistance changes proportionally to temperature (**bolometer**)
- Floating metallic structure concentrates charge generated by pyroelectric substrate over an integrated GFET
- Operates at **room temperature** in **direct current mode**
- **No chopping, nor load resistor required** due to the floating structure
- MIR-LWIR spectral range, with **tunable spectral selectivity**





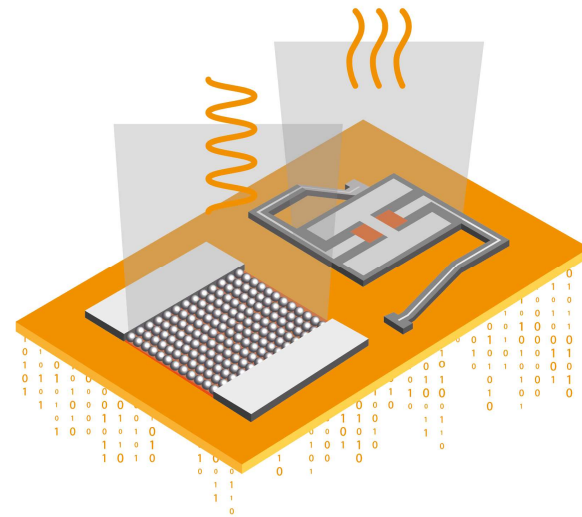
# Broadband Imager

- Broadband Imager (400nm – 14000nm)
- VIS/SWIR/LWIR detector using a single pixel
- Performance of VIS/SWIR array with NEI  $10^{-6}$  W/m<sup>2</sup>
- NETD < 20mK uncooled (target)
- Unique Lens capability

## **Unique Benefits:**

Ultrasensitive superpixel covering VIS/SWIR/LWIR bands  
Graphene FET Integrated charge transducer  
Custom ROIC solution  
Low Noise

VGA Array of broadband imager will be available in 2021

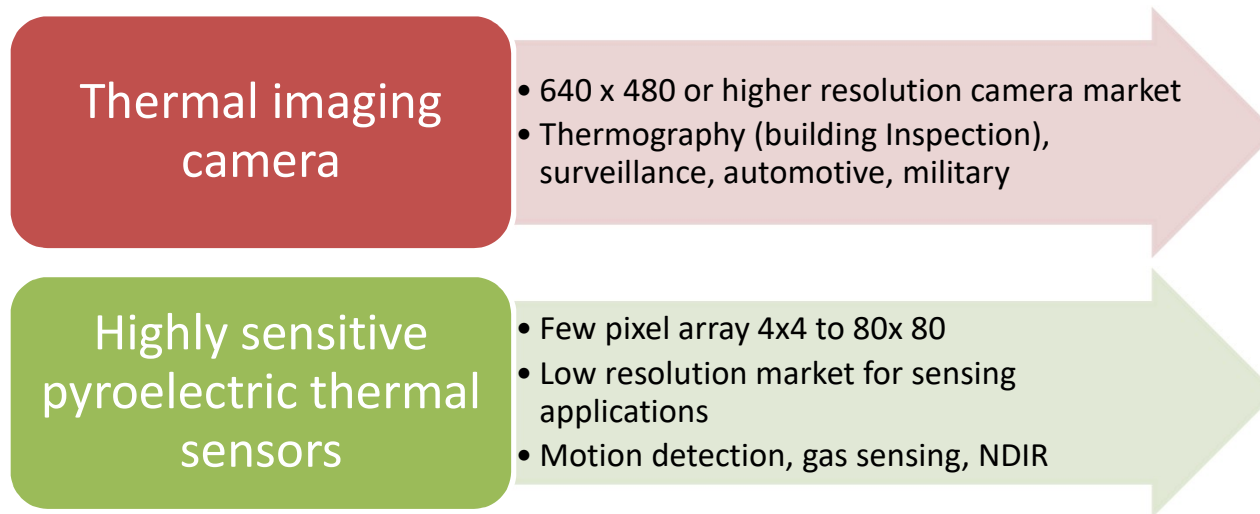


Schematic of a Broadband super pixel



## Roadmap towards productization

- Our roadmap in thermal imaging market is to provide cooled detector performance at room temperature levels, i.e. NETD between 15 mK and <30 mK
- Main target is to create highly sensitive camera arrays for high end markets in which the use cooling mechanism is cost-prohibitive. Emberion's detector price will be competitive for adaptation from low to high resolution applications





# Addressable market

## Thermal imaging market by application

1. Military & Defense (Night Vision)
  2. Commercial (High End Surveillance)
  3. Residential (Building Survey)
  4. Industrial (Predictive Maintenance)
- The four key areas have different segments based on various resolution of the cameras (**low, mid & high resolution**)
  - Our focus area would be in the high end & mid level cameras.

Resolution in thermal cameras is defined by the number of pixels with a key figure of merit being Noise Equivalent Temperature Difference (NETD)



Military & Defense



Commercial



Residential



Industrial



# Emberion Product Datasheets

## VIS-SWIR DETECTOR MODULE



### Overview

Emberion's graphene photodetectors convert light to an electronic signal using graphene charge transducers combined with nanocrystal light absorber. They provide superior responsivity with very low noise over a broad spectral range from visible to near infrared/short-wave infrared (NIR/SWIR) wavelengths without cooling below room temperature. The dynamic range of the detectors is very large, owing to low noise and a response that does not saturate. The size of rectangular photosensitive active area is tailorable.

The photodetectors are packaged into standard TO-5 cans. For evaluation purposes, we also offer detectors in TO-8 cans with a built-in thermo-electric cooling (TEC) element for thermal stabilization. In addition to discrete analog components in a TO-5/8 can, our photodetectors are available as digital modules, i.e. circuit boards comprising HW&SW implementation for calibration, signal pre-processing, analog-to-digital conversion and digital I/O. Potential applications include spectrometry, optical gas detection and optical power measurements.

### Technology in Brief

- Ultra-sensitive photodetector combining a graphene field-effect transistor charge transducer with an efficient light absorbing layer
- Wide spectral range from visible light to short-wave infrared covered with a single photodetector
- Excellent detector performance achieved at room temperature



Customer sample and evaluation kit for performance measurements



Analog component package for detector chip and TEC element

### Unique Benefits

- Low noise-equivalent irradiance (NEI)
- Non-saturating detectors, large dynamic range
- Broad range of wavelengths
- Scalable pixel size

### Technical Data

Spectral range	400 - 1800 nm
Photosensitive area (rect)	0.5 × 0.5 mm <sup>2</sup>
Specific detectivity*	> 10 <sup>14</sup> Jones
Noise-equivalent irradiance*	< 10 <sup>-4</sup> W/m <sup>2</sup>
Sampling rate	max 100 Hz
Full dynamic range	120 dB
Stability	< 5 % per year
Hysteresis	< 1 %
Full scale non-linearity**	< 3 %
Analog detector package***	TO-5
Analog detector I/O	5 pins
Supply voltage to analog detector	0.5 V
Supply voltage to digital module	5.5 V
Digital module board size	3 × 3 cm <sup>2</sup>
Digital module I/O	SPI with 1.8 V

\* at λ = 1600 nm, sampling rate 100 Hz  
 \*\* after correction  
 \*\*\* TO-8 with 12 pins available for evaluation purposes

## VIS-SWIR LINEAR SENSOR



### Overview

Emberion's graphene photodetectors convert light to an electronic signal using graphene charge transducers combined with a nanocrystal light absorber. They provide superior responsivity with very low noise over a broad spectral range from visible to near infrared/short-wave infrared (NIR/SWIR) wavelengths in room temperature operation. The dynamic range of the detectors is very large, owing to the low noise and a response that does not saturate.

The pixel geometry and linear array design follow the conventions of spectrometry applications. Other potential applications lie in line scan imaging and machine-vision areas.

Emberion's VIS-SWIR LINEAR sensor comprises a detector array monolithically built on a tailor-made CMOS readout integrated circuit (ROIC). The ROIC contains analog front-end, performs analog-to-digital conversion and provides digital data output. Sensors are available in a tailored package with an optional built-in thermo-electric cooling element for operation temperature stabilization. In addition to sensor component, Emberion offers modules with HW&SW implementation for pre-processing, thermal control, power management and a digital I/O.

### Technology in Brief

- Ultra-sensitive photodetector combining a graphene field-effect transistor charge transducer with an efficient light absorbing layer
- Wide spectral range from visible (VIS) light to short-wave infrared (SWIR) covered with a single photodetector
- Excellent detector performance achieved at room temperature
- Monolithically integrated detector array and ROIC with digital output



ASiC layout illustration for linear detector array ROIC

Performance evaluated at λ = 1600 nm, 100 fps, T = 20 °C unless otherwise noted

### Unique Benefits

- Very sensitive due to low noise-equivalent irradiance (NEI)
- Non-saturating detectors, large dynamic range
- Very wide spectral range
- Cost-efficient manufacturing

### Technical Data (preliminary)

Spectral range	400 - 1800 nm
Pixel size	25 × 500 μm <sup>2</sup>
Array size	512 × 1
Photosensitive area	12.8 × 0.5 mm <sup>2</sup>
Pixel pitch	25 μm
Exposure time	1 - 1000 ms
Frame rate (max)	100 fps
D* (30 / 100 fps)	1×10 <sup>14</sup> / 5×10 <sup>14</sup> Jones
NEI (30 / 100 fps)	2×10 <sup>-4</sup> / 6×10 <sup>-4</sup> W/m <sup>2</sup>
Full dynamic range	80 dB
Full scale non-linearity	< 3 %
Stability	< 5 % per year
Inoperable pixels	0 %
Shutter mode	Global electronic
Timing	Internal / external trigger
Trigger delay	< 1 μs
ADC resolution	max 16 bits
Control interface	SPI
Digital I/O	LVDS or SLVS, with proprietary protocol
Package	customized, metal or ceramic, 54 I/O pins
Optical interface	AR coated VIS-SWIR transparent window
Operation temperature	-40 - +70°C
Performance and reliability standard (as applicable)	MIL-PRF-38535, JEDEC JSD47H
Power consumption (standby / typical / peak)	25 / < 50 / 600 mW
Supply voltage (A / D)	3.2 / 1.8 V
Imaging module I/O	USB, other options available

## VIS-SWIR VGA IMAGE SENSOR with analog output ROIC



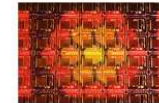
### Overview

Emberion's graphene photodetectors convert light to an electronic signal using graphene charge transducers combined with a nanocrystal light absorber. They provide superior responsivity with very low noise over a broad spectral range from visible to near infrared/short-wave infrared (NIR/SWIR) wavelengths without cooling below room temperature. The dynamic range of the detectors is very large, owing to the low noise and a response that does not saturate. Potential applications include hyperspectral imaging, night- and machine-vision.

Emberion's VIS-SWIR VGA image sensor comprises a detector array monolithically built on a tailor-made CMOS readout integrated circuit (ROIC). The ROIC provides an analog multiplexed data output. The size of the pixels is tailorable and various standard imaging sensor package options are offered with an optional built-in thermo-electric cooling element for stabilization to room temperature operation. In addition to the image sensor component, Emberion offers imaging modules with HW&SW implementation for analog-to-digital conversion, image pre-processing, thermal control, power management and a digital camera interface.

### Technology in Brief

- Ultra-sensitive photodetector combining a graphene field-effect transistor charge transducer with an efficient light absorbing layer
- Wide spectral range from visible (VIS) light to short-wave infrared (SWIR) covered with a single photodetector
- Excellent detector performance achieved at room temperature
- Monolithically integrated VGA detector array and readout integrated circuit (ROIC)
- Imaging sensor module readily utilizable as a camera core



### Unique Benefits

- Very sensitive due to low noise-equivalent irradiance (NEI)
- High resolution (MTF)
- Non-saturating detectors, large dynamic range
- Very wide spectral range
- Scalable pixel size
- Cost-efficient manufacturing

### Technical Data (preliminary)

Spectral range	400 - 1800 nm
Pixel size	20 × 20 μm <sup>2</sup>
Array size	VGA (640 × 512)
Array area	12.8 × 10.24 mm <sup>2</sup>
Pixel pitch	20 μm
Optical fill factor	99 %
Exposure time	1 - 1000 ms
Frame rate (max)	100 fps
D* (30 / 100 fps)	2×10 <sup>14</sup> / 7×10 <sup>14</sup> Jones
NEI (30 / 100 fps)	2×10 <sup>-4</sup> / 5×10 <sup>-4</sup> W/m <sup>2</sup>
Full dynamic range	< 3 %
Full scale non-linearity	< 3 %
Stability	< 5 % per year
Shutter mode	Global electronic
Timing	Internal & external trigger
Trigger delay	< 1 μs
Package	BGA or similar
Optical interface	AR coated VIS-SWIR transparent window
ROIC I/O (data / control)	Mixed analog / SPI
Operation temperature	-40 - +70°C
Performance and reliability standards (latest version, as applicable)	MIL-PRF-38535, JEDEC JESD47
Supply voltage	3.3 V
Imaging sensor module I/O	CameraLink, Gig E Vision, USB

Performance evaluated at λ = 1600 nm, 100 fps, T = 20 °C unless otherwise noted

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