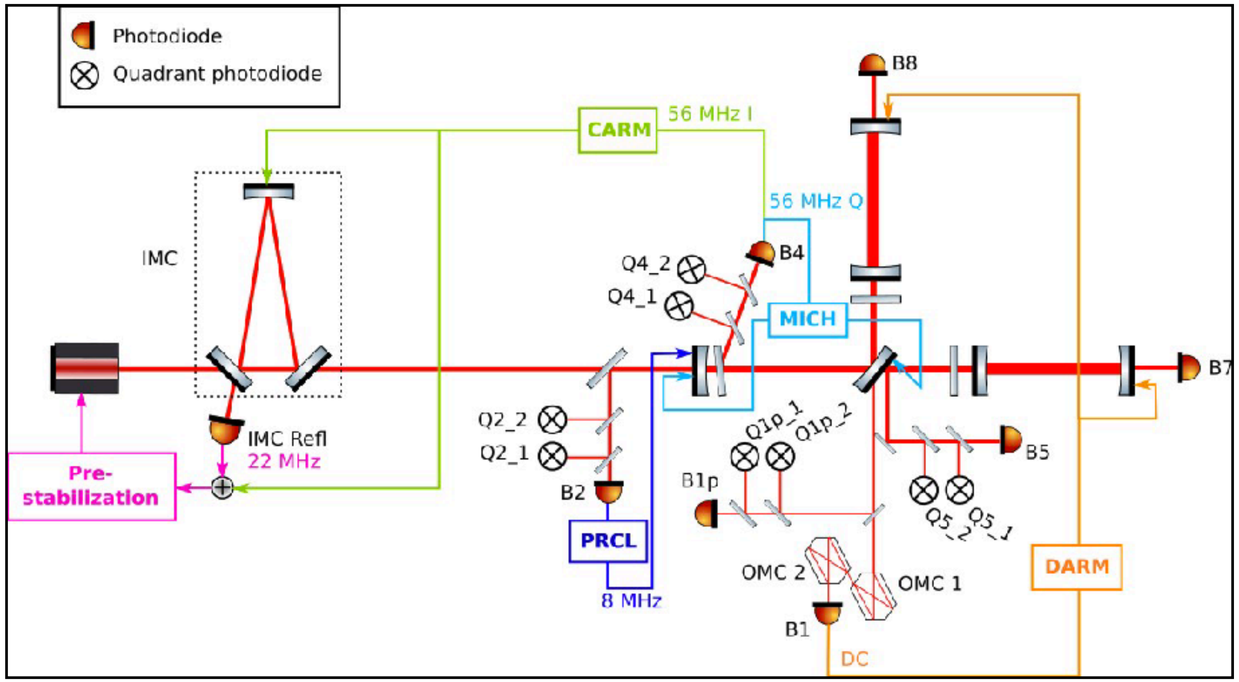
Sensors

for Gravitational Wave Detectors

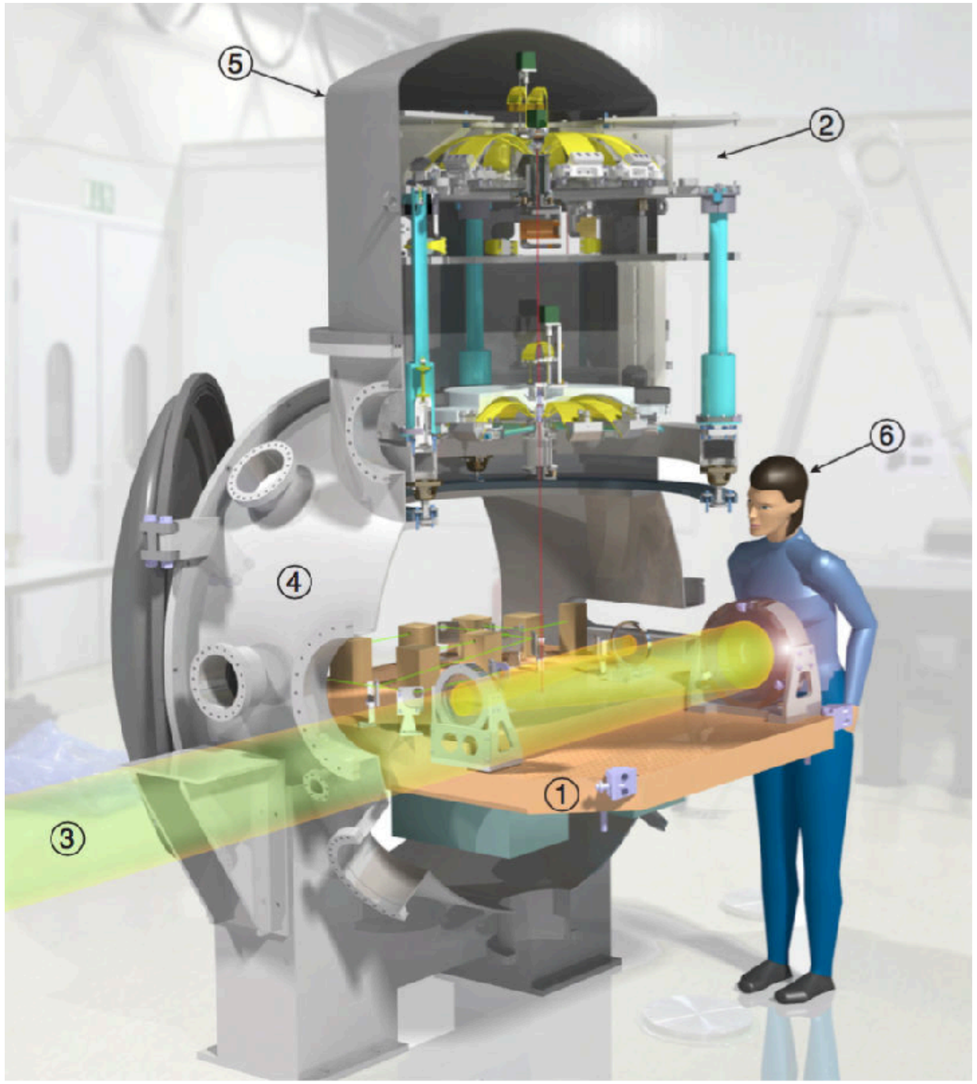
Niels van Bakel & Martin van Beuzekom

Sensors - Optical



- Photo diodes (PD, HQE-PD & QPD)
  - *Light power & beam centering*
  - *Longitudinal & angular alignment*
- Phase cameras
  - *To correct for mirror distortions*
- Beam cameras for (pre) alignment of the interferometer and monitoring:
  - *InGaAs pixel detectors, phosphor coated CCD or CMOS*
  - *For 1550 nm and 2000 nm?*

Sensors - Displacement, tilt, …



- Accelerometers
- Displacement sensors (LVDT)
- Inertial rotation sensors (BRMS type)
- Optical levers for mirror tilt
- Inertial motion measurement (Triaxial Nanometrics TC–120 seismometers)

- Many environmental sensors: temperature, pressure, microphones, magnetometers…. (see Controls)

- Voice–coil actuators
- Piezo-electric stack actuators (PZT)
- Actuators and shadow sensors in a single unit (BOSEM)
- Laser for thermal compensation

R&D examples

- Accelerometer
  - ***MEMS sensor*** *with integrated readout*

INNOSEIS

LIONIX INTERNATIONAL

- Photodiodes for LISA
  - ***InGaAs QPD*** *with amplifier*

BRIGHT Integrated PHOTONICS

SMART PHOTONICS

SRON Netherlands Institute for Space Research

Max-Planck-Institut für Gravitationsphysik Albert-Einstein-Institut

- Voice coil mirror driver
  - ***3D printing*** *in Aluminum*

oceanz. Your 3D printing professional

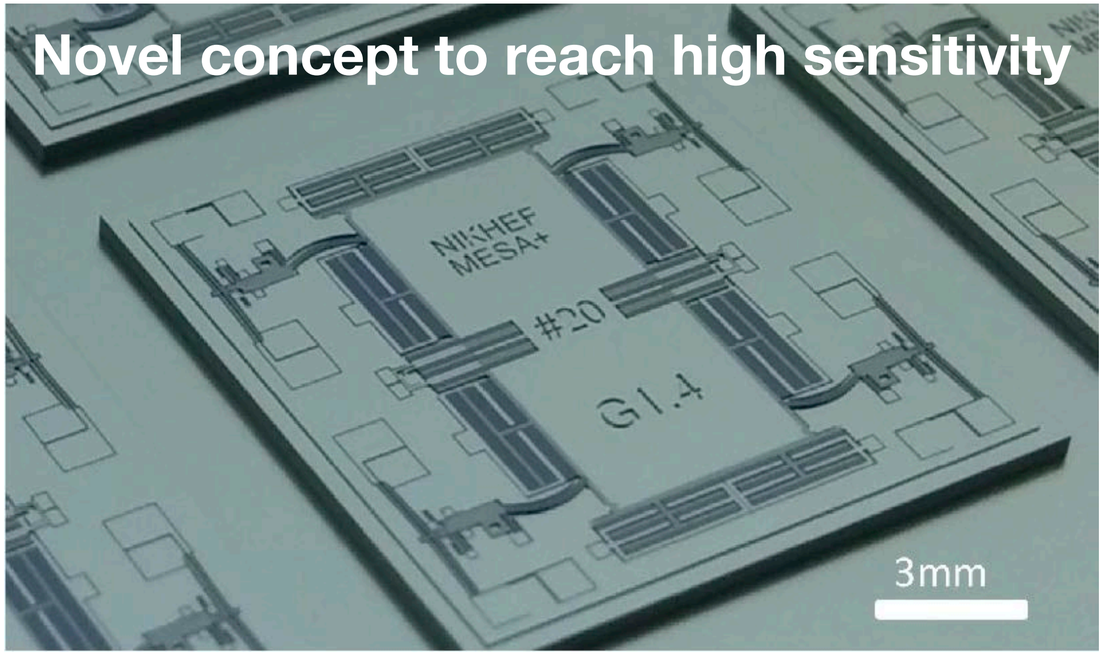
- Readout electronics for photo-diodes
  - *Discrete and integrated (ASIC) electronics*

KU LEUVEN micas

UNIVERSITY OF TWENTE.

Accelerometers

- For Newtonian Noise subtraction aiming at **1 ng/√Hz** with our **MEMS sensor** at low frequencies
  - *Similar level for vibration monitoring*
- Requirements for tilt meters in ET:
  - *For controls around **0.01-0.1 nrad/√Hz** between 0.01-1 Hz;*
  - *for NN suppression we look at **1 prad/√Hz** above 1 Hz.*



INNOSEIS LIONIX INTERNATIONAL

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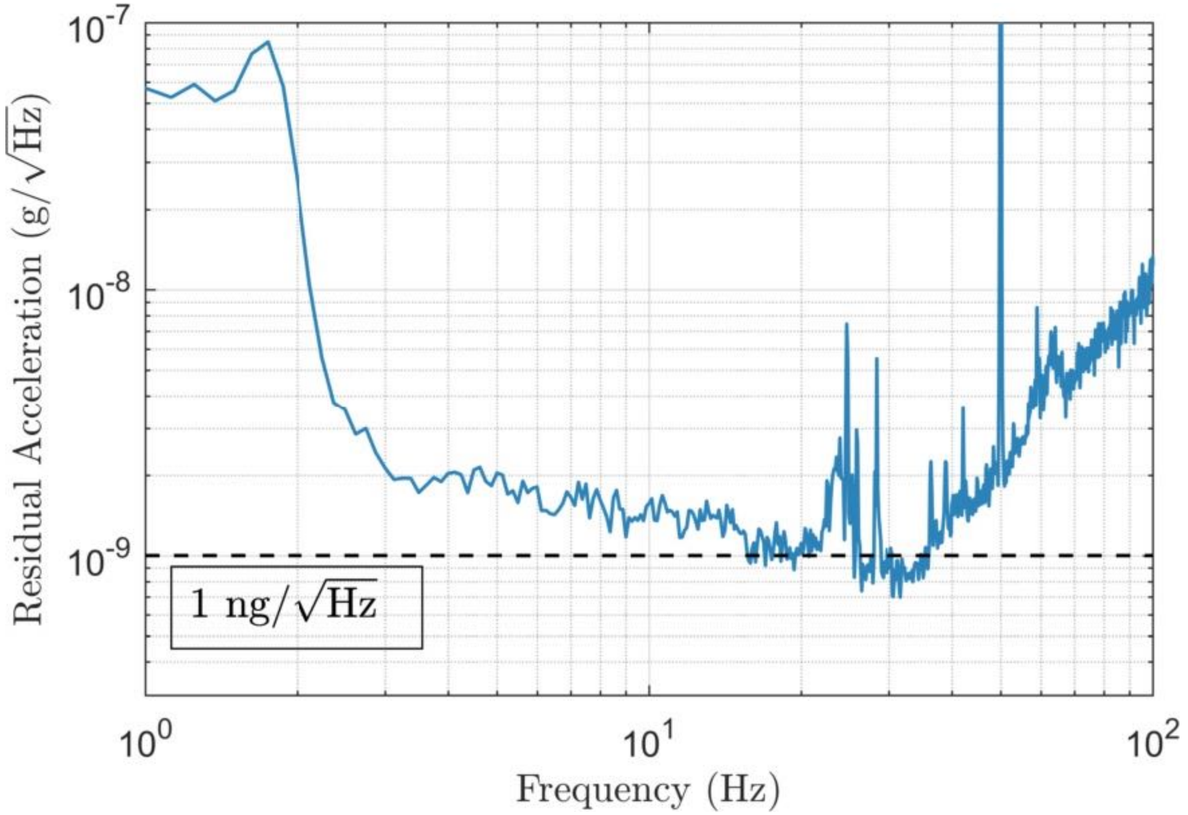

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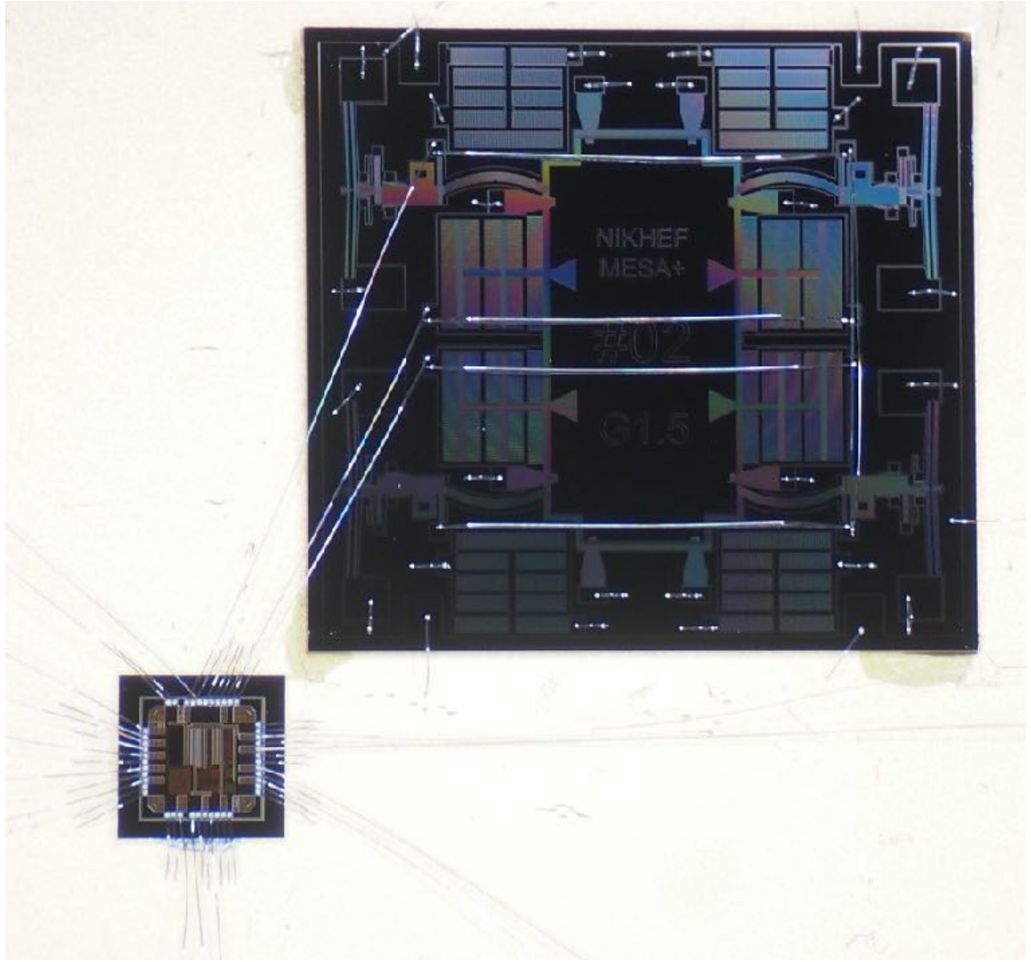
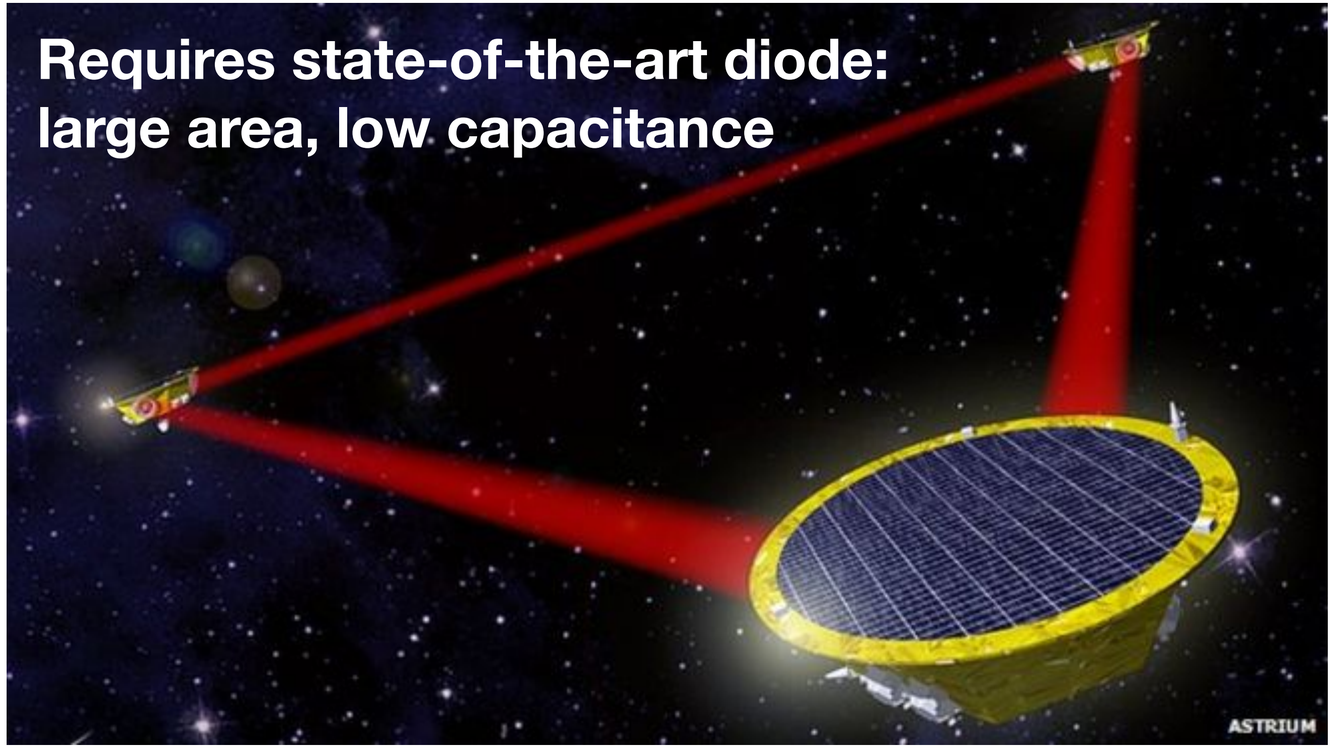


InGaAs Photodiode

- Quadrant diode with
  - ➡ 2 mm diameter, small gaps (10 - 20 µm)
- Input-referred current noise
  - ➡ < 2 pA/√Hz (per segment)
  - ➡ Hence, low capacitance
- Responsivity
  - ➡ > 0.7 A/W at 1064 nm $\Longrightarrow$ InGaAs
- Bandwidth
  - ➡ 2..25 (30) MHz
- Low power dissipation (QPD & TIA)
- Radiation hardness, mechanical & thermal stability …….



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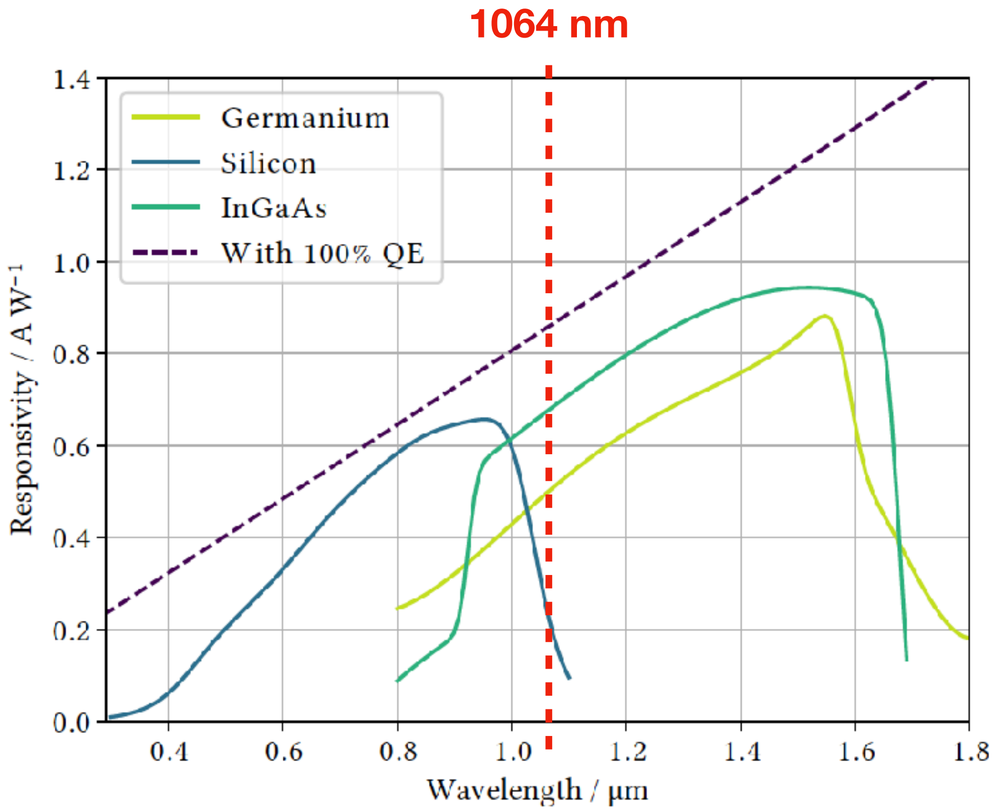

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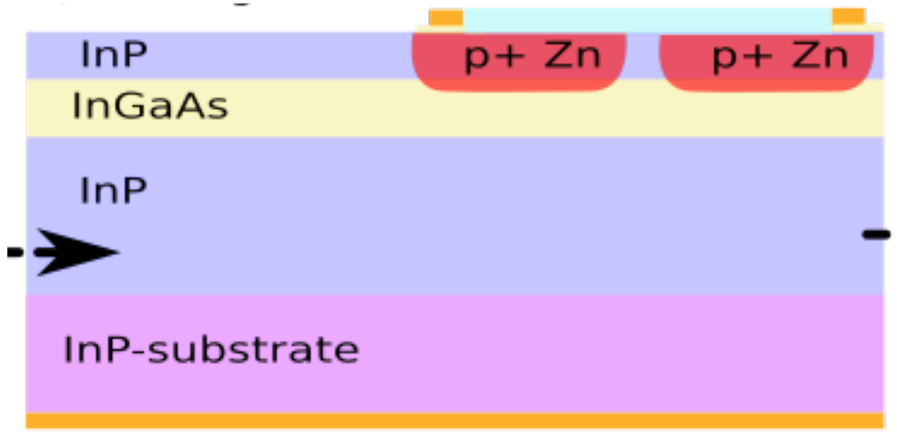


LISA QPD development

- Bright Photonics
  - ✓ *Design house for Photonic Integrated Circuits*
  - ✓ *Experience with InP & InGaAs materials*

- Smart Photonics
  - ✓ *Device processing of Indium Phosphide based components*

Fotonica: een nieuwe chipindustrie ziet het licht

Technologie Een strategische lening van 20 miljoen euro bestempelt Smart Photonics tot spil van een nieuwe, veelbelovende Nederlandse chipindustrie.

Marc Hijink 30 juni 2020 Leestijd 2 minuten

https://www.nrc.nl/nieuws/2020/06/30/nieuwe-chipindustrie-ziet-het-licht-a4004596

Diodes for ETp & ET

- Diodes for 1550 nm and 2000 nm laser light

  ➡ *Shot-noise limited*

  ➡ *InGaAs for 1550 nm (commercial)?*

  ➡ *Extended InGaAs or HgCdTe (MCT) photodiodes for 2000 nm?*

- In air-filled enclosure in vacuum

  ➡ *Requires low power electronics*

ET Pathfinder

Description	Quantity
PD 1550 nm	6
HQE PD 1550 nm	2
QPD 1550 nm	12
PD 2000 nm	6
HQE PD 2000 nm	2
QPD 2000 nm	12

ET Table?

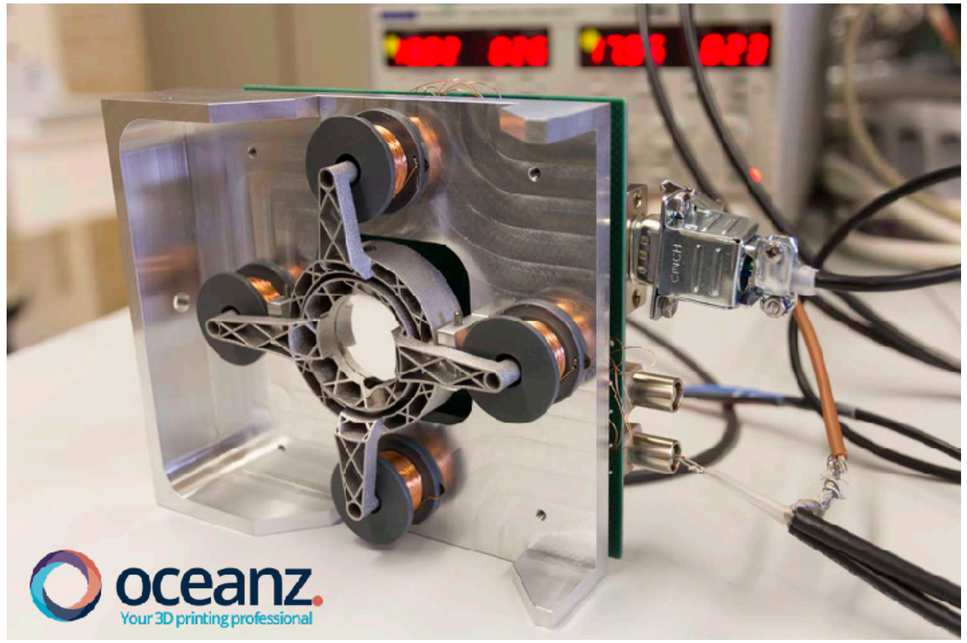
Diodes - specs

- Adv Virgo: developed QPD systems with commercial Si-diodes
- LISA: developing InGaAs diodes
- ETp & ET: use expertise for further development in collaboration with industry

	Virgo	Virgo	LISA	ETp	ET
λ [nm]	1064	1064	1064	1550	2000
QE	~55%	>99%	>80%	xxx & >99%	xxx & >99%
Material	Si	InGaAs	InGaAs	InGaAs	Extended InGaAs or MCT ?
Active area	7 x 7 mm^2	mm	2 mm	mm	mm
AC BW	1..150 MHz	DC?	2..25 MHz	1 .. 200 MHz	1..200 MHz
Light power/ segment	~10 mW		~200 µW	1-100 mW	1-100 mW
	Commercial	Custom	Custom	Comm or custom	Custom

3D printing in Aluminum

- Nikhef developed an In-Air Galvano Gimbaled Mirror for the Virgo experiment.
- To keep a laser beam centered on a quadrant Photo-diode
- Nikhef ordered 20 3D printed aluminium gimbals

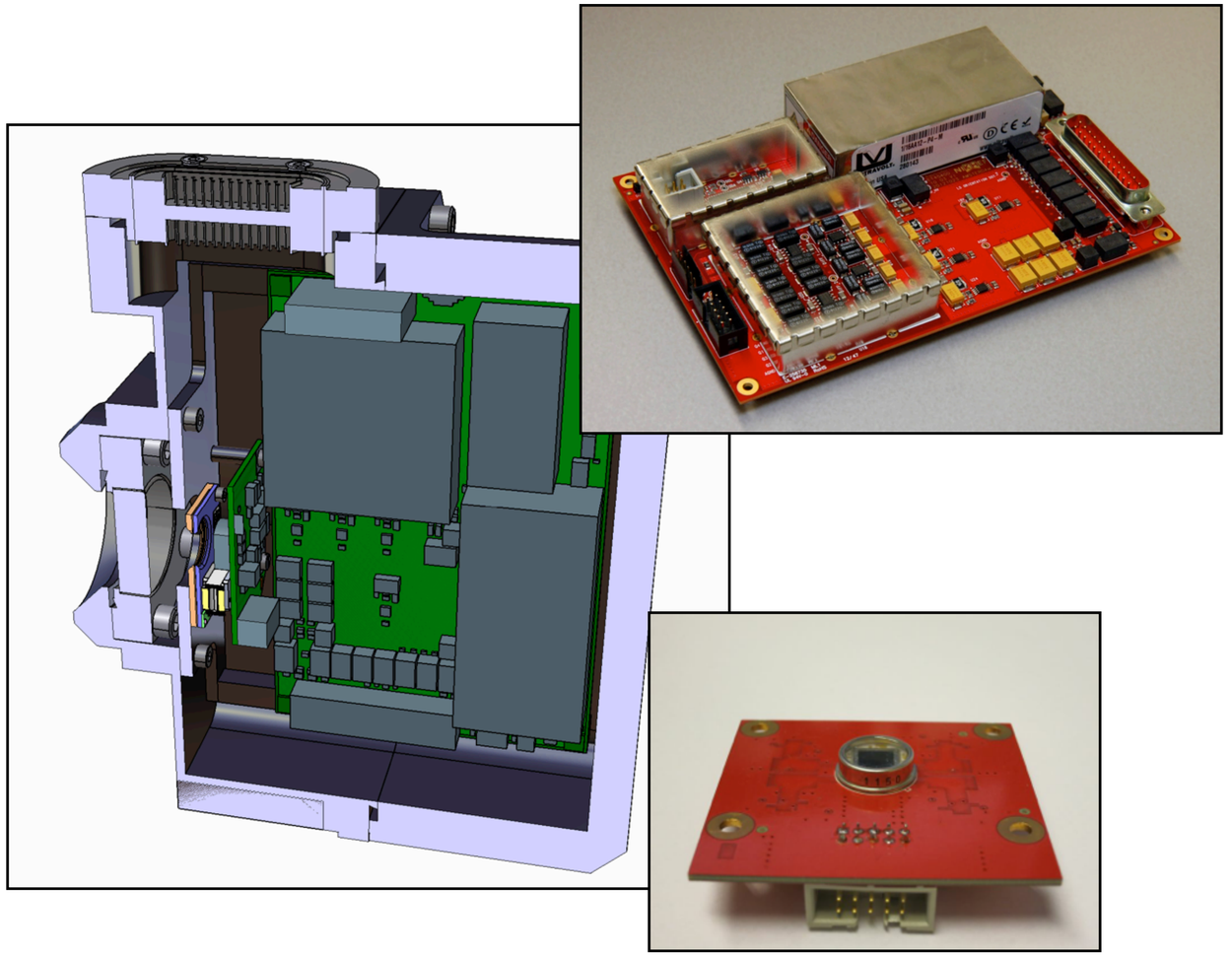


https://youtu.be/mPrhaDXAT9Y

https://www.oceanz.eu/over/praktijkcases/3D-printen-in-Aluminium-voor-In-Air-Galvano-Gimbaled-Mirror-Nikhef/

Readout electronics

- For example Nikhef **Virgo QPD Box**
- Phase camera - ADC & digital signal processing (see Controls)
- QPD readout LISA diodes - discrete and ASIC options
- LVDT readout
- …….



Sensors: what we need

- What we have
  - Big Science pushing the boundaries
  - Exploring novel sensors & techniques (R&D)
- Challenges
  - Develop instrumentation because not commercially available: low noise, low power, high dynamic range, bandwidth, vacuum, radiation ……
- What we need
  - Collaboration with industry and research institutes on photonics, MEMS fabrication, wafer level packaging, integrated electronics, new materials ….

Ronald Broeke (Bright Photonics): “*The development of the diodes for LISA provides us with new knowledge that we will use in other applications in the future. Through collaboration with the NWO institutes Nikhef and SRON, we have explored new grounds in photonics regarding materials, simulation and application development for space*”