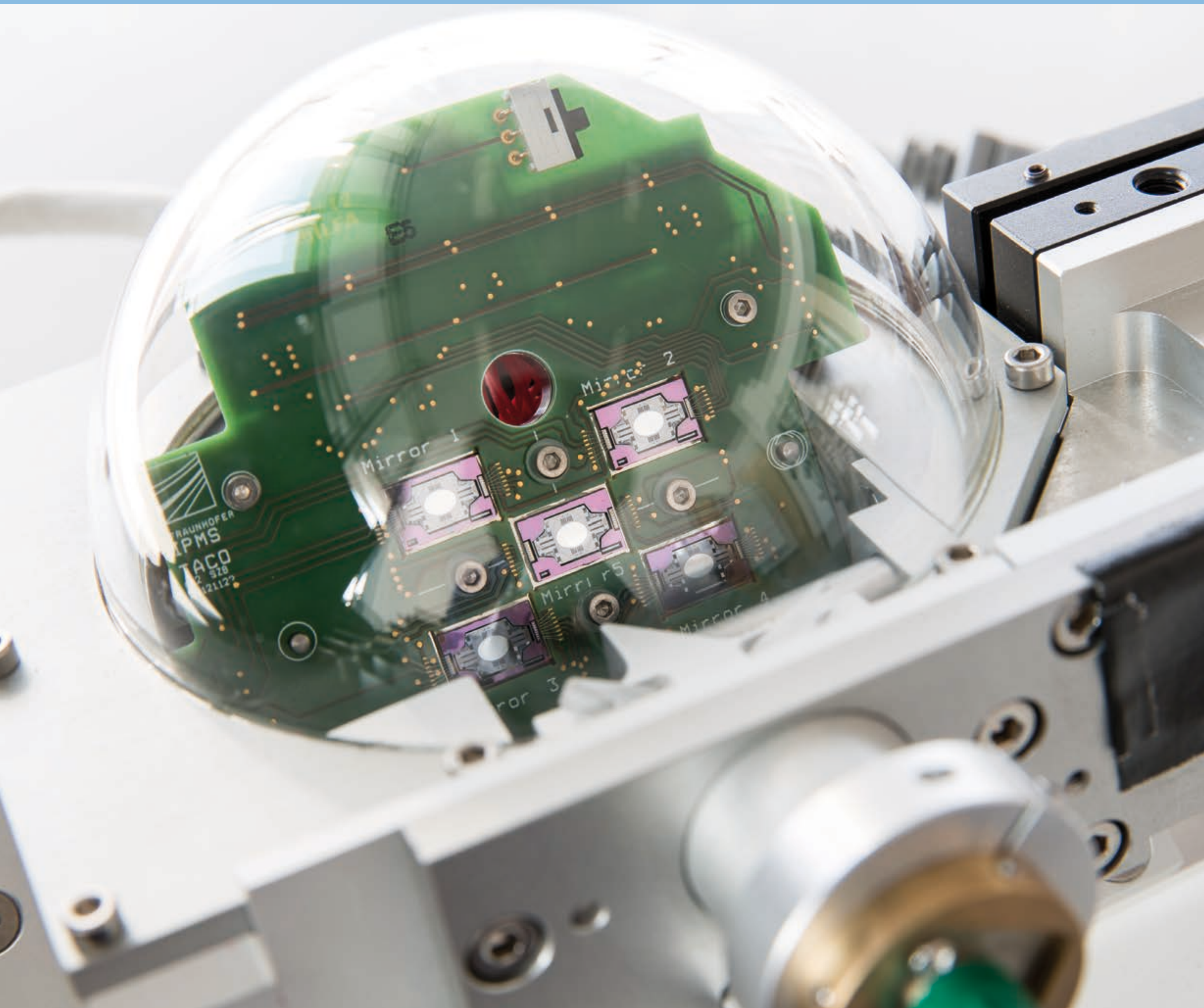
Forschungsfabrik Mikroelektronik Deutschland

RESEARCH FAB MICROELECTRONICS GERMANY

FRAUNHOFER GROUP FOR MICROELECTRONICS IN COOPERATION WITH LEIBNIZ INSTITUTES FBH AND IHP

LiDAR+
Solutions for Automotive and Industrial Applications



LiDAR$^+$ as a key factor for Smart Mobility and Industry

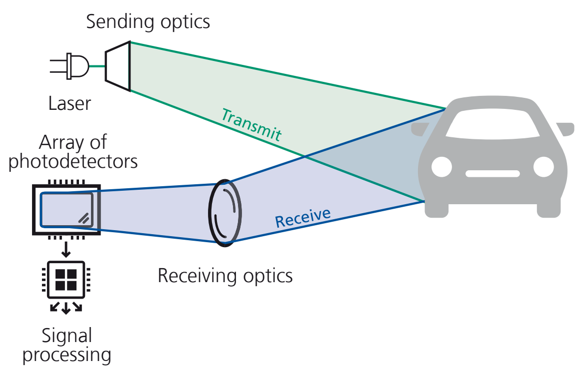
LiDAR (Light Detection And Ranging) is a technology to measure the distance to an object by illuminating this object with laser light and calculating the distance from the time taken by the light to travel to the object and back to the sensor. This measurement principle is called time-of-flight (ToF). It can be achieved by pulsing the laser, phase shift, and frequency modulation.

In the automotive sector, LiDAR systems are a key factor on the way to fully **autonomous driving (AD)**, because they form an important part of the **advanced driver assistance system (ADAS)**. In this context, LiDAR systems are used to detect obstacles, such as other vehicles or pedestrians, in the environment of the vehicle. Furthermore, LiDAR systems are applied for range detection and simultaneous localization and mapping (SLAM). A 3D model of the environment can be created by processing the data obtained from a LiDAR system.

Autonomous driving is based on the intelligent combination of complementary technologies: LiDAR, RADAR, video, and the communication with the traffic infrastructure and other road users (vehicle-to-everything). Within this **combination of sensors** and the subsequent **sensor data fusion**, the importance of LiDAR for consumer cars increased in the last few years due to reductions in costs and size of the systems. Mobility as a service (Maas) is becoming an important business model in the automotive sector. **Robotic cars** with high-end LiDAR systems will be used to offer fully autonomous services while reducing the costs per mile and improving the quality of life in urban areas.

There are generally two different designs of LiDAR systems. The mechanical scanning LiDAR physically rotates the laser and receiver to gain a 360° view whereas a solid-state LiDAR (SSL) has no moving parts, but a limited field of view (FoV) in combination with lower costs and a higher degree of reliability. Although there are different types and approaches of SSLs, the systems can be subdivided into two main types: **Flash LiDAR** without moving parts to illuminate the entire target area for short- and mid-range detection and a **MEMS-based scanning LiDAR** with micro mirrors to steer the beam for long-range detection.

The different LiDAR technologies also vary in their wavelengths depending on the detector materials. In automotive systems, typically silicon-based detectors with 905 nm wavelength are used. By using compound semiconductors, a LiDAR system can be operated by using 1550 nm wavelength. In addition to the automotive sector, LiDAR systems offer a broad variety of solutions for industrial applications like precision farming, autonomous mobile robots for intralogistics, and large-scale infrastructure monitoring, to name only a few.



Flash LiDAR.

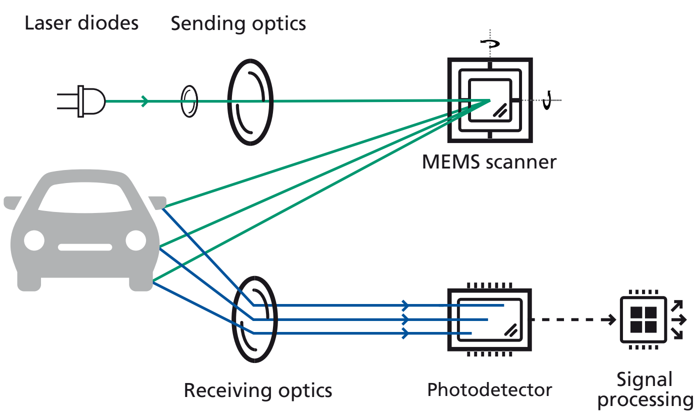
Research Fab Microelectronics Germany: The One-Stop-Shop for LiDAR solutions

In terms of automated driving, advanced driver assistance systems have to work in a reliable and redundant way not only to guarantee the safety of the driver, but also to protect pedestrians and other road users. For this purpose, the functional and technological requirements for every single component of a LiDAR system can be very complex and challenging.

LiDAR systems consist of sophisticated components depending on their type:

- Laser sources and laser diodes
- Optical elements (lenses, mirrors, and diffusors)
- Beam steering elements for MEMS-based scanning LiDAR systems
- Photodetectors
- Signal processing units

We offer **tailored solutions for specific applications** of our customers based on our long-standing expertise on every component along the **entire value chain of a LiDAR system**.

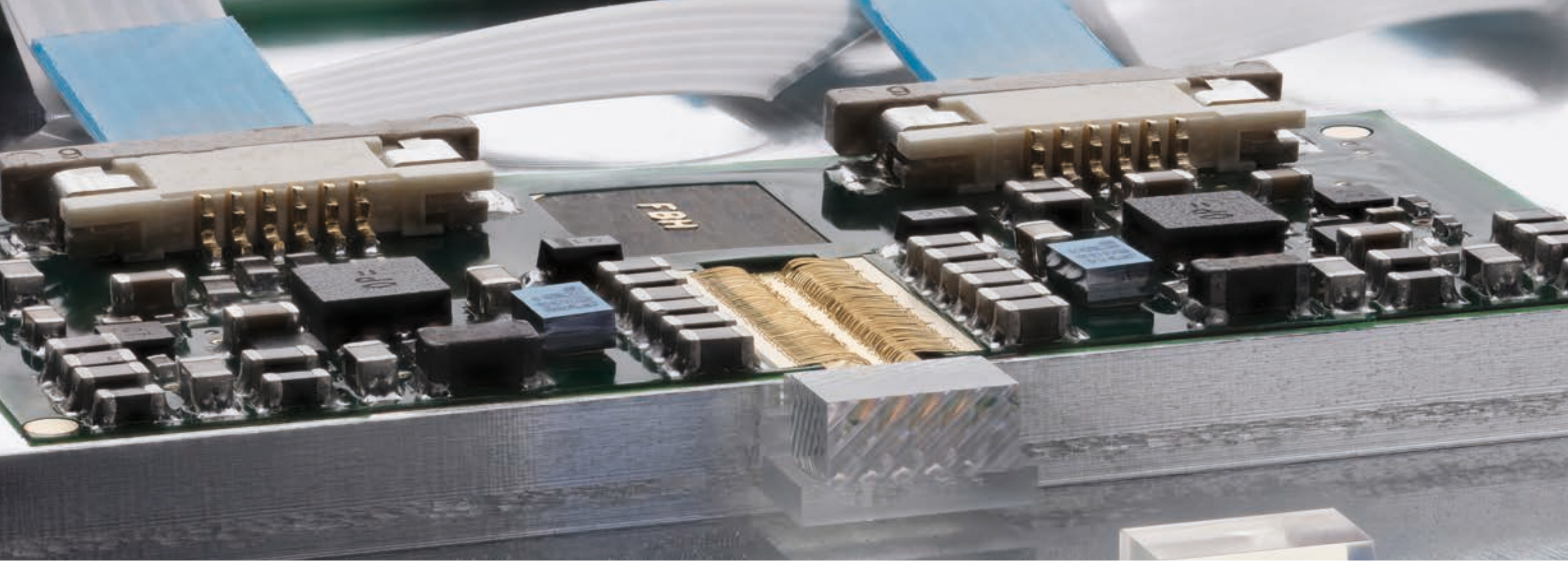


MEMS-based scanning LiDAR.

The **Research Fab Microelectronics (FMD)** is the single access point for customers to a broad variety of technological competencies in the field of LiDAR solutions. Our experts conduct research at **different wavelengths** (e.g. 905 nm, 1550 nm and others) as well as **different types of LiDAR systems**: Flash LiDAR, MEMS-based scanning LiDAR and further systems.
Furthermore, we offer our expertise on complementary technologies such as RADAR, camera, and sensor data fusion to **develop the best solution together with our customers**.

Services

- Industrial contract research
  - R&D projects
  - Feasibility studies
  - Technology and process development
  - Pilot fabrication
- Services for manufacturers
  - Demonstrators and prototypes
  - Technology services
- Technology transfer
  - Licensing of technologies and processes
- Cooperative projects
  - R&D projects jointly funded by public and industrial sources



Laser diodes and laser sources

Due to the tailored properties of the semiconductor laser diodes, LiDAR systems can be designed very flexibly according to the needs in question. Depending on the semiconductor material of the laser diodes, the wavelengths and the light output of the LiDAR systems can be modulated: GaAs-based lasers operate in the range of 0.62 µm up to 1.2 µm, whereas InP-based lasers operate in the range of 1.25 µm up to 1.7 µm.

LiDAR systems make use of different ranging methods: pulsed time of flight, phase shift, and frequency modulation. Lasers in **pulsed operation** are used for measuring pulsed or direct time of flight (dToF) to determine the time period of the emitted light to reach the object and reflect back onto the detector. Long detection ranges demand high powers, good resolution needs high beam quality and eye safety requires short pulse operation. By using lasers in **continuous-wave (cw) operation**, the phase difference (phase shift) and frequency modulation of a continuous wave (FMCW) can be measured.

FMD offers the suitable laser sources for both operating methods, pulsed and cw. For Flash LiDAR systems, pulsed laser sources with short pulse durations and high output power are mandatory. Within FMD, **high-power LiDAR-compatible light sources for ns-pulse operation** are available. They deliver pulses of a defined duration and repetition rate, providing output power values exceeding 100 W per single device. Lasers in cw operation are used for LiDAR systems based on phase shift and FMCW.
A monolithic integration of the light source and the correspondent detector can be offered by FMD.

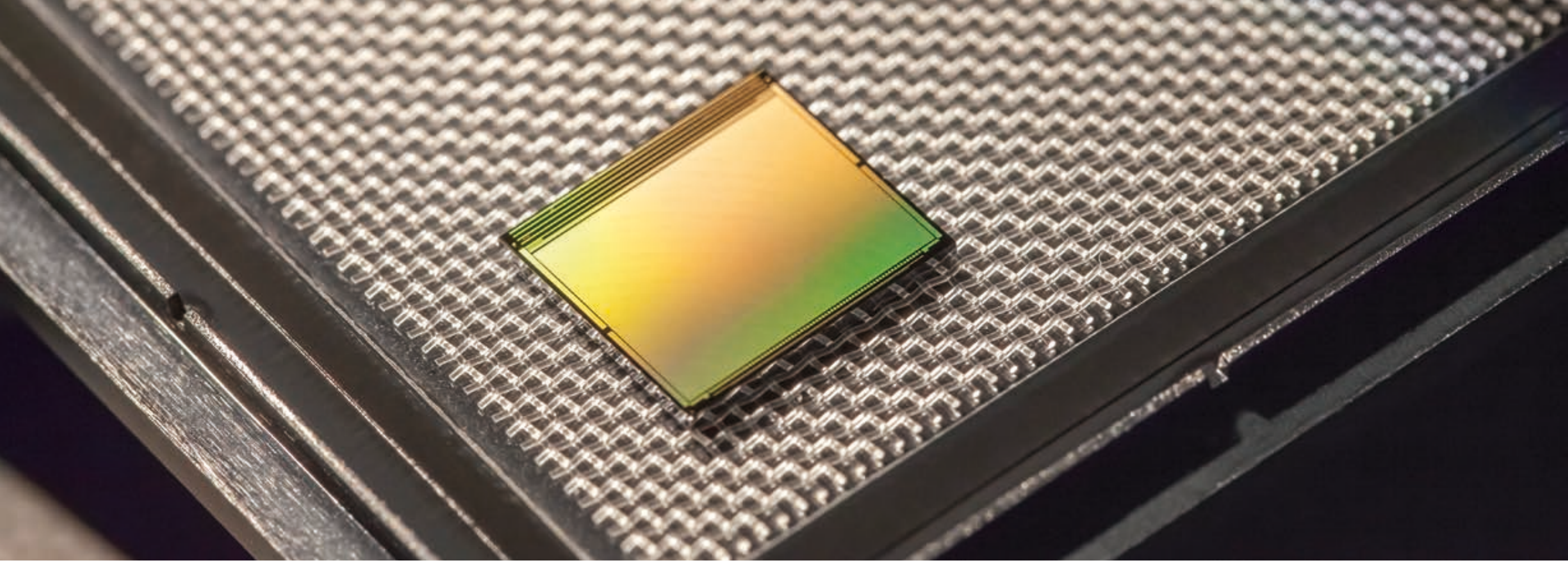
Beam steering

Scanning LiDAR systems use different technologies to steer the laser beam. MEMS-based scanning LiDAR systems use **MEMS scanners**, also called scanning micro mirrors, for fast deflection of the laser beam. **1D and 2D scanning devices** are built from polysilicon or single crystalline silicon with a qualified, fully CMOS-compatible bulk micromachining process, suitable for mass fabrication resulting in a highly robust and reliable MEMS device.

In contrast to LiDAR systems with conventional scanner components, the scanner modules enable (3D) LIDAR systems to become smaller (diameters: 0.5 mm - 50 mm) and more robust while enabling higher scan rates (scan frequency: 0.1 Hz - 100 kHz). By using our MEMS scanner construction kit, customers can receive customized demonstrators within a few weeks at low cost. The drive mechanisms of the MEMS scanners are designed in an application-specific manner: electrostatic, piezo, or magnetic. Furthermore, 2D MEMS scanners can be vacuum packaged at the wafer level by hermetic encapsulation with inclined glass caps. Depending on their design, MEMS scanners have different technical properties: Reduced power consumption compared with conventional approaches, fatigue free, high temperature resistant, highly reflective coatings (R>99%), on-chip position detection and optical scan ranges from 0.1° up to 120°.

Optical phased arrays (OPA) are a novel approach for beam steering in scanning LiDAR systems. The beam steering is achieved without moving parts by controlling the phase of an array of lasers.

MEMS mirrors with diameters of 2 mm up to 20 mm.



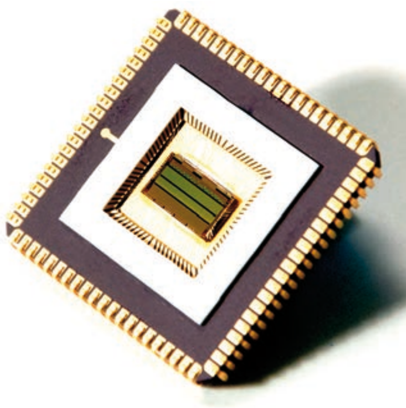
Detectors

The role of photodetectors is crucial for the functionality, safety, costs, and performance, especially the range and spatial resolution, of a LiDAR system. Light is emitted by the laser source of a LiDAR in different directions. This light is reflected by an object and has to be received by the detector. Within the detection process, photons of the reflected light have to be identified correctly. Therefore, the prevention of **spoofing** from other LiDAR systems as well as **ambient light rejection** are important.

In general, there are four types of detectors for LiDAR: PIN Photodiodes, Avalanche Photodiodes (APD), Single-Photon Avalanche Diodes (SPAD) and Silicon Photomultipliers (SiPM). Depending on the application, single-element detectors or arrays of detectors are used in the LiDAR system. SiPMs are limited to silicon technologies, whereas the other detectors can be based on silicon (sensitive below 1000 nm wavelength) or compound semiconductors (sensitive also above 1000 nm wavelength).

In terms of silicon-based detectors, SiPM and SPAD arrays are promising solutions. SiPMs enable the continuous measurement of the intensity of the reflected light with single-photon resolution. SPAD arrays, integrated in standard CMOS technology, are able to detect single photons in every detection element with precise timing resolution at the same time. This allows the highest photon detection sensitivity in a fast digital photoreceiver and enables SSL sensors without any mechanical parts. The SPAD receiver is designed as a system on chip by integrating the SPAD itself and its readout circuit into one CMOS chip. Decisive algorithms are part of the readout and are fundamental to achieving reliable results, even outdoors with changing weather conditions. A new approach for fabricating SPADs is the so-called BackSPAD (backside illuminated SPAD) by using 3D integration technology. This process makes use of chip-to-wafer (C2W) and wafer-to-wafer (W2W) solutions to fabricate SPAD arrays with high resolution as a module with a customized ROIC (Readout Integrated Circuit).

In the field of III-V compound semiconductors, our experts especially provide InGaAs-based APDs with internal signal amplification (gain) and a spectral sensitivity up to 1650 nm wavelength. A monolithic integration of these short-wave infrared detectors and the corresponding laser source can be realized. High-resolution InGaAs APD focal plane arrays with 640 x 512 pixels have already been demonstrated within laser gated viewing (Flash LiDAR) systems. Coherent photodetectors, which are needed for FMCW or phase shift LiDAR systems, as well as InGaAs-based SPADs can be designed, too.



SPAD LiDAR sensor in CMOS.

The FMD provides the **design**, **qualification** and **characterization of customized detectors** with high sensitivity, high gain, and fast acquisition speed as well as the corresponding high power light sources. Furthermore, high-performance receiver circuits for detectors as well as driver circuits for vertical-cavity surface-emitting lasers (VCSELs) can be designed and manufactured. In addition, we provide algorithms for ambient light rejection, distance evaluation, and full-chip integration with digital front- and backend.

Silicon-based detectors

	PIN-PD	APD	SiPM	SPAD
Gain	1	10^3	10^6	10^6
Single photon detection	No	No	Yes	Yes
Operational Bias	Low	Medium	Medium	Medium
Temperature Sensitivity	Low	High	Low	Low
Array possible	Limited	Limited	Limited	Yes
Readout / Electronics	Complex	Complex	Medium	Simple
Rise time	Medium	Slow	Fast	Fast

Sensor Data Fusion

The intelligent combination of data gained from complementary technologies is the basis for a valid decision-making process. In this context, sensor data fusion or multi-sensor data fusion is the combination of sensor data acquired from disparate data sources so that the resulting picture of the situation and processes has less uncertainty. For automotive and industrial applications, sensor data fusion is a crucial point for guaranteeing the safety of all road users, employees, and others by increasing accuracy and mitigating risk through potential technical failures.

Within the FMD, there are many years of expertise on **RADAR systems.** RADAR systems still work under harsh weather conditions like rain, fog, and snow, whereas LiDAR systems may struggle with these influences depending on their wavelength. Although knowledge within the field of RADAR and the transfer of established processes from RADAR to LiDAR offer considerable potential, cameras will still be needed to read road signs and identify colors. Only the intelligent combination of the advantages of the single detection technologies enables complete perception of the environment.

Heterointegration

Heterointegration is the bonding of all parts and components of a system into a **single functional unit**. Researchers and companies are improving the performance of every single component of the LiDAR system along the entire value chain. To achieve small, affordable, and high-performance LiDAR systems for volume production, new approaches to heterointegration for the components and the complete system are essential.

Especially in terms of laser sources and detector arrays, 3D integration technologies like wafer level packaging and assembly, **CMOS integration of SPADs and SiPMs**, as well as **3D IC technology with TSV and RDL**, can contribute to the performance of the LiDAR system.

Areas of application

- Aerospace
  - Atmospheric research and earth observation
  - Distance determination of satellites and space debris
  - Data collection for geographic information systems (GIS) and building information modelling (BIM)

- Agriculture and Forestry
  - Automated harvesting machines
  - Precision farming and precision forestry

- Industry and Manufacturing
  - Process monitoring and inspection
  - Image-based quality control in harsh environments
  - Monitoring of workspaces at the human-machine interface (HMI)
  - Intralogistics

- Transport & Smart Mobility
  - Gesture recognition in vehicle interiors
  - Range, side, and corner detection of obstacles (pedestrians, vehicles, and other road users)
  - Simultaneous localization and mapping (SLAM) for specialized commercial vehicles (road sweepers, garbage trucks, winter road clearance)
  - Traffic surveillance and vehicle classification
  - Rail measurement (contact wire, rail track)

- Robotics
  - Consumer robotics
  - Environmental perception for autonomous mobile platforms
  - Drivability estimation of the ground (roughness, slope, obstacles)
  - Autonomous mobile robots in hazardous environments (decommissioning of nuclear power plants, decontamination tasks)

- Safety and Security
  - Coastal and environmental monitoring
  - Mine planning and slope stability assessment
  - Exploration and mapping of disaster areas
  - Safety applications for cooperation with robots
  - Obstacle recognition and tracking

- Water Management & Fish Farming
  - Underwater measurements
  - Underwater infrastructure and aquaculture monitoring

- Energy
  - Large scale infrastructure monitoring
  - Industrial inspection of oil and gas facilities

Contact

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