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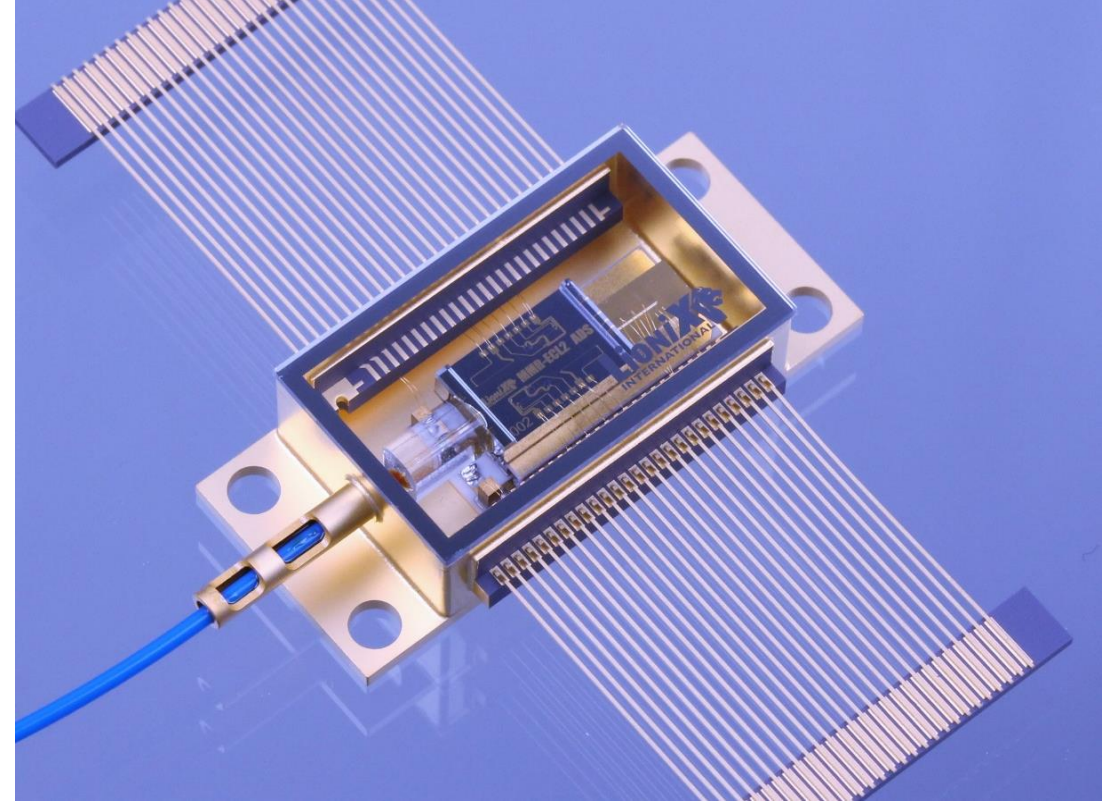
Gateway to Integrated Photonics

Megatrends in the automotive & mobility sector and the role of integrated photonics

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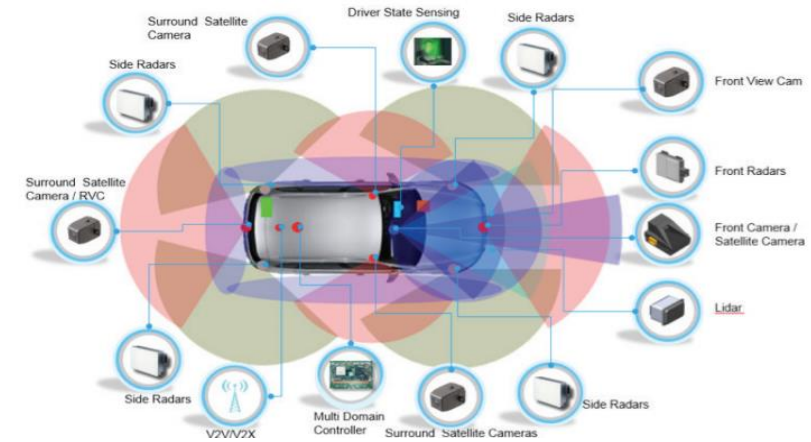
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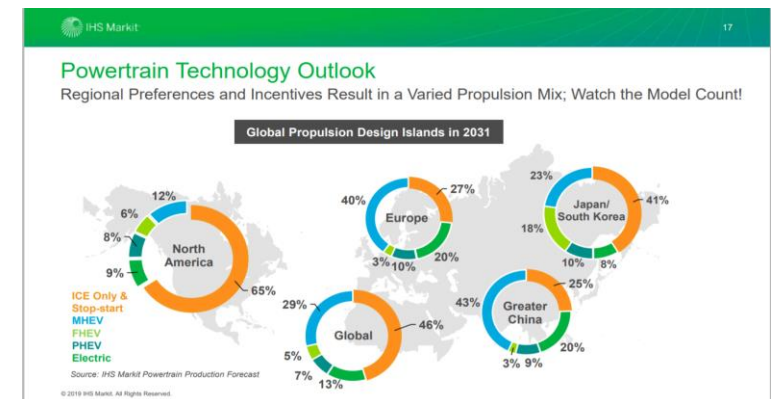
Automotive and mobility environment: Megatrends

- The automotive industry is facing 3 revolutionary changes
 1. Electrification
 2. ADAS and the drive towards autonomous vehicles
 3. Mobility pattern changes,
 - Different e-vehicles
 - Robotaxis and transporters
 - “Sustainable cities” influencing traffic patterns
- At the same time existing combustion engine vehicles face increasing emission legislation demands
- This leads to accelerated innovation and a very strong increase of electronics in vehicles
 - Power electronics and sensors in EV
 - Sensors and computing/networking for ADAS en autonomous vehicles
- The huge investments lead to reshaping of the automotive landscape,
 - Cooperations
 - An increased focus on new technologies, away from combustion engine vehicles



Combustion engines and the electrification of the drive train

- The scandals in the automotive industry have forced real action in emission reduction
 - In the EU, car makers will have to manage the total emissions of their fleet or face huge penalties
 - In the coming years, car makers will massively introduce hybrids (plug-in, full , mild) for this reason
- Full EV will become more attractive as battery prices fall
 - Expectation is > 15% share by 2030, the transition will go quickly after that in developed countries
- EV have superior efficiency compared to ICE and better driving characteristics
 - Cost parity on TCO level is expected before 2024
- Developing EV platforms, drive trains and Battery packs is very expensive.
 - Only a few players will be able to keep this up. Others will disappear or make alliances
- Trucks will have their own dynamic, with short range delivery going first hybrid and then EV
 - Long haul transport will use some hybridization (accelerate-stop), and H2/fuel cells??/EV
 - City buses go electric rapidly



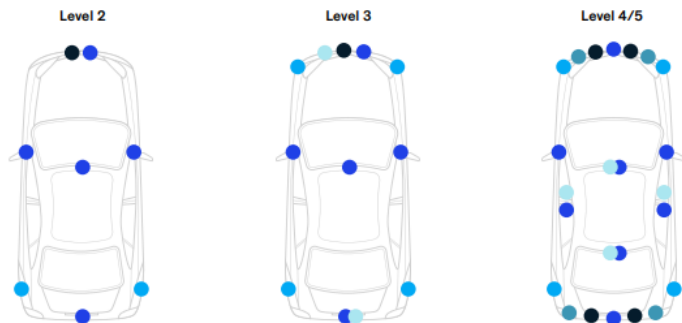
Autonomous driving

- Autonomous driving has been a huge hype in the past years, with several companies announcing level 5 cars in the coming years
- After trials and some first experience, a sense of reality has come in, on open roads this will not happen before 2030 at best
- Huge investments are still made, but most players now first introduce improved ADAS systems. There is a different business case for controlled environments (e.g. warehouses, industry), robo-transport and robotaxis
 - Controlled environments are simpler
 - Robotaxis can allow for much more expensive cars, because absence of the driver will create a strong business case

Exhibit 9

Sketch of a vehicle and its sensor setup for AD

● Long-range radar ● Short- and medium-range radar ● Camera ● Long-range LIDAR ● Short-range LIDAR



SOURCE: Expert interviews; Waymo Safety Report; Audi press announcements; GM investor presentation



New mobility patterns, mobility as a service

- Increasing urbanization (>70% of the world population in cities) will put pressure on the available space
 - City centers will need more living space, greener and less roads
 - Parking problems are huge and very expensive for drivers and infrastructure
- Alternative transportation has come up, enabled by electrification, like e-bikes, motors, steps, etc
- As cars stand still for >90% of the time, sharing services have become more popular in cities
- Increasing integration of services will allow for multimode transport, handled through your smartphone
- Robotaxis can fulfill a large part of last miles transport as well (Uberification...)
- The same logic applies to autonomous transport to city centers, package delivery, ...
- This can lead to less roads with less cars and more mixed traffic patterns in cities
- Shared cars drive more kilometers and will recycle faster
- This means a huge change in every aspect of the mobility chain.



What does this mean for (integrated) photonics applications

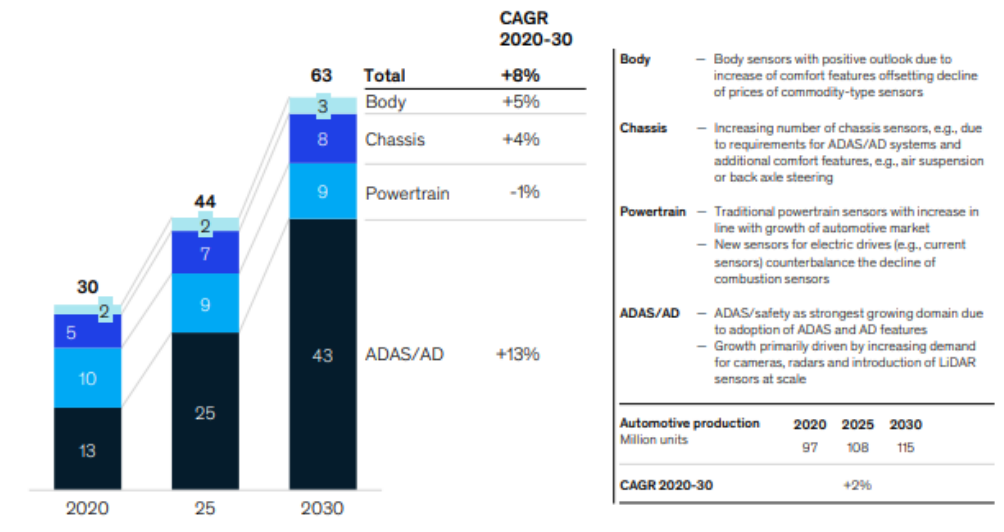
- EV require different sensors and the amount and value of sensors is growing very fast
 - The two biggest areas are EV powertrain and battery management and ADAS systems
 - More autonomous vehicles require more sensors
 - Also trucks and (delivery) drones see a growing amount of sensors
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- Typical segmentation of automotive system function areas

Segment	Examples of photonic options
ADAS & autonomous driving	Lidar, camera's , detectors
EV drive train and battery management	temperature, pressure strain
Cabin & comfort	Air quality , gesture control, driver wellbeing
Infotainment	Heads up display
Connectivity & networking	V2V, V2C, car networks, LiFi, security
Body & chassis	Gyroscope
Lighting	Lights, structured lighting

Exhibit 8

Total automotive sensor market will outgrow automotive sales primarily driven by strong growth in ADAS sensors

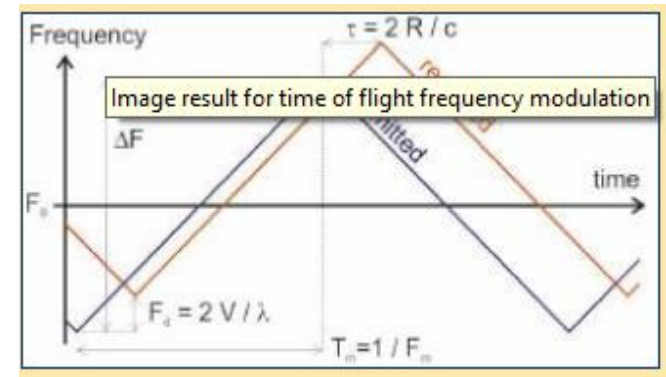
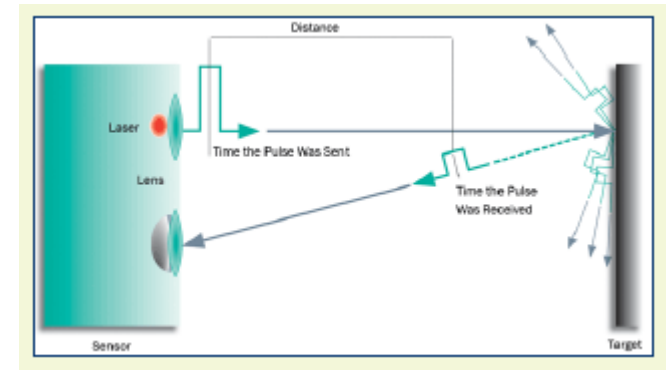
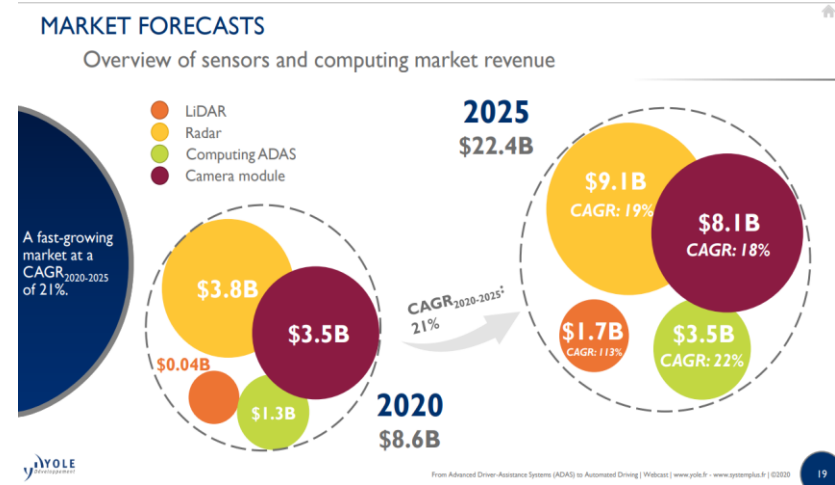
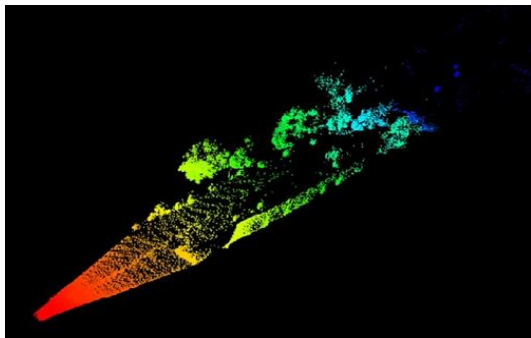
Total automotive sensor market, USD billions



SOURCE: McKinsey analysis

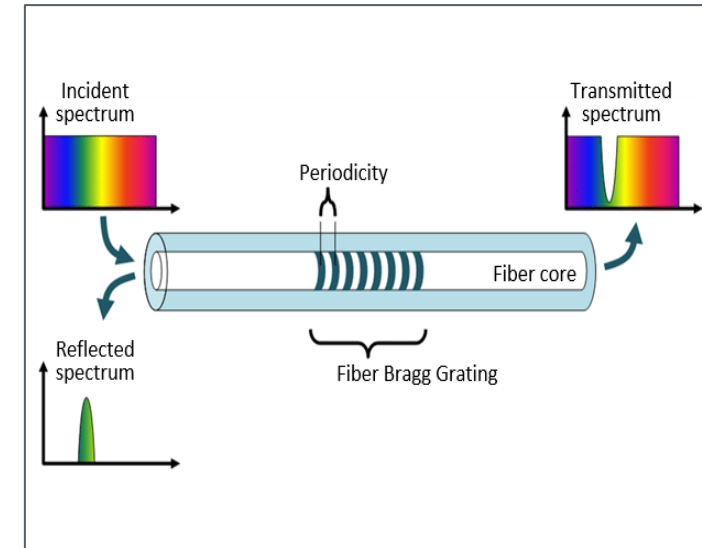
Application example for (integrated) photonics

- **Lidar** for ADAS systems and Autonomous driving
 - Lidar uses (IR) light to measure distance and velocity of objects.
 - It is a complementary technology to radar and camera technology
 - New and predicted to grow very fast
- There are different systems , **ToF** and **FMCW** are most prominent
 - **Time of flight** uses very short laser pulses, measures distance
 - **Frequency modulated coherent wave** uses a frequency modulated wave and coherent detection, can measure both distance & speed
- **ToF** Lidar needs a laser array with a MEMS mirror or a VCSEL array to send sufficient pulses, detection with a SPAD array
- **FMCW** can use integrated photonics for the tuneable laser, phase array beam control, grating and coherent detection



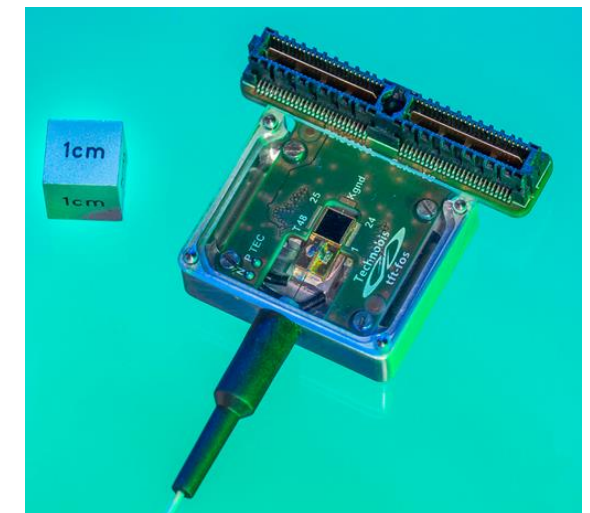
Applications example with integrated photonic content

- Fiber Bragg grating interrogators
 - Measurement of strain, temperature or pressure using a Fiber Bragg grating
 - This measures these parameters at the point of the grating in the fiber
 - Making use of different wavelengths and different gratings means you can measure many points with one fiber
 - These so-called interrogators can be extremely sensitive as well as handle many different measurement locations.
 - They are insensitive to magnetic and electric fields and insulating
 - Integrated photonic circuits are used for light generation and detection and the system is very compact



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Source: Technobis