Automotive Engineering Using Optical Technologies

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The introduction of the laser in the early 1960s has brought light to countless new applications. The photons' strength is not just in their ability to propagate at maximum speed. A major technical advantage is their immunity to electromagnetic interference. Another result from the potential for high-level integration of optical and optoelectronic systems. This, in addition to design options, also permits high efficiency and economies of scale. But what is this field of technology, photonics, all about? Where in the vehicle can photons have an advantageous impact, today or in the future? Is the state of the art comparable to that of the electronics world, and what impetus can be expected to automotive engineering?

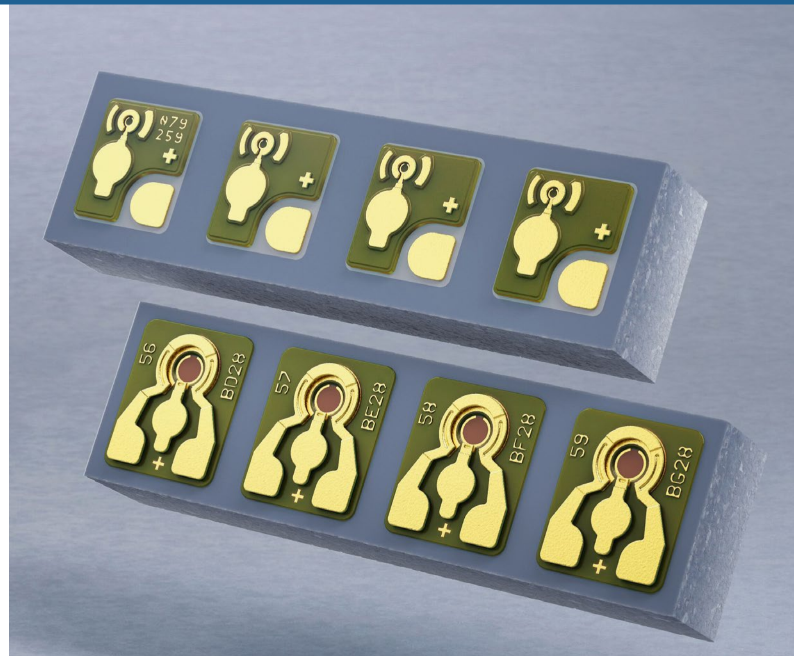
Very often, the term optical technologies has been used as a synonym for photonics. In the widest context, optical technologies cover the generation, manipulation, and transmission of light. Applications that are relevant to vehicles are found in body design, 3-D printing, optosensors, as well as optical data communication and data processing. One of the latest research areas in photonics are quantum technologies, including quantum computing, quantum communication and quantum cryptography. They use the so-called qubit as a fundamental information element, and each photon features several properties that enable it to act as a qubit.

Photons, the quanta of light, are a key to vehicle functionalities that pure electronics can only accomplish to a limited extent or not at all. Optical technologies therefore no longer just limit their scope to cameras and lighting. Today, light also carries sensor information and data. Correlations can be drawn to the evolution of semiconductor technologies.

SOURCES OF LIGHT

The laser is the fundamental tool of photonics. Using lasers, it is possible to control light and, for example, add information to it to transfer data through fiber optic cables at high rates. In such applications, laser diodes as compact, energy-efficient beam sources are particularly relevant to the automotive industry. They can be advantageously integrated into assemblies or even chips. In addition, they are suitable for direct modulation, which means they can change their optical power rapidly and precisely – a basic requirement for use in connection with signals and data.

Regarding photonics integration, Vertical-Cavity Surface-Emitting Lasers (VCSELs) are particularly well suited for direct chip assembly. The components, for example from the German manufacturer Trumpf Photonic Components, are primarily distinguished by their temperature stability and reliability. VCSELs feature a good beam quality, and since they emit their light via the surface, rather than through the edge, as is otherwise the case with laser diodes, they can be used to build addressable arrays. In the infrared spectral range, VCSELs are the beam sources of choice for solid-state lidars or for sensors in the passenger compartment, such as for 3-D face recognition [1].



Compact photonic components: laser diodes and photodiodes from the manufacturer Trumpf Photonic Components; the laser diodes (top) are of VCSEL type and thus particularly well suited for integrated photonics [1]

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The Austrian-German photonics specialist ams-Osram also manufactures VCSELs [2]: lithographically in a wafer process on gallium arsenide substrates. The manufacturer sees applications for its VCSEL arrays primarily in lidar. The addressable chips are otherwise found in so-called Direct Time-of-Flight(dToF)-vision applications, where they are used for highly precise and fast runtime measurements. Technologies like these could pave the way for additional future sensor technology in the passenger compartment [3].

PHOTONICS MEET SEMICONDUCTOR TECHNOLOGY

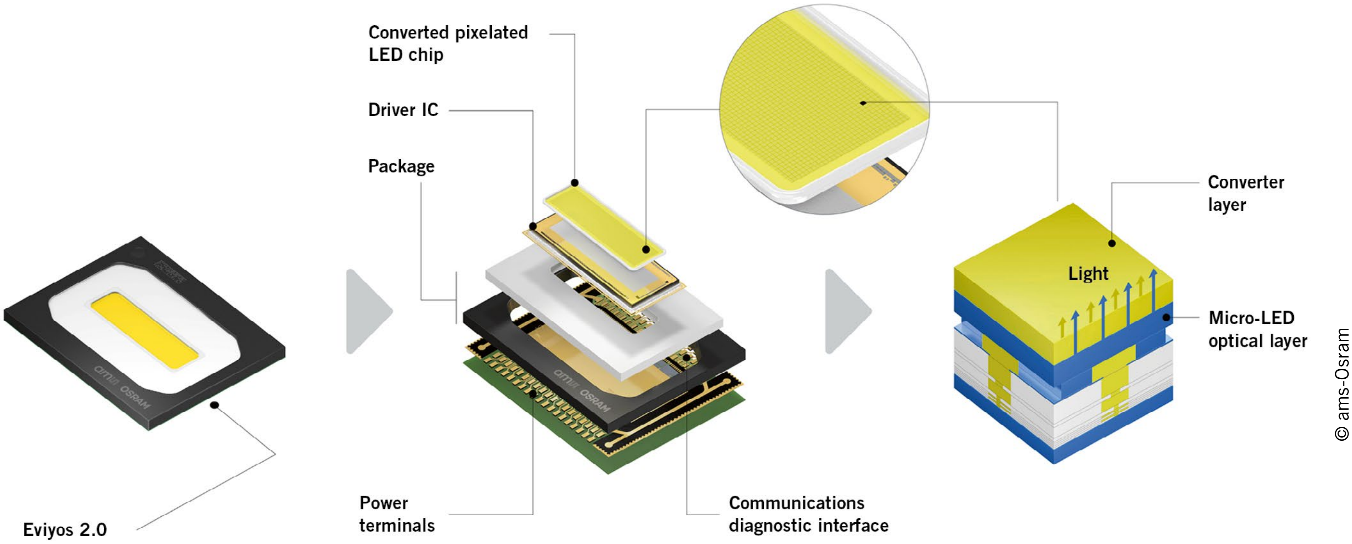
Photonic Integrated Circuits (PICs) are the core components of so-called silicon photonics. They may comprise entire photonic systems, sometimes consisting of thousands of elements that generate, guide, distribute, and detect laser light and change its amplitude, phase, or polarization. Higher efficiency due to the lack of heat dissipation and the direct coupling of signals into fiber optic cables, which does not require the traditional electronic-to-optical conversion, are among the most important advantages of silicon photonics over electronic devices. System integration in PICs not only benefits the bill of materials and space requirements. In general, it also leads to more robust, reliable and functionally superior designs.

"Today, you can define hundreds of thousands of optical elements lithographically," says physicist and photonics researcher Michal Lipson of Columbia University in New York (USA) [4]. Due to the manufacturing technology established in microelectronics, the world of optics has undergone an entire transformation in the last 15 years. Nobody in optics would have used silicon 15 years ago, she says. And now, silicon photonics is everywhere. All major components of microelectronics today would also be realized with silicon photonics, and the rapid pace of development results from a huge demand for integrated optics in all industries. Analysts have estimated the cross-application global market for photonic integrated circuits in 2022 at close to eight billion US dollars; by 2027 it is expected to grow to more than 26 billions [5]. According to their report, a particular potential of PICs is in further reducing power consumption by half compared to today's values and in the 1000 to 10,000 times higher frequencies that can be addressed.

HIGHLY INTEGRATED LIGHTING

LED-based lighting technology has progressed rapidly in recent years. While it serves decorative as well as functional purposes in interior applications, it can also provide safety improvements to front lighting. Here, the integration topic mostly refers to advanced co-packaging with communication and driver circuits; it provides advantages in terms of efficiency, installation space, bill of materials, wiring, and system costs. The Osire E3731i RGB LED, recently presented by ams-Osram [6], is an example of advanced LED technology in interiors. In addition to the real high-power light-emitting diode, the component contains a circuit featuring three LED drivers, a serial bus interface, a temperature sensor, as well as an on-chip memory. The optical performance data of the LED is stored in the memory to facilitate the end-of-line calibration of interior lighting systems for automotive manufacturers. Up to 1000 of these LEDs can be daisy-chained and controlled by a microcontroller to create dynamic lighting effects. Thanks to an open protocol, the component can communicate with any microcontroller, according to ams-Osram.

Intelligent matrix or multipixel LEDs for adaptive operation play a key role in front lighting. Infineon and Nichia have jointly developed the µPLS Light Engine, a module that can individually drive 16,384 micro LEDs by means of pulse-width modulation. On-chip temperature monitoring is also integrated, as are interfaces for transmitting the video signal from the light pattern generator. According to the manufacturers, the driver IC activates only those LEDs that are physically needed for generating the respective light pattern. This special feature should improve the efficiency compared to matrix solutions with micro mirrors. The Eviyos 2.0 chip from ams-Osram even contains 25,600 individually controllable LEDs, which in addition to the headlight function, can also project high-resolution images, such as warning symbols, onto the road. According to the company, all pixels are manufactured monolithically as a so-called micro-LED chip array, which is supposed to result in special color homogeneity and uniform distribution of brightness. For the automotive industry, high-resolution adaptive headlighting is set to become a distinguishing feature for the vehicles of premium brands – and they will have a greater impact on the added value in the future [7].



All pixels of the Eviyos 2.0 from ams-Osram are monolithically manufactured as a micro-LED chip array

PHOTONICS IN SENSORS

Silicon photonics has emerged as a key technology for automated driving. "One example of application is lidar," says Lipson. The biggest challenge here, she says, is steering the laser beam and finding solutions that save volume, weight, and cost [4]. Lidars are used in Advanced Driver Assistance Systems (ADAS) to map the vehicle's environment, with a much higher resolution than radar. The sensing technique is based on either time-of-flight (ToF) measurements using a pulsed laser beam or on frequency modulations of continuous laser radiation. The sensor variants are referred to as ToF or Frequency-Modulated Continuous Wave (FMCW) lidars, respectively. Range, miniaturization, and cost reductions for the modules – as basic requirements for product acceptance in the automotive segment – are primarily critical to both types of sensors.

With the Munich-based lidar specialist Blickfeld and the Ulm-based manufacturer Scantinel, two German representatives of both technology options have recently reported technical breakthroughs. For its new Qb2 sensor generation, for example, Blickfeld has optimized the MEMS scanner used for beam steering and the laser detector module to improve range, resolution, and intensity contrast [8]. Thanks to a new software architecture, sensor data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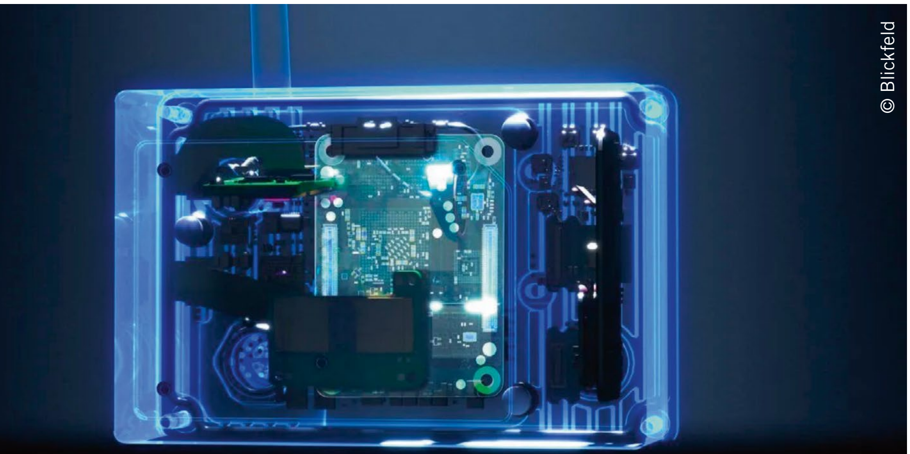
Carlos Pardo
CEO and Co-founder of Knowledge Development for POF S. L. (KDPOF)

2 QUESTIONS FOR ...

What progress are you seeing for your new semiconductor plant?
PARDO _ We are making important progress and will set up an assembly and testing facility as a backend for KDPOF products, which will also be open to third parties. Currently, we are setting up the clean rooms for the labs, and we are initiating the design of the assembly lines. We plan to start with two fully automated lines for optoelectronic components. Later, we will expand to ten lines and intelligent cloud manufacturing systems.

Which do you consider the most important challenges in automotive multigigabit Ethernet?
PARDO _ Many OEMs have already made the move into optical Ethernet as the speed in the vehicle network has increased significantly. We and our partners produce a competitive optical solution that can compete with copper in terms of robustness and price. Finding excellent people to work with is one of our biggest challenges. With full automation, Europe can compete with Asia; this is our biggest challenge and our greatest opportunity at the same time.



Blickfeld's new Qb2 sensor generation comes with improved MEMS scanner and optimized laser detector module

analysis can now take place entirely within the device, which should reduce data traffic over industrial networks.

"Scantinel's FMCW lidar, on the contrary, is based on silicon photonics," says co-founder and Technical Managing Director, Andy Zott. The company uses the same CMOS-compatible semiconductor platform [9] for the laser, scanner, and detector. The entire photonics including FMCW functionality, explains Zott, is integrated within a PIC as a single-chip solution, developed by Scantinel and initially manufactured at Imec in Leuven (Belgium). This enables Scantinel to benefit from the advantages that are typical for the semiconductor industry, including scaling to large volumes, cost optimization, miniaturized design and high reliability. The measurement technique of an FMCW lidar utilizes the so-called coherent amplification: a superposition of the backscattered light at the target with a local copy of the emitted laser light. "It leads to a very low-noise measurement," Zott continues, "which makes it possible to generate a sensor signal from only a few backscattered photons." This is considered a requirement for lidar ranges of 300 m and more, as demanded by OEMs and Tier-1 suppliers. At present, lidar development at Scantinel is at the prototype stage. One of the most important development challenges is packaging with regard to the required automotive certification. Zott predicts ready-to-use, fully automotive-qualified products to be available within the time frame of 2028 to 2030. To further optimize detection range by then, he sees FMCW lidar as the technology of choice.

OPTICAL DATA HIGHWAY

With the multitude of smart functions, from battery management to intelligent lighting to ADAS sensors, the data load on in-vehicle networks increases. Today, their bandwidth already tends to several gigabit per second. In view of the steep increase in transmission rates and the interference-impacted environment in the motor vehicle, optical can clearly outperform copper-based communication technology [10]: Glass Optical Fibers (GOFs) or Polymer Optical Fibers (POFs) are galvanically isolated, EMI compatible, energy efficient and do not require any shielding. This makes them particularly lightweight and, for example, interesting with regard to a range extension of electric cars.

Carlos Pardo puts the bandwidth trend at 100 Gbit/(s×m). The closer the data rate gets to this mark, the more the switch from copper to optical transmission gains momentum. Pardo, CEO and co-founder of KDPOF, sees his company as pioneers in the field of automotive optoelectronics. Focusing, for instance, on transceiver ICs and PHY circuits for Ethernet communications via optical fibers, KDPOF's pioneering work, Pardo says, is to establish certain semiconductor processes in Europe to help counteract Europe's dependence on chips from Asia and the USA. For this purpose, the company is building a semiconductor assembly and test factory at its headquarters in Tres Cantos near Madrid (Spain). Wafer production is only commercially viable in very large volumes and hardly pays off for a small company, explains Pardo. For the subsequent assembly and test steps, however, the machines are relatively inexpensive, he says: "These phases can be accomplished with lower volumes, as we currently have in the automotive industry."

According to Rubén Pérez de Aranda, also co-founder and CTO of KDPOF, fiber-optic multigigabit Ethernet in vehicles has recently taken an important step: The IEEE published a revision of its Ethernet standard with the 802.3cz-2023 (nGBASE-AU), which now includes PHY specifications and management parameters for up to 50 Gbit/s. Pérez de Aranda highlights the importance of this publication: "The 802.3 task force includes many people associated with major automotive manufacturers such as PSA, Toyota, BMW, Ford, GM, and Volvo, Tier-1s, and component suppliers." All of them, he points out, will help establish optical Ethernet in vehicles now at up to 50 Gbit/s. KDPOF collaborates with Würth Elektronik for the development of reference designs. Together, the companies have presented a solution for an integrated automotive multigigabit system that includes VCSELs, optics, and fibers, as well as electronics and connectors. It is said to be suitable for

KDPOF's optical 1000BASE-RH small-formfactor module EVB9351-SFP for automotive-Ethernet applications connecting displays and ADAS sensors in addition to serving as a backbone for sensor fusion.

CONCLUSION

Advances in LED technology and compact, highly efficient laser beam sources help establish light as a tool in automotive development. Examples of photonic functionalities range from multipixel LEDs for adaptive headlights to lidar sensors [11] to fiber-optic automotive multigigabit Ethernet. Silicon photonics in particular, which is based on processes from the semiconductor industry, holds tremendous potential for efficient and cost-effective implementations in automotive technology.

Matthias Laasch

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OPINION

"Light is a powerful and extraordinarily flexible tool for automotive engineering. Automotive technology provides impressive examples for the innovative power of light, even beyond laser-based production. Applications with optical technologies range from vehicle electrical systems to driver assistance sensors to smart lighting. The advances in integrated photonics – often referred to as silicon photonics – show clear parallels to the evolution of semiconductor technology, and there is a huge potential in this. In many cases, photonics can take advantage of established chip technology. Where this succeeds, we can expect exponential development in performance parameters, miniaturization, scalability, and cost reduction."

Dr. Matthias Laasch
is an independent technical journalist and author as well as editor-in-chief, among others at the trade journal "LP.PRO – Laser.Photonics.Professional".