AUTO 2.0 : *photonics inside*

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Photonics manufacturers are always on the lookout for new application fields beyond the more established markets in defence, science and telecommunications, in order to sustain the growth of their sector. About 15 years ago, the introduction of powerful lasers for welding, marking or cutting glass and metal gave photonics a toehold in the motor industry, but its use since then has mainly been confined to the outside of the vehicle, with the notable exception of headlight optics.

This is despite major reductions in costs over the past two decades, not just in production, but also in aftercare and maintenance. We have moved from the early technology that was prohibitively expensive and required the expertise of astronomers or military personnel to the mass production of tens of millions of cheap and extremely reliable car parts. These tumbling costs and the emergence of new needs have created exciting opportunities for in-vehicle photonics. As we will see below, photonic devices will mainly be used to acquire a highly accurate picture of the vehicle's environment and communicate this information to the driver in as natural a way as possible. Radar and sonar technologies already allow us to analyse the immediate environment, but mapping wider areas requires new technologies.

So what are the latest products and how widely are they being used?

A rapidly growing world market for cars

While the statistics for France's automotive industry generally make for gloomy reading, the global market continues to enjoy sustained growth. Production plunged to around 64 million light vehicles per annum in the wake of the economic and financial crisis of 2008, but by 2013 it had bounced back to more than 83 million vehicles, and most industry observers expect it to top the 100 million mark around 2019.

This growth is mainly being driven by rising purchasing power in emerging nations. Above a GDP (at purchasing power parity) of $10,000 per capita, car ownership goes up significantly, stabilizing at around 500-600 per 1000 people (rate achieved in most OECD countries). Countries like China, Malaysia and Turkey are currently hovering around this threshold, reflected in a massive increase in new consumers.

These new consumers have a very different perception of cars from the one that prevails in Europe, and

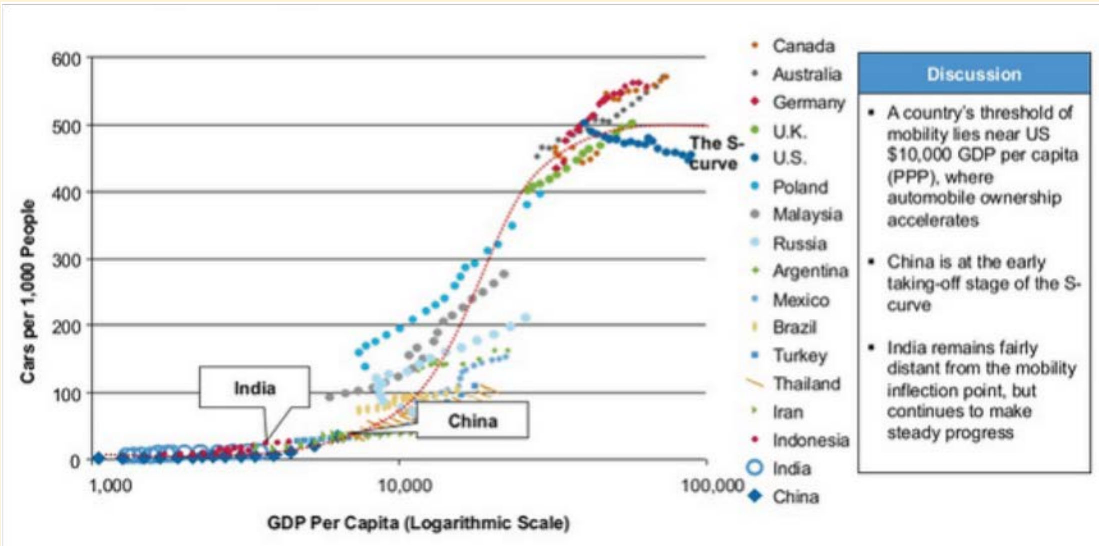

Figure 1. Number of registered motor vehicles per country (source: *China Automotive Industry Yearbook*, 2014).

automatically assume that they will be connected (e.g. vehicle-to-vehicle, vehicle-to-infrastructure, vehicle-to-home). This, of course, is good news for two areas of the photonics industry in particular (information display and 3D mapping).

Vehicles assembled closer to their markets

Although this growth in consumption is having an impact on motor production and assembly, with a major shift to East and Southeast Asian countries (from 8% of production in 2000 to 36% in 2014; see *Fig. 2*), it has not so far dented European production, which has remained stable at around 20 million vehicles per annum for the past 15 years.

Within the European Union, Germany is currently home to 20% of all assembly plants (41 out of 208) and 30% of Europe's production of motor vehicles. In 2014, France produced 1.8 million vehicles at 33 plants. These figures give us a good idea of the size of the different markets that are accessible to photonics:

- parts and systems for light vehicles: 80-100 million vehicles;
- parts and systems for luxury cars: 10% of world production (i.e. 8-10 million vehicles), mainly manufactured by Mercedes, Audi and BMW;

- systems for production lines: approximately 1000 assembly plants (20% in the 28 countries of the European Union);
- testing systems (headlamp beam testers, crash tests): 100 or so testing and R&D facilities.

Strong growth in photonic products and technologies

The market for in-vehicle photonic components (i.e. first five categories listed in *Table 1*) was estimated to be worth **$16.7 billion in 2013, and is expected to rise to $26.7 billion by 2018**, corresponding to a mean annual growth of 9.8% over the next 5 years. This growth is unevenly distributed across the different segments, being mainly focused on advanced driver assistance systems (ADASs) - technologies that will ultimately give rise to automated vehicle (AV) solutions. The ADAS market is expected to grow by 21.4% - growth that should be set against the far more modest growth of the automotive market (3.2%) and megasuppliers (3.0%) over the same period (source: Roland Berger management consultants, 2013).

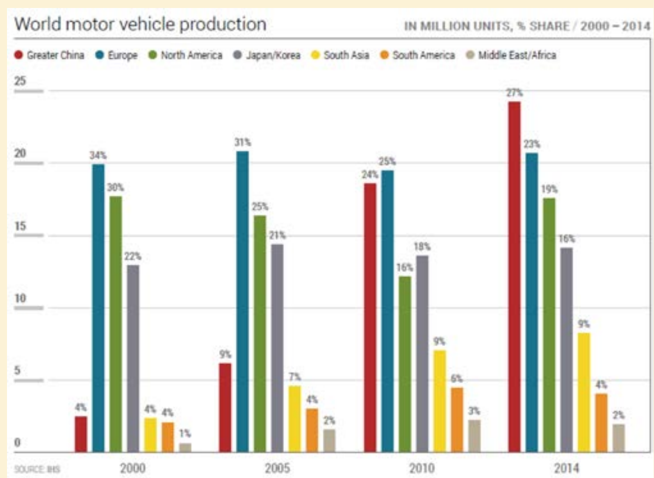

Figure 2. Motor vehicle production in each geographical zone (source: Information Handling Services (IHS), 2014).

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Where?	In the Car					Car Manufacturing	
Types of Systems	Sensing and imaging systems	Communication systems	Screens, Displays, Projectors	Systems based on LED, OLED and other sources	Photovoltaic systems	Laser systems	Sensing and imaging systems
Photonic Functions	Acquiring information	Transmitting information	Delivering information	Light providing	Energy providing	Processing	Acquiring information
Products examples	- Imaging: CMOS cameras, IR cameras ... - Sensing: Various types of sensors (see figure below) - Proximity and gesture control	Optical communication systems in cars: - MOST networks, - FlexRay ...	Displays for: - Entertain-ment, - Driver information, - GPS information, - Others ...	Lighting systems (inside & outside the car) based on: - LED, - OLED, - Lasers ...	Photovoltaic devices for energy providing in cars.	Laser systems for: - Welding, - Cutting, - Drilling, - Marking ...	Non Destructive Testing & QA/QC: - Machine vision, - Reflectometry, - Thermography - Profilometry - Shearography ...

Table 1. Photonics components according to function (source: Tematys, 2015).

Lighting: a market undergoing a major overhaul

Optics made early inroads into the automotive industry via lighting, where the light from halogen, xenon and now light-emitting diode (LED) headlamps needed to be distributed as efficiently as possible. This continues to be the most important segment (more than 62% of value in 2018), and is undergoing increasingly rapid technological advances, as shown in *Figure 3*.

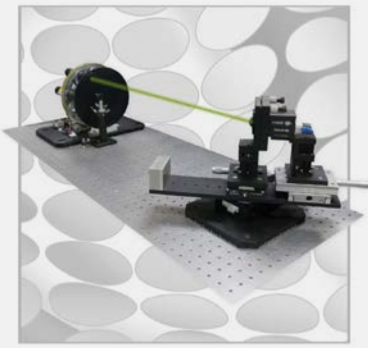
The simultaneous advent of new, energy-efficient light-source technologies (LEDs and possibly lasers), display technologies, digital image processing, and greater in-vehicle integration is giving rise to very high value-added advanced frontlighting systems (AFS) that reduce glare to oncoming vehicles and may, in the medium term, be used to signal to pedestrians.

In-vehicle equipment dominated by Asia

Following in the wake of network telecommunications developments, the early 2000s saw growth in both in-vehicle communication systems (transceivers and plastic optical fibre (POF) transmission) and low-cost components (photodiodes, LEDs for automotive interior lighting) for noncritical systems. Production of these components mainly took place in Asia (Taiwan, Japan, South Korea, then China).

Fisheye lenses for ADAS

In the motor industry, the term *fisheye* refers to the ultra-wide-angle lenses used in ADAS. If they are to deliver reliable identification in variable and complex environmental conditions, they must have uniform contrast across the field of view and for the whole of the visible spectrum. Their high level of intrinsic distortion must also be calibrated, in order to guide the identification algorithms.
It is vital to optically characterize these lenses so that the best ones can be selected and the suppliers' compliance with specifications can be checked. To gauge the actual impact of a lens on image quality, it is not enough to measure the optical transfer function (OTF). Wavefront measurement does, however, meet the needs of manufacturers, as it gives direct access to all the components of the light transmitted through the lens. In partnership with Renault, Phasics has developed a rigorous, automated polychromatic test bench that supplies the OTF, aberration and distortion values for the optical system's exit pupil in a single acquisition for each field of view.



△ Test bench developed by Phasics

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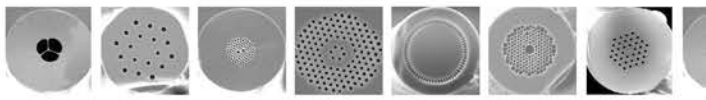

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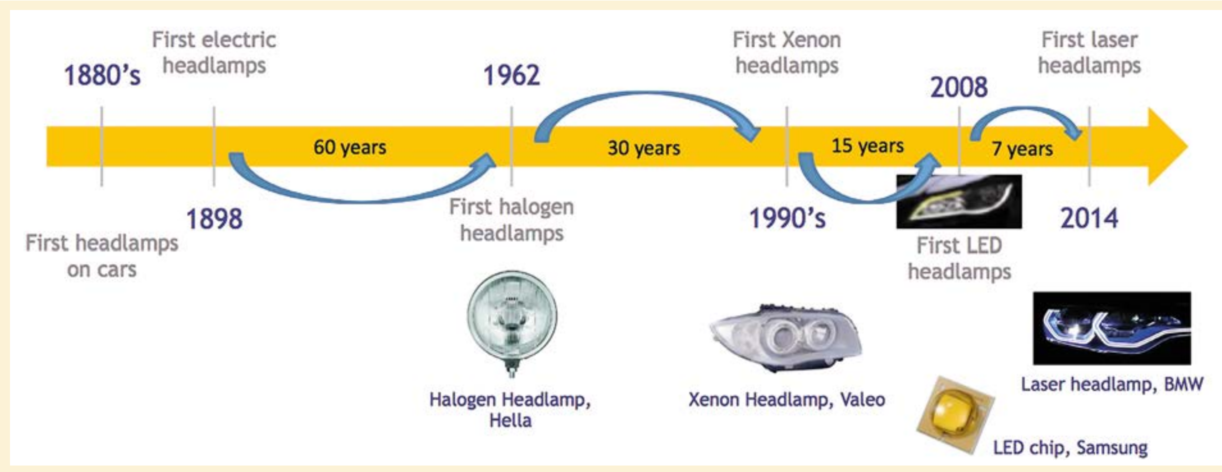

Figure 3. Changes in motor vehicle lighting (source: Tematys, 2015).

Assisted driving: considerable potential for growth

Today, however, the greatest potential for growth lies in driver assistance, which is set to undergo massive expansion within the near future. In 2014–2015, six of the largest parts manufacturers (Bosch, Magna, Continental, Denso, Hyundai, ZF) embarked on major development and integration programmes. Bosch, the world leader, reported a doubling of sales of cameras and radars between 2013 and 2014, and they almost doubled again over the previous 12 months. As for motor manufacturers, Toyota had equipped the whole of its range with ADAS by the end of 2016, while Renault intends to do the same for many of its models over the next 3 years. As Cap Gemini's 2015 report made clear, many consumer countries are already looking beyond driver assistance to self-driving or driverless cars.

The cameras and radars that are currently on the market clearly have limitations when it comes to, say, authorizing a vehicle to automatically change lanes. By providing 360° digital images of the environment, light-detection and ranging (LiDAR) sensors will prove crucial for automated driving in environments that are simple to model, such as motorways and bypasses. Valeo and its partner Ibeo, along with Bosch, which already has more than 10 sensors developed in house (cameras, radars, LiDARs), are expanding the footholds established by Velodyne for in-vehicle LIDARs and Vitronic for infrastructure LiDARs. Experts predict that, in 4 years' time, the market for these cameras, novel sensors and innovative display modes will be worth in excess of €8 billion.

These components still have one or two technical issues affecting their reliability in complex environments (e.g. rain or fog), while costs remain prohibitive (Velodyne's second-generation LiDARs have a hefty price tag of $30,000), but in a few months' time

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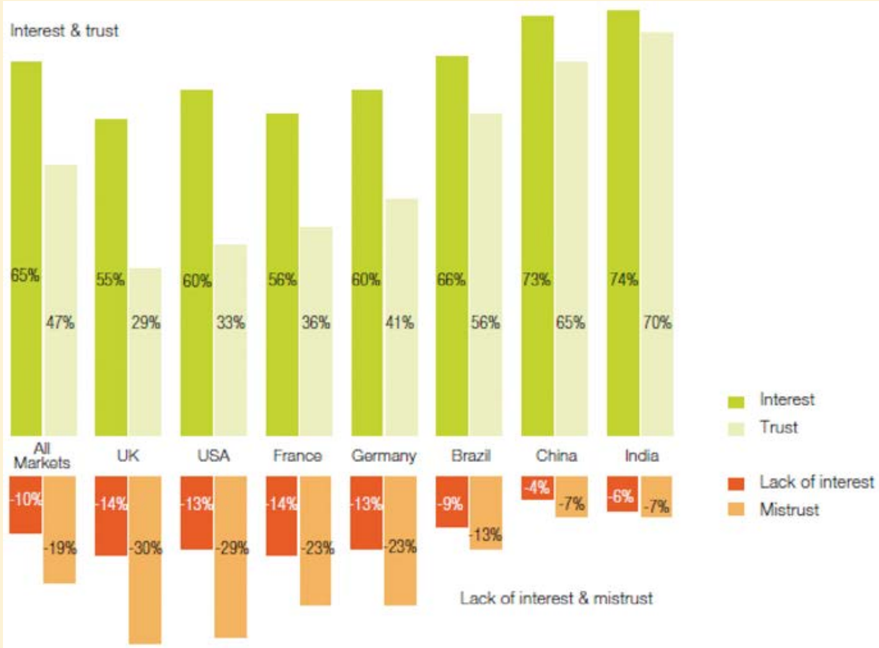

Figure 4. Interest and trust in self-driving cars by country, 2015 (source: Cap Gemini).

we should start to see prices plummet to below €1000 with no significant loss in performances.

Alongside these components, most future growth is expected to be in data analysis software. With the increasing use of sensors, the data they yield will have to be organized and analysed in real time, be it for safety purposes or for monitoring driver vigilance. This will offer opportunities for new players to come into the motor industry. The Israeli company MobilEye is already working with most of the world's leading parts manufacturers to deliver safety diagnoses, while French firms such as Innov+ and Chronocam are positioning themselves in specific market segments (e.g. driver vigilance assistance).

Potential pitfalls facing the photonics industry

Photonics offers the only means of generating a 3D map of the environment (via visible-light and infrared cameras, and LiDARs), meaning that today's radar-based and ultrasound sensors will be relegated to secondary roles in the future. The first markets (premium and luxury ranges) for this new technology represent 10-15 million vehicles. If the 70 million vehicles in the lower categories are to be equipped, costs will have to be substantially reduced (which is precisely what the manufacturers of visible CMOS cameras are doing).

Recent changes in the way that polluting emissions are measured, and the

	INTERIOR				
	IMAGING	SENSING	LIGHTING	COMMUNICATION	DISPLAYS
COMFORT	Cameras for rear passengers observation	Spectroscopy for air quality monitoring IR active systems for gesture recognition	Halogen lamps, Neon lamps, LEDs, Optical fibers OLEDs		LED/LCD for dashboard
ENTER-TAINMENT			Diffractive optics*	MOST (Media Oriented Systems Transport) for communication between media in the car Plastic Optical Fiber	LCD, electrochromic displays, ... for passengers

Table 2. Photonics components for the vehicle interior (source: Tematys, 2015).

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	ADAS				
	IMAGING & SENSING INSIDE	IMAGING & SENSING OUTSIDE	LIGHTING	COMMUNICATION	DISPLAYS
SAFETY	Thermopiles for detection of passengers presence Cameras for driver drowsiness monitoring	Photodiodes, IR sources for rain detection, luminosity monitoring, ... Backup camera LIDAR and cameras for collision avoidance, traffic sign recognition Active and passive IR systems for night vision and pedestrian protection	Adaptive frontlighting systems	Optical communication (VLC, ...) for V2V and V2I communication	Head-up displays (HUD) (holography, projectors, augmented reality)

Table 3. Photonics components for ADAS functions.

environmental impact of these emissions in new consumer countries (China, Malaysia), will require the development of devices to measure emissions of pollutant gases and particulates not just on the outside of the vehicle but also, probably, on the inside, too, as the air quality of vehicle interiors is particularly poor. This will open up new markets for a whole range of spectroscopy components.

These fast-growing markets are not just attracting the attention of photonics manufacturers. The problem of vehicle emissions measurement has led to the development of very reasonably priced electrochemical solutions. In the fields of vehicle-to-vehicle and vehicle-to-infrastructure communication, WiFi offers an attractive alternative to LiFi, with established standards and a wide range of available expertise, plus the ability to spread development costs across huge fields of application and, ultimately, support the cost reductions inherent to the motor parts market. As for in-vehicle communication, the winner so far in the competition between Ethernet and media-oriented systems transport (MOST) fibre-optic transceivers has been the standardized Ethernet technology, as the MOST format has failed to make headway in other application markets.

Although these new photonic technologies will benefit from the large automotive markets in the medium term, they still need to find other major applications if leading manufacturers are to come together and set industry-wide standards. It should also be borne in mind that there is no point collecting good-quality information if it cannot be properly analysed and exploited. It is therefore vital for photonics and IT manufacturers to team up to ensure the lasting development of in-vehicle photonics. ■

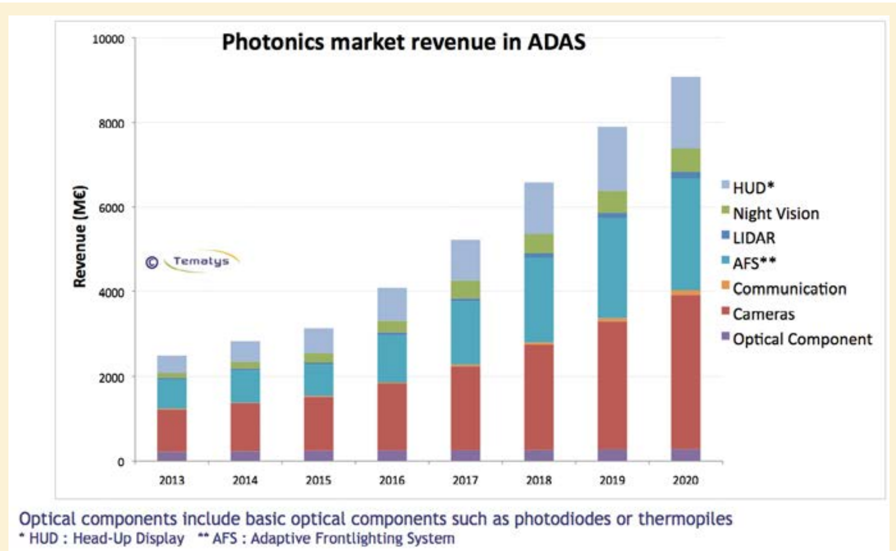

Figure 5. Photonic component market for ADAS functions (source: Tematys, 2015).

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