Evolution of Automotive LEDs 2015–2025
•
Outlook on Innovation Opportunities

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1 • Executive Summary

This report identifies and describes the main types of LEDs in automotive applications, and their evolution.

It starts with discussing the development and future projections of physical parameters like input power, luminous flux, flux density, and thermal flows for white LEDs for headlighting, and coloured LEDs for signalling. LED evolution is approaching a saturation in the foreseeable future, so competitive advantage will shift away from these physical characteristics. Instead, LED innovations enabling new or strongly improved applications are sharply growing in importance: miniaturisation and digitalisation, plus possibilities offered by new wavelength ranges.

A decade ago, white LEDs for headlighting illumination were in their embryonic phase with very simple products including a connector and thermal and mechanical interfaces to enable reliable operation of the LED dies positioned on such a device. The next generation of white headlight LEDs were designed as SMDs for direct soldering onto PCBs. A next big evolutionary step was driven by the car industry seeking light sources supporting the development and commercialisation of matrix and ADB front lighting systems. In response, the LED industry brought forth two innovative solutions: single-die SMD LEDs with a very small footprint for extremely narrow spacing on circuit boards; and SMD LEDs containing 2-5 dies, each individually addressable to support matrix applications. A further evolution was the creation of digital light enabled by pixellated LEDs. The first such products with more than one kilopixel were announced in 2020; a further significant increase in pixel count with up to 25 kilopixels is projected for 2023.

Another important trend of car industry is to reduce the height and size of headlight cavities. To keep adequate illumination levels, high-luminance LEDs have been developed (despite their non-optimal efficacy).

For signalling applications, LEDs were already in use before the turn of the century. A new technology has been developed based on the same principle as with white LEDs: the radiation of a high-energy, low-wavelength LED die is covered with conversion phosphors to create light of the desired colour. Phosphor-converted LEDs like this deliver higher efficacy and relatively little intensity degradation over the entire operating temperature range.

The configuration of signalling LEDs over the years has shifted from mechanical clinch frames to SMD for PCB soldering. Another application trend is the launch and use of standardised replaceable LED light source modules—"LED bulbs", so to speak. The current generation of these modules was first commercialised in 2018, and they're on their way to high-volume application notably in mass-market, popular-priced vehicles.

RGB LEDs are unlocking opportunities for innovative interior ambient lighting. For premium cars the expectation is that in the next years more than 300 RGB LEDs will be installed to create time- and space-dependent, variable-colour lighting in the cabin. A key question for car makers is how to control the colour impression in view of varying parameters like binning batches, temperature dispersion between the three colours, and ageing. A consortium of companies named ISELED have developed solutions for this problem, greatly facilitating the use of sophisticated RGB cabin lighting. Another innovative technology still in the research phase involves displays based on RGB microLED assemblies.

With the ongoing trend for automakers to install sensors for better-performing driver-assistance and automated-driving systems, the LED industry has been launching and developing IREDs (infrared-emitting diodes) to grasp this business opportunity. Another significant business opportunity has arisen at the other end of the light spectrum, accelerated by the coronavirus pandemic: disinfection of vehicle interiors has become a top priority, and there's been considerable developmental effort toward UVEDs (ultraviolet-emitting diodes) which can radiate in the required UV-C wavelength range for efficient cleaning of surfaces and air flow.

Finally, this report gives an overview of the main automotive application areas and describes where the various LED types are deployed to generate the best value for automakers, suppliers, and end users.

2 • Introduction

LED light sources are revolutionary in their own right; a radical departure from filament bulbs and all other previous light sources. Too, LEDs are revolutionising the whole of the vehicle lighting business for all three main functions—headlighting, rear lighting, and interior lighting. This trend is still ongoing, though a saturation can be expected in the middle of this decade. Furthermore, LEDs now are becoming a new pillar to create other application segments like driver and passenger monitoring and cabin disinfection.

In this report we describe the evolution of LEDs in the last decade and give an outlook on the expected trends for the next five years. Main topics include the evolution of basic LED characteristics like efficacy, luminance, and thermal resistance; specific light source developments driven by the requirements for the main applications, and light source evolutions enabling new fields of vehicle lighting innovations. Finally, the various automotive application areas enabled by the new LED technologies are described, with a forecast on future innovation opportunities.

3 • LED Evolution: Physical Characteristics

The main parameters characterising a light-emitting diode are its light output, its luminous efficacy, its luminance, and the thermal resistance between its junction and its base plate. Certain application-specific requirements, such as irradiation characteristics, also define the developmental direction of LEDs. In this context it is important to note that coloured LEDs for signalling—red and amber—follow very different evolutionary paths than white LEDs for road illumination, DRLs, and other high-flux applications. Coloured LEDs were first used in vehicle signals in the mid-1980s, years before white illumination LEDs existed. Therefore, they are on different areas of the technology evolution curves; plus, the fundamental materials and technical principles are quite different. Figure 3.1 shows efficacy curves of the two material systems.

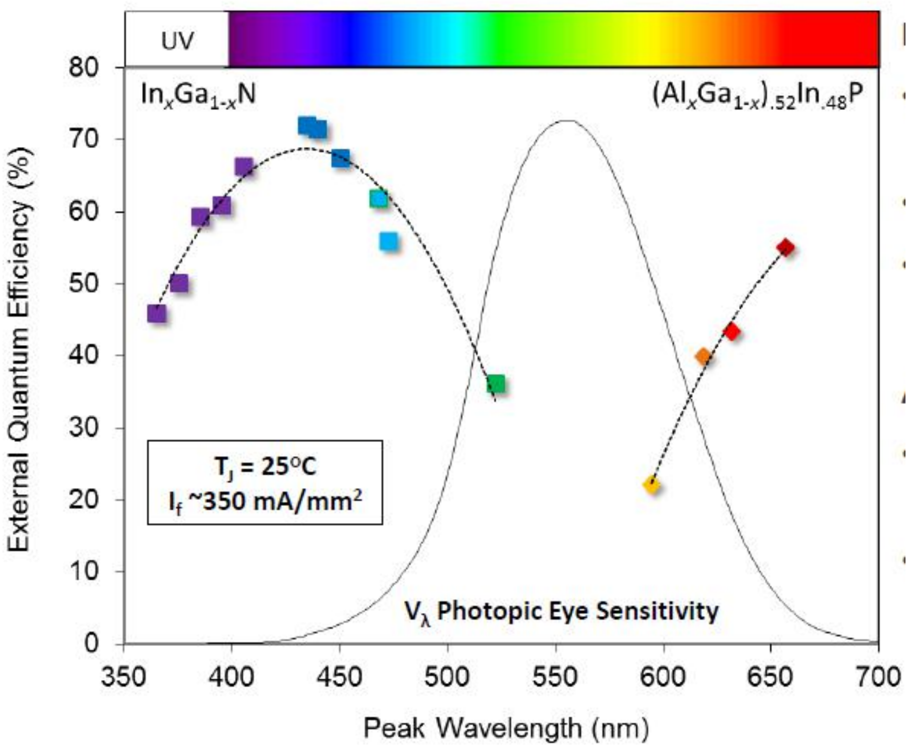


Figure 3.1 : Typical efficiency of InGaN and AlInGap material (Lumileds)

To generate red or amber light, LED dies consisting of a compound of Aluminum-Indium-Gallium-Phosphor (AlInGaP) are used. White light emission comes from phosphor-converted blue LED dies made from Indium-Gallium-Nitride (InGaN).

3.1 White LEDs

Performance aspects of white automotive LEDs include:

- Junction Temperature: 150 °C continuous, 175 °C intermittent (less than 1 hour)
- Light emission angle: 120°
- Lifespan (B_3): more than 15,000 hours

The analysis in this chapter is based on these parameters.

Luminous Efficacy and Luminance

The dies of the blue LEDs operate normally around 450 nm, and yellow phosphor converts the blue radiation to a white spectrum as shown in figure 3.2.

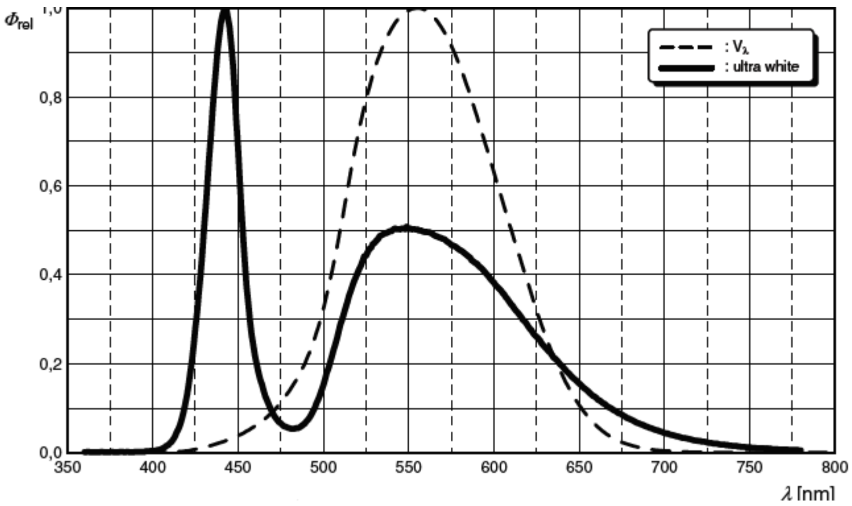


Figure 3.2: Typical spectrum of phosphor converted white LEDs (Osram)

General-purpose LEDs are operated at relatively low forward current densities—around 0.1 A/mm^2. Figure 3.3 gives history and forecast of the efficacy development of general-purpose phosphor-converted white LEDs:

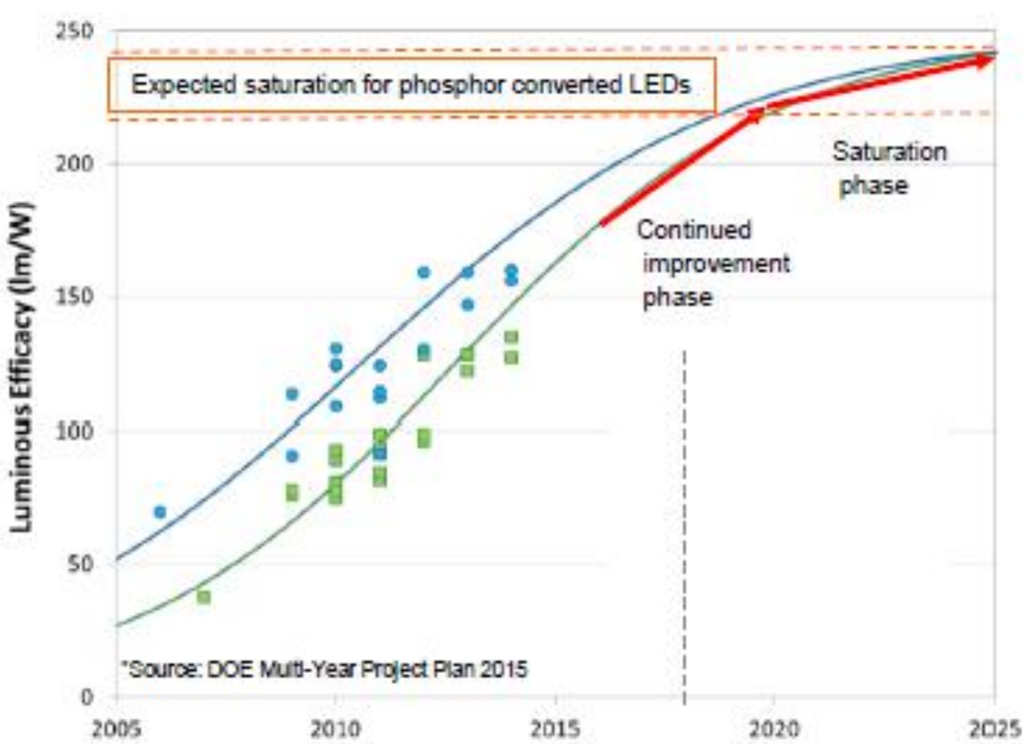


Figure 3.3: Efficicacy development of general-purpose white LEDs (Osram)

From about 150 lm/W around 2015, the forecast is a saturation until 2025 between 220 and 240 lm/W.

High-power LEDs with current densities in the range 0.3 to 1 A/mm^2 are used for road illumination lamps on vehicles. Figure 3.4 depicts an extrapolation of DVN's forecast about the efficacy development of high-power LEDs. In general, LEDs with higher current density show a lower efficiency due to the "droop effect" explained in the next section.

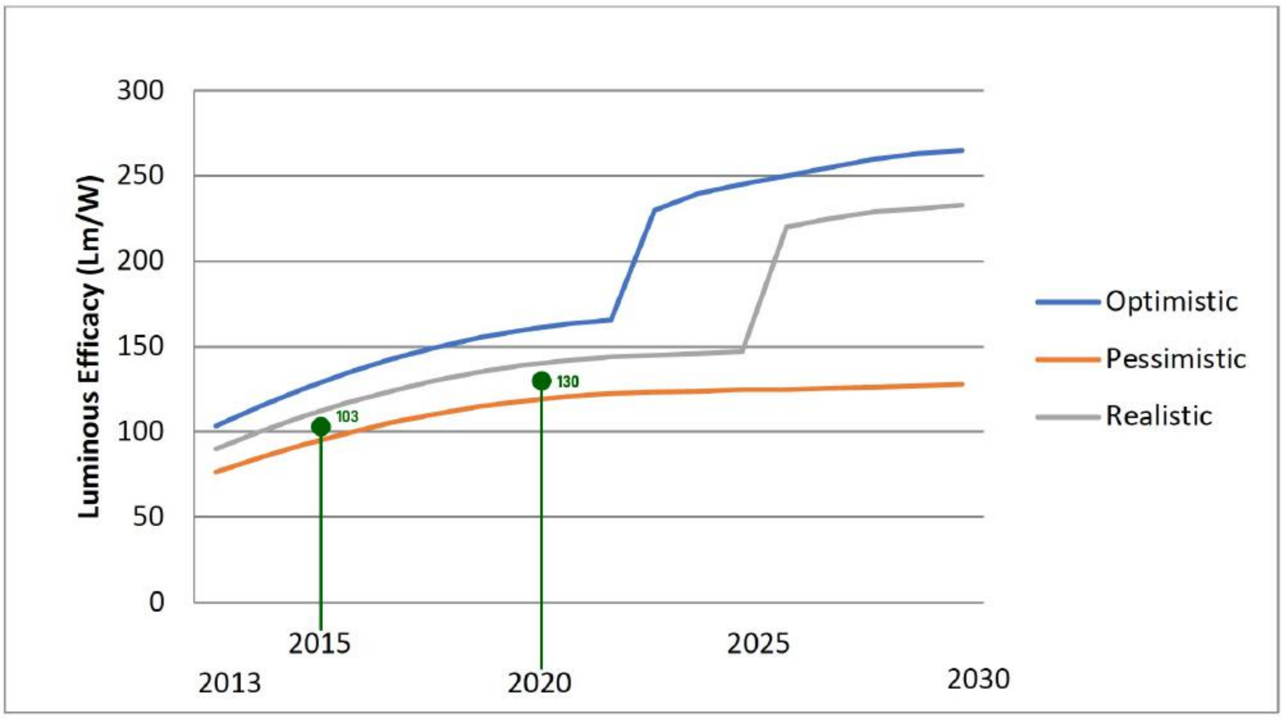
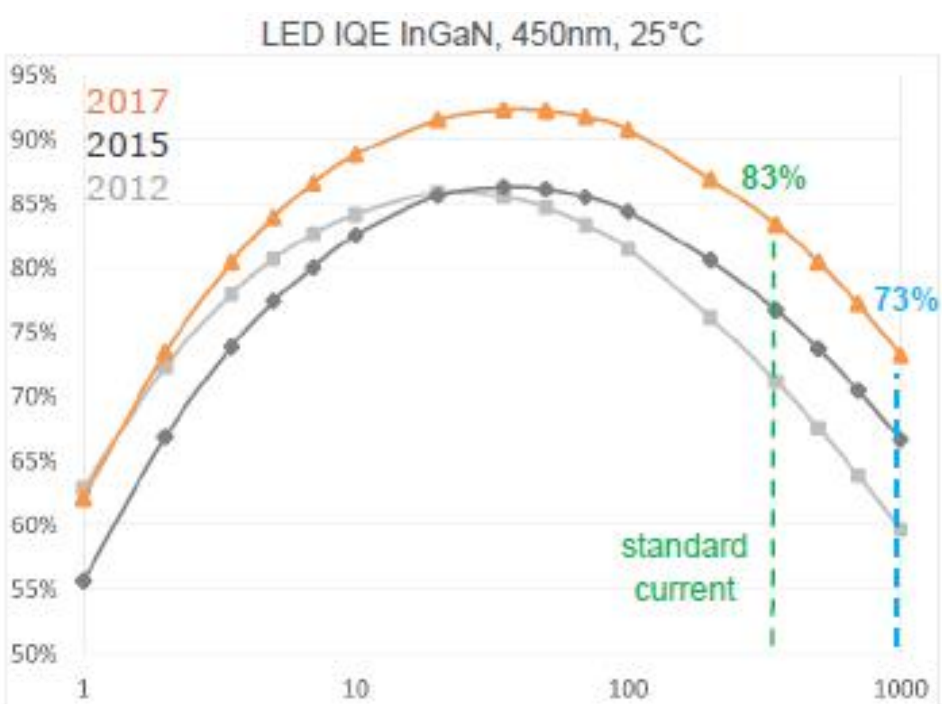


Figure 3.4: Efficacy Projection of High-power LEDs (DVN)

Due to the droop effect, the efficiency of high-power LEDs is far below the values of general-purpose LEDs. On the other hand, the evolution curve follows about the same trend as for low-current-density LEDs. The step increases would involve a new die technology, which at this moment is not on the foreseeable horizon. One of the reasons is that development resources are focussed more on application-orientated innovation than on boosting the basic LED characteristics. The dots in figure 3.4 indicate the achievements of the most advanced products in 2015 and 2020, showing that reality is better than the pessimistic view and close to the realistic view.

Droop Effect

The reason for the efficacy differences between general-purpose LEDs and high-power LEDs is output droop at high current densities. The physical explanation for this phenomenon is the Auger Effect: at high densities of holes and electrons in the depletion area of an LED junction, the recombination equilibrium shifts from creating photons to generating heat. Therefore the luminous efficacy of white LEDs decreases with increasing current density. Typical curves of IQE (internal quantum efficiency) of InGaN material used commonly for white LEDs is shown in figure 3.5.



Current Density (mA/mm^2)

Figure 3.5: Typical development of IQE as function of current density (Osram)

As we can see from this graph, optimal luminous efficacy is achieved with a current density of about 50 mA/mm^2 , whereas high-power LEDs today operate at at least 1A/mm^2. This explains the lower efficacy of high-power LEDs (fig. 3.4) versus general purpose LEDs (fig. 3.3).

The droop effect will become even more dominant for high-brightness LEDs discussed later. With these products much greater current densities—up to 6A/mm2—are applied, which reduces luminous efficacy further, but greatly increases luminous flux density per mm^2 as shown in figure 3.6.

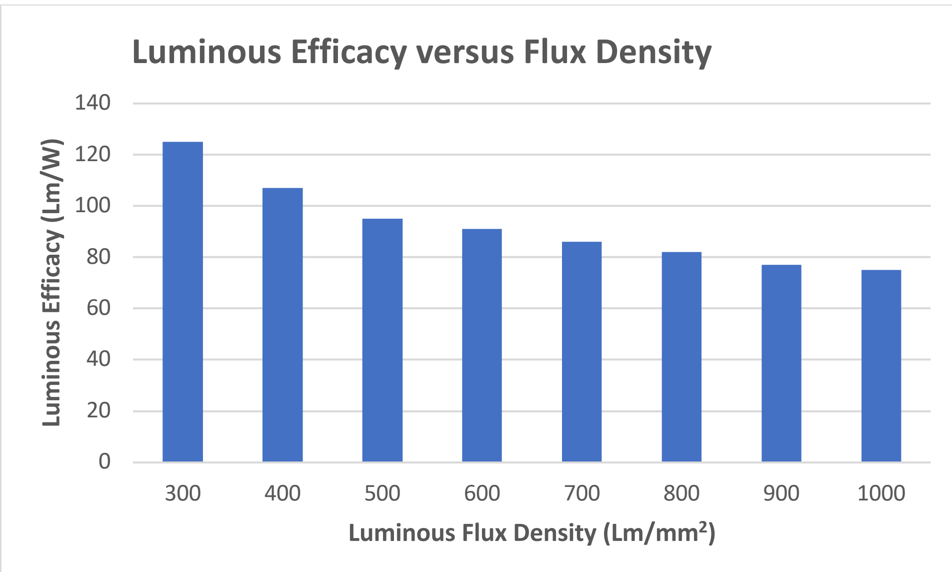


Figure 3.4: Luminous efficacy as function of luminous flux density (DVN)

Standard high-power LEDs operate at current densities of about $1A/mm^2$ and yield a flux density of $300\text{-}400\ Lm/mm^2$, while high-brightness LEDs can withstand much higher current densities of up to $6A/mm^2$ and deliver flux densities of $800\text{-}900\ Lm/mm^2$, but at drastically reduced luminous efficacy.

Thermal Resistance

Another critical parameter of high-power LEDs is the thermal resistance R_{th} between the junction of the LED and its base plate (or case) as thermal interface to the surrounding—see figure 3.5. The junction temperature must be kept below its critical level of 150-175 °C, or the LED will be destroyed. Lower R_{th} means smaller heat sinks can be used, thus reducing cost and size of the total system.

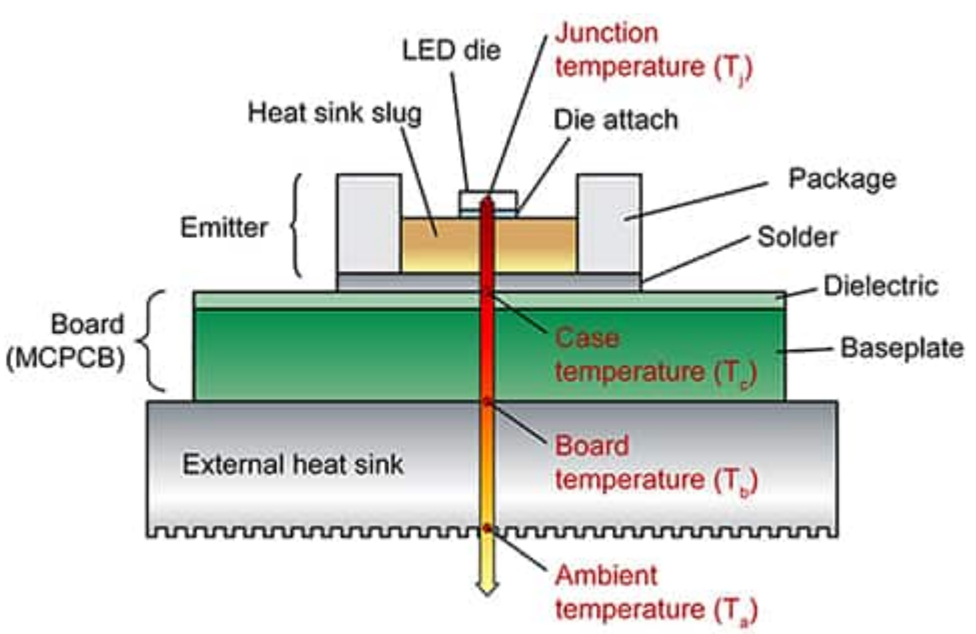


Figure 3.5: Thermal resistance scheme of a SMD LED (US department of Energy)

Figure 3.6 shows an example of how thermal resistance has been decreased by ever-improving LED die packaging from the early years of LED application.

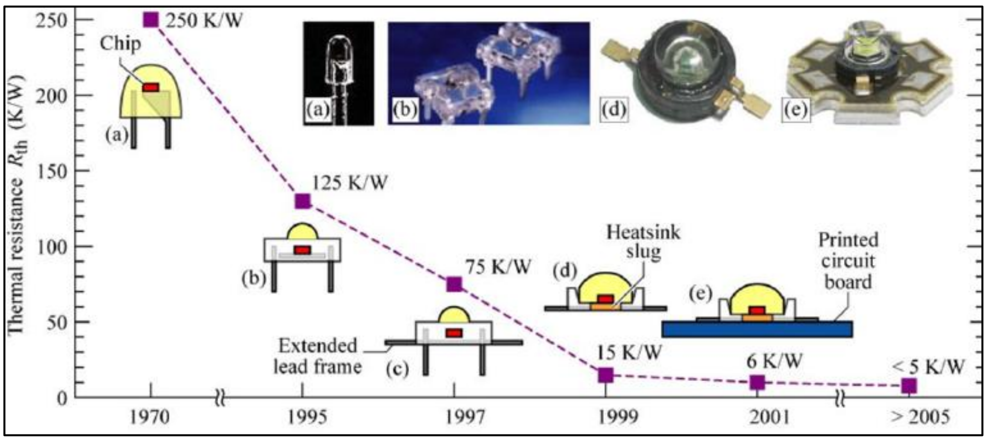


Figure 3.6: Historic development of thermal resistance (HP)

For modern high-power LEDs with wattages of 10-20 W, the thermal resistance is typically in the range of about 1 W/°C. As a further sophistication of the concept of thermal resistance, two different parameters have been introduced to characterise LEDs: the *electrical* thermal resistance $R_{th\ (electric)}$, which is determined with the LED not dissipating high power, and the *real* thermal resistance $R_{th\ (real)}$ measuring the thermal resistance taking into account also heat generation within the LED and thus also the LED's efficacy. The real thermal resistance is more adapted to use conditions with high power operation. As an example, the development trend of these two measures of thermal resistance is depicted in figure 3.7 for SMD LEDs with a 1×4 die configuration.

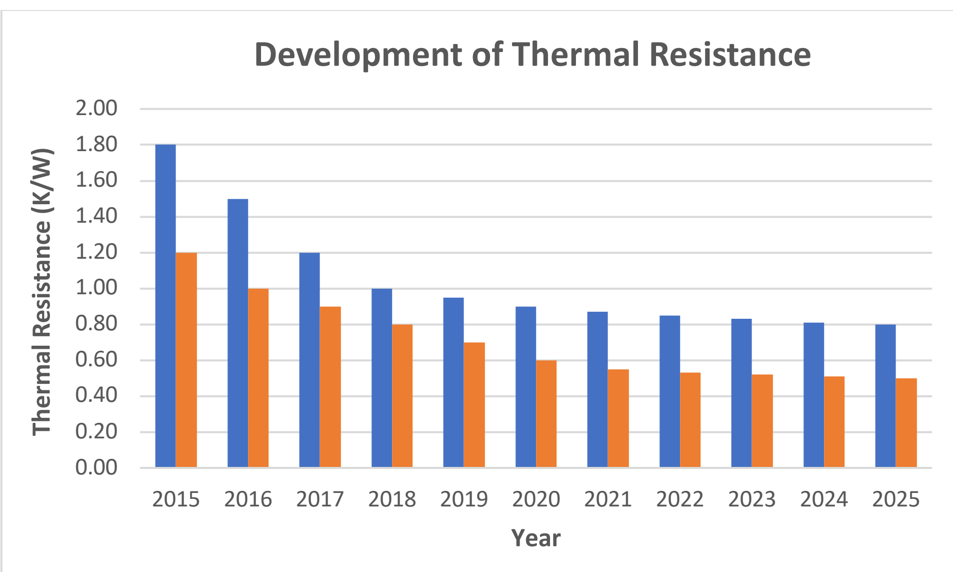


Figure 3.7: Typical values of $R_{th\ (real)}$ in blue and $R_{th\ (electric)}$ in orange (DVN)

3.2 • Coloured Signalling LEDs

Most coloured LEDs—but not all of them; we'll get to that later—emit their coloured light directly, without phosphor conversion. The dominant wavelengths are 591 nm for amber, 615 nm for red-orange, 632 nm for red, and 630-635 nm for "super red". Though the quantum efficiency at the different wavelengths is quite different (see figure 3.1), the luminous efficacy is about the same due to the sensitivity curve of the human eye which compensates by higher sensivity for the lower quantum efficiency in the orange area. Therefore these LEDs are characterised by the suppliers mainly with one efficacy value independent of wavelength. In deeper analysis, slightly different data are given per wavelength range.

Luminous efficacy

Unlike with white LEDs, the luminous efficacy evolution of coloured signalling LEDs since 2015 was not driven by evolution of the die technology, but rather primarily by the design of different LED configurations. Depending on the specific configuration of the LED , the luminous efficacy ranges from 50 to about 90 Lm/W at 25 °C for direct-emitting LEDs (see also chapter 5).

A significant characteristic of direct-emission LEDs is the temperature-dependence of their light output, which significantly decreases as junction temperature increases. Figure 3.8 shows a typical curve depicting the light output of a coloured direct-emission signalling LED as function of junction temperature. The striking feature is the strong decrease of light output with higher temperatures, which has to be taken into account and compensated by the design and construction of the lamp and and electronics system.

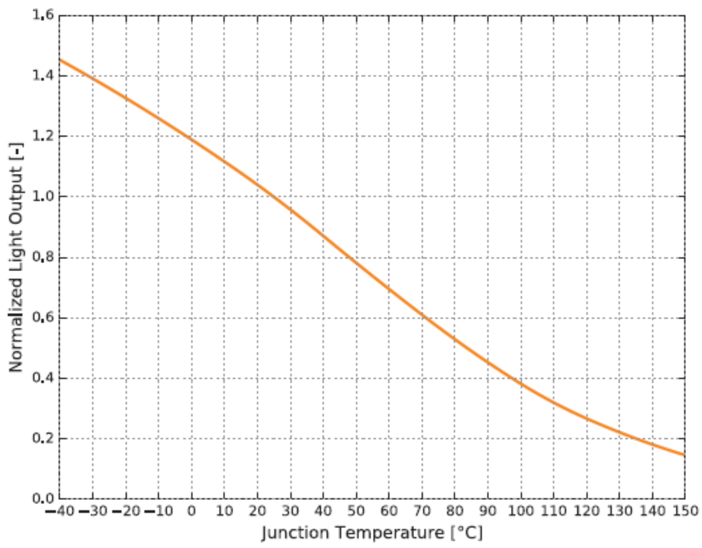


Figure 3.8: Typical light output of amber AlInGaP LEDs as function of junction temperature (Lumileds)

When the ambient temperature—and thus the junction temperature—is increased , the output power of AlInGaP LEDs decreases dramatically due to carrier leakage or overflow caused by a small band offset between the active layer and cladding layers, which is dictated by the need to maintain lattice match between the layers of AlInGaP and the GaAs substrate on which they are grown. Large bandgap discontinuity in the nitride system leads to very weak temperature dependence.

A temperature-dependence breakthrough is offered by phosphor-converted amber (PCA) LEDs, which offer superior luminous efficacy of 125 Lm/W and a reduction of the temperature dependence of the light output as shown in figure 3.9. Compare the output at 120 °C junction temperature—about 83% for PCA, versus about 25% for direct-emitting amber LEDs as shown in figure 3.8. Chapter 5 of this report contains more information about phosphor-converted colour LEDs.

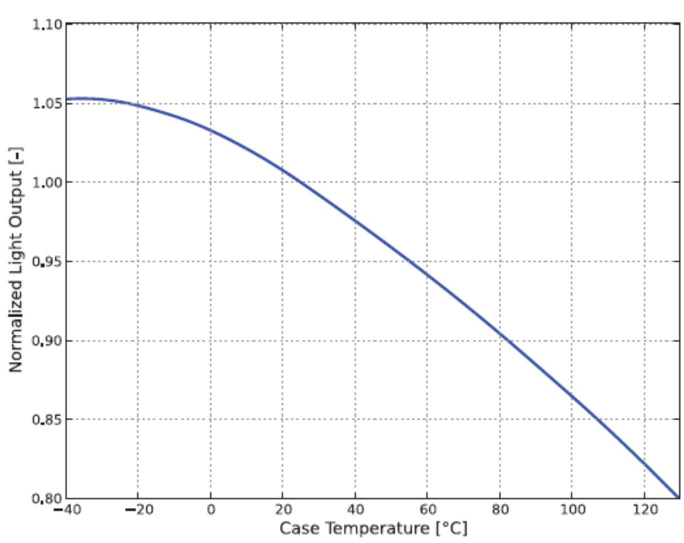


Figure 3.9: Typical Light Output of PCA as Function of junction Temperature (Lumileds)

Thermal Resistance

The thermal resistance of signalling LEDs is in general 10-50 times higher than that of high-power white illumination LEDs. The reason is the much lower required power consumption of signalling LEDs, normally in the range of 0.3 to 1 Watt. With such low wattages, the thermal management of the respective luminaires is much easier and a strongly reduced thermal resistance will not deliver strong competitive advantage, so there's little incentive to push for it.

3.3 • Application-driven technology evolution

In recent years the focus of automotive LED development shifted from performance and styling to two areas dictated by the application possibilities—see figure 3.10. The first trigger was the possibility to digitalise vehicle lighting, which has created new breakthroughs like ADB and will carry on opening new spaces for innovation.

Figure 3.10: The three axes of automotive LED evolution (DVN)

Another innovation area not yet fully in the focus of industry is the application of invisible-light emitting diodes: IREDs and UVEDs. Sensors based on IR will strongly contribute to driver-assistance and automated-driving applications for exterior and interior lighting, while UV-based disinfection of cabin surfaces and air will generate strong innovation. We will deal with both of these opportunities in the next chapters.

4 • White Headlighting LED Evolution

In the recent period between 2015 and 2020, two different main trends for the evolution of white headlighting LEDs can be identified. One is improvement in the basic characteristics of luminous efficacy and thermal resistance as described in chapter 3. Both parameters are crucial for the size and cost of the LED system, because they determine the number of LEDs needed for a prescribed luminous flux output from the lamp, and the size and mass of the heat sinks.

The second trend is to adapt the configuration of the LEDs for best possible fit with the required application design. Application examples are presented in chapter 8, along with description of the characteristics of the different type of light sources and our forecasts for the 2020-2025 timeframe.

4.1 • Connector-type LEDs

High-power LEDs around 2010 mostly had a well-defined connector, mechanical interface, and thermal interface—see figure 4.1. These LEDs were available with two to five dies sized 1×1 mm2. In this way they could be used flexibly to fulfil the luminous flux requirements of various applications.

Figure 4.1. LEDs with defined electrical/mechanical/thermal interfaces (Lumileds, Osram)

The next step was for this type of LED to include more functionalities. A binning resistor could be used to detect automatically the respective flux and colour bin. As another important function a temperature sensor was included which signalled that power derating was necessary to protect the LED chips against overheating. An example of this kind of augmented LED is in figure 4.2.

Figure 4.2: LED with binning resistor and temperature sensing (Lumileds)

4.2 • SMD LEDs

As a next step in the evolution, SMD LEDs were introduced starting around 2013. Their output and thermal characteristics were similar to the connector-type versions, but the SMDs are designed to be mounted by soldering onto PCBs as shown in figure 4.3.

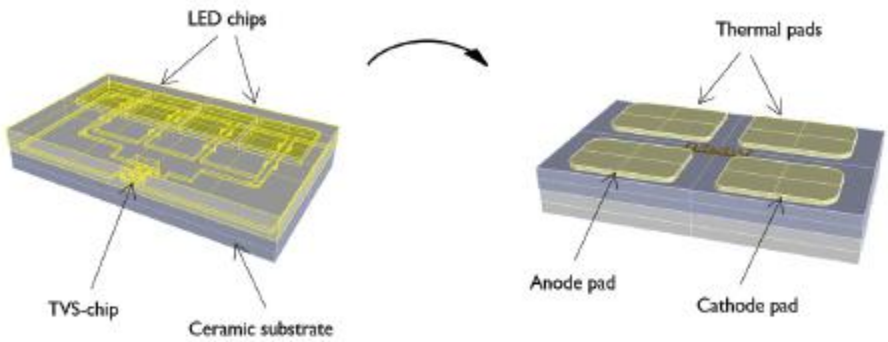


Figure 4.3: SMD LEDs (Lumileds)

A ceramic substrate forms the base. On the lower surface of the substrate, electrical contacts—the anode and cathode pad—are mounted, and also thermal pads for the heat flow out of the LED. On the upper side of the construction, a number of LED dies are placed and connected with each other and the electrical contact pads. A TVS chip (transient-voltage suppression) is connected in parallel to avoid die damage by voltage surges or spikes. Specific guidelines have been established for the handling of such LEDs to avoid damage to the sensitive dies during the soldering processes.

Figure 4.4: Examples of SMD LEDs (Nichia, Osram)

With the advent of these SMD LEDs another important evolutionary step occurred: individually-addressable dies. This was one of the enablers of matrix headlighting technology, and brought forth another important design parameter for LEDs: the contrast ratio between the dies. This greatly determines how sharp or blurred the LED images will be in a headlight beam.

4.3 • LEDs for Pixel Light

A new differentiating parameter for matrix or pixel light applications is the spacing between the individual dies. The target of the automaker is to create a smooth image on the road without dark spots and visible boundaries between the images of the different dies. But if a segment of the beam has to be dimmed out for glare control, this segment should have sharp boundaries. These conditions can be fulfilled optimally with a close spacing of the individually-addressable dies, while an increasing number of dies will create more possibilities to fulfil the other existing criteria. Two different directions of LED developments have been established: SMD LEDs with one die and minimised surrounding of the die, and microLEDs with thousands of individually-addressable pixels.

Single-Die LEDs

For the first approach, the LED industry developed single-die light sources with minimal mechanical surroundings of the light emitting surface, as shown in figures 4.5 and 4.6.

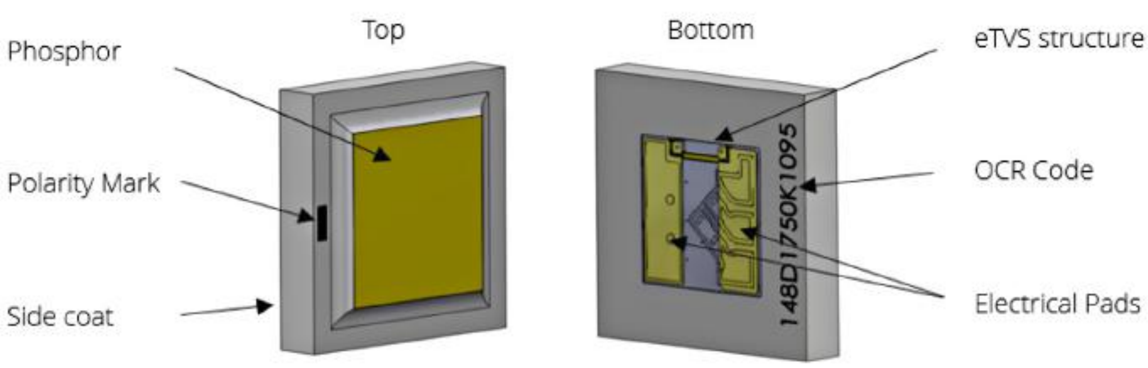


Figure 4.5: Construction of a single-die LED for pixel lighting (Lumileds)

On the bottom side are the electrical and thermal contact pads together with the TVS structure. The main area of the top side is used by the blue LED die covered with its yellow phosphor. A remarkable other feature is that a side coat is applied to reduce stray light, which enables a high contrast ratio between the chips.

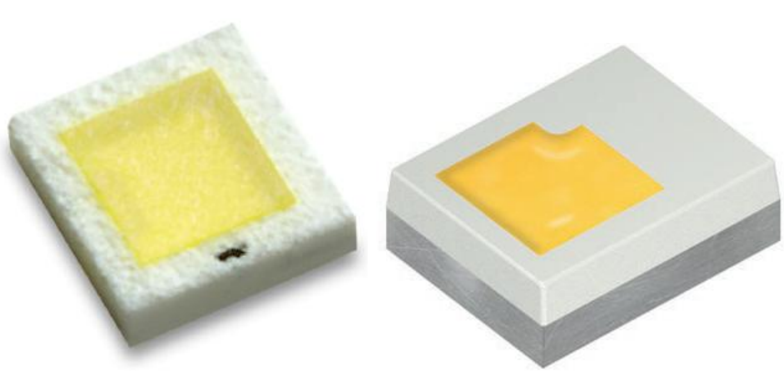


Figure 4.6: Single-die LEDs (Lumileds, Osram)

Another remarkable feature is that the die area of such LEDs has been reduced from the normal 1×1 mm dies to 0.7×0.7 mm. In this way an even higher spatial resolution of the beam becomes possible. See figure 4.7 for a typical example of the application of this product concept, wherein 84 single-die LEDs are placed on a PCB.

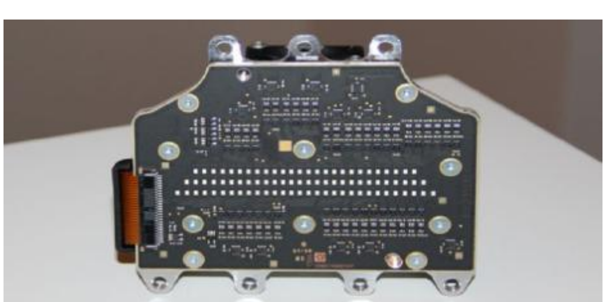


Figure 4.7: PCB with 84 single-die LEDs for matrix/ADB lighting (Hella)

It eventually became clear during the further evolution of matrix/ADB lighting that placing and electrically managing more than about two hundred LEDs would pose significant technological and especially cost barriers. Therefore, around 2015 the industry started to investigate the possibility of pixellation of LED dies—"MicroLEDs", they're called, often shortened to µLEDs.

Monolithic µLEDs

With growing interest in the vehicle lighting industry for ADB systems and nascent ideas about road guidance projections, the LED industry started a technology jump from individually-addressable dies to a matrix of individually-addressable LED pixels—as shown in figure 4.8.

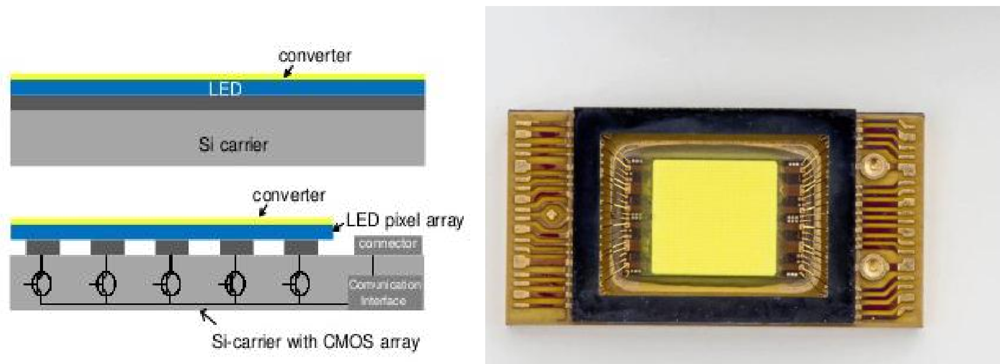


Figure 4.8: 1st-generation monolithic µLED (Osram)

The base plate is a silicon carrier including a an array with individually-addressable CMOS elements connected to a layer of blue LEDs. The current flow to every LED is controlled by exactly one CMOS element. The LED structure is then covered by the yellow conversion phosphor. One of the key problems of such a µLED is crosstalk between adjacent pixels, which causes blurred images on the road. Special precautions are taken in constructing the phosphor layer to minimise crosstalk.

This first generation of µLEDs contained 1,024 individually-addressable pixels with a pixel pitch of 125 micrometres, located on a square of 4 × 4 mm. Prototype samples became available in 2017 and a series-production market launch is supposed to happen this year. Key LED suppliers are working on a second generation with considerably higher pixel count: between 15 and 25 kilopixels; see figure 4.9—allowing the start of HD (high definition) road projections. The active LED area is planned to increase from 16 mm^2 in the first generation to about 40 mm^2.

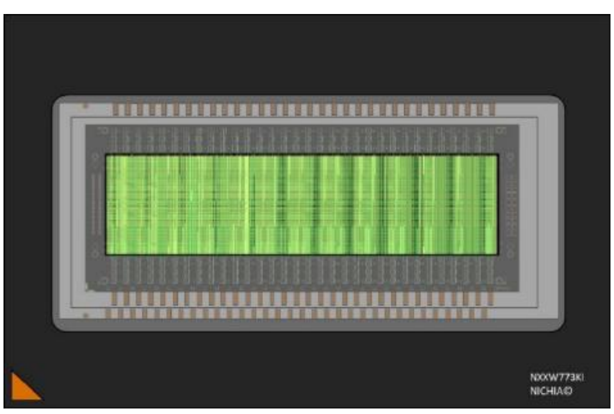


Figure 4.9: Concept of µLED allowing HD projections (Nichia)

The concept is that the pixel pitch will be reduced to about 40 micrometres. This means a decimation of the pixel size, which combined with the increased LED area allows the increase to 25 kilopixels.
Another important change is that the active die area will move from a square to a rectangular shape which is more readily adaptable to the required illumination pattern of a car headlamp. The market launch of these HD LEDs is targeted for 2023. If a similar evolution of pixel number will continue, weexpect in the second half of this century that µLEDs with up to 200 kilopixels will become available, which should be more than enough to fulfil the needs for automotive illumination as well as road projections.

4.4 • High luminance LEDs

Application trends triggered the development of high-luminance sources incorporating high current densities, even at the expense of sacrificing luminous efficacy due to the droop effect. This is justified by the trend to extremely small headlight cavities, which need high-luminance light sources to create sufficient road illumination, and by the trend to projector headlamps with high pixel counts, based e.g. on DMD technology—they need high luminance sources. Since lasers are still quite expensive, in this field there is an opportunity for high-luminance LEDs.

Figure 4.10: High-luminance LEDs (Osram, Nichia)

These high-luminance LEDs cover wattage ranges from 5 to 50 Watts.

Power W	Current A	Light Flux Lm	Die Area mm^2	Flux Density Lm/mm^2	Efficacy Lm/W	$R_{th\ (real)}$ °C/W
5 - 55	1.5 - 6	450-4000	0.5 - 5	500 - 900	70-90	0.7 - 1.8

Table 4.1: Parameter range of current high-luminance LEDs (DVN)

In line with the evolution trends of key applications, a consolidation of the product portfolio will happen in the next 3 to 5 years. Otherwise the LEDs industry will not be able to offer affordable solutions to the market. This segment of high-luminance LEDs will especially come under pressure by the evolution of lasers' technology and cost.

5 • Evolution of LEDs for Signalling

Red LEDs were the first ones to be used in car exterior lighting—first in CHMSLs in the mid-1980s. One of the important features of this signalling technology was the development of different colour impressions of the signalling function by tuning the spectrum of the LEDs.

5.1 • Spectral characteristics of LED signalling sources

At first the main LED wavelength for automotive use was red for tail and stop lights (and rear turn signals on the North American regulatory island). After their market introduction, interest developed for yellow/amber LEDs for rear turn indicators everywhere else in the world, and—as available intensity increased—front turn signals everywhere. Figure 5.1. depicts the spectral response curves for the different signalling colours.

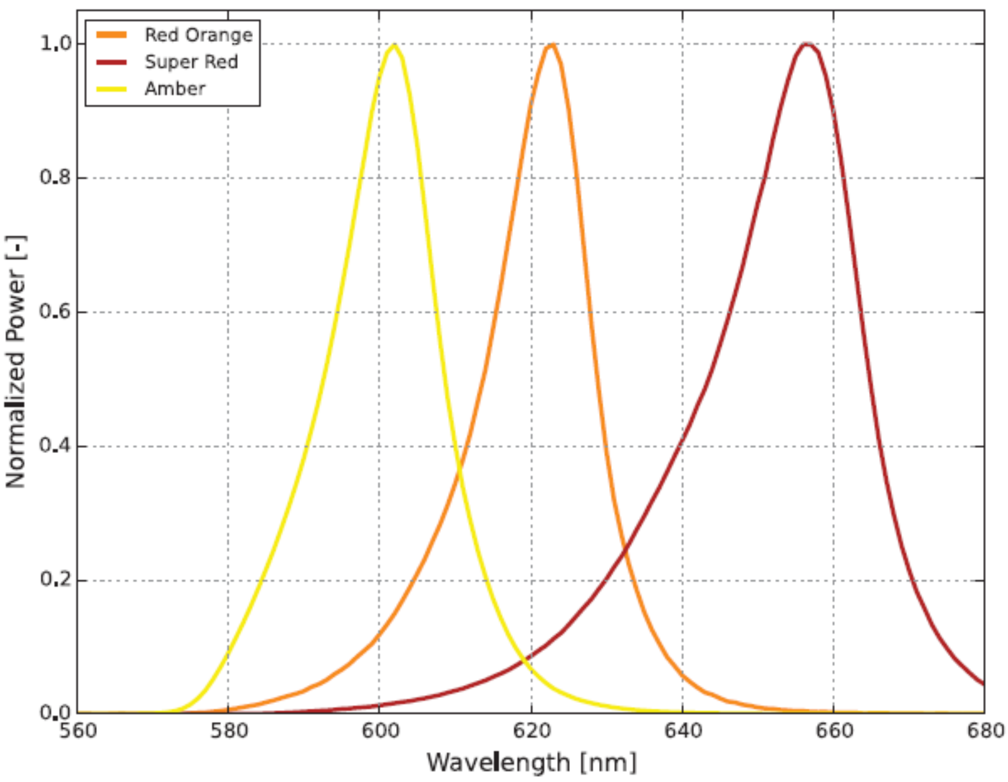


Figure 5.1: Spectrum of signalling LEDs for different colours (Lumileds)

The launch of "super red" LEDs was achieved by moving the normal red colour impression up by about 10-20 nm. This step was heavily driven by stylists to create a clearly differentiating impression of rear lights. The "super red" colour makes ordinary red lights look orange-ish by comparison.

5.2 • Evolution of signalling LEDs

"SnapLEDs" are a prominent example of one of the first product families mounted on clinch frames by a mechanical fixation process without high temperature load for the sensitive LEDs.

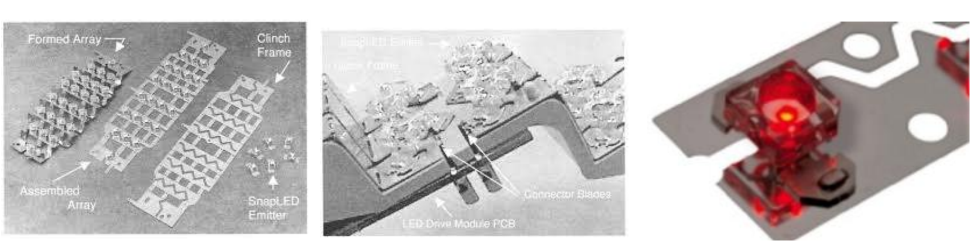


Figure 5.2 SnapLEDs and Clinch Frame (Lumileds)

One of the reasons for a broad application of this technology was uncertainty over SMD products' robustness during the soldering process due to excessive temperature profiles. Improvements in soldering process control increased trust in SMDs, so soldering on PCBs became the preferred norm. Various executions of such products were developed by the different LED companies active in this area.

Figure 5.3 SMD signalling LEDs (Osram, Lumileds, Nichia, Seoul Semi)

Also in this segment a consolidation of the product portfolios will have to take place in the next 3-5 years to follow a consequent cost roadmap.

A technological breakthrough for signalling LEDs—namely, phosphor-converted coloured LEDs—is showing promising advances. It's well established for white, obviously (DRLs, reversing lamps, interior lights) and for yellow-amber (marker lights, turn signals), and several PC red products are available as well, opening the door for other rear lighting functions.

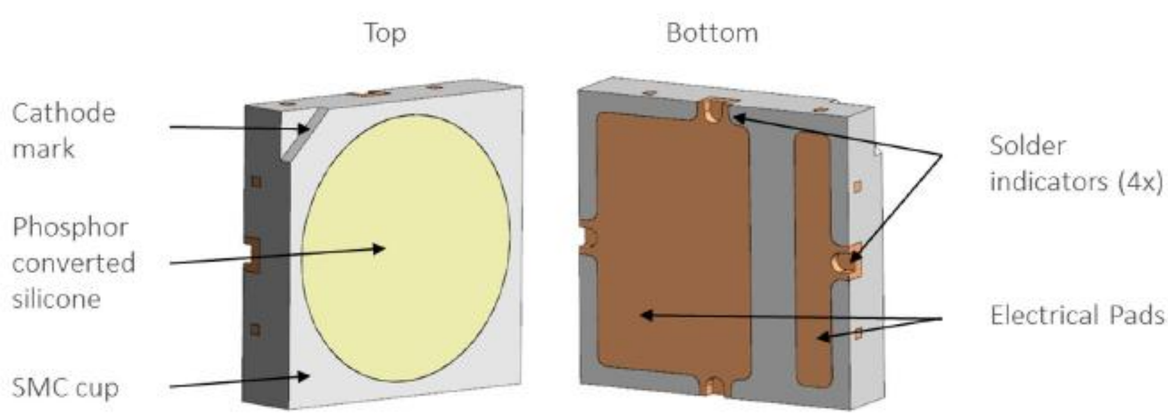


Figure 5.4: A PC LED for signalling applications (Lumileds)

The LED shows the normal SMD construction with electrical solder pads attached to the base carrier. A shorter-wavelength LED die is mounted on this carrier and covered with a silicone layer containing a conversion phosphor contributing longer-wavelength components. The spectra of the emitting die and the phosphor are adjusted such that the desired colour of light is generated.

Figure 5.5: Phosphor-converted SMD signalling LEDs white, amber, red (Lumileds, Nichia)

A wide range of performance is exhibited by different kinds of signalling LEDs:

	Power W	Efficacy Lm/W	$T_{junction}$ °C	T_{case} °C	R_{th} °C/W
SnapLed	0.4-0.8	60-70	130-150	110	20-40
SMD LEDs	0.8	80-90	130-150	110-140	10-20
PCA LEDs	0.5	120-130	150	125	20

Table 5.1: Comparison of signalling LED parameters

On nearly all parameters the spread is big and no clear trend can be observed. Requirements for signalling are less stringent, and therefore a choice from a broader product portfolio is possible.

5.3. Standardised Signalling LEDs

The first "LED bulb" intended for use as a ready-made light source in vehicle signals was the Osram Joule, shown here, which was used in the brake/tail/turn signal lights of the 2010 Ford Mustang and in the same application on the 2012 Chevrolet Malibu LTZ, and in a few other vehicles mostly made by Ford. These were not catered for in UN Regulations, so could only have been used as permanent, non-replaceable light sources.

UN Regulations for standardised LED signal light sources have been worked out in recent years. Since the end of 2018 such exchangeable "LED bulbs" have been available in red, yellow, and white for use worldwide. They've been deployed in high-volume vehicles such as the Toyota Corolla, which is an early success in the industrial push for this product category to pave the way for affordable LED lights in high-volume, price-sensitive vehicle segments. The cost reduction comes from not having to design, engineer, package-rectify, tool, and produce bespoke LED arrays, drivers, and heat sinks for every different lamp—only the housing, optics, and cover lens must be designed, just like in the incandescent-bulb days. The range of five different light sources can cover all the important signal applications in vehicles. Its benefits are to allow simple replacements, reduced complexity and reduced system costs for car manufacturers and will facilitate faster development processes.

Table 5.1 gives the application area and typical data of this product range and figure 5.6 shows examples of this product category.

Type	LR4	LR5	LY5	LW5
Application	Stop/Tail	Stop/Tail/Fog	Turn	DRL/Reverse
Power (W)	3/0.75	2.5	6.0	4.8
Light Flux (Lm)	80/6	120	280	350

Table 5.1 : Application and key performance parameters of regulated signalling bulbs

L1

L1W LY5 LR5

Figure 5.6: Standardised LED signalling "bulbs" (Lumileds, Osram)

With protection against electrostatic discharge, polarity reversal, and overvoltage, these "LED bulbs" meet all requirements for modern vehicle electronics. Integrating the heat sink and electronics in the light source eliminates the costs for their design and approval for each individual solution. All this considerably reduces overall costs for car manufacturers across the supply and quality control chains. For car workshops and car owners a standardised solution means the light sources can be directly replaced in the event of a fault (or the lamp housing alone can be replaced in the event of a crunch), which means lower repair costs and greater road safety. Long-term availability of this lamp category will encourage broad establishment in the market during this decade.

5.4 • OLEDs for signalling

OLEDs are a technology not belonging to the LED family, but because they are LED-adjacent and used for automotive rear lights we make some short remarks here. Figure 5.7 shows an example of an advanced concept for using the features of OLEDs.

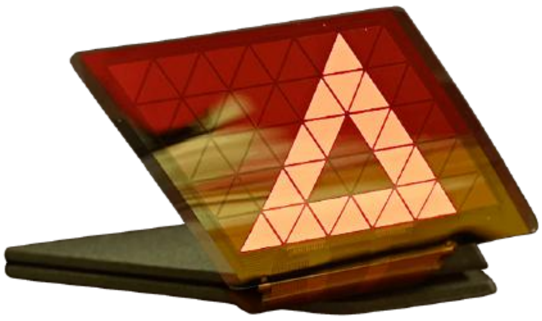


Figure 5.7: OLED rear light concept with more than 50 segments (OledWorks)

The intensity of the single segments can be varied between 1 and 100% at a speed which too fast for the human eye to see. In this way animated rear lights are enabled—they're in the early market introduction phase.

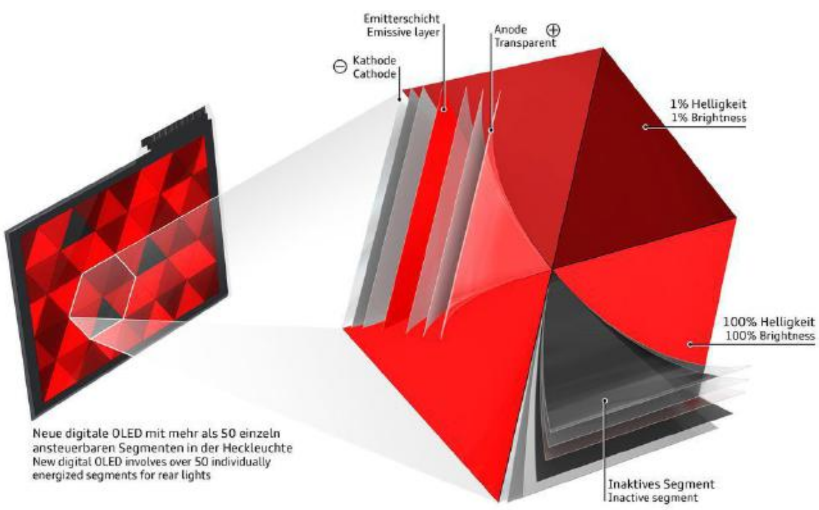


Figure 5.8: Build-up of a segmented OLED (Audi)

6 • Evolution of RGB LEDs

In the automotive market, RGB LEDs have been used for ambient interior lighting for about a decade now, and as a new application field, RGB LED displays are starting to gain traction.

6.1 • RGB LEDs for interior ambient lighting

The increasing use of RGB LEDs for interior lighting originates from their possibility to create a nice atmosphere for the vehicle occupants. Colour-tunable RGB LEDs are becoming more and more prominent for car interior ambient lighting, allowing the passengers to adapt the lighting to their mood. The number of LEDs used for interior lighting is steadily increasing.

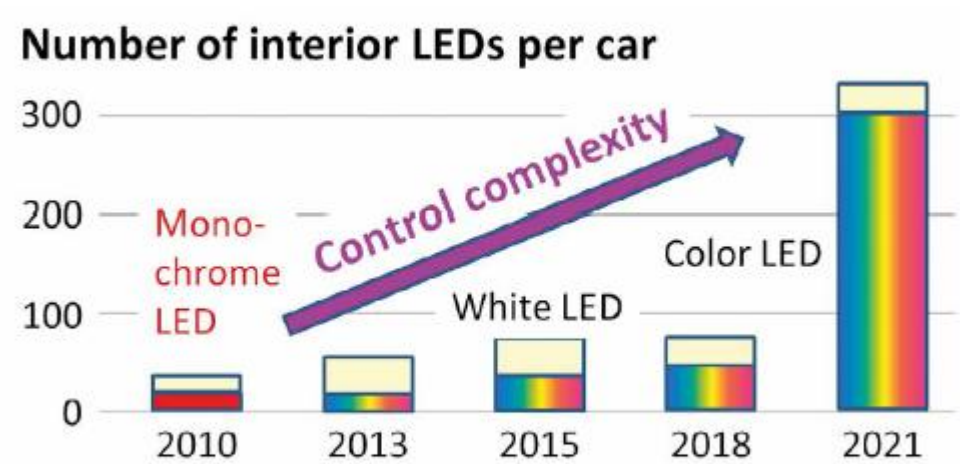


Figure 6.1: Interior LED count trend (BMW)

This trend has created the problem of controlling the large number of LEDs in a manner that is sufficiently flexible and efficient. In a first step, interior ambient lighting was created by light guide technology with one tunable LED at the entrance—called "edge-lighting"—as depicted in figure 6.2(A). This allows to change the ambient light colour and intensity uniformly in the whole interior space where the light guide is installed.

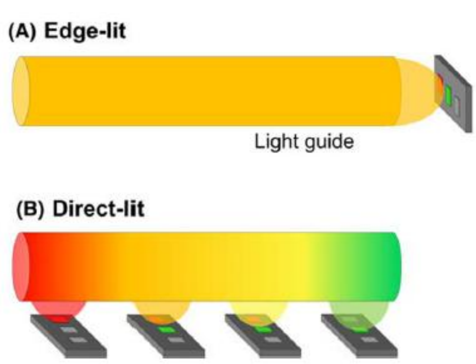


Figure 6.2: Concepts for interior ambient lighting with light guides (ISELED)

To gain additional flexibility, as a second concept, "direct-lit" light guide technologies were developed as shown in figure 6.2(B). This concept enables a variable, space-dependent illumination of the car interior, thus allowing individual lighting atmospheres in different areas of the vehicle. Of course, this creates a lot more complexity to control the RGB LEDs. A consortium of companies set up the ISELED initiative to overcome this problem.

The ISELED Concept

One of the big challenges of this concept is the different temperature-dependence and also ageing behaviour as well as binning of the three LED colours; figure 6.3 shows shown typical data. To be able to compensate for these factors, each RGB LED has an integral electronic controller.

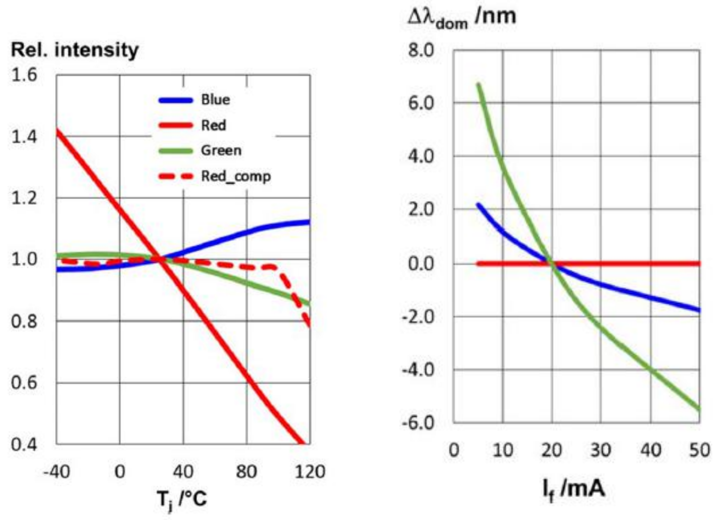


Figure 6.3 : Colour and intensity behaviour of RGB LEDs

In this way, a simple control setup along the light guide as shown in figure 6.4 is made possible.

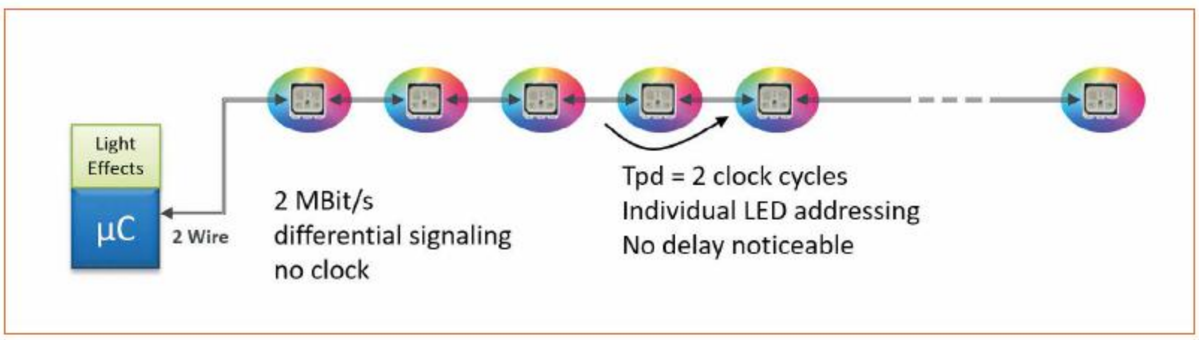


Figure 6.4: Scheme of ISELED control setup for RGB LEDs

Up to 4,096 individual RGB LEDs can be controlled with one system as shown in figure 6.5.

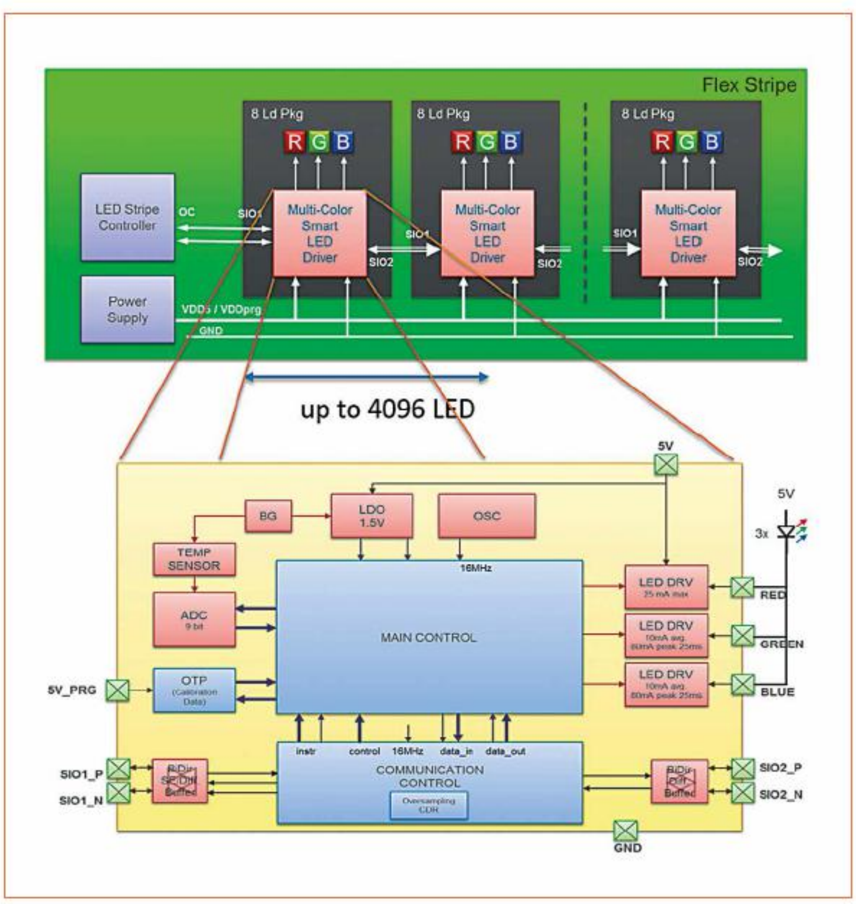


Figure 6.5: RGB control setup using ISELED smart LED drivers

6.2 • RGB Displays

Another interesting technology still in the very early development phase involves displays using RGB µLEDs. Different-colour LEDs are as usual produced on wafers and then cut into single products with dimensions much smaller than 100 micrometres. These single dies are then bonded to a ground plate creating the matrix displays shown in the scheme of figure 6.6.

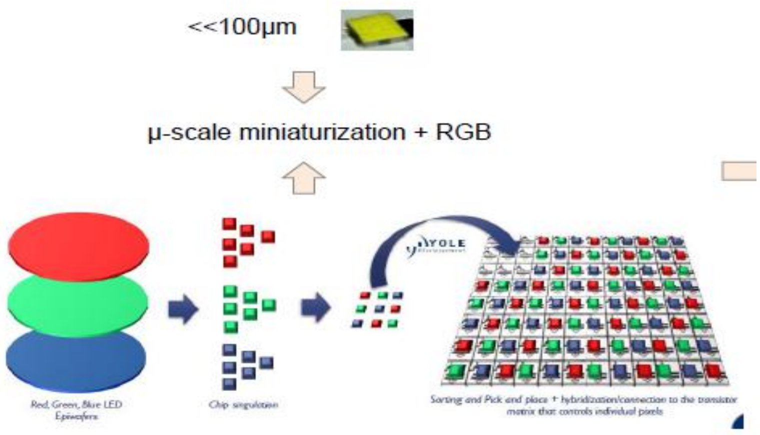


Figure 6.6: Manufacturing scheme of a µLED display

A number of companies are working on this concept, notably for the entertainment industry but with automotive applications very much in mind. A market launch date is still uncertain due to the early development phase.

7 • Evolution of Invisible-Light LEDs

Invisible light will become a major growth opportunity for LED lighting in this decade. There are two main areas for evolution in the automotive field, corresponding to light of wavelengths longer and shorter than the boundaries of human-visible light. IREDs (infrared emitting diodes) can enable new technologies like flash lidar, facial recognition, and object recognition. And even before the coronavirus pandemic, UVEDs (ultraviolet emitting diodes) were being developed to emit UV-C radiation to disinfect air and surfaces in vehicles. This trend has of course been accelerated by the pandemic, and has become a new focus area of development.

7.1 • IREDs

IREDs will find a promising future in automotive sensing applications. The application field includes short range flash lidar, driver and passenger recognition and monitoring, and gesture recognition for handling of e.g. navigation, HVAC, and infotainment systems.

IREDs for such automotive applications first appeared around 2010, in active night vision systems. Since then, the interest has increased to develop new application fields, and LED manufacturers have stepped up their efforts to develop this innovative new field of business opportunities.

Spectrum of IR LEDs

For present-day automotive applications, two main wavelengths are in focus: 850 and 950 nm, as depicted in figure 7.1.

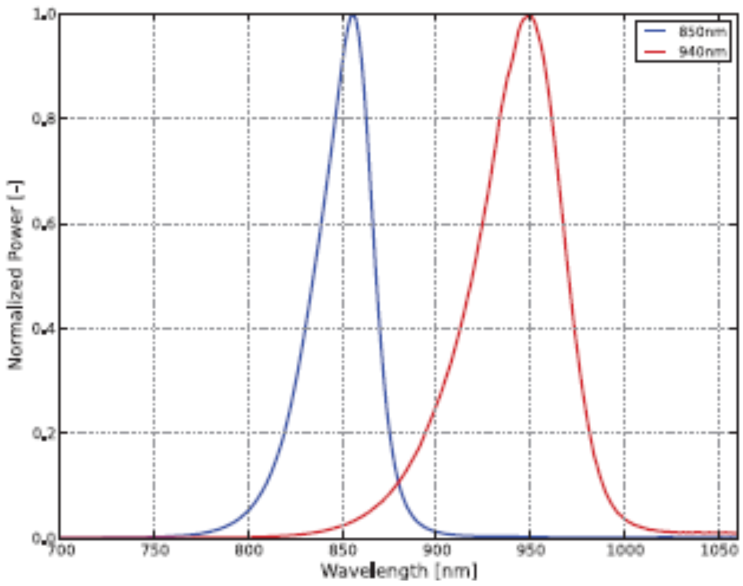


Figure 7.1: Spectrum of main IRED wavelengths for sensing applications (Lumileds)

IRED technology is based on material compounds of Gallium Arsenide (GaAs) and/or Aluminium-Gallium-Arsenide (AlGaAs) to create the appropriate wavelength range.

The application-orientated choice of the wavelength range is determined by three important factors:

• At 850 nm, the sensitivity of today's automotive cameras is twice as high as at 950 nm;

• At 850 nm, the human eye will still detect a red glow, which may disturb or distract especially in front lighting applications, and

• The allowed IR eye exposure levels are higher for 950 nm than for 850 nm.

IRED suppliers have decided to offer both wavelength options to the automotive industry.

Example of IREDs for automotive sensing

In figure 7.2 we depict automotive-targetted IREDs. All these products are equipped and configured to limit junction temperature of 145 °C and exhibit a decrease of radiant IR power of 30% from 25 °C to 125 °C.

Figure 7.2: IREDs for automotive sensing applications (Osram, Lumileds)

The first category are plain IREDs having a radiation cone of 150°. For applications like face or gesture recognition, only a limited field of view is needed, so the flux can be concentrated in a smaller field of view for higher intensities. The industry is also developing products including an optical dome to focus the radiation in the angular space where it is needed. In figure 7.3 are sample emission curves.

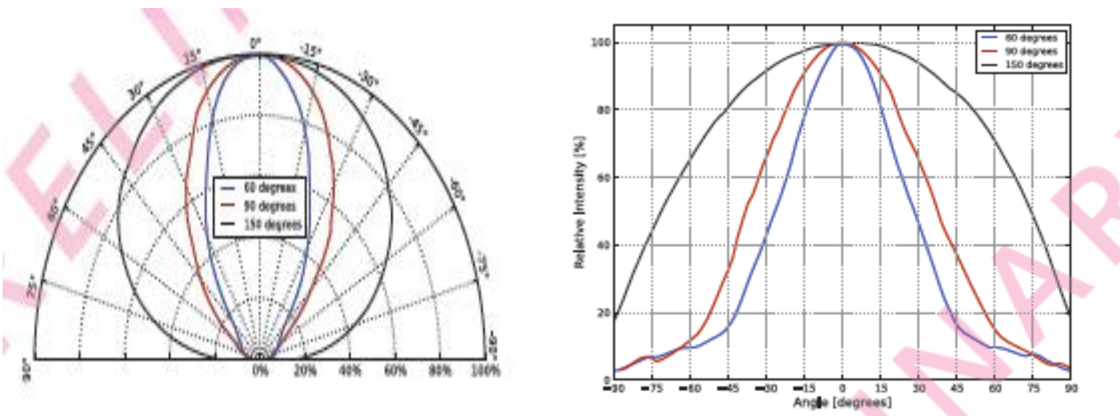


Figure 7.3: Emission profiles of IREDs for sensing (Lumileds)

In Table 7.1 we have given a rough overview of relevant parameters for this innovative application opportunity.

	850 nm Wavelength
Input Power (W)	0.5-3
Radiation Power (W)	0.2-1.5
Forward Current (A)	1-1.5 A
Direction Angle (degree)	30-125
Product Size (mm^2) Height (mm)	2.5 – 5 0.8-2
Emitter Size (mm^2)	0.7-1

Table 7.1: Basic Parameter Ranges of Automotive IR LEDs

7.2 • UVEDs

UV-C radiation can effectively destroy germs like bacteria and viruses with a short exposure time. Even before the coronavirus pandemic, but certainly accelerated by it, R&D work has been put on this topic, especially in the car cabin equipment industry. Figure 7.4 schematically explains how disinfection by UV-C radiation works. The high-energy photons destroy the DNA of the germ.

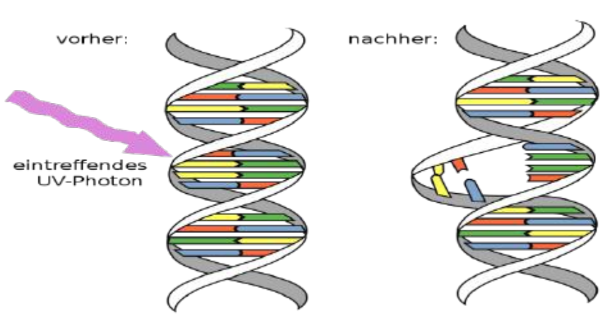


Figure 7.4: Interaction of UV-C radiation with a germ

Afterwards the germ is no longer able to infect other cells. Therefore this method can be very efficient, but needs to be deployed with care not to hurt other beings (such as humans!). UVEDs are regarded as the appropriate UV-C sources for automotive use.

UV-C UVEDs use as material an Aluminium-Gallium-Nitride (AlGaN) compound. The basic substrate consists of AluminumNitride (AlN) which is manufactured today in a very complex process chain. Therefore the price of the material is still high. Manufacturers of UV-C UVEDs are working on tuning their centre wavelength by varying and doping the composition of the compound to reach as close as possible the target of 265 nm, where the best effectiveness for disinfection can be reached.

Figure 7.5 shows a typical UV-C UVED sample. The black centre part is the UV-C UVEDs, and the remaining part of the body comprises electrical units and heat spreaders. The typical outer dimensions can range from 4×4×2 to 7×7×2 mm^3.

Figure 7.5: UV-C UVEDs for disinfection (Klarna, Stanley)

The typical UV-C radiation output of such diodes is in the range from 60-80 mW at a power input to the LED of about 4 Watts.

8 • Main LED Application Trends

8.1 • History

Figure 8.1.1: Lexus LS 600 LED Headlamp

For a long time, due to their limited colour and flux, LEDs were only applied on signal functions. The invention of white LEDs allowed the application for DRL. But one of the most significant milestone was the first worldwide application of LEDs for front lighting with the low beam of the Lexus LS600 in 2007. At that time, LEDs had limited efficiency and so five optical units—three projectors and two reflectors—were necessary, each module using four LED chips. Despite the 20-chip count, the total amount of flux on the road was squarely in halogen territory at roughly 500 lm, but with the differentiating blue-white colour of LEDs for the first time. It was a start! Koito were the producers of this very complex, expensive, innovative headlamp.

Then in 2008, the Audi R8 was the first car to have a full LED front lighting system including low and high beams and DRL. With this AL realisation, it was the first time that all lighting functions of a vehicle headlamp were realised by using only electronic light sources.

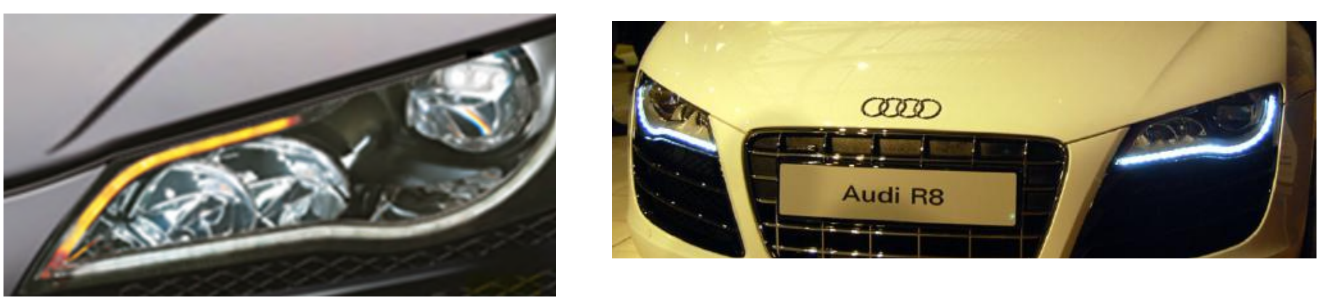


Figure 8.1.2: Audi R8

These first applications were naturally at that time awfully expensive, several times more costly and with less flux than HID systems. Low performance and high cost like this is often the case with innovations. But these early efforts demonstrated that LEDs were able to bring innovation in style, the key for their future success.

Quickly after that, all car manufacturers and set makers developed their own applications with LED lighting, progressively from high range vehicles to medium and then low range vehicles thanks to the tremendous performance increase and cost decrease of LEDs and the parallel evolution of electronics and modules. Compared to these first LED applications, the current cost of an LED headlamp has fallen more than tenfold!

8.2 • Headlighting

Compared to previous kinds of light sources, LEDs have some specific characteristics crucial for the realisation of optical modules:
• LED light emission is roughly hemispherical, with most of the light concentrated in a limited solid angle. This property contributes to the good global efficiency of LED optical units, which often reach 50% where halogen and HID systems were limited to around 30%, in part due to those light sources' spherical output—a large proportion of which was necessarily lost or wasted. Whole new kinds of optical systems, like direct lenses and projectors with folding mirrors, are possible only with LEDs thanks to their specific pattern of light emission.

• Flexible number of chips: The chip count is frequently from one to five, each chip having initially a surface of roughly 1 mm^2, or now even smaller in the case of high-luminance LEDs. The small surface of LEDs is allowing compact units with reduced focal distances. However, the consequence of this compactness is the need to have more accurate precision for the LED position and the optical unit realisation. In LED arrays or monolithic systems for ADB systems, the number of elementary LEDs is now reaching around 100 and will reach some thousands in the foreseeable future.

• Low temperature constraint: Inside the LED, the maximum temperature is 150 °C for the junction instead of 3,000 °C for a halogen filament, and so the immediate proximity of the light source is less hostile to materials when the source is an LED. Halogen technology needed 65 W—mainly transformed into heat—compared to just 12 W for the same light flux from an LED, and with dramatically less proportional heat production. That makes it possible to use thermoplastics, acrylics, and polycarbonates for reflectors as well as thermoplastics and acrylics for lenses.

Even though LEDs produce much less heat than halogen and HID light sources, the temperature very close to the source can exceed 130 °C. This precludes the use of polycarbonate in some cases, for instance for some kinds of light guide. Consequently, silicone is used for primary optics in some ADB applications particularly with LED arrays.

With these properties catered for, many types of optical modules are used with LED light sources.

Direct Reflector

In this technology a reflector alone is used as optical element for one LED. The LED can be put at the bottom of the reflector, or more often now at the top to hide more easily the LED source. Reflector technology can be used as complementary module for wide beam, or to achieve a full LED system with low beam and high beam. In that case, often three modules are used, two for low beam, the first one for the range and the other for the width, and the third module is dedicated for the high beam. As the light distribution is done totally by the reflectors including the cut-off for low beam, the realisation must be very precise to avoid heterogenous beam and to align perfectly low beam and high beam.

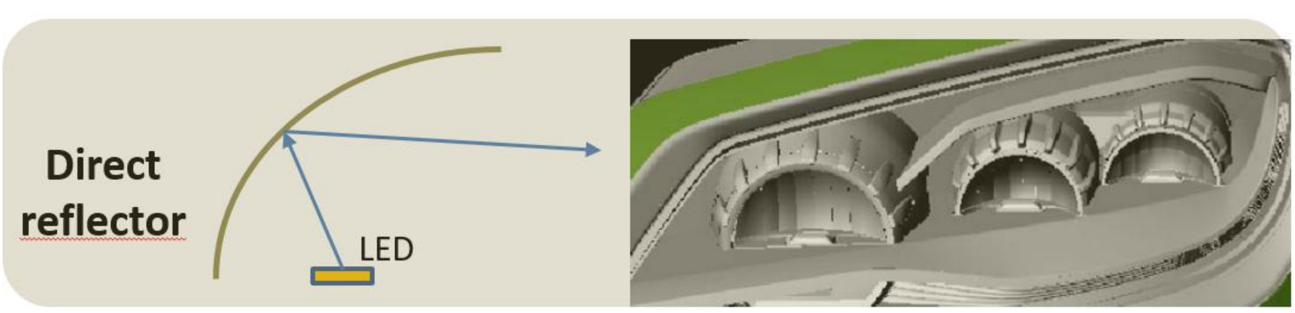


Figure 8.2.1: Principle of direct reflector technology

Figure 8.2.2: VW Jetta (USA) 2018

Figure 8.2.3: Renault Clio 5

Direct-reflector technology is the most affordable solution and is now more and more used for many low- and mid-range headlamps. Different types of LEDs can be used from one to four chips, depending on the performance target. When cost is the main target with limited performance (halogen-level performance of 500 to 700 lumens on the road), bi-chip LEDs can be used for each reflector. LEDs can be the old connector type, but the trend is toward the SMD types for cost and packaging reasons.

This technology is not exclusively used in low-price applications; it can also be found in premium cars as for instance for some versions of the Mercedes C-class.

Figure 8.2.4: Mercedes headlamp with reflector technology

For style, reflectors can have a typical height of 50-60 mm. The height can be decreased, but performance is reduced, and so more expensive LEDs have to be used. That is not generally the main target when using this technology.

Projector module with ellipsoid and Lens

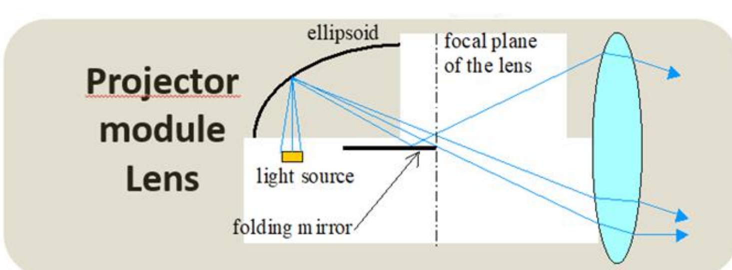


Figure 8.2.5: LED projector concept

The basic principle is the same as with halogen or HID, with the LED source being placed at the first focal point of an ellipsoid reflector and the shield at the second focal point. But thanks to the hemispheric emission of light, a folding mirror is generally used allowing to get back roughly 40% of the light lost with the use of a standard shield. Due to styling request, the lenses are now often rectangular. The trend is also to reduce the height. Initially close to 50-60 mm, lenses are reaching currently 20 mm and in some concepts even targetting just 10 mm high.

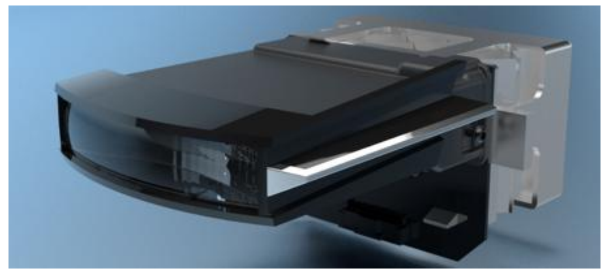


Figure 8.2.6: Opel projector module ***Figure 8.2.7: Varroc concept module, 15 mm high***

The projector system was the first technology used—the only one—for LED front lighting during many years. It is still intensively used with many variants; there are several levers here for style and performance.

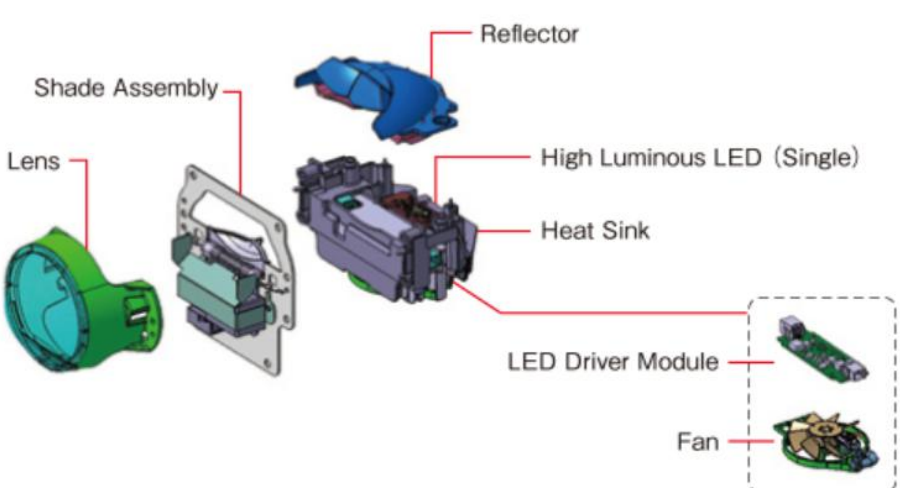
For style, Lenses can have various shapes—round, rectangular, oblong—with bezel or not, with or without jewelled effects. The typical height of the lens is now around 40 mm, but this can be reduced to 20 or even 10 mm when using high-luminance LEDs. Some, however, are considering that this trend for decrease of height must be limited to maintain the perception of an eye for the headlamp.

Figure 8.2.8: Hella prototype with 10mm height

Projector systems can use every type of LEDs—connector type or SMD type—with the trend toward SMD types thanks to their reduced packaging.

Bifunctional projector modules

Many applications are using a single module producing both the low beam and the high beam. This makes the whole headlamp smaller and reduces system cost at the price of perhaps a little bit less differentiating style. Many bifunction modules from different set makers are using several LEDs, both for high beam and low beam. But some can also achieve good light performance with only one LED emitting more than 2,000 lm. Figure 8.2.9 shows an example of a bifunctional module with one



single LED.

Figure 8.2.9: Koito Bi-Beam LED high/low beam projector

Projector module with ellipsoid and reflector

In projector systems, the lens can be replaced by a reflector with a source placed at the focal point to transform the beam in parallel rays as shown in figure 8.2.10.

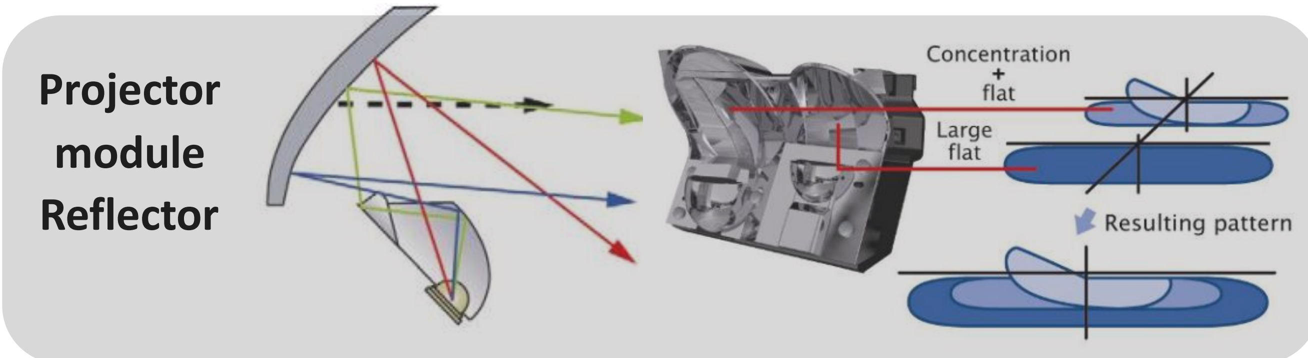


Figure 8.2.10: Projector-reflector module

The first realisation using this technology was for the 2010 Nissan Leaf. Now it is used for example for Volvo headlamps, but in an application where the optical units are hidden to better see the DRL in Volvo's trademark "Thor's Hammer" shape. Here, too, the trend is toward SMD LEDs.

Figure 8.2.11: Volvo headlamp

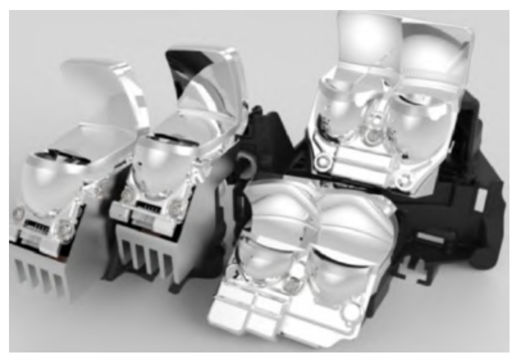


Figure 8.2.12: Projector-reflector modules

Direct lens

In this realisation, the light is going directly from the LED to the lens, which does the entire light-shaping job to create the beam pattern. This system allows for the best efficiency, reaching up to 60%. Naturally, one of the difficulties is the good realisation of lenses, as they can be very thick.

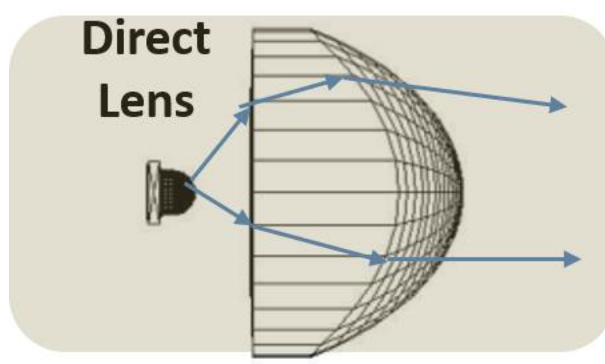


Figure 8.2.13: Direct lens optics

Some realisations of this concept can be quite spectacular—like the system developed by Honda and Stanley in "jewel eye" technique employing double-reflections inside the lens.

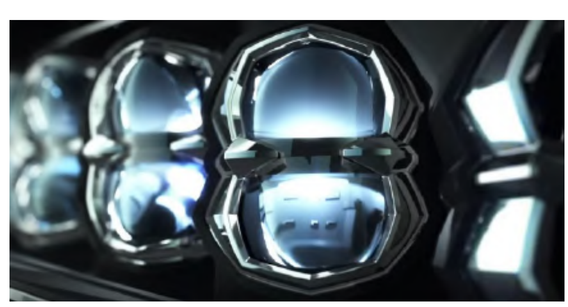


Figure 8.2.14: "Jewel eye" Acura Headlamp

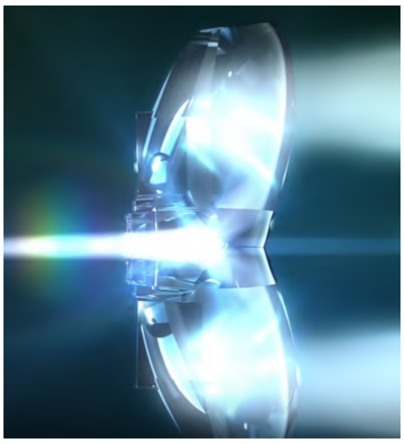


Figure 8.2.15: Double reflection in lens of Acura "jewel eye" headlamp

Adoption of LEDs for front lighting

Introduced only in 2007, LEDs lighting is now roughly systematically used for new vehicles, at least in developed countries. Cost was during many years the braking factor, slowing down the adoption despite the strong push from styling and lighting departments. Now, some solutions with LEDs can be very affordable, especially with all the other cost factors taken into account such as better compactness, no access requirement for bulb service, no warranty cost for bulb changes, and so on. But the main factors for the complete adaption are naturally style and now more and more energy saving. Halogen is not immediately disappearing as models launched in the past are still produced, but the clear trend is to go quickly to 100% LED equipment for main front lighting.

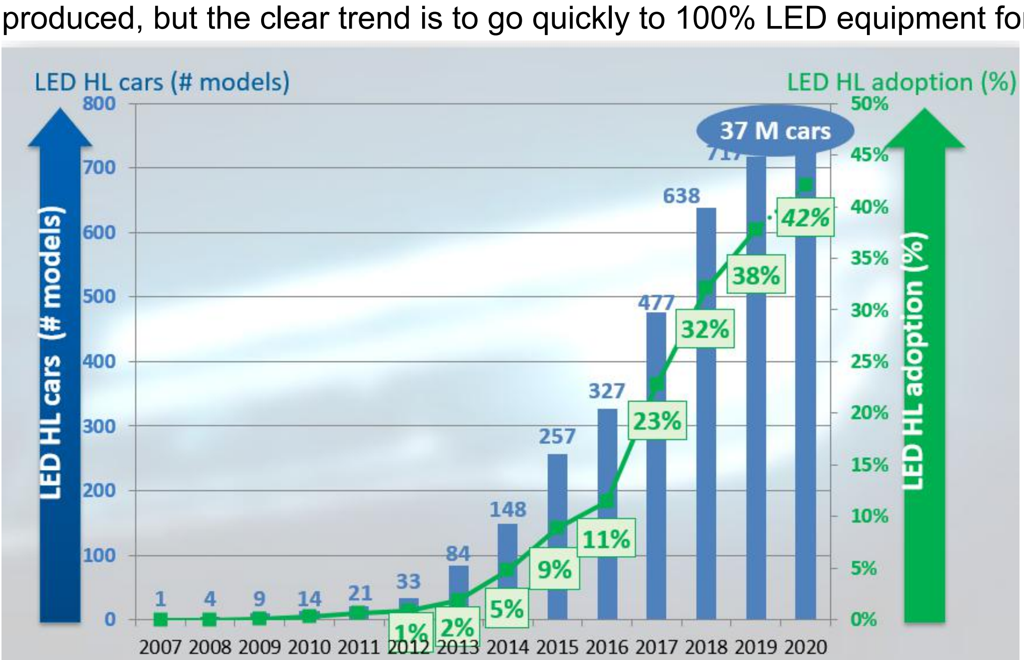


Figure 8.2.17: Car population with LEDs for main front lighting functions (Lumileds)

Other trends for LED front lighting

Standardisation: There is currently a huge number of technologies for LEDs, and generally many models for each technology for every set maker. The corresponding diversity is very expensive, particularly as some headlamps are using more than 50 elementary parts. The target of car manufacturers and set makers is to standardise and modularise components as much as possible. Some projector modules, especially those producing both low and high beam, are already used in multiple cars. Most set makers have a portfolio of standard modules, and differentiation can still be realised with bezels and sometimes with specific lens shapes.

Another domain of standardisation is the use of common electronic units. Several car makers have decided to use common ECU used by their different set makers and realised often by electronics specialists.

Some LED makers are also pushing for the use of standard LEDs and electronic control systems. One of the targets is to facilitate service if a problem occurs during the lifetime of the car. However, this target is not simple as many modules are now very compact, some imposing an upper position of the LED source with a very slim thickness allowed. Due to the different technologies and style constraints, standardising LED technology is difficult for front lighting, except for some basic realisations.

Figure 8.2.18 Example of Hella's attempt to standardise future ADB modules

High performance for costly cars, affordable solutions for cheap cars

The performance range in LED low beams spreads from a very halogen-like 500 lm to a better-than-HID 1200 lm. All premium cars have now exceptionally good lighting performance particularly with their ADB systems (except in the USA, which—alone in the developed world—still doesn't allow ADB). Some have also remarkably high performance for high beam with laser or high-luminance LED systems. Laser is still better for seeing distance of up to 600 m, but systems equipped with high-luminance LEDs are not far behind with 550 metres' range and with generally a better width for the beam.

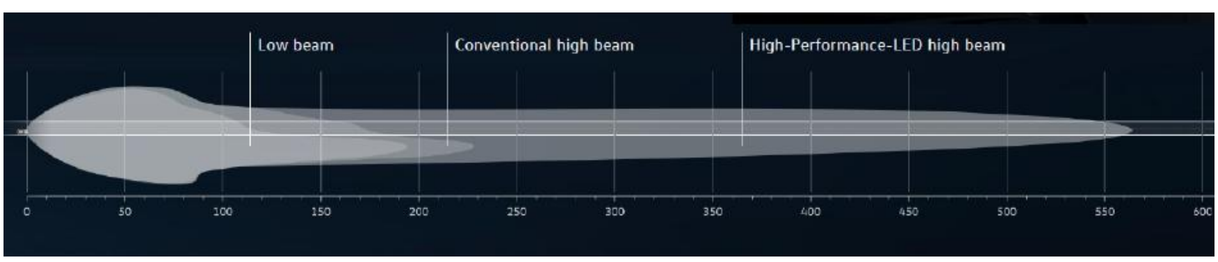


Figure 8.2.19: VW Touareg high beam, conventional versus high-performance LED

At the other end of the continuüm, entry level systems are using the minimum number of chips to achieve 500-600 lm, more often with reflector systems. Due to the democratisation of LED and their generalisation, this is becoming a major part of the market.

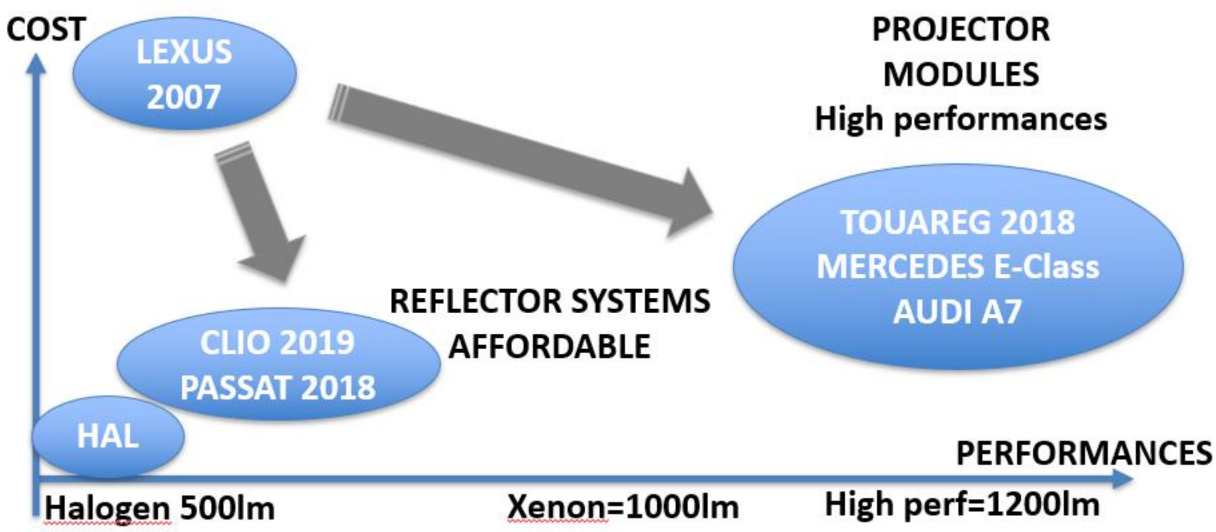


Figure 8.2.20: cost versus output of various headlight technologies

ADB systems and HD systems with LEDs

The other important trend for LED applications is their use in ADB systems and particularly in future HD systems.

First ADB system with LEDs

ADB first saw the dark of nighttime roads in 2010. At that time, LEDs were not powerful enough to provide an acceptable ADB system, and cost too much. So HID light sources were used in projector modules using a rotating drum to change the cutoff shield shape and provide low beam, high beam, L-shape for ADB, and flat cutoff for town beam. When LEDs were enough powerful, the same principle was used with several LEDs replacing the HID bulb. Other solutions using a dedicated module to realise the L-shape, for instance, were used particularly by BMW (who are still using this principle now). So with these systems, the left headlamp is producing the left part of the ADB beam and the right headlamp the right part, the beams being moved horizontally by stepper motors according to the position of other users with the creation of a shadow with no light, centred on leading or opposing vehicles so their drivers aren't glared.

Figure 8.2.21: ADB Light

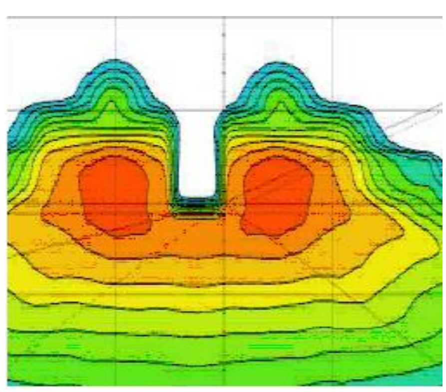


Figure 8.2.22: ADB Isolux with the two vertical cutoffs

Matrix beam ADB

Audi introduced matrix beam in 2013 on their A8 model. This technology has several advantages compared to L-shaped-half-beam systems: individual control of each segment of light allowing to optimise the light when there are several other cars, and allowing in some cases to follow curves as a bending light.

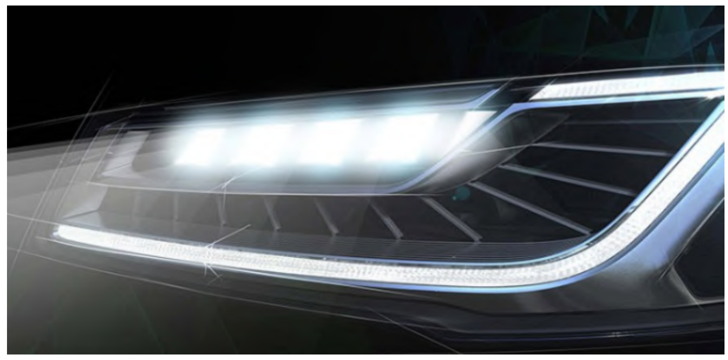


Figure 8.2.23: Audi matrix light

Other advantages include the possibility to have high performance depending on the number of LEDs; flexibility about number of segments from three for very low range ADB to several tens for high range systems. Twelve segments are already giving a relatively good ADB system. Also, it's a static system with no mechanical horizontal movement, and there's ample opportunity for styling differentiation.

LED-array ADB

Systems with LED array are using the principle of projector system. But in this system the LED array or the light concentrated from LEDs through a primary optic element is directly projected by a lens.

First systems launched with this technology in 2016 with Mercedes CLS used a LED array of 84 LEDs with three rows.

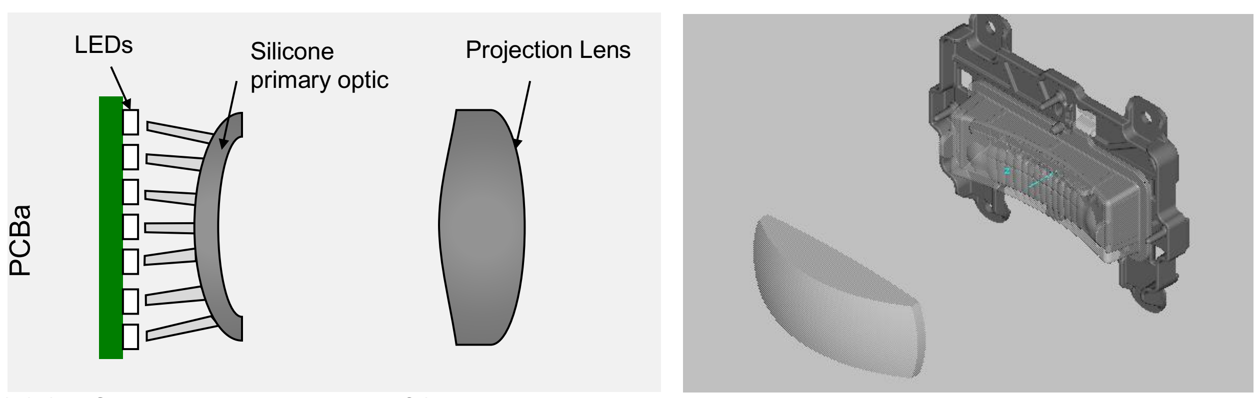


Figure 8.2.24: Conceptual illustration of 84-LED matrix (Hella)

Other systems are now in production with a similar technology including different number of LEDs, for instance in VW's IQ Light system.

Here's a VW Touareg IQ Light with 128 LEDs per headlamp and LED projector array for the low beam and ADB function with total flux of 1,300 lm (low beam) and 2,100 lm (high beam) per side of the car.

For these applications with LED arrays, a single-die LED source as described in §4.3 is used.

High Definition ADB with ADB DMD

Currently the first HD (High Definition) application is a DLP-DMD system introduced on the Mercedes S-Class in 2016. The main advantage of this kind of system is the remarkably high number of pixels allowing all new functions including road projection. The main drawback is the low efficacy at roughly 15 lm/W, so around 1/3 that of static LED systems. The source of light for this kind of micromirror system needs to be based on high-luminance LEDs with high power as described in §4.4. This expensive system is reserved to extremely high range cars and generally currently sold as an option.

Figure 8.2.25: DMD module with 1.3 million micro-mirrors (TI)

µLED ADB systems

µLED systems are an evolution of LED array ADB. Very small LEDs are on a monolithic array with very tiny gaps between chips, and with the electronic control behind. This new technology is currently under development with first applications in 2021-'22. A first system was developed with 1,000 pixels, but the trend is now to develop systems with several kilopixels to allow road projection functions.

DVN's forecast is that µLED systems will be the dominant system for HD in the future, as µLED has the potential to be a standard source, at least for several applications, to achieve a resolution of 50 kilopixels in the next five years, enough to have very nice performance and some applications of road projection, and moreover having an acceptable energy efficiency with an intermediate cost between matrix and DMD systems.

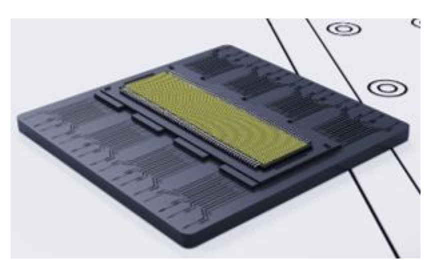


Figure 8.2.26: µLED ADB light engine

Figure 8.2.27: Valeo module with 15- 25 kilopixels using monolithic μLED (Valeo)

8.3 • Signalling

History and interest of LEDs for signal functions

LEDs were first used for rear signals as their performance was very limited and red LEDs were first to reach acceptable output levels. The first application was the CHMSL on the 1986 Chevrolet Corvette, followed in 1993 by the first rear lamp with LEDs. A strong driver for the use of LEDs for signal functions was and is still style, though LEDs have other attractive technical advantages of long lifespan, vibration resistance, compactness, colour, and quick rise time. Many technologies were developed for the use of LEDs for signals; many were new and only possible with LEDs. One decisive advantage of LEDs is their relatively low temperature constraint allowing to put plastic light guides close to the source, this generating many differentiating styles.

Main rear signalling technologies with LEDs

• Reflectors

One of the simplest and least costly technologies is the reflector. LEDs can be put at the top or at the bottom position depending on the style target. Generally, several units are used to reduce the size of each both for style and compactness. This technology can be used for every kind of rear signal function, so for rear lamp and CHMSL, and for all front signal including DRL and with a good efficiency reaching 50%.

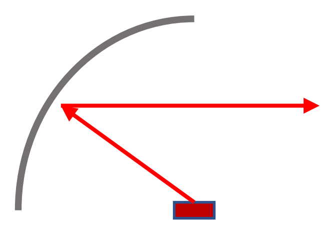


Figure 8.3.1: Audi A1 tail light

• Direct from Fresnel lens

The distribution of the light can be done with a Fresnel lens. However frequently, the main target is to have a very homogeneous aspect both lit and not lit. So, to better achieve this target, a first layer sometimes distributes the light with a diffusing lens. The result is producing some nice illuminated appearances, but at the cost of a reduced efficiency that can be as low as 20%.

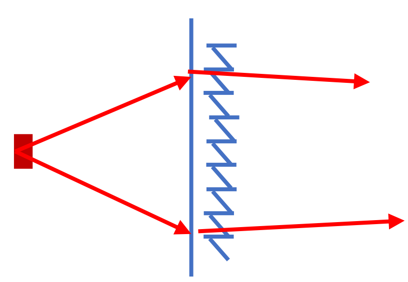
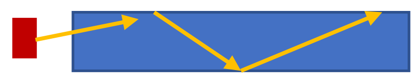


Figure 8.3.2: BMW X3 tail light with light guide technique

• Light guide



Light guide technology is certainly the most used with LEDs for signalling.The principle is simple: an LED is placed at the extremity of the light guide and the light is following the guide till some prisms placed along the guide extract the light. Light guides allow realisation of many kinds of shapes: straight lines, curves, bends, round, etc. They provide good homogeneity of the function, though complex calculations and precise tooling and manufacture are necessary for it. And they allow for relatively free positioning of the light source, which helps save space.

The homogeneity of light guide has a price: efficiency is relatively low at around 15%. But the improvement for cost and performance of LEDs have helped to democratise this solution.

Figure 8.3.3: Renault Megane rear lights with light guides

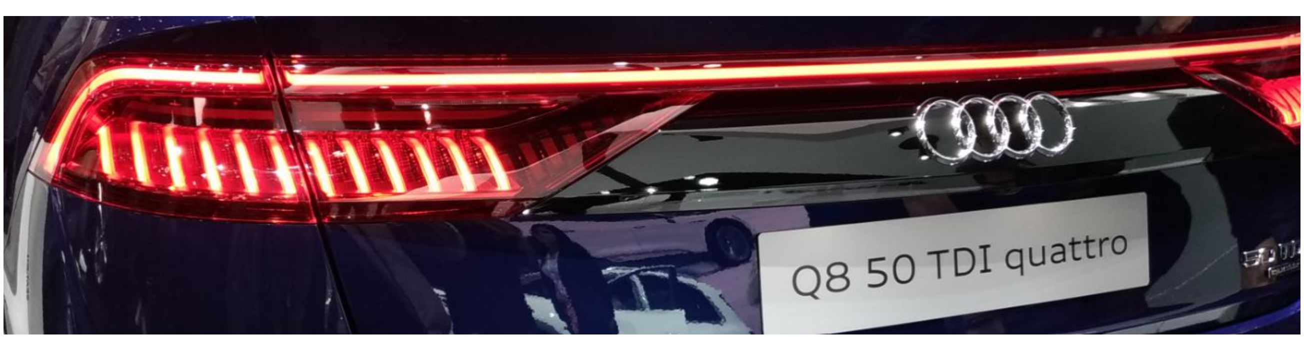


Figure 8.3.4: Audi Q8 rear lights with light guides

Light guide technology is helping to support the current trend to have exceptionally large rear lamps spanning from one side to the other, with thin illuminated areas.

• Curtain/surface light guide

Several LEDs are placed on the side of a surface and the light is following the surface in different directions. This technology with very low efficiency is used for position lights and for decoration that is more and more seen in new models; its efficiency is considered too low for higher-intensity functions like stop lights and turn signals.

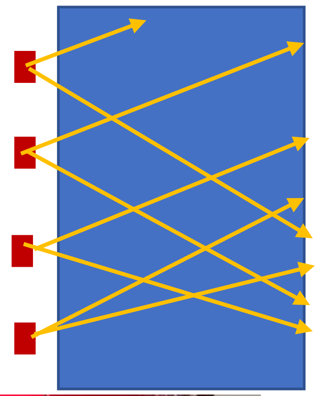


Figure 8.3.5: Alfa Romeo Tonale rear lights

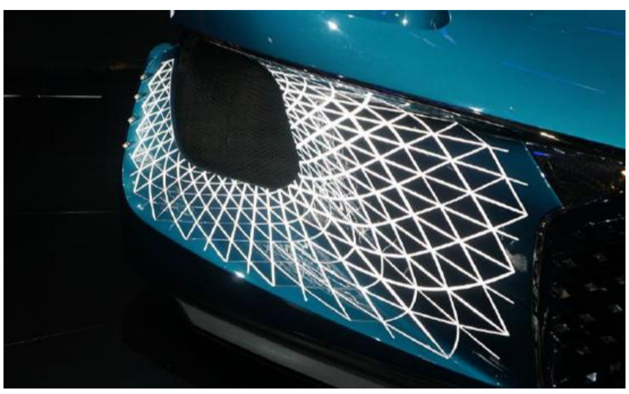


Figure 8.3.6: Curtain light

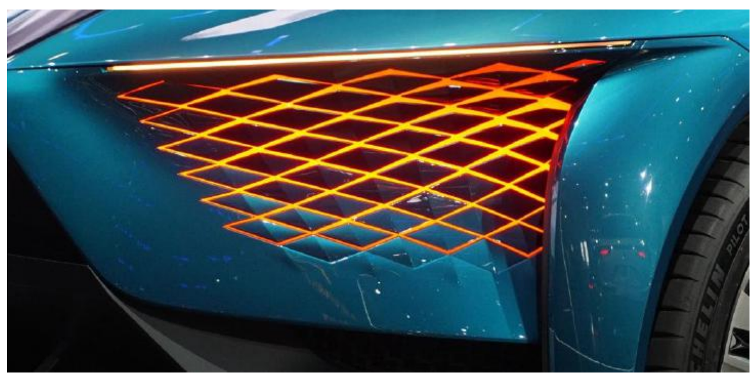


Figure 8.3.7: Curtain light

New trends

Rear lamps are now not only an element of style, but the cornerstone of the rear signature of the car. Until recently they had to be homogeneous, nice, and distinctive. Now they have also to be dynamic with change of geometry, as exemplified by the "dynamic" direction indicators with their sweeping or wiping effect.

It is also the case for tail-stop function with for instance the click-clack system from VW: the lit area changes not just intensity but also shape for the tail versus stop lights.

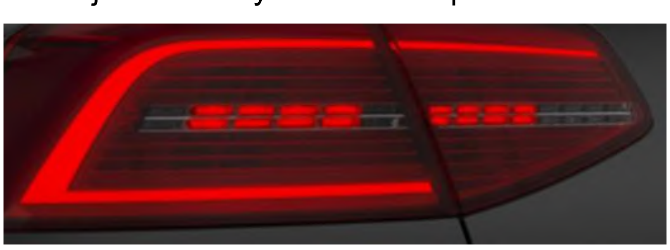


Figure 8.3.8: VW Click-Clack tail function

Figure 8.3.9: VW Click-Clack stop light function

DRL

At the front of the car, the DRL as a signalling function can use most of the same technologies used in rear signalling. However, there is a dominant use of light guides to give a strong signature to the car's face. DRLs now are using similar LEDs to those used in road illumination lighting—mostly the SMD type as described in §4.2.

Figure 8.3.10: Audi e-tron 55 Quattro

Figure 8.3.11: Toyota CR-V Hybrid

8.4 • Communication and Decoration

LEDs are not only used for the basic functions to see and be seen, but also increasingly for communication and decoration functions, and we predict a strong and enduring increase in these new kinds of applications.

The communication functions are orientated to the equipped driver, other drivers, VRUs (vulnerable road users—pedestrians and cyclists), the equipped car's system, other cars' systems, and the static environment. These communication will be intensified with increasingly sophisticated ADAS and autonomous cars, but have strong interest for safety with traditional cars.

These communication by light can be done by signals, by displays, by high definition ADB systems or with MLA (micro-lens arrays) for road projection. That means with LEDs sources for signals described in §5.3, with LED arrays described in §4.3, with µLED displays described in §4.3, or with MLAs or HD systems using LEDs described in §4.3.

Examples of communication functions using LEDs:

Figure 8.4.1: On-car display with LED light sources

Figure 8.4.2: Road-projected turn signal with LED

Figure 8.4.3: HD front lighting system road projection

Decoration is also a new field of use for LEDs growing quickly. Decorative lighting can be installed everywhere on the exterior of the car, at the front for instance on the grille, at the rear, or on the sides. Technologies used are mainly light guides and MLA. Colour and dynamic change of colour can also be used with RGB LEDs described in chapter 6.

Figure 8.4.4:
Front grille illuminated (Osram Continental)

Figure 8.4.5: Illuminated grille badge (Mercedes)

Figure 8.4.6: Mercedes concept with wheel decoration

Much more detailed information about these new functions for communication and decoration can be found in the DVN study "New Lighting Functions 2020-2030", now available.

8.5 • Sensors

LEDs are also involved for the use of sensors. One of their first such applications is to provide light necessary for a good detection and recognition with cameras. As cameras are installed now all around the car for 360° detection, lighting systems with LEDs are needed also around the car.

Some vision systems are using IR light to improve the range perception beyond the normal visible light and naturally IREDs are now used for that purpose—a big technical improvement over inefficient halogen lights with IR-pass filters.

LEDs could also in the future be used for flash lidars. However, currently, lidars are mainly using laser IR.

Figure 8.5.1: Valeo lidar

8.6 • Interior Lighting

For a long time, interior lighting was a poor sibling compared to exterior lighting—the vehicle occupants got maybe a single 5- or 10-watt bulb in the middle of the ceiling, and maybe one or two reading lights with incandescent bulbs. Now, the trend to use 100% LEDs with innovative solutions to have a cocooning interior with warm atmosphere, adaptive colours, and flexible shapes.

Technologies for interior lighting with LEDs

The main technologies used are often light guides that can be with linear tubes, surfacic treatments, or with more complex shapes. The target is generally to have a good homogeneity, and an acceptable efficiency. The colour is obtained thanks to RGB LEDS and ISELED systems described in chapter 6. There are several types of technologies depending on the target: One LED at the extremity of the guide for static application, several LEDs along the guide when a dynamic light is required, with a number of LEDs increased when high resolution is targeted.

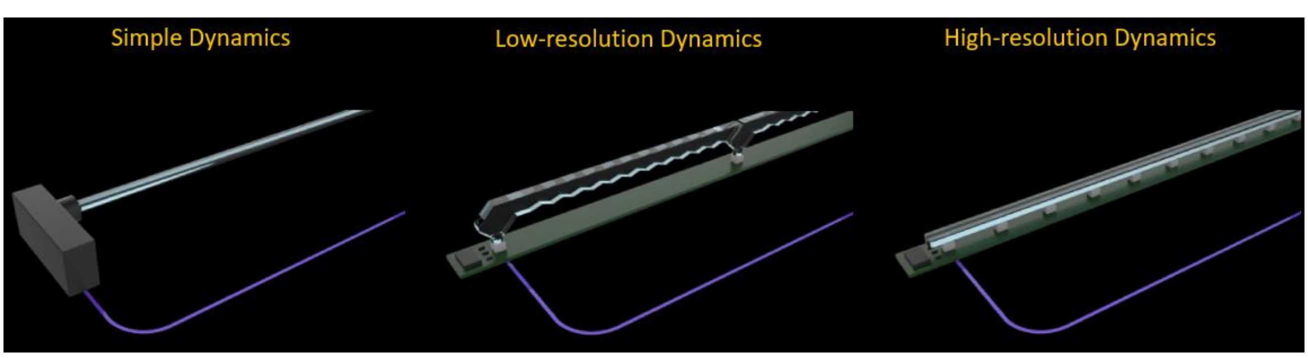


Figure 8.6.1: Interior light guide techniques (Hella)

Styling trends for LED interior lighting

Figure 8.6.2: Long light guides all around the interior of a BMW X5

Figure 8.6.3: Interior new BMW X5

Another important trend is the colour can be changed depending on the desired atmosphere.

Figure 8.6.4: various interior lighting modes (Hella)

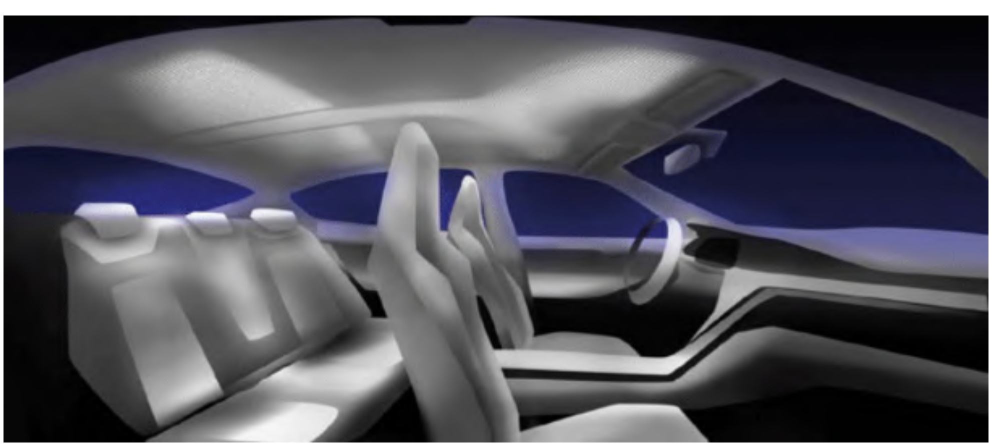


Figure 8.6.5: Large lighted surfaces on the ceiling of the car.

This trend to transform the interior in living room will certainly be amplified with the development of autonomous vehicles in the future.

Figure 8.6.6: Large illuminated panels with flexible colours

8.7 • Occupant monitoring using IREDs

The presence and doings of passengers—for instance for belt checking or the analysis of the head of the driver to analyse the risk of drowsiness—can be done by a camera with an illumination by infrared from IREDs described in §7.1.

8.8 • Cabin cleaning using UVEDs

The coronavirus pandemic has greatly increased interest in car interior sanitation, and UV-C light is a prime candidate. These systems use UVEDs described in §7.2 for their disinfection functions.

Figure 8.8.1: Car interior disinfector with UV-C UVEDs (Yanfeng)

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About the authors and Driving Vision News

Ralf Schäfer joined Philips Research Labs in Aachen, Germany in 1977 gathering experience on halogen and HID light sources. He became Head of Xenon Development within Philips Automotive Lighting in 1990 with the task to introduce this new technology to the market based in the Aachen facilities. Following positions have been Global Headlighting Development Manager of Philips Automotive Lighting Ralf became Vice President for automaker marketing of Philips Automotive Lighting with the task to balance LED technologies versus conventional light sources. Since his retirement, he works as a freelance consultant

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