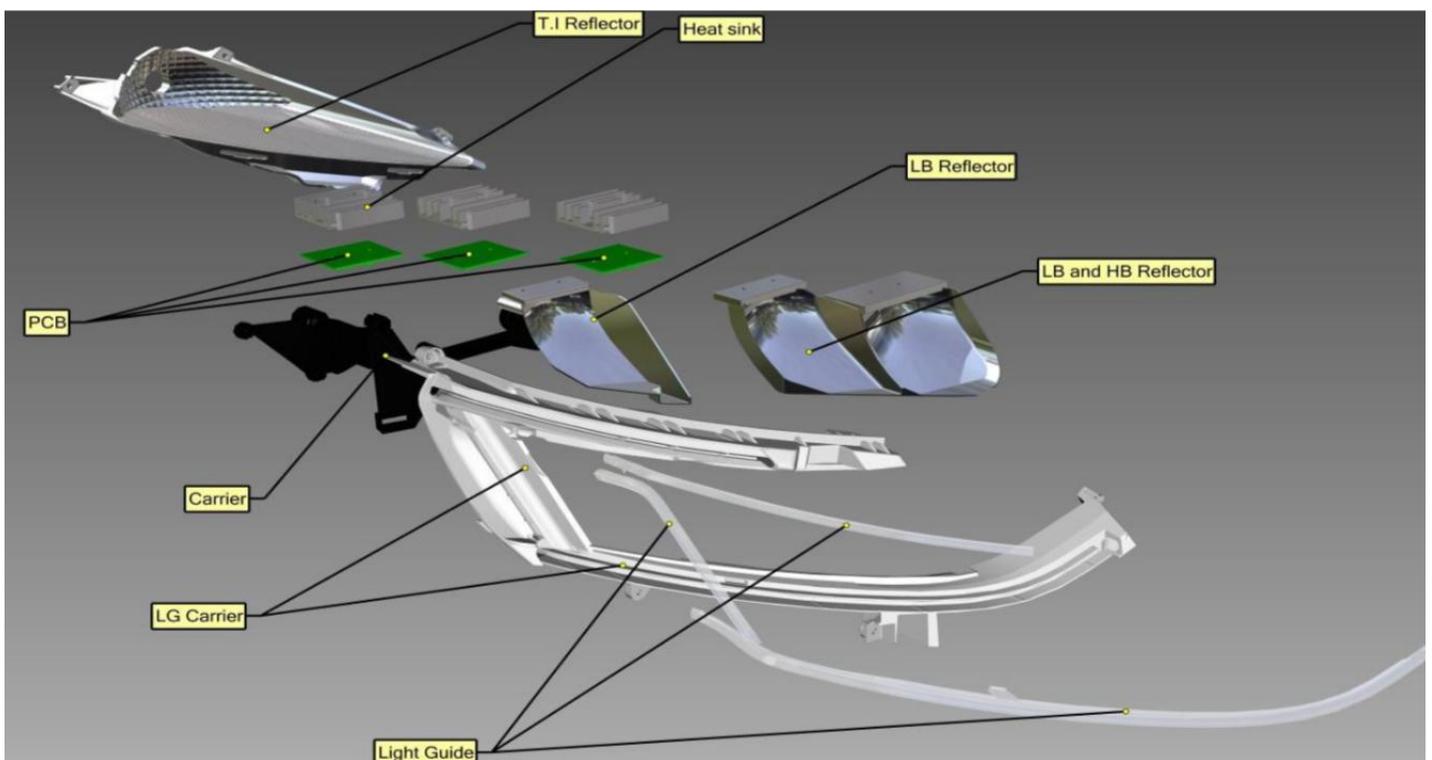


Materials in Vehicle Lighting

Published 4 June 2019



Published by Driving Vision News · 3 rue Daumier · 75016 Paris · France
T: +33 (0)1 55 60 18 25 · F: +33 (0)1 55 60 18 39 · DrivingVisionNews.com

Table of contents

| | |
|-----------------------------------------------------|-----------|
| About the Author & Author's Foreword..... | 3 |
| Executive Summary..... | 4 |
| Introduction..... | 5 |
| History of Materials for Lighting Systems..... | 6 |
| Lighting Materials and their Properties..... | 9 |
| - Polycarbonate..... | 9 |
| - PMMA..... | 11 |
| - Polypropylene..... | 13 |
| - BMC thermoset..... | 14 |
| - Glass..... | 15 |
| - Silicone..... | 17 |
| - Magnesium..... | 17 |
| - PBT..... | 21 |
| - POM..... | 22 |
| - ABS..... | 23 |
| Materials for Headlamps..... | 25 |
| - Cover Lenses & Coatings..... | 25 |
| - Housing..... | 31 |
| - Adhesive bonding..... | 32 |
| - Reflector..... | 33 |
| - Reflector coating..... | 35 |
| - Reflector metalising..... | 36 |
| - Bezel..... | 37 |
| - Projector lenses..... | 39 |
| - LED components..... | 40 |
| Materials for Signal Lamps..... | 41 |
| - Housing & reflector..... | 41 |
| - Cover lenses..... | 41 |
| - Welding..... | 43 |
| Selected Suppliers..... | 44 |
| - Arkema..... | 45 |
| - Covestro..... | 46 |
| - Dow..... | 49 |
| - DSM..... | 53 |
| - Evonik..... | 54 |
| - GXC Coatings..... | 55 |
| - Gore..... | 56 |
| - Holophane..... | 60 |
| - Lyondellbasell..... | 64 |
| - Menzolit..... | 66 |
| - FGN Fujikura Kasei-Red Spot..... | 67 |
| - Mitsubishi Chemical..... | 69 |
| - Optoflux..... | 71 |
| - Sabic..... | 75 |
| Annex I: BMC injection success factors..... | 76 |
| Annex II: Sample material data sheets..... | 78 |
| DVN Gold Members..... | 80 |
| DVN Reports..... | 81 |

About the author

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Author's Foreword

I thank all those who supported me in building this report, notably Michael Pickholz from Automotive Lighting; Ronan le Goas from Covestro, Marie-Mélanie Levecq from Dow, Dr. Ulrike Geissler and Mary Ann Seal from Gore; Laurent Guerin, Michel Blin, Nicolas Michelat, and Bertrand de l'Eprevier from Holophane; Thomas Luce, Thilo Maul, and Lea Kichener from Optoflux, and Laurent Barré and Marc Brassier. All these experts and specialists provided tremendously helpful knowledge, information, and advice.

I also thank Thu Le for authorship of material in past DVN reports on this subject, DVN President Hector Fratty for his advice and support, and DVN Chief Editor Daniel Stern for his editing, image selection, and content contributions.

Executive Summary

During lighting-related conferences and workshops, most presentations are about new safety systems or new solutions to improve performance or design. This is logical as this is what is seen by the final customers. Almost never highlighted are the materials used to realise these innovations and to ensure the requested lifespan and reliability. They are nevertheless crucial for these achievements; hence this report.

There is a large and growing variety of materials used in lighting. Forty years ago, only steel and glass were used for headlamps in Europe, and just glass in America and Japan for their sealed beams. Now, particularly with LEDs systems, we see PC (polycarbonate) for cover lenses; PP (polypropylene) with talc or with glass fibre for housings, PC, thermoset, PMMA (acrylic), PEI (polyetherimide), aluminium, and magnesium for reflectors; PC or PBT (polybutylene terephthalate) for bezels; PC, PMMA, silicone, or glass for projection lenses; PA (polyamide), PET (polyethylene terephthalate) or PBT for brackets; PMMA or specific grade of PC for light guides; aluminium, magnesium, or thermal polymers or compound resins for heatsinks, POM (polyoxymethylene) and other technical materials for some mechanical parts, and so on and on. For each material, a variety of makers offer many grades with different properties in relation to optics, appearance, thermal resistance, stiffness, precision, and other characteristics. This variety makes set makers' technical choices simultaneously simpler (at least one solution will usually exist for their requirements) and more complex (the menu is larger).

These materials are brought forth by international companies who, like their automotive customers, cover the world. Some material suppliers are very big indeed—consider Sabic, Covestro, Dow, and Mitsubishi Chemical, for just a few examples. They are generally integrated companies producing from crude oil all the different intermediate components necessary for their deliveries to the automotive industry. For these companies, automotive and particularly vehicle lighting is a small part of their activities, generally diversified to many domains. But there are also medium-sized companies delivering to set makers specific parts like glass lenses, silicone primary optics, thermoplastic light guides, and venting membranes. Vehicle lighting is often an important part of these tier-2 companies' activities, and they maintain active development centres and generally achieve good financial results.

All these material makers are participating actively to the innovation race of vehicle lighting. Plastic materials were initially introduced in headlamps mainly to allow new shapes with height reduction and integration of other lighting functions such as front turn signals. And now some recent innovations are only possible with new materials; for instance, matrix beams with their large LED arrays need silicone materials for the realisation of primary optics. It's easy to think thermoplastic materials that have been around awhile, like polycarbonate or polypropylene or PMMA, are still the same as always, but material makers are constantly innovating and improving and introducing new grades to better fulfil specific needs and reduce cost.

So definitely, materials are important in lighting and will only grow in importance with new needs for integration of sensors and communications systems, all with constant price-and-performance pressure as electronics and software take a growing share of resources and budgets.

Introduction

When we talk about lighting, very often we are speaking about performance, intelligent lighting, communication, size, and design. This is natural, as these characteristics are central to the main safety and style functions of car lights as directly seen by the final customers. But to achieve these results, a lot of hidden work is done upstream, especially with the materials integrated for the realisation of lighting systems.

A great big variety of material is required to build today's advanced lighting systems, unlike past lamps made of glass and steel, glass and a single type of plastic, one type of polycarbonate and one type of plastic, or even just glass alone in the case of the sealed beam headlamp. Plastics have now supplanted many other materials—we have polypropylene and ABS and PEI for lamp housings, thermoset or polycarbonate for reflectors, polycarbonate and PMMA for lenses, and so on. A long evolution, sometimes needing changes to the regulations, was necessary to go from yesterday's thick and heavy glass and steel lamps to today's thinner, lighter, and more variously styled products.

This evolution is far from finished. As rules are becoming more and more restrictive for CO₂ emissions, weight is again a decisive factor. In their last report in 2018, the European Federation for Transport and Environment estimated that each increase of 12.4 kg in a car means another 1 g/km of CO₂. Each additional g/km of CO₂ is becoming so expensive for car makers that new solutions to decrease the weight of parts, including lighting systems, is urgently required. And so the materials industry steps up to help set makers and car makers achieve their lightweighting targets.

But plastic material are not the only ones used. Heat sinks for LEDs are often made of aluminium or magnesium; glass and silicones are often used for the most advanced matrix beams' primary optics; selectively-permeable membranes are necessary for efficient condensation control, and many other small components and subcomponents contain other-than-plastic materials. And that's not even to mention the materials used in construction of LEDs, OLEDs, lasers, and other suchlike—those materials are outside the scope of this present report.

After a brief history, this report presents the main materials used currently in vehicle lighting with their main properties. It describes the material needs for the main parts of lighting systems, and the technical and economic benefits and drawbacks for the various material choices. For each type of material, main suppliers are outlined; some of them are more comprehensively presented in the last chapter, and there are interviews with managers.

So, we wish you an enjoyable and informative reading of this report. It may be a bit on the long side, but it's packed with information usually not readily available about materials for vehicle lighting.

History of Lighting System Materials

Reflector and lens materials through the 1970s

For many decades, round stamped steel reflectors and round glass lenses were used. Those were the materials available with adequate temperature resistance, and round parabolic reflectors were what was possible to produce. The lens contained the optics to distribute the light. Materials selection was limited: soda-lime glass in colourless or selective yellow, or colourless borosilicate glass.



Starting in 1940, sealed beam headlamps were mandated in the USA. They became popular throughout the British Empire and in Japan. Most of them were all-glass units. This strict standardisation with a simple design allowed very low cost, but severely limited possibilities for style differentiation.

In 1961 the new Citroën Ami 6 presented a new concept: rectangular (or oblong) headlamps. Still with parabolic stamped steel reflector and optically-faceted glass lens, but the departure from the round shape was a major achievement and a first portent of things to come.



1980s: First plastic headlamp reflectors

At the beginning of the 1980s, thermosetting **polyester BMC** (Bulk Moulding Compound, at first called DMC for Dough Moulding Compound) entered use for headlamp reflectors; Lucas were among the first companies to do extensive R&D and commercialisation. BMC offers good heat resistance to 200°C, good physical stability without the hysteresis ("spring back" effect) of a stamped steel reflector, and above all, offered the ability to achieve much more intricate shapes not possible with steel. First bifocal and then complex-surface reflectors made of BMC quickly came to dominate the market. Compared to steel, plastic reflectors allowed much more design freedom, too, in terms of lamp shape and aspect ratio.

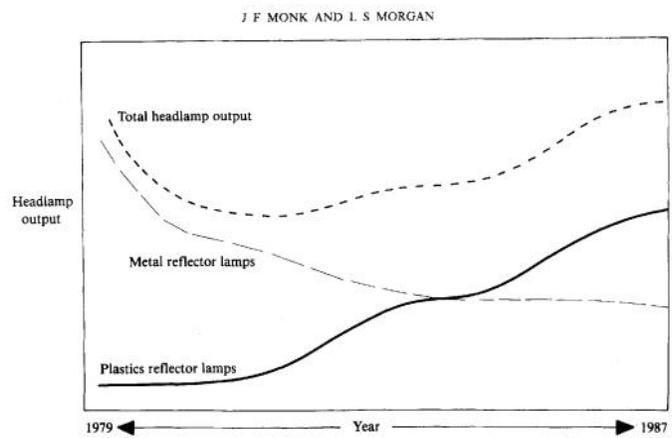
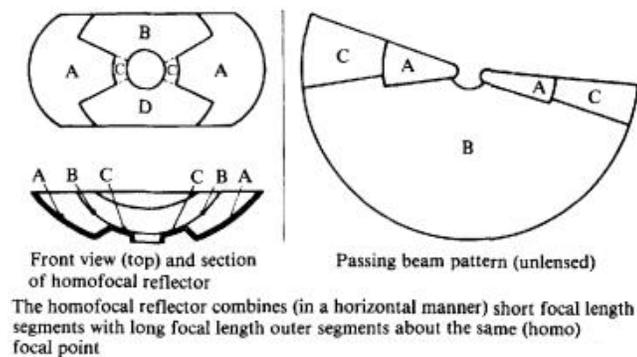
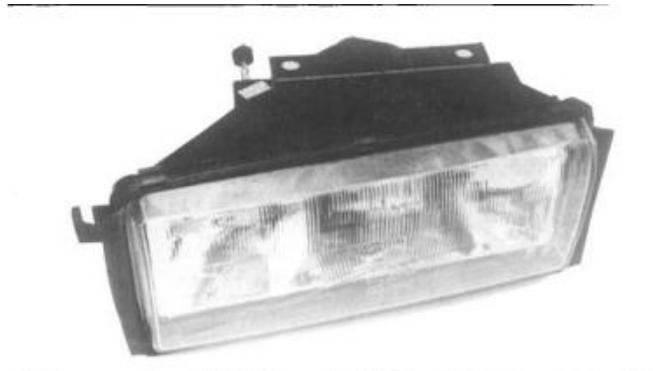


Fig. 2 Output of metal and plastics reflector headlamps

However, BMC could not replace metal in applications with small reflectors resulting in high temperature constraints—such as in polyellipsoidal (projector) headlamps and in small fog lamps. Those still had to use stamped steel or cast alloy reflectors.

By the end of the 1980s, **thermoplastic** reflectors had been applied for headlamps particularly in America where the lack of a low-beam cutoff made thermoplastic's relatively low thermal shape-stability less important (with the European beam, reflector dimensional changes with temperature made the low beam cutoff's sharpness and location unstable). Materials improved in this regard, and by the end of the 1990s thermoplastic materials such as **polyetherimide** entered service even for lamps producing a sharp cutoff, and even for small, hot-running reflectors. More recently, LEDs with their reduced power consumption and forward-light/rearward-heat have eased the thermal load on reflector materials, allowing the use of **polycarbonate** for reflectors.

Plastic headlamp lenses



Polycarbonate lenses were experimented with as early as 1979, and were first widely commercialised on Ford's 1984 Lincoln Mark VII—the first US-market car since 1939 with replaceable-bulb headlamps rather than sealed beams. Polycarbonate can be degraded by UV, abrasion, and solvents, so a hard coat was specified. Europe began permitting plastic lenses in late 1992. (Photo: a Ford engineer describes Lincoln's new lamps in 1983)

Clear lenses: The US-market 1990 Honda Accord was the first car with window-clear, optics-free headlamp lenses and all light-distribution optics in the moulded plastic reflector. By the end of the 1990s, such lenses were practically a must, as fluted and faceted lenses now looked old-fashioned. Optical calculations grew much more complicated as the reflector was no longer a parabola (or sections of different parabolas), it was now a complex surface with over 50,000 individually-specified points. Precision and care had to be greatly increased at every step from toolmaking to assembly; the window-clear lens meant any tiny defect could clearly be seen, so there could be none. (Photo: 2007 Jeep Wrangler US headlamp)

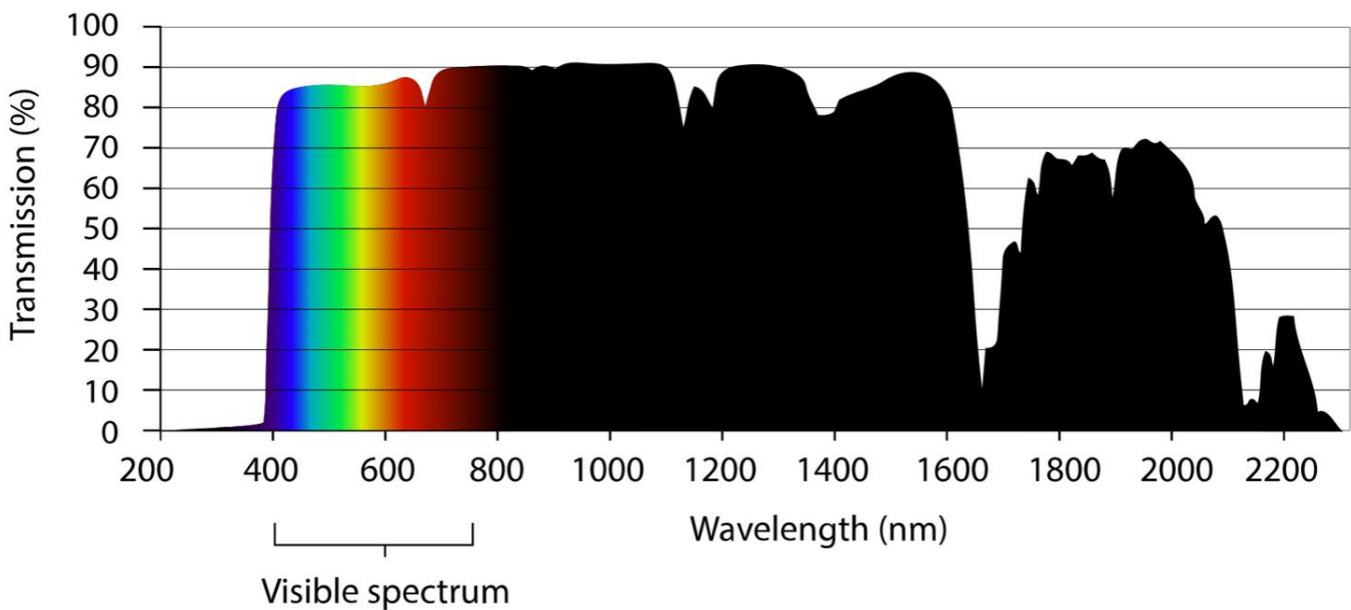


Lighting Materials and Their Properties

Polycarbonate

Polycarbonates are a group of thermoplastic polymers containing carbonate groups in their chemical structures. These materials have very good mechanical properties and some grades are optically transparent. They are generally easy to work, mould, and thermoform—some high-heat grades have high viscosity and are more difficult to mould. Polycarbonates were first discovered in 1898 by Alfred Einhorn, a Jewish scientist working at the University of Munich. However, after 30 years of laboratory research this class of materials was abandoned without commercialisation. Research resumed in 1953, when Hermann Schnell at Bayer in Uerdingen, Germany patented the first linear polycarbonate. The brand name "Merlon" was registered in 1955, and later changed to Makrolon in the 1980s. Also in 1953, and one week after the patent was submitted by Bayer, Daniel Fox at General Electric in Schenectady, New York, independently submitted a closely related patent on a branched polycarbonate.

Polycarbonates find many industrial applications, and naturally in lighting systems due to their good optical properties. Visible-light transmission of around 85% makes PC suitable for lenses, but its absorption is generally too much for successful use in long light guides.



Chromatic Aberration

The refraction index for standard PC is relatively high at 1.585, a bit higher than glass or PMMA. This allows thinner lenses, but causes chromatic-aberration issues (colour fringe) for thicker pieces such as projector lenses. Abbe numbers of about 30—this quantifies how widely the lens disperses different wavelengths of light as light passes through it—are relatively good, but not as good as glass (60 or higher); that is to say, glass is more transparent. Another favourable property of

polycarbonate is the ease of obtaining a good surface finish allowing good reflection ratio after metallisation at around 85%: much better than ABS, but not as good as coated BMC (around 90%).

Mechanical properties

Polycarbonate's low density of about 1.21 g/cm³ translates to lower-mass parts compared to glass which is roughly twice as dense. The young's modulus (stiffness) of PC is as high as 2.0-2.4 GPa, and the tensile strength at 55-75MPa gives very good impact resistance—a definite advantage for headlamp lenses exposed to rocks and other missiles on the road. PC's heat deflection temperature at 1.8 MPa is between 128 °C and 138 °C, which allows use with sustained temperatures of about 130 °C. That's better than standard PMMA, but still constrains PC's use with hot-running (e.g., halogen) light sources: a PC lens must be at least 80 to 120 mm from the bulb, depending on the optical system.

PC molecules absorb UV radiation. This absorbed energy causes cleavage of covalent bonds, which initiates the photo-ageing process. Therefore, PC must have a UV-resistant coating on the exterior surface of an external lens. This coating must at the same time fend off damage by abrasion and exposure to chemicals likely to be found near vehicles, such as detergents, acids, aromatic hydrocarbon, and ketones.

The polycarbonate market:

According to Research and Markets, the global automotive polycarbonate market is expected to grow with the CAGR of over 17% during the period 2017-2024. Since the 1990s, headlamp lenses have almost universally been made of PC. It is used also for projection lenses, reflectors, and bezels—particularly with LEDs as the temperature is much lower than with halogen. It is also used as a compound particularly for rear lamp housings in combination with ABS to achieve a better temperature resistance and a better reflection. Aside from lighting, there is strong interest in using PC for glazing (windows). However, its cost is high relative to glass glazing, and stringent regulations make it difficult to use in windshields.

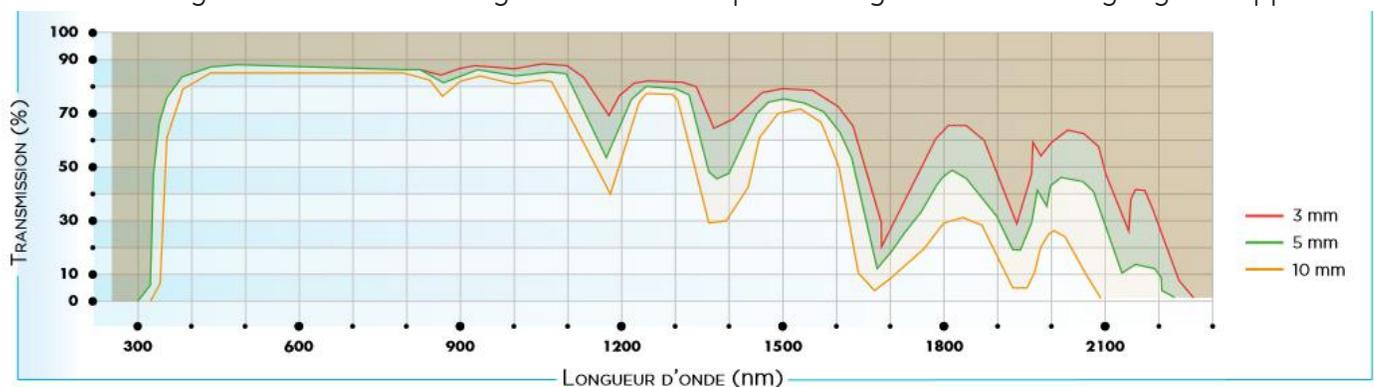
Key automotive polycarbonate suppliers include Sabic (Saudi Arabia), Covestro (Germany), Teijin (Japan), Trinseo (U.S), Idemitsu Kosan (Japan), and Mitsubishi Chemical (Japan).

PMMA (Polymethyl Methacrylate, "Acrylic")

PMMA is a transparent, strong, tough, lightweight material. These properties let it replace glass for many applications. The first acrylic acid was created in 1843. A methacrylic acid derivative was formulated in 1865. Polymethyl methacrylate was discovered in the early 1930s by British chemists Rowland Hill and John Crawford at Imperial Chemical Industries in England. About the same time, chemist and industrialist Otto Röhm of Rohm and Haas in Germany attempted to produce safety glass by polymerising methyl methacrylate between two layers of glass. The polymer separated from the glass as a clear plastic sheet, which Röhm gave the trademarked name Plexiglas in 1933. Another brand, Perspex, and Plexiglas were commercialised in the late 1930s. In the United States, E.I. du Pont de Nemours (now known simply as DuPont) subsequently introduced their own product under the trademark Lucite.

Optical properties:

The transmission of light for a sheet of 3 mm thickness is 92%, and this changes very little with increased thickness. This good transmission of light makes PMMA particularly well suited for light guide applications.



The refractive index is 1.49 at 589.3 nm, close to the index of glass, and the abbe number is a very favourable 58. This means less chromatic aberration (colour fringe) in projection lenses compared to those made of PC.

Mechanical properties:

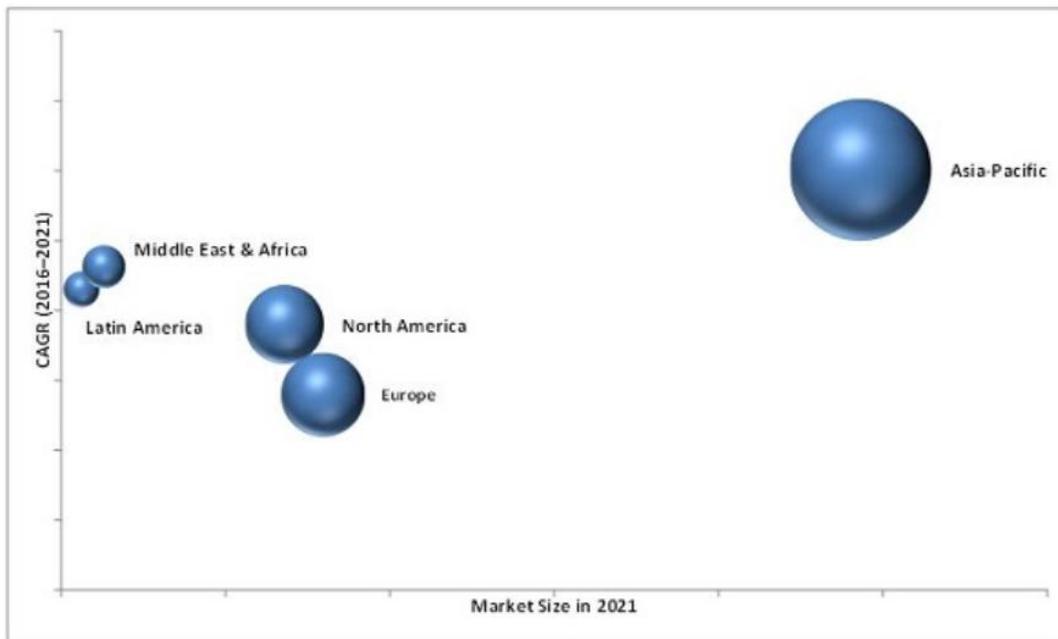
Certain grades of PMMA have robust enough mechanical properties for use in external parts (such as front lenses) without coating, as the UV resistance, solvent resistance, and scratch resistance are adequate. However for front lenses, its impact resistance of 4 kJ/m² is generally considered insufficient—compare PC's 220 kJ/m². Some grades of PMMA have resistance of up to 120 kJ/m², but with poorer transmission at higher temperatures. Most PMMA has a limited temperature resistance at around 110 °C – 115 °C. There are some grades with better heat resistance, but they are more expensive as well.

PMMA market:

According to Markets and Markets, the PMMA market was worth USD \$4.20bn in 2015 and is projected to reach \$5.56bn by 2021, at a CAGR of 4.7% between 2016 and 2021. This market is increasing thanks to many application as LED flat screens, but also the needs for automotive particularly in relation to the strong demand of PMMA for interior lighting with LEDs.

Main PMMA manufacturers include Arkema (France), Evonik Industries (Germany), Mitsubishi Rayon (Japan), SABIC (Saudi Arabia), Sumitomo Chemical (Japan), Asahi Kasei (Japan), Chi Mei (Taiwan), GEHR Plastics (Germany), and Kolon Industries (South Korea).

PMMA Market, by Region, 2021 (USD Billion)



Source: Marketandmarkets

Uses of PMMA in lighting systems:

PMMA is widely—almost universally—used for signal light lenses. It can be used in some particular cases for front lighting lenses, for instance for motorbikes or foglamps, only with LEDs as temperature is generally a challenge, and with limited surface area to bolster effective impact resistance. The other main use of PMMA is for light guides, thanks to its good light transmission, and for some projection lenses when temperature factors allow it. This widespread use in automotive applications is also explained by its relatively low price, at least for standard grades.

Polypropylene

Polypropylene is a polyolefin. It is partially crystalline and non-polar. Its properties are similar to polyethylene, but it is slightly harder and more heat resistant. Polypropylene is the second most widely produced commodity plastic (after polyethylene) and it is often used in packaging and labeling.

Phillips Petroleum chemists J. Paul Hogan and Robert Banks first polymerised propylene in 1951. Propylene was first polymerised to a crystalline isotactic polymer by Giulio Natta as well as by the German chemist Karl Rehn in March 1954. This pioneering discovery led to large-scale commercial production of isotactic polypropylene by the Italian firm Montecatini from 1957 onwards.

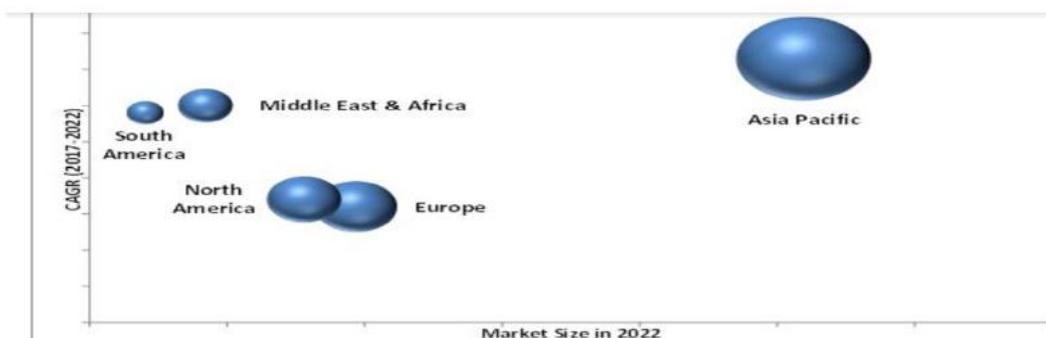
Mechanical properties:

The density of polypropylene is particularly low—between 0.895 and 0.92 g/cm³—so PP is the commodity plastic with the lowest density. This also means the stiffness of PP is low, so when it is used for structural parts like headlamp housings, PP is often reinforced with talc or glass fibre, which increases its density. PP with 40% talc fill has temperature resistance up to around 125 °C. Long-term exposure to temperatures above 100 °C, however, can degrade the material. One of the main reasons for its prominent use is its very low cost compared to other plastic materials, and the ease with which it is injection-moulded.

Polypropylene market;

After polyethylene, polypropylene is the most important plastic with revenues expected to exceed USD \$100bn by 2022. The sales of this material are forecast to grow at a rate of 5.8% per year until 2021. In 2013, the global market for polypropylene was about 55 million tonnes. For automotive applications, the market is projected to grow from \$28.2bn in 2018 to \$47.3bn by 2023, at a CAGR of 10.9%.

The world's main PP suppliers are LyondellBasell (Netherlands), SABIC (Saudi Arabia), Exxon Mobil (U.S.), DuPont (U.S.), INEOS (Switzerland), Total (France), Formosa Plastics Group (Taiwan), China Petrochemical (China), LG Chem (South Korea), and Sumitomo Chemicals (Japan).



Uses of PP for lighting systems:

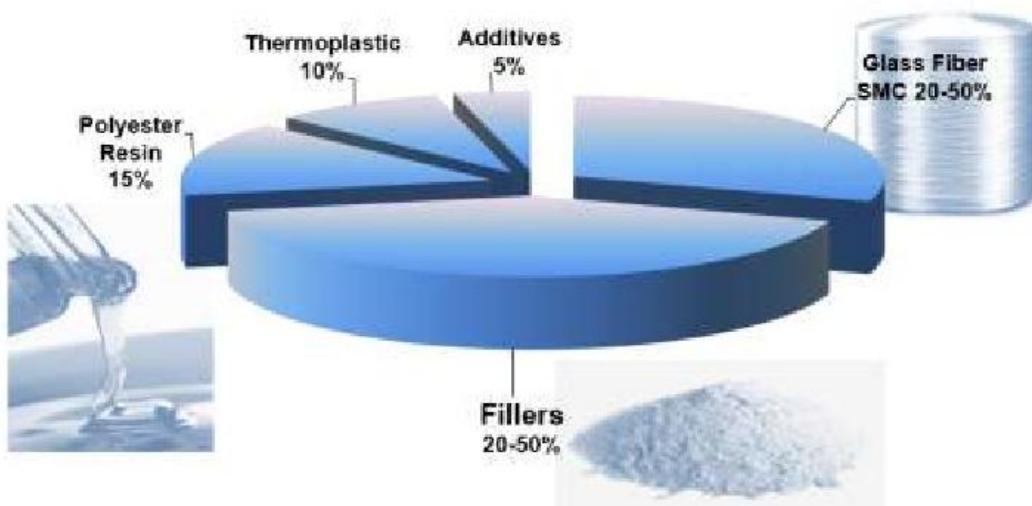
PP is one of the best material taking into account cost and mechanical properties. It is so widely used for headlamp housings. There were some attempts to use it for signal lamps in the past, sometimes with paint, but this has not flourished and by now has ended.

BMC Thermoset

Polyester Bulk moulding compound (BMC), also called dough moulding compound (DMC), is a ready-to-mould, glass-fibre reinforced thermoset polymer material primarily used in compression moulding, as well as in injection moulding and transfer moulding. Typical applications in general include demanding electrical and corrosion-resistant applications, and in the automotive sector, headlamp and fog lamp reflectors.

BMC is manufactured by mixing strands between 3 and 50 mm long of chopped glass fibres, styrene, an initiator, and filler in a mixer with an unsaturated thermoset resin—commonly polyester. The mixing is done at room temperature and stored at low temperatures to slow down curing prior to moulding. The concentration of the mixture can vary depending on application, but is typically 30% glass fibres, 25% filler, and 45% resin; styrene, and initiator. The material is provided in bulk or in logs approximately 10 cm in diameter. The glass fibres in BMC increase the strength properties of the product so that they are higher than standard thermoplastic products. They are also much more dimensionally stable.

The viscosity of BMC dictates how effectively it can fill a mould. At high viscosity the pressure applied to the BMC is not enough for it to flow, but at low viscosity the fibres will stay in one place while the rest of the material flows without them. The viscosity constrains the amount of each component that can be used when mixing BMC. Having a large amount of fibre or longer fibres improves mechanical properties but makes the BMC more viscous. Adding fillers can lower the cost of the BMC or improve a certain property but causes the BMC to become more viscous. Adding more styrene lowers viscosity but causes the moulded BMC to become brittle. With optimal viscosity to allow flow, BMC components can be up to 405 mm long before the components of the mixture begin to separate.



Market:

For vehicle lighting, BMC replaced steel for reflectors and was almost the only material used during several decades with halogen sources. The arrival of LEDs changed the constraints particularly as the temperature decreased allowing new materials. Nevertheless, BMC is still currently the main material for headlamp reflectors, as more than 60% of cars are still using halogen bulbs. Menzolit are the European leader for BMC supply.

Glass

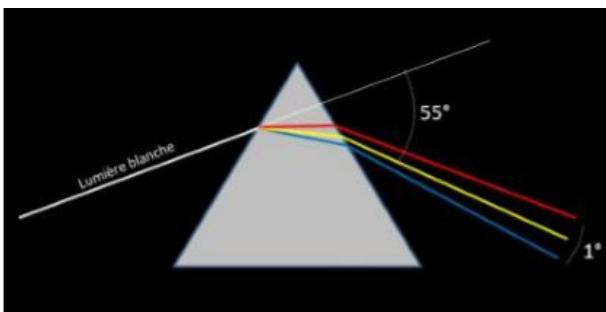
Natural glass—especially volcanic obsidian glass—was used by many Stone Age societies across the globe for the production of sharp cutting tools. But the first true glass realised by humans was made in coastal north Syria, Mesopotamia or ancient Egypt in the mid third millennium BCE. The most familiar and oldest types of manufactured glass are based on silica (silicon dioxide, or quartz)—the primary constituent of sand. After by adding other components, new properties including colours were discovered with many applications during the past centuries.



For lighting applications, two main types of glass are used. **Soda-lime-silica glass** ("soft glass") consists of silica, sodium oxide (Na₂O), lime (CaO), magnesia (MgO), and alumina (Al₂O₃). It is naturally transparent and easily formed. It has a relatively high thermal expansion and relatively low resistance to heat (500 to 600 °C), with good surface quality. A specific treatment is generally needed to avoid ugly marks due to bleeding of lime. This phenomenon is particularly sensitive with heat and humidity.

Sodium borosilicate glass ("hard glass"), widely known in the popular cookware called Pyrex, consists of silica, boron trioxide (B₂O₃) + soda (Na₂O) + alumina (Al₂O₃). Borosilicate glass withstands thermal shock much better than soda-lime glass. It has fairly low coefficients of thermal expansion (e.g., $3.25 \times 10^{-6} \text{ K}^{-1}$ versus about $9 \times 10^{-6} \text{ K}^{-1}$ for soda-lime glass). This makes borosilicate glass more dimensionally stable. The lower coefficient of thermal expansion makes boro glass less subject to stress caused by thermal expansion, thus less vulnerable to cracking from thermal shock.

Headlamp lenses have been made of both kinds of glass; in Europe the French industry (Cibié, Marchal, etc) tended to use soda-lime glass while the German industry (Hella, Bosch...) used borosilicate. Both types were used by Japanese and American makers.



Glass is well known for its ability to refract, reflect, and transmit light following geometrical optics, without scattering it due to the absence of grain boundaries. Common glass has a refraction index of around 1.5. This may be modified by adding low-density materials such as boron, which lowers the index of refraction or increased to as much as 1.8 with high-density materials such as (historically) lead oxide or, in modern uses, less toxic oxides of zirconium, titanium, or

barium.

For vehicle lighting applications, glass is optically an interesting material for instance for projection lenses thanks to its good transmission, low chromatic issues, and low diffusion (high Abbe value, above 60). Glass is better in these three ways than polycarbonate.

| | Refraction: | Chromatic dispersion |
|--------|-------------|----------------------|
| Glass | 1,52 | 64 |
| PMMA : | 1,49 | 53 |
| PC: | 1,58 | 28 |

Mechanical properties of glass:

In the manufacturing process, silicate glass can be poured, formed, extruded and moulded into forms. For lighting applications, glass is systematically moulded. Glass is durable, recyclable, with better resistance to abrasion than plastic. It is impervious to UV, with no yellowing or opacification over time as is found with plastic—careful study has revealed this as the crux of the reason why it has become progressively more dangerous to be a pedestrian in America than it was when headlight lenses were glass: the average age of a vehicle on U.S. roads is nearing 12 years and vehicles are generally not inspected for roadworthiness; plastic lenses degrade and severely reduce headlight performance, while glass lenses do not. Glass has a good tensile strength, but is relatively sensitive to impact. Soda-lime "soft" glass is more easily broken than

borosilicate "hard" glass. Both types can be hardened or tempered to improve impact resistance. Glass resists higher temperatures than plastic, but standard glass is sensitive to thermal shocks, a characteristic significantly improved with tempered glass or with borosilicate glass versus untempered or soda-lime glass. Another important characteristic of glass is its relatively high density around 2.5, roughly two times more than plastic.

Glass market:

For many years, all headlamp lenses were glass. Reflectors, too, in the case of most sealed beams (though toward the end of the sealed beam era, plastic ones were commercialised on a limited basis in America). Since the introduction of plastic and particularly polycarbonate for front lenses, glass took a back seat, used only for foglamps lenses due to the small size imposing high level of temperature and for projection lenses for elliptic systems, also for temperature reasons. These applications are rapidly moving toward plastics, since the introduction of LEDs has eased the temperature constraint. However, as lenses grow smaller and smaller, the excellent optical property of glass keep it in the running—as do its competitive production and tooling costs. Glass is still a main material for projection lenses. Major makers of glass projector lenses include Docter Optics in Germany, Holophane in France, and Bicom Optics in China.

Silicone

Silicone is a relatively new material used for primary optics and light guides for LEDs applications. It's interesting mainly in relation to its material flexibility and mould replication fidelity, which enables complex optical shapes, fine surface features, and integrated mechanical features not possible with traditional plastics. Silicone is also heat resistant, which allows positioning very close to the LEDs, which in turn improves efficiency. Other materials like PMMA must be spaced further away from LEDs to avoid degradation triggered by heat or blue-light exposure.

Dow are the main supplier of silicone materials, and Optoflux are a key silicone lens maker. Further information is contained in the Dow and Optoflux sections of this report.

Magnesium

Magnesium is a material with very interesting properties particularly for weight and has been promoted notably by Michael Picklolz when he was with Sea Link more than a decade ago. Presently Magnesium has found only a few applications for vehicle lighting. Nevertheless, as lightweighting becomes more and more crucial, it could be a material for the future.

Main characteristics:

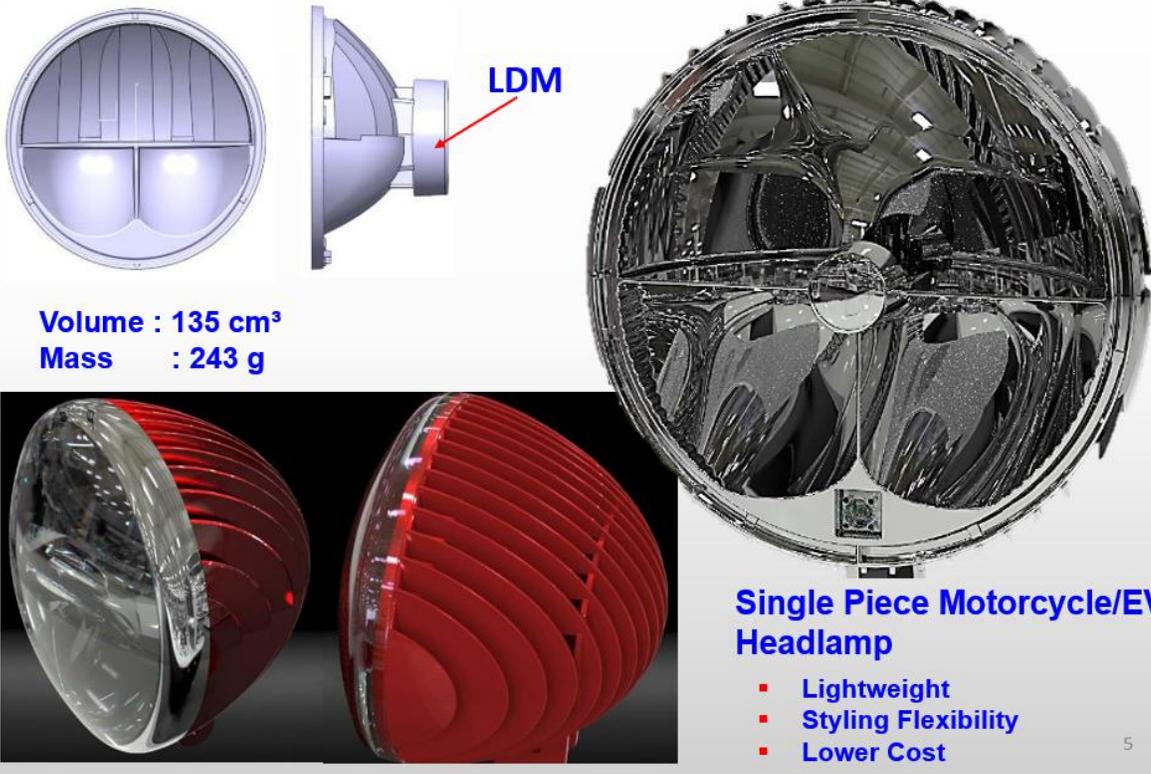
- Density: 1.738 g/cm³, that is 33% lower than aluminium.
- Relatively low melting point of 650 °C
- Protected against corrosion by a thin layer of oxide that is impermeable and difficult to remove
- Highly inflammable, though it is difficult to ignite in mass or bulk. The flammability can be reduced with specific alloys.

Thixotropic moulding

Thixomolding® is a fast magnesium injection moulding process: in a single step, the process transforms room-temperature magnesium chips, heated to a semi-solid slurry (a thixotropic mixture) inside a barrel and screw, into precision-moulded components. It allows the moulding of very thin walls.

In this process, room temperature magnesium alloy chips are fed into the back end of a heated barrel through a volumetric feeder. The barrel is maintained under an argon atmosphere to prevent oxidation of the magnesium chips. A screw conveyor located inside the barrel feeds the magnesium chips forward as they are heated into the semi-solid (thixotropic) temperature range. The screw rotation provides the necessary shearing force to generate the globular structure needed for semi-solid casting. Once enough slurry has accumulated, the screw moves forward to inject the slurry into a steel die.

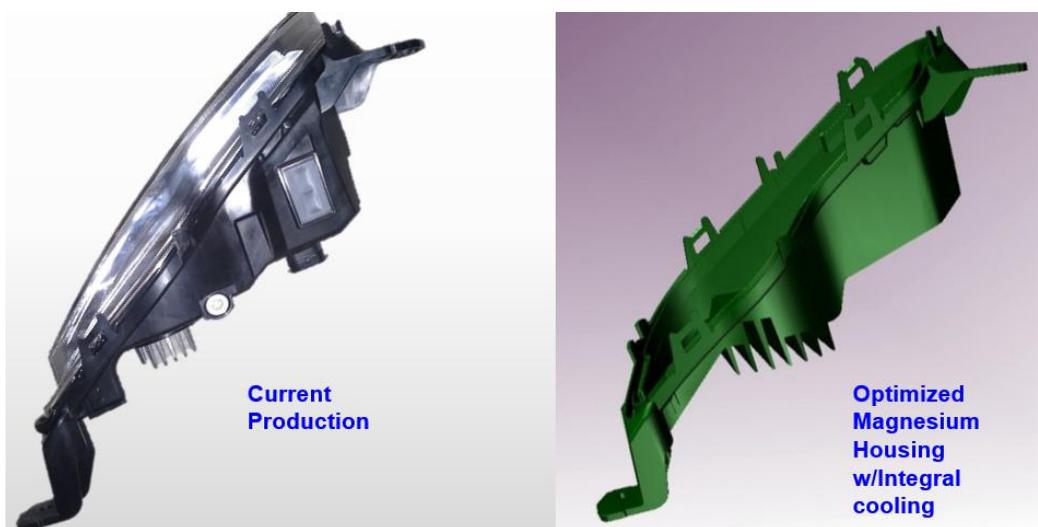
Examples of thixomolding part: Motorcycle LED headlamp ø 178 mm :



Ultra-Lightweight + low-cost LED fog Lamp



Study for use of magnesium for headlamp housing:



Interview: Michael Pickholz, magnesium & Thixomolding® Expert

DVN: Can you introduce your personal involvement with the magnesium technology?

Michael Pickholz: I was responsible for introducing Sea Link International to the use of magnesium in the first place, following my patent application in 2009 for utilising Thixomolded magnesium as an alternative to plastic housings and aluminium heat sinks, which still remain an industry standard approach.

DVN: What is the weight saving with magnesium?

MP: Weight savings are ranging from 33% (die-cast magnesium vs. aluminium) to 50% (Thixomolding®), on account of its ability to reduce wall thickness down to 0.5 mm, principally via the use of thixotropic moulding rather than casting as is done with aluminium and conventional magnesium technology. For housings, ability to reduce wall thickness from ~ 2.5 mm (plastic such as 30% talc-filled PP, a typical lamp housing material) down to 0.7–1.0 mm for thixo magnesium, which yields over 40% in mass reduction yet, with a significant gain in strength and highly effective cooling performance.

DVN: What about moulding cycles?

MP: Moulding cycles are essentially the same as with plastic parts for thixomolded components.

DVN: Despite these strong advantages for the weight, thixo magnesium is still rarely used for lighting systems. Why is that?

MP: Switching from plastic to magnesium entails switching process and equipment, thereby obsoleting large numbers of plastic injection moulding machines; requiring the purchase of multiple magnesium injection moulding machines in their place, and setting up a magnesium infrastructure in place of the established plastic one. There is also the need to retrain engineers and manufacturing people. Furthermore, many tier-1s purchase the majority of their ancillary components, hence they view the switch to magnesium—currently purchased from 3rd parties—as relegating them to the role of only lighting *assemblers* without a core manufacturing competency.

Thus far, switching to magnesium construction has been viewed only as a potential improvement, clearly not as a requirement.

DVN: Now, you are with Marelli/Automotive Lighting with responsibilities addressing areas of ADAS and AVs. Do you think the global evolution towards EVs, AVs, connected cars, and car sharing could impact the magnesium strategy?

MP: EVs being introduced by Volvo, Audi, MB, Jaguar, GM and many others are having clear issues with effective single-charge operating range. Outside of Tesla, most established tier-1s do not seem to achieve a single-charge range of 400 km. Recent tests, during the truly cold Polar Vortex which the Northern USA experienced this past winter, illustrated that many EVs lost nearly half their operating range in cold weather. Tesla's cars were affected, but cars like Nissan's Leaf and the Chevy Bolt were much more seriously handicapped. EV performance is clearly compromised by vehicle mass + power consumption; this is a well-known fact—mass is the enemy.

Unfortunately, lighting has been steadily growing in mass for the last few years. As the recent guest editorial by Rainer Newman pointed out, new types of DLP headlamps already exceed 10 kg in weight and 100 Watt in power consumption...each! Per Rainer's comments, LED was initially touted as a green technology with the ability to achieve, using 16 watts, similar performance to a 65 watt halogen lamp. Clearly, advanced LED lighting has numerous benefits, but such marked increases in power consumption and mass further exacerbate the issue of EV range.

Connected and autonomous vehicles further complicate the issue with their high count of additional electronic sensors (e.g. radar, lidar, visual and IR cameras, ultrasonics, LiFi, etc) and the related electronics required to process and distribute these signals. The additional power consumption, as well as related mass of these components impose additional parasitic loads on the propulsion batteries, impose further loss of operating range. Remember, the electrical load of a Level-5 EV has been characterised as equivalent to carrying 50 laptop computers in the vehicle.

Little differentiation is expected between a shared versus a privately-owned vehicle in terms of requirements. Maximisation of range while minimising cost will continue to be the top priority for either type of application. Whether and whenever fully autonomous Level-5 vehicles become widespread, it is crystal clear that ADAS systems and, at the very least, limited automation are here to stay and grow rapidly in their application scope. The problem, once again, is how to deliver levels of operating range which fulfill the needs of individual owner-operator customers or shared-mobility operators alike. 200-watt headlight systems with 20 kg mass just simply will not do!

I should also mention that lidar and radar systems not only consume power, they also require their respective cooling systems, which further add mass as well as power consumption. One recent lidar application requires liquid cooling (a liquid circulating system with two heat exchangers, such as with a combustion engine) to actively cool each of the multiple lidar units.

One of the top DLP matrix headlamp also employs a Peltier-type heat pump to cool each headlamp, which means more weight and more power consumption. Actually, some of the new Headlamps are so heavy that tier-1s are having to resort to the use of two leveling motors per lamp to cope with the increased internal mass. Of course, this recursively increases the mass!

Effectively, tier-1 lighting suppliers have been engaged in a technology and performance race, focused primarily on premium-brand applications. Yet as both premium and mainstream brands are now forced to electrify their fleets to achieve government mandates, the demands on the lighting community to deliver solutions is already clear. Pressure to reduce mass, if not power consumption, is also being felt on combustion-engine applications. For instance it was just announced that FCA established a deal with Tesla to "pool" their emissions to avoid heavy EU fines for exceeding CO₂ emissions—without this pooling, FCA would miss the requirements by a rather large margin. This shows there is clear pressure to reduce mass on all fronts.

Bottom line: lighter weight, what was once just a nice benefit, is now effectively a requirement. No lighting tier-1 seems to have anything in terms of lightweight construction solutions—actually, exactly the opposite. It remains to be seen what the tier-1 community will do. I have demonstrated that magnesium LED/laser headlamp housing construction as outlined in my US Patent N^o [8845128](#) works as advertised in terms of allowing up to 60% in mass reduction as well as in excess of 25% improvement in cooling capabilities.

Let's see what happens as the OEMs seek to solve the excessive-mass problem while the industry continues to deliver even more mass as well as power consumption...!

PBT

Polybutylene Terephthalate (PBT) is a thermoplastic engineering polymer that can be used in headlamps for brackets and bezels, particularly when temperature could be an issue for PC.

PBT is close to other thermoplastic polyesters. For instance, compared to PET (polyethylene terephthalate), PBT has slightly lower strength and rigidity, slightly better impact resistance, and a slightly lower glass transition temperature.

Mechanical properties:

- Temperature: Melting point at 223 °C, practically, PBT can be used up to 170°C
- Density: 1.31
- Good surface finish when metallised
- Good dimensional stability
- Possibilities of relatively thin injected parts, but with specific tooling realisation. As with all polyesters, PBT is very sensitive to humidity, so it is essential to dry the material before injection.
- PBT has also good dielectric strength, allowing its use for electrical devices.

PBT can be combined with ASA and with PET.

Main Suppliers:

Dupont (Crastin®), BASF(Ultradur®),
Celanese (Celanex®), Mitsubishi (NOVADURAN™),
Radici (Raditer®), and Sabic (VALOX™)



Uses in vehicle lighting:

For lighting systems, the materials used for bezels have to be directly metallisable and show excellent surface as well as fog-resistance. For instance, BASF offer several grades for these purposes: with Ultradur® B 4520, bezels can be directly metallised. It is a premium PBT grade with excellent fogging behaviour and demoulding properties. Parts made of Ultradur® S4090 G4 can show a textured surface or metallic effects. For structural frames of LED modules, Ultradur® B4040 G10 is the BASF PBT of choice.

DuPont's Crastin® PBT resin is also adapted for bezels realisation. It provides higher temperature resistance (up to 170 °C) than polycarbonate, with less outgassing compared to competitive materials and involves a lower overall cost. It provides very high stability and very low thermal degradation during the moulding process.

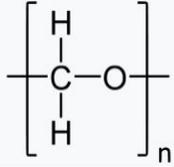
POM (Polyoxymethylene—also "acetal" or "polyacetal")

POM is used in relatively small quantity in lighting systems, but is important for specific parts, particularly to ensure low friction for small mechanisms, for instance the aiming systems for headlamps.

It was discovered by German Hermann Staudinger in 1920, a German chemist who received the 1953 Nobel Prize in Chemistry.

But it was really industrialised in 1960 first by DuPont.

Polyoxymethylene



Properties:

- High resistance to traction and shocks
- Good fatigue resistance
- Good resistance to chemical agents
- Excellent dimensional stability
- Low friction coefficient
- Good wear resistance
- Good temperature resistance
- Density: 1.41



Main suppliers:

The main brand names are Delrin from DuPont, Celcon and Hostaform from Celanese, Ramtal from Polyram, Duracon by Polyplastics, and Kepital (Korea).

ABS (Acrylonitrile Butadiene Styrene)

ABS is an amorphous terpolymer formed by polymerising styrene and acrylonitrile in the presence of polybutadiene. Usually, the composition comprises half the amount of styrene with the remaining balance divided between acrylonitrile and butadiene.

Mechanical Properties:

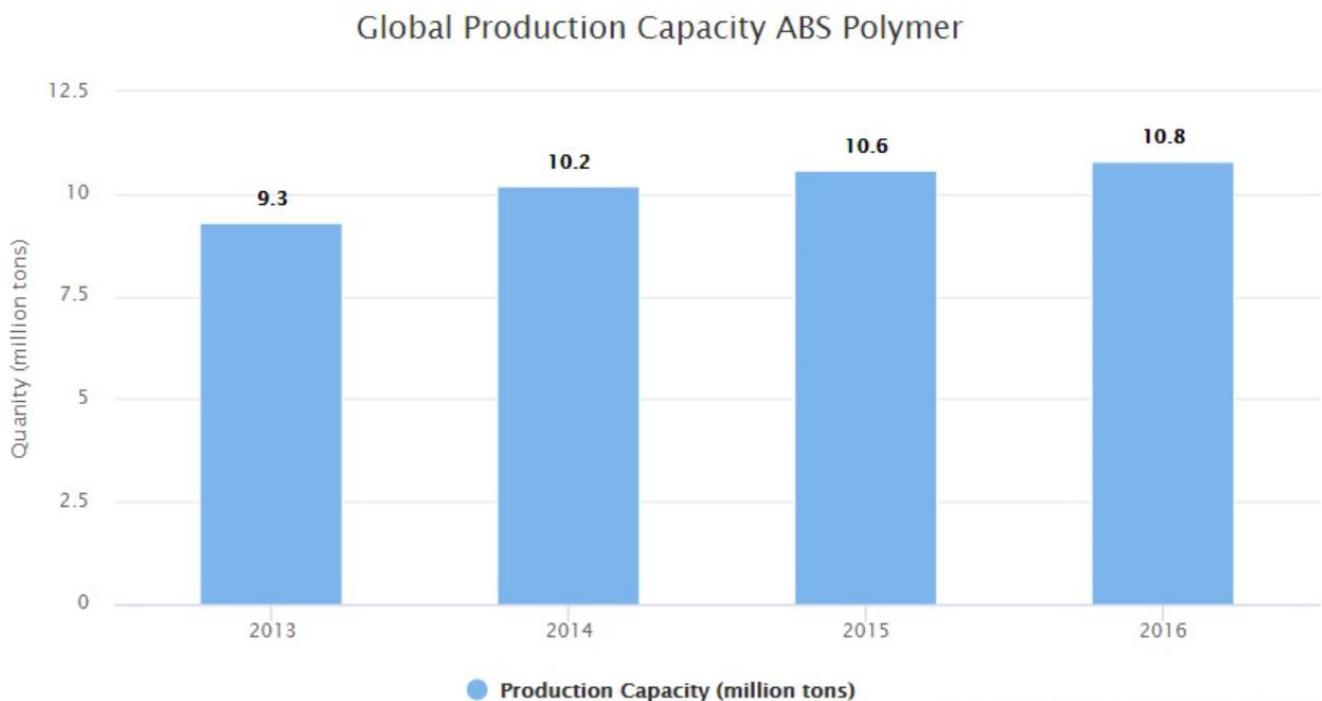
- Temperature resistance: The glass transition temperature is approximately 105 °C. As an amorphous, it has no precise melting point. Continuous operating temperature up to 95 °C.
- Density (average): 1.0 to 1.05
- Good impact resistance
- Good toughness
- Good appearance, allowing it to use for many visible parts
- Good resistance to acids, alkalis, oil, and grease; relatively poor resistance to aromatic hydrocarbons and alcohols.
- Outstanding formability, high ductility.

Optical properties:

- Ability to receive directly metallisation, even if the reflection ratio alone is not very good at around 70%
- Ability to receive paint with very good aesthetics.
- The reflection ration as well as the temperature resistance can be improved by compounding particularly with PC resulting in ABS/PC blend.

ABS Market

Estimated at \$27bn in 2018 growing to \$34bn in 2024.



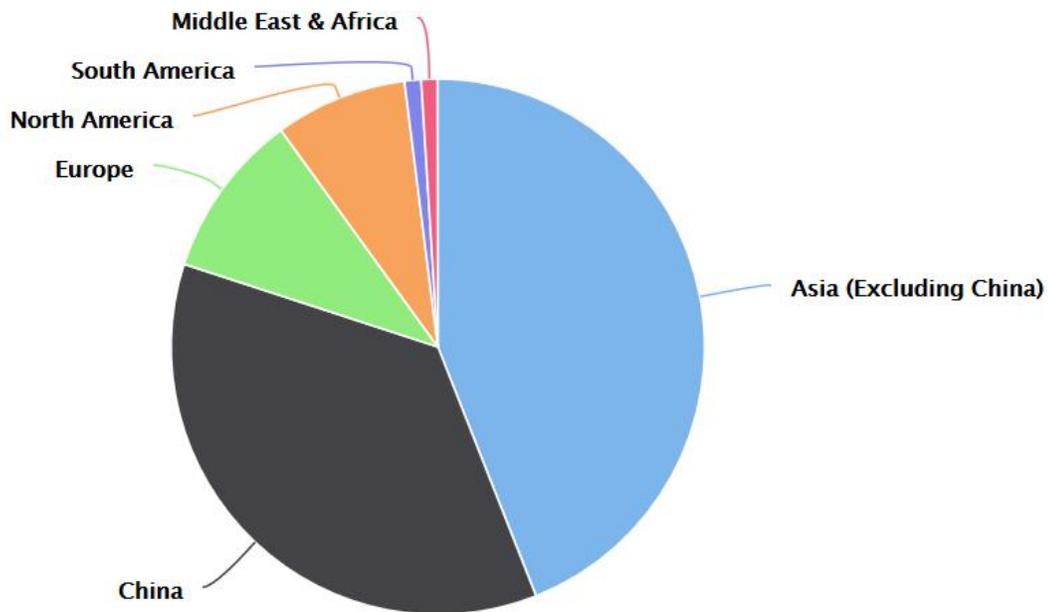
Source: *Plastic Insight*

Main suppliers of ABS:

Chi Mei, LG Chemicals, Styron, Kumho Petrochemical, INEOS Styrolution, Asahi Kasei, Sabic, China Petroleum and Chemical, Formosa plastic, Elix Polymers, BASF, Toray, Ampa, Rochling, Dow Chemicals, PolyOne, Entec Polymers, and Techno-Polymers.

Regional Production Capacity of ABS

In (2016)



Source: Plastics Insight

Use of ABS and ABS/PC in Lighting

ABS and ABS/PC are mainly used for signal lamp housings and reflectors. Its ability to receive metallisation means that ABS is both an optical part serving as reflectors and a housing fixed to the body of the car. ABS or ABS/PC is also used for interior lighting applications. ABS can also be used for 3D printing, particularly for realisation of lighting mock-ups

Materials for Headlamps

Front cover lenses

Requirements for front cover lens materials:

Naturally, the lens must be as transparent as possible to avoid losing a significant part of the light. And it must be robust enough to avoid being damaged by gravel or by cleaning fluids. It must be durable not only mechanically but also optically. And increasingly it must be capable of conforming to the new shapes requested by designers, particularly with long and thin modern headlamps.

Choice of materials for front lenses:

| Importance of each criteria | | | | | |
|-----------------------------|------|--------------------|--------------------|------|----------------------|
| Halogen | LEDs | Criteria | PC | PMMA | Glass |
| 2 | | Shock resistance | +++ | = | - |
| 2 | | Scrach resistance | ++ (With coating) | + | +++ |
| 2 | | Solvent resistance | ++ (With coating) | + | +++ |
| 2 | | UV resistance | ++ (With coating) | ++ | +++ |
| 1 | 3 | Thermal resistance | ++ | = | +++ |
| 2 | | Light transmission | + | +++ | +++ |
| 3 | | Light diffusion | + | +++ | +++ |
| 1 | | Style flexibility | +++ | +++ | -- |
| 2 | | Weight | ++ | ++ | -- |
| 2 | | Part Cost | + | + | ++ (Depending shape) |
| 2 | | Investment cost | + | + | ++ |

Polycarbonate is the almost universal material for front cover lenses

Polycarbonate began replacing glass in the mid-1980s in the United States, and about a decade later in Europe (where regulations had to be amended to allow it). Compared to glass, PC offers increased styling adaptability, reduced weight, and better impact resistance. It has also acceptable optical characteristics particularly for light transmission. However, the drawback of PC is its undesirable long-term weathering weakness, primarily due to UV exposure and the softness of its surface.



PC headlamp lens: new (left) ruined by UV (right)

Therefore, an external protective coating is required, in conjunction with light sources made so as to sharply limit UV output. Another relative weakness of polycarbonate is its thermal resistance, limited to around 130 °C (though this can be increased slightly by adjusting lens thickness). With reflectors and halogen bulbs, a minimum distance from the bulb to the lens is necessary to avoid the concentration of the light on the lens and so a too high temperature, a distance that can be around 80–100 mm depending of the optical definition.

With projector systems using halogen bulbs, there is also a thermal challenge due to high concentration of thermal load within a small surface area. Therefore, there are different PC classifications to support a wide range of thermal loading. Examples from Covestro's Apec and Makrolon ranges:

| | Lexan HF1110R | Lexan LS1 | Makrolon AL-2447 | Apec 1697 | Apec 1797 | Apec 1897 | Apec 2097 |
|-------------------------------------------|--------------------------|----------------------|-----------------------------|----------------------|----------------------|----------------------|----------------------|
| Temp °C Deflection under load, at 1.8 MPa | 126 | 129 | 124 | 137 | 147 | 157 | 172 |

Physical/mechanical characteristics of some PC materials

| | | | | | |
|---------------------|--------------------------------------|---------------------|---------------------|-----------------------|-----------------------|
| Grade | Makrolon LED2045/2245 | Makrolon AL2447 | Makrolon AL2647 | Apec 1603 | Apec 1803 |
| Color | Natural color / ice color | Crystal clear | Crystal Clear | Crystal Clear | Crystal Clear |
| Flow | Easy flow | Easy flow | Medium viscosity | Medium viscosity | Medium viscosity |
| Transmission | 89-90% | 88 % | 88 % | 87% | 87% |
| Typical application | LED-Light guides, collimator lenses, | Outer HL lens cover | Outer HL lens cover | Fog lamps, inner lens | Fog lamps, inner lens |
| Availability | Global grade | Global grade | Global grade | Glob.grade | Glob.grade |
| Vicat ISO 30* | 145°C | 144°C | 143°C | 159°C | 184°C |

The grades with superior temperature behaviour, however, come at a much higher price limiting it to some specific applications, for instance foglamps whose small size increases thermal intensity.

To reduce system cost and weight, the industry prefers to reduce the thickness of the lens to a minimum. This requires sophisticated thermal simulation technology to ensure the lens won't deform under thermal load. This endeavour also presents another challenge with regards to the design of the tool so the lens can be injection-moulded with minimum internal stress, A good simulation for instance with software such as Moldflow® is necessary to define with accuracy the positions of the different injection points. This type of constraint is even more important with higher heat resistant materials that have a higher viscosity and so a more difficult injection.

So the thickness of a PC lens is generally between 1.6 and 2.0 mm. Going further for thickness reduction was attempted many times in the past, but besides the technical difficulties came a bad perception from customers who reacted poorly to the excessive flexibility of the lens.

PMMA for cover front lenses: limited use

PMMA was the standard material in the past for front signals when the corresponding part was separate from the headlamp with its glass lens. For modern long and thin headlamp, PC is clearly the standard material, but PMMA is also possible in some cases and could be interesting due to better optical properties, UV stability, and relative scratch resistance without coating. However, compared to PC, PMMA has lower temperature stability and is sensitive to humid heat. With improved LED efficiency and more experience with efficient thermal management, temperatures inside LED headlamps are lowering; this opens the door for possible use of PMMA, at least for some applications. Standard PMMA is not good enough generally for impact resistance with a level of 4 kJ/m² while PC is much sturdier in this regard at 220 kJ/m². Specific grades of PMMA are developed by suppliers as Evonik with a much-improved level at 120 kJ/m², unfortunately with a degraded transmission of light when the temperature increases. PMMA can be used currently for DRL and for motorbike applications, but not really for mass production of automotive headlamp cover lenses.

Other technical possibilities for front cover lenses:

PMMI

PMMI, polymethyl methacrylimide, is a specific PMMA. A special moulding compound for optical parts in headlamps gives lens manufacturers a material that can cope with the high heat loads and permits dynamic styling at the same time. Evonik's Pleximid® TT70, for instance, could be suitable for optical parts in automotive headlamps because of its significantly enhanced optical properties. Its high light transmission remains virtually unchanged even after 40 days' storage at 150 °C, and therefore provides constantly high luminous efficiency. By comparison, the transmittance of polycarbonate (PC) and its heat-resistant variant (PC-HT) diminishes visibly after storage under similar conditions. As a result, the luminous efficiency of these materials deteriorates perceptibly. However, PMMI is difficult to injection-mould, and so has not found much use in vehicle lighting as of yet.

Tarflon

Tarflon is also a material sometimes used for lenses (somewhat in between PC and PMMA).

PSU, Polysulphone

Polysulphone (PSU) is a nearly water-clear polymer with higher heat resistance than polycarbonate. PSU has long been known for transparency and clarity, but desirability for automotive headlamp lenses has been hampered by the slight yellow cast heretofore typical of the material. The newest PSU is a low-colour grade specifically engineered to be nearly water-clear. In general PSU is a tough, rigid, high strength, high-heat thermoplastic with properties retained at temperatures from -100 to +150 °C. The heat deflection temperature at 1.82 MPa is 174 °C. Other key properties of PSU include resistance to acid and alkaline chemicals. In addition, the resin is resistant to a wide range of cleaners and disinfectants, alcohols and aliphatic hydrocarbons. These materials could exhibit the main needs for cover lenses: excellent surface appearance, high temperature resistance, excellent impact properties, and high flow rates. Many of the more traditional high temperature polycarbonate products are plagued by poor flow because of their relatively high viscosity; the newest PSUs have shown to be excellent materials for these critical and demanding lighting applications with easy-to-work-with flow characteristics. Moreover, PSU could be more durable, with an impact rating announced over twice that of other medium-heat materials. Solvay are an example supplier of Polysulfone; their range is branded Udel®.

COC (Cyclo-olefin Copolymer)

COC is a potential candidate for lens usage. COC materials are commercially available from a handful of pilot-scale plants around the world. Current world production of these resins is only about 9 million kg/yr from four suppliers. Three are in Japan (Nippon Zeon, Mitsui Chemical, and JSR /formerly Japan Synthetic Rubber) and one is in Germany (Ticona). As applications multiply, producers are increasing capacity. Nevertheless, the price of this material is too high for a practical application for front cover lenses. It is, however, used for the very small optics of cameras.

Comparison of various optical polymers. (1: Bad – 5: Good)

| | PMMA | PC | COC | PSU | Glass |
|----------------------|-------------|-----------|------------|------------|--------------|
| Transmittance | 5 | 3 | 4.5 | 2 | 5 |
| Refr. index | Low | High | Medium | High | Low |
| Water absorp. | 1 | 3 | 5 | 3 | 5 |
| Inj. molding | 4 | 4 | 5 | 3 | 1 |

1=Poor 5=Good

Comparison of various optical polymers

Lens Coating Materials

Polycarbonate lenses must be protected from three different factors: weathering (yellowing of the substrate when exposed to UV, mainly from the sun), abrasion (scratching by dust, sand, rocks, and cleaning pressure), and chemical attack (cleaning, spilled automotive fluids, etc). PC lenses are therefore coated to achieve these performance requirements as prescribed by international UN as well as US regulations. In the American regulations, coatings are not approved alone, but systematically by association with each substrate of each material supplier. The list of possible combinations is maintained by [Ameca](#) after completion of three-year outdoor-exposure tests in Florida (for humid heat +UV) and Arizona (Dry heat + UV). The requirement is that tested materials show not more than 30% haze at the end of three years outside in the sun. During development, manufacturers use accelerated tests in which UV, heat, and humidity are cycled for 2,500 hours, and accelerated testing is also specified in the UN Regulations. But in America, the three-year Florida and Arizona tests cannot be avoided, so the newest authorised materials are always at least three years behind the state of the art.

Suppliers of lens materials approved in USA include Covestro, Formosa Idemitsu Petrochemical, Mitsubishi Engineering, Mitsubishi gas chemical China, Sabic, Sam Yang, Teijin, and Thai Polycarbonate.

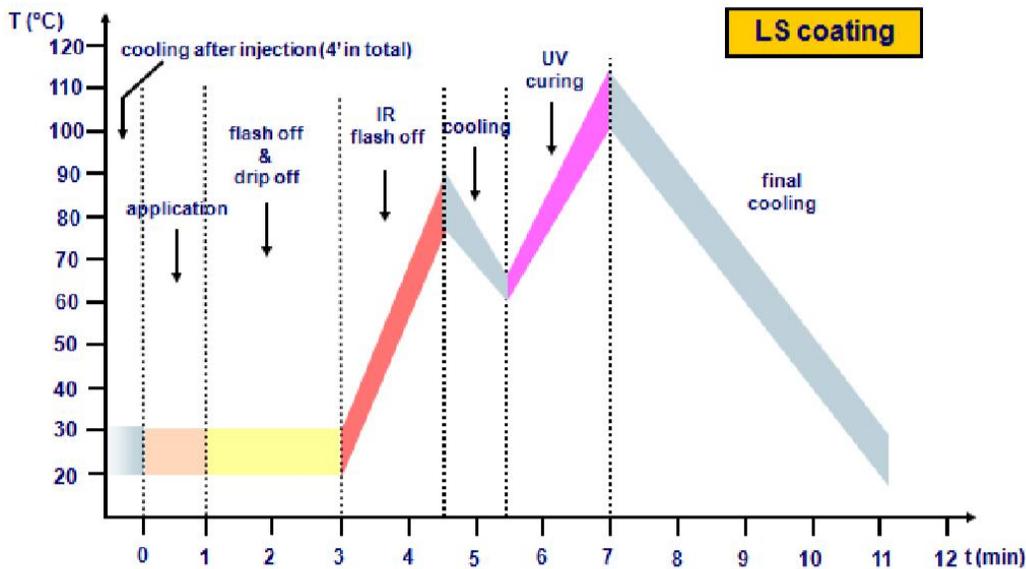
Suppliers of coatings approved in USA include Fujikura Kasei, KCC, Mitsubishi Chemical, Momentive Performance Materials, and Red Spot Paint and Varnish.

Process for protective lens coating:

There are fundamentally two types of coating materials: UV-cured and thermally-cured. The UV-cured materials, typically polyurethane based, are applied onto the outer surface of the lens either via spray or low-volume dispersion flow. After the coating is applied, the coated lens is subjected to a specific dosage of infrared to drive off the solvent and then to UV for final curing. The thermal cure materials are typically silicon based, with two coats needed to achieve the performance requirements: a base coat or primer cured thermally, and a final silicon top coat also cured in an oven. Both coatings are typically applied by a high volume, low pressure spray system. Any coating process must be done under cleanroom conditions to avoid inclusion of dust specks, insects, clothing fibres, and other contaminants that could spoil the appearance and functional clarity.

Hardcoat processing

Process diagram : steps and global temperature profile



Typical UV coating process

Advanced Lens Coating Technologies:

Lens coating is costly and intricate, so there is a general desire to either eliminate the protective coating or to integrate the coating process into the injection process. Several alternatives have been put forward:

- Co-injection of an acrylic layer in conjunction with the polycarbonate base substrate has been an ongoing application development for a number of years. The acrylic material is not prone to UV degradation and possesses excellent optical characteristics, but its thermal performance as compared to polycarbonate is still a major concern.
- Co-injection of a thermally cured coating material has been investigated heavily in the past as a means to integrate the coating process with the injection process. This approach would eliminate one primary concern of lens coating (cleanliness), but film thickness control and high thermal performance material for in-mould injection are still major challenges.
- Thin-film in-mould transfer has also been investigated. The fundamental idea is to integrate a customised die cutter into the injection mould with a thin film already prepared with protective characteristics to be "mapped" throughout the contour of lens, either during or after the cooling cycle of the injection process. Major challenges ahead include film adhesion performance and the wrinkling effect when interfacing with sharp and complex geometry of the lens, especially around corners.
- PECVD with fluromonomers (plasma-enhanced chemical vapour deposition) as a precursor to hexamethyldisiloxane, a silicone compound, is being investigated to further improve its physical properties particularly for anti-fogging functionality.

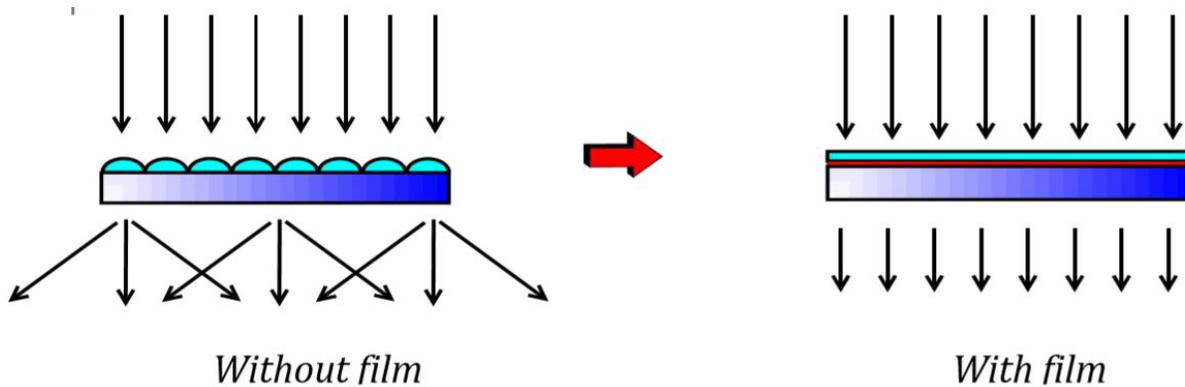
Anticondensation coatings

Another challenge in headlamp design is internal moisture condensation that can spoil the crystal clarity of today's lenses, and in severe cases can impede headlamp photometric performance. This is due to the venting of the system resulting in direct atmospheric exchange of the lamp interior with the outside atmosphere.

Composite headlamps must be allowed to breathe to reduce condensation effect, to maintain the internal pressure roughly at the level of the external one, and partly to dissipate the internal heat of the lamp. This was practically discovered by the British in the 1970s and the Americans in the 1980s, independently of each other, in the course of their first tentative steps away from sealed-beam headlamp construction. Initially in both markets, attempts were made to have "semi-sealed" headlamps in which the replaceable bulb was supposed to be hermetically sealed into the headlamp. It was discovered that if the lamp's thermal load is not released and stabilised, severe consequences can occur: bonding integrity suffers due to mechanical stress on the bond joint resulting from physical deformation of lens/reflector, and physical deformation of interior components and the mounting structure can result in photometric and aiming concerns. These two primary bad effects can have knock-on effects, such as the accumulation of liquid water inside the headlamp from prolonged condensation with no escape path provided. So, composite headlamps must be vented.

With LEDs the thermal constraints can be less severe than with halogen—but not necessarily; some complex ADB systems, even though they're fully LED, have halogen-like power dissipation.

One way to cope with condensation is the use of an anti-fog coating. This is typically applied to the inner surface of the lens in a flow coat process, and thermally cured. Hydrophilic anti-fog coating avoids visible condensation permanently. It reduces the contact angle between water and surface, it avoids droplets, and forces condensate to form invisible films. It prevents water condensation on the inner surface of headlights, fog lamps, and rear lights as well as camera-based driver assistance systems; an ideal clear view is accomplished. Performance durability, however, is still limited.

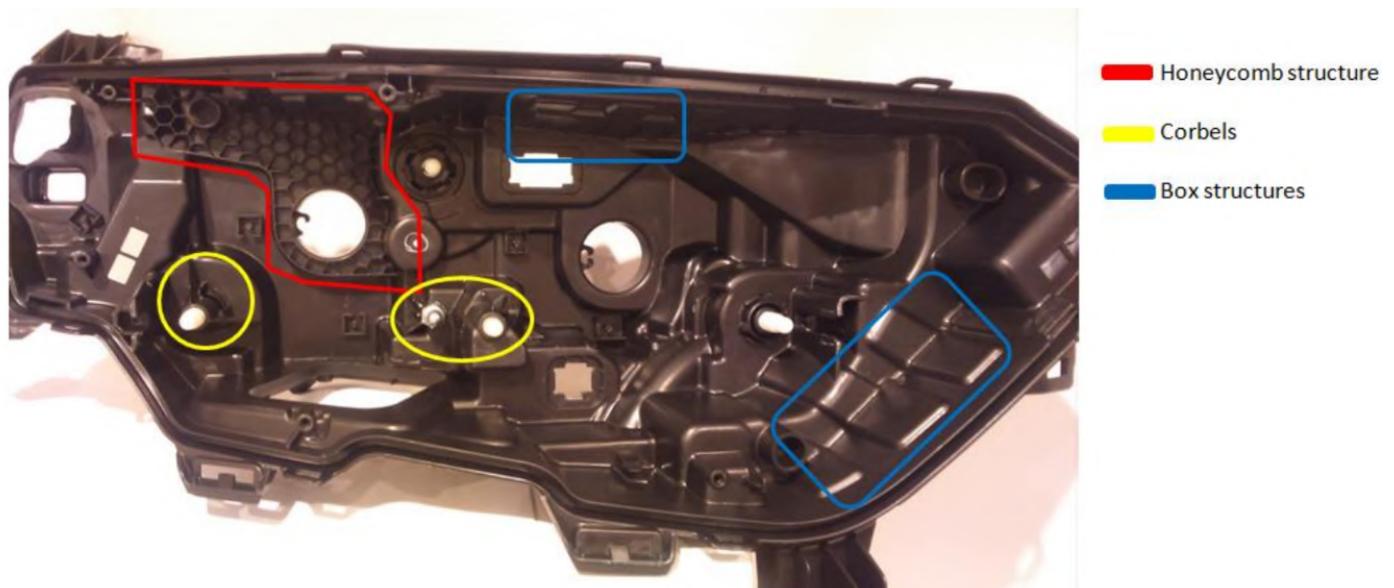


The coating resins are polyacrylates, polyurethanes or polysiloxane. Some are based on nanotechnologies. Modern 2-in-1 coating processes allow internal and external coating in one step. As the external coating is mandatory to comply with UN as well as US regulations, the internal coating is applied at minor additional cost. With external and internal coatings alike, particular care must be taken with regard to the cleanliness of the lens and the masking of the area reserved to bond the lens to the housing, otherwise a good and durable bond may not be achieved.

Materials for Headlamp Housings

Requirements for headlamp housing material

The housing of headlamp is a very important part with many jobs. It must (along with the cover lens) protect all internal components. It must resist severe vibration and mechanical shock, so its geometry must be optimised by simulation to have a high enough resonance mode. More geometry is involved with positioning and a rigid structure and sometimes a final adjustment of the fixation brackets. Rigidity and stability of support for internal components contributes to achieving stable photometry from the headlamp, particularly with the UN Regulations requiring a stable beam ($\pm 0.1\%$) despite operating temperature ranges. In some cases, surface appearance matters when a part of the housing is directly visible. And naturally, it must achieve all these things at minimal cost.



Renault Koleos housing – benchmark analysis by ELS students

Polypropylene is one housing material of choice. To improve the stiffness and to decrease the cost, talc is added generally at a level of 40%. Nevertheless, when a part of the housing is visible, the ratio of talc has to be limited to 20% to avoid seeing ugly marks. The thickness of the injected part can be around 2 mm or less with some specific structures to improve the stiffness. PP+talc is an interesting material for the housing as it can resist the necessary range of temperatures generally met on housing even with two halogen bulbs. In that case, an evaluation has to be done to check the reached temperature to avoid outgasing or deformation that could occur above 110 °C.

Some recent complex headlamps, such as matrix ADB headlamps, are very heavy—10 kg or even more. In that case the stiffness of PP talc is not enough, and PP is instead reinforced with glass fibres, generally at a level of 30%. There is research ongoing into the use of carbon fibre.

Other materials for headlamp housings include BMC, described above, and PEI (polyetherimide). New approaches involve structural housing/reflector combinations thixotropically moulded of magnesium.

Adhesive bonding for lens and housing assembly

To join the lens to the housing and form a tight waterproof joint, an adhesive is used to bond the two dissimilar materials. Due to the low surface energy of polypropylene, it must be surface-treated prior to bonding. This can be done by flame treatment or by Corona-plasma treatment.

Two-part **polyurethane** is the most commonly used adhesive; the two constituents crosslink when mixed together. Curing takes place under normal ambient environmental conditions. However, the speed of the cure—how long it takes for the crosslinking to occur—is very critical. If it is too fast, for a large lamp system the curing process has already taken place before all of the adhesive has been dispensed, so a uniform bond is not achieved. If it is too slow, a large system of clamping and holding is required to ensure the dimensional integrity of the system.

Hot melt material can also be used due to its forgiving characteristics: ease of operation, minimum processing equipment investment, and low material cost. Application is fairly straightforward: the solid material is melted with heat to become a viscous liquid and then dispensed onto the substrate. Upon cooling down, it returns to its solid state and therefore acts as a seal. It must be assured that the bond line is not subjected to a thermal environment exceeding the operating temperature of its solid state. Despite advantages of simplicity and low cost, hot melt is less dependable than structural bonding for long term reliability.

Silicone bonding was mainly used when temperature constraints were severe, for instance with halogen fog lamps. LED technology has eased the thermal challenge and so silicones, which are more expensive, are less frequently used.

Advanced Bonding Technologies:

Numerous advanced material concepts have been investigated in an effort to secure the bonding integrity between the housing and lens and simplify processing cycle. Infrared-cure materials have been investigated to reduce the curing cycle time. Microwave excitation bonding material has also been investigated to speed up the curing process. Reactive hot melt with urethane has also been tried in different compositions and formulations to increase the thermal performance of the base hot melt material. This technology has limitations due much higher material viscosity and a fairly lengthy cure time for the material to develop its full performance. Laser welding has been tried with mixed results due to the complexity of the geometry of the lens contour and the dissimilar substrates. Current application of this technology resides primarily with inner lens components with similar substrates, and for signal lamps.

Materials for Headlamp Reflectors

General requirements:

One of the main needs is to facilitate a good reflection surface after metallisation. A level of 90–92% is generally targeted for the main beam reflectors while a reduced level can be accepted for signal functions. To obtain that level with standard metallisation processes, direct metallisation can be done on some materials such as PC, PEI, and PPS. On BMC reflectors a smooth varnish must be applied.

Another requirement is dimensional stability with mechanical stress and strain and, of course, with an appropriate range of ambient and operating temperatures which, with halogen bulbs, can reach 200 °C immediately above the bulb. To improve stability characteristics, reinforcements can be added to the structure of the reflector, but this must be done with care as shrinkage is not permitted on the aluminised surface to avoid photometric issues and visible defects.

Thermosets: the typical material used for reflectors with halogen sources is a thermosetting substrate such as polyester BMC, alkyd, or phenolic—sometimes with glass-fibre or other reinforcement material such as calcium carbonate added. These materials generally offer greater dimensional stability than thermoplastics, over a wider heat range. One major benefit of thermosetting material is few shrinkages, which facilitates forecasting photometric performance and minimises the need for debugging tooling surface integrity. As with thermoplastics, during the course of the design of the reflector, many considerations must be taken into such as: draft angle, wall thickness, gassing at sharp angles/corners, etc. In particular, when gassing occurs, the end result is a very porous surface on the moulded part that would allow base coating material to penetrate into the substrate. If UV cured base coat is used, it would be impossible for the radiation to penetrate deep into the substrate. The result would be uncured material that can cause fogging.



BMC needs a specific injection for headlamp reflectors for a good respect of shape and a good surface finish. Annex 1 of this report lists ten machine factors critical with BMC injection. Some set makers have a policy against slides in their tooling to reduce burrs, limiting the possibilities to integrate functions in the part. In either case, after injection and before varnishing, the remaining burrs need to be removed, now generally with an automatic process.

Main suppliers of BMC machines include Battenfeld, Ferromatik Milacron, and Krauss-Maffei.

Advanced Thermoset Materials:

No-basecoat thermoset materials are of great interest to the industry, because coating the reflector requires major investment and factory floor space to support the tedious process. So attempts are under way to develop a material which, after the injection process, would have a resin-rich surface to accommodate the metalising process without a base coat. Major challenges must be overcome such as reflectivity capability, uniformity of the metal film, and outgassing.

Replacing thermoset with polyphenylene sulfide (PPS) with the introduction of LED modular light sources is an ongoing investigation with a lot of potential benefits. System weight reduction and the ability to perform direct metallisation are major beneficial targets. However, PPS does present some challenges in itself; its inherent physical properties present a big challenge in structural integrity of the reflector mounting system. Just as with any thermoplastic material, prediction of shrinkage to meet the exact reflector geometry so as to deliver optimum photometric performance always presents a major challenge to the tool designers.

Thermoplastics with direct metallisation

BMC is a very good solution for heat resistance, stiffness, and material cost, this one being particularly affordable. However, the global cost including the deburring and the vanishing, the limits of design with slide limitations in the tools, and geometric deformation introduced by the varnish have spurred efforts to use a much simpler process with directly metallised thermoplastics. With halogen bulbs this is a challenge as temperature in the upper part of the reflector can reach 200 °C. Now with LED systems, the menu of thermoplastic materials for reflectors is longer; the main ones are:

- **PEI (polyetherimide)** can be withstand 170 °C and has been avidly used for reflectors by ZKW. The real limit of PEI (Sabic's brand for it is Ultem) is the price, which is high relative to other thermoplastic materials. Another issue: there is only one supplier; Sabic have no competitors.
- **PPS (polyphenylene sulfide)** has also been used with halogen bulbs, but with very few applications in the past. Unlike PEI, PPS is produced by many suppliers, including China Lumena New Materials, Solvay, Kureha, SK Chemicals, Celanese, DIC Corporation, Toray Industries, Zhejiang NHU Special Materials, SABIC, and Tosoh. PPS has a very good temperature resistance at around 200 °C and is still considered for future applications for reflectors. The reflection ratio for optics, though, is lower than that of PC.
- **PC (polycarbonate)** has been used with halogen bulbs in the past, but in very specific conditions when heat constraint was not too high. Now with the generalisation of LED sources and their much-reduced constraints for temperature, PC is a very good solution and is intensively used for LED headlamp reflectors. However, with the very small dimensions of LED optics, the requirement for very high precision moulding means PC could have difficulties to accurately realise the designed shape, both with deformation after injection and by limited stiffness.
- **PMMA (acrylic)** can now be used for reflectors with LEDs in some cases, as the operating temperature is relatively low. However, PMMA's relatively low heat resistance still limits its current use as material for reflectors.
- **Aluminium** With halogen or HID bulbs, aluminium was used particularly for projector reflectors and also for fog lamp reflectors—two domains where operating temperature is very high, requiring a material with high temperature resistance. It was used for replacement of steel reflectors, allowing a better surface finish, eliminating hysteresis (springback) found in stamped-steel reflectors, and bringing the possibility of additional function integration. The development of LEDs is reducing interest in aluminium for reflectors.
- **Magnesium** has interesting properties particularly with thixotropic moulding technology allowing very thin walls. The interest with LEDs would be the integration of the heatsink directly with the reflector, which could substantially reduce system mass (weight). Inherent advantages to magnesium include:
 - Excellent thermal conductivity removes the need for internal cooling
 - Ability to shape/mould any part, as with plastics
 - Higher degree of accuracy, coupled with tighter tolerances compared to plastics
 - Very low mass; thin wall capability to 0.5 mm
 - Possibility of competitive cost with worldwide availability.
 - Can be readily polished.

Despite these technical advantages, magnesium is not yet used extensively for headlamp reflectors.

Steel reflectors were the standard until the 1980s, when they were replaced mainly by BMC. Nevertheless, steel was still used during several decades with halogen or HID bulbs for projector system reflectors and for fog lamp reflectors due to their small size and resultant high running temperature. Steel is inexpensive particularly for high volume production, but has limited possibilities of design.

The development of LEDs is now eliminating steel as a common reflector material.



Glass was almost universally the material used for sealed beam reflectors made in North America, Japan, and Britain for many years. This technology began to die in the 1980s, and glass is no longer used as a material for headlamp reflectors.

Reflector Coating

To achieve maximum reflectivity with the metal film, reflectors of thermoset, steel, aluminum, and magnesium must be base coated. The reflectors must be washed in special solution to eliminate all contaminants, then dried completely. The base coat also acts as a barrier to prevent outgassing of the material when exposed to high heat. There are typically two different types of reflector base coat materials: UV-cured and thermally-cured. Either material can be sprayed or flow-coated. Care must be taken when a UV-cured material with a flow coat process is used; UV must be presented to all coated surfaces to ensure that the coating is fully cured, or uncured coating material can seriously damage the interior of the headlamp assembly including severe chemical fogging when the lamp heats up in use. This effect will cause not only major cosmetic issues, but also will severely damage the photometric performance of the headlamp.

In any event, care must be taken when pockets or holes exist in the mechanical parts of the reflector (as for mounting fasteners or clips). Dimensional characteristics for holes on the reflector designed for fasteners must be prescribed early on, taking into account that their diameters will be reduced due to the thickness of the coating. Also, specific types of fasteners must be clearly identified for the thread to engage into the substrate to secure structural mounting integrity. Otherwise, failure due to vibration may occur. Coating is a very complex process directly impacting both the surface finish and the photometric performance of the reflector. The thickness of the coating is a key element to be controlled to achieve the best results.

Metalising material for reflectors

The base material for metalising a reflector is aluminium with 99.99% purity. The process for applying the aluminium film can be achieved via the traditional evaporation process under vacuum or with advance technology such as an electron gun that bombards electrons onto an aluminium target under high vacuum level for deposition. In some instances, when higher reflectivity values are needed, an aluminium-silver compound is used to achieve higher level of reflectance. The percentage of silver can be fine-tuned for optimal results.

Top coats

To protect the aluminum reflective layer from oxidation, an overcoat must be applied. Typically, the application of such protective coating is performed within the same vacuum chamber. The most commonly used material is hexadimethylsiloxane (HMDS) polymerised under a plasmatic environment and deposited on top of the metal film to protect it. Due to its low thickness, it has minimum effect on the optical performance of the reflector.

If scratches of the reflectors due to handling is a concern, a third film, on top of the HMDS film can also be applied. Typically, silicon oxide (SiO) is thermally vapourised within the same vacuum chamber to achieve this result.



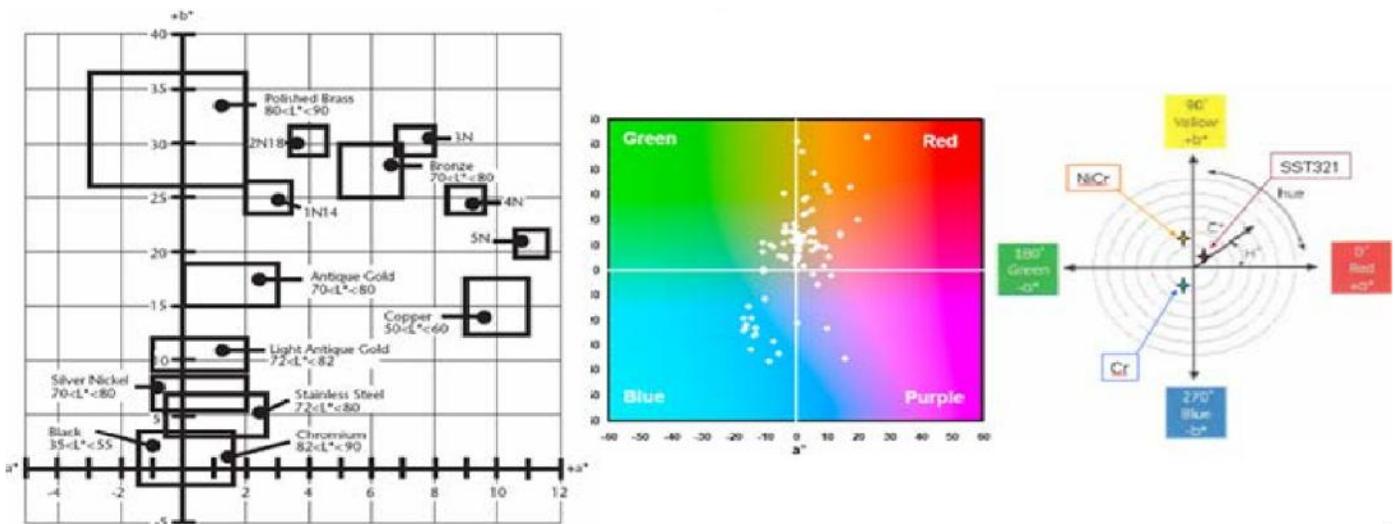
Typical Thermal Evaporation System



Typical Sputtering System

Advanced technologies:

Coloured metalising: colour possibilities are linked to metals and alloys available. Reactive PVD (physical vapour deposition) allows additional aspects.



Materials for Headlamp Bezels

Requirements:

Bezels and other decorative metallised components of headlamps are important design features to strengthen the emotional relationship of the driver to the car. Therefore, the optical quality of these metallised components has to be perfect. They also must be stiff enough, and with high fidelity to the designed geometry. As they are generally long and follow the shape of the cover lens, this is important to avoid vibration-induced material abrasion between lens and bezel.

Various materials are used for bezels. Depending upon the environment and aesthetic conditions required, there are typically two groups of material application today: amorphous and semi-crystalline.

Amorphous materials include PC, high-flow PC, and PEI. The benefits are good dimensional capability, high gloss surface, no post shrinkage after moulding, and the mechanical properties stay more constant over a broad temperature range. Covestro, for instance, offer polycarbonate-based materials for a broad temperature range for all kinds of head lamp and rear lamp bezel applications. The materials show a broad processing window to enable complicated shapes and are well established at all major makers. But weaknesses for amorphous materials include moulding difficulties due to high flow characteristics and relatively high cost. Here's a sample of Covestro amorphous materials:

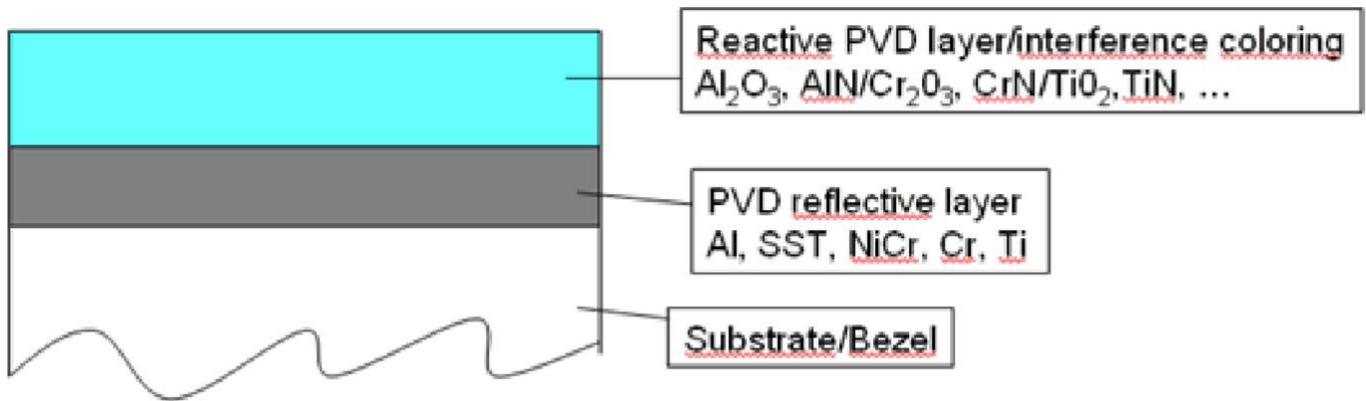
| Material | Bayblend T80XG | Makrolon 1260 | Makrolon 2405 | Apec16 95 | Apec1795 | Apec 1895 | Apec 2095 |
|-----------------------------|----------------|------------------------|------------------------|------------------|-----------------|-----------------|-----------------|
| Vicat ISO 306* | 127°C | 142°C | 145°C | 158°C | 173°C | 183°C | 203°C |
| RTI (UL 746B Yield Stress)* | | | 125°C | 140°C | 140°C | 150°C | 150°C |
| Typical application | Bezel for rear | Bezel for front & rear | Bezel for front & rear | Bezel for front | Bezel for front | Bezel for front | Bezel for front |
| Colors | All opaque | All opaque colors | Clear and opaque | Clear and opaque | Clear & opaque | Clear & opaque | Clear & opaque |

Semi crystalline materials include PA/Nylon, PET, and PBT. They are favoured for high flow characteristics and lower cost than amorphous materials, but the drawback is high moisture absorption and difficulty to be released off the tool when dealing with complex geometry, in particular with PBT material.

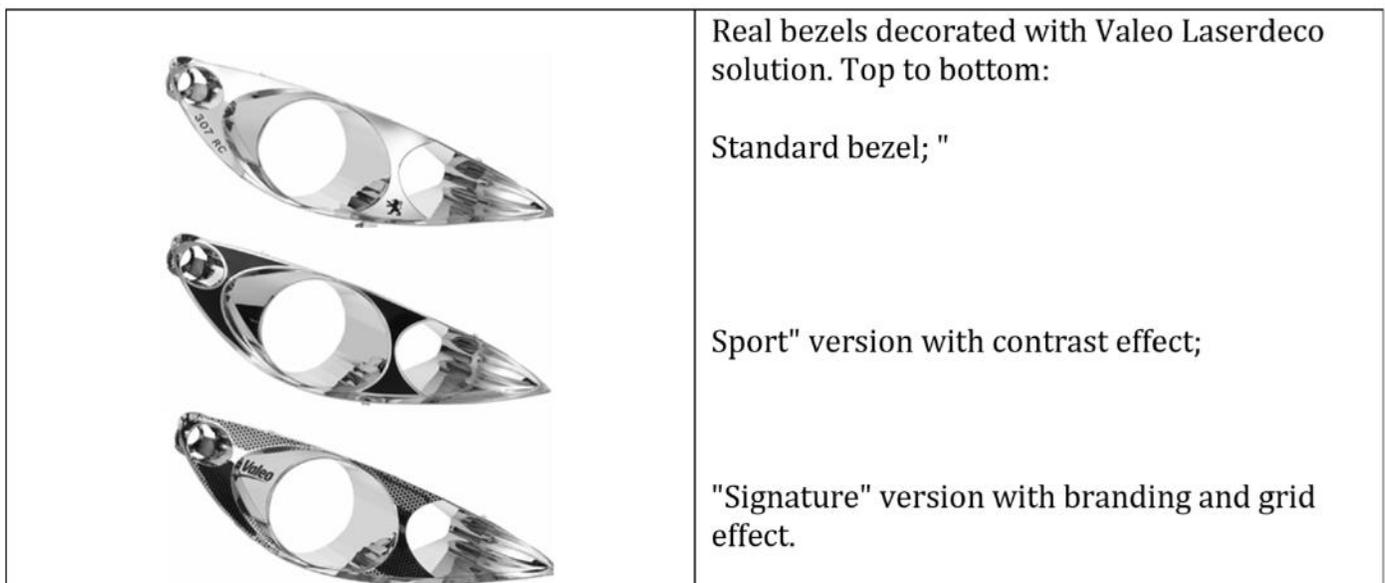
Bezel Coating

The inner bezel of the headlamp is a critical cosmetic component that is clearly seen through the window-clear lens. Stylists seek unique aesthetics, and therefore request different metallic aspects and colours of the bezel. Bezels can be used directly without any treatment, generally in black colour.

Most of them are metallised with aluminium. Other effects can be realised via painting or metalising with different materials and processes. For instance, chromium can be used to achieve a dark, metallic effect. Also, there are very specific instances that metal film cannot achieve the desired effect; then a specially formulated paint can be sprayed onto the bezel to achieve the expected cosmetic target.



Coloured metalising can also be applied. With coloured metalising, there are heat limitation for dome solutions and the interference pileup is driven by thickness-limiting 3D applications.



Laser ablation techniques are also used to imprint directly onto the bezel specific logos or legends as desired by the stylists.

Materials for Projector Lenses



Requirements

- Good light transmission with low chromatism
- High precision geometry
- Thermal resistance
- For some car makers, low diffusion

Projector lenses have successfully been made out of glass and various plastics.

Glass was the standard material in the past with halogen and HID bulbs, as the operating temperature was too high for plastics. With the

introduction of LEDs, the market shifted strongly to plastic; however, there is a current new trend to consider again glass as the components are smaller, so with less weight impact, and as the cost factor is now more important for new projects for mass production. Another requirement lately at the request of some car makers is to see only the DRL function, and so to reduce as much as possible the diffusion inside the projection lens. In that case, glass is often chosen.

Glass lenses' main advantages are good light transmission and low chromatic aberration, long-term thermal endurance, low piece and investment costs, and quick and affordable prototyping.

Plastic lenses, on the other hand, allow a high degrees of variance for very complex lens shapes giving styling freedom. They weigh less, and mounting features can be integrated more easily.

PMMA is generally the first choice for thermoplastic material. Compared with PC, PMMA is easier to inject, has optical properties closer to glass, and has less chromatism.

PC is used when the temperature is too high for PMMA, sometimes with a blue grade to avoid the yellow appearance of the standard grade.

Silicone is a material used particularly for primary lenses in matrix ADB systems, as its softness is necessary for demoulding these parts integrating up to 90 light guides.

| Criteria | PC | PMMA | Glass |
|--------------------|--------------------|------|----------------------|
| Shock resistance | +++ | = | - |
| Scrach resistance | ++ (With coating) | + | +++ |
| Solvent resistance | ++ (With coating) | + | +++ |
| UV resistance | ++ (With coating) | ++ | +++ |
| Thermal resistance | ++ | = | +++ |
| Light transmission | + | +++ | +++ |
| Light diffusion | + | ++ | +++ |
| Style flexibility | +++ | +++ | -- |
| Weight | ++ | ++ | -- |
| Part Cost | + | + | ++ (Depending shape) |
| Investment cost | + | + | ++ |

See more details about glass lenses in Holophane chapter and about silicone lenses in Dow and Optoflux chapters.

LED components



Heatsinks are essential for dissipating heat that can detract from an LED's optimal useful life of 50,000 hours. Traditionally, they have been made from cast aluminium. Aluminium has a good thermal conductivity at 150-200 W/mK for cast parts, a little bit less than a pure aluminium bar reaching 237 W/mK, but still good. The diffusion of heat can also be improved by black painting or anodisation of these parts—with an extra cost associated. Aluminium has a density of 2.7 g/cm³, not so bad for a metal, but as the fins need to be relatively thick

for a good heat transmission, final-part mass can be an issue.

Alternatives with other materials were so developed to try to decrease the weight and the cost of heatsinks:

Conductive resins such as Sabic's LNP Konduit can exhibit thermal conductivity 10 to 50 times better than standard thermoplastic resins, reaching up to 18 W/mK—but that is still far from the ≥ 180 W/mK of cast aluminium. Nevertheless, this solution offers greater design freedom, including the ability to create shapes with greater surface area for improved thermal management.

Metal sheets: folded aluminium sheets can also be used for heatsinks. These sheets are generally very thin, so a lot of folds are required—like the fins in a radiator. The process for realisation is more complex than with injected aluminium, but cost and weight can be better.

Fans are used for active cooling in LED headlamps. Active (fan) or passive (fanless) cooling is a kind of permanent discussion when a new LED design has to be done. Fans are mechanical products, and so can bring a dependability chokepoint. Practically, though, with the very severe specifications imposed currently, they are sufficiently reliable. There is also an added cost for the fan, partly compensated by a smaller heatsink. In fact, for some advanced applications, for instance matrix ADB and high-power LED systems, the level of power to dissipate is so important that only a system with fan can do that in a compact packaging.

Structural parts of LED modules

The materials used need to have a good stiffness, strength and a low warpage. They need also to have no outgassing and no moisture absorption. PA (Polyamide) has good mechanical specifications and is affordable, but grades with low moisture absorption need to be used. PBT and PET (for instance Arnite from DSM) are good alternatives avoiding the risk of moisture absorption.

Materials for Signal lamps

Signal lamps are generally simpler than headlamps, with a reduced number of parts—at least, this was the case for many years with lamps using bulbs, wherein the rear part is both a reflector for the different signalling functions and a housing attached to the car body. These parts are generally made with ABS or ABS-PC. The cover lens is injection-moulded PMMA. Now with LEDs and with the research of better appearance and homogeneity, other parts are added: specific reflectors, Fresnel lenses or other optics for LEDs, intermediate diffusing sheets, and naturally LED boards—sometimes with heatsinks.

Materials for signal lamp housings

Requirements:

- **Stiffness.** The material need to be stiff and precise, as the accuracy of positioning for a good fit and finish requires precision often better than 0.5 mm.
- **Appearance:** For popular-price cars, the housing can be seen when the trunk is open and a good enough appearance is required, with generally a black or red colour. However, now many tail lamps are using a complementary bezel to improve the appearance and hide the housing.
- **Reflectivity:** When this part is also used as a reflector, it is directly metallised, and a good enough reflectivity is necessary. ABS is not very good for that with not much better reflection than 65%. This can be improved with an ABS-PC blend, increasing the potential of reflectivity up to 80% depending on the ratio of PC used.
- **Temperature resistance** was an important factor with bulbs. In that case, for low-height reflectors, it was even necessary with ABS or ABS-PC blend to add a small metal heat shield to avoid material degradation. With LED systems, temperature is generally less severe, and ABS alone is often the standard material.
- **Welding ability:** signal lamp housings are generally welded to the PMMA lens. ABS and ABS-PC blend have a good ability for welding.
- **Affordability** is naturally another important criterion.



ABS and ABS blend are the standard materials for signal lamp housings, with good abilities in most of the foregoing criteria. For low-cost applications some housings are PP, sometimes painted to reflect light. However, PP cannot be welded, and the much larger gluing path is not easy to hide.

Materials for Signal Lamp Lenses

Requirements:

- Good appearance is particularly important for tail lamps
- Good precision moulding for a good fit and finish
- Good light transmission
- Adequate temperature resistance
- UV resistance
- Scratch and shock resistance
- Welding ability
- Affordability

PMMA corresponds well to these requirements, so it is the most common material for signal lamps. However, other materials are making inroads—for example, the **Grilamid-TR™** family of amorphous transparent polyamides made by Switzerland-based EMS-Grivory. Grilamid® TR 90 grades, in particular, offer excellent weathering and UV resistance, over and above the product range's general benefits:

| Property | TR 55 | TR 90 | Poly-carbonate (PC) | Polymethyl methacrylate (PMMA) |
|--------------------------------------------------------------------------------|-------|-------|---------------------|--------------------------------|
| Tensile E modulus (ISO 527, cond.) [MPa] | 2200 | 1600 | 2300 | 3200 |
| Notched impact strength, Charpy 23°C (ISO 179/1eA, cond.) [kJ/m ²] | 8 | 13 | no break | 2 |
| Glass transition temperature, DSC (ISO 11357, dry) [°C] | 160 | 155 | 148 | 110 |
| Heat deflection temperature HDTB, 0.45 MPa (ISO 75, dry) [°C] | 145 | 135 | 137 | 95 |
| Transparency with 2 mm wall thickness (ASTM D-1003) [%] | 93 | 94 | 90 | 94 |
| Density (ISO 1183, dry) [g/cm ³] | 1.06 | 1.00 | 1.20 | 1.19 |
| Fatigue strength (DIN 53442; 23°C) [MPa] | 25 | 32 | 20 | 15 |

- high transparency, even with thick walled components
- clear and light inherent colour
- resistance to chemicals and stress cracking
- very high flexural fatigue strength
- very good toughness, even at low temperatures
- dimensional stability and dynamic strength
- light weight due to low density
- low water absorption compared to standard polyamides
- high heat deflection temperature thanks to high glass transition temperatures
- low and mainly isotropic shrinkage
- easy processing
- easily colourable

Hella's LED centre of excellence in New Zealand makes extensive use of Grilamid for outer lenses on lamps intended for rough service on commercial vehicles. They have this to say about it:

Grilamid® offers an unbeatable combination of properties including toughness against impact, long term UV stability, and resistance to commonly used chemicals and washes—so it has become the specified

material of choice for many of Hella's valued commercial customers and end users. Hella have responded to this strong customer demand and significantly expanded the range of products with available Grilamid® lenses. Practical advantages include:

- *Grilamid® will not lose its lustre or embrittle over time but will remain clear, transparent and impact tough for the life of the product. Grilamid® retains its superior optical performance without discolouration.*
- *The use of cleaning chemicals and even general liquid detergents is sometimes used as a reason to void warranties for products made of polycarbonate, which can be cracked or crazed by cleaners. Grilamid® is highly resistant to chemicals commonly used in the transport industry, even in applications where it is regularly exposed to chemicals used to wash and sterilise equipment. It is the ideal material for fit-and-forget performance.*
- *Grilamid® Retains its Toughness—truck and trailer lamps are frequently exposed to mechanical impacts by stones, tree branches and general shocks. Uncoated polycarbonate will lose its impact resistance over time. Tests prove and market feedback confirms the superior strength and toughness of Grilamid®.*



Image: Hella New Zealand

Welding lenses and housings

Welding is an important process for signal lamps. The welding line needs to be as small, discreet, and homogeneous as possible. Different processes are used:-

- Hot plate welding is realised by heating the two parts and then joining them. This process generates reliable welds, but it's very difficult to have a good appearance of the welding line.
- Vibration welding is a simpler process wherein a high-frequency vibration between the two parts increases the temperature to the melting point. The welding line has a better appearance than with hot plate, but this process has two important limits: the geometry of the parts needs to be adapted to the vibration movement, and long-term reliability of the weld, particularly for water tightness, is difficult to achieve.
- Laser welding is a relatively recent innovation. The principle is to increase the temperature of the housing with a laser through the PMMA lens, with a robot or light guides. The appearance is much better, with less "dead" surface beyond the weld line, but it is a more expensive process.

Important suppliers for materials

- Arkema
- Covestro
- Dow
- DSM
- Evonik
- Gore
- GXC
- Holophane
- Lyondellbasell
- Menzolit
- Fujikura Kasei-Red Spot
- Mitsubishi Chemicals
- Optoflux
- Sabc



LG Chemical Yeosu Complex, Korea (PC,ABS,..)

Arkema are a global manufacturer of specialty chemicals and advanced materials, with three business segments: high-performance materials, industrial specialties, and coating solutions. The company came to exist in 2004 when French oil company Total restructured their chemical business. In 2015, Arkema acquired Bostik from Total SA.

Main figures :

- Annual sales of €8.8bn
- Employees: 20,000
- Arkema operate in 55 countries with 136 plants (60 in Europe, 38 in Asia, 38 in North America) and 15 research centres gathering 1,600 researchers with expenses representing 2.7% of sales.



Arkema's plant at Carling-St Avold in the East of France is an excellence centre for Acrylic and production of PMMA

Products

Arkema are an important supplier of PMMA for signal lenses and light guides. Their brand names for PMMA sheet and resin include Altuglas®, Plexiglas® (in the American market), Oroglas®, and Solarkote®. Standard resins are sold for vehicle lighting under the names Altuglas V825T and Altuglas HT121. They have a transmission of 92% and a level of haze of 0.5%.



The PMMA activity represents 10% of Arkema's global activity; i.e., around €880m and 5.5% of employees. PMMA is produced in eight sites worldwide with two R&D centres— one in France and the other in USA.

Arkema's other activities include high-performance materials, particularly Adhesives (Bostik) and specialty polyamides, as well as coatings.

Covestro:



Covestro, formerly Bayer MaterialScience, came to exist in Autumn of 2015 as a Bayer spinoff. The Bayer enterprise dates back to 1863. Among their long history of chemical engineering achievements they lay claim to the first synthetic coating material in 1927, the invention of polyurethane in 1937, and the invention of polycarbonate in 1953. Bayer MaterialScience became an independent subgroup in 2004, and on 1 September 2015, Bayer MaterialScience became a separate legal entity operating under the Covestro name.

They introduced the first car with an all-plastic body in 1967 and have steadily introduced mobility-related innovations ever since.

Main figures

As of 2018, Covestro had 16,770 employees (+3.7% from 2017) and sales of over €14.6bn (+3.4%).

Main products and markets:

Covestro make high-tech polymer materials and develop innovative products used in many areas of daily life. They supply key industries around the world, including automotive, electrical and electronics, construction, and medical as well as furniture, sporting goods, and textiles.

Covestro have three core business segments:

- **Polycarbonates:** Since its introduction more than 50 years ago, polycarbonate has become one of the most versatile and successful plastics ever. Covestro are a leading producer, offering a broad portfolio of polycarbonate grades. As clear and transparent as glass, with high impact resistance and design flexibility, polycarbonate is well-suited to a variety of automotive applications, notably in lighting.
- **Polyurethanes:** Covestro are global leaders in the development, production, and marketing of polyurethane raw materials for use in thermal insulation, adhesives, electrical housings, furniture, mattresses, and many other applications. In the automotive market, polyurethanes are found in numerous interior and exterior applications ranging from headliners and instrument panels to exterior body panels.
- **Coatings, Adhesives and Specialties:** Covestro offer a wide range of polyurethane raw materials for the production of high-performance polyurethane coatings. These raw materials make end products in the automotive, building and construction, infrastructure and textiles markets more attractive and durable. In the automotive market, Covestro raw materials help automotive coatings stay glossy longer, are scratch and weather resistant, and can even heal themselves.

Covestro's Polycarbonate activities:

In the Polycarbonates segment, Covestro are constantly developing new polycarbonates, including materials tailored to meet increasingly complex customer requirements in the mobility, health, and electronics/LED technology areas. According to Covestro, in mobility applications polycarbonate can reduce the weight of a vehicle component by 50 percent, cutting fuel consumption and, in turn, CO₂ emissions without sacrificing strength or safety. Obvious applications include cover lenses, LED reflectors and optics, but PCs also find application elsewhere. For example, Covestro have developed new car-interior solutions with innovative aspects for modern displays.



Car prototype designed by Covestro with substantial use of polycarbonate

In the lighting market, Covestro are providing support for the growing LED technology trend with newly-developed material grades that combine better optical properties with excellent longevity. Covestro are also involved in the use of holographic technology. Holographic films based on polycarbonate can be used, for

example, to integrate various lighting functions into the bodywork. Due to their particularly thin properties, the films open up new possibilities for using light as a design element. A 3D effect can also be achieved by backlighting the films with LEDs and reflectors.

Covestro also are looking at how autonomous vehicles can benefit from polycarbonate. For instance, lidar sensors are used for obstacle detection—they are important "eyes" for self-driving cars. Integrating lidar sensors directly into the body, an approach made possible with Covestro materials, helps autonomous cars detect obstacles, which contributes to passenger and pedestrian safety.

Interview: Covestro's Ronan le Goas



Ronan Le Goas is an automotive industry global key account manager at Covestro. He has over 20 years of experience in specialty plastic resins and films, and is responsible for Covestro's membership in DVN. He holds a degree in marketing and business management.

DVN: Can you describe your company and involvement in the automotive industry?

Ronan le Goas: Our mission is to make the world a brighter place. Covestro fulfill this mission by inspiring innovation and driving growth through leading technologies and products that benefit society and reduce the impact on the environment. Covestro posted €14.6bn in sales in 2018 (of which €4bn was for the polycarbonate business unit).

Approximately 15% of total sales is in the automotive and transportation market. As an inventor of polyurethane and later of polycarbonate (at that time under Bayer), Covestro have always been at the forefront of innovative engineering materials for Mobility. Our goal is to continue on this path.

DVN: Covestro are currently a strong supplier for polycarbonate; what are its main auto applications?

RIG: Polycarbonate and polycarbonate blends have many applications. In lighting systems, these include the outer lens, inner lenses (including collimators), light guides, bezels, filters and reflectors. Interior applications include the centre console, large displays, door trim, air vents and HVAC bezels. You'll also find polycarbonates used in such exterior components as spoilers, pillars, and transparent roof modules, to name a few. When we also include applications incorporating our polycarbonate films, we cover an even broader scope.

DVN: What do you consider the main benefits of your products for the vehicle lighting industry?

RIG: Polycarbonate is a very versatile material that can be used for a multitude of automotive applications. The success of our broad portfolio of polycarbonate is due to the unique combination of clarity, mechanical properties, impact resistance, thermal resistance and high surface quality—which can all be achieved with the same basic polymer, at an affordable cost.

DVN: How do you see competition for these products and what is your evaluation of your market share?

RIG: Our brands—Makrolon® polycarbonate, APEC® high-heat polycarbonate, Bayblend® blend resin, and Makroblend® blend resin—have historically set the benchmarks in automotive applications. We constantly push the boundaries of chemistry to deliver bold material solutions that help drive automotive innovation forward in order to help automakers gain a competitive advantage and appeal to evolving consumer tastes.

DVN: Can you explain your strategy with the current strong evolutions of the lighting industry towards more electric, more connected and more autonomous cars?

RIG: The design and production of new passenger vehicles will continue to evolve over the next decade. Mobility trends that are shaping the future of vehicle lighting include autonomous technologies, vehicle electrification, and connectivity and digitalisation. Based on these trends, we are seeing sensor integration and more compact lighting systems, which lead to new requirements that create the need for advanced materials. Due to lighting design trends, including large head lamps with complex shapes, rear lamps corner-to-corner with light strips and evenly light diffusing decoration parts, we are also seeing shifts toward polycarbonate usage. Simply put, our innovative materials and technologies for exterior, interior and lighting components help advance the mobility of today and tomorrow.

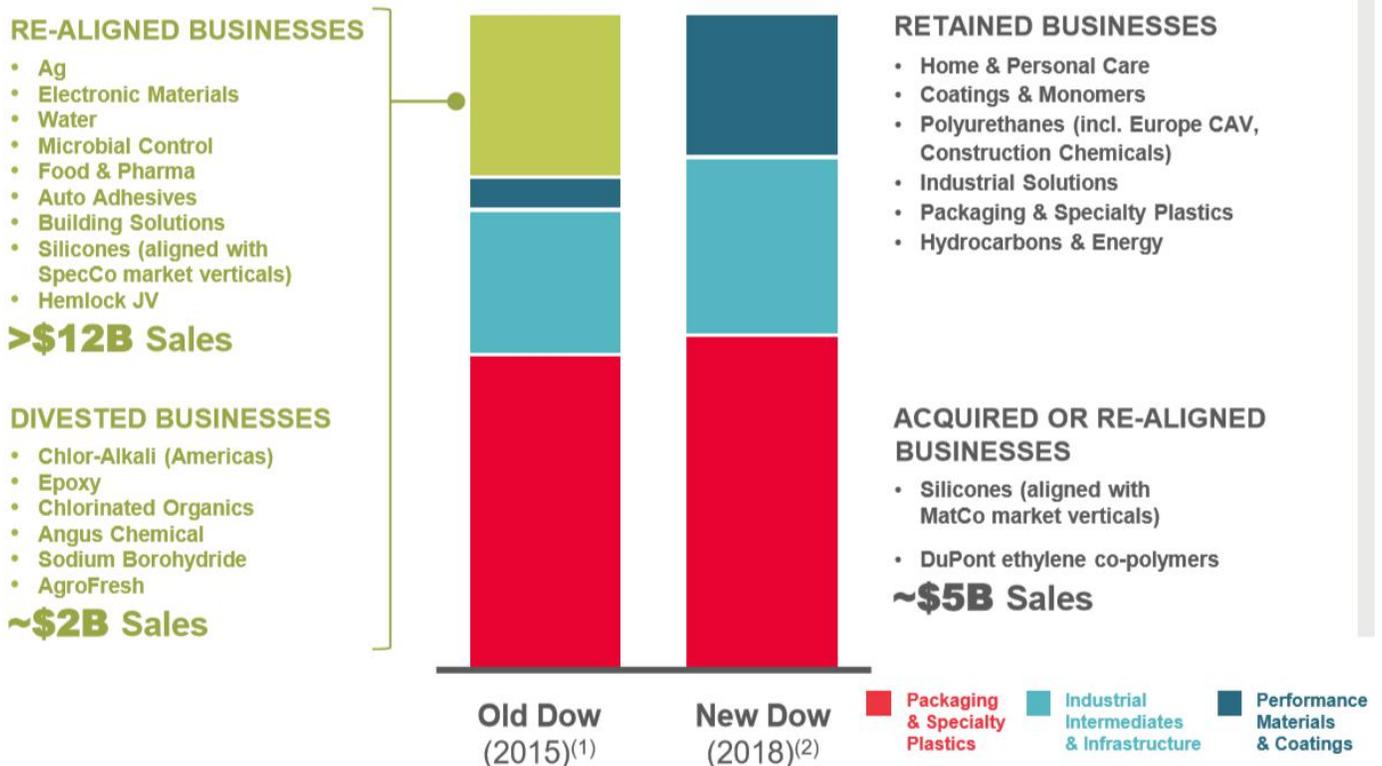


Dow first operated in 1897, founded by the chemist Herbert Henri Dow to produce bromine. The company quickly grew and diversified. Dow acquired many companies over the years, notably Union Carbide in 2001 and Rohm & Haas in 2009. In 2015, Dow and Corning announced a definitive agreement to restructure ownership of Dow Corning; Dow became the full owner of the previously 50:50 joint venture. Dow and DuPont merged into Dow-DuPont and agreed to subsequently spin off into three independent companies. In 2016 Dow completed a strategic ownership restructure of Dow Corning and became 100% owner of Dow Corning's silicones business. On 1 April 2019, Dow and Dupont de-merged and Dow became an independent, publicly-traded company.

Main figures:

- 2018 Pro Forma Net Sales: \$50bn
- Employees: 37,000
- Manufacturing Sites: 113
- Countries where Dow manufacture products: 31

Dow's main activities with the evolution after the divorce from Dupont:



(1) FY 2015 data is based on reported Op. EBITDA, excluding Corporate
 (2) Source: Dow Holdings Inc. Amendment #3 to the Form 10 filed on 2/12/2019

Dow products for the vehicle lighting industry

Silicone-based materials are one of the main family of products sold by Dow to auto lighting set makers. Among these products, Moldable Silicone is particularly interesting for lenses and primary optics thanks to its specific properties:

- a refractive index of 1.41-1.42; PMMA has 1.49, PC has 1.58, and glass has 1.52. Naturally, optical designers can design optics in accord with any of these refractive indices.
- Optical grade silicone has also a relatively high abbe number (~ 50), close to PMMA (~ 57), both significantly higher than PC (~ 30). Silicone's high abbe number means low diffraction, which facilitates homogeneous colour mixing of white light from LED light sources used in lamps.
- Excellent optical properties with non-yellowing performance, unless external contaminants impair optical quality.
- Material viscosity enables high precision replication of mould surface for complex optical shapes, fine surface features, and integrated mechanical features not possible with traditional plastics
- Processing performance enables high throughput with low stress on mould tools
- Lighter than glass and other optical materials to reduce part weight
- Flexible and soft material
- Good heat stability
- Efficient injection moulding
- No secondary polishing
- It can be soft and pliable or tough and firm, depending on material selection and wall thickness
- Outstanding physical and optical performance in demanding environments, including high heat, low temperature, high relative humidity, and UV exposure, as well as combinations of these conditions
- Resistant to scratches, cracks, vibrations, and other damage

These features enable LED lamps to achieve high IP (ingress protection) and IK (impact protection) ratings by using silicone optics.

Drawbacks:

- Relatively high thermo-optical coefficient (dn/dT) that has to be considered for the optic design according to each application.
- Relatively high coefficient of thermal expansion (CTE) that must be considered for design of optics and corresponding mould tooling, particularly for design of projection systems needing very accurate control of the beam angle and focal distance. Thus, the limiting factor is CTE rather than dn/dT .
- Given the coefficient of light attenuation within today's optical silicones, the length of light guides should be limited to about 10 cm for applications using white light sources, to avoid colour shift and loss of intensity.

Dow silicone compared to PC, PMMA, and glass for realisation of optical components

| | DOWSIL™ Moldable Silicone | PC | PMMA | Glass |
|---------------------------------------|------------------------------|---------|---------|--------|
| Light Transmission | 94% | 88-90% | 93% | 95% |
| Refractive Index | 1.42 | 1.58 | 1.49 | 1.52 |
| UV Resistance | High | Low | Medium | High |
| Chemical Resistance | Medium | Medium | Low | High |
| Service Temperature Maximum (°C) | >150 | 120 | 90 | >200 |
| Yellowing* | Low | High | High | Low |
| Micro Detail Replication | High | Low | Medium | Low |
| Ability to Mold Large and Thick Parts | High | Low | Low | Medium |
| Minimum Thickness** | <0.5 mm | 2 mm | 2 mm | — |
| Draft Angle (Manufacturing)** | <0° | 1 to 2° | 1 to 2° | — |
| Weight | Low | Medium | Medium | High |
| Flexible Material – Integration | High | Low | Low | Low |

* Yellowing due to high temperature, high lumen density, or UV exposure
 ** Injection molding process

Silicone application in vehicle lighting

Silicone is used in an increasing variety of parts, including freeform collimators, secondary lenses, micro lens arrays, and light guides. For instance, silicone is used as collimators for high end matrix ADB for the high end matrix Adaptive Driving Beam (ADB) designed and fabricated by Hella. Silicone was chosen because:

- The complicated primary lens structure is incorporating 84 light guides. Most of these optics are needing to be placed at an angle that, in turn, is requiring them to incorporate a strong undercut that would have been impractical or impossible to achieve with glass or transparent plastics, as demoulding the proposed lens design require a highly flexible material.
- To optimise optical efficiency, the light guides are positioned in close proximity to high-power LED dies. Consequently, the primary lens material needs to perform reliably despite long exposure to high temperature and photon density—organic plastics such as PMMA and PC would darken and turn brown within a relatively short time.

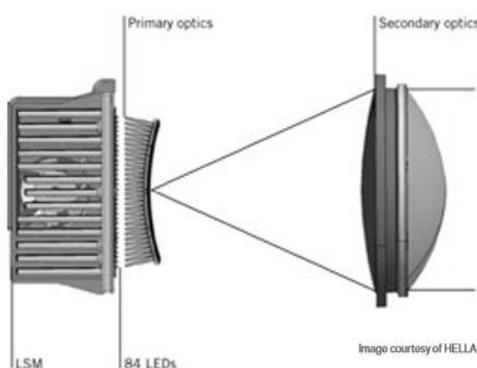


Image courtesy of Hella

The material used for this application is Dowsil™ MS-1002 having the following specifications:

- Shore A hardness: 74
- Elongation: 80%
- Tensile strength: 11.2 MPa
- Transmission for 3.2 mm thickness: 91% at 450 nm; 94% at 760 nm

Other grades of Dowsil optical mouldable silicone have been developed and commercialised, such as MS-1003, MS-4002, and MS-4007. These offer various mechanical and optical characteristics to enable various types of silicone optics with complex shapes and highly demanding requirements.

Another grade of silicone, the MS-2002 in white, has been developed for reflectors—note its very good reflectance of 97% at 450 nm and 99% at 630 nm.

Dow also supply the automotive industry with other products: adhesives and sealants; conformal coatings for circuit board protection, thermal interface materials, thermally-conductive potting, and other suchlike.

◀ Back

▶ Lens/assembly

- Adhesives and sealants
- Moldable optical silicones
- Reflective material

▶ Control/heat sink

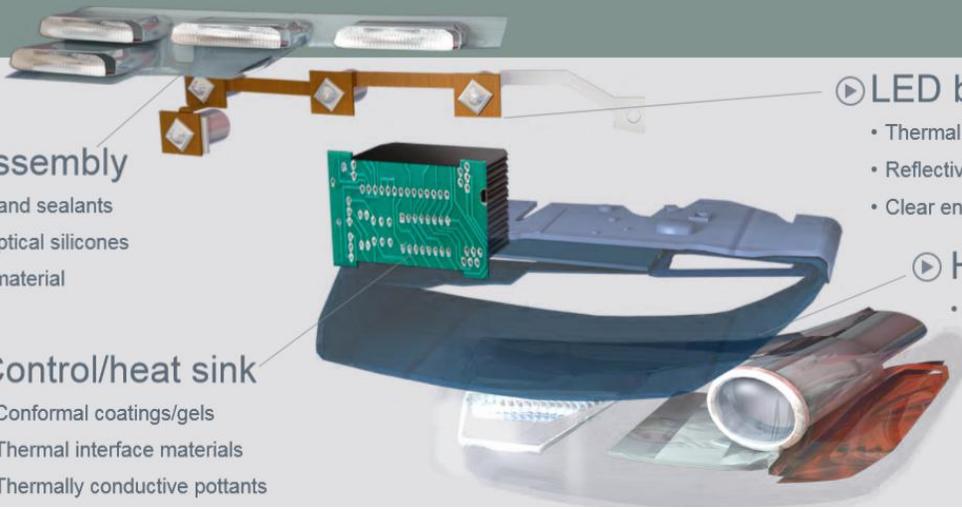
- Conformal coatings/gels
- Thermal interface materials
- Thermally conductive pottants

▶ LED board

- Thermal interface materials
- Reflective material
- Clear encapsulants

▶ Housing

- Adhesives and sealants



DSM History:

The Dutch state formed DSM in 1902 to mine coal reserves. The name DSM is still a heritage of that period meaning Dutch State Mines. During World War II, DSM worked secretly on Penicillin that was introduced just after the war. The privatisation began in 1989 with 70% of the shares, completed at 100% in 1996. During the last two decades, DSM have strongly modified their portfolio by many acquisitions and divestments.

Main figures:

- Sales: € 9.3bn (2018) including €5.7bn for nutrition and €2.9 for materials
- Employees: 21,000

DSM are one of the world's leading suppliers of engineering thermoplastics. For automotive, they are developing tough, lightweight plastics covering a wide variety of applications in braking systems, body and chassis, drivetrains, electronics, engines, interiors, exteriors, and steering and suspension systems

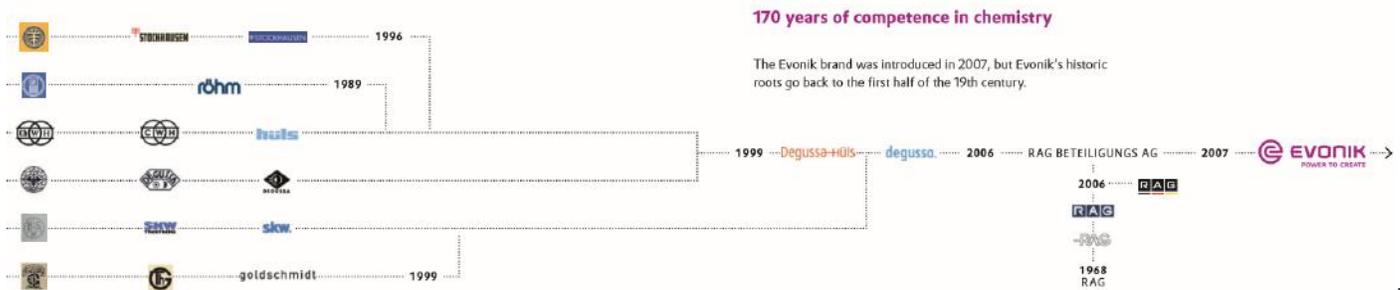
For lighting systems, DSM offer:

- Polyamide with different brands (Stanyl® for polyamide 46, Akulon® for PA6 and PA66, and EcoPAXX® PA410 with low moisture absorption.
Polyamides are generally used in headlamps for brackets
- PPS (Polyphenylene Sulphide) with the brand Xytron®.
PPS is a potential material for reflectors with high temperature constraint
- PBT PET with the brand Arnite®.
This material is adapted for brackets.
PBT PET can also be used for bezels in headlamps



Evonik - Advent

Evonik's roots: The chemist Theodor Goldschmidt founded the company "Chemische Fabrik Th. Goldschmidt" in Berlin 170 years ago in 1847. In 1889–90, the company relocated to Essen where they laid the foundations for today's Goldschmidtstrasse site. The Evonik brand was introduced recently in 2007, gathering the experience of many former brands.



In March 2019, Evonik agreed to sell their methacrylate business to Advent, a private equity company, for €3bn. This business represents €2bn in sales and would become independent from Evonik.

Main figures:

Evonik are one of the world's leading specialty chemicals companies.

2018 figures:

- Sales: €15bn including €2bn for the methacrylate business
- Employees (end December 2018): 36,000 including 3,900 employees in 18 sites for the methacrylate business

Main material products



- PMMA products sold under the Plexiglas® trademark on the European, Asian, African and Australian continents and under the Acrylite® trademark in the Americas.
- For lighting systems inside and outside the vehicle, PMMA moulding compounds are used for signal lamp covers, projector lenses, light guides for DRL, tail, and signal functions or for contour lighting and ambient lighting in the vehicle interior.
- Pleximid, a PMMI, polymethyl methacrylimide, suitable for optical parts in automotive headlamps because of its significantly enhanced optical properties and higher temperature properties.

GXC are a young, fast-growing company, founded in 2000 in Germany.

They got their start in 2000 in the field of chemical nanotechnology, to apply functional coatings on optical parts for vehicle lights, cameras, and sensors. GXC and their customers stepped into the new field of nanotechnology as one of the first companies applying that science in the area of automobile manufacture.

Main figures

GXC's markets are international; the firm serve approximately 50% of their customers in Germany, 40% in the European Union, and 10% in Asia. They offer coating material and technology for glass, transparent plastics, and metal surfaces, as well as tool coating.

Main products for vehicle lighting:

- Exterior coating for headlights and taillights
- Antifog coating for headlamps with the brands:

GXC NuGlass® AFG (on glass)

GXC NuGlass® AFPC (on polycarbonate)

GXC NuGlass® AFPM (on acrylic, PMMA)

These coatings have a thickness between 1 to 5 microns



Gore

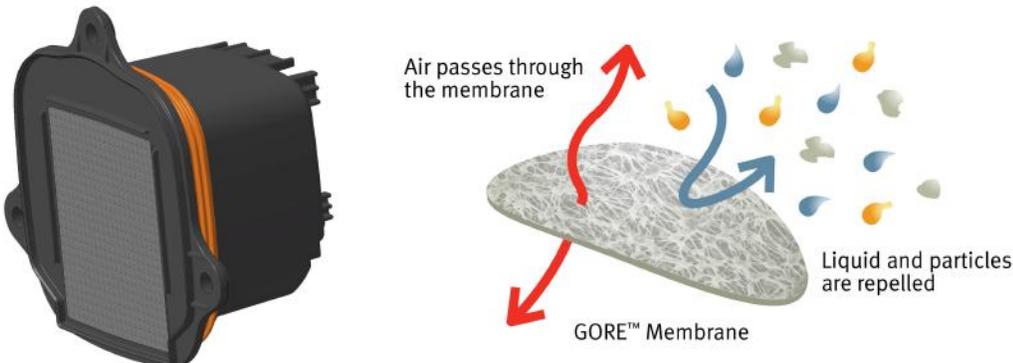


Gore got started 60 years ago by Bill and Vieve Gore. The company are well known in lighting for the use of their membranes for venting, and more publicly known in the domain of textiles on strength of their Gore-tex material.

Main figures:

- Sales: USD \$3bn
- Employees: 9,500

Main product for lighting: Membrane for venting and related products



Interview: Dr. Ulrike Geissler

Automotive Venting Product Manager for Europe

DVN: Can you describe your company and their involvement in the automotive industry?

Dr Ulrike Geissler: We are a global materials science company headquartered in the United States in Newark, Delaware, dedicated to transforming industries and improving life. Founded in 1958, Gore have built a reputation for solving complex technical challenges in the most demanding environments — from revolutionising the outerwear industry with Gore-Tex® fabric to creating medical devices that improve and save lives to enabling new levels of performance in the automotive, aerospace, pharmaceutical, and mobile electronics markets, among other industries. The company are also known for our strong, team-oriented culture and continued recognition from the Great Place to Work® Institute.

Our innovative technologies, backed by decades of research and testing, deliver proven reliability in the harshest environments. To support and enhance the performance and reliability of today's automotive applications, we offer solutions for EMI shielding, fuel cell components, and venting for exterior lighting, electronics, and sensors, drivetrain and driveline components, fluid reservoirs and electronic power steering systems; also there's our Active Condensation Management system, and data and power cables.

DVN: What are the main products you are currently delivering to the vehicle lighting industry?

Dr. G: Our vents for exterior lighting help protect against condensation, pressure differentials, and contamination by fine dust, dirt and water, which can compromise lamp performance and lead to warranty claims. These low-profile adhesive vents are designed for use in headlamps (with attention to the special challenges of LED lamps), rear lamps (including our newest vent for clear-lens rear lamp applications), specialty and auxiliary lamps, and fog lamps. Billions of these vents have been installed in automotive applications worldwide, and today, virtually every global OEM and leading Tier supplier trusts Gore® Automotive Vents to extend the reliability and longevity of their exterior lighting. With technical support and

testing centres in the US, Germany, Japan, Korea, and China, our application engineers are easily accessible, and ready to work in close partnership with our customer's design team, from product concept through manufacturing integration.

Gore® condensation management products represent an entirely new solution. They're based on a revolutionary technology developed by Gore, with potential for far-ranging applications.

The first application, for automotive headlamps, was developed in collaboration with AML Systems, a world leader in actuator technology. Introduced as "CMD," this Condensation Management Device is a new actuator design by AML. CMD offers a new level of protection for headlamps: It is the first product that actively removes moisture from, and prevents condensation within, the headlamp interior—as opposed to merely masking condensation as anti-fog coatings attempt to do.

DVN: What are, for you, the main interests of your products for the vehicle lighting industry?

Dr. G: Automakers and suppliers trust Gore to help their exterior lighting products withstand the environmental challenges that could limit lighting performance, reliability and longevity. Gore products and technologies benefit sealed lighting assemblies by:

1. Protecting the integrity of the assembly in two ways:
 - Reliably preventing the entry of contaminants (fine dust, water, oils, detergents, low-surface-tension automotive fluids, dirt) that could foul the lamp interior, cloud lenses and threaten the sensitive electronics therein;
 - Rapidly and continuously equalising interior pressure differentials (vacuums and over-pressures) that could otherwise stress seals to premature failure.
2. Reducing condensation, by diffusing interior moisture to avert issues like fogging lenses and damage to electronic components, while also protecting the assembly against pressure differentials and contaminant ingress.
3. Actively removing and expelling humidity from the assembly, while also providing rapid, continuous pressure equalisation and blocking entry of both liquid and particulate contaminants.

DVN: How do you see the competition for these products and what is your evaluation of your market share in this market?

Dr Ulrike Geissler: The problems for lighting—equalising pressures, blocking contaminants, dealing with condensation—are of course not new issues! Over the years many adaptations have been tried, from open tubes and foam caps, to other types of membrane vents. But when performance is measured in lab tests and on-car field trials, our proprietary GORE™ Membrane technology shows itself to great advantage. For example, when it comes to condensation clearing time, our Moisture Vapor Transmission Rate (MVTR) outperforms everything from open tubes to foam caps to other membranes – by a factor of as much as 10.

As for our latest innovation, the Condensation Management Products, there simply is nothing comparable. The CMD (Condensation Management Device) available from AML Systems, enabled by Gore® Condensation Management Products, is the first-ever solution that actively removes and expels condensation from a closed headlamp assembly, while also equalising pressures and protecting against contaminants. Because CMD does all of this, it totally eliminates the need for anti-fog coating, or any other venting technique or desiccant. It represents a new and totally integrated solution to three long-standing problems. By eliminating condensation from the headlamp, the CMD can enable other equally important advantages, including savings in development time, validation expense, greater styling flexibility and lower total systems cost for both OEMs and Tier suppliers.

DVN: What were the main developments in the past in relation to your products for the vehicle lighting industry?

Dr. G: Gore have a long history of partnering with and supporting global automakers and leading suppliers. Decades ago, Gore introduced our first membrane vent for automotive exterior lighting, a vent that would "breathe" to equalise pressures, while also keeping water and dirt from entering a lamp enclosure. Subsequently, we advanced our proprietary membrane technology to incorporate oleophobic protection, enabling our vents to protect against the entry of not just water, but also oils, common automotive fluids, and detergents. And of course, we pioneered the whole field of condensation reduction in vehicle lighting. More than twenty years ago, we developed the industry's first membrane vent with condensation reduction properties. Since then, we've evolved and enhanced those properties. And now, our Condensation Management Products will enable new levels of active protection against condensation.

DVN: What are you preparing for the future to improve the applications?

Dr. G: From gas and diesel to electric and autonomous vehicles, technological advances have made this a time of great opportunity for the auto industry. To capitalise on these opportunities and still put out reliable cars that customers can depend on, manufacturers need equally reliable suppliers, whose products can help them to:

- reduce component and vehicle weight to increase fuel economy
- shorten and simplify design and validation cycles to meet customer demand
- incorporate new features and other technological upgrades

One thing is certain: the rate of technological change will exert new demands on all sectors of the automotive industry. As technologies such as lidar are incorporated into lighting assemblies, industry standards and specifications will have to evolve. Performance reliability, especially as it impinges on safety-related technologies, will be paramount. Reliability will also be essential to avert excessive warranty claims on tomorrow's extremely high-value "smart" assemblies. Accordingly, the demand for products that enhance the reliability and longevity of such lighting assemblies will soar. And this is where Gore excel.

This is not only true for lighting, of course. Many of these changes and demands will also manifest broadly in everything from EV battery systems, to fuel cells, to in-dash and under-hood and externally-mounted "smart" systems, and the wiring and cable systems that connect them.

Our Customer Application and Development centres are actively developing new Gore technologies to answer these challenges. Already, we are collaborating in partnership with global automakers and suppliers to explore new options and achieve new performance benchmarks. Together we are looking beyond merely keeping pace with the technological changes; we are focused on leading the way to performance excellence in the automotive industry's applications of the future.

DVN: How do you see in your company the future of these applications with the evolution of lighting?

Dr. G: With regard to vehicle lighting specifically, the need to incorporate additional benefits and more functions into lighting assemblies will pose added challenges in multiple areas:

- Miniaturisation/optimisation: the need to fit more things into less space will tend to limit design flexibility, until and unless component suppliers provide options that are lower-profile, and more efficient in both performance and space utilisation. Our adhesive vents for lighting are already low-profile and lightweight, and we are working to fine-tune and customise other properties to achieve maximum performance in minimum footprint.
- Thermal management: with more electronics and heat inside lighting assemblies, better airflow is one of several thermal management solutions that can be effective. At Gore we are working to enhance our membranes' airflow and other properties for maximum breathability, and we are also developing additional technologies—for lighting, for batteries, for fuel cells and electronic systems—centred on more advanced thermal management functions. Watch for more news about these in the months ahead.
- Condensation management and active moisture removal: as previously noted, we are breaking new ground

with our Condensation Management Products. For headlamps, the new CMD is the only solution that actively removes enough moisture from the headlamp, to the degree that condensation simply cannot form. This is a most desirable outcome for any lamp technology, but it is particularly effective for LED lamps, which typically have a cold spot at the lens that encourages condensation to form.

We are continuing to advance our technologies, and we are collaborating with our industry partners on new products that address the complex design challenges facing exterior lighting suppliers and automakers, both now and in their next-generation applications.

In 1893, Andre Blondel, a French scientist, and Spiridion Psaroudaki, a Turkish engineer, invented a kind of cross-prismatic glassware moulding based on the Fresnel lens principle. The invention was patented under the name "Holophane", which stems from the Greek words *Holos* (whole or entire) and *Phanein* (to appear or to seem); thus, *holophane* means "to appear completely luminous." The patent was bought up by an American businessman, Otis Mygatt, who created a company on each side of the Atlantic Ocean, one in the USA and one in Britain, for the production and sale of Holophane products. In 1920 The UK company merged with a French manufacturer to create a production site at Les Andelys; Holophane SA came to be. For the following years, Holophane based their developments on the glass expertise of employees from the East of France, notably the famed Baccarat, with the common thread being development of Fresnel optics, styling, and glass transparency. They developed high-bay lighting for the economical illumination of large factories. During WWII, Holophane lit war plants and airplane hangars around the world. Holophane Glass Company coined the term "illumineering" based on the visual and physiological needs of the human eye, a concept that is still dominant in lighting technology. Associating pressed glass and optics, Holophane rapidly expanded into more technical applications for various sectors such as street lighting, architecture, water meters, and automotive, a sector where Holophane are a world leader for glass lighting components.

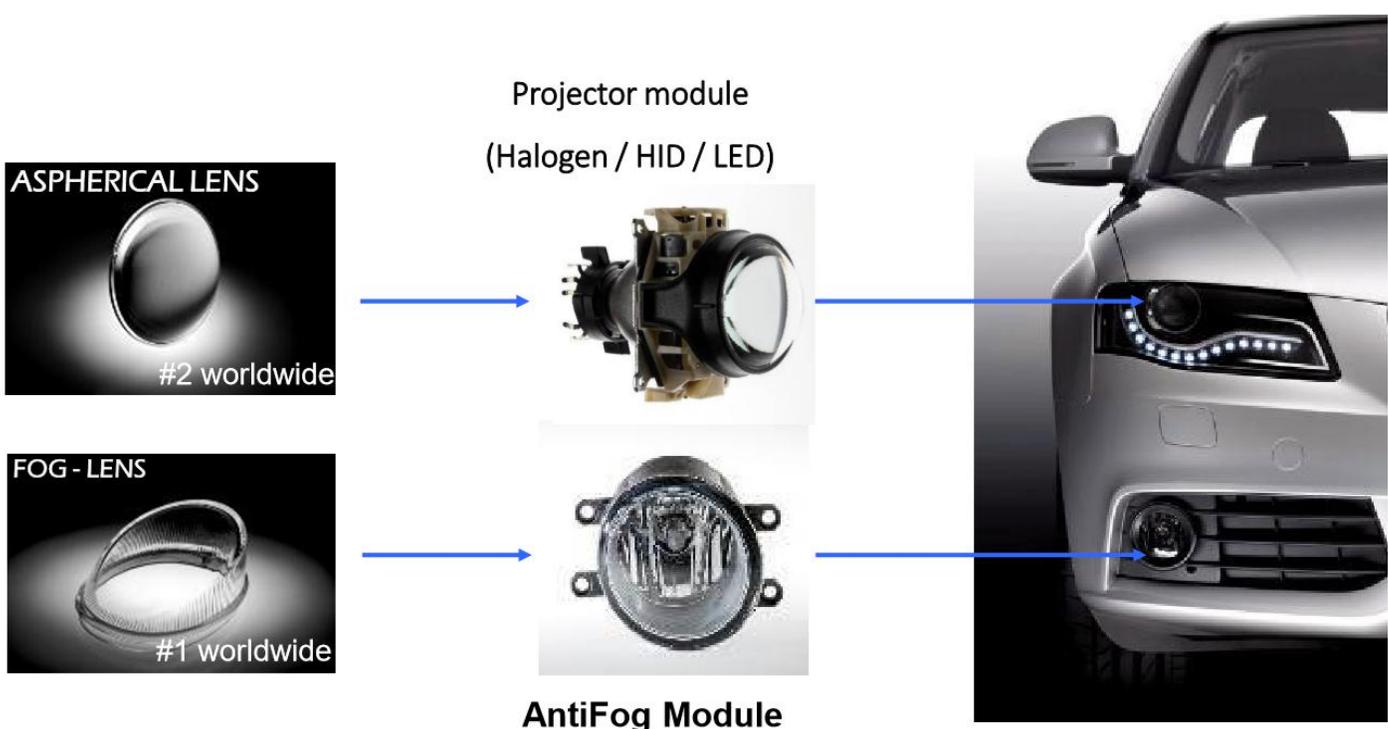
In 2002, Holophane opened a factory in Dalian, China, and in 2014 an American location in Bloomfield Hills, Michigan. Target markets include street lighting, art glass, optical units for lights and beacons, road signage, and headlamps, and flat lights for cars.

Main figures:

- Annual sales approximately €50m
- Projector lenses represent half of their activity, fog lamp cover lenses one third, and the rest is for non-automotive and for the few remaining glass headlamp cover lenses.
- Sales by region: Europe: 44%, China: 41%, North America: 15%, South America <1%
- Employees: France: 309, China: 220
- Plant & production: 8,000 m² and 10 million lenses per year.

Holophane products:

Holophane claim the title of world leader for projector lenses and fog lamp cover lenses.



Main techniques:

Aspherical lens:

To avoid chromatism, aspherical lenses have been defined by set makers for many years. This technique is also used for LEDs systems. Microstructures on the lens are often necessary to soften the cutoff in projector systems.

Overmoulded lens: To integrate aspherical lenses into lamps with the greatest precision, Holophane have developed and patented the plastic overmoulding process around lenses. This system is particularly used for BiXenon systems.



Soft Focus Texture® lens: This Holophane innovation has a surface preparation process to meet an increasingly higher level of optical demand. Based on an inspected surface finish on the aspherical dome, this technology is adapted for elliptical modules with smooth, homogeneous cutoffs.

LED optics in glass: LED systems are very demanding on optics, for they are smaller, thus needing top fidelity to the intended shape. Holophane have developed new techniques allowing adapted shapes for LED lamps with improved precision.



Benefits of glass for LED systems, according to Holophane:

- Stable and optimum transmission of light, whatever the operating temperature
- Better light dispersion, particularly versus polycarbonate, allowing less chromatism and "zero lux" application (no glare above the cutoff line)
- Optimum service life, with no variation during the lifetime
- Processes adapted to mass production of thick optical parts at affordable costs

On the other hand, glass is relatively heavy compared to plastic, with a density of 2.5 versus 1.2 for polycarbonate, but this drawback is less important now as LEDs systems are using smaller parts. Another drawback is the difficulty with glass to integrate functions, for instance how to attach glass parts to other-material parts when it's more than just a simple perimeter bond needed.



External lenses for fog lamps

Holophane are currently the world leader on the fog lens market with a production of nearly 30 million per year. To meet the highest standards in this area, Holophane have an innovative process called "Hologlass 100" with high resistance to thermal shock and impact as well as "sandblasting" (pitting due to impacts too minor to break the glass). Holophane's tests demonstrate that The Hologlass 100 fog lens has the highest level of strength on the market.

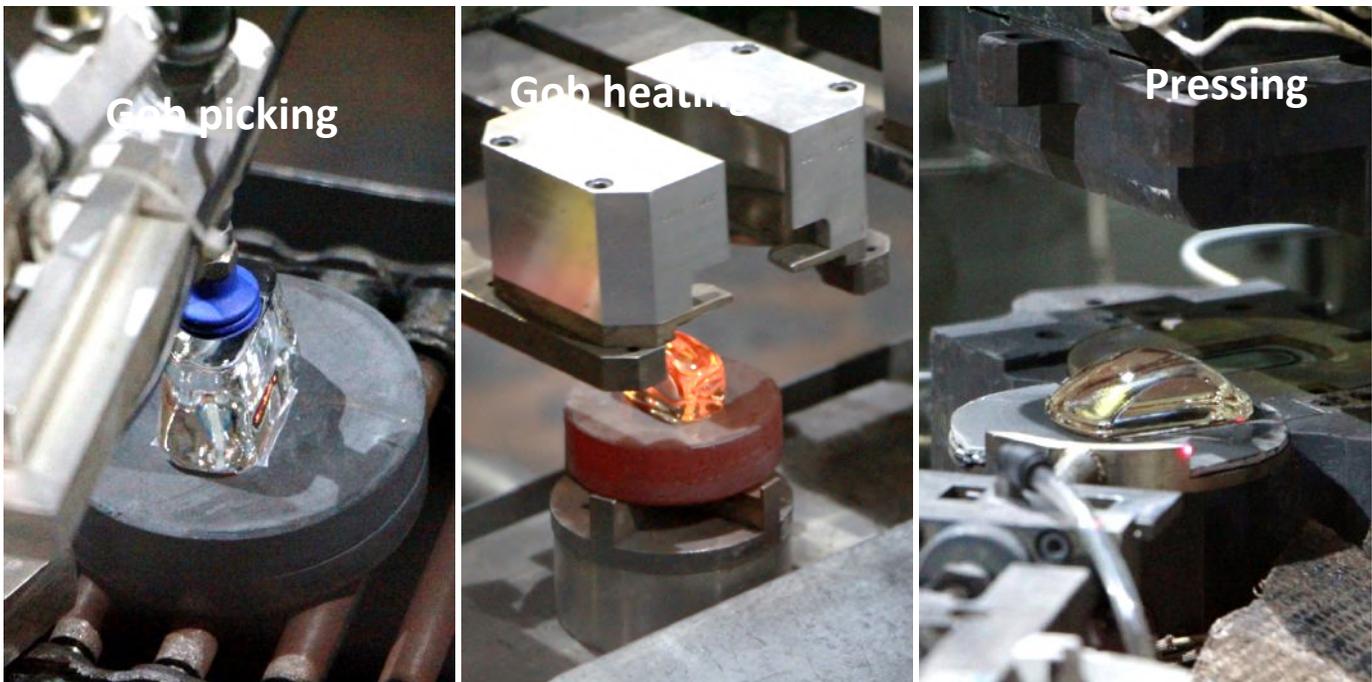
Visit to Holophane in April 2019

DVN's Hector Fratty and Jean-Paul Ravier went visiting Holophane, where they met new President Laurent Guérin and former President and current advisor Michel Blin, as well as Nicolas Michelat (sales) and Bertrand de l'Eprevier (R&D).

During the meeting, Holophane conveyed their confidence in the glass market. For fog lamps, Holophane's tough, tempered Hologlass is the worldwide leader with 30 million pieces per year.

Holophane lenses equip one out of five cars with projector headlamps. After a period when LED headlamp mostly used plastic for their projector lenses, there is a movement back to glass again—for cost reasons as the piece price and the investment are significantly reduced, as well as reduced time for development. The intrinsic qualities of glass are also helping for this new changeover: good transmission, low dispersion, and good heat resistance. Conversely, the traditional drawback in relation to weight is less important as the systems are more and more compact.

DVN visited the industrial site in Les Andelys in France, that has changed a lot in recent years, particularly with the installation of three new automated gob pressing machines that can use different types of glass.



The final operations are milling and polishing followed by an automatic camera-driven control giving the photometric results to ensure a good quality, a control currently done by sampling but targeted to be systematic.

Holophane's R&D is quickly evolving with now 11 persons in France and China pushing the limits of possibilities of glass use with new shapes and new materials more adapted to the current needs. Holophane have also developed specific microstructures for customers' needs, particularly with respect to cutoff homogeneity and sharpness. To quickly and efficiently validate new technical developments, a dedicated prototype line has been installed.

Holophane are also preparing for the arrival of digital lighting, and are thinking that glass will be a good material to support this technology with its high demands on the quality of the imaging system.

Holophane interview with:

- **Laurent Guerin - President**
- **Michel Blin - Former President and special advisor**
- **Nicolas Michelat - Sales Director**
 - **Bertrand de l'Eprevier - R&D Director**

DVN: Holophane are one of the oldest companies involved in lighting. Can you describe your company and mission?

Laurent Guerin: Holophane's mission is to be a leader in technical optical glass for the automotive industry. We are realising a turnover of €46m with 309 employees in France and 220 in China. The Holophane enterprise is owned by AIAC, a private equity firm based in the USA.

DVN: What do you think about the market for pressed glass for vehicle lighting? How significant is this activity in the total turnover of Holophane?

Nicolas Michelat: Thanks to our global footprint (factories in France and China and a logistic platform in the USA), Holophane are today N° 1 for cover lenses (fog lamps & headlamps), and N° 2 for projector lenses. Those two product lines account for 94% of Holophane's turnover.

DVN: What are the main families of products delivered to the automotive industry and their respective share?

Nicolas Michelat: Cover lenses for fog and headlamps, 48%; projector lenses 46%.

DVN: What were the main techniques developed in the past by Holophane? What were your main achievements during the last ten years?

Michel Blin: Holophane have partnered with the automotive industry since the 1960s; optical know-how has always been a differentiation factor. We have been through main glass cover lenses to HID projection lens we are now in the LED era. The last 10 years have been marked by installation of automatic gob pressing in China and in France, a process dedicated to LED applications.

DVN: What are you preparing for the future to improve your techniques for glass? Are you targeting new applications?

Bertrand de l'Éprevier: We are working on the shift from illuminating optics to imaging optics to move with our customers toward digitalisation of lighting. It will be applied for HD matrix, DMD, and MEMS applications. This leads us to deep improvement in the tooling manufacturing, process control, and measurement equipment down to the nanometre scale.

DVN: What are for you the main interests of your products for the vehicle lighting industry?

Bertrand de l'Éprevier: Bringing the best optical material, glass, at cost and volume compatible with mass production. This allows the democratisation of best-in class optical performance to all car levels.

DVN: How do you see the competition between glass and plastics for lenses currently and in the future?

Nicolas Michelat: We see today that allocation decisions between plastic and glass are never obvious. What is sure is that glass has higher optic performance than plastic, bringing better light control, allowing for example low glare in "0 lux" applications and less chromatic dispersion. And there are other favourable properties, like durability and recyclability. Additionally, shorter processing time leads to lower investments, more capacity, and better cost, compared to injection of plastic. We estimate the market geared toward glass lenses for high end applications and using plastic for low end mass applications.

DVN: Lighting is quickly evolving towards 100% LEDs, and matrix and pixels beams are increasing their share. How do you see the corresponding risks and opportunities for your company with these evolutions?

Bertrand de l'Éprevier: Matrix and pixel beams are a great opportunity for Holophane. Glass property in term of volumic scattering and chromatic dispersion, significantly lower than PC or PMMA, present a key advantage for these applications. In terms of risk, of course tighter geometric tolerance will be requested but we are working on it and thermal stability of the material already almost compensate the gap with polymer material.

DVN: We were impressed by your automatic module for making LED lenses. Could you present this module, and do you expect to extend this concept?

Laurent Guerin: Automated gob pressing is an internal development focused on LED application. The idea is to reheat preformed glass gobs, which allows us to locate this process overseas, close to our customers. The process is fully automated and actuated with the precision requested by LED application. To cope with increasing diversity and reduced lifetime of model tooling cost have been significantly reduced compared with previous processes. We are now at the third generation of AGP, focused for matrix and pixel light applications. In total six AGP lines will be in operation by next month, four in China and two in France.

Photo: DVN visit to Holophane in April 2019. Left to right:
Bertrand de l'Eprevier (Holophane R&D), Jean-Paul Ravier (DVN), Hector Fratty (DVN), Michel Blin (Holophane), Laurent Guerin (Holophane President), Nicolas Michelat (Holophane Sales)



Lyondellbasell are the most important actor for Polyethylene (PE) and the second worldwide for Polypropylene (PP). For PP, Lyondellbasell are the largest producer in North America and Europe (2.6 million tonnes per year of capacity in Europe). The company have American and European roots, with headquarters in Dallas, Texas. There's a global operations office in London, and the company are incorporated in the Netherlands.



In 1953-1954, predecessor company scientists Karl Ziegler and Giulio Natta made breakthrough discoveries in the creation of polyethylene and polypropylene. They were jointly awarded the Nobel Prize in Chemistry in 1963. PE and PP resins are used today to make numerous products including automobile parts, surgical gowns, children's toys, wind turbines, and water pipes.

In December 2007, LyondellBasell was formed by the acquisition of Lyondell Chemical Company by Basell Polyolefins for USD \$12.7bn.

Main figures:

- Sales 2018: \$39.0bn
- Operating income: \$5.2bn
- Capital expenditures: \$2.1bn
- Employees: 19,450 (8,900 in North America; 8,100 in Europe)

Strategy: Involvement in most high-growth markets segments, including automotive, presented a \$14bn market with 7% CAGR. The PP market is representing 15% of the global turnover of Lyondellbasell.



Menzolit



History:

- 1948 Establishment of Menzolit
- 1995: Merger to Menzolit-Fibron
- 2000: Takeover of DSM compounds
- 2009: Menzolit becomes member of Senata, a german owner-operated, self-financed holding company

Menzolit main figures:

- Sales: €90m
- Employees: 250
- 7 SMC lines, 11 BMC mixers.

Menzolit are a leading Sheet Moulding Compound and Bulk Moulding Compound global supplier with plants in Italy, Spain, and UK and partners in China, India, and Turkey.

Product description:



Menzolit's BMC 3100 (photo) is a bulk dough moulding compound based on unsaturated polyester resin. It is glass-fibre reinforced and contains mineral fillers. In case of fire the product doesn't melt or form droplets, and smoke generation is moderate. The material is injection-moulded in heated steel moulds, preferably chrome-plated. BMC 3100 does not contain halogens nor any chemicals from the REACH SVHC list.

The Fujikura Global Alliance was created in 2000 between Fujikura Kasei, Red Spot Paint and Varnish, and Sonneborn and Rieck. Fujikura Kasei acquired Red Spot in 2008 and Sonneborn and Rieck in 2010. This company changed their name to Fujichem Sonneborn after the acquisition.

Fujikura Kasei

History:

Fujikura Kasei was established in 1938 as a chemical manufacturer. They began to use Red Spot coatings in 1972. International development with a liaison office in Singapore began in 1995, and in Bangkok in 1997. In 2002 came the establishment of Fujikura Kasei Thailand; in Tianjin China in 2004, in Foshan in 2005, and in Shanghai in 2009. In 2008, FK bought Red Spot. In 2010, FK bought Sonneborn and Rieck.

Main Figures 2018:

- Consolidated sales: ¥57.4bn (€464m)
- R&D expenditure: 4.6% of sales

Red Spot

Red spot Paint and varnish got started in 1903 in Evansville, a small town in the US state of Indiana. After paint, most of Red Spot's success and innovations in the past 75 years have been tied to high-performance coatings for plastic. From the time someone thought to paint plastic—a new material back in the 1940's—Red Spot began developing specialised coatings that would perform on this new material. When polycarbonate was introduced as a replacement for glass in the early 1980s, the challenges quickly unfolded to develop coatings that would adequately protect the plastic from UV degradation and provide key properties of scratch and chemical resistance. This has been done for many years, first with thermal coatings and now largely with UV curable technology due to the performance, process, and environmental advantages that UV can offer. In 2008, Fujikura Kasei became the parent company of Red Spot.

Locations

Red Spot have manufacturing locations in the US states of Indiana and Michigan; in Canada's Ontario Province, and in Mexico. They also have joint ventures in Brazil (with Arpol) and in Korea.



Eco-friendly coating solutions

First commercialised in 1993, Red Spot's UVT200 series has been a global mainstay and is used by over 40 automakers. It can be applied by either spray or flow coat methods and is reclaimable by nature.

Introduced in 2008, UVT610 series is the next generation of hard coat that brings improved exterior durability necessary to meet the stringent performance expectations of the industry.

Performance related features include weatherability, clarity, and resistance to chemical and abrasive attack. It offers long-term stability, ease of application by spray or flow coat (photo), and ease of reclamation and recycling.

Not only must vehicle lamps fulfil safety requirements for light output and durability—which continue to become more stringent—but they must do this in an aesthetically pleasing way. Thus, during the last 20+ years, the coatings have evolved from a solely functional purpose to a combination of function and design.

Lamp designs have become more complex with many models having very imaginative designs that are more difficult to apply coating to. Additionally, design effects such as multi-shot moulding, decorative paints, HID and LED lighting has affected the role of coatings and the demand placed on the protective coatings.

Base coat

Red Spot also supply base coats for use on the reflector and extension portion of headlamps. Base coats applied to the reflector or bezel substrate provide a smooth, high-gloss surface for the metal, most commonly aluminium. The base coats can also help to seal the surface and prevent unwanted outgassing of the plastic materials under a high thermal load.

Anti-Fog

Red Spot also offer anti-fog coating for the interior surface of polycarbonate lamp lenses. As lighting technology evolves in shape, size, and light source technology, the ability of the lamp to resist condensation weakens. The use of anti-fog coating will protect and resist condensation build-up in some of the harshest of environments.

Mitsubishi Chemical

Mitsubishi Chemical is the result of the merge of former companies Mitsubishi Chemical, Mitsubishi Plastics, and Mitsubishi Rayon in 2017.



Main figures-

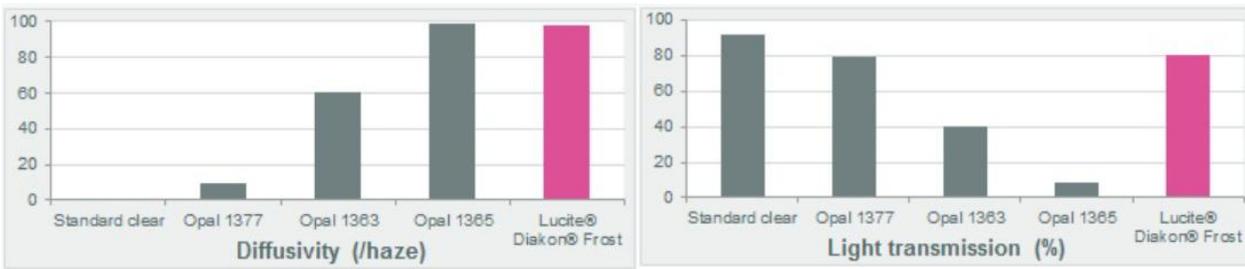
- Sales (FY2017): ¥2548bn (€20.6bn)
- Employees (End March 2018): 40,290
- Number of group companies: 358

Main products for vehicle lighting:

Mitsubishi Chemical are involved in several important material particularly Polycarbonate and PMMA. They are also producing PBT that can be used for bezels and POM that can be used for aiming parts in headlamps.

PMMA: Mitsubishi Chemical acquired Lucite international in 2009, Lucite having already received the PMMA activities of ICI and Dupont. Mitsubishi Chemical call their PMMA polymers Diakon®. They have met extensive automotive industry approvals for use in exterior rear and indicator light covers and for interior light covers and fascias.

PMMA can be used for a good homogeneity both for exterior signal lamps and for interior lighting. In that case, some specific diffusing grades can be used:



Polycarbonate:

Mitsubishi Chemical also supply normal grades of PC. They have developed the special grade HL-3503 for use in light guides, as the normal PC has relatively weak transmission not allowing long light guides.



Here's Mitsubishi Chemical's comparison table:

| | HL-3503 | GENERAL PC | PMMA |
|-----------------------|----------------|------------|-------------|
| Optical properties | ○ | △ | ◎ |
| Mechanical Property | ○ | ○ | △ |
| Heat resistance | ○ | ○ | × |
| Processability | △~○ | △ | ○ |
| Dimensional stability | ○ | ○ | ×~△ |

Optoflux are specialists in the development and production of optical devices and precision optics made of plastic and silicone. They make lenses, light guides, and reflectors for automotive applications as well as for medical and other lighting domains



History:

Since 1998, Eschenbach Optik were producing technical optics at a site of Nuremberg. In 2014, Optoflux took root as an independent company by a spinoff of the technical optics division of Eschenbach Optik, with the two Nuremberg plants. In 2015, a third plant was acquired for new automotive projects, particularly LEDs headlamps lenses and HUD, with the installation in 2016 of a PVD (physical vapour deposition) sputtering system.



In 2017, Optoflux Mexico-Queretaro was founded. In 2018, Optoflux bought HPOI in the Philippines from Hoya, a site with 250 employees, mainly dedicated for production of optics and sensors for cameras, lidars, and mobile devices.

They have 450 employees, including 250 in the Philippines and 40 in R&D. There are five production sites totalling 28,000 m², with 110 injection machines from 18 to 650 tonnes and 8 PVD coating machines. Main competencies are about optical and mechanical design with simulation, silicone injection in a separate room for complex and flexible geometries with high accuracy, and PVD coating for enhanced mirrors and beam splitters. Their sales of €26m in 2017 increased in 2018 and 2019 with Queretaro and Philippines (photo)



activities.

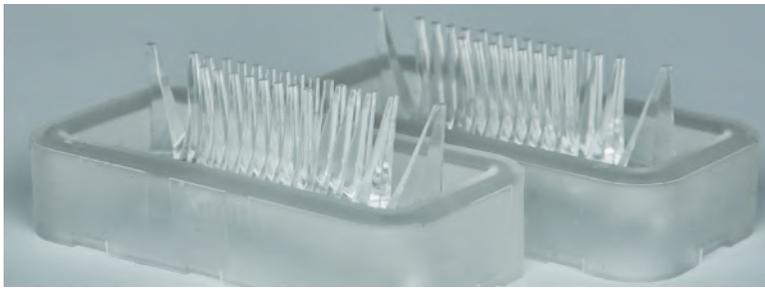


Main competencies:

- Optical and mechanical design with simulation
- Realisation of prototypes with diamond machining or injected parts
- Silicone injection in a separate room for complex and flexible geometries with high accuracy.
- PVD (physical vapour deposition) coating for enhanced mirrors and beam splitter
- Hard coating with UV curing for abrasion and scratch-resistance
- Assembly for quantities from small to over 1,000,000 units per year including laser welding and cutting
- Testing

Innovations from Optoflux:

Optoflux in 2008 made the lenses for the first full LED headlamp, the Audi R8, and they have developed thick-wall and multilayer technologies with up to 16-cavity tools. They are producing some of the most challenging optics, for instance the primary optics for the 84 light guides of Mercedes' Multibeam ADB, and are leading



the way in optical silicone injection. They also have developed competencies for design and production of light guides. Aside from vehicle lighting, Optiflux are producing optics—lenses and reflectors—for HUDs, lidars, compact cameras, and medical visual aids.

Optoflux make optics for driver monitoring and mirror replacement cameras as well as for lidars and optics for medical visual aids. All components can be coated with AR PVD (physical vapour deposition) coatings, using sputtering and evaporation technology.



Optics for sensor



HUD combiner



Surgery lamps

Visit to Optoflux by DVN on 23 May 2019

DVN's Jean-Paul Ravier visited Optoflux HQ in Nuremberg, meeting CEO Thomas Luce, Sales Director Thilo Maul, and Business Development Account Manager Lea Kichener.

Nuremberg is both the headquarter of the company and the location of three production sites in the same area where they are doing silicone and plastic injection. Cleanliness of the production, high level of automation, and numerous controls for quality checking are impressive.

Optoflux were first to inject silicone parts for vehicle lighting around 13 years ago. They presently hold top-level expertise in it, and are the world's top producer with more than 60% of the market for automotive. For the injection of silicones, four production lines are installed in their Nuremberg site. We have particularly seen the production of the primary optics for the 84-LED Multibeam matrix. Silicone is a bi-component material, so these two components are simultaneously injected. Silicone is like liquid during the injection phase, requiring very highly precise execution of tools to avoid burrs. Geometry control is done just after injection; parts having any burr are rejected. The burrless parts are then cured for silicone polymerisation.



The shape of this part calls for soft material for demoulding, and optical silicone is the lone material having this softness ability with high precision geometry and high temperature resistance.

After curing, complete controls are done checking first the geometry and then the photometric value of each elementary

light guide.

Optoflux then assemble the silicone part inside the mechanical support, followed by a temperature stabilization before sending the parts to set makers.

Optoflux do plastic injection for lenses, light guides, and other high-tech components—for instance, HUD reflectors. For lenses they have developed multilayer technology, but due to the higher level of investment and maintenance, they generally prefer to inject thick lenses with more simple processes despite the longer cycle times.

They also injection-mould light guides, with long and thick parts, and have developed a specific manufacturing process for HUD reflectors. These parts are very complex due to the perfect shape required. After injection, cooling is done in a specific area, each part being maintained at the right shape. These PC parts are then protected by a hard coat varnish on the two sides, then UV cured before a complementary PVD coating. For each part, very severe controls are done to check the perfect geometry.

Interview with Optoflux CEO-CTO Thomas Luce



Thomas Luce worked at Philips as an application engineer, at Schefenacker as Director of Lighting Technology, at Valeo as Projector Director for LEDs, at Eschenbach as VP of Technology/Production, and since June 2014, as CEO-CTO of Optoflux.

DVN: Optoflux was a spinoff from Eschenbach in 2014. Who owns Optoflux?

Thomas Luce: Since the 2014 start of Optoflux as an independent company, the investors are the same: BWK, Keiga, and the management. These investors have a long-term view allowing investment for growth as it was the case for the implementation in Mexico or more recently the acquisition of HPIO in Philippines.

DVN: At the beginning of Optoflux in 2014, sales were at the level of €16m with 140 employees with a production area of 7,000 m² for 2.5 million automotive lenses. What are the corresponding figures today?

T.L.: Optoflux today are a more international company with around 450 employees. Sales in 2017 were at €26m and we add in 2018 the sales of Queretaro and Philippines plants.

We have much larger production facilities that are installed now on 28,000 m², with 110 injection machines and eight PVD processes. The number of lenses is not very significant as there is a large variety, but we should produce around 100 million per year with now our Philippines plant.

DVN: How could you define the main missions of Optoflux?

T.L.: We are specialists in high precision optics in mass production. We have in Optoflux all the competencies to design, develop and produce high-tech optics for automotive and non-automotive markets. In our sales, the share of automotive is higher than 50% and is increasing. In this amount, deliveries for automotive lighting is currently the large majority and is also growing. However, we are more and more involved in the new sensors for ADAS as optics for cameras or lidars.

DVN: In your activity for lighting, which materials are you using and in what proportion?

T.L.: We are using mainly for automotive lighting silicone, PMMA, and PC. Silicone that is used mainly for advanced ADB systems is representing currently one third of our automotive market. For the other applications, PMMA is the main material both for lenses and light guides and should represent around 60% of the material used and the trend is to use it more. PMMA has a better appearance than PC even if we can use blue PC to avoid the yellow perception of the standard grade. PC is only used in some cases when temperature is too high for PMMA.

We are also injecting COC and COP due to their low refringence properties, but it is mainly for cameras optics or medical applications as these materials are more expensive

DVN: What are the main reasons for set makers that have also strong competencies for injection to choose Optoflux for some of their most technical parts?

T.L.: Plastic lenses started in automotive with LEDs as with halogen or even with HID, the temperature constraint was too high. Set makers were accustomed to outsourcing these glass lenses. So, at the beginning of LEDs, set makers had not a good enough experience for the difficult injections of thick plastic lenses. We have begun with the lens of the first full LED headlamp made by AL for the Audi R8 in 2008 and have realized many since that period, some with a thickness around 40 mm. In parallel, set makers have acquired competencies for these lenses injection and have realised by themselves some parts. But now, we are observing the inverse trend, set makers having other priorities and outsourcing again more and more these components—particularly light guides.

Many companies in the world are realising plastic lenses or light guides, as DBM in Canada, or others in Korea, Japan or

China. But we are certainly the biggest for realisation of mass production complex products. Optoflux have the longest experience in volume production of complex injected parts for optics. In silicone injection, we are producing around two thirds of the parts used for vehicle lighting. Our recent involvement in optics for ADAS is well completing our portfolio. And now, with our plants in Mexico and in Philippines, we have a strong base in low cost countries.

DVN: How do you see your future with the current evolution of the automotive industry?

T.L.: We are going to autonomous cars. The future of lighting will have to be defined, but we are confident that our expertise will be useful for the next generations of lighting and signalling products. And for these future cars, we shall need more and more cameras, lidars, and communications devices where optical components will increase their importance.

Sabic (from **SA**udi **B**asic **I**ndustries **C**orporation) are a diversified chemical company, one of the world's top three, with more than 40 years of organic and inorganic growth. They originally focused on petrochemicals, not surprisingly given Saudi Arabia's vast oil activities, and have developed their vertical integration in three other core businesses: specialties, metals, and agri-nutrients for a large palette of markets:



Headquartered in Riyadh, they have a global footprint serving clients in 100 countries while operating in 50 countries across the Americas, Europe, the Middle East, Africa, and the Asia-Pacific region.

In 2007 Sabic acquired General Electric's plastics division for USD \$11.6bn and launched Sabic Innovative Plastics. Today they are a multibillion-dollar company with operations in more than 25 countries and over 9,500 employees worldwide.

Main figures:

- Sales (2018): \$45bn
- Net income (2018): \$5.7bn
- Assets: \$87bn
- Production: 75.3 megatonnes/year
- 18 dedicated technology & innovation facilities in Saudi Arabia, the USA, the Netherlands, Spain, India and China with 1,270 scientists.
- SIP's strategic business unit invests \$500m annually in technology and manufacturing.

Products for lighting:

PC: Starting from the GE Lexan™ basis, Sabic have developed Lexan-FR™ resins for diffusion applications and transparent lighting. These provide flame retardance without the use of brominated or chlorinated additives, helping to ensure regulatory compliance. Aside from transparent grades, also available are three standard diffusion grades that provide high light transmission with hiding power for a softer, more homogeneous look. Colours include three standard shades of white as well as natural; custom colours and diffusion levels can be provided to meet specific requirements. Millions of vehicles worldwide have lamps that use Sabic's Lexan™ for high impact resistance, heat resistance and clarity in headlight lenses, reflectors, and bezels. Lexan™ XHT brings an improvement in the balance of flow and heat resistance previously available for high heat lenses and bezels that require direct metalisation and high surface quality, while permitting faster cycle times and greater productivity.

Polyetherimide (PEI): Sabic's Ultem™ resin also delivers very high modulus, plus very good heat resistance up to 230 °C. Also, it offers exceptional dimensional stability, strength and durability, and presents opportunities for recycling.

ABS & ABS/PC: Sabic also produce ABS and ABS/PC blends for signal lamps.

Annex I

BMC injection success factors

According to an article from plasticstoday.com written by Taras Konowal from Apex Plastic Technologies, here are ten crucial machine factors to be specified with BMC injection:

Fast fill. Finished reflectors require a super high-gloss surface finish uniform across all areas of the parabola. Any variations or blemishes in this finish will be highlighted when the reflector is metallised. To force resin to the surface to achieve a better surface gloss and consistency, higher-than-normal mould temperatures are used. But the material may start setting up as soon as it hits hot tool steel. Therefore, the BMC must be injected at a very high speed to ensure even curing across the entire moulding surface. Typical fill rates should be below 2 seconds. The press must be equipped for such high-speed injection, with no lag time between injection start and complete fill.

High pressure. High-speed filling literally puts additional pressure on a machine. BMC is stationary in front of the screw and must be started and moved quickly into the mould to prevent premature crosslinking. So, a press that is moulding headlight reflectors must be capable of generating a minimum of 1,380 bar (20,000 psi) of injection pressure to hasten the BMC along to yield quality surface finishes. A machine capable of producing injection pressures of at least 1,500 bar (22,000 psi) is recommended.

Accurate shot size repeatability. If shot sizes vary, cavity pressures will vary shot to shot. That means surface finishes also will vary shot to shot. Without consistent cavity pressure it's impossible to mould cosmetically acceptable BMC parts. With all the bosses, fastener holes, and bulb holes in today's reflectors, there's a lot of potential for flash. If shot sizes vary, so will the flash. Variations in the flash level and thickness make it difficult to use cost-effective flash removal automation. Also, if the flash is not properly removed, it can break off when the part is metallised or assembled, resulting in the scrapping of the finished product. So, closed-loop injection unit control either with servoelectric valves on a hydraulic press, or AC servomotors on all-electrics, are a must. It's also essential that the screw design meets the requirements of the material used and the screw motor output.

Mould heating accuracy and recovery time. Mould surface temperature is critical for producing high gloss. If mould temperatures are not high enough, the polyester molecules in the BMC won't completely cure, resulting in craters and pits in the finished parts—flaws highlighted by metallisation. The mould heating source must be sufficient and mould temperatures must be maintained within $\pm 2.75\text{ }^{\circ}\text{C}$ ($\pm 5\text{ }^{\circ}\text{F}$). Mould heaters integrated into the machine control for easy monitoring are a wise choice. When a moulded part is ejected, heat is removed from the mould. The mould's heating circuitry must be capable of quickly recovering the post-ejection heat lost to maintain shot-to-shot repeatability. An undersized heating circuit will extend the cycle time and will increase the likelihood of surface blemishes on the moulded part.

Hold pressure profile. Post-injection material flow in the mould creates stress within the moulded part that can cause surface imperfections. The thin vents and lands in the reflectors must be cured prior to applying the higher hold pressure needed for forcing resin to the parts surface to create a high-gloss finish. However, the material will move in the mould, and flow lines or surface blemishes will be evident if this pressure is prematurely applied. It's critical to profile hold pressure to first create a seal and then stage the necessary pressure. This calls for machinery with closed-loop hold and pack pressure control.

Barrel cooling. Variations in barrel temperature will vary shot size and material pressure, thereby impacting the surface quality of the moulded part and the level of flash produced. Water-cooled barrels are a must. Water channels machined into the barrel wall provide the best heat transfer. Having at least two independent zones controlled by water temperature controls accurate to within $\pm 2.75\text{ }^{\circ}\text{C}$ ($\pm 5\text{ }^{\circ}\text{F}$) is recommended. These, too, should be interfaced with the press controller to allow alarm limits to be set and can halt production before scrap parts are produced.

Nonreturn valve. A nonreturn valve specifically designed for thermoset moulding is essential for the shot

control accuracies required to mould headlight reflectors. If the clearance between the check ring and barrel wall is not large enough to process BMC, premature curing can occur because there's too much shear heat in the material as it passes the nonreturn valve. This can spoil the surface finish. Conversely, if the clearance is too large, material will flow past the nonreturn valve during injection, compromising shot-to-shot consistency.

Machine clamp. With the high injection rates and pressures involved, clamp design is key. It must automatically compensate for tiebar temperature changes to ensure even and consistent lockup. It also must be sturdy enough to eliminate movement during injection. Any movement will create a higher level of flash and release the so-called pressure seal, mentioned above, which is needed to create a cosmetic surface. If the tiebar spacing is inadequate, the core and cavity will fall outside the strongest part of the clamp and allow the mould to open during injection.

Ejector. Ejector pins, natural vents for releasing trapped gases, can become worn out and not allow proper pressure build-up in the mould. The ejector system must be accurately guided and have accurate position control to minimise this phenomenon. Most thermoset presses use ejector-actuated gate cutters to create a clean gate vestige when degating parts. Machines must be capable setting and actuating the pressure, speed, and positioning of the ejectors while the mould is closed.

Vacuum adaptability. To help eliminate the voids and charring problems caused by air trapped in the mould, it is highly recommended in-mould vacuum assist, as well as using vents.

The vacuum system is tied into a vacuum ring on the mould. Vacuum is applied before and during injection until the material has filled out the part. The machine specified must be capable of signalling the vacuum system when to turn itself on and off.

Annex II: Sample Material Data Sheets

PMMA Acrylic Polymer Lucite® Diakon® CLG35

| PROPERTY | TEST METHOD | UNITS | VALUE |
|-----------------------------|--------------------------|-----------------------------|---------|
| THERMAL | | | |
| Melt Flow Index | ISO 1133 | gms/10mins | 15 |
| Vicat Softening Point | ISO 306A | °C | 98 |
| | ISO 306B | °C | 93 |
| Heat Deflection Temperature | ISO 75A | °C | 88 |
| | ISO 75B | °C | 91 |
| Coefficient of Expansion | ASTM E831 | cm/cm/°C x 10 ⁻⁵ | 7.1 |
| OPTICAL | | | |
| Light Transmission | ASTM D1003 | % | 92 |
| Haze | ASTM D1003 | % | 0.4 |
| Refractive Index | ISO 489 | - | 1.49 |
| MECHANICAL | | | |
| Tensile Strength | ISO 527 | MPa | 75 |
| Elongation Flexural | ISO 527 | % | 4.0 |
| Modulus Flexural | ISO 178 | GPa | 2.9 |
| Strength | ISO 178 | MPa | 105 |
| Izod Impact Strength | ISO 180/1A | kJ/m ² | 1.7 |
| Charpy Impact Strength | ISO 179/1eA | kJ/m ² | 2.0 |
| | ISO 179/1eU | kJ/m ² | 18 |
| GENERAL | | | |
| Relative Density | ISO 1183 | - | 1.18 |
| Rockwell Hardness | ISO 2039-2 | M Scale | 85 |
| Ball Indentation Hardness | ISO 2039-1 (H 961/30) | MPa | 175 |
| Mould Shrinkage | - | % | 0.4-0.7 |
| Water Absorption | ISO 62 | % | 0.30 |
| Flammability | UL94 | - | HB |
| Glow Wire Test | IEC 695-2-1 | °C | 650 |

PP talc 40% data sheet:

PROPERTIES & AVERAGE VALUES OF INJECTION MOLDED SPECIMENS

| PERMANENCE | English | SI Metric | ASTM TEST |
|----------------------------------------------------------|----------------------------|------------------|------------------|
| Primary Additive | 40 % | 40 % | |
| Specific Gravity | 1.25 | 1.25 | D 792 |
| Melt Flow Rate @ 230 °C, / 2.16 kg | 10.00 g/10 min | 10.00 g/10 min | D 1238 |
| Molding Shrinkage 1/8 in (3.2 mm) section | 0.0070 - 0.0100 in/in | 0.70 - 1.00 % | D 955 |
| MECHANICAL | | | |
| Impact Strength, Izod notched 1/8 in (3.2 mm) section | 0.6 ft-lbs/in | 32 J/m | D 256 |
| unnotched 1/8 in (3.2 mm) section | 7.0 ft-lbs/in | 374 J/m | D 4812 |
| Tensile Strength | 4500 psi | 31 MPa | D 638 |
| Tensile Elongation | > 10.0 % | > 10.0 % | D 638 |
| Tensile Modulus | 0.70 x 10 ⁶ psi | 4826 MPa | D 638 |
| Flexural Strength | 7600 psi | 52 MPa | D 790 |
| Flexural Modulus | 0.50 x 10 ⁶ psi | 3448 MPa | D 790 |

BMC Characteristics from Menzolit

TYPICAL PROPERTIES

| | Standard | Units | |
|----------------------------|-----------------|-------------------|------------------|
| Density | ISO 1183 | g/cm ³ | 2,0 |
| Shrinkage | ISO 2577 | % | 0,00 |
| Heat Distortion Temp. | EN ISO 75-2 | °C | >200 |
| Continuous Service Temp. | Menzolit | °C | 190 |
| Young's Modulus | EN ISO 527-4 | GPa | 14 |
| Tensile Strength | EN ISO 527-4 | MPa | 25 |
| Flexural Strength | EN ISO 14125 | MPa | 100 |
| Flex Modulus | EN ISO 14125 | GPa | 12 |
| Impact Strength | EN ISO 179 | kJ/m ² | 15 |
| Glow Wire Index | IEC 60707-3 | °C | |
| Fire Retardancy | UL 94 | | |
| Surface Resistivity | IEC 60093 | Ohm | 10 ¹² |
| Comparative Tracking Index | IEC 60112 | Level | CTI600 |
| Water Absorption | ISO 62 | % | < 0,5 |

FORM of SUPPLY

menzolit® BMC 3100 is packaged in styrene tight bags and placed in cardboard or wooden boxes. Various kinds of packaging available. For alternative packaging please contact our technical service team. Available in limited colours.

List of DVN Gold Members

Car Makers

Audi, Germany
Bentley, UK
BMW, Germany
Changan Design Centre, Italy
FCA, USA
Daimler, Germany
Ford, Germany
GM, USA
Great Wall, China
Harley-Davidson, USA
Honda, Japan, USA
Hyundai, Korea, Europe
Jaguar-Land Rover, UK
Mahindra Mahindra, India
Nio, China
Nissan, Japan, Europe, USA
Opel, Germany
Porsche, Germany
PSA, France
Renault, France
SAIC TC UK
Shanghai-Volkswagen, China
Seat, Spain
Skoda, Czechia
Toyota, Japan, Europe, USA
Volkswagen, Germany
Volvo Cars, Sweden

Universities, Labs, Consultants

FEP, Franhauser, Germany
Darmstadt university, Germany
DEKRA laboratory, Netherlands
Fudan university, China
GranStudio, Italy
Hannover Leibniz Univ.(HOT), Germany
Institut d'Optique Graduate School, France
Karlsruhe Lighting Institute, Germany
LAB, France
Light Sight Safety, Belgium
Nuremberg university, Germany
Pacific Insight, USA
Parma University, Italy
Rensselaer university, USA
UMTRI, USA
University of California, Santa Barbara
YoungNam University, South Korea
Mr Shunxing Wang, China
John Peek- Soraa

Set Makers

AL, Germany, USA
Auer Lighting, Germany
Denso, Japan
Elba, Romania
Farba, Turkey
FIEM Industries, India
Flex'N'gate, USA
Grote, USA
Harbin Good Time, China
Hella, Germany
Hyundai IHL, Korea
Ichikoh, Japan
J.W. Speaker, USA
Koito, Japan, Europe
Lear, USA, Europe
Lite-On, Taiwan
Lumax, India
Magna, USA, Austria
Microlight Auto Parts, Taiwan
Mobis, Korea
NAL, USA
Neolite ZKW, India
Nordic Lights, Finland
Odelo, Germany
Olsa, Italy
Plastic Omnium, France
Peterson, USA
Shanghai Koito, China
SL Corporation, Korea
Stanley, Japan
Truck-Lite, USA
Valeo, France, Spain, China
Varroc, Germany
Wipac, UK
Xingyu, China
ZF-TRW
ZKW, Austria
Zodiac, France

Lighting Suppliers

A2Mac1, France
AML Systems, France
Anrui Opto, China
Astron-Fiamm, France
Auer-lighting, Germany
Bicomoptics, China
Bühler Alzenau, Germany
Covestro, US, China, Europe
DBM Reflex, Canada
Delvis, Germany
Docter Optics, Germany
Elmos, Germany
Enmech-Mektec, Germany
Everlight Electronic, Taiwan, Germany
GXC Coatings, Germany
Hitachi, Japan
Holophane, France
IAV, Germany, USA
Infineon, Germany
Innotec Group, USA
Instrument Systems, Germany
Jenoptik, Germany
Keboda, China
LG Innotek, South Korea
LG Electronics, South Korea
LMT, Germany, China
Lumileds, Netherlands
Merck, Germany
Mentor Graphics, Europe, USA
Myotek Industries, USA
Nalux, Japan
Nichia, Japan
NXP, UK
ON Semiconductor, Europe, Asia, USA
Optis, France
Optoflux, Germany
Osram, Germany
Oxyphen, Switzerland
Panasonic, Japan
Proper Group, USA
Sabic, USA
Samsung LED, Germany
Sapphire, USA
Sea Link International, USA
Segula Technologies, France
Seoul Semiconductor, Korea
Synopsys, USA, Germany
Texas Instruments, USA
TQ Technology, Taiwan
Vosla, Germany
WL Gore, USA
Zollner, Germany

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