

High optical quality polycarbonates:

For automotive interior, exterior and lighting.



Optical material portfolio:

Automotive interior, exterior and lighting.

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*All values are typical, not specified values.



Increasing need for innovative, highly demanding optical applications.

Travel by automobile is undergoing a transformation, as the car itself becomes more of a multifunctional living and working space that gives passengers new ways to spend their time. All participants in traffic must adapt to new situations, and new communication channels are required to maintain and improve safety.

With LED technology, integrating light into vehicle design has become easier and more flexible than ever. In the future, many car components will be able to integrate lighting functions that enhance both design and safety.

Autonomous electric-powered vehicles also bring new styling possibilities, enabling OEMs to even further differentiate their car models.

Interiors include seamless surfaces, large displays and improved haptics. Ambient lighting and sensors are integrated into all aspects of the vehicle to ensure passengers remain comfortable.

Designing the light gives car makers the opportunity to expand the customer experience outside the vehicle, for example by providing an "exterior welcome mode" of lighting.

Headlamps are no longer just a matter of safety. They become a major signature/branding design element in mobility, accompanied by increasing design possibilities and complexity.

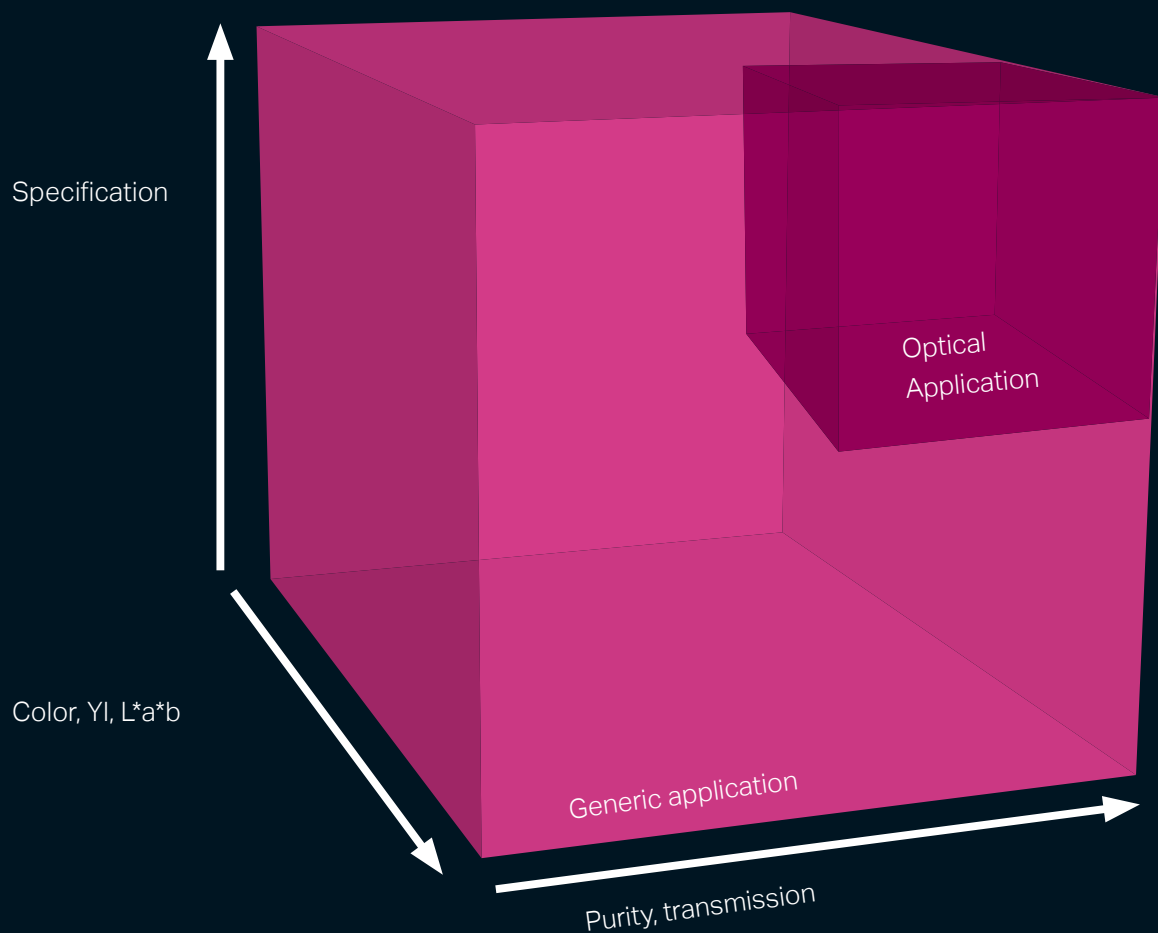
The headlights themselves will merge with other exterior parts such as the front grille and the rear of the car. Light will be also used for ambient or functional effects in all kind of exterior applications, such as lighting the edges in the side of a car for a distinctive nighttime profile.

Lighting is not simply confined to exterior surfaces. Today, light is projected onto the road to assist the driver – and can shine in all directions for communication purposes.

What does optical quality mean for us? And what opportunities does it offer for applications?

Every application is defined by a distinct set of multiple properties. In addition to meeting the standards set for its field, a component also has specifications regarding visual appearance, mechanics, aging behavior, service life, and other properties. For visible components such as decorative bezels or panels, there is special emphasis on tight color properties, stable and weatherproof colors and optimal surface quality.

Illuminated decorative components must offer a very high light transmission (T_y) and very low yellowness index (YI). Optical light guiding and shaping applications face a similar set of requirements. These components are sometimes used behind the scenes, yet still require pure, unhindered conductivity and diffusion of light. In most cases, the parts must not affect the light color, yet may also be required to direct it with an added function. All components must take a full range of testing into consideration, from resistance to LED light aging, sunlight, and heat, to meeting regulatory standards and safety requirements.

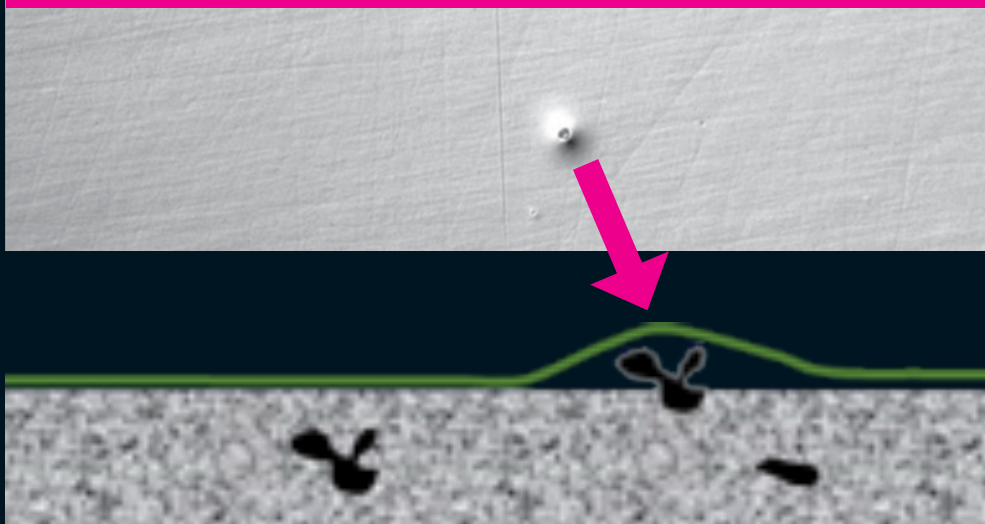


Application areas

Many individual steps in producing optical parts can lead to surface defects or impurities within the part. Covestro takes great efforts to ensure very high degree of purity in all of its optical **Makrolon®** grades. In addition, our technical labs are constantly developing expertise and exploring ways to avoid surface defects and black specks in the molding and coating of optical parts. We are happy to share this knowledge with customers of our optical **Makrolon®** grades.

As illustrated in the comparison below, there is always a possibility of impurity or pigments accumulating. In combination with a coating, this can lead to a lens effect, with a resulting higher scrap rate. (Defects in picture below are magnified by 10.) In common applications, these accumulations are usually not a problem.

Possible defects in standard polycarbonate






However, optical applications such as sensors, homogenous light distribution, and surface lighting with high transmittance and purity, all require the highest level of material quality. High purity materials for optical parts with homogenous coloring can enable you to lower your scrap rate (see picture below).

Makrolon® with high optical purity



Application areas

Our optical mobility portfolio couples the highest available optical quality parameters with the added reassurance of tested and proven colorants and optimization for application-related specifications.

	 Exterior		 Interior	 Headlamp	
	Makrolon® AX	Makrolon® AG	Makrolon® Ai	Makrolon® AL	Makrolon® LED
Description	High surface quality for decorative and functional opaque exterior parts	High purity resin, suitable for wet coating systems for decorative and functional transparent/translucent exterior parts	High optical purity resin with excellent surface quality for decorative and functional interior parts	Industry standard for headlamp outer lens covers	Highest transmission quality for inner light guiding parts of headlamps , exterior and interior parts
Specifications	Exterior specification with specific coating systems	Exterior specification with specific coating systems (AMECA/ECE listing, if required)	Interior specifications	AMECA/ECE listing with specific coating systems	AMECA/ECE listing without coating, for protected/covered applications only
Color and transparency	Available in opaque colors, with functions like sensor transparency on request	Transparent or translucent light stable colors, with special functions on request	Available in aesthetic opaque, transparent, translucent and functional colors	Available in select transparent colors for high volumes	Available in natural, transparent, translucent and functional colors
Individualization	Limited color development	Color development on request	Customized color development	No color development	Limited color development

Nomenclature:

The following system of nomenclature is used for most **Makrolon®** and **Apec®** grades: The designation of **Makrolon®** and **Apec®** sales products are based on a 4-digit, self-explanatory nomenclature.

Makrolon® LED	22	4	5
The first two digits denote the viscosity: 22 low viscosity 24 low viscosity 26 medium viscosity 28 medium viscosity 31 high viscosity			
Digit 3 differentiates between standard grades and special grades: 0 standard grade 1 or 4 special grade, often specified by a prefix, such as OD, LED, AL or LQ			
The fourth digit denotes the additive package: 5 easy release 7 easy release, UV-stabilized			

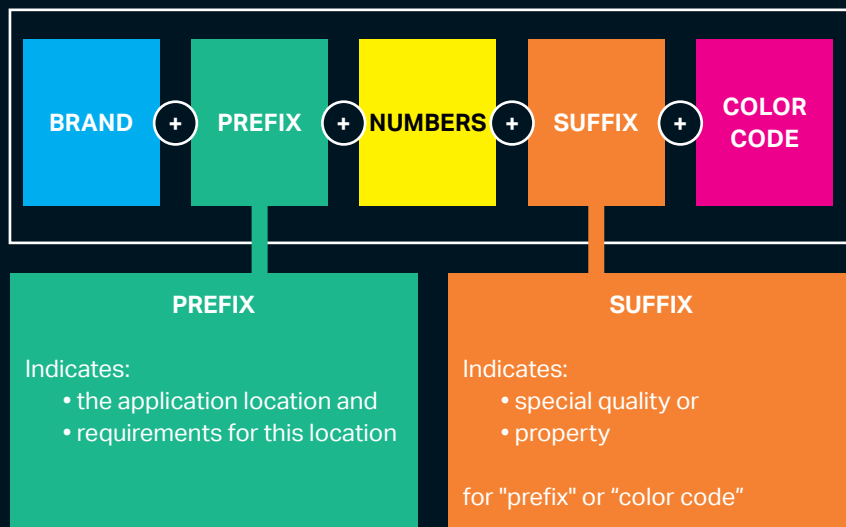
Apec®	20	9	7
The first two digits denote the heat resistance: 16 Vicat approx. 160° C 17 Vicat approx. 170° C 18 Vicat approx. 185° C 20 Vicat approx. 203° C			
Digits 3 and 4 describe the grade: 95 easy flowing, easy release 97 easy flowing, UV-stabilized, easy release 03 grade with elevated viscosity, UV-stabilized			
The fourth digit denotes the additive package 5 easy release 7 easy release, UV-stabilized			

Color designation

The material designation is followed by a 6-digit color code. The first two digits indicate the main color, the other four digits serve to distinguish between different shades. The designation 000000 refers to a natural shade with no added color.

	Opaque colors	Transparent colors	Translucent colors	Transparent IT controlled
Natural	00000	00000	-	-
Colorless	-	55...	-	-
White	01...	-	02...	-
Yellow	10...	15...	12...	17...
Orange	20...	25...	22...	27...
Red	30...	35...	32...	37...
Violet	40...	45...	42...	47...
Blue	50...	55...	52...	57...
Green	60...	65...	62...	67...
Grey	70...	75...	72...	77...
Brown	80...	85...	82...	87...
Black	90... / 999900	95...	92...	97...

Nomenclature optical mobility portfolio for **Makrolon®**:

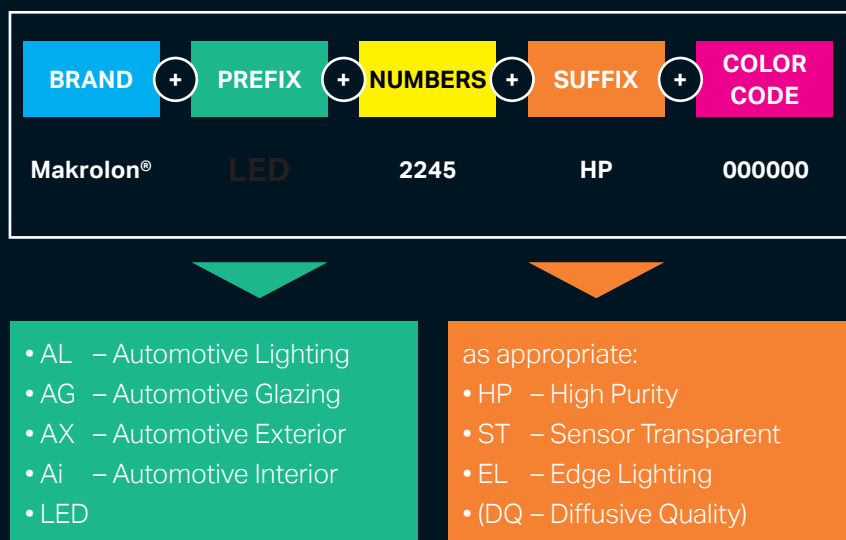


This nomenclature is based on the familiar **Makrolon®** one and subdivides the **Makrolon®** optical portfolio into three different application areas on the basis of application-related features.

For example, different requirements may consist of:

- **Material properties (exceptional color stability),**
- **Regulatory issues,**
- **Specific testing or treatments**

The assignment of a material to the respective area of application is made via the prefix, while the suffix represents a specific feature such as quality or color. Figure 2 outlines the various prefixes and suffixes with their respective explanations.







Makrolon® Ai stands for **Makrolon®** automotive interior.

We have created this product portfolio to ensure that the automotive industry can achieve excellent optical performance in future applications using our optical grades.

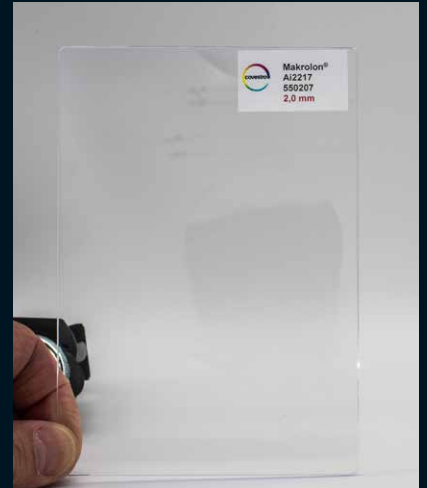
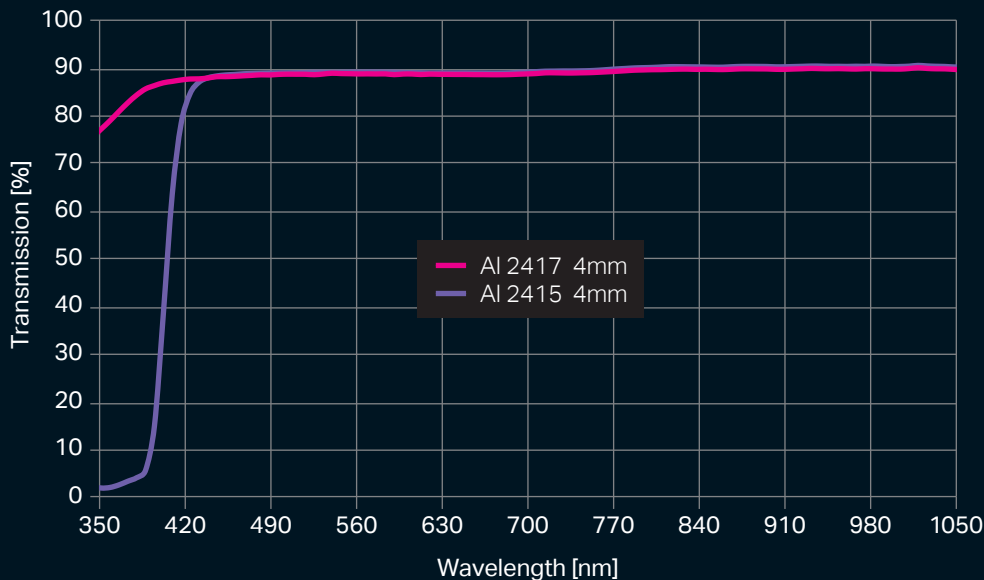
The transparent and translucent materials in the "Ai" portfolio are produced under extremely pure and clean conditions, using selected additives and melt filtration equipment. They are available in a wide variety of colors and light performance specifications.

We make every effort to deliver the high-quality materials that can help reduce your scrap rate. High purity for transparent material, low agglomerates for opaque high gloss material, and low intrusion for translucent color are what we aim to deliver with the new **Makrolon®** Ai portfolio.

Transparent interior parts

High optical transparency interior applications:

Our crystal clear grades have extraordinarily high transmission. Here you can compare the spectra of **Makrolon® Ai2417** with Ai2415 (without UV-absorber).



The Makrolon®Ai crystal clear appears neutral and absolutely clear.

Makrolon® Ai2417 versus Ai2415 550207

The Makrolon®Ai2415 can be used when optical adhesives become UV-cured through the front cover.*

Large display covers in 3 dimensions manufactured in a visually brilliant quality with **Makrolon® Ai2417**.

A perfect application would be a 3-dimensional shaped display cover, directly molded onto an OLED screen (2.5D). The haptically-formed 3D surface allows direct contact with infotainment slider controls.



We are colorful.

Why not apply more color in your transparent applications?

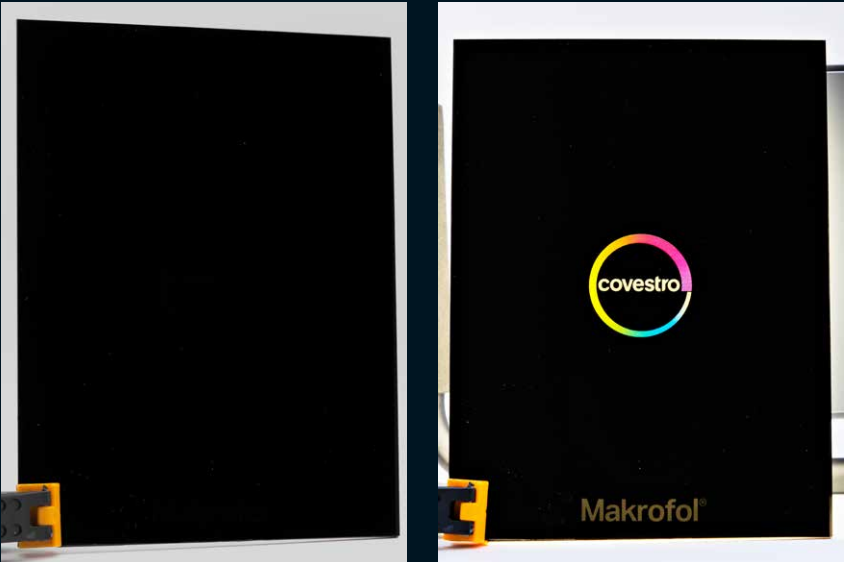
Differing colors for signals are normal, but for interior applications, colors can bring an entirely new dimension to the in-car experience.

Using transparent and/or diffuse colors allows signage for more safety, the display of useful information, or finely tuned ambient lighting for a perfect sense of well-being.



Black panel lighting – hidden until it's lit.

In daylight you won't see anything. But when backlit, all of the concealed content comes to life!



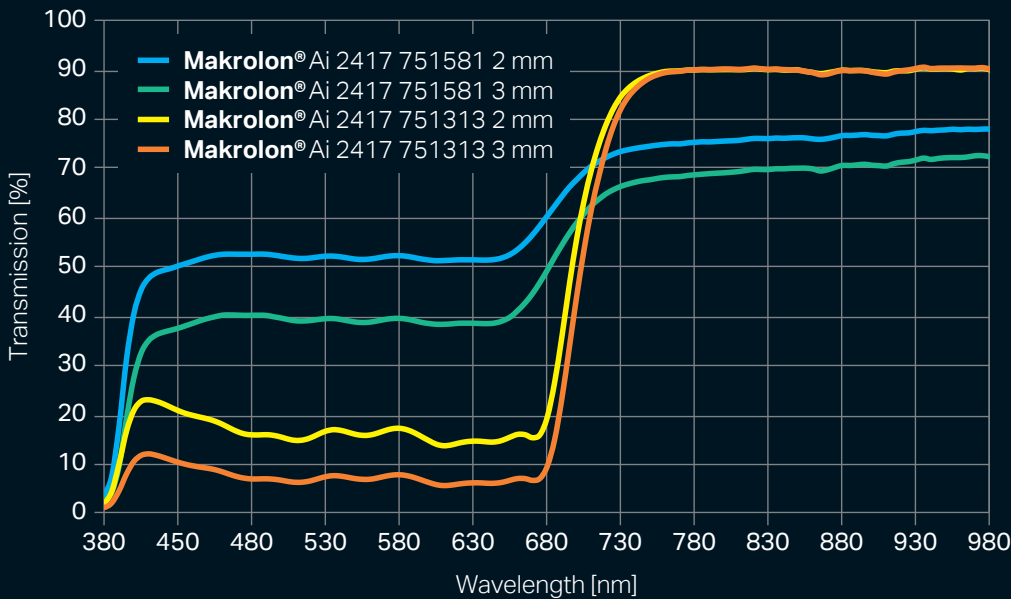
Color code	Ty/% 2mm thickness	Ty/% 3 mm thickness
751313	16	7
751449	41,5	27.5
751581	52	39
751451	37	23,5

Selected colors black transparent,
Based on **Makrolon®** Ai2417 (Ai2217).*

Tailor-made black panel colors are available on request. Please
contact our sales representatives.

Black panel and high-gloss piano black:

This deep black effect appears when light is absorbed by tinted **Makrolon®** Ai2417. The difference between this and the black panel effect may be only minimal. It can be tailored at customer request, and also tuned for wall thickness.



Transmission curves of gray-transparent colors: Thanks to the dosage of the colorants, we were able to achieve a neutral color reproduction and transmission in line with the requirements.

3D display cover case study

Thermoplastics for displays of the future.

Covestro collaborated with Continental Automotive, a company that develops pioneering technologies for the automotive industry.



Task: Develop large curved display concept

Our goal was to create an innovative display with Continental Automotive that meets the needs of future autonomous and electric vehicles. We wanted to demonstrate how we bring new applications to market by solving previously unmet material needs and supporting our partners with our technical expertise in polycarbonate resin and films.

We were excited to develop the first large curved display cover with Continental. With a strong partner like Continental, coupled with our technical support and material development technology, we were able to explore the possibilities of new technology and develop tailor-made material for the future interconnected auto. The result: the first large display made entirely of polycarbonate.

Ciro Piermatteo/Global Technical Marketing Mobility Interior, Covestro

Solution: Rely on proven materials and processing knowledge

Working together with Continental Automotive, we developed the OLED display with **Makrolon® Ai 2417** polycarbonate, which offers high optical purity, and **Makrofol® HF** polycarbonate film. Film insert molding technology was used to create the display's decorative effect.

The surface utilizes in-mold decoration technology for scratch and chemical resistance, combined with injection compression molding to achieve optical properties.

The combination of different processing technologies like FIM and compression molding for large optical parts is a leap into the next generation of decorated plastic parts. We were thrilled to take an active role in this huge project and to contribute innovative solutions for diverse processing challenges.

Roland Künzel/Head of Technical Center Films (TCF), Covestro

Challenge: Find the right material with high optical quality

The selected materials and supporting technologies, such as film insert molding, needed to meet a variety of development requirements. This included a material with high optical purity and excellent mechanical capabilities along with a tailor-made color shade with extreme tight color specifications designed for the OLED display.



The surface utilizes in-mold decoration technology for scratch and chemical resistance, combined with injection compression molding to achieve the ideal optical properties.

"Our display solution shows the next evolutionary step for large size automotive user interfaces. Smaller curvature radii in combination with topographic surface elements significantly improve the user experience of multi-display systems in the vehicle and offer a new level of design flexibility."

Martin Lenz/Technical Project Manager Curved Plastic Lens, Continental

Translucent colors for functional and ambient lighting.

Translucent colors are widely used for ambient lighting to support and enhance the well-being of passengers. An increasing number of translucent color settings offer varying degrees of transmission and light diffusion. A special application is backlit switches, which carry white lighting for applications like infotainment boards, and require red for functions such as alarm buttons. These can be coated, and the symbols in red created by laser-etching.

Makrolon® Ai will supply diffusion to your specification.



The color 020083 is rather opaque – nevertheless it has a certain transmission for seeing symbols when backlit in the dark. At the same time, it offers good reflection in daylight.

Translucent grades:

for light design (ambient, dynamic, and signal lighting):
Makrolon® Ai2257,
Makrolon® Ai2457,
Makrolon® Ai2657
translucent colors, applied
on **Makrolon®** Ai2457



The color 921061 appears dark black, but is in reality translucent. This means there is no color-shift when backlit.

Color code available in M. Ai	Thickness mm	Half power angle HPA (average)	Transm. Ty (%)
020003	1	54.5	29.2
020003	2	56.9	16.3
021173	1	46.0	59.1
021173	2	56.0	48.7
021182	1	29.3	72.4
021182	2	49.9	56.7
021528	1	20.5	83.1
021528	2	34.4	70.7
021533	1	22.6	82.0
021533	2	39	67.1
921061	1	1.7	18.7
921061	2	30.1	3.8
921062	1	34	27.5
921062	2	46.2	8.6

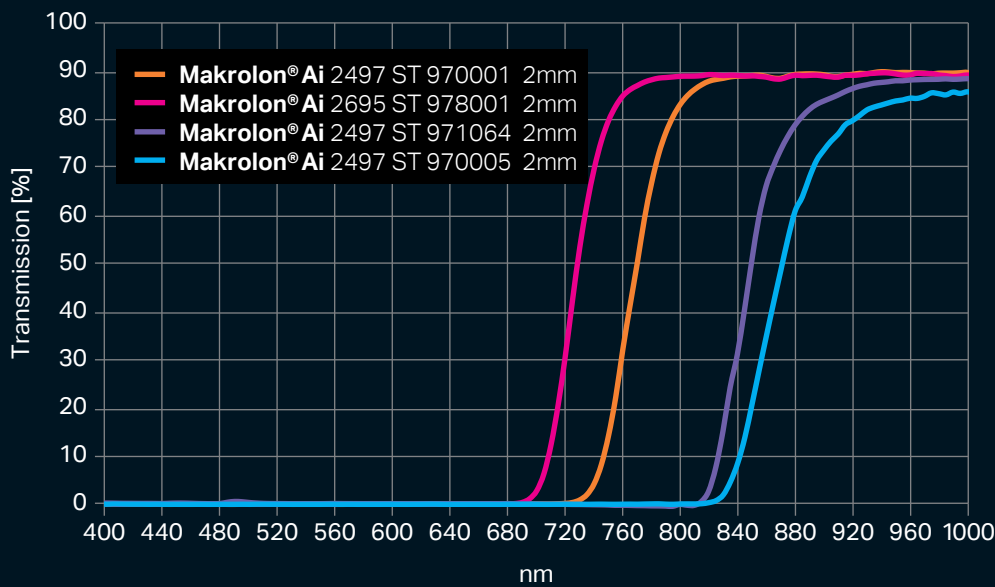


Interior sensor transparent applications:

Makrolon® Ai – ST for interior sensors.

Infrared sensors are also required in car interiors. Cameras and sensors can be used to monitor and prevent the driver from falling asleep. IR-open Makrolon® can be used for camera covers and for 'simple' lenses that focus the light on the driver.

The driver should not even notice that he or she is being monitored with red LEDs. In addition to a very high surface quality, Makrolon® IR-open color formulations also show an amazing depth effect. For this reason, some NIR transparent colors are recommended for aesthetic reasons, or for signal transmission, in applications such as light barriers, remote controls, and laser absorption welding. More NIR colors are available on request.



Comparison of Makrolon® Ai ST-Colors 978001 vs 970001; 971064; 970005

ST stands for Sensor Technology. Depending on the application's need, we can choose from different color matches – although all simply appear black. These can open transmission at different wavelengths, for example to avoid 'red glimmering'. All colors in this range are transmission-controlled.*

Makrolon® Ai... has a nomenclature determined by its appearance.

Appearance ↓	← Viscosity →		
Clear	Makrolon® Ai 2215 Makrolon® Ai 2217 Makrolon® Ai 2215 EL	Makrolon® Ai 2415 Makrolon® Ai 2417	Makrolon® Ai 2617
Translucent	Makrolon® Ai 2257	Makrolon® Ai 2455 Makrolon® Ai 2457	Makrolon® Ai 2657
Opaque	Makrolon® Ai 2295 Makrolon® Ai 2297	Makrolon® Ai 2495 Makrolon® Ai 2497 Makrolon® Ai 2497 ST	Makrolon® Ai 2695 ST Makrolon® Ai 2697 ST

Transparent grades -15 and -17 | Translucent grades -55 and -57 | Opaque grades -95 and -97 | 5 without/7 with UV absorber EL = edge lighting, ST = sensor technology

Case study for slim design via overmolded electronics

Makrofol® and Makrolon® Ai enable smart surfaces in cars.

Injection molded structural electronics (IMSE*) technology brings electronics into thin, durable 3D plastic surfaces. Using **Makrofol®** film and **Makrolon®** Ai resin, we helped our partner TactoTek® to create a fully functioning demonstrator overhead control panel that is strong, lightweight and sleek.

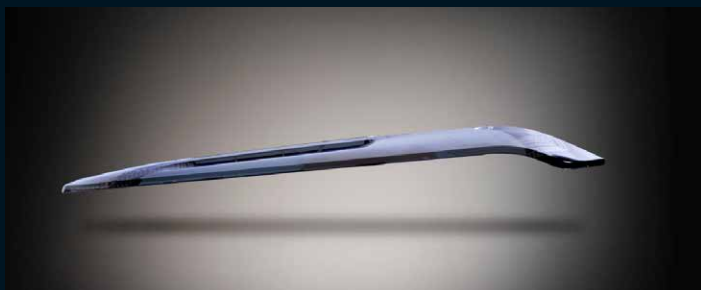


Task: Create a slim, light and smart overhead control panel

The way passengers interact with their vehicles is changing rapidly. Almost any visible surface in an automobile, from door trim to cover panels, can now integrate buttons, controls, switches and lighting. Our partner **TactoTek®** is a Finland-based specialist in Injection Molded Structural Electronics (**IMSE™**). For **CES®** 2019, they wanted to create a lightweight, durable overhead panel that integrated printed circuitry and controls, to prove how this technology increases design freedom.

Challenge: Combine different functionalities with low height and a cutting-edge design.

Our challenge was to demonstrate how double-sided Film Insert Molding (FIM) technology can be used to create an elegant, low-profile and lightweight structure that integrates touch controls and lighting at a minimum depth of the molded part. Printed electronics and components had to be combined with a slim, elegant 3D shaped surface that is both durable and appealing, while saving both weight and space.



IMSE™ and FIM Technology with polycarbonate material create ultra-slim parts

"The combination of different processing technologies like FIM and compression molding for large optical parts is a leap into the next generation of decorated plastic parts. We were thrilled to take an active role in this huge project and to contribute innovative solutions for diverse processing challenges."

Marko Suo-Anttila/SVP Engineering, TactoTek Oy

Solution: A robust, smart surface produced with Makrofol® film and Makrolon® Ai resin

For the **TactoTek®** demonstrator, we supplied a two-in-one FIM solution, with products qualified for use in IMSE applications. For the touch surface on the front, we used a hard-coated UV curable **Makrofol®** HF312 film, ensuring scratch and chemical resistance. On the back side, an uncoated **Makrofol®** DE1-1 was printed with conductive inks. The electronic components were integrated on the printed **Makrofol®** DE1-1 film. The two films were formed and trimmed before **Makrolon®** Ai 2217 polycarbonate was injected between the two film inserts. **Makrolon®** Ai resins offer a high optical purity and enable tailor-made coloration.

Electronics enabled in 3D shaped plastic surfaces

- **Design freedom** **Makrolon®** Ai resin allows complex 3D shaped smart surfaces with high mechanical stability.
- **Functional Makrofol® film and Makrolon®** Ai resin allow the integration of electronics into plastic parts.
- **Ultra-slim formable** hard-coated films and resins minimize weight and enable space-saving designs.
- **Lightweight** Film and resin materials are combined in a single lightweight structural part.
- **Robust Makrofol®** film ensures a surface that is scratch and chemical resistant.
- **Printable Makrofol®** HF312 hard coated film can be printed on, thus allowing for customized designs.



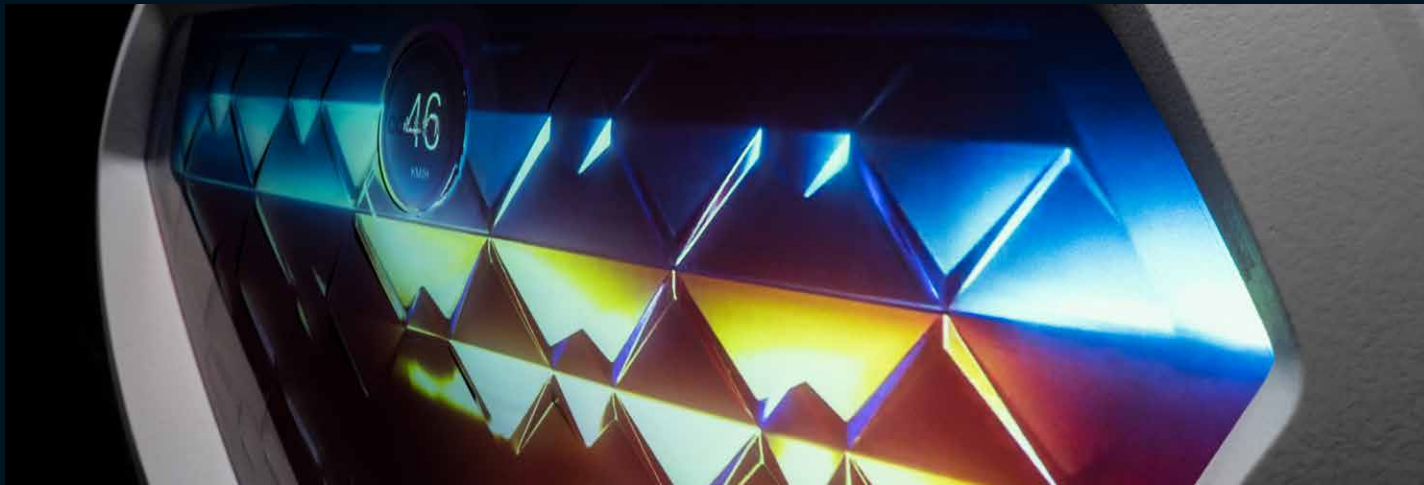
Automotive exterior:

For automotive exteriors, Covestro offers customized polycarbonate grades for transparent and opaque applications:

Makrolon® AG and AX have a high degree of purity and are optimized for interaction with surface coatings thanks to special raw materials and additives. They are manufactured on selected production lines with the necessary special melt filtration systems. Weather-stable colorants in combination with established coating systems ensure the necessary longterm color stability (see graphic page 25). When using **Makrolon®** AG and AX, Covestro offers intensive support in terms of component design, mold design and optimization of the injection molding and coating process.

Transparent exterior parts

Makrolon® AG Visually transparent optical polycarbonate in light or dark colors for automotive exteriors.



Makrolon® AG (Automotive Glazing):

Makrolon® AG (Automotive Glazing) is ideally suited for existing and new transparent applications in automotive exteriors. It has already been used successfully for years for glazing, and is now also found in components such as design panels on the front of vehicles. These enable new, exciting and seamless designs. Thanks to its optical properties, **Makrolon® AG** enables the integration of attractive color and light accents on the exterior. In the future, large-area display covers for pedestrian communication in autonomous vehicles will also benefit from the dimensional stability and transparency of **Makrolon® AG**. Many exterior components must also meet high requirements in terms of pedestrian protection and crash safety – among transparent materials, only polycarbonate offers the necessary impact strength. Polycarbonate is also ideally suited for the invisible integration of sensors in self-driving vehicles: As **Makrolon® AG ST** (Sensor Transparency), it offers excellent transmittance for LiDAR, RADAR or cameras. Another application for design-driven or safety-relevant light integration is opened up by **Makrolon® AG DQ** (diffusive quality). This translucent **Makrolon®** enables a wide range of combinations in light diffusion, color and transmission.



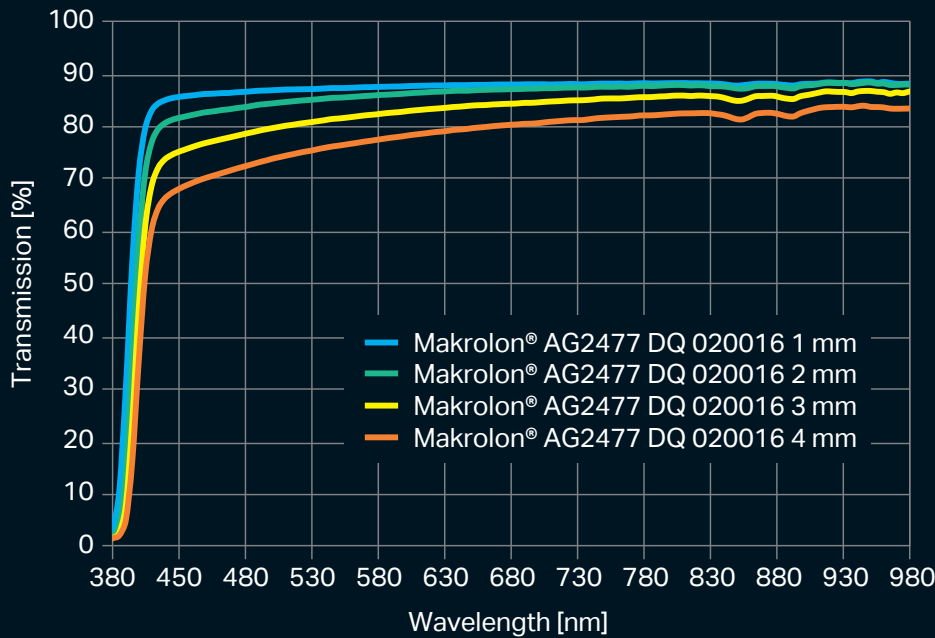
Grade	MVR (300 °C, 1.2 kg) cm³/10 min	Key properties
Makrolon® AG 2677 Standard transparent colors x5xxxx	12	<ul style="list-style-type: none">• Well known Makrolon® AG quality• Optimized for transparent automotive exterior applications• Wide range of transparent colors
Makrolon® AG2677 IR-absorbing colors x7xxxx	12	<ul style="list-style-type: none">• IR absorption• Optimized for transparent automotive exterior applications• IR-absorbing properties that reduce heat energy transfer from the sun into the car

Makrolon® AG DQ (Diffusive Quality):

Makrolon® AG DQ (Diffusive Quality) is the ideal polycarbonate for diffuse or translucent exterior parts. These can be illuminated emblems or radiator grill frames with light integration. The ratio of transmission to scattering angle, **Makrolon® AG DQ** efficiently resolves individual light sources and produces very homogeneous luminance distributions. In addition to white-appearing colors, gray translucent colors are also available. As in all grades of the **Makrolon® AG** and **AX** family, only light-stable dyes and scattering pigments are used in **Makrolon® AG DQ**.



Grade	MVR (300 °C, 1.2 kg) cm³/10 min	Key properties
Makrolon®AG2477 DQ Translucent colors 02xxxx	19	<ul style="list-style-type: none">• Optimized for translucent automotive exterior applications• Translucent white/gray colors• Best combination of transmission and HPA (half power angle)



Weathering data of painted
Makrolon® exterior samples: Curves to
Makrolon® AG2477 DQ.v.*

Makrolon® AX:

Black and visually opaque optical polycarbonate for automotive exteriors.

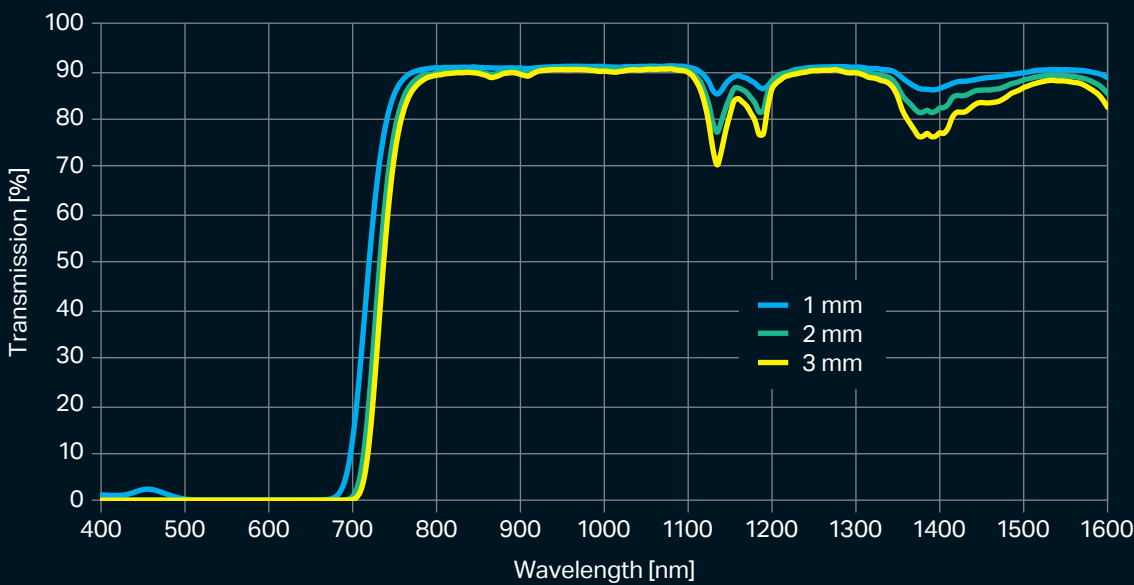


Makrolon® AX (Automotive Exterior) is used for high-quality black roof panels and exterior door pillar covers. It is optimized for brilliant surface qualities, color stability in exterior applications, and high consistency of its properties from batch to batch. A protective coating on the surface of the components provides weather resistance and scratch resistance as well as a glass-like surface appearance. Specified and sensor-permeable grades are also available here (**Makrolon® AX ST**).



Grade	MVR (300 °C, 1.2 kg) cm³/10 min	Key properties
Makrolon® AX2675 ST Sensor Transparent blackcolor 978001	12	<ul style="list-style-type: none">• For black LiDAR covers• Excellent near-IR transparency for LiDAR signal transmission• IR-transmission specification: > 89% @ 2 mm @ 905 nm

Makrolon® AX2675 ST color 97800:



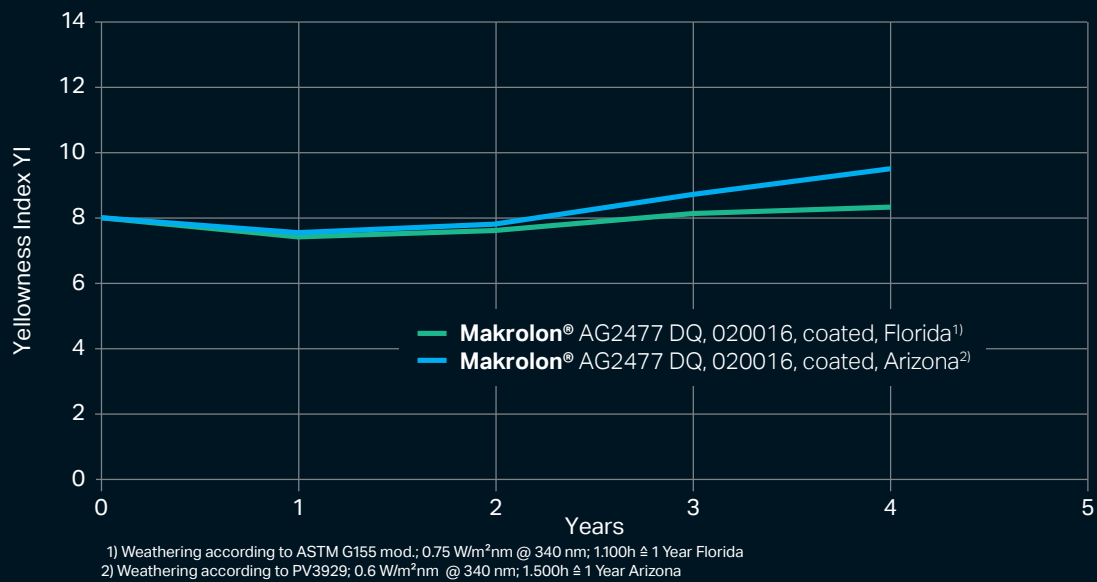
Sample transmission for
Makrolon® AX2675 ST
color 978001.*

Makrolon® AX2675 ST **Makrolon®** AX ST (Sensor Transparent) is black to the human eye, but has a high signal transmission in the near infrared range (NIR) up to approx. 1600 nm. This combination makes it the ideal material for the covers of LiDAR sensors. Covestro guarantees that every delivered batch of **Makrolon®** AX ST guarantees a minimum transmission of 89% at 905 nm and 2 mm wall thickness. In addition, this polycarbonate grade also produces very good surfaces in combination with transparent protective coating.

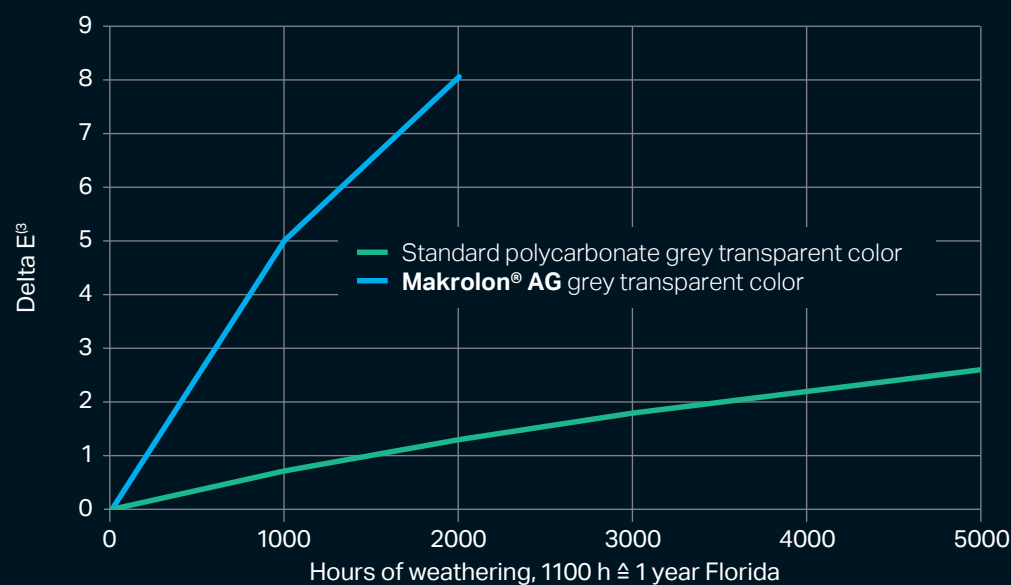


Grade	MVR (300 °C, 1.2 kg) cm³/10 min	Key properties
Makrolon® AX2675 Standard black color 901510	12	<ul style="list-style-type: none">• Well-known Makrolon® AX quality• Optimized for opaque automotive exterior applications which do not require increased weathering performance• Not IR-transparent
Makrolon® AX2675 IR-transparent black color 900346	12	<ul style="list-style-type: none">• Significantly increased weathering performance compared to standard black• Near-IR transmission not specified• Not suitable for safety-relevant applications where sensors rely on IR transmission (e.g. LiDAR)

Exterior weathering performance



Light fastness of **Makrolon® AG2477 DQ**.*



acc. to ASTM G155 mod.; 0.75 W/m²nm @ 340nm.*

Exterior weathering performance

Hard-coated **Makrolon®**: Perfect solution for design-driven exterior parts.

The most visually perceptible change in polycarbonate when exposed to UV light is yellowing. Other properties that deteriorate with weathering/UV exposure are:

- Decreased transmission due to increased yellowing and haziness of **Makrolon®**
- Bleaching of colorants in tinted **Makrolon®**, in both transparent and opaque grades
- Deterioration in surface properties, such as cracking and haze formation
- Deterioration in mechanical properties, e.g. impact strength and stiffness, due to the decomposition of **Makrolon®** initiated by UV light




Therefore, UV stabilization is essential when parts made of **Makrolon®** are expected to withstand intensive UV exposure. Over the past few decades, our coating labs have built know-how and experience in the field of surface protection. Based on this, we have developed solutions for automotive lighting and exterior applications:

- UV absorber embedded in Makrolon® resin combined with one- or two-layer hard-coats containing concentrated UV absorbers
- In addition, all **Makrolon®** AG and **Makrolon®** AX
- use lightfast colorants exclusively and
- are optimized for coatability

Weathering performance of hard-coats depending on substrate color.

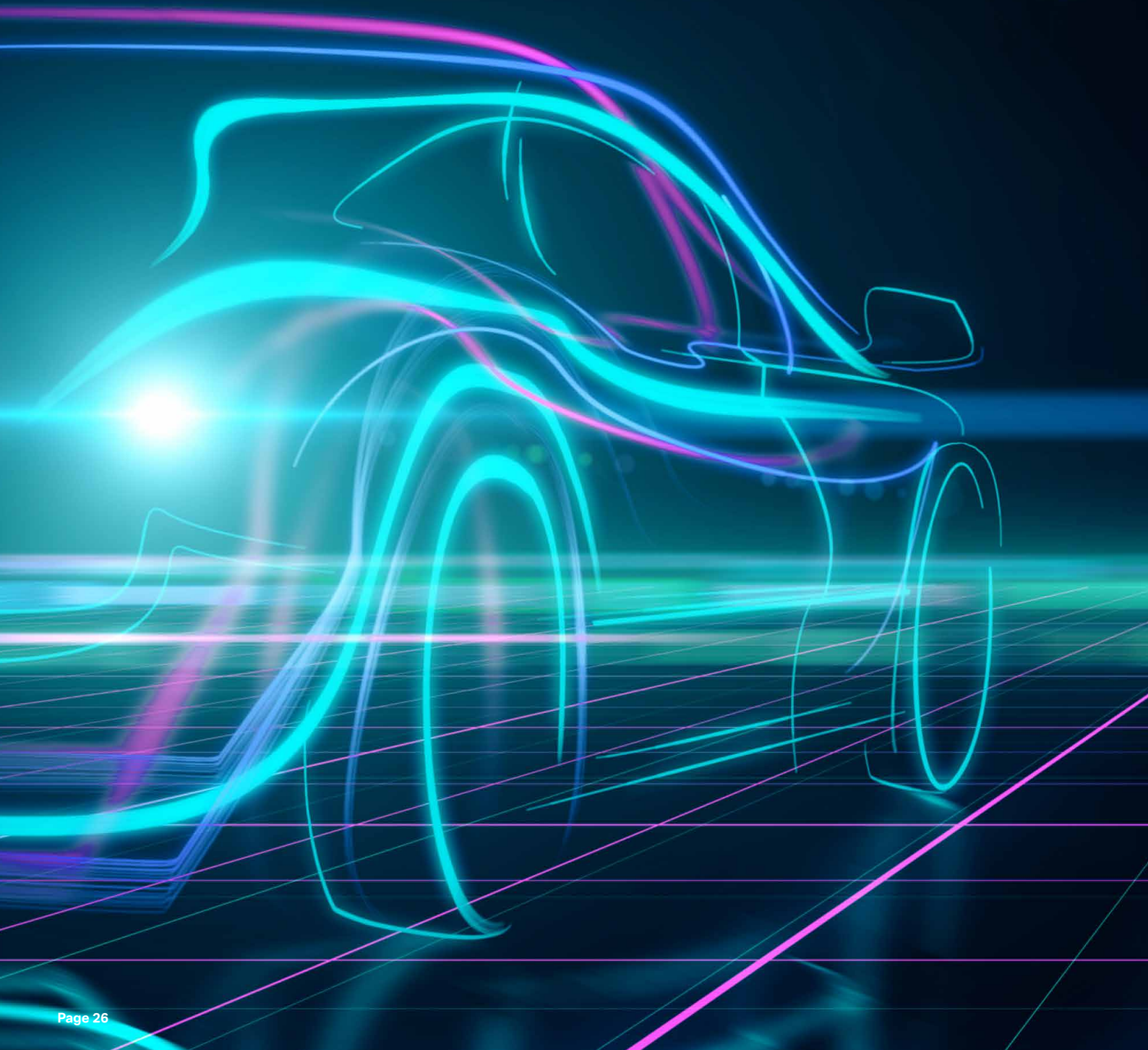
Substrate and color	1100 h	2200 h	3300 h	4400 h	5500 h	6600 h	7700 h	8800 h	9900 h	11000 h
Clear transparent Makrolon® AG2677 color 550396	no damage	no damage	no damage	no damage	no damage	no damage	no damage	no damage	starting micro cracks	starting micro cracks
Light tinted transparent Makrolon® AG2677	no damage	no damage	no damage	no damage	no damage	no damage	no damage	starting micro cracks	starting micro cracks	starting micro cracks
Dark tinted transparent Makrolon® AG2677	no damage	no damage	no damage	no damage	no damage	no damage	starting micro cracks	starting micro cracks	starting micro cracks	starting micro cracks
Cool black IR-transparent Makrolon® AX2675 color 900346	no damage	no damage	no damage	no damage	no damage	starting micro cracks	starting micro cracks	starting micro cracks	starting micro cracks	starting micro cracks

Further data available on request.

	no damage		starting micro cracks		strong micro cracks/delamination
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Two-layer polysiloxane coating.

weathering acc. to ASTM G155 mod.; 0.75 W/m²nm @ 340 nm; 1.100 hours ± 1 year Florida.*



Safety communication styling/ branding lighting is the signature of the car.

Every car has its own identity, expressed in a unique headlamp and rear lamp design. Safety communication, styling and branding are three basic requirements for automotive lighting applications, and the right choice of materials for optical parts can help achieve all three.

Furthermore, materials with special colors and effects are also needed to help underscore the unique nature of the headlamp. Light integration and the use of LEDs will increase tremendously in the future, so materials will need to couple high optical performance with the ability to withstand long-term exposure to LEDs. Covestro offers **Makrolon®** (polycarbonate) optical grades which can bring out the most efficient LED lighting and enable great freedom of design with a wide range of color effects. **Makrolon®** offers superior optical, mechanical, thermal properties and long-term stability with LEDs, already anticipating the future needs of headlamp/rear lamp manufacturers and automotive OEMs.

Transparent/translucent applications:

One of the most common applications for **Makrolon®** in the automotive sector is in headlamps and rear lamps, thanks to its high optical transmission properties.

Makrolon® AL in combination with a coating system is a state-of-the-art material for headlamp cover lenses, and fulfills all requirements of the ECE and AMECA.

Makrolon® LED offers the highest optical transmission and optical quality, and is suitable to be used for optics and light guides with regulatory approvals (e.g. AMECA).

Outer headlamp cover

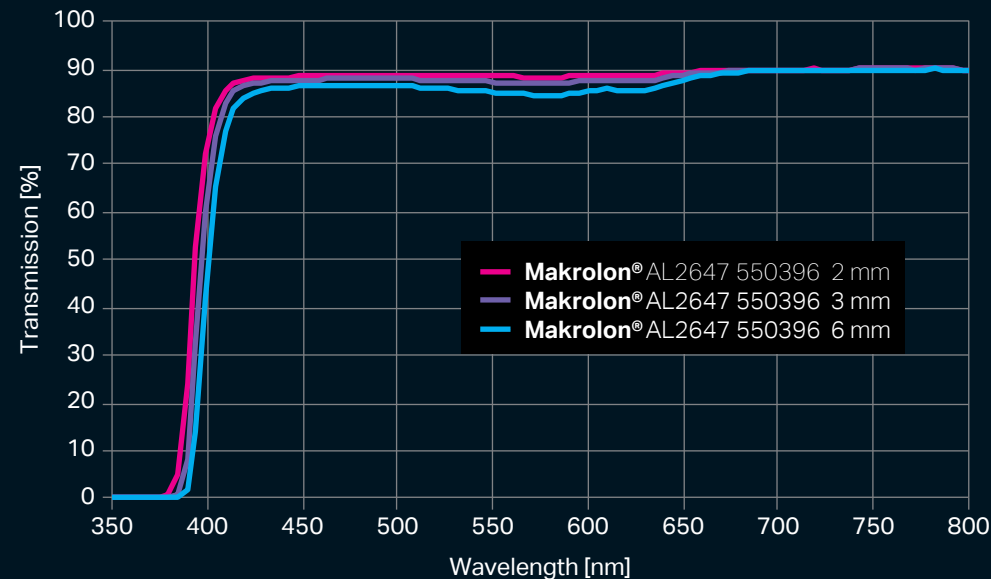
Protective function and design freedom in headlamp shapes.

Makrolon® AL, industry standard grade for headlamp covers.



Makrolon® AL is an industry standard polycarbonate grade for headlamp covers. It offers an optimal trade-off between melt-flow and the mechanical properties that enable design freedom in terms of geometry. The properties are tailored to the high demands of this mass application in terms of optical quality, impact resistance and heat resistance. In order to achieve good weathering performance and scratch resistance, a special coating needs to be applied. **Makrolon® AL** in combination with coating is approved by AMECA and UNECE.

Materials	MVR (300 °C, 1.2 kg) cm³/10 min	Key properties
AL2447 MS	19	High melt-flow with increased thermal stability at 350 °C to obtain very thin-wall components
Makrolon® AL2447	19	High melt-flow for thin-wall parts
Makrolon® AL2647	12	Medium melt-flow for superior impact resistance



Transmission spectra of **Makrolon® AL2647 550396** at different thicknesses.*

Control the light, the way you like it.

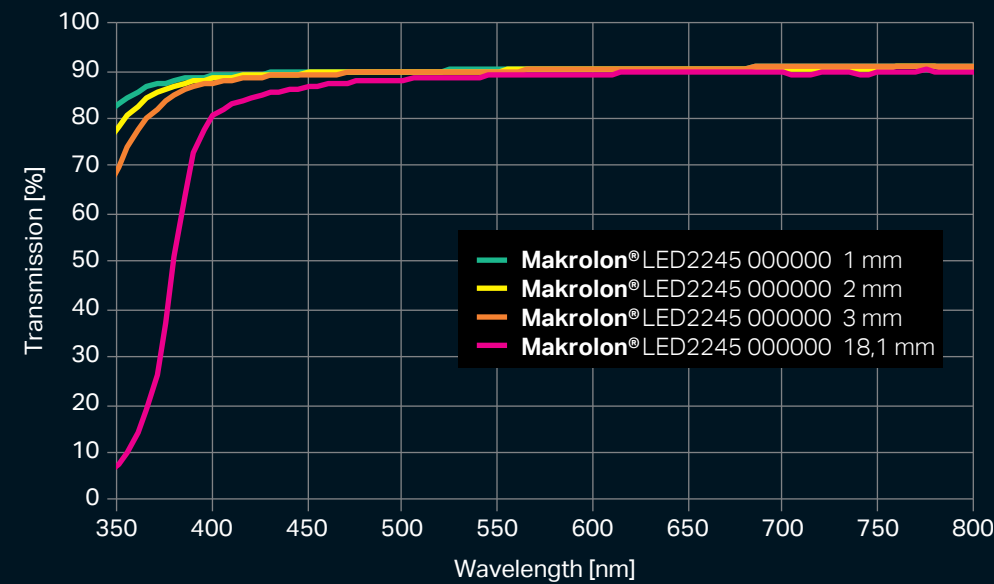
Makrolon® LED offers our highest transmission for light guidance applications such as DRLs.



Makrolon® LED offers the high transparency (90% at 4 mm thickness) and excellent optical quality which are necessary for accomplished light distribution in daytime running lights, signal functions and other ambient lighting applications. It combines long-term color stability under LED light with good melt-flow and heat resistance. For protected applications (e.g. behind coated **Makrolon®** AL2447/AL2647 cover) it is approved by AMECA and UN ECE in a range of different colors.

Materials	Colors	MVR (300 °C, 1.2 kg) cm³/10 min	Key properties
Makrolon® LED2245 HP	natural	34	Excellent transmission and high optical purity for thick-walled lenses with the best color consistency
Makrolon® LED2245	natural, 550207 (ice color)	34	excellent transmission
Makrolon® LED2245⁴⁾	natural	61	Excellence transmission with very high melt-flow

4) Available only in APAC and NAFTA countries



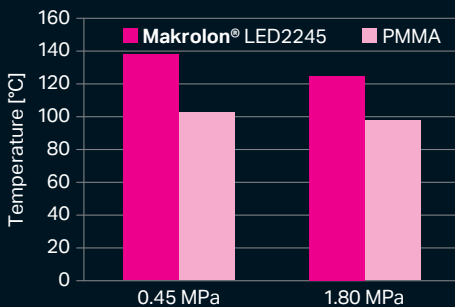
Transmission spectra of **Makrolon®** LED2245 000000 at different thicknesses.*

Makrolon® LED provides an optimal balance of optical and mechanical properties for light guides and thick lenses.

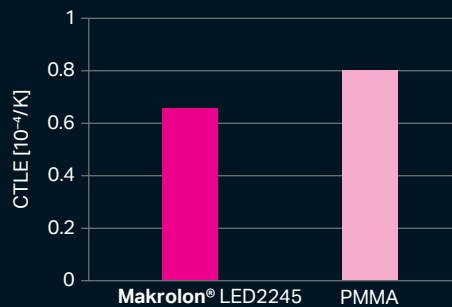


Complex optical components such as the thick lenses in daytime running lights require precise optical properties united with high mechanical requirements. For example, when it comes to the necessary fastening elements or the component stability in application and production, a correct balance of optical and mechanical properties is necessary. **Makrolon® LED** offers the opportunity to produce long, thick optical lenses for DRL in high optical quality combined with mechanical strength.

Ask about optical data for our materials to help design your automotive parts.



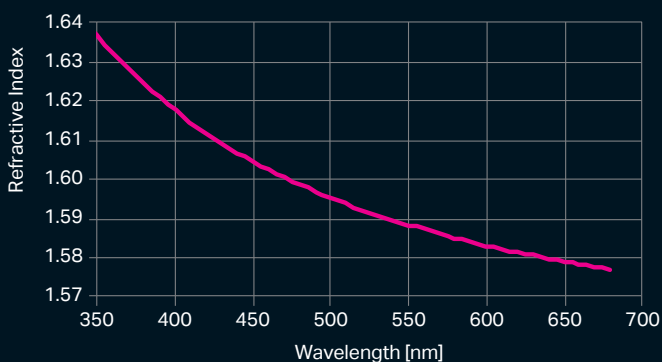
Heat deflection temperature Heat deflection temperature of **Makrolon® LED2245** and **PMMA**.*



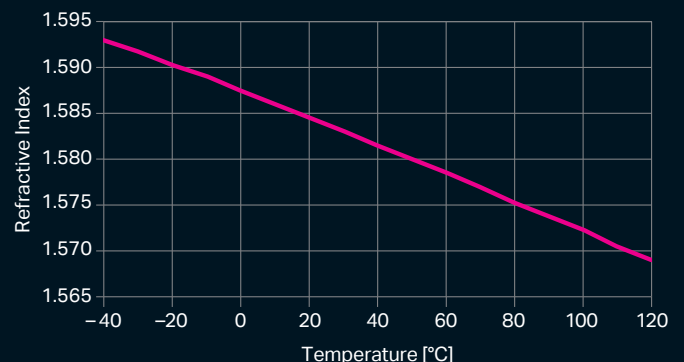
Coefficient of linear thermal expansion (CLTE)
Coefficient of linear thermal expansion at 23-55 °C of **Makrolon® LED2245** and **PMMA**.*

Makrolon® LED offers the opportunity to produce long, thick optical lenses for DRL in high optical quality combined with mechanical strength.

An additional benefit of using **Makrolon® LED2245** instead of **PMMA** as light guide and optic material is the dimensional stability at higher temperatures. The above left hand graphic shows that **Makrolon®** has thermal resistance performance superior to **PMMA**, as **Makrolon** starts to deform at a temperatures of 125°C (at 1.80 MPa) and 138 °C (at 0.45 MPa) while **PMMA** already deforms at 100 °C. Furthermore, **Makrolon® LED2245** offers less thermal expansion, as shown in graph above.



Refractive index as a function of wavelength of **Makrolon® LED2245** 000000.*

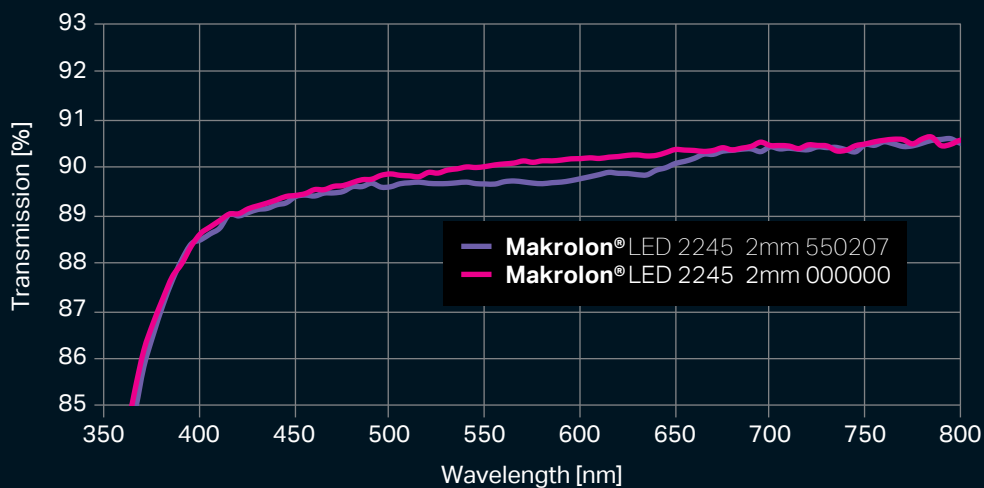


Refractive index of **Makrolon® LED2245** 000000 at different temperatures.*

Light guide and optics

Makrolon® LED is available in different transparent color

The visual impression of a light such as a daytime running light is determined by its color temperature, and by how the component looks when switched off. So **Makrolon® LED2245** materials are available in high transparency settings for light color temperatures ranging from warm white to cool white.



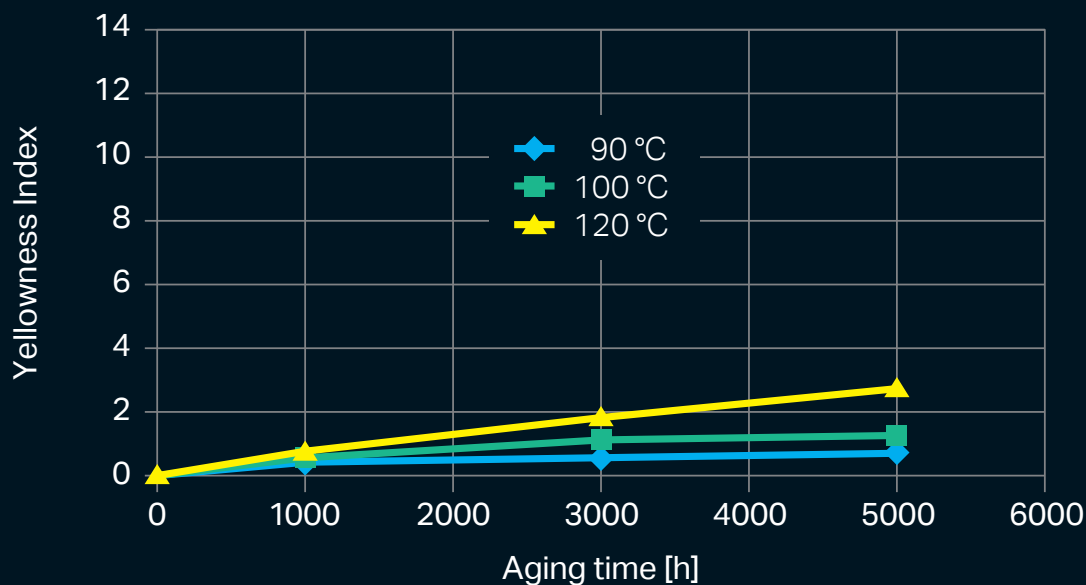
Transmission spectra of **Makrolon®** LED2245 in neutral (000000) and ice color (550207).*

Crystal clear/ice color impression parts are possible with **Makrolon®** LED2245 (color code 550207). However, as illustrated above, the the transmission of ice color material is slightly lower than than with natural color (color code 000000).



Makrolon® LED offers lowest tendency towards yellowing

Components made of **Makrolon®** typically display high temperature resistance. A distinction is made between short- and long-term temperature resistance. Different methods exist for measuring short-term temperature resistance, such as the glass transition temperature, the Vicat softening point, and heat distortion temperature (HDT) test. Short-term temperature resistance is comparably high within the group of clear, transparent **Makrolon®** grades. Extended exposure to extreme temperatures can lead to yellowing over time. The kinetics of the yellowing also depend on the individual **Makrolon®** grade. **Makrolon®** LED2245 000000 and **Makrolon®** LED2245 HP 000000 display the lowest tendency towards yellowing. This behavior is illustrated for **Makrolon®** LED2245 000000 below.

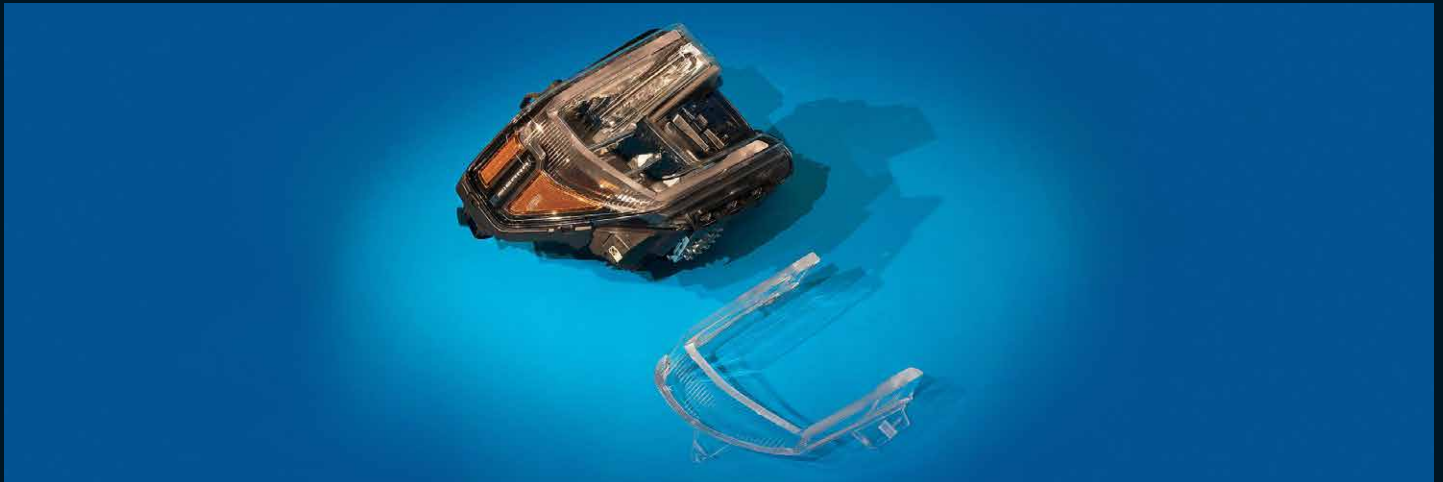


Thermal aging of **Makrolon®** LED2245 000000 (4 mm) at different temperatures*

This graph shows that **Makrolon®** LED2245 000000 displays a very low tendency towards yellowing at temperatures up to 120 °C. In contrast, discoloration occurs much more rapidly at higher temperatures. Apart from yellowing, other changes in properties can also occur after extended exposure to high temperatures. However, yellowing is the first in transmission or the gradual appearance of a cloudy haze, occur only after even longer exposure to heat. Nonetheless, the mechanical properties such as good impact strength still remain at a high level, even after an extended period.

Makrolon® polycarbonate drives innovation in a thick light

General Motors Company (GMC) wanted to achieve a unique, crystal-like effect for the light bar component of its 2019 Sierra 1500 LD truck headlamp. GMC teamed up with Valeo Lighting Systems and Covestro to bring this design to life, using a tailor-made color and highly transparent polycarbonate from Covestro.



Task: Create a light bar with a sculptured crystalline appearance

GMC, Valeo and Covestro collaborated to create an advanced light bar design for the headlamp, which features a larger and brighter daytime running lamp for improved visibility in clear or inclement weather. In addition to improved safety, the thick light bar also allowed GMC to create a unique brand differentiation for the vehicle. Non-standard, multi-shot thick molding, tooling and processing were instrumental for achieving the light bar's unique styling and functionality.

Challenge: Achieve unique crystalline aesthetics with minimal shrink and warpage

The team aimed to design a light bar that looks like crystal, with low yellowness after a long life cycle. With the part's large, complex shape, the tooling needed a modified surface and special ejection design to properly eject the thick light bar. Since there was a risk of high stress in the part, dimensional accuracy and warpage were also areas of concern.

Why Makrolon® LED2245 polycarbonate was the right solution for the light bar

- **Good optical quality** offers high optical clarity in extremely thick cross-sections.
- **Unique aesthetics Custom color development** enables crystal-like appearance and effects.
- **Dimensional accuracy** maintains the desired size with minimal shrink and warpage.
- **Replicated micro-optics** enables replication of micro-optic surfaces.

"Automotive lighting plays a dual role, contributing to a vehicle's safety and its distinctive styling. This light bar illustrates how using Covestro materials can create new opportunities to enhance both of these important aspects."

Michael George/Polycarbonates Market Manager, Lighting Covestro

Solution: Makrolon® LED2245 illuminates the road ahead

To meet color and optical clarity requirements, **Makrolon® LED2245** polycarbonate from Covestro was manufactured using a different process than standard polycarbonate. As a result, this grade offers high optical clarity in extremely thick cross-sections and provides crystal color development to reduce the yellowness that often occurs in traditional, unlit thick polycarbonate parts. Additionally, Valeo used a proprietary molding process for a low-stress part with high clarity and minimal shrink and warpage.

Decorative and functional colored parts

Color the light the way you like it:

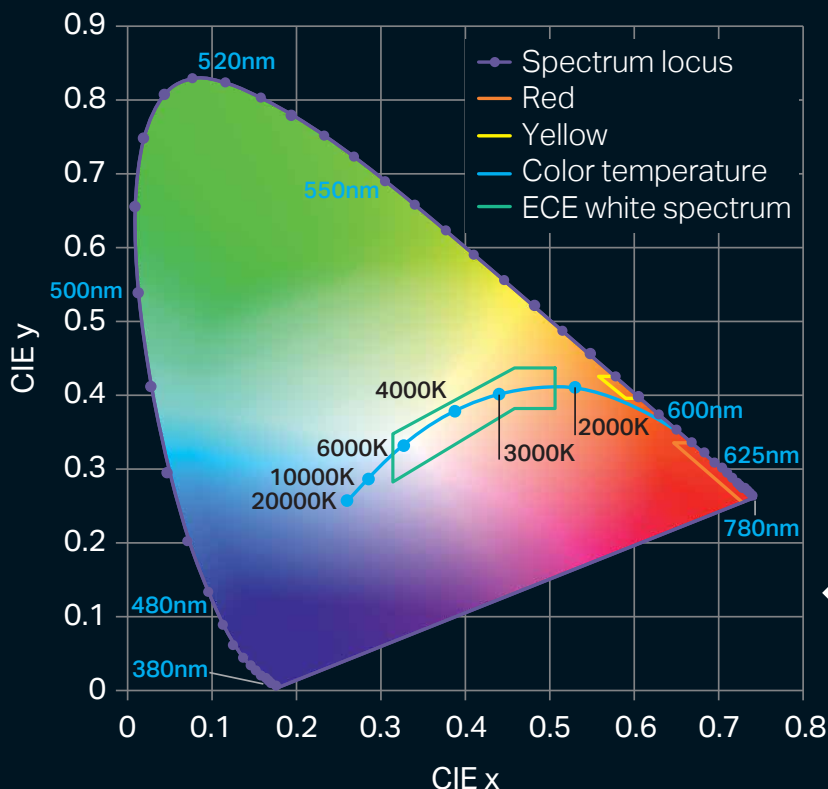
Makrolon® is available in signal colors and a variety of additional transparent colors.

Transparent signal colors have been used for many years in various applications such as automotive lighting, signal transmitters and signal lights. Furthermore, thanks to its excellent mechanical properties and very high heat resistance, **Makrolon®** is qualified for automotive applications including turn signals, daytime running light, rear lights, traffic lights and warning lights on emergency vehicles.



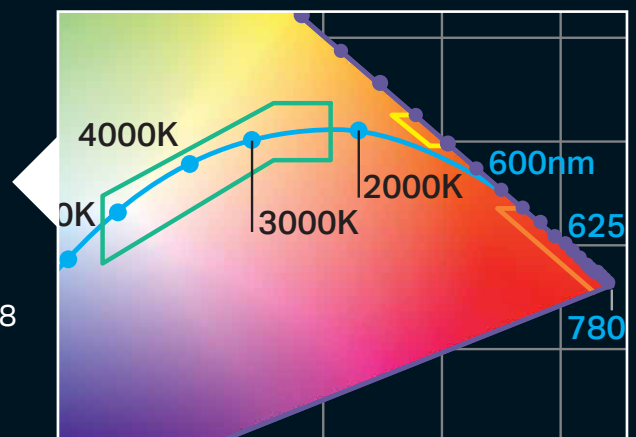
As a safety and communication tool, these colors are subject to strict requirements in terms of accuracy and stability. Whether in standard colors such as yellow for turn signals, red for taillights, or in new requirements such as turquoise for autonomous driving, our competence in colors ensures that all requirements will be met. All current colors are AMECA and ECE compliant, and future colors will be developed to meet current legal standards.

Beyond signal colors, **Makrolon®** offers a rich spectrum for design and branding themes. Ask our experts and color competence team to meet your specific color request in a high purity **Makrolon®** to suit your optical application.



CIE 1931 (2° observer)

shows the current range of signal colors in accordance with the standard specifications in the CIE chromaticity diagram. Some of the typical signal colors – white, yellow and red – are shown in the diagram to illustrate the large number of signal colors available.*



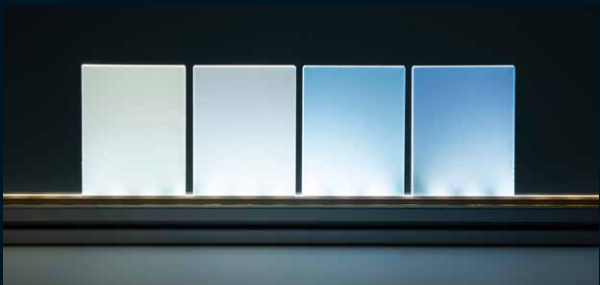
Decorative and functional colored parts

Shape the light the way you like it:

Makrolon® LED2245 EL offers functional colors for illuminated surface applications.

In addition to the many possibilities of color design of a component, there is also the need to shape the light in a component so that there is, for example, a uniform illumination area without a recognizable origin of the light source. Our edge lighting colors are among these special functional colors.

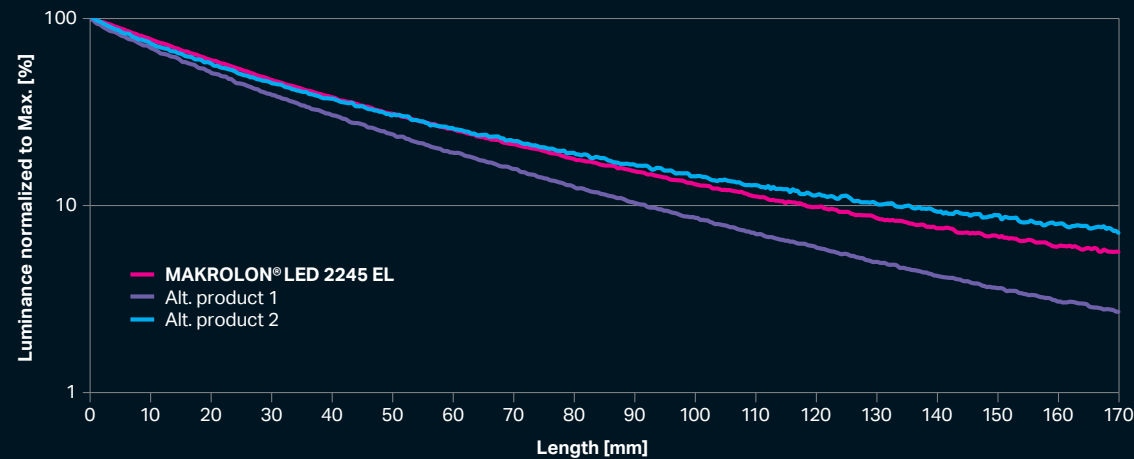
Makrolon® LED2245 EL offers a translucent effect under LED light with optimized transparency, giving more freedom of design.



The material has a high transparency with minimal haze in the non-illuminated state, which can also be used for optical applications. If light is coupled to one edge of the component, the entire surface lights up translucently. LED2245 EL is available in different color impressions from warm white to cold white:

Materials	Colors	MVR (300°C, 1.2 kg) cm²/10 min	Haze	Transmission (%)	Key properties
Makrolon® LED2245 EL	021760	34	3	88	Edge light effect, warm white
	021769	34	3	86	Edge light effect, cool white
	021754	34	6	85	Edge light effect, warm white
	021767	34	6	85	Edge light effect, cool white

Optical properties (4 mm)
and color impression of
Makrolon®LED2245 EL.*



Luminance compared to alternative products
Luminance of the luminous surface as a function of the distance to the light source (light coupling at a plate edge).*



Light shaping applications based on material solutions for reflective parts.

Beneath the characteristic transparency of **Makrolon®** which offers multi-application benefits for lighting, **Makrolon®** also offers a variety of possibilities for directing and shaping light in non-transparent versions. In reflective applications, **Makrolon®** RW offers diffusive potential while **Makrolon®** DS is focused on imaging reflection.

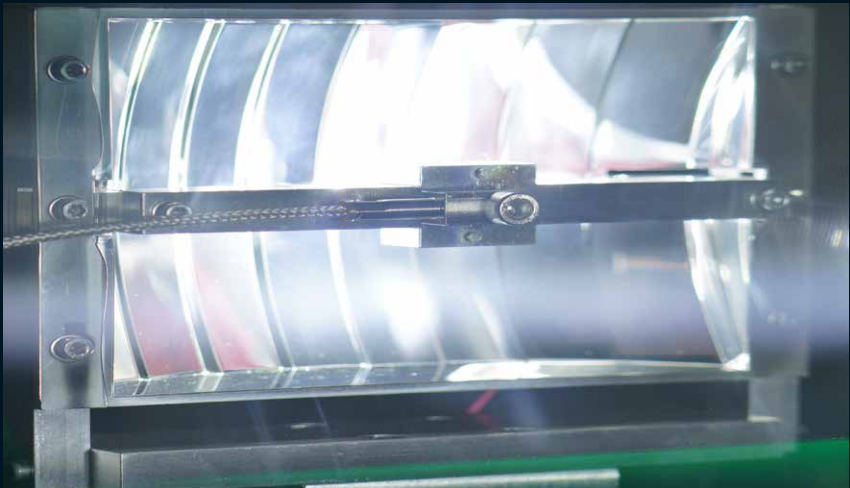
Makrolon® RW enables the shaping of a diffusive reflector where both high reflection and uniform light distribution are needed, allows it without additional processing steps.

Makrolon® DS is a highly filled product. In combination with variothermal injection molding, it offers a high quality surface in combination with high dimensional stability, making it a good solution for items such as imaging reflectors that require a precise light pattern under widely varying temperatures.

Imaging reflectors:

Precise and stable light pattern independent of temperature.

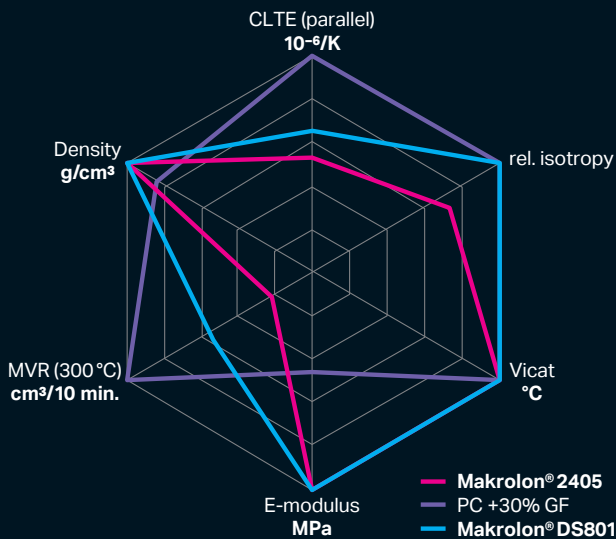
Makrolon® DS offers dimensionally stable (low isotropic CLTE) properties at a wide range of temperatures. Headlamp reflectors are growing more complex and miniaturized, as is the case with multi-cavity reflectors. An intelligent combination of innovative processes and suitable materials can give you the opportunity for flexible and efficient production.



Makrolon® DS801 Development Demonstrator suitable for full headlamp light pattern, stable under varied temperature conditions.

Makrolon® DS offers high dimensional stability at temperatures up to 120 °C, making it suitable for precise light-pattern reflectors. The material offers excellent surface quality via variothermal heating in addition to low isotropic coefficient linear thermal expansion (CLTE) values. It can be metalized through a sputtering process. Ask us for high-temperature or improved CLTE versions!

Materials	MVR	Key properties
Makrolon® DS801	10	Mineral-filled polycarbonate with low (isotropic) CLTE

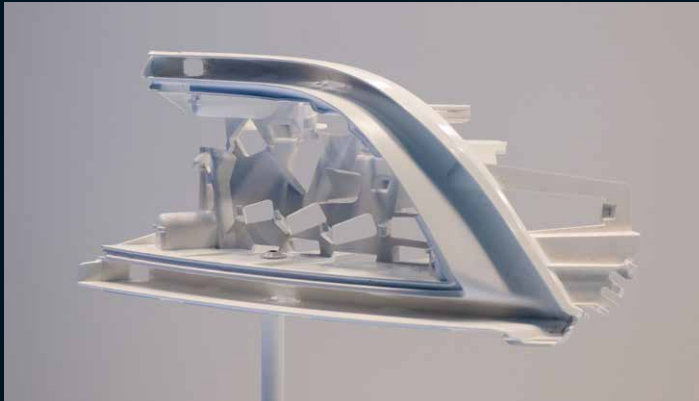


Properties of **Makrolon® DS801** compared with unfilled and fibre-filled polycarbonate.*

Diffuse reflectors

High luminous efficiency with uniform light distribution

Makrolon® RW offers reflectivity up to 97% combined with excellent light blocking and impact resistance.



Characterized by their high efficiency in diffuse reflecting visible light, high-reflectance white **Makrolon®** grades are noted for their increasing application as raw materials for LED rear lamp reflectors and similar components.

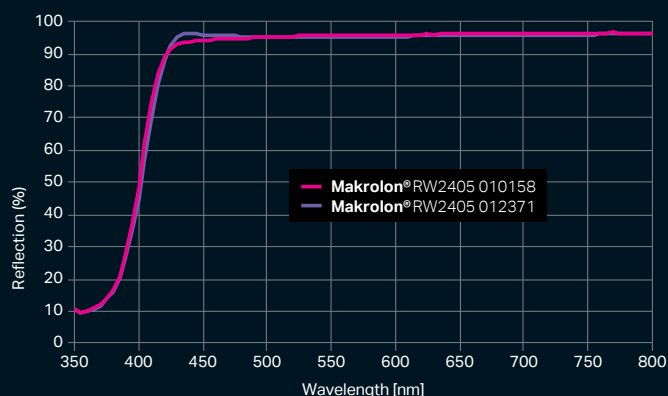
Makrolon® RW offers highest diffuse reflectivity, up to 97% total reflectance, together with excellent light blocking properties, which make it suitable for non-metalized reflectors and other decorative parts inside headlamps and rear lamps.

We offer several reflective white colors with a range of color impressions and light blocking properties. The graph in the lower left corner shows the reflectance spectra in the visible range of two representative colors.

Also available as **APEC®** grades for high temperature applications.

More information about this material is available upon request.

Materials	MVR (300°C, 1.2 kg) cm ³ /10 min	Key properties
Makrolon® RW2405	19	High melt-flow reflective white polycarbonate
Makrolon® RW2407	19	High melt-flow reflective white, UV-stabilized polycarbonate
Makrolon® RW5181	26	Improved melt-flow with increased Impact resistance



Reflection of **Makrolon®** RW colors at different wavelengths.*

Color	Thickness [mm]	Rest transmission % (D65 10°)	Reflection % (D65 10°)
010158	0.5	1.15	96
	1	0.25	96
	2	0.02	96
	3	< 0.01	96
012612	0.5	0.02	87
	1	< 0.01	87
	2	< 0.01	87
	3	< 0.01	87

Example of reflectance and transmission values of different thicknesses for two selected colors.

Mono-material headlamp concept

Reimagining automotive forward lighting with polycarbonates.

When it comes to materials and technologies for future auto lighting, Covestro is driving ahead of the curve, developing a functional headlamp concept to illustrate how polycarbonates enable functional and aesthetic benefits. This visionary approach can also reduce weight, space and cost while offering greater sustainability.



Part consolidation: less is more:

Traditional headlamps are complex, usually incorporating dozens of components and screws. Covestro advocates a forward-looking approach to forward lighting, with a headlamp module concept comprised of a reflector/housing, collimator lens, bezel and outer lens cover that results in significantly fewer parts.

Multi-shot molding of **Makrolon®** TC629 thermally conductive polycarbonate and **Makrolon®** DS801 dimensionally stable polycarbonate, along with a molded-in-place design strategy, enable the low- and high-beam LED modules and their corresponding reflectors to be

produced less expensively through the elimination of added heat sinks, attachments and other components. The bezel of **Makrolon®** polycarbonate uses multi-shot molding to consolidate turn signals and daylight running lamps, while also hiding sensors behind a LiDAR-transparent mask. Beyond reducing system complexity and costs, simplifying assembly and saving valuable space, this novel approach also reduces headlamp weight, which improves fuel mileage while lowering emissions or increasing battery range.



Mono-material headlamp concept

Integrating electronics:

Future automotive headlamps will integrate electronics such as LiDAR, radar and cameras in addition to light sources. This will require the use of thermally conductive materials to dissipate the heat generated by the electronics and light sources.

The headlamp demonstrator is the first of its kind to work with **Makrolon®** TC629 polycarbonate.

The low- and high-beam reflectors utilize **Makrolon®** DS801 polycarbonate for highly efficient reflectivity of visible light. The reflectors can be molded directly into the **Makrolon®** TC629 polycarbonate housing with multi-shot molding and vario-thermal mold control techniques. This eliminates the need to attach the reflector with brackets and fasteners, contributing to lightweighting.

The **Makrolon®** DS801 polycarbonate material provides a metalizable, smooth surface finish similar to unfilled polycarbonate and can enable greater lumen output compared to other systems. In fact, the single, metalizable component yields a beam pattern performance that remains stable throughout the operating temperature of the LED lamp system due to its low, isotropic thermal expansion.

The bezel is a three-shot molded part with **Makrolon®** LED2445 in both amber color for the turn signals and a diffusion color for the DRLs, coupled with **Makrolon®** ST sensor transparent polycarbonate. The bezel hides advanced driver-assistance systems (ADAS) sensors and consolidates daytime running lights (DRLs), turn signals and pedestrian communication lighting into a single part. The bezel blends cutting-edge performance and aesthetics, including a "dead front," seamless appearance, a high gloss finish enhanced with laser-etched effects, and diffused back-lighting for safety and signature lighting.

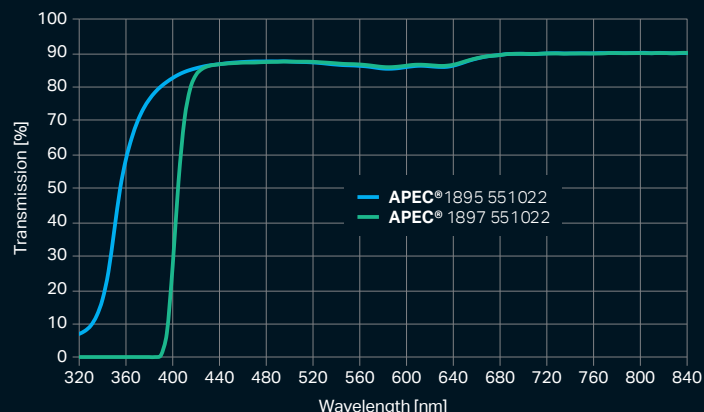


Beat the heat in lighting applications:

Apec® offers high-temperature resistance.

Apec® offers elevated short-term thermal resistance and good optical transmission which is suitable for items like fog lamp outer covers, optics and lenses. It features good outdoor weathering performance, and in combination with a coating system, offers AMECA and ECE approvals.

Apec® is the brand name for co-polycarbonates that constitute a further development of **Makrolon®** polycarbonate. Its unique combination of toughness, transparency, light stability, flowability, and its high heat resistance – which can reach 203°C (VST/B 120) – make **Apec®** ideal for molded parts that are subject to pronounced thermal stressing that general-purpose polycarbonate cannot cope with.



Transmission spectra of **Apec® 1895 551022** and **Apec® 1897 551022** (4mm).*

The variable composition of the Apec® grades is reflected by their refractive index (Fig. 23). As the bisphenol TMC content rises (rising heat resistance), the refractive index drops.

	Very high-flow Apec® grades	High-flow Apec® grades				High-viscosity grades	
Properties*	Apec® 2095HF	Apec® 1695/1697	Apec® 1795/1797	Apec® 1895/1897	Apec® 2095/2097	Apec® 1703	Apec® 1803
Crystal-clear color	551022	551022	551022	551022	551022	551022	551022
Vicat temperature (50N 120 K/h ISO306)	203 °C	158/157 °C	173/172 °C	183/182 °C	203/202 °C	171 °C	184 °C
Transmission Ty ³⁾ (1 mm DIN5036-1)	89%	89%	89%	89%	89%	89%	89%
Refractive index nD (ISO489A)	1.566	1.578	1.576	1.573	1.566	1.578	1.573
Abbe number	30	30	30	30	31	30	30
RTI relative temperature index (static yield stress) (UL 7468)	–	140/140 °C ⁵⁾	140/140 °C ⁶⁾	150 °C	150 °C	140 °C	150 °C
UV protection	no	no/yes	no/yes	no/yes	yes	yes	yes

5) Expected RTI

6) Typical value, no specification

Typical values and properties of Apec grades.

Apec® grades are frequently used in **Makrolon®** applications where elevated temperatures occur, particularly in automotive lighting. More detailed information is available in our Apec® brochure.

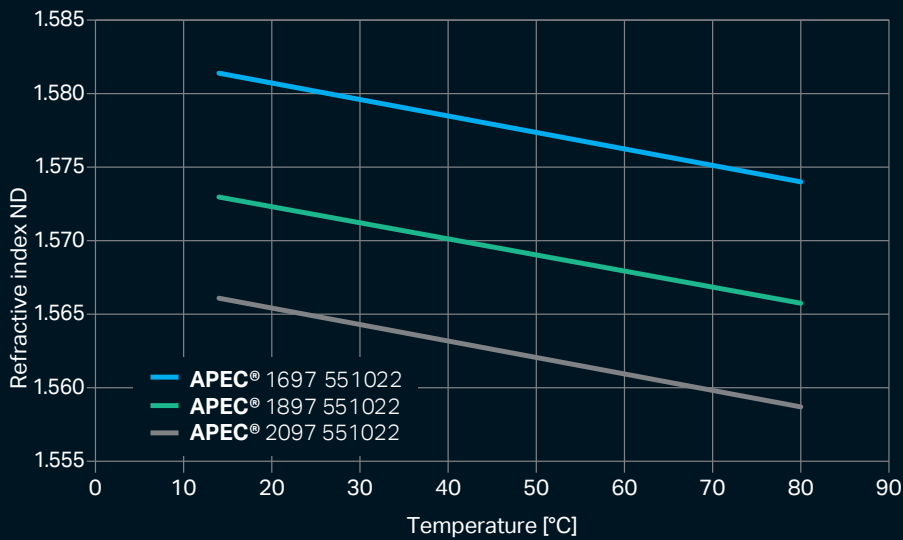
High temperature applications

Apec® offers outstanding transparency and brilliance paired with a high resistance to heat.

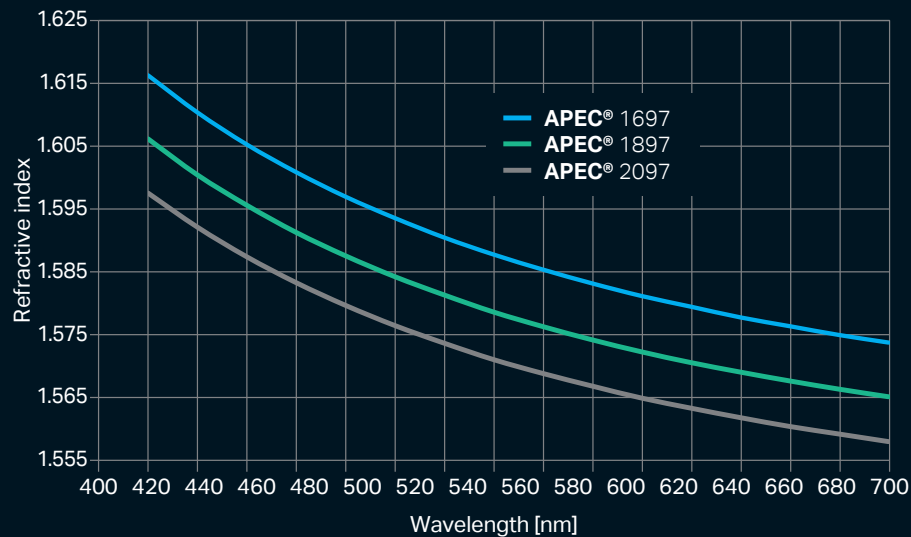
The dispersion of the refractive index is similar to that of **Makrolon®**, but shifted as a function of the bisphenol TMC content.



Internal lens which can be made from Apec



Refractive index nD as a function of temperature*



Refractive index as a function of wavelength*



Covestro – leading in polymer materials.

Covestro creates materials the world relies on every day. Our high-tech polymers are used in nearly every area of modern life and in a wide range of industries: automotive, construction, healthcare, cosmetics, energy, electronics, sports and leisure.

But we don't just produce materials. Together with our partners and customers, we're taking big steps to tackle a fundamental challenge: shifting towards a Circular Economy. To achieve this bold goal, we're innovating efficient ways to close energy and material cycles, pushing the boundaries of what is possible with polymers.

We are a global partner with local production and customer support capabilities.

As the inventor of polycarbonates, Covestro has been one of the largest producers of these materials on a global scale for over 60 years. We operate around 30 production sites in Europe, Asia and America – eight of which have world-scale plants.



Innovation process:

Collaborative approach with our customers from the beginning on.

Definition of customer requirements

Distinctive and innovative automotive concepts.



Material and concept development

Specialized material solutions providing function integration and safety.



New application technologies

Optimized and highly integrated manufacturing process
Advanced processing support.



Material and concept development Scale up and customer production

Global competitive offerings
Comprehensive and competent product support.



YOU CAN'T TURN 80 YEARS OF EXPERIENCE INTO A FRESH PERSPECTIVE. WHY NOT?



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1) Please see the "Guidance on Use of Covestro Products in a Medical Application" document.

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