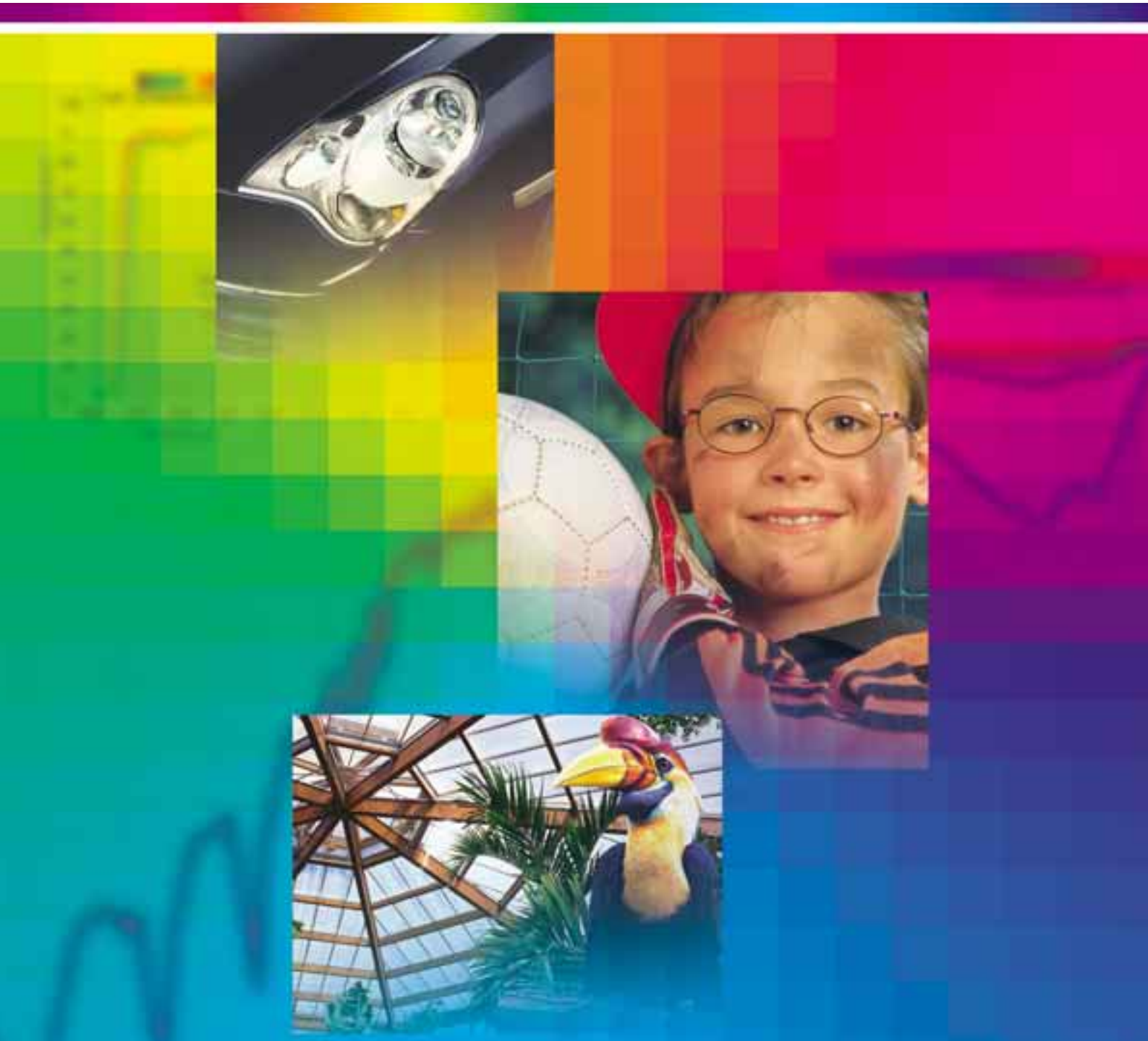
ATI 8043e Makrolon® /Apec®

Transparency and Color



Bayer

Makrolon® / Apec®
Transparency and Color

Bayer

Makrolon®/Apec®
Transparency and Color

Determination of optical data

Makrolon®

General purpose grades

Solid/multi-wall sheet

Automotive lighting

Optical lenses

Apec®

Colors

Signal colors

Translucent white colors

Color numbers of Makrolon and Apec grades for optical applications

BAYER makrolon®
High-tech plastic from Bayer

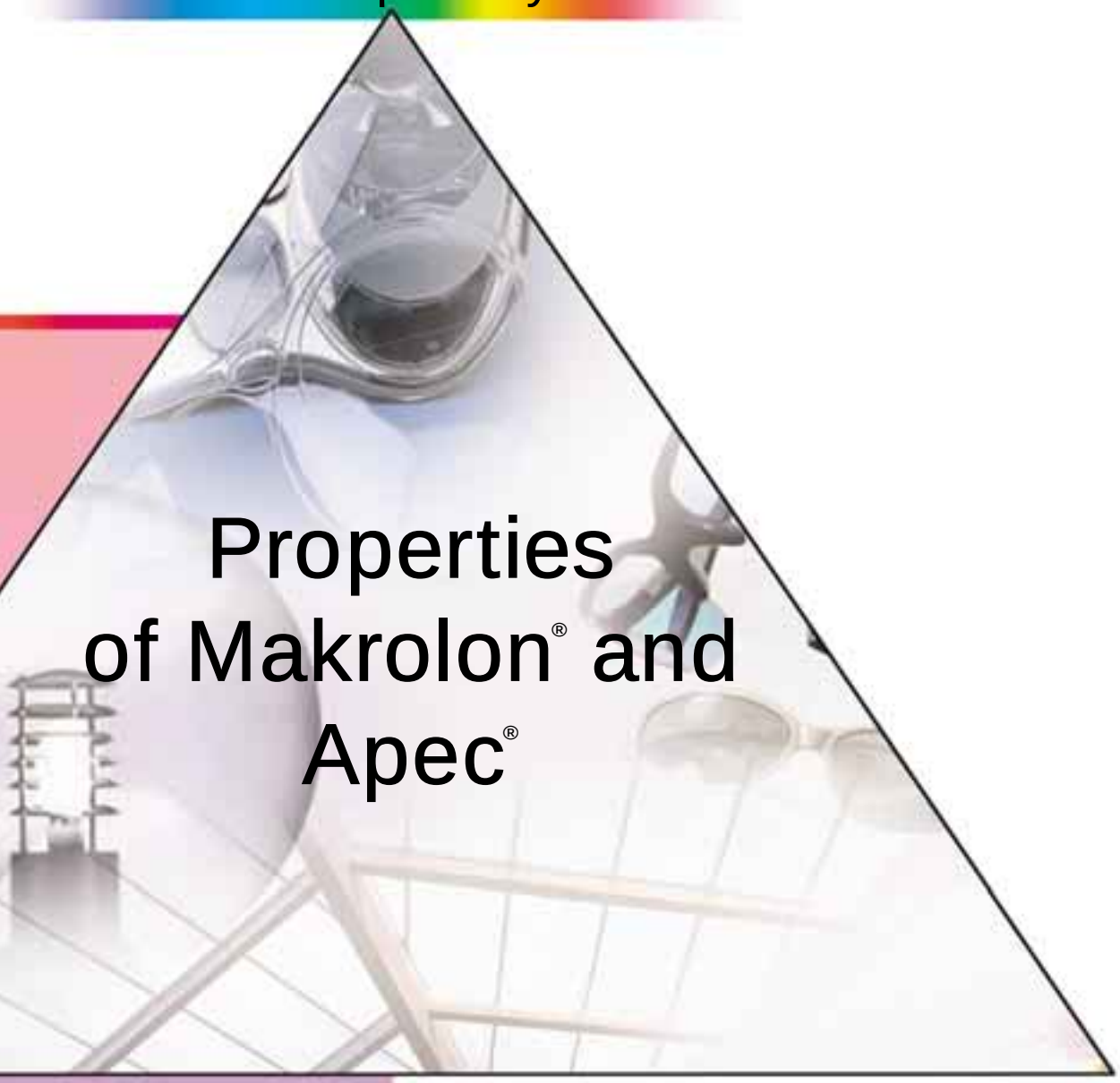
Makrolon®/Apec®

Makrolon and Apec are the trade names of polycarbonates manufactured by Bayer AG, Bayer Antwerp N.V. (Europe) and Bayer Corp. (USA). Makrolon is also a trade name of Bayer Polymers Co., Ltd. (Thailand).

Toughness

The key properties of Makrolon and Apec are transparency, excellent heat resistance and high toughness.

Transparency



Properties of Makrolon® and Apec®

Heat resistance

Determination of optical data

Optical properties of Makrolon® and Apec®

Makrolon and Apec generally transmit wavelengths in the 300-2500 nm range of the solar spectrum (Fig. 1). Their transmittance properties can be modified, however, by means of selective coloring or by using additives such as absorbing or scattering colorants to:

- block UV light in the 300-400 nm range
- induce selective transmission behavior in order to achieve a particular color effect
- create a high level of light scattering, e.g. for translucent white effects
- obtain a specific color range, e.g. for signal effects

Fundamentals

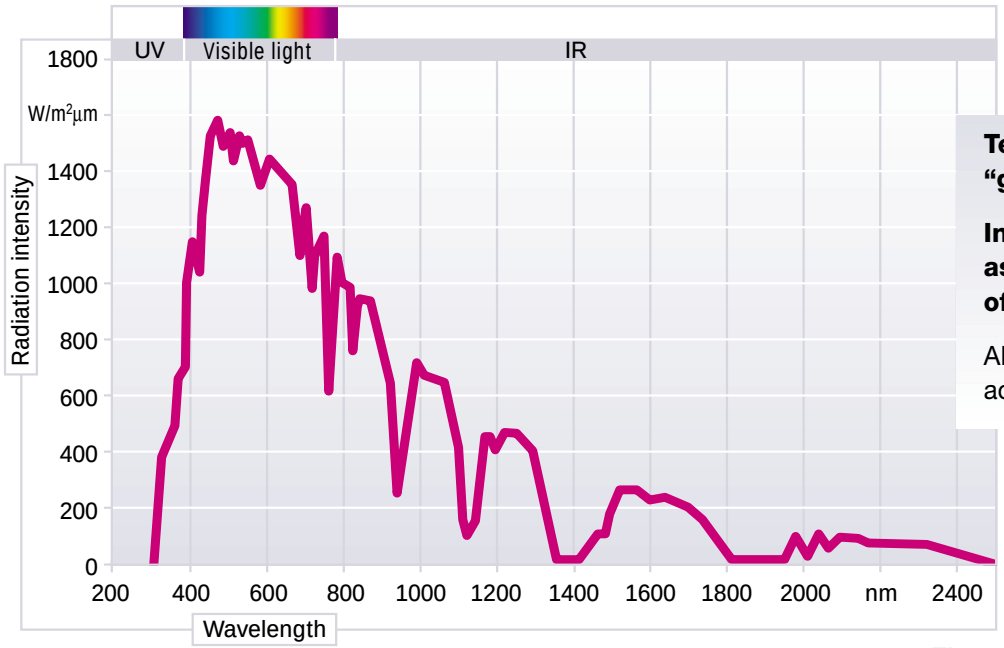
The **transmittance** values which are so important for these applications were obtained using a two-beam spectrophotometer coupled with a sphere photometer (Perkin Elmer Lamda 900). The measurements shown were recorded mainly in the 200-2300 nm range of the spectrum.

This measurement system registers all the radiation transmitted, including **directly transmitted** and **scattered** light. At the same time, however, the sphere photometer enables the direct and scattered components to be separated, values which can be used to calculate **haze**.

For transparent optical applications, haze is low. For translucent applications with significant light scattering, however, it is high.

From the transmittance values in the visible light range, it is possible to calculate the “tristimulus” values X, Y and Z of the color. In this brochure, Y represents **luminous transmittance**. In turn, the tristimulus values can be used to calculate the **yellowness index**, a measure of the tendency of a plastic to turn yellow upon long-term exposure to light.

The color of the samples is determined by their **color coordinates**. In the CIE chromaticity diagram, colors are represented by their x



Terrestrial solar spectrum “global radiation”

Intensity of radiation as a function of wavelength

AM 1.5 Global, according to Bird/Hulstrom

Fig. 1

Optical applications

and y co-ordinates, regardless of their brightness. Those colors located closer to the locus (edge) show greater saturation (see CIE chromaticity diagram shown in Figs. 24 and 25).

Two other important values for optical applications are the **refractive index** and the **Abbe value**. Both are determined using the Abbe refractometer and are temperature-dependent. **Gloss** describes the reflective properties of the surface.

Optical applications of Makrolon® and Apec®

Makrolon and Apec have excellent optical properties which meet the requirements of high-specification optical applications such as:

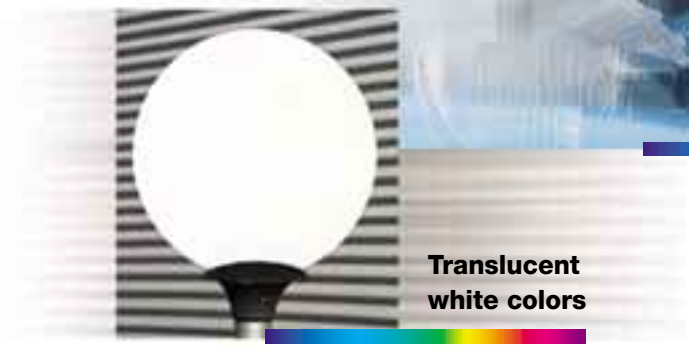
- Solid, multi-wall and corrugated sheet
- Automotive glazing
- Automotive lighting
- Optical lenses
- Use of signal colors

Use of signal colors

Solid, multi-wall and corrugated sheet

Optical lenses

Automotive lighting



Translucent white colors

Makrolon®

General purpose grades

The wide range of Makrolon grades is characterized by polymer chains of different lengths which result in a large selection of products with low-to-high viscosity. This has very little effect on the optical properties of the products, with the various grades having almost identical characteristic data.

The **transmittance** values are shown in Figs. 2 and 3. In the UV range, light up to a wavelength of 275 nm is completely absorbed. At longer wavelengths, transmittance then increases sharply, reaching a value of around 89 % at wavelengths of 400 nm, the start of the visible range, then remaining almost constant until the near IR range.

Luminous transmittance (Fig. 4) is dependent on wall thickness. The effect of the particular grade of Makrolon or the additives is negligibly small, however. At normal wall thicknesses of between 1 and 4 mm, more than 86 % of light within the visible range is transmitted by general purpose products.

Transmittance as a function of wavelength (200–2400 nm)

Makrolon ..05-, ..58-grades

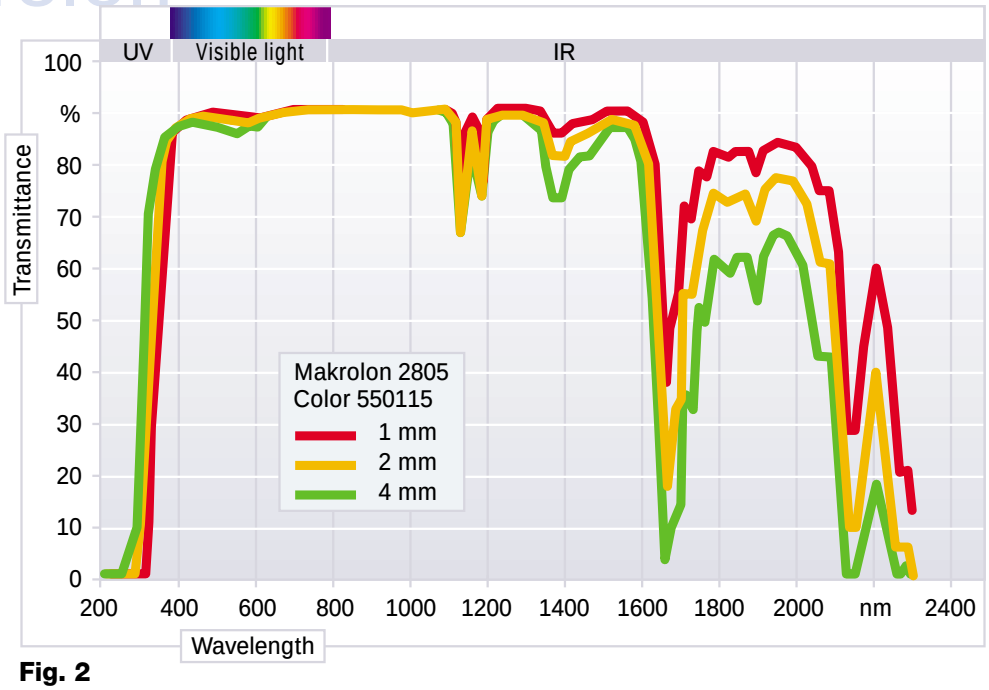


Fig. 2

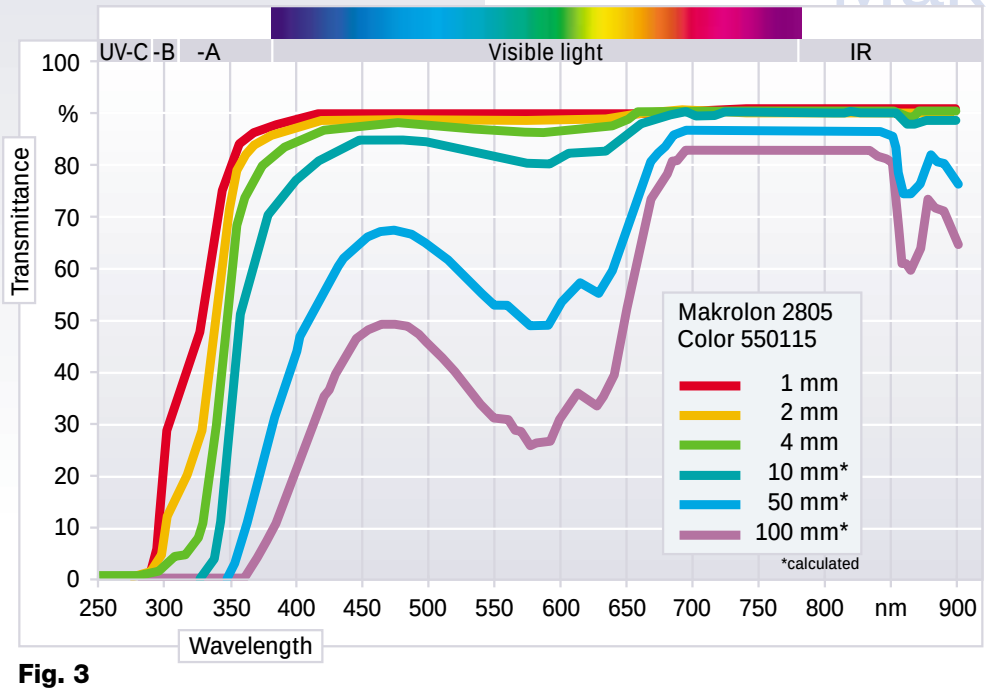


Fig. 3

Transmittance as a function of wavelength (250–900 nm)

Makrolon ..05-, ..58 grades

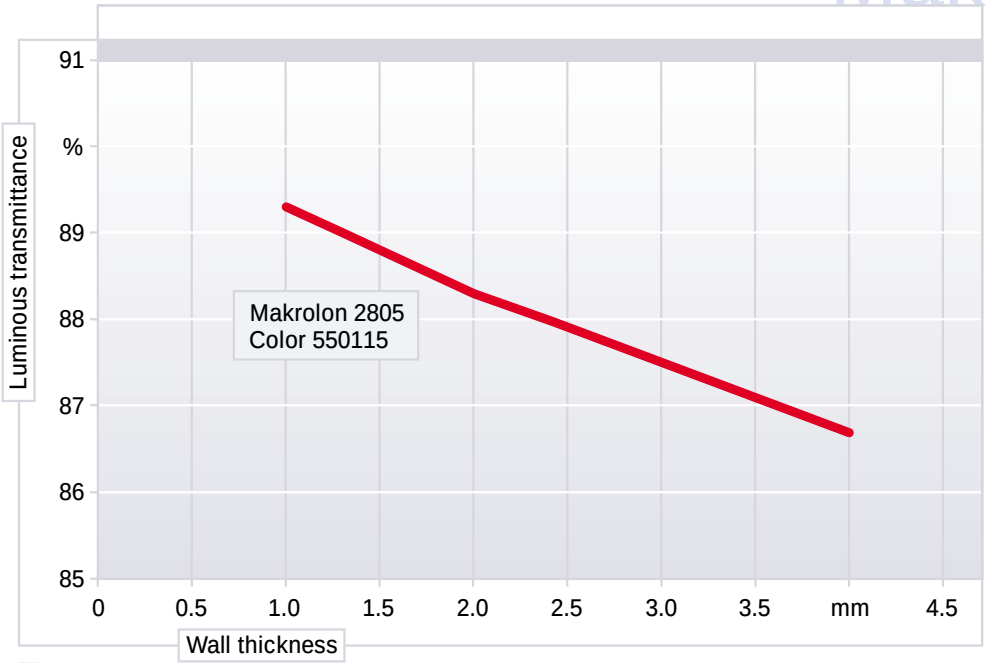
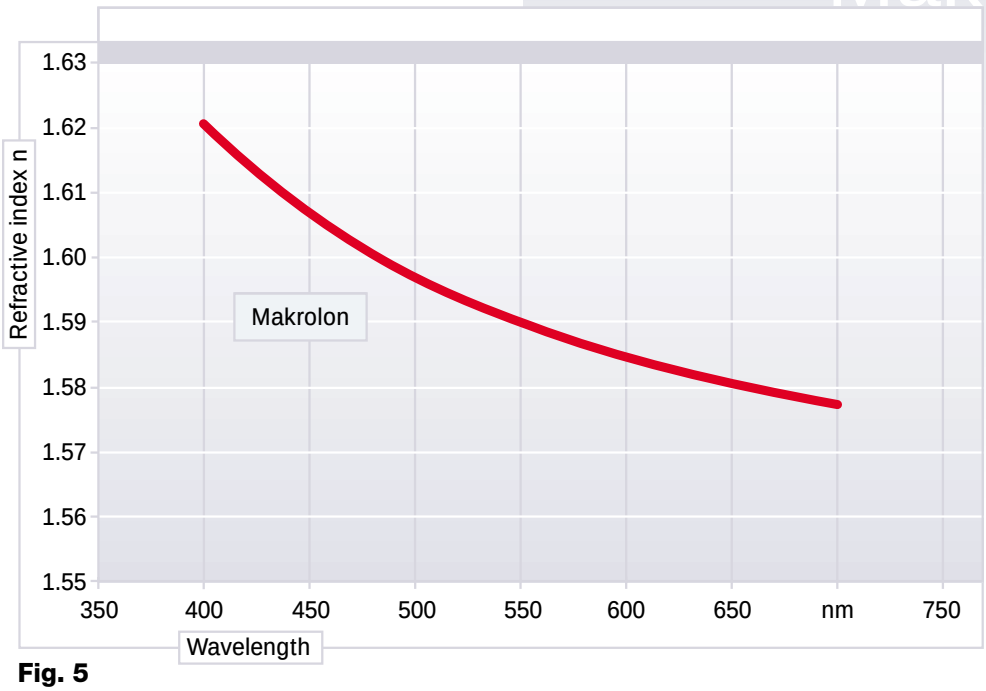


Fig. 4

Luminous transmittance as a function of wall thickness

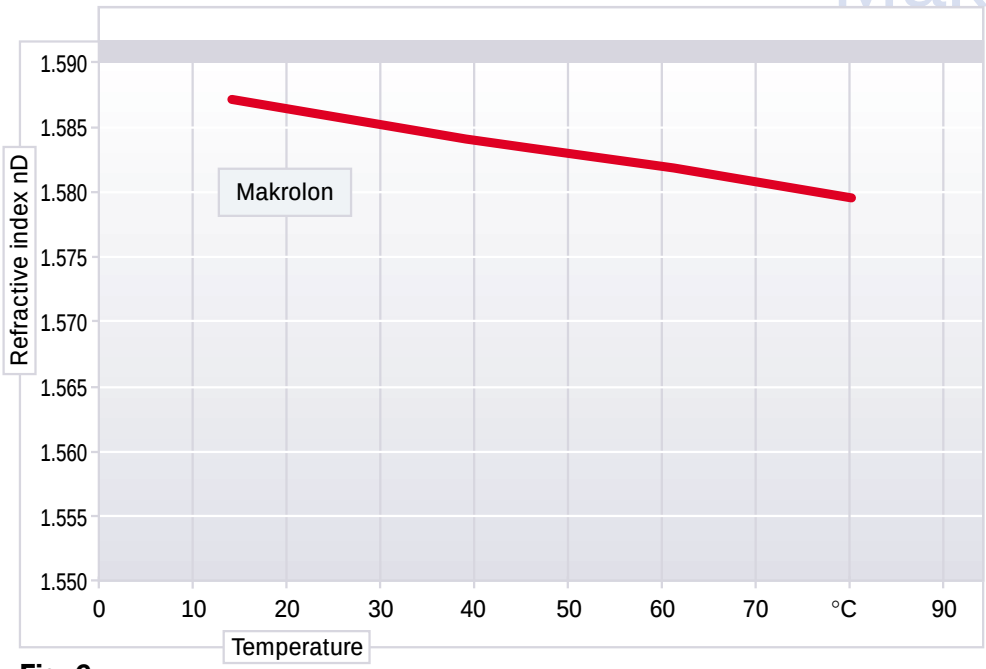
Makrolon ..05-, ..58 grades

Makrolon®
General purpose grades



Refractive index as a function of wavelength

Fig. 5



Refractive index – at 589 nm – as a function of temperature

Fig. 6

The **refractive index** nD for Makrolon® (measured at 589 nm/23 °C) is approximately 1.586. The viscosity of the Makrolon has very little effect on this value, which fluctuates within a range of around 1.584 to 1.588 (Figs. 5 and 6).

Makrolon is clear and transparent, with less than 0.8 % haze. It is not possible to differentiate between the different Makrolon grades in terms of either haze or **gloss** measurements. These values are heavily dependent on the surface finish of the molding. In other words, they are more a measure of processing quality.

With increasing exposure to UV light, either in the form of outdoor weathering or UV-emitting light sources, Makrolon gradually yellows, starting at the surface. With the passage of time, hairline cracks may form on the surface and a tendency to brittleness may develop. Where Makrolon moldings need to demonstrate high resistance to UV light and weathering, **UV stabilization** is therefore essential. The aging characteristics of the polycarbonate can be determined by monitoring changes in the yellowness index over time. The effect of appropriate UV stabilization is illustrated in Fig. 7 by a reduction in the increase in the yellowness index.

After 10 years of exposure to outdoor weathering in a Central European climate, UV-stabilized Makrolon moldings with a thickness of 4 mm can be expected to show a reduction in luminous transmittance of around 8 percentage points.

In addition to the standard range, special grades have been developed for specific applications:

- Makrolon LQ grades for optical lenses
- Makrolon LQ grades “UV 400 cut-off” for 100 % UV protection
- Makrolon AL grades for automotive lighting
- IR absorbers as additional protective filters for welding visors
- Makrolon in IR-transmitting colors for IR emitters and receivers
- Makrolon 1243 for multi-wall sheet and profiles
- Makrolon UV absorber concentrates for the coextrusion of Makrolon sheet
- Makrolon DP1-1265* and CD 2005 for optical storage media (DVDs/CDs/see ATI 8016)

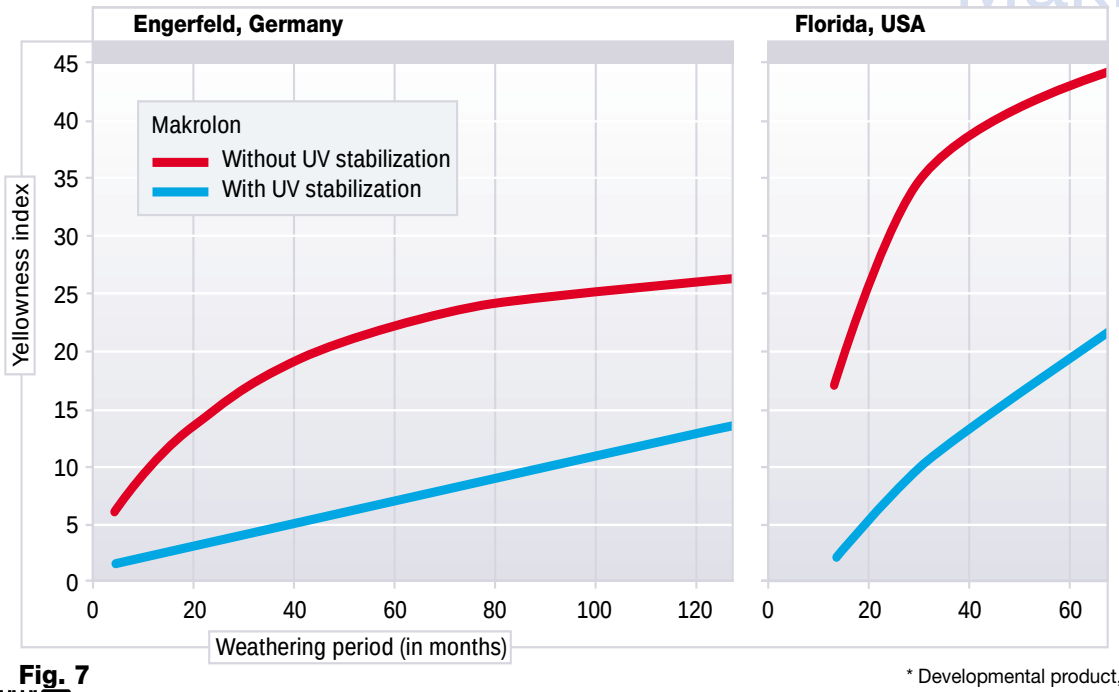


Fig. 7

Makrolon® with and without UV stabilization

Yellowness index as a function of weathering period

Outdoor weathering in Germany and Florida

* Developmental product, see back page

Makrolon® sheet

Makrolon sheet (Figs. 8 to 10) has excellent impact strength, high resistance to breakage, low weight per unit area and excellent heat resistance compared with other transparent materials. It also benefits from a good flammability classification and is very robust during transport and assembly.

The high transparency and excellent processing characteristics of Makrolon makes it possible to manufacture transparent **solid sheet** characterized by low optical distortion. **Multi-wall sheet** is also characterized by good luminous transmittance, although its structure prevents it from being completely transparent. On the other hand, it demonstrates even lower weight per unit area than solid sheet, as well as superior thermal insulation properties.

For outdoor applications Makrolon sheet can be specially protected against weathering to increase its service life. The conventional way of doing this all over the world is to use the **coextrusion process** with special Makrolon UV absorber concentrates. During this process, a thin, highly effective weather-protection layer which almost completely prevents yellowing is coextruded onto the sheet (Fig. 10). The special UV absorber concentrates needed for this are supplied by Bayer along with the relevant basic grades.

Major applications for Makrolon sheet include not only all types of roofing, but also break-resistant glazing (e.g. for machine guards) and noise barriers. However, Makrolon sheet is also used for windows or in do-it-yourself applications.

Glazing with Makrolon sheet can be found in industry, structural and municipal engineering (e.g. in factories and warehouses), in sports facilities, walkways, greenhouses and conservatories.

Automotive glazing made of Makrolon has to meet high standards in terms of visual appearance, mechanical strength, long-term resistance to weathering and scratch resistance. Because of its high resistance to breaking, it is safer than glass. It is also characterized by lower weight and offers greater design freedom. Scratch resistance and long-term resistance to weathering can generally be enhanced by coating the sheets with a thin, highly effective protective layer.

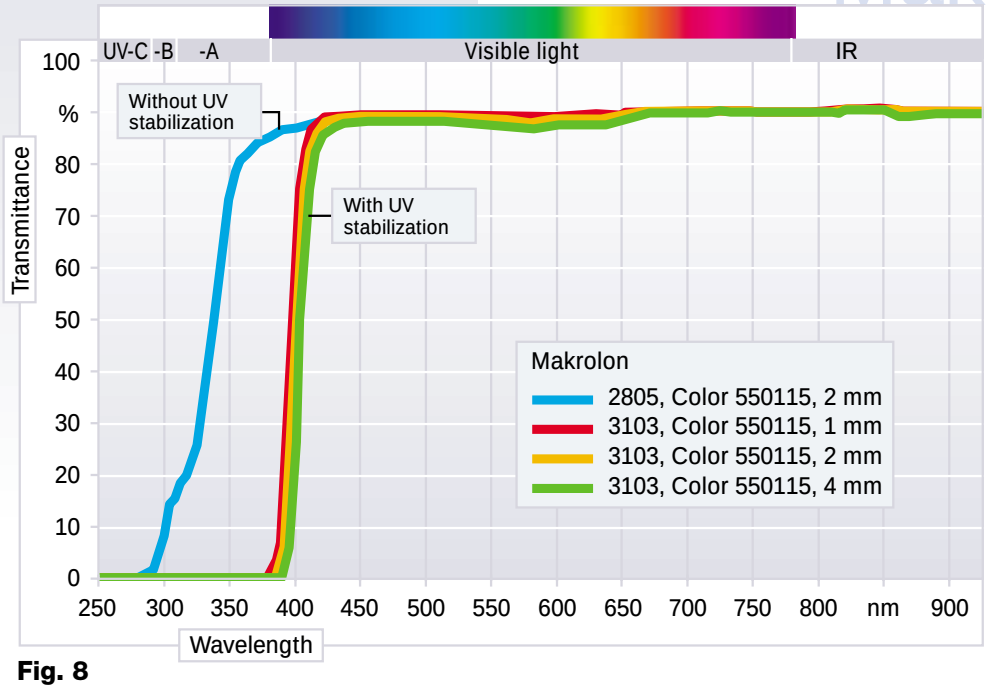


Fig. 8

Solid sheet

Transmittance as a function of wavelength

Makrolon 3103 and 1243

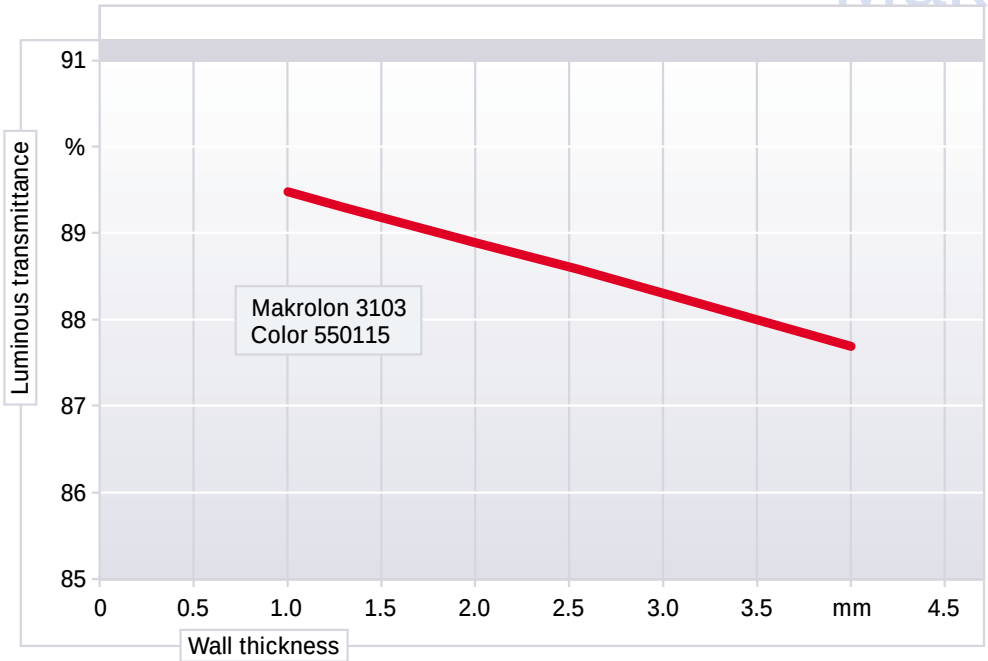


Fig. 9

Solid sheet

Luminous transmittance as a function of wall thickness

Makrolon 3103 and 1243

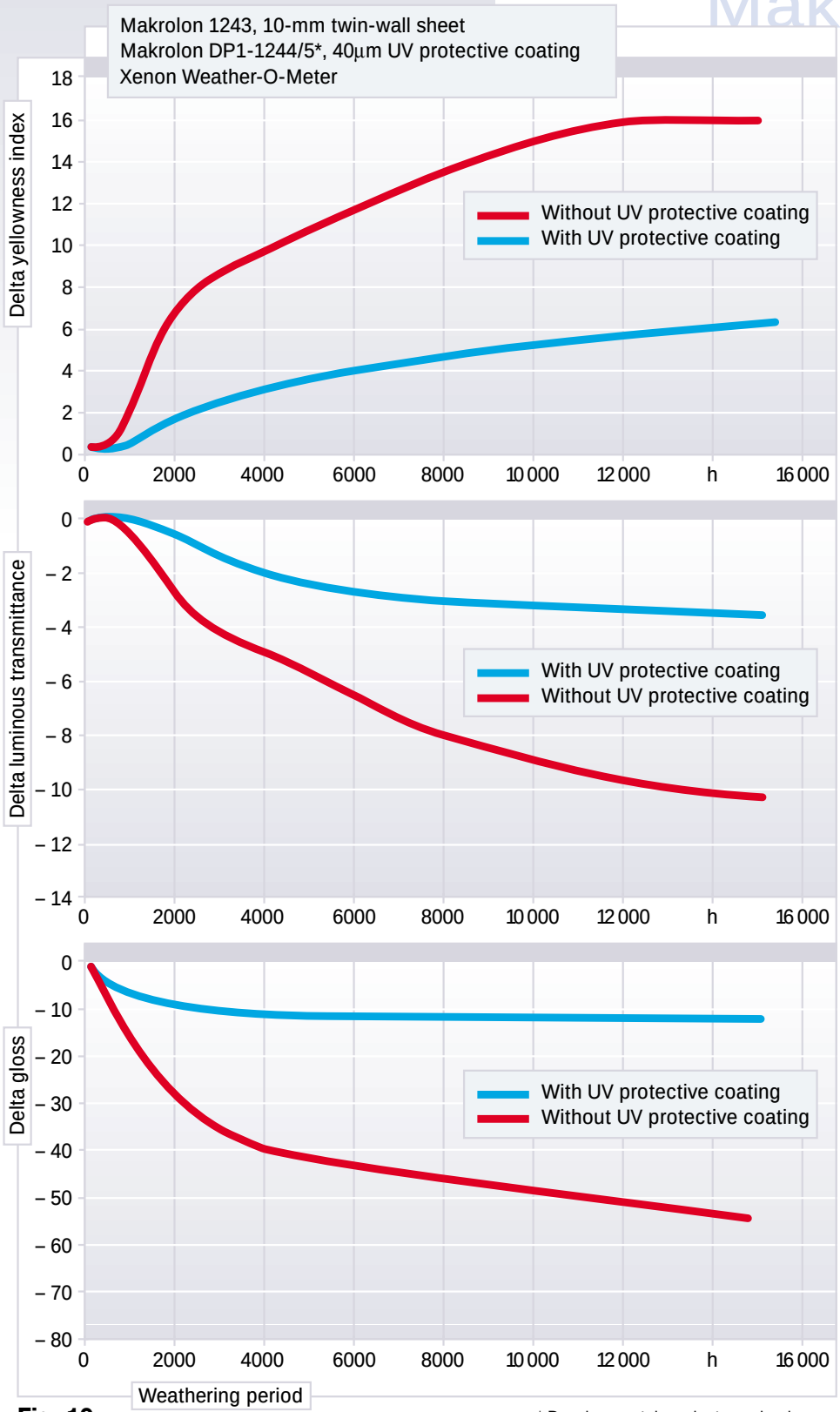


Fig. 10

Multi-wall sheet with and without UV-protective coating

Yellowness index, luminous transmittance and gloss as a function of weathering period

UV-protective coating:
Coextrusion, 40 µm
UV absorber concentrate
Makrolon DP1-1244/5*

Accelerated weathering:
Xenon Weather-O-Meter
(102:18)

Makrolon 1243 and
DP1-1244/5*

* Developmental product, see back page

Makrolon®
Automotive lighting

Plastic lenses made of Makrolon offer considerable advantages over glass, the conventional material, in terms of freedom of design and weight reduction along with high resistance to breaking.

In order to meet the high requirements for plastic lenses in terms of scratch resistance, long-term resistance to weathering and resistance to chemicals associated with vehicles such as fuel, brake fluid, coolant, etc. in accordance with current standards, the surface has to be treated with a scratch-resistant coating.

The Makrolon AL grades were developed specifically for this application. These are UV-stabilized and are characterized by good release properties and low or medium viscosity. All AL grades are manufactured on special production lines with higher specifications in terms of cleanness and purity.

Automotive lighting

Transmittance as a function of wavelength

Makrolon AL2447 and AL2647

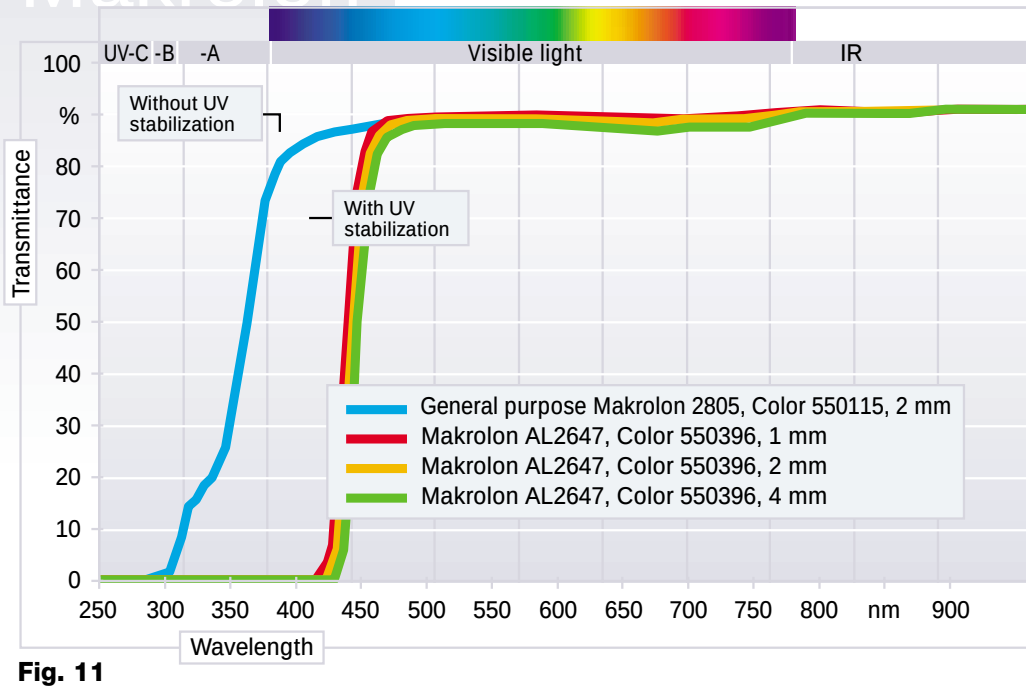


Fig. 11

Automotive lighting

Luminous transmittance as a function of wall thickness

Makrolon AL2447 and AL2647

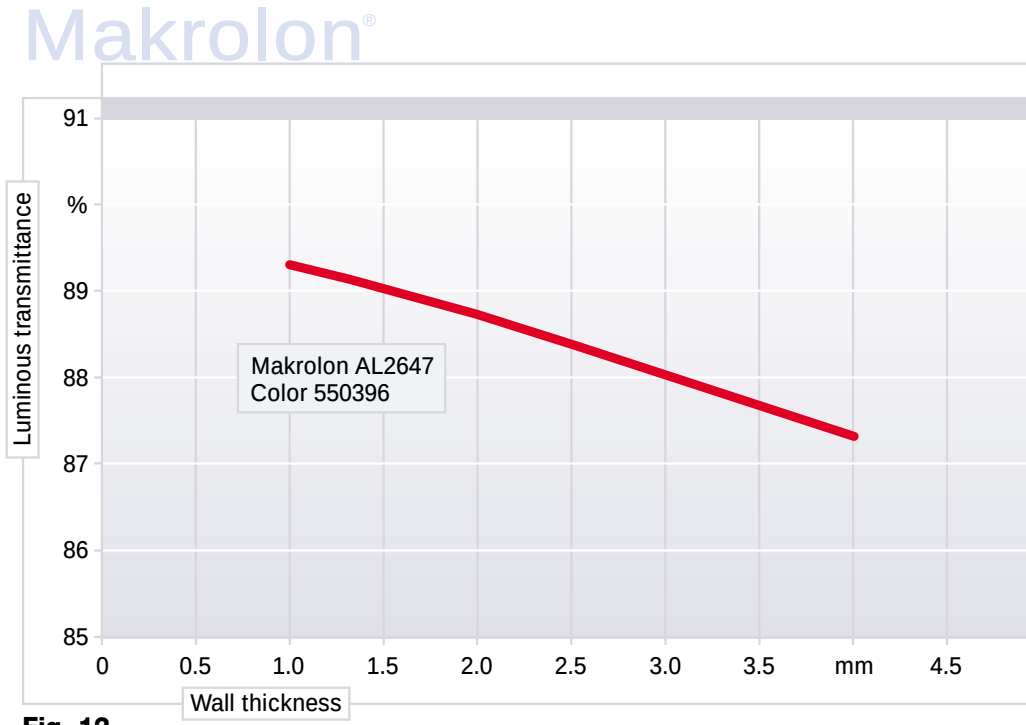


Fig. 12

Makrolon®
Optical lenses

Optical lenses

Transmittance as a function of wavelength

Makrolon LQ2647 and LQ3147

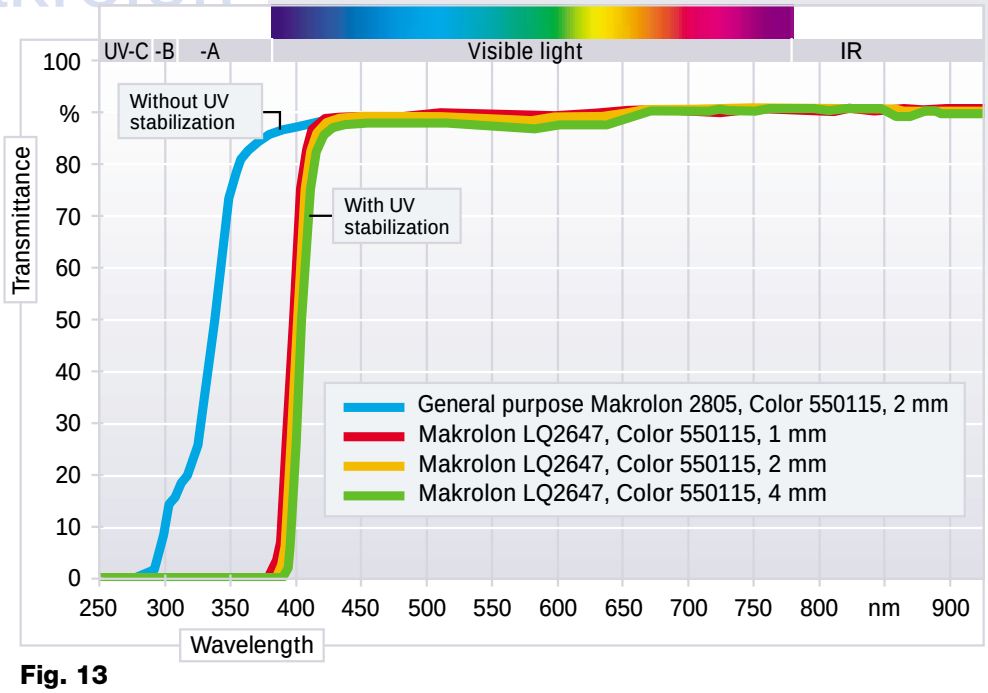


Fig. 13

Optical lenses

Luminouis transmittance as a function of wall thickness

Makrolon LQ2647 and LQ3147

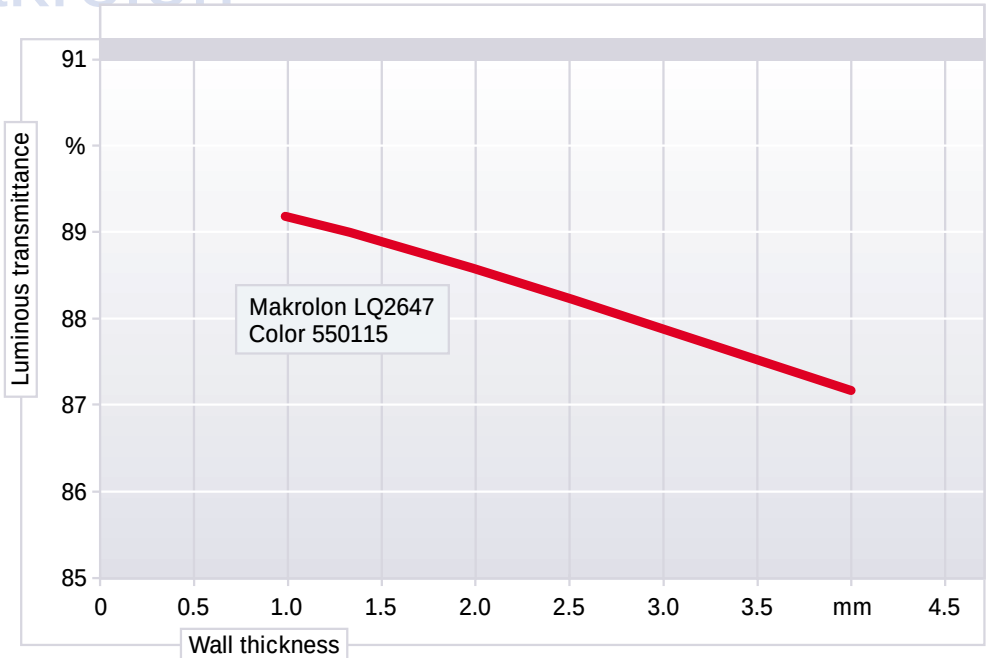


Fig. 14

LQ Makrolon® grades are also manufactured on special production lines. In the manufacture of optical lenses, there are also strict requirements in terms of **freedom from fish-eyes**. The products designed for this application are characterized by medium-to-high viscosity.

Makrolon LQ also has advantages over other lens materials in terms of mechanical strength and cost-effective thermoplastic processing as well as low weight. LQ grades are only available in a neutral, transparent color.

Makrolon lenses can be further improved in terms of scratch resistance, anti-fogging properties and anti-reflex properties by means of **surface treatment**.

	Makrolon LQ	Acrylate	CR 39 – ADC	Crown glass
Density (g/cm³)	**1.20**	**1.18**	**1.32**	**2.5**
IZOD notched impact strength based on ISO 180-A 3.2 mm thickness (kJ/m²)	**90**	**2**	**2**	**–**
Refractive index nD	**1.587**	**1.492**	**1.500**	**1.523**
Abbe value	**30**	**58**	**58**	**59**
Luminous transmittance 4 mm thickness (%)	**87**	**91**	**91**	**90**

Comparison of Makrolon LQ and other lens materials

Makrolon®
Optical lenses

For some applications (e.g. protective goggles), there is a need to inhibit the transmission of certain wavelengths. Transmittance properties can be modified with the selective use of additives.

- Makrolon LQ grades, with an absorption edge of 400 nm absorb all light within the UV range of the spectrum (Fig. 15). Lenses made of this material are used in applications such as sunglasses and protective goggles.
- Lenses for laser safety applications are also made out of Makrolon. They are colored to suit the type of laser. Transmittance can be set for partial or 100 % absorption.
- It is impossible to produce the large number of possible colors for sunglasses and laser safety goggles economically on our large-scale production lines. This is an area in which in-plant coloring by the customer has proven effective.
- Special color formulations have been developed for IR emitters and receivers, e.g. in remote control units. Depending on the applications, they transmit little to no light in the visible range but permit a high level of transmittance in the IR range (Fig. 16).
- In protective filters for welding visors, the protection levels can be set specifically in accordance with EN 169. Bayer supplies Makrolon in basic colors and the IR absorber. The various protection levels are set by the customer (Fig. 17).

With 100 % UV protection

Transmittance as a function of wavelength

Makrolon LQ2687 and LQ3187 "UV 400 cut-off"

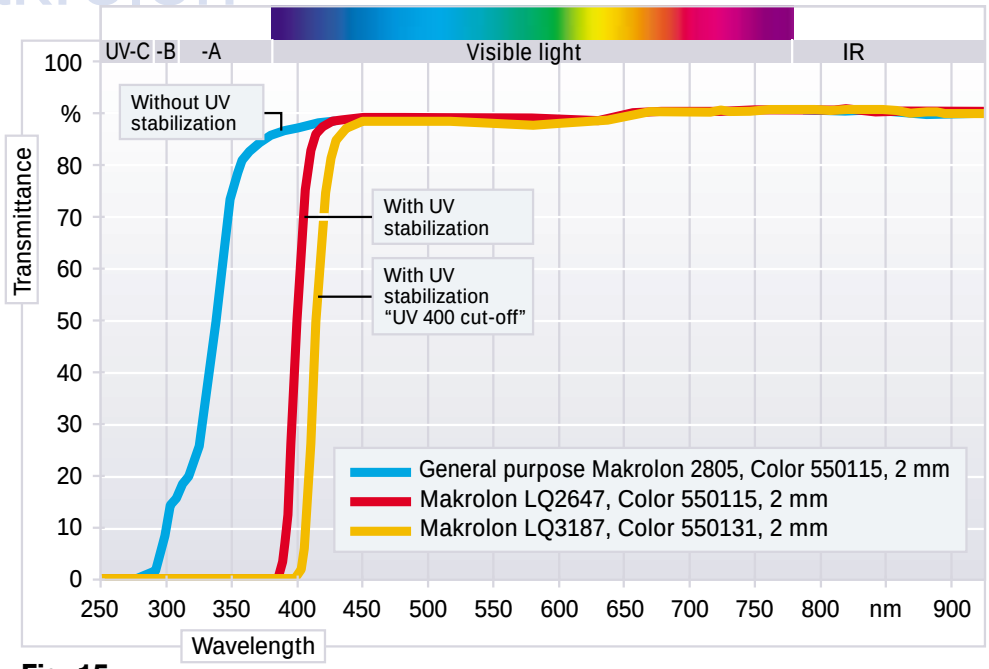


Fig. 15

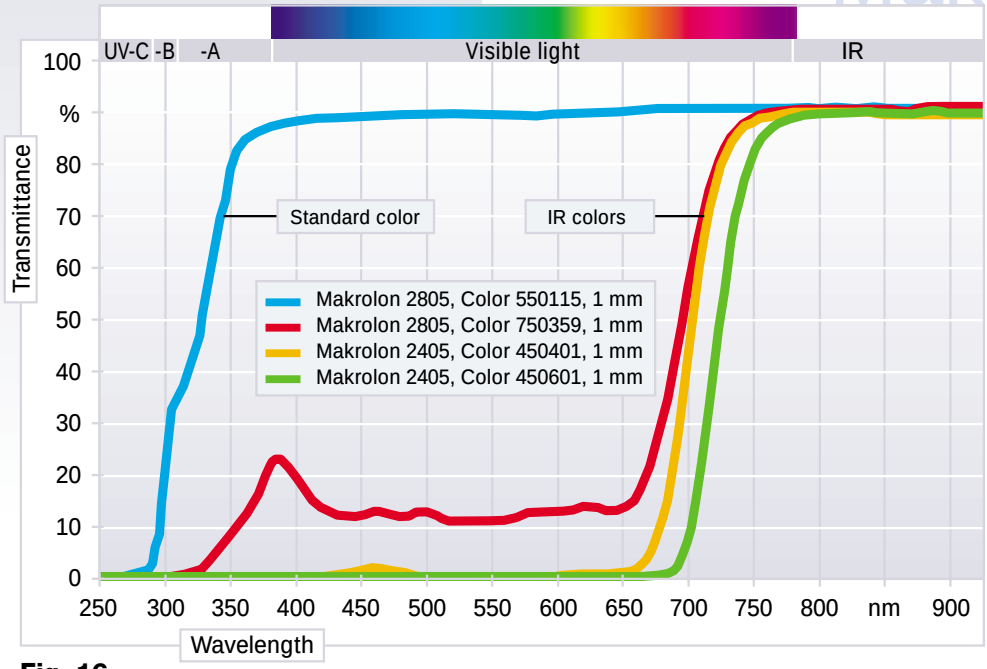


Fig. 16

In IR colors

Transmittance as a function of wavelength

Sample IR colors

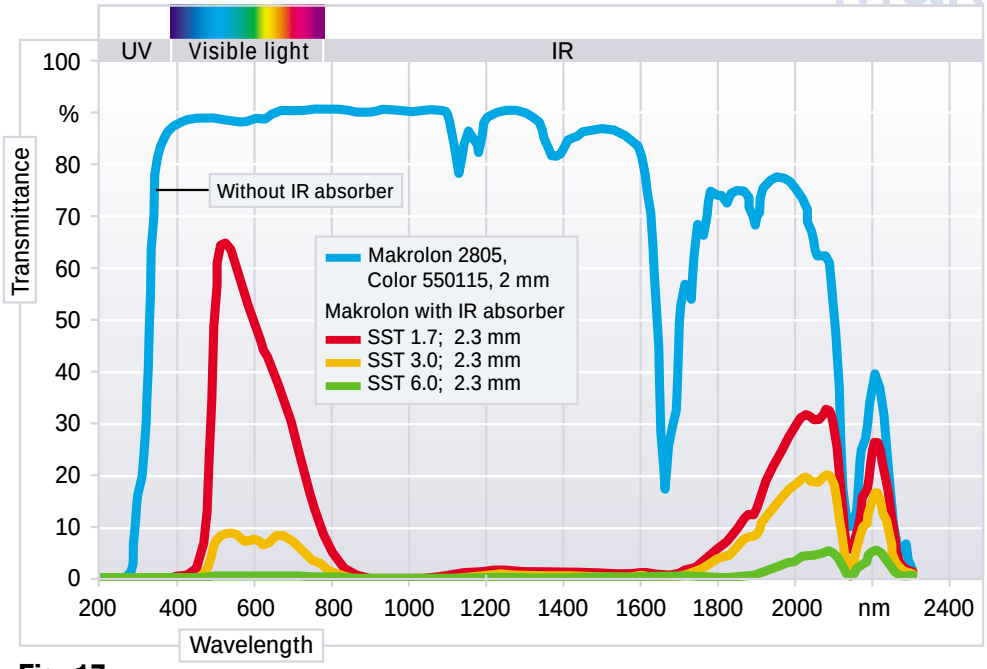


Fig. 17

With IR absorber

Transmittance as a function of wavelength

Sample welding protection ratings (SST)

Apec®

Apec is a material based on Makrolon® that offers even higher heat resistance. The copolycarbonate is made up of the Makrolon building block, bisphenol A, and bisphenol TMC. Depending on the proportions of the two components, products with heat resistance of up to 220 °C (Vicat softening point) are obtained.

The transmittance/luminous transmittance properties of Apec are similar to those of Makrolon (Figs. 18 to 20). The different composition of Apec grades is apparent from their refractive index values (Figs. 21 and 22). As the bisphenol TMC content rises (indicated by rising grade number), the refractive index decreases.

Apec grades are used in those Makrolon applications where higher temperatures occur, particularly in automotive lighting.

On September 1, 2001, major Apec grades were renamed as their status changed from developmental product to sales product.

The following table gives examples of this new naming system:

New	Old
Apec 1600	KU1-9331
Apec 1800	KU1-9351
Apec 2000	KU1-9371
Apec 1803	KU1-9353
Apec 1705	KU1-9341/5

Transmittance as a function of wavelength

Apec 1600, 1800 and 2000

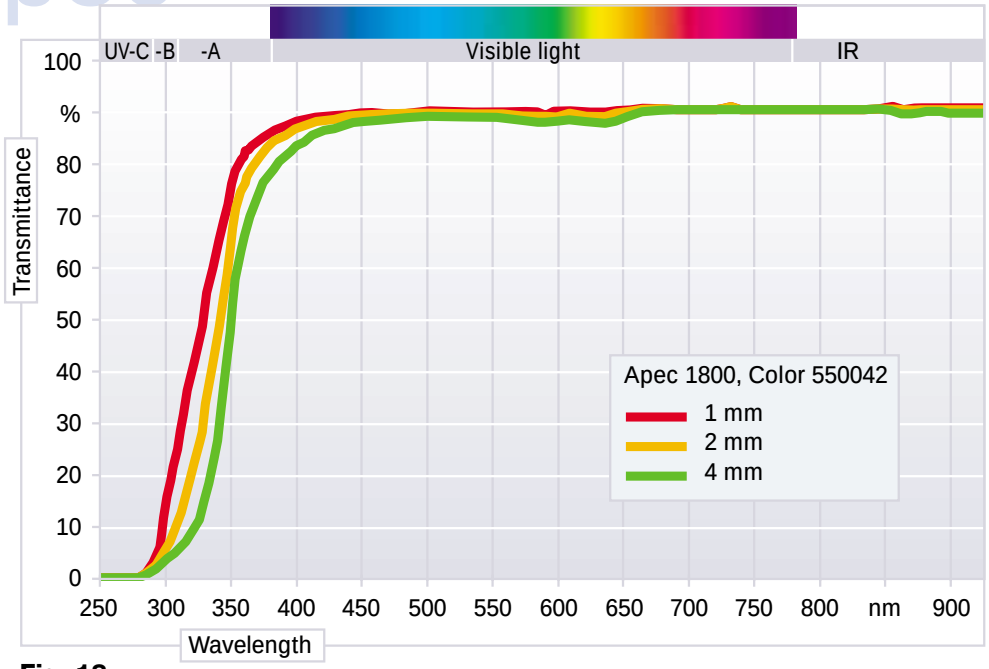


Fig. 18

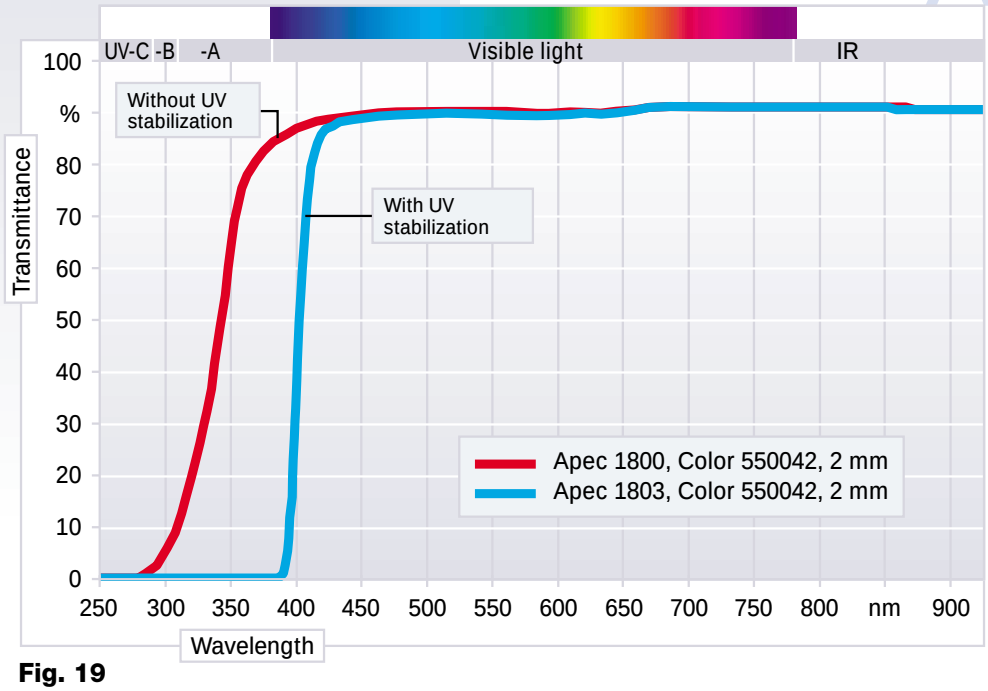


Fig. 19

With and without UV stabilization

Transmittance as a function of wavelength

Apec 1803

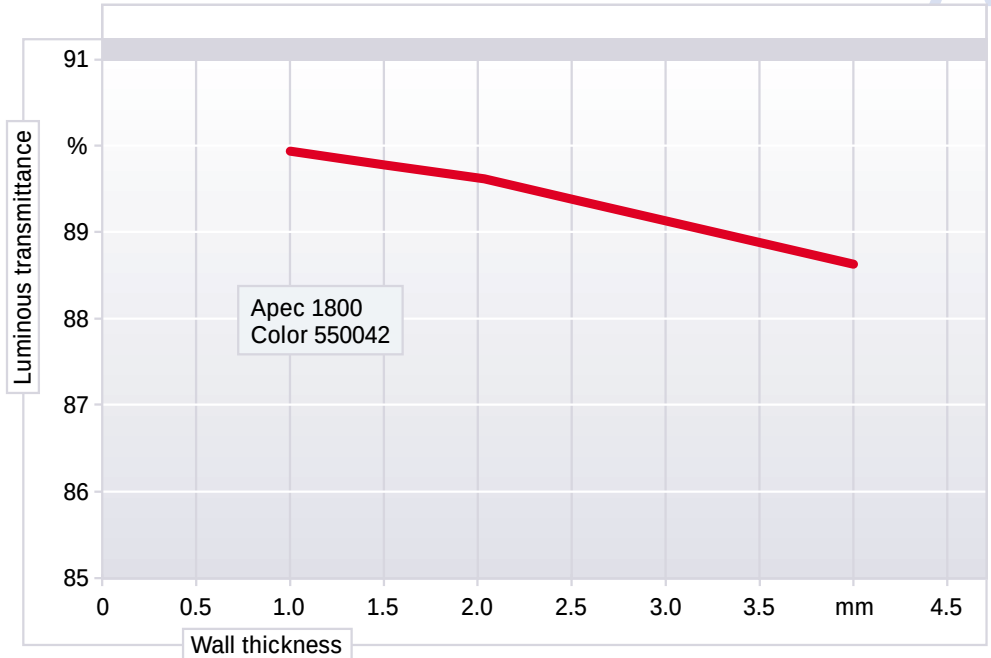


Fig. 20

Luminous transmittance as a function of wall thickness

Apec 1600, 1800 and 2000

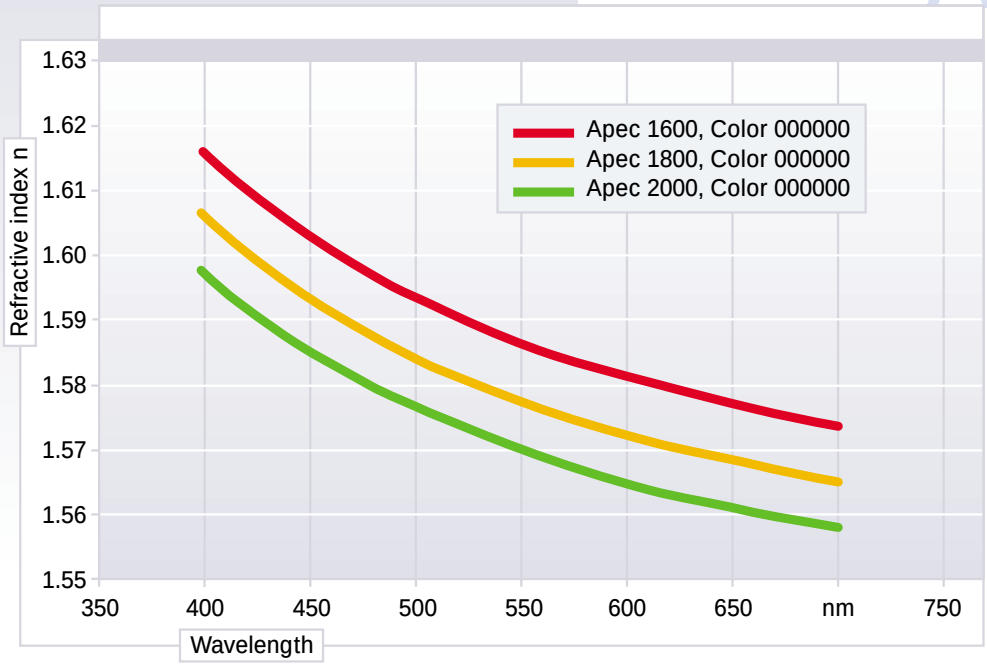


Fig. 21

Refractive index as a function of wavelength

Apec® 1600, 1800 and 2000

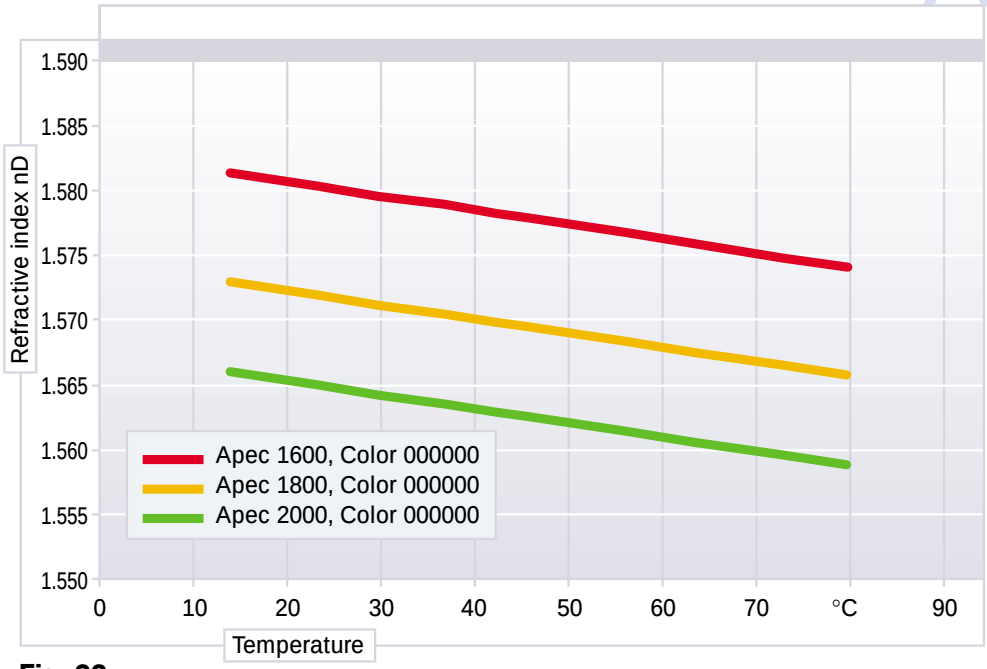


Fig. 22

Refractive index – at 589 nm – as a function of temperature

Apec 1600, 1800 and 2000

Colors
Signal colors

Makrolon® and Apec® can be produced in almost any color.

Makrolon and Apec in transparent signal colors have been used in automotive lighting, signal transmitters and signal lights for many years. Because of their excellent mechanical strength and high heat resistance, Makrolon and Apec are ideal for use not only in applications such as indicators, rear lights, traffic lights and warning lights for emergency vehicles, but also in aircraft, rail and shipping applications.

Makrolon and Apec signal colors comply with the requirements of SAE (USA), ECE (EU) and DIN (Germany) specifications. Fig. 24 shows the current range of signal colors in accordance with the standard specifications in the CIE chromaticity diagram. Sample colors for each of the basic colors are also shown for various wall thicknesses to represent the large number of signal colors available.

The signal colors of relevance to automotive lighting in various

Makrolon grades comply with the stringent 3-year weathering requirements in accordance with SAE J 576 (Part of FMVSS 108) and appear in the Ameca list. The colorimetric guide data of signal colors were calculated in accordance with light type A, 2° observer. In Figs. 23 to 25, Makrolon signal colors are shown as examples. Various other Apec signal colors are available.

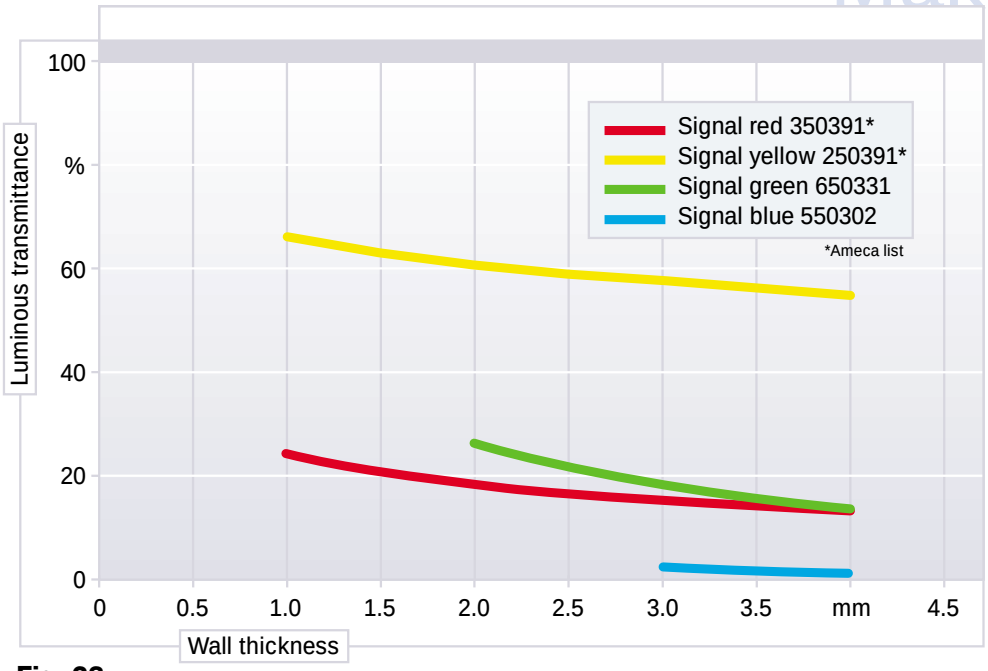


Fig. 23

In signal colors

Luminous transmittance as a function of wall thickness

Sample signal colors

Colors
Signal colors

Makrolon®/Apec®

Signal colors and signal ranges

Position of main signal ranges and sample signal colors (for various wall thicknesses) in the CIE chromaticity diagram

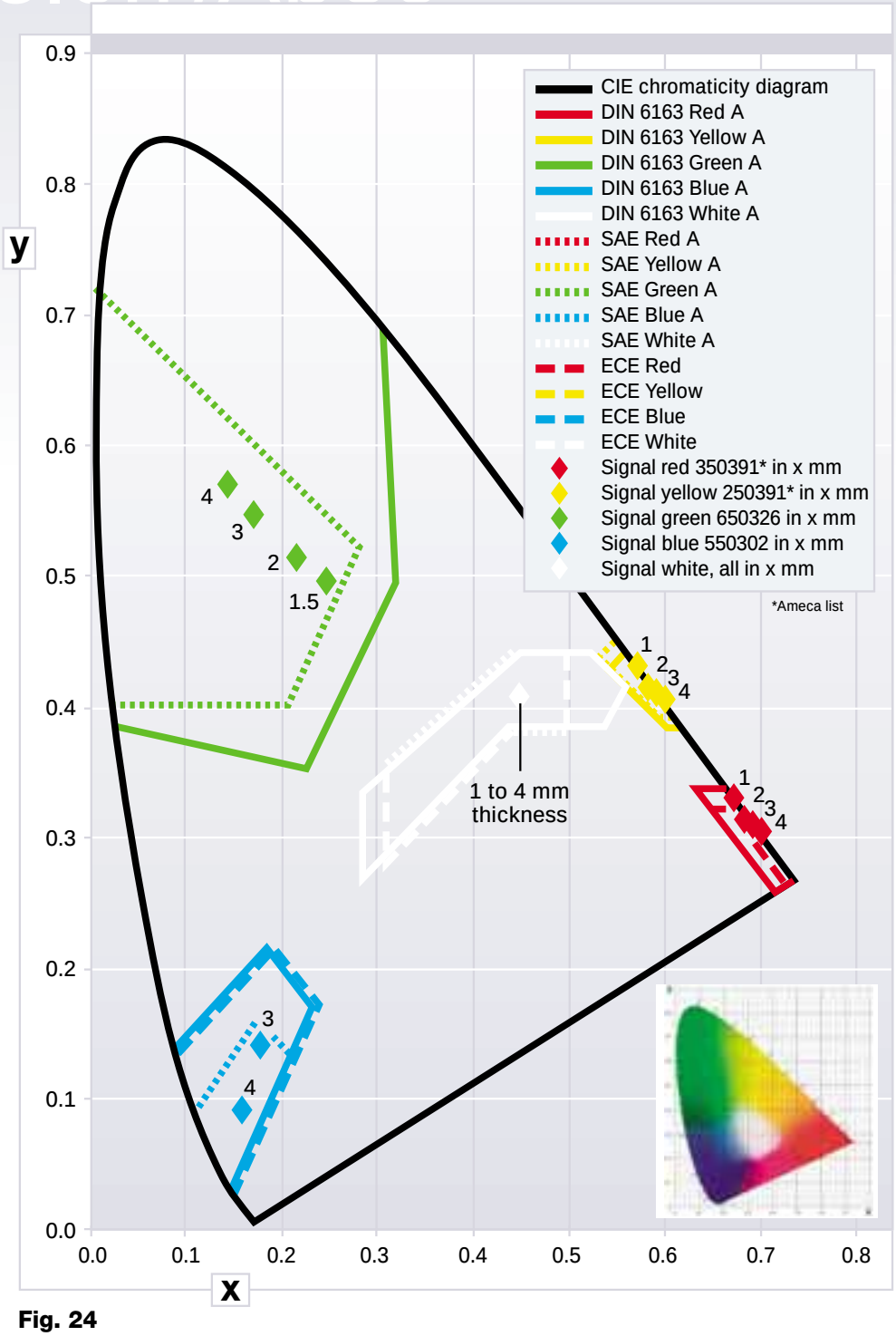
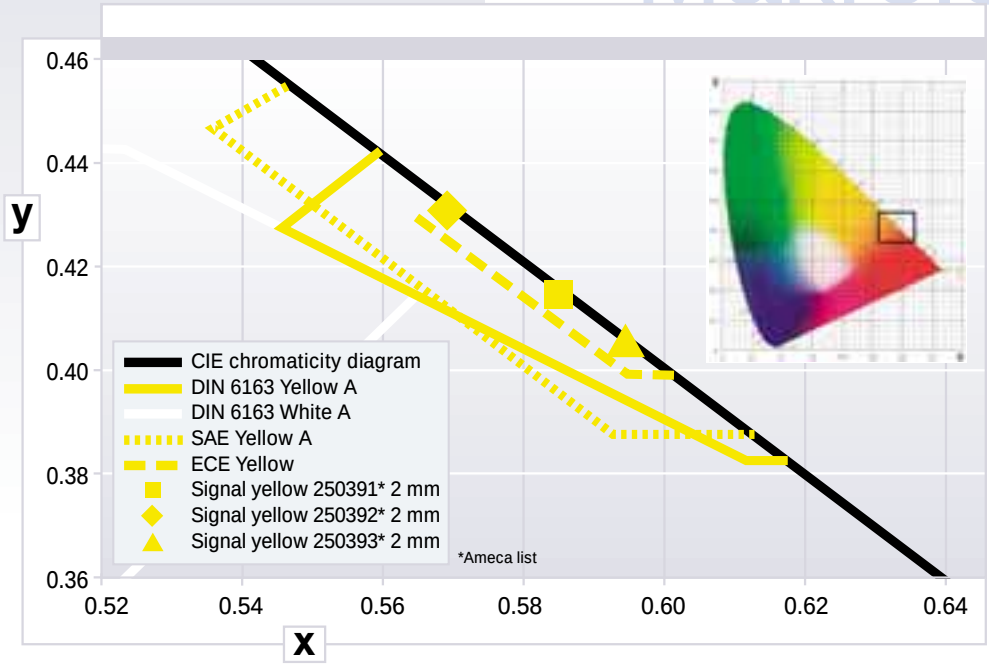


Fig. 24



Signal colors and signal ranges

Position of yellow and red signal ranges and sample signal colors in the CIE chromaticity diagram

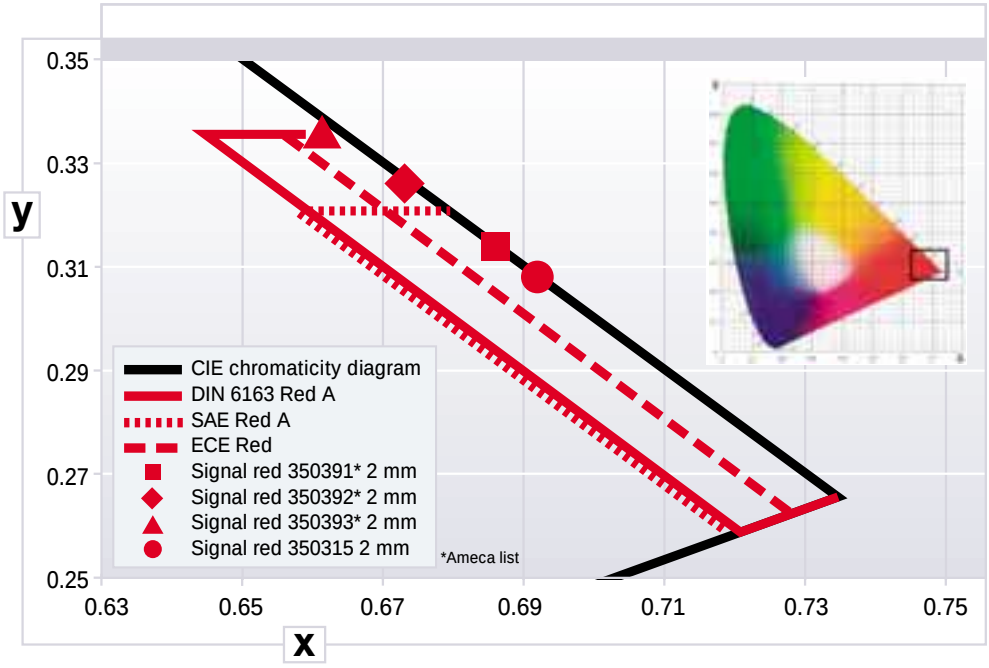


Fig. 25

Translucent white colors

Translucent white colors

For scattered light effects in which good luminous transmittance is required without the light source becoming visible, Makrolon is available in various translucent colors. For use in light diffusers, it is often necessary to use translucent white colors which range from slightly translucent to almost completely opaque.

Makrolon®

In translucent white colors

Transmittance as a function of wavelength

Sample translucent white colors

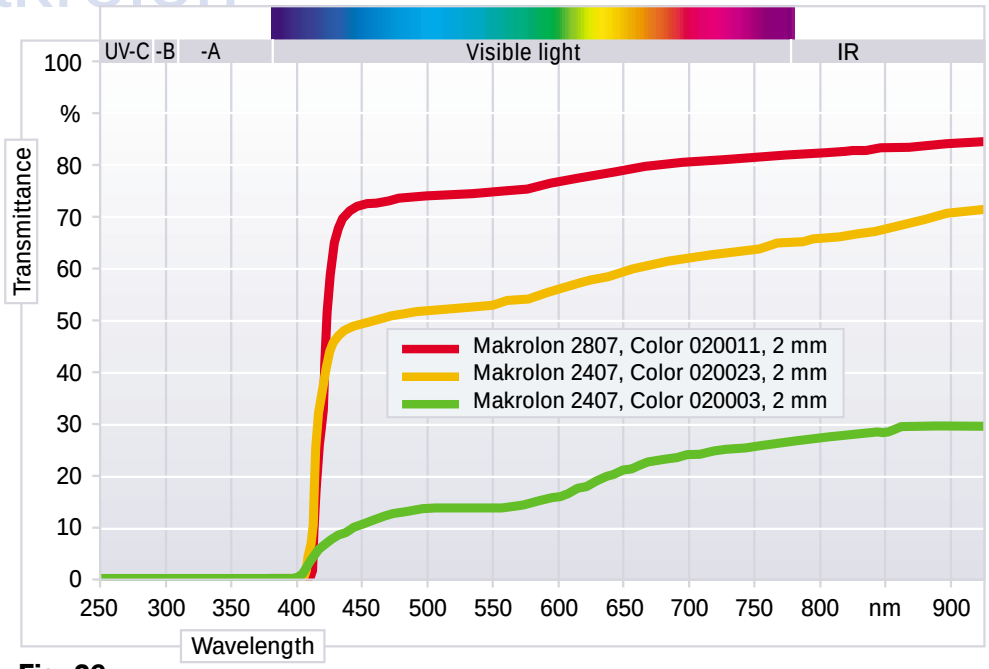


Fig. 26

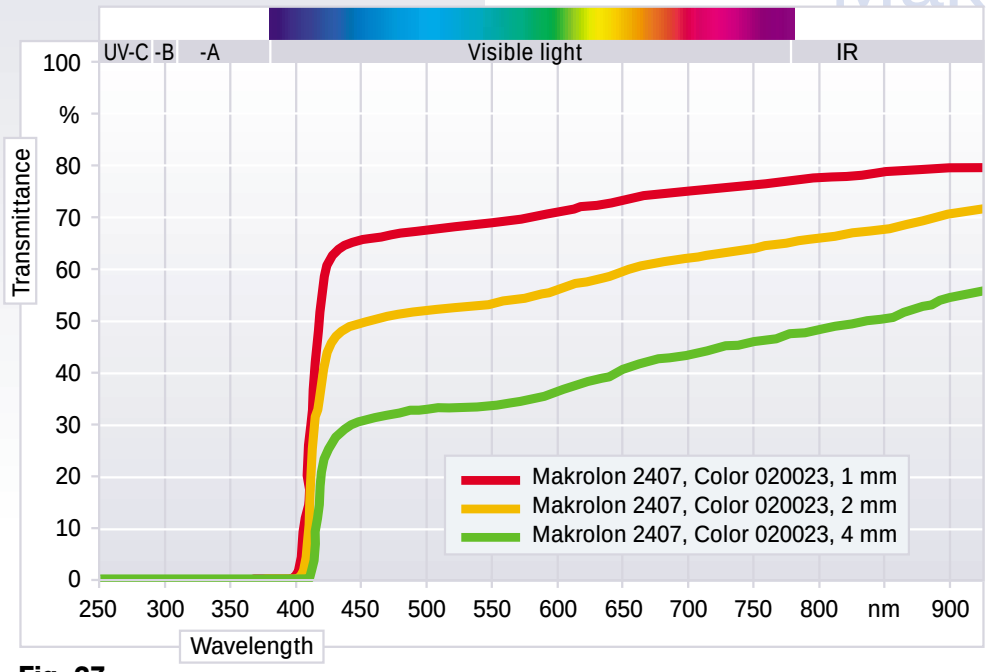


Fig. 27

Translucent white color at various wall thicknesses

Transmittance as a function of wavelength

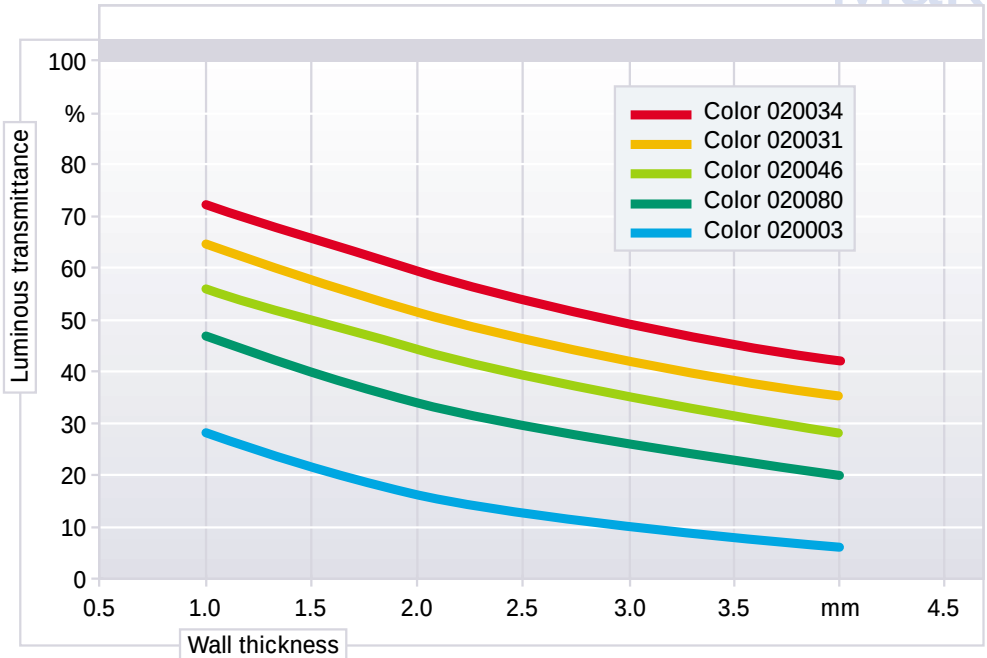


Fig. 28

In translucent white colors

Luminous transmittance as a function of wall thickness

Sample translucent white colors

Color numbers
for Makrolon® and Apec® grades for optical applications

Since September 1, 2001, Bayer AG has used an internationally standardized color number system for its thermoplastic polymers.

When the colors were renumbered, it was possible in most cases to retain the figures used in the old color numbers.

The following table gives an overview of the old and new color numbers of current grades for optical applications.

Makrolon®	Grade	Clear transparent	Colored transparent	Color numbers New	Color numbers Old
General purpose grades	..05 ..07 ..58	X		550115	55/115
Sheet					
Solid sheet	3103	X		550115 550060	55/115 55/060
Multi-wall sheet	1243	X		550111	11/111
UV absorber concentrates	KU1-1241/1* DP1-1244/5*	X		550054	55/054
Optical lenses	LQ2647 LQ3147	X X		550115 550116	55/115 55/116
UV 400 cut-off	LQ2687 LQ3187	X		550131	55/131
Welder protection colors	2407 2407		X X	750611 750612	75/611 75/612
IR colors	2805 2805 2805 2805		X X X X	450401 450601 750351 750359	45/401 45/601 75/351 75/359
Automotive lighting					
Signal color white	AL2447 AL2647	X		550396	55/396
Others	Various		X	Various	
Translucent white colors					
Various	Various		X	Various	
Apec®					
General purpose grades	1800 DP1-9359/5* DP1-9359/7*	X		550042	55/042
	1803	X		550042 551022	55/042 55/130
Automotive lighting					
Signal color white	1803	X		550042 551022	55/042 55/130
Others	Various		X	Various	

*Developmental product, see ba

These measurements were performed with reference to CIE publications as well as national and international standards such as:

Transmittance	ASTM E 179, DIN 5036
Luminous transmittance	ISO 13468-2, ASTM D 1003, DIN 5036
Refractive index	ISO 489, DIN 53491 (also covers Abbe value)
Yellowness index	ASTM E 313, DIN 6167
Haze	ASTM D 1003, DIN 5036
Gloss	ASTM D 523, DIN 67530
Colorimetry	ASTM E 308, DIN 5033, Color differences CIELAB formula, DIN 6174

A selection of our technical information sheets:

Makrolon®

ATI 8001	Makrolon grades/typical properties
ATI 8007	Makrolon 3xxx grades
ATI 8012	Makrolon AL
ATI 8013	Makrolon LQ
ATI 8014	Makrolon 1243 and DP1-1244/5*
ATI 8016	Makrolon CD 2005 and DP1-1265*
ATI 8029	Makrolon with IR absorber

Apec®

ATI 2001	Apec grades/typical properties