Tailored Materials for Automotive LiDAR, RADAR, Near-IR & Antenna Applications

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ANTENNA

Automobile industry is changing rapidly to CASE

The automotive industry is undergoing a major transformation to **connected**, **autonomous**, **shared** and **electric** (CASE). The switch from the internal combustion engine to hybrid and battery electric vehicles is a major driver of this change. Multiple indicators testify to the speed of this transformation:

- Nearly every OEM is working on assisted or autonomous driving.
- Driving assistance is becoming more and more prevalent.
- Advanced functions are already available in the mid and premium segments.
- Safety functions are becoming mandatory, e.g. brake assistant, emergency calls, driver recognition.
- Vehicle to X (V2X) communication functions are in development.
- Well-established electronics manufacturers are pushing into the automotive sector.
- Cars are already offering more digital functions than ever before.

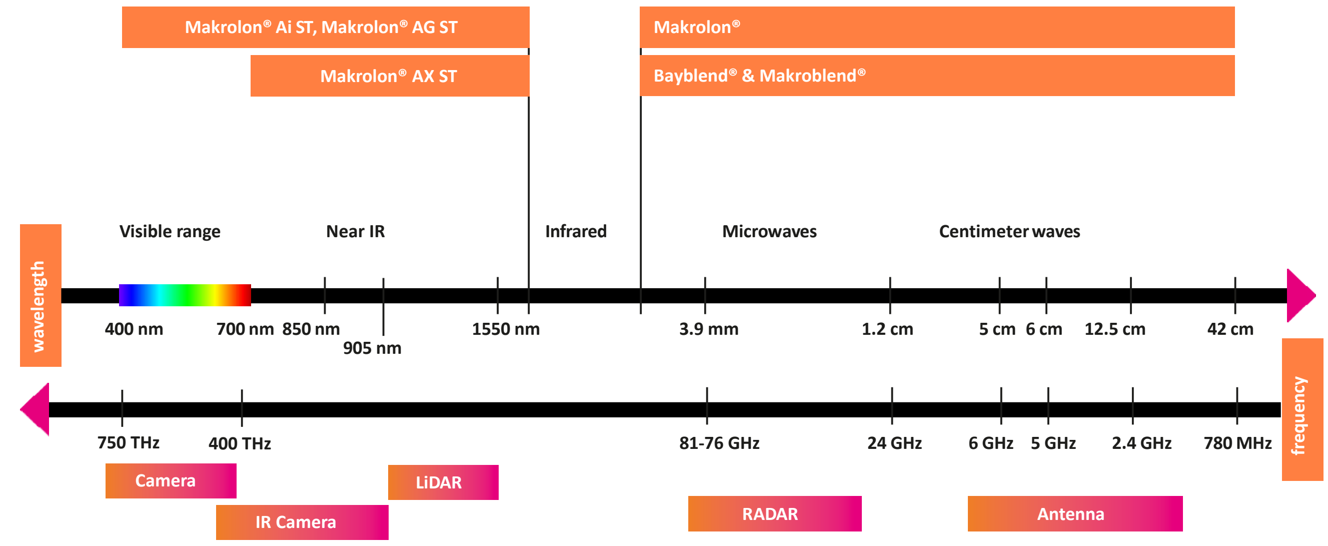
Need for reliable high-performance sensor-transparent materials.

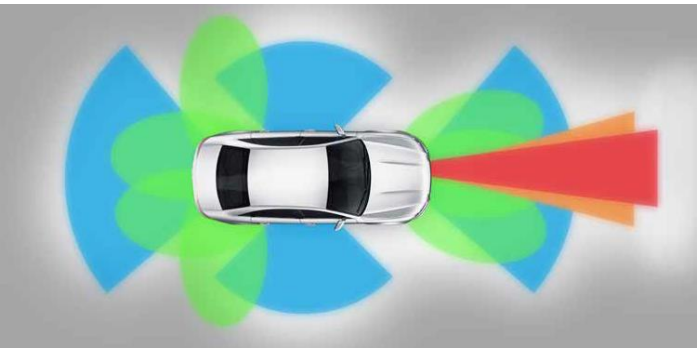
To meet the needs of this new generation of vehicles, established electronics companies are becoming more and more active in the automotive sector. Today's cars offer more digital functions than ever before, which creates a growing need for reliable high-performance sensor-transparent materials such as polycarbonates.

The amorphous structure of Makrolon® leads to excellent sensor transparency. This is a major benefit for the implementation of sensor technologies like LiDAR and RADAR, because these systems can be safely covered and seamlessly integrated into automotive exterior parts using polycarbonates.

Sensor transparency (ST) is one of the keys to Advanced Driver Assistance Systems, it leads to high sensing range and stable signal quality. In order to achieve optimal ST levels, Makrolon® covers must not cause any electromagnetic signal damping or electromagnetic wave distortion. New sensor applications are demanding the combined expertise of the chemical, electronics, and optics sectors.

Sensor applications by wavelength and frequency





Covestro material solutions:

Makrolon® AG ST

IR transparent exterior polycarbonate in clear or neutral density tinted colors as covers for LiDARs and IR cameras with light integration.

Bayblend®

PC+ABS, PC+ASA, high ductility, easy processing behavior, low and homogeneous dielectric constant (Dk) and dissipation factor (Df), suitable for radar and antenna covers.

Makrolon® AX ST

IR transparent black polycarbonate as exterior cover for LiDAR or NIR sensors.

Makroblend®

PC+PBT, PC+PET, mineral-filled blends, low CLTE, good ductility, good paintability, low and homogeneous dielectric constant (Dk) and dissipation factor (Df), suitable for radar and antenna covers.

Makrolon® Ai ST

IR transparent interior polycarbonate in various colors for covers for IR driver monitoring systems and IR cameras.

Near IR transparency

LiDAR

LiDAR

LiDAR is the abbreviation for **Li**ght **D**etection **A**nd **R**anging. This method uses infrared laser technology to measure the distance of objects (so-called ranging) in its field of view. By emitting pulsed laser beams (of 905 nm or 1550 nm wavelength for automotive applications) and detecting the light reflected off the objects, their distance can be measured, and vectors of their movement can be calculated.

LiDAR systems are based on either rotating mirrors or digital micro mirror devices to generate a scanning beam, or they may be fully solid-state, producing flashes of fan-out beams. The detectors may be photo diodes or other highly light-sensitive systems. Ideally, emitter and detector are covered with one large cover lens made of a single polymer material. This polymer must possess specific optical spectrum filtering properties: It must transmit light at the exact operating wavelength, while blocking any stray light that does not match the operating wavelength.

Compared to a multiple camera setup, LiDAR offers several unique advantages: It provides distance information directly and thus requires less computing power. It is not influenced by shadows, light reflections or the headlights of oncoming cars, and works equally well or even better in complete darkness. Compared to RADAR, its resolution is higher by an order of magnitude. On the downside, rain, fog and snowfall are disturbing the signal; in those situations, RADAR or camera systems have advantages.

The LiDAR sensor cover is an essential part of the optical path, and plays a determining role in overall system performance:

- The direct **transmission** correlates directly with the range of the sensor.
- The material pureness (**low haze**) and **homogeneous** color distribution directly correlates to the maximum resolution of the sensor and leads to a clear image.
- The material must be **stiff and ductile** while also resisting stone chipping and minor impacts over its lifetime, and also function properly over a wide temperature range (-40°C to 120°C).
- A low CLTE and a smart **mounting concept** leads to high optical quality through the window. The material properties should remain **constant over lifetime**.
- The surface must be protected with **hard coatings**, which at the same time could even increase the level of direct transmission.
- Automotive sensors require **integrated heating in most cases,** as well as an attached **cleaning system** which works well in all environmental conditions.

Makrolon® AX2675 **ST,** color 978001

- Black opaque LiDAR sensor cover
- IR transparency of ≥ 89% @905nm and 2mm high purity grade
- High batch-to-batch consistency
- High impact resistance
- Proven for polysiloxane hard coatings for weathering and scratch protection
- Internal electrical heating

Near IR transparency

Driver Monitoring System

Driver Monitoring System using NIR camera

Driver Monitoring Systems (DMS) use a near infrared camera sensor to monitor the driver's face continuously. Sophisticated algorithms in the software can identify several driver behaviors and conditions, including for example whether the driver is tired. A much wider range of attributes including age, sex, and mood – whether talkative, happy, sad, tired, nervous or relaxed - could also be detected via software. It can even spot if driver is wearing glasses or a hat.

Technically, optical Driver Monitoring Systems usually consist of two components: one NIR camera, and one NIR LED which acts as an additional lighting source to brighten up the face.

For optimal working conditions, both elements must be placed in the drivers' field of view. Black IR transparent polycarbonate covers are one solution for hiding these elements beneath a clean and sleek cover.

Often these covers are equipped with a hard coating to protect against scratches. Polycarbonate is easy to process, offers very high mechanical properties, including snap fits for durable mounting concepts. It is also easily used together with PC/ABS structures in 2K injection molding concepts. Covestro can offer individual colors that prevent NIR LEDs from being visible in the so-called "glow in the dark" effect, as the human eye can detect wavelengths of up to 780 nm, even in low intensities.

Glow in the dark effect of NIR LEDs captured with a cellphone camera, which is usually more sensitive than the human eye in the IR range.

Product Recommendations

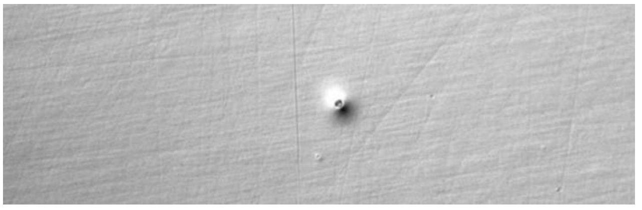
Driver Monitoring System cover:

- Makrolon® Ai2497 ST, 978007
- Makrolon® Ai2497 ST, 978006
- Makrolon® Ai2497 ST, 971064
- Makrolon® Ai2497 ST, 970005

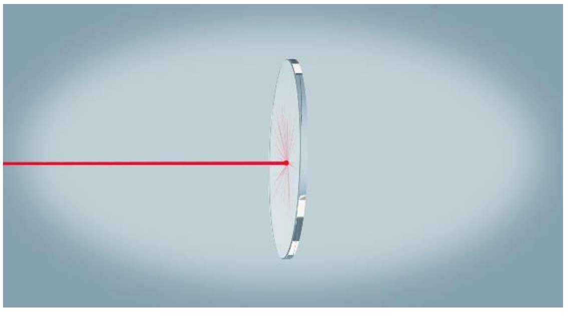
Advantages of Makrolon® Ai, AG, AX

Standard commercial grade

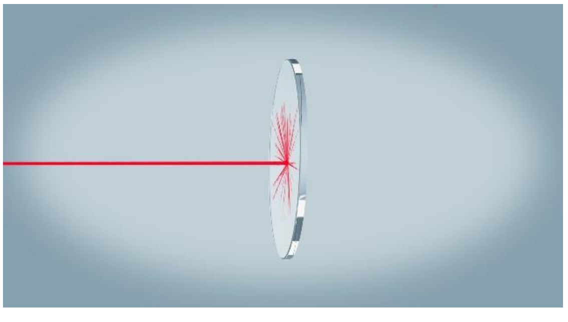
Pigment agglomerations plus coating lead to
a lens effect (10x magnification)



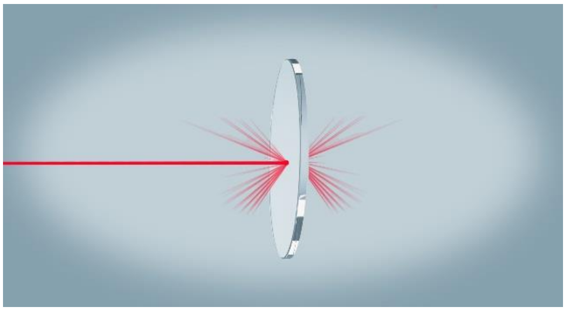
Absorption



Internal scattering



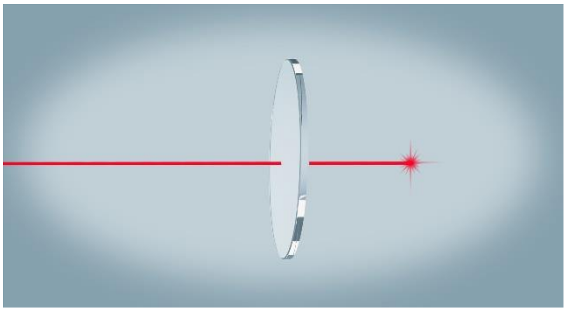
Surface scattering



Makrolon® Ai, AG & AX

Homogeneous colorant distribution
and high purity base material

Excellent transmission with minimum loss



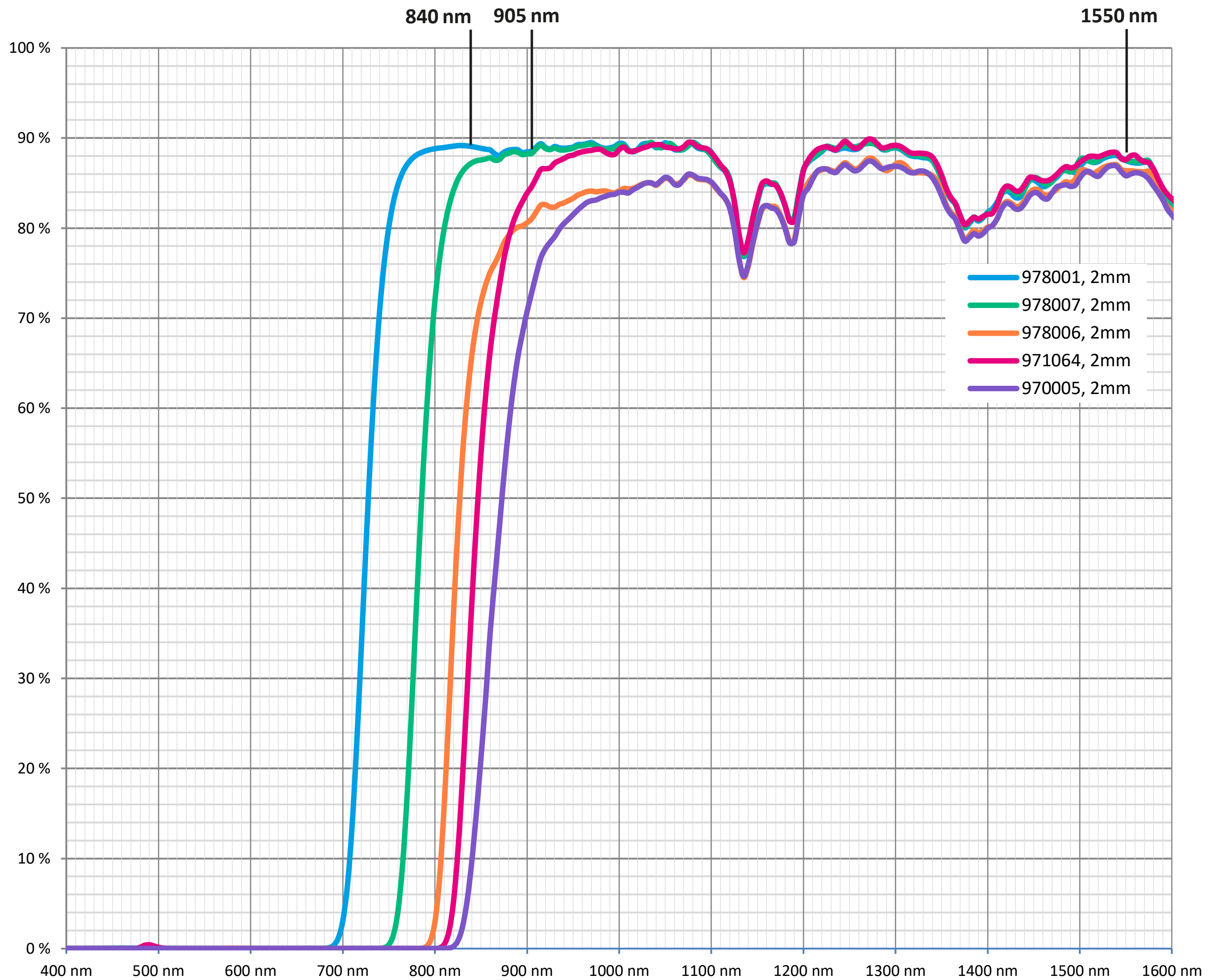
Sensor-transparent Makrolon® from Covestro is the ideal material for precision molding with additional hard-coating.

During the production of Makrolon® Ai, AG and AX, we pay particular attention to the pureness and optical properties of the material, as these are required for sensor covers and lenses. Even if the material appears black outwardly, it is still treated to the same high standards as our other optical resins.

The materials are produced using a special melt filtration in which only optically pure base resins are used to avoid agglomeration of colorants, black particles and other defects which might interfere with the laser beam.

All additives and colorants used are also suited to an additional hard coating process.

Total transmission of selected IR transparent colors



For example: Makrolon® AX2675 ST, color 978001, T>89% at 905 nm and 2 mm, ensured in specifications.
Individual customer specifications are available for ST products.

Product recommendations

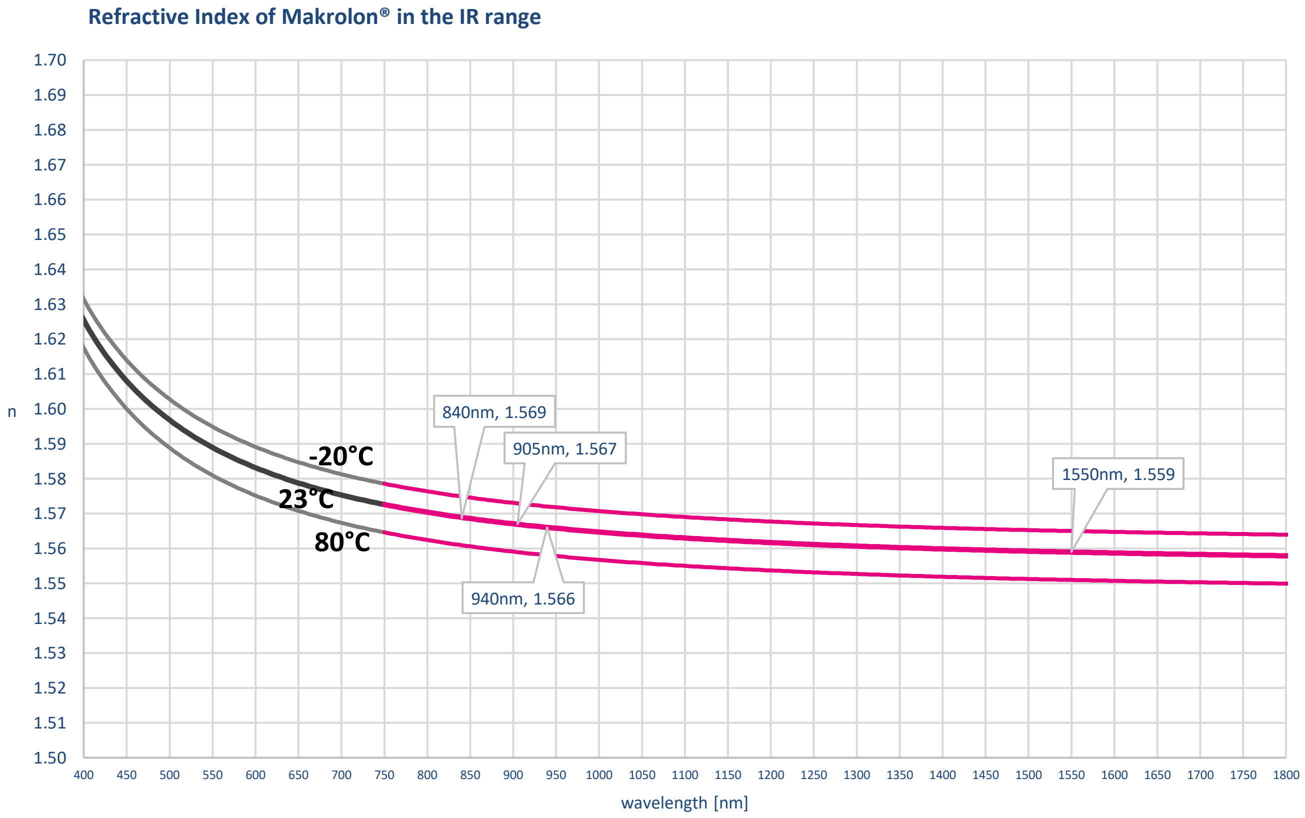
LiDAR cover, exterior:

Makrolon® AX2675 ST, 978001
Makrolon® AX2675 ST, 978007

Driver Monitoring System cover:

Makrolon® Ai2497 ST, 978007
Makrolon® Ai2497 ST, 978006
Makrolon® Ai2497 ST, 971064
Makrolon® Ai2497 ST, 970005

Refractive Index

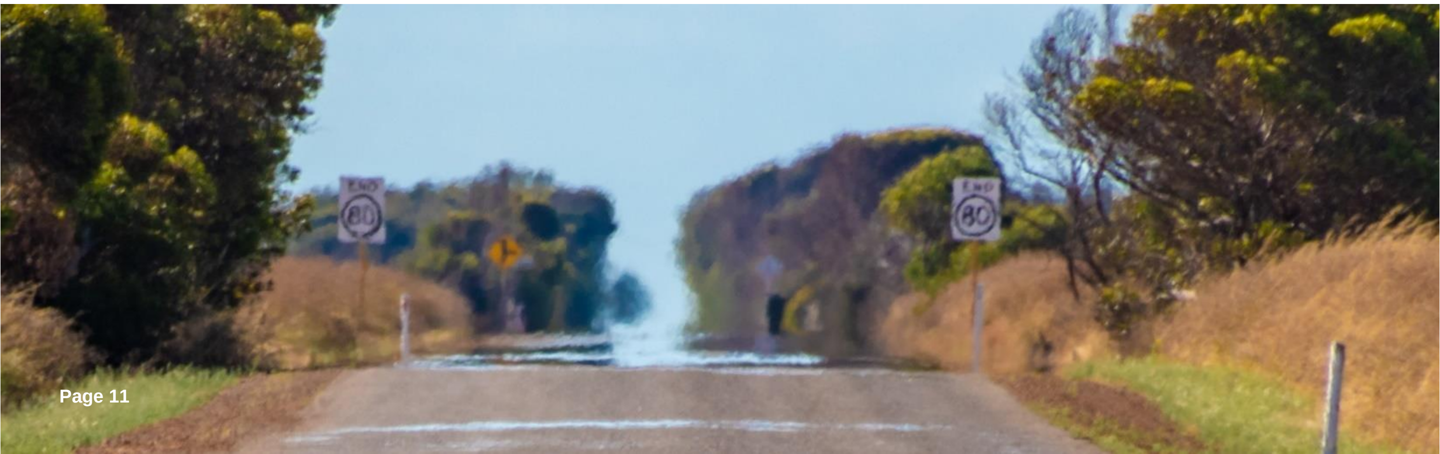


The refractive index of Makrolon® is wavelength-dependent. The refractive index is higher in the visible than in the near infrared regime. The corresponding Abbé number, Vd (589.6 nm) is 30.

The graph above shows the refractive index as a function of wavelength and temperature. The slope is referred to as the dispersion. The red portion of the curve indicates the IR range.

A refractive index which does not change much under varied wavelength and temperatures is of fundamental importance for cover lenses which must remain calibrated, even at very low or high ambient temperatures. Deviation from the calibration results in beam divergence and pointing errors.

Makrolon® shows a highly stable refractive index in the operating range of any LiDAR system. The wavelength range of operation may be higher than 900 nm for driver monitoring systems, or either 905 nm or 1550 nm for laser-based long-range LiDAR systems. As the laser operates in a very narrow wavelength range anyway, the refractive index remains very stable under a wide range of temperatures. This makes Makrolon® a very good material for optical applications.

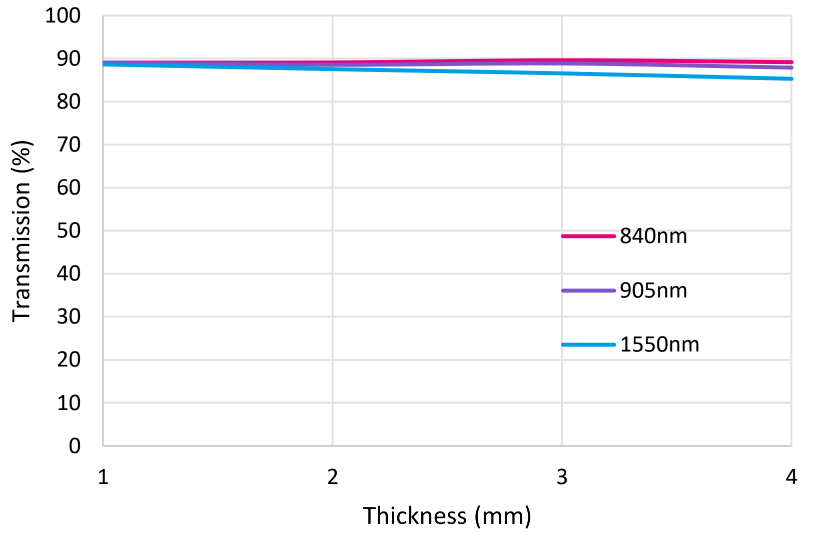


Part thickness influence on direct transmission

The part thickness has a direct influence on the transmission. There is always a compromise to be made between mechanical strength and mold filling behavior (as thick as possible) and optical performance (as thin as possible).

Typical values are around 1.5 mm to 2.5 mm for smaller covers, or around 4-5 mm for integrated, complete frontend parts.

The graph on the right shows a sample single point measurement of color 978001.



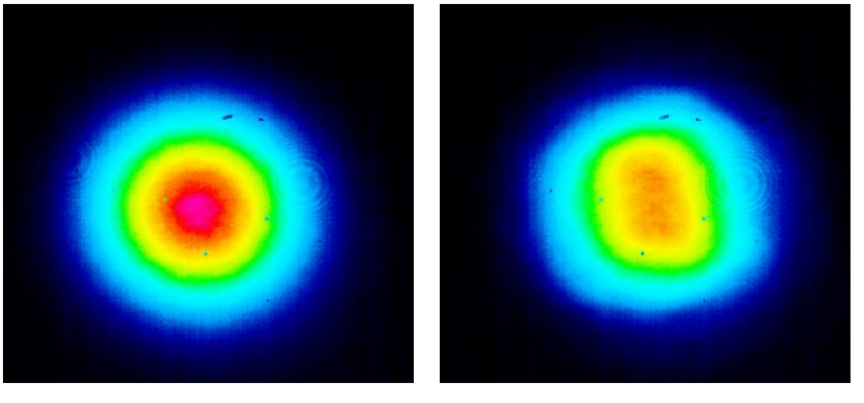
Surface roughness influence

Surface roughness can have a negative impact on both laser beam power and quality. This will reduce the performance in long-range sensing. Our recommendation for a maximum mold roughness is Ra<60 nm (arithmetic line-scan average) and Rz (DIN)<500 nm (maximum amplitude). This applies to both outer side (A-side) and inner side (B-side) of the Makrolon®-based cover lens. Dependent on the lens' layer stack, it may apply to either an uncoated or coated surface.

We recommend the following:

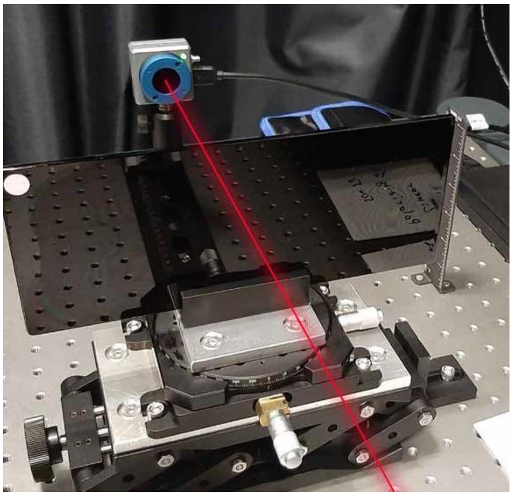
- Use of high-gloss polished molding tools
- Proper molding parameters which help to minimize the anisotropic shrinkage during cooling
- Smooth coating surface without bubbles, orange peel, waves or steps

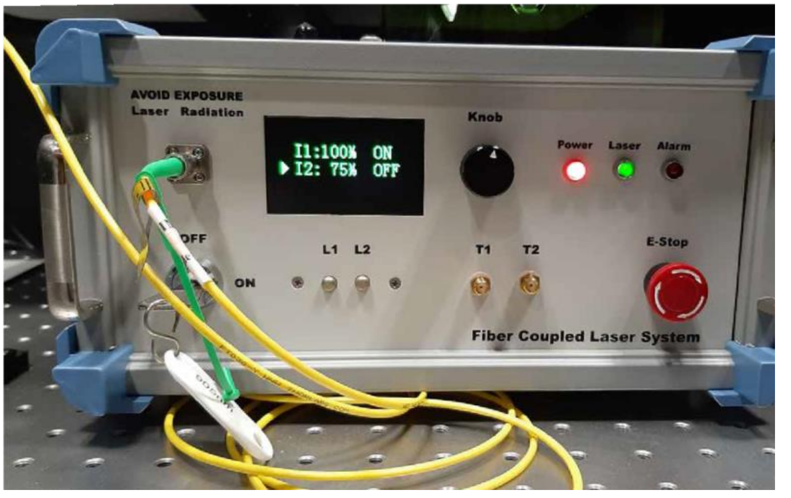
Sectional images of a laser beam profile with circular Gaussian shape. The pseudo-color scale from deep blue to purple indicates the increasing power from the outer ring to the center:



Left: *profile of an IR laser beam incident to a LiDAR cover lens.* ***Right:*** *profile of a transmitted beam showing the damping and distortion that results from a cover lens with insufficient surface quality.*

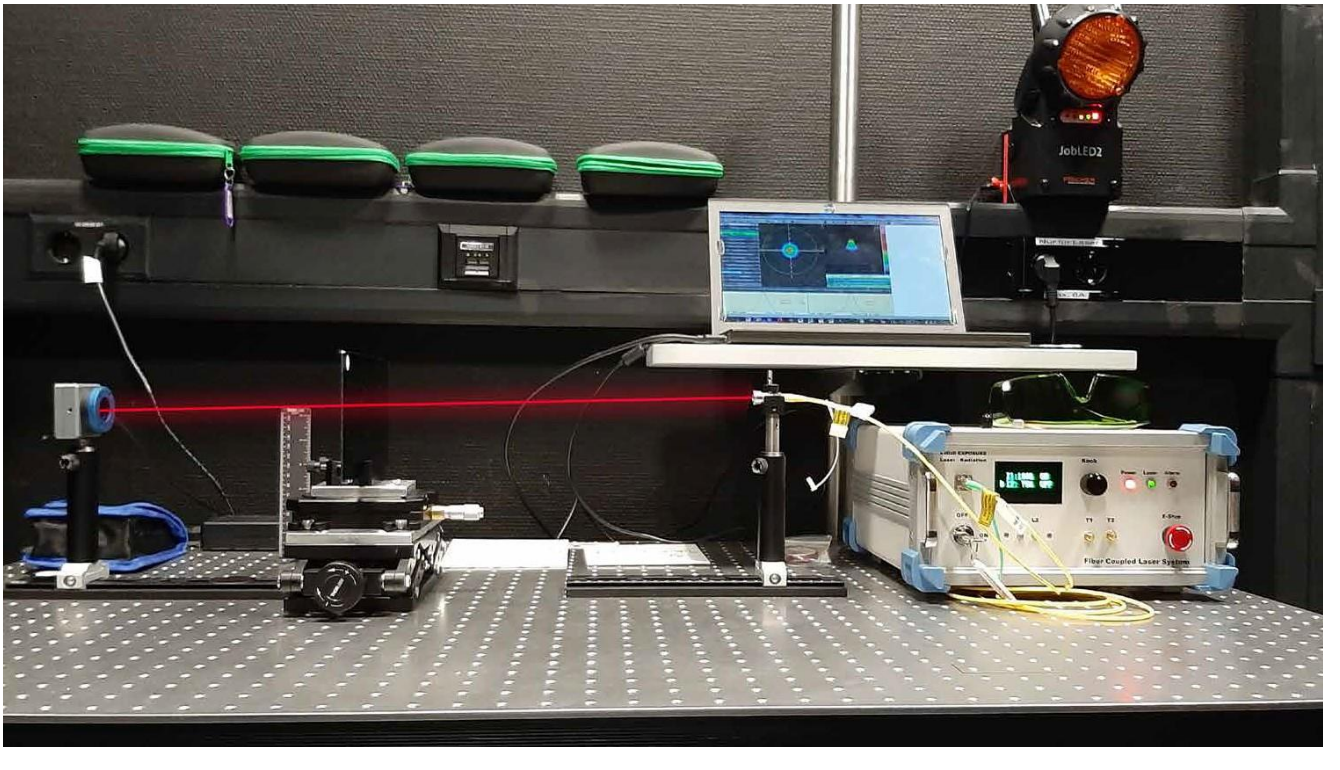
Optical Metrology



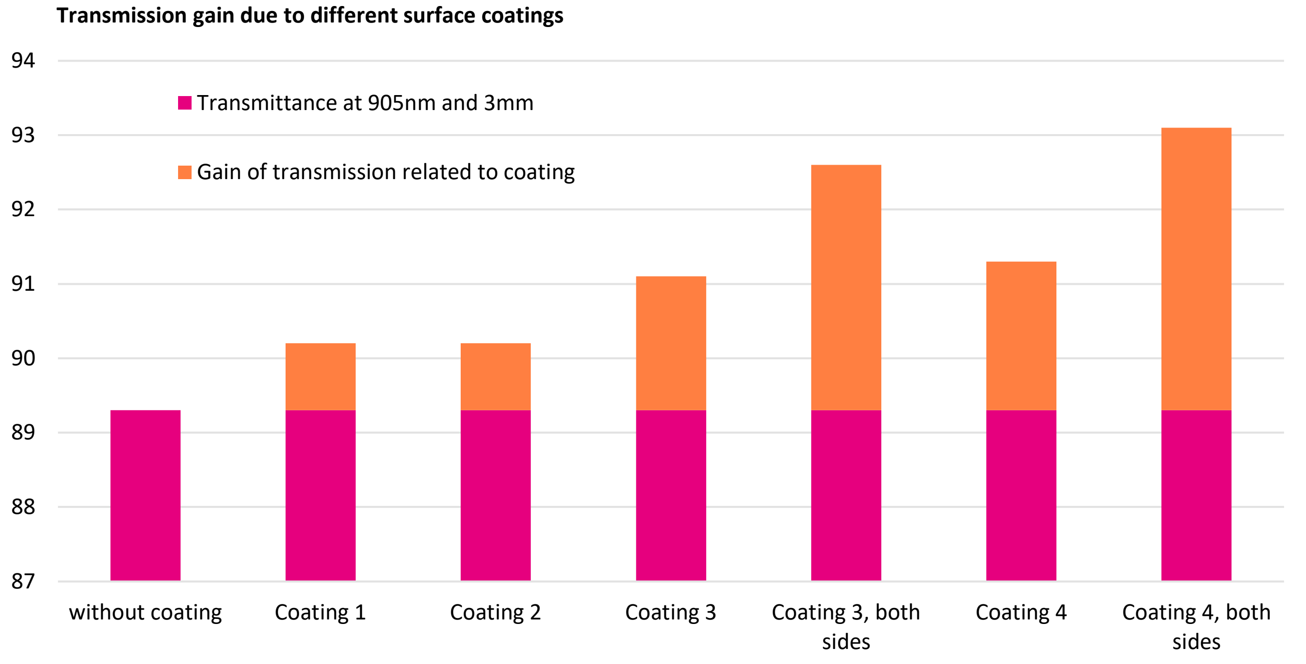


Covestro can measure the laser beam peak transmission and beam quality on a sample. We make use of a test setup based on a static 905 nm laser built exclusively for LiDAR cover lens performance tests. Experimental data from this setup will complement data from other optical metrology devices such as spectrometers, spectrophotometers and interferometers, allowing for a root cause analysis on signal losses.

Covestro is continuously expanding its optical capabilities to support customers with the best optical data on materials and samples and state-of-the-art know-how. Application development services for customers cover optical engineering.



Increase of transmission vs. hard coating



To fulfill the automotive exterior requirements of most OEMs, polycarbonate surfaces have to be treated with a hard-coating process to withstand abrasion and weathering. This added coating can also have the welcome effect of helping to increase the transmission level, and thus the range of the LiDAR, since the maximum permitted power of the laser is limited.

According to Fresnel's reflection law, a hard coating with an index of refraction lower than the index of its substrate will reduce the total reflection. Accordingly, the transmission will increase. The graph above gives transmission examples for an uncoated Makrolon® plaque (violet segments) and the gain that results from coatings on a single side and both sides. With an index of refraction higher than industry-approved solutions such as siloxane-based, acrylate-based or urethane-based coatings, Makrolon® achieves transmission levels of 90 to 93% when combined with hard coatings, illustrated by the orange segments.

Covestro front end demonstrator with optical area ready for LiDAR sensor and equipped with integrated de-icing film.

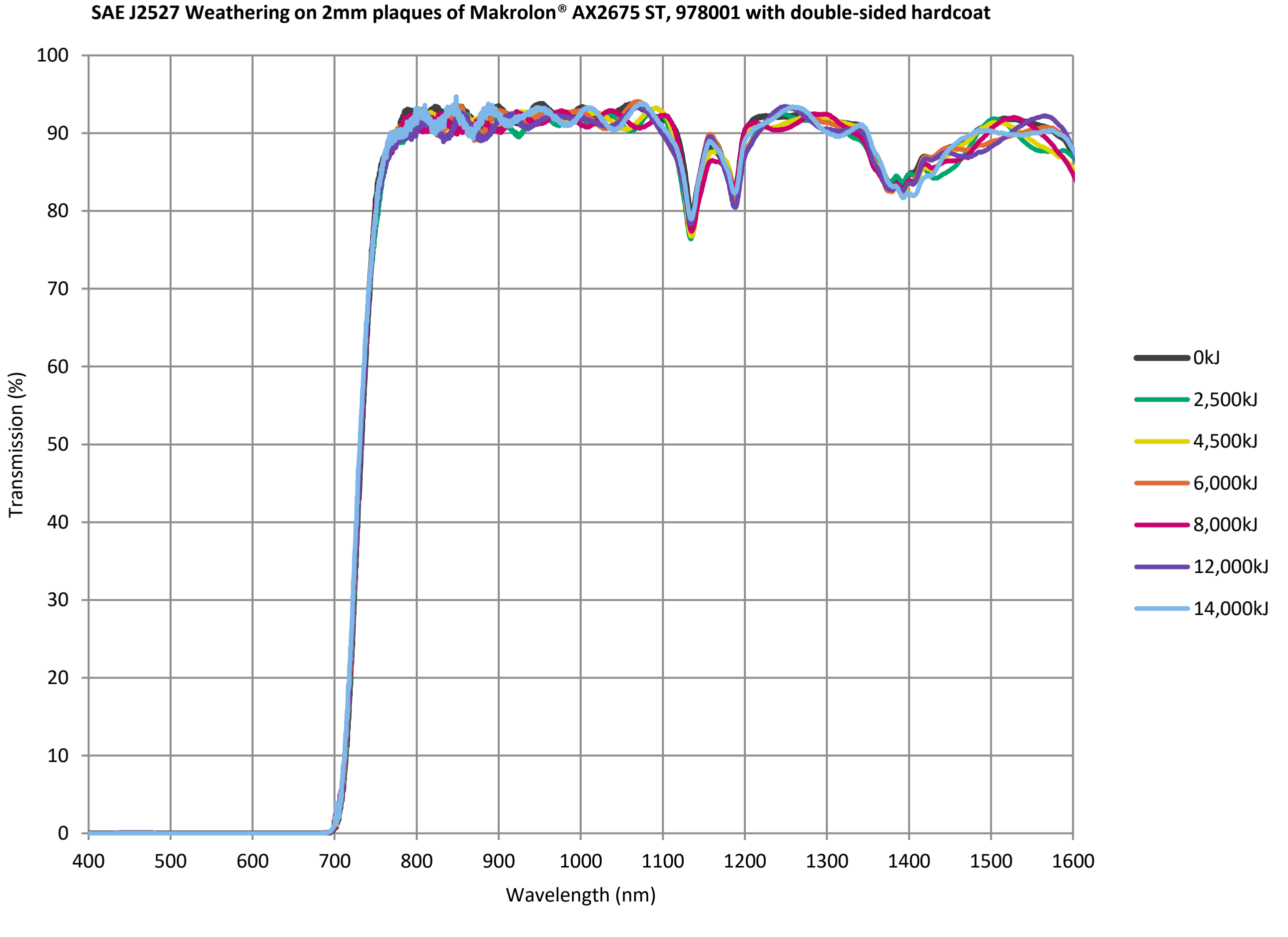
Aging and weathering behavior

Cleaning, contamination and the performance over time are probably the most difficult design topics for exterior sensor housing surfaces.

The aging and weathering performance of polycarbonate depends mainly on its surface treatment, i.e. on the performance of the coating. In the graph below, our study showed that the black, infrared transparent color itself didn't change its properties and the measured transmission remained stable over time, up to 14,000 kJ light dosage, according to SAE J2527. Nevertheless, in this test the coating already showed some small cracks, which could disturb the laser signal. It seems that the overall lifespan of sensor covers is determined by the coating performance rather than the color stability of the Polycarbonate.

Transmission is not the only criteria for sensor performance. Surface defects should also be considered. These may depend on the position of the sensor, and lower, central exterior sensors will be particularly exposed to dirt and gravel during their lifetimes. A smart cleaning system and optimized aerodynamic air flow can help minimize this.

Polysiloxane based coatings are recommended here, as they provide the best overall performance regarding scratch and weathering performance. Together with UV curing coatings they are the current industry standard for headlamp applications.
Transmission spectroscopy is only one measure of weathering. Designers should also develop an understanding of how other aging processes can impact their specific sensor resolution. Also, dirt, scratches and flaking after stone chipping will can have an impact of laser transmission. Here one simple solution could be to make the cover bigger and place the internal sensor with more distance to the outer cover, so that the relative size of the surface defect gets smaller.



Microwaves Transparency

RADAR

Microwaves Transparency

RADAR is short for **RA**dio **D**etection **A**nd **R**anging. Covestro's Makrolon® polycarbonate has proven to be an ideal material for forward-facing automotive exterior parts such as headlights and EV grilles. Covestro has taken our experience in these applications and looked at radomes for forward-facing radar. As we investigated, we realized Makrolon® polycarbonates are an ideal material for radomes on all parts of the vehicle – front, sides, rear and interior.

Radome: A blended word from 'radar' and 'dome'. (1) A protective cover for a radar antenna. (2) A radar cover made of stable, well-characterized materials and engineered to minimize radar signal losses caused by absorption, reflection or distortion.

On the following pages, we discuss the basics of a radar system operation. We provide an overview of permittivity (dielectric constant) and how that value is used to design a radome to minimize reflection losses, and then review the material characteristics that stabilize permittivity values. Finally, we will review some other reasons why Makrolon® can keep radar systems performing well over the vehicle lifetime.

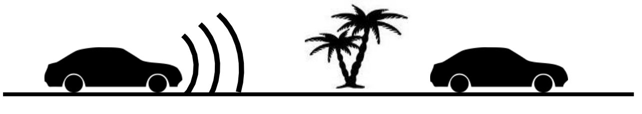
Which vehicle systems use radar?

- blind-spot detection (BSD)
- lane-change assist (LCA)
- front/rear cross-traffic alert (F/RCTA)
- autonomous emergency braking (AEB)
- adaptive cruise control (ACC)

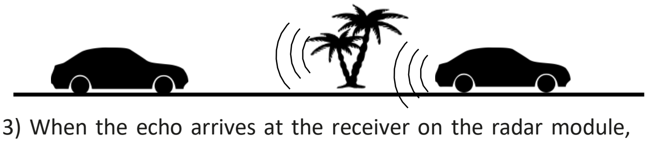
How does radar work?

Radar uses the same basic theory as LiDAR and ultrasound to detect an object as follows:

1) A typical transmitter generates short signal known as a "ping" or a "chirp" at a specific frequency and a carefully controlled duration (i.e. a specific number of full waves). As the chirp leaves the antenna, a very accurate time stamp is recorded.



2) The chirp travels down range and may eventually hit one or more objects and some portion of that chirp energy is reflected back towards the radar as an echo.



3) When the echo arrives at the receiver on the radar module, the time is again recorded.

4) The initial and final time stamps are used with the speed of light to calculate the current distance from the objects.

This is the basis of so-called 3-D radar with the three dimensions being angle, elevation and distance.

Typical automotive radars repeat this process about 10 times per second. The distance to each object on two consecutive measurements can be used to calculate the relative velocity (speed and direction) of each object detected.

The latest generation of radar is called "4-D" and can determine the slight frequency shift between chirp and echo (doppler effect) which allows the velocity of each object to be determined by the frequency shift in each measurement, meaning that two consecutive measurements are no longer needed to determine the velocity.

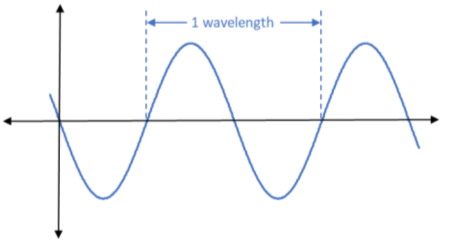
Permittivity and anti-reflection

Most countries have allowed automotive radar to operate in the 76 – 81 GHz frequency range (77 GHz is typical). This frequency range is a gift to automotive radar engineers because the wavelength of these signals is close to the thickness used for automotive plastic parts. Let's take a look at how anti-reflectiveness is achieved.

Like many other transmitted signals, a radar signal can be thought of as a wave. Reflections can be avoided if the signal energy is low (close to the node) as it enters and leaves the material. The Final reflection is the result of the interference between the reflected waves from the 1st interface and the 2nd interface. That is, reflections can be minimized if the material has a thickness of ½ wavelength, 1 wavelength, 1 ½ wavelengths or 2 wavelengths of the signal as it travels in the material.

First, lets calculate the wavelength (λ) of the signal using the speed of light in a vacuum "c" (299,792,458 m/sec) and 77 GHz (77,000,000,000 cycles/sec). Dividing, we get the wavelength in a vacuum:

$$\lambda = \frac{c}{77{,}000{,}000{,}000\ \text{Hz}} \sim 0.00389\ \text{m} = 3.89\ \text{mm (Full wavelength)}$$



Because the speed of light in a material is slower than the speed of light in a vacuum, the wavelength in the material will be shorter in the material as well - but the frequency remains the same. To calculate the wavelength in the material, Covestro has measured the relative permittivity (also known as dielectric constant) of our materials. The quasi-optical relationship can be used at millimeter wavelengths where the square root of dielectric constant equals the refractive index. The refractive index is the scaling factor of the speed of light in vacuum vs. speed of light in the material. Equivalently, the refractive index is the scaling factor in determining the wavelength of a signal in a material vs. its wavelength in a vacuum.

Given the permittivity of Makrolon® AX2675 is 2.78, then the refractive index is 1.667, and the wavelength of a 77 GHz (3.89 mm in vacuum) in Makrolon® AX2675 = 3.89 mm/1.667 = 2.33 mm.

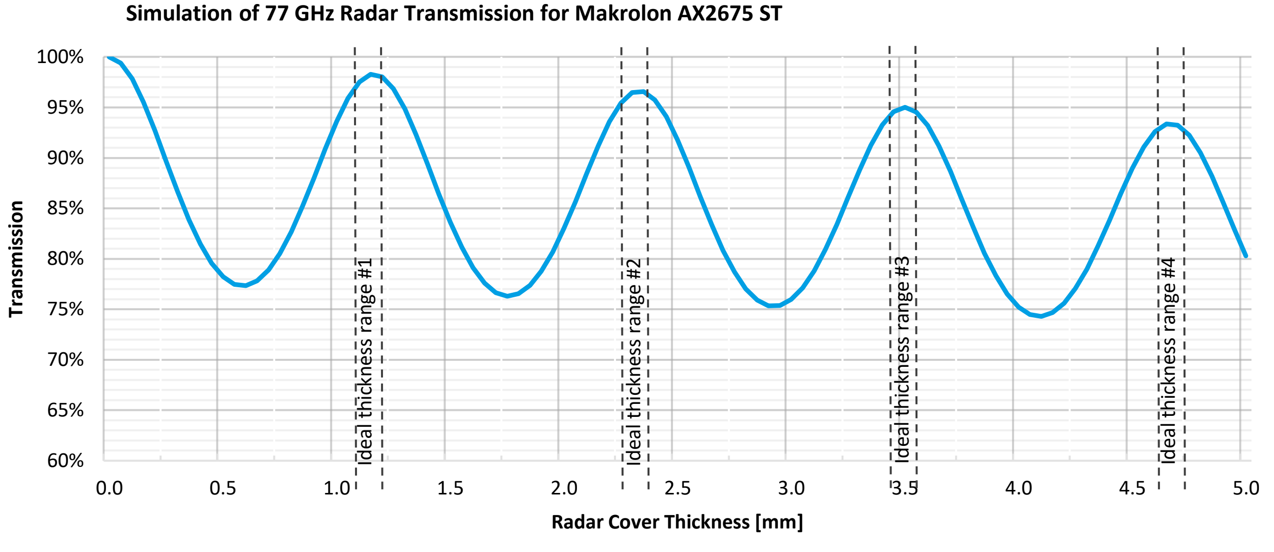
As mentioned above, low reflection losses will be realized in radomes that are ½, 1, 1½, 2 multiples of 2.33 mm. Specifically, good results will be achieved with 1.17 mm, 2.33 mm, 3.50 mm or 4.67 mm. The table below shows permittivity for specific Covestro materials and corresponding part thicknesses that will minimize reflection losses.

		Preferred Radome Thicknesses (mm)				
Material	**Permittivity at 77GHz**	**N = 1 N x λ/2**	**N = 2 N x λ/2**	**N = 3 N x λ/2**	**N = 4 N x λ/2**	**N = 5 N x λ/2**
Bayblend® T95MF 901510	**2.91**	1.14	2.28	3.43	4.57	5.71
Makrolon® AX2675 901510	**2.78**	1.17	2.34	3.51	4.67	5.84
Makrolon® AX2675 900346	**2.76**	1.17	2.35	3.52	4.69	5.86
Makrolon® AG2677 650020	**2.75**	1.17	2.35	3.52	4.70	5.87
Makrolon® AG2677 751092	**2.76**	1.17	2.35	3.52	4.69	5.86
Makrolon® AL2647 550396	**2.78**	1.17	2.35	3.51	4.67	5.84
Please contact Covestro for further specific values as the permittivity is depending on the grade and the frequency						

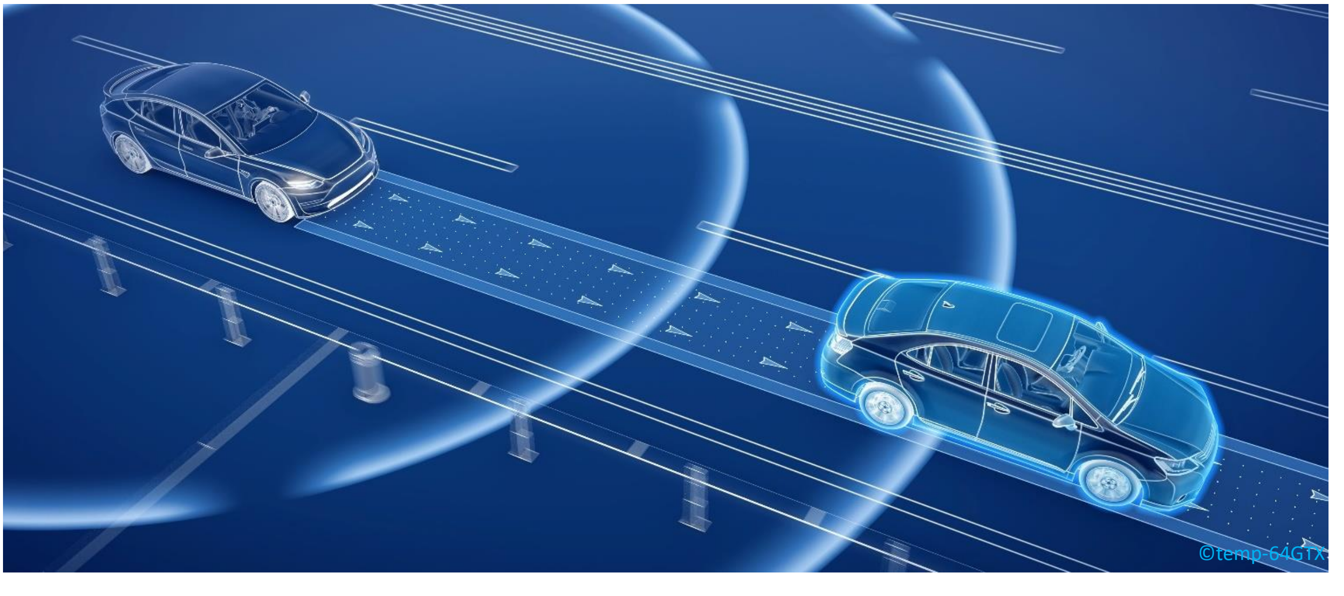
Permittivity is frequency-dependent

Permittivity or dielectric constant has been listed in material datasheets for years, but these values have generally been collected at much lower frequencies like in the MHz regime. Permittivity values measured at these low frequencies should not be used because the values are frequency dependent, and materials will behave quite differently in the MHz to GHz spectrum. If permittivity data is not immediately available on a datasheet for the material you want to use, please contact Covestro.

Influence of radome thickness on transmission



Please keep in mind that for RADAR applications, the signal waves need to pass through the cover twice, so the effective transmission has to be squared in order to get an estimate for the signal strength: $I_{signal} = T^2$
with I_{signal} being the signal intensity and T being the one-time transmission, shown in the graph above.



Makrolon® AX and AG grades – excellent physical properties and mineral fillers.

Makrolon® polycarbonate has great mechanical properties without the aid of mineral or glass fiber fillers. Most other common resins used in automotive exterior applications like polypropylene, TPO and even PBT require mineral or glass fillers to improve stiffness and compressive strength, or to limit the spread of cracks. Exterior automotive Makrolon® grades contain no mineral or glass fillers, which eliminates the risks of permittivity variations across the surface of an injection-molded part.

Shear-induced phase separation can separate mineral or glass fillers across the surface of an injection-molded part to various degrees. The chances of shear-induced phase separation increase when the filler is not spherical – a common polypropylene filler consists of talc and mica which have plate-like geometries.

Filled materials also create a potential variable in lot-to-lot consistency. Naturally mined materials, that are used as fillers may contain small contaminants which can significantly shift permittivity – mica, for example, has a published permittivity range of 2.5 to 10. Glass can range from 2.5 to 7.

Compare PC towards filled PA and filled PBT:

	PC	PA6 GF30	PBT GF30
morphology; haze	amorphous; transparent	semi-crystalline; opaque	semi-crystalline; opaque
density	lower (no GF)	high (GF)	very high (GF)
water absorption	low	high	low
molding shrinkage	isotropic	anisotropic	anisotropic
post-shrinkage	no	yes, anisotropic	yes, anisotropic
thermal expansion	isotropic	anisotropic	anisotropic
part accuracy at different environmental conditions	low warpage, precise	warpage	strong warpage

Advantages of amorphous polycarbonate structure

Water absorption:

Water is naturally attracted to some polymers and can form a significant percentage of weight over time. The permittivity of water is 78, so even a small amount in a polymer can shift permittivity outside of acceptable limits, so that reflection losses will get so high that the detecting range of the radar is reduced.

Polycarbonate can absorb up to 0.12% at 23C/50% r.h. and results in only a minor change in permittivity to the molded radome. A minor change in this case, is a change that can be expected from part-to-part dimension differences in an injection-molding production process. On the other hand, resins such as Nylon 6 (PA6) can absorb up to 10 wt% water. PA66, PA6 and PA610 all absorb more than 1.0 to 2.5% water at 20℃ and 60% relative humidity. (Covestro internal measurements)

Homogeneous permittivity:

The injection molding process could cause phase separation within crystalline structures which leads to a non–homogeneous permittivity. Amorphous Polycarbonate on the other hand – even if filled with mineral additives – doesn't show this behavior. Each generation of radar increases the information extracted from the echo signal, so the demand for homogeneous permittivity will increase accordingly.

Summary

Covestro offers a broad range of design support information and well-characterized materials for use in radomes. Ideal for front grilles, headlight modules, A pillars & B-pillars, Mirror housings, and rear lighting modules or roof- mounted "tierra" radomes.

Covestro also offers lidar-transparent grades of PC that can serve as a single cover to protect both lidar and radar on the same surface.

Product recommendations

Dimensionally stable and precise materials with excellent visual appearance:

- **Makrolon®**
- **Bayblend®**
- **Makroblend®**

Centimeter waves transparency

Antennas

Mobile devices on wheels

Cars are in the middle of a transformation from a pure driving experience towards an online multimedia experience. The expectation of costumers, particularly in the Asian market, is that a modern car will be seamlessly integrated into the digital lifestyle. This trend, combined with some useful safety and comfort-related features, for example Vehicle to Vehicle (V2V) or the Vehicle to “everything” (V2X) connectivity, lead to an increase in the importance of antennas with the best possible connection.

Still, the biggest task in the upcoming years will be the upgrading of infrastructure such as traffic lights and highways, and the developing of unified standards to accelerate the potential of the fully connected driving experience. Nevertheless, the need for antenna-transparent material has never been greater than it is for projects today.

Amorphous thermoplastics such as Makrolon®, Bayblend® or Makroblend® do offer excellent overall physical properties for use as antenna covers. In fact, for many non-automotive applications such as 5G antenna housings, home Wi-Fi routers and laptop covers, polycarbonates are already the material of choice.

For automotive applications, additional requirements must be fulfilled, such as: low thermal expansion (CLTE) to assure that the gaps between metal chassis and its cover remain small; good paintability including color adhesion; and high heat resistance, particularly for large horizontal parts in dark colors. (Keep in mind that additional heat is generated due to the electronics within.) Good mechanical properties are also needed in cases like a rear spoiler with both its impact requirements and durability for the mounting process on assembly line.

At most global OEMs, frequencies are divided by function as follows:

Radio and TV broadcasting

- f_{AM}: 520 - 1710 kHz
- f_{FM}: 76 - 108 MHz
- f_{TV}: several bands between 47-862 MHz
- f_{DAB}: 174-240 MHz and 1452-1492 MHz

Communication

- f_{TEL} (4G, 4.1G, 5G, 5G_low, 5G_high): various bands between 600 MHz and 71 GHz)
  - low band: <1 GHz (older generations)
  - mid band: 1-7 GHz (today)
  - high band: 24+ GHz (future)

Navigation

- f_{GNSS} (GPS, GALILEO, GLONASS, BEIDOU): 1559.052 – 1605.375 MHz

Satellite Digital Audio Radio Service

- f_{SDARS}: 2320 - 2345 MHz

Remote keyless system and Telestart

- f_{RKS}: 315 MHz and 433.92 MHz
- f_{TELE}: 868 MHz

Recommended products for large horizontal exterior parts

Bayblend® T85 XF
Bayblend® T85 X
Bayblend® T90 MF-20
PC+ABS, high ductility, easy processing behavior, low and homogeneous dielectric constant (Dk) and dissipation factor (Df)

Makroblend® UT235 M
Makroblend® UT215 M
PC+PET mineral-filled blends, low CLTE, good ductility, good paint ability, low and homogeneous Dielectric constant (Dk) and dissipation factor (Df)

Makrolon® AX2675
PC in black color to archive a glass like, deep gloss effect in combination with a transparent hard-coating

Amorphous PC and PC blends offer overall excellent antenna permittivity

Common 5G antenna frequencies lie between 3.1-5.8 GHz, with correlating wavelengths between 52-97 mm.

The material-wave interaction is based on the orientation and relaxation of molecular dipoles. There are two relevant material parameters:

- The **dielectric constant (Dk)**, also called relative permittivity, is a dimensionless number which describes the property of an electrical insulating (= dielectric) material.

  Typical values (depending on frequency and temperature):

  Air: ~1, Water: ~78.4

  PC: ~2.8, ABS: ~2.6, PMMA: ~3.4, PP+LGF: ~2.7, PA6: ~3.2, PBT: ~2.9

- The **dissipation factor (Df)** also known as tan “δ“ is a measure of loss-rate of energy which dissipates in all dielectric materials, usually in the form of heat.

For antenna frequencies below 6 GHz, a lower dielectric constant and dissipation factor means less energy is lost from the electric field of the antenna. But for higher frequencies (>10 GHz), the part thickness has a major influence on the losses, the material choice (Dk-value) should be aligned to the part thickness and frequency. It is not always true that “lower Dk values equals better performance”.

Grade Color code	Makrolon® AX2675, 901510	Makroblend® UT235M, 901510	Bayblend® T90MF20, 901510	Bayblend® T95MF, 901510	Bayblend® T85XF, 901510
Dk @5.0 GHz	2.80	3.15	3.11	2.97	2.78
Df @5.0 GHz	0.005	0.008	0.007	0.005	0.005

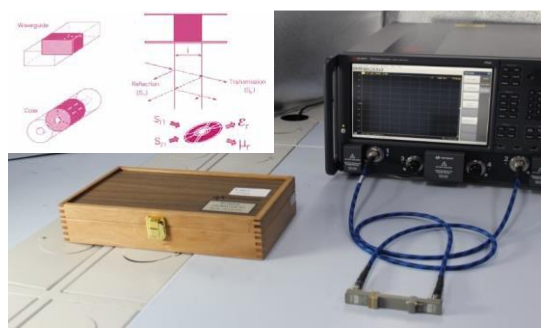
Dielectric constant measurement equipment at Covestro

Resonant cavity method

High resolution

Single frequency testing

1.1 GHz, 2.5 GHz, 5.0 GHz, 10 GHz, 15 GHz, 28 GHz, 40 GHz



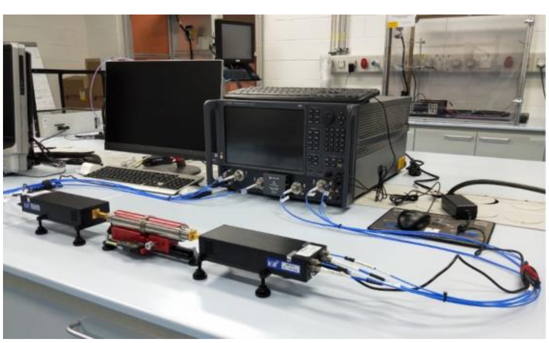
Transmission line method (wave guide)

Continuous frequency band testing

K band: 18 - 26.5 GHz

R band: 26.5 – 40 GHz

Q band: 33 – 50 GHz



Free space method

Continuous frequency band testing

High frequency testing: 66-110 GHz

General information on the design of roof modules

The thermal change in length is a function of the material, i.e. the coefficient of linear expansion (CLTE), but is also strongly influenced by the adhesive bead and the curvature of the roof.

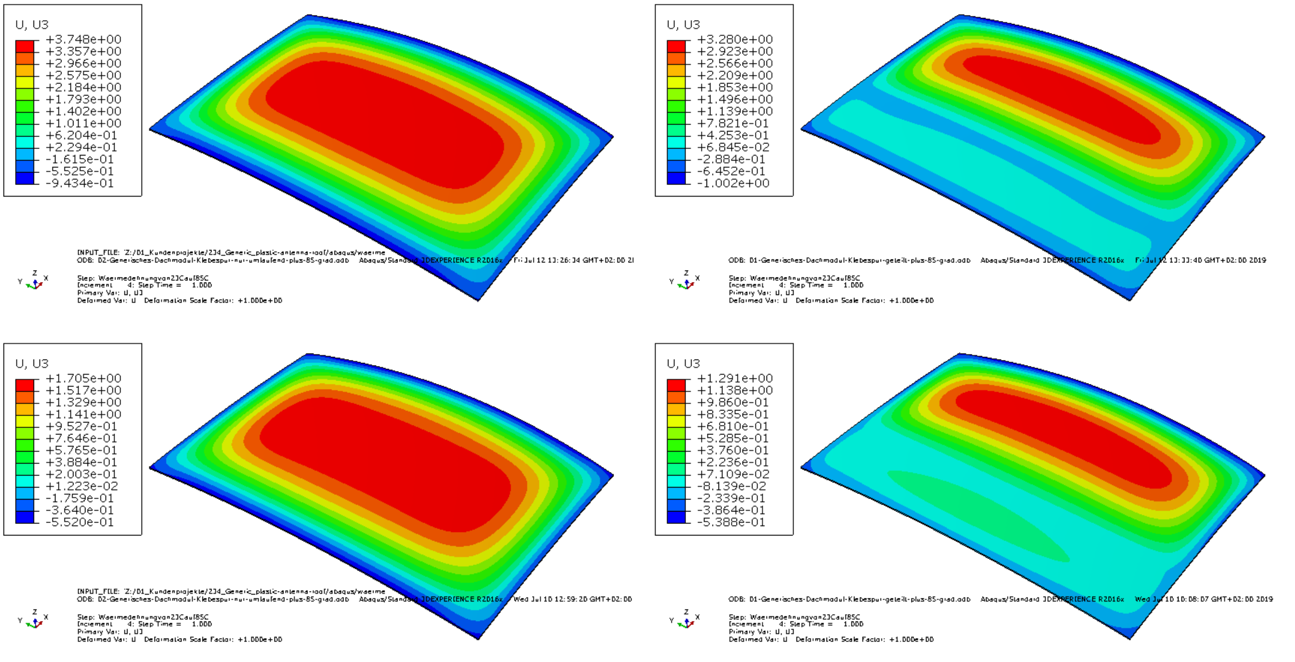
In particular, the deformation under the influence of temperature in the vehicle vertical axis (z-direction) changes significantly if the stiffness of the adhesive is changed (hard / soft) or the stiffness of the adhesive bead is changed by geometric variations (high / flat adhesive bead).

If you try to prevent the roof from changing its length in the X / Y direction with an extremely stiff adhesive connection in order to reduce gaps, this can result in a higher curvature of the roof in the z-direction.

An attempt is often made to support the roof in central areas or to stick it to the body areas underneath. This can disrupt the overall course of the previously harmonious curvature.

The stresses and strains that occur under the influence of external temperatures are usually negligible with a one-component roof and have no negative influence on the thermoplastics. In the normal case - in our experience - no overload is to be expected, provided the adhesive bead is properly designed.

In addition to the materials, the performance of a full thermoplastic roof is heavily dependent on the geometry. We are therefore happy to support you in the design and assessment of the component!



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

- Sensor related engineering know-how
- Application development support
- Expertise in surrounding technologies
  e.g. coatings, deicing, film insert molding
- 5G, RADAR and laser-specific measurement laboratories
- Dedicated team for sensor-related applications

TAKING THE AUTONOMOUS, ELECTRIC AND EFFICIENT GAME TO THE NEXT LEVEL.

Version 1.3

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