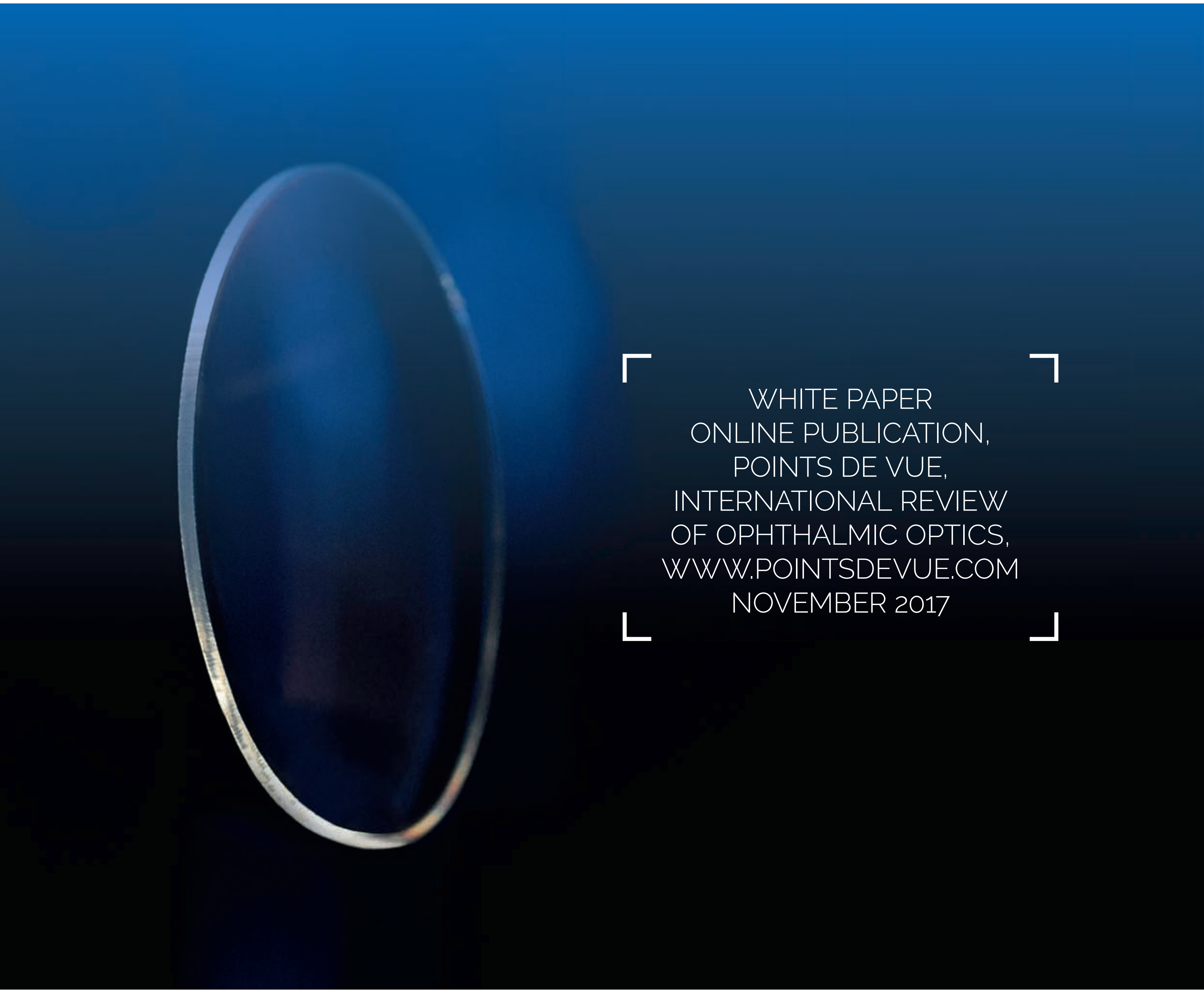
CRIZAL® SAPPHIRE™ 360° COATING*

RESEARCH BEHIND MULTI-ANGULAR REFLECTIONS TOWARDS BEST-IN-CLASS TRANSPARENCY[1]



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*Commercial name can vary depending on countries: Crizal® Sapphire™ 360° UV coating, Crizal® Sapphire™ ccoating, Crizal® Sapphire™ UV coating.
(1) Perceived transparency based on Wearers Test 2017 (Fr) N=50 - Resulting from a better perception of anti-reflective feature - Best in class: among the best within a certain category.

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Maxime joined Essilor International in 2010 after a Masters in Optometry and Vision Sciences from the university of Paris Sud XI (Orsay, France).
He works as a consumer experience study manager, specialized in the evaluation of innovations by consumers. In parallel, he has been teaching optometry to dispensing opticians since 2012.

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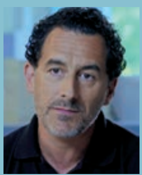

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Tito graduated from the University Pierre & Marie Curie (Paris, France) in Plasma Physics in 1996 and obtained his PhD in plasma physics and material science at Ecole Supérieure d'Optique (Orsay, France) in 1999.
He worked for two years as a postdoc at North Carolina State University (Raleigh, USA), where he conducted applied research in thin films for microelectronics applications. He joined Coherent Inc. R&D (East Hanover, NJ, USA) in 2001. Tito started at Essilor International R&D in 2004, working on thin film processes and anti-reflective designs (Crizal Forte®, Crizal® UV). In 2016, he joined the consumer Young Adult Road Map.

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INTRODUCTION

People are increasingly exposed to multiple light sources, resulting in **overall light saturation**. In our modern indoor and outdoor environments, **light comes from all directions** and generates **reflections on lenses**, which is a source of discomfort for eyeglass wearers.

Crizal® Sapphire™ 360˚ coating is the Essilor **optimal anti-reflective coating**, designed to reduce reflections on both the front and back of the lens regardless of the light's incidence angle.

Thanks to **new calculation tools** and the introduction of a **new nanolayer**, Essilor is now able to manage higher complexity in coatings without having to compromise on anti-reflective efficiency and UV protection.

Crizal® Sapphire™ 360˚ coating is now the most sophisticated product in the Crizal® range, with **360˚ Multi-angular technology™** in addition to all benefits of Crizal Forte® UV coating.

KEY WORDS: light pollution, anti-reflective coating, Crizal® Sapphire™ 360˚ coating, 360˚ Multi-angular technology™, anti-reflective performance, multi-angular efficiency, transparency.

1. THE CONTEXT

LIGHT POLLUTION AND WEARER NEEDS

The light in our indoor and outdoor environments has changed dramatically over the past few decades. Artificial lights, computer screens, LEDs, smartphones and a whole array of connected devices have all had a strong impact on our everyday lives. What's more, the diversity and intensity of lights are not about to decrease any time soon – on the contrary, if anything they are expected to continue to increase.

The term **light pollution**, or photo-pollution, is often used to describe this environmental trend. It is generally defined as excessive, misdirected or obtrusive artificial light.

Light pollution is a major side effect of urbanization and industrial civilization. Its sources include outdoor and indoor lighting, advertising, commercial properties, offices, factories, streetlights and illuminated sporting venues. It is most severe in the highly industrialized, densely populated areas of North America, Europe, Japan and Southeast Asia.

This **trend has been accelerating** as technology has progressed and countries have continued to develop. It covers the following:

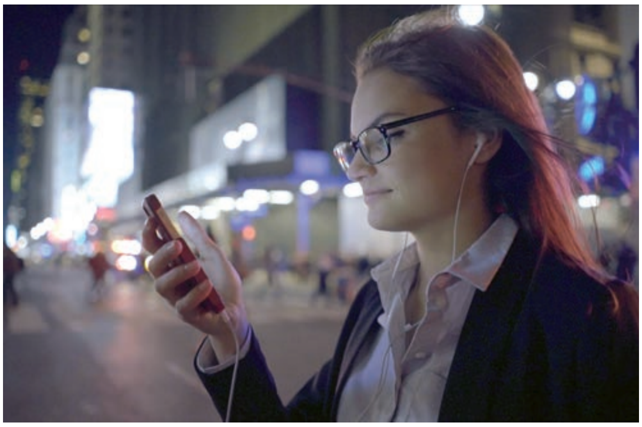
- Changes in indoor lighting such as energy-saving light bulbs, neon lights and LEDs
- New outdoor lighting, in particular street lights
- A massive increase in the use of screens of all sizes and types for a host of different activities
- New screens used for advertising and other public displays

The result is many people feel they are constantly exposed to different types of artificial light, and more often than not it is either unwanted or uncontrollable, coming from diverse sources and **from all directions**.

From an eyeglass wearer's standpoint, the situation is critical. New optical issues such as **backside reflections, optical diffusion** caused by smudges or scratches and **ghost images** induced by multi-reflections within lenses have become common. This could lead to **increased visual discomfort**, forcing wearers to find new alternative strategies.

If properly designed, the eyewear solution can limit intrinsic drawbacks, such as reflections and ghost images.

The new ***Crizal® Sapphire™ 360˚*** anti-reflective coating interacts with light **taking into account its wavelengths** (visible and UV), **intensity** (reflections and ghost images) and **direction** (multi-angularity). As a result, it successfully resolves these issues.



2. THE APPROACH

A NEW WAY OF THINKING ABOUT ANTI-REFLECTIVE COATING

Essilor studied and analyzed the indoor and outdoor lighting environments, identifying many key factors and consumer insights. This led us to rethink the way anti-reflective coatings are designed. Until now our anti-reflective coatings were designed to be efficient around the **normal incidence direction**, which is typically below ± 15°, as required by international ophthalmic standards to be considered anti-reflective (ISO 8980-4 norm). But this configuration doesn't match real-life situations because reflections are only considered in a narrow angular range – lateral and back reflections are not taken into account. In the new approach, illustrated in **Figure 1**, **both the wearer and its luminous environment are considered together.**

FIGURE 1. EVOLUTION OF INCIDENCE ANGLE OF FRONT, BACK AND LATERAL REFLECTIONS

A NEW WAY OF DESIGNING ANTI-REFLECTIVE COATING

For many years producing anti-reflective coatings on a large industrial scale with multiple optical features and a guarantee of high-quality standards (adhesion, durability, scratch resistance, water repellency, etc.) has required significant technical expertise, as well as know-how developed over many years in R&D.

Our main challenge when designing *Crizal® Sapphire™ 360˚* coating was to combine the **wearer's needs** and expectations regarding light pollution with a high level of **UV protection** (same level than Crizal Forte® UV coating with E-SPF® 35 index) while keeping in mind our **industrial constraints**.

Multi-angular efficiency against light pollution. The key parameter used in international standards to assess anti-reflective efficiency is luminous reflectance **Rv** [1]. This factor indicates the light intensity reflected by the lens, as perceived by human eye:

FIGURE 2. LUMINOUS REFLECTANCE FACTOR

$$Rv = \frac{\int_{380}^{780} \mathrm{R}(\lambda).\,\mathrm{D65}.\,\mathrm{V}(\lambda).\,\mathrm{d}\lambda}{\int_{380}^{780} \mathrm{D65}.\,\mathrm{V}(\lambda).\,\mathrm{d}\lambda}$$

R(λ) is the spectral reflectance of the lens, D65 is the spectral power distribution of the standard illuminant and V(λ) the spectral luminous efficiency function of the average human eye for daylight vision, as specified in ISO/CIE 10527.

To quantify the overall anti-reflective efficiency whatever the light direction, **a multi-angular α criterion has been proposed**, defined from an integral in the angular range (0°-45°).

FIGURE 3. NEW MULTI-ANGULAR CRITERION

$$\alpha = \int_{0°}^{45°} Rv(\theta).\, sin\theta.\, d\theta$$

θ *is the incident angle of light;*

UV protection. Although our lenses are UV-absorbing and protect the eye from light coming from the front of the wearer, it has been shown that UV radiation can impact the eye from the side by reflecting on the back surface of the lens [2]. The latest generation of Essilor coatings offers **full protection of the eye from the hazards of ultraviolet radiation**, taking into account UV reflection on the back surface of the lens. The optimized coating for UV protection is therefore the one on the concave side of the lens. A dedicated UV reflection factor R_{uv} [3] was proposed by Essilor R&D experts to measure the UV anti-reflective efficiency of a coating.

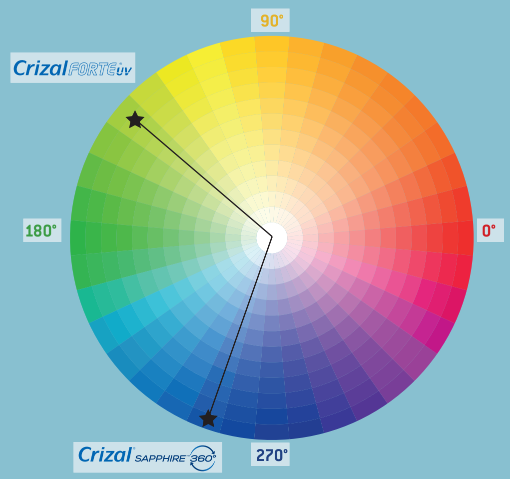
FIGURE 4. UV REFLECTION FACTOR

$$R_{UV} = \frac{\int_{280}^{380} W(\lambda).R(\lambda).d\lambda}{\int_{280}^{380} W(\lambda).d\lambda}$$

R(λ) is the back reflectance of the lens and W(λ) = E_s(λ) S(λ) is the UV eye-exposure function.*

Industrial constraints. Each anti-reflective coating displays a residual color of reflection. A mathematical representation of the color is used, where the hue is expressed as an angle (h°). The saturation of the color or chroma (C*) is the distance that separates the circle center to the color position of the coating [4]. In order to develop products that can be manufactured in various production facilities, anti-reflective stacks are optimized with **high standards in terms of colorimetric stability**, called colorimetric robustness by R&D experts. The colorimetric robustness is defined as the dispersion of the hue angle when applying a random variation of layer thicknesses. Until now, the best compromise that could be found in terms of colorimetric stability was in the green area (h=135°).

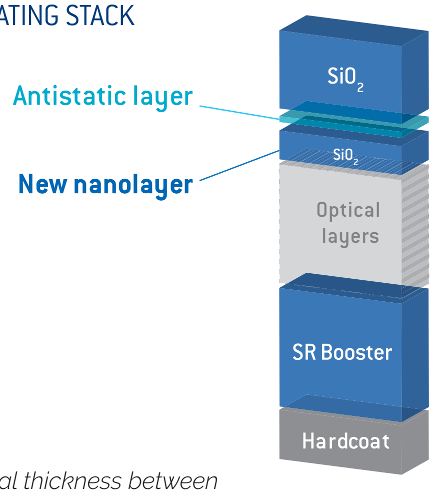
FIGURE 5. CRIZAL FORTE® UV AND CRIZAL® SAPPHIRE™ 360° COATINGS COLORIMETRIC POSITION



THE INNOVATION BEHIND THE CONCEPT

Crizal® Sapphire™ 360˚ coating optimization is the result of innovation over the last four years in combining multi-angular anti-reflective efficiency and a high level of UV protection on both sides of the lens with a high color stability to meet our industrial constraints. Thanks to special and continuous effort, Essilor R&D experts have developed **faster and more powerful algorithms**, allowing to explore new design possibilities and find new solutions out of the green region, and in particular in the **blue region** where level of Rv is lower (Figure 5). Moreover, the introduction of a **new SiO2 nanolayer** underneath the antistatic layer enables ultimate performance. Essilor has filed patent applications to protect this new stack structure.

FIGURE 6. CRIZAL® SAPPHIRE™ 360˚ COATING STACK



Total thickness between 350nm and 400nm

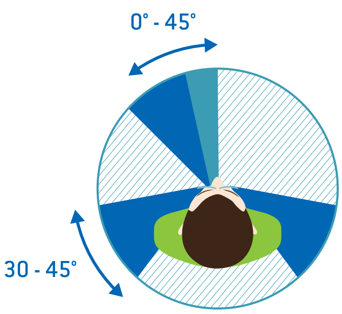
3. CRIZAL® SAPPHIRE™ 360˚ COATING PERFORMANCE

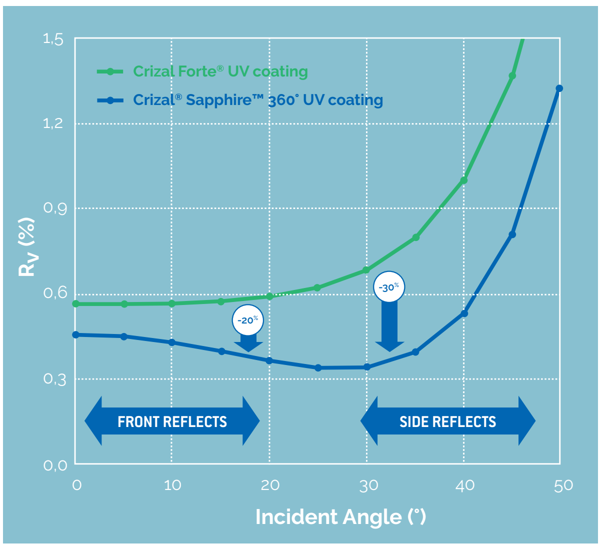
MULTI-ANGULAR EFFICIENCY

The Figure 7 represents the multi-angular anti-reflective efficiency of *Crizal® Sapphire™ 360˚* coating compared to Crizal Forte® UV coating. The curve shows the evolution of the Rv according to the incident angle.

The **lateral reflections are reduced up to 30% and the front reflections up to 20%** for similar substrate/hardcoat configurations.

FIGURE 7. RV EVOLUTION WITH INCIDENT ANGLE





SENSORY EVALUATION

Sensory analysis is a scientific discipline that applies principles of experimental design and statistical analysis to the use of the five senses for the purposes of evaluating consumer products. The discipline requires panels of human assessors on whom the products are tested and recordings of their responses.

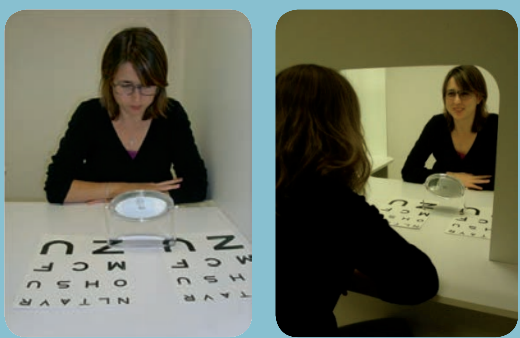
Sensory analysis is used during the design of a new product to measure the impact of a new property or to optimize its formulation. The aim is to **translate consumer perception into words** (indicators) and to **correlate them to the product's measurable physical properties**. Whereas a device measures only one aspect of a product, people give multi-dimensional information, which includes a wide range of visual, tactile, olfactory, gustative and auditory data [5, 6].

In the ophthalmic industry, Essilor was the first to use sensory analysis to assess the efficiency of its new lenses. In the context of *Crizal® Sapphire™ 360°* coating, **two indicators were developed** for assessing multi-angular anti-reflective efficiency:

Front Reflecting (Wearer & Observer point of view)

The wearer looks at him/herself in the mirror, or an observer looks at him/her, and sees the reflection of his/her environment on the lenses with more or less intensity.

FIGURE 8. WEARER ASSESSING FRONT SIDE REFLECTIONS



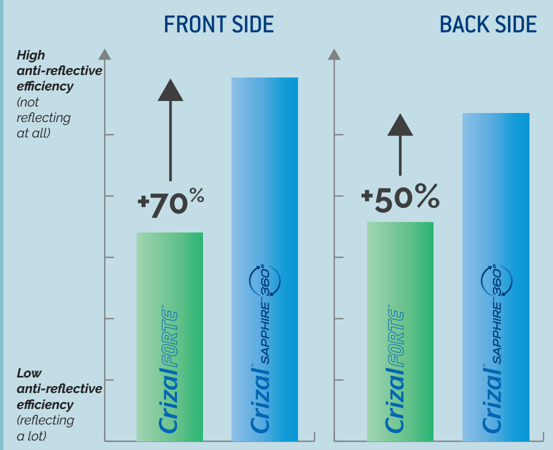
Backside Reflecting

The wearer sees his/her eyelashes, eyes, cheeks and wrinkles on the lens with more or less intensity.

FIGURE 9. WEARER ASSESSING BACK SIDE REFLECTIONS

The evaluation results have shown that ***Crizal® Sapphire™ 360°* coating is better perceived than Crizal Forte® UV** coating by the panel of experts. These results were confirmed on 1.5, 1.6 and 1.67 substrates.

FIGURE 10. ANTI-REFLECTIVE EFFICIENCY PERCEIVED BY WEARERS



+ *70% anti-reflective efficiency in front side perceived by wearers*
+ *50% anti-reflective efficiency in back side perceived by wearers*

WEARERS TEST THE LENSES IN REAL LIFE

In 2017 Essilor commissioned a wearer test on lenses with *Crizal® Sapphire™ 360˚* coating. The objective of this study was to validate the **overall performance** of the lenses with the new coating, as well as the **performances in various daily situations where light could be an issue**. The study was conducted in the US by an independent third party. Before taking part in the study, the 107 wearers had worn lenses on a daily basis either with an anti-reflective coating (n=53) or without an anti-reflective coating (n=54).

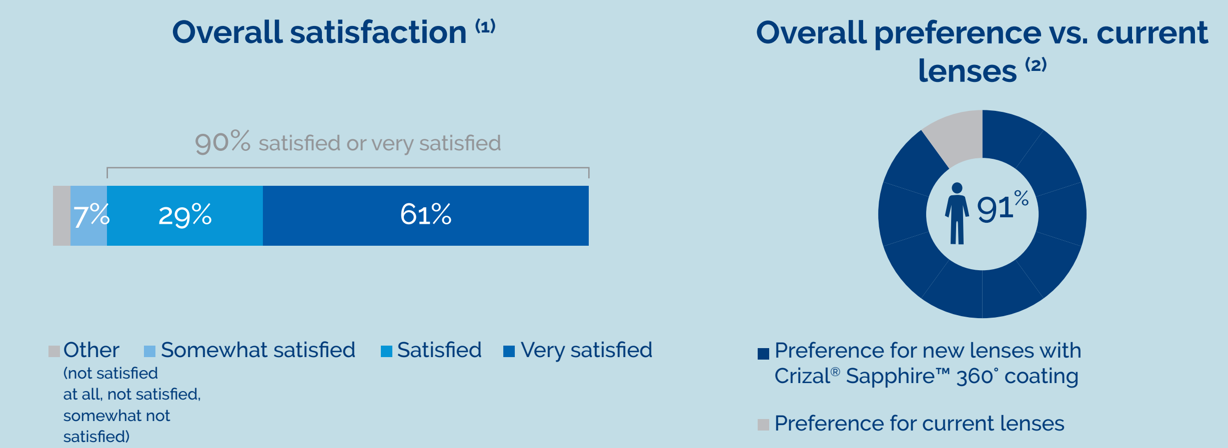
During the study, the participants were provided with the lenses for a three-week wearing period for daily usage, with no specific instructions. After this period, they answered a questionnaire, providing an overall evaluation and a more specific one related to the key benefits of *Crizal® Sapphire™ 360˚* coating.

As can be seen on Figure 11, **9 wearers out of 10 declared being satisfied or very satisfied** with the lenses with the *Crizal® Sapphire™ 360˚* coating, and **91% preferred these lenses** in comparison to their current lenses.

Beyond their overall evaluation, wearers also evaluated the transparency of the lenses in two kinds of conditions:

- When looking at the lenses as an observer to evaluate the **"aesthetic transparency"** (for example, when the wearer was looking at him/herself in a mirror or on a picture).
- When looking through the lenses to evaluate the **"visual transparency".**

FIGURE 11. OVERALL SATISFACTION WITH LENSES WITH CRIZAL® SAPPHIRE™ 360° COATING AND PREFERENCE OVER CURRENT LENSES



(1) 6-point scale from 'Not satisfied at all' to 'Very satisfied' (n=107/107)

(2) 4-alternative forced choice from 'Prefer current lenses a lot" to 'Prefer new lenses a lot' (n=107/107)

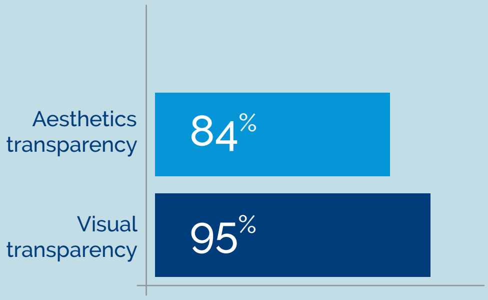
EUROSYN – 2017 – USA (n=107 - 53 current anti-reflective wearers + 54 current non anti-reflective wearers)

As displayed on Figure 12, **84% of the wearers considered the lenses as transparent or very transparent** from the aesthetic point of view. This percentage rises to **95% when the wearers evaluated the transparency when looking through the lenses**.

Finally, wearers evaluated their level of satisfaction when performing various activities in which they were particularly exposed to light pollution, meaning they were exposed to multiple light sources at the same time. Figure 13 shows **86% of wearers were satisfied or very satisfied during these kind of activities in general**. Moreover, when considering certain specific activities, such as **walking in a mall** with multiple artificial light sources or **driving at night** exposed to headlights and streetlights, **up to 90% of the wearers were satisfied with the new lenses**.

It is interesting to note that all the results shown in Figures 11 to 13 are very similar when considering the wearers who usually wear lenses with an anti-reflective coating separately from those who don't.

FIGURE 12. PERCEIVED TRANSPARENCY WITH LENSES WITH CRIZAL® SAPPHIRE™ 360° COATING

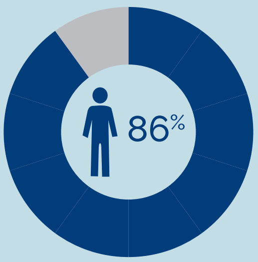


6-point scale from 'Not transparent at all' to 'Very transparent'; % of wearers who answered 'Transparent' or 'Very transparent' (n=107/107)

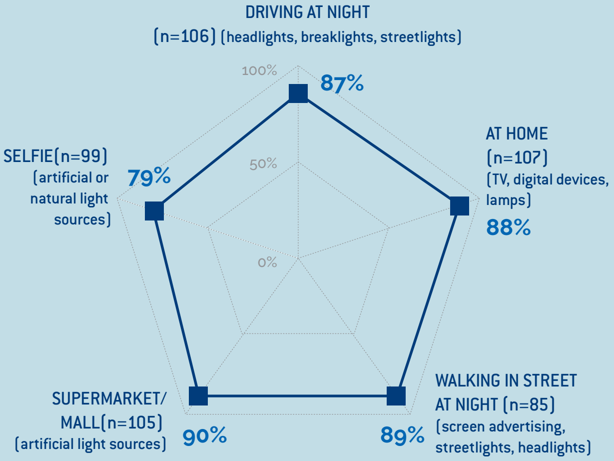
EUROSYN – 2017 – USA (n=107 - 53 current anti-reflective wearers + 54 current non anti-reflective wearers)

FIGURE 13. SATISFACTION IN ACTIVITIES WITH MULTIPLE SURROUNDING LIGHT SOURCES

Overall satisfaction (1)



Satisfaction in various activities (2)



(1) 6-point scale from 'Not satisfied at all' to 'Very satisfied'; % of 'Satisfied' and 'Very satisfied' wearers (n=107/107)

(2) 6-point scale from 'Not satisfied at all' to 'Very satisfied'; % of 'Satisfied' and 'Very satisfied' wearers (n=79 to 107/107 depending on activities)

EUROSYN – 2017 – USA (n=107 - 53 current anti-reflective wearers + 54 current non anti-reflective wearers)

4. COMPETITIVE POSITIONING

Crizal® Sapphire™ 360˚ coating has been designed and optimized in order to be an optimal anti-reflective coating both in UV and visible ranges. It has been compared with competitors' products in terms of multi-angular anti-reflective efficiency and UV protection. The comparison was realized by mapping performance as follows:

1. The new **multi-angular efficiency** α criterion was defined previously. For better understanding and communication purposes, the vertical axis corresponds to $100^*(1-\alpha)$ so that the best performance has the highest value.

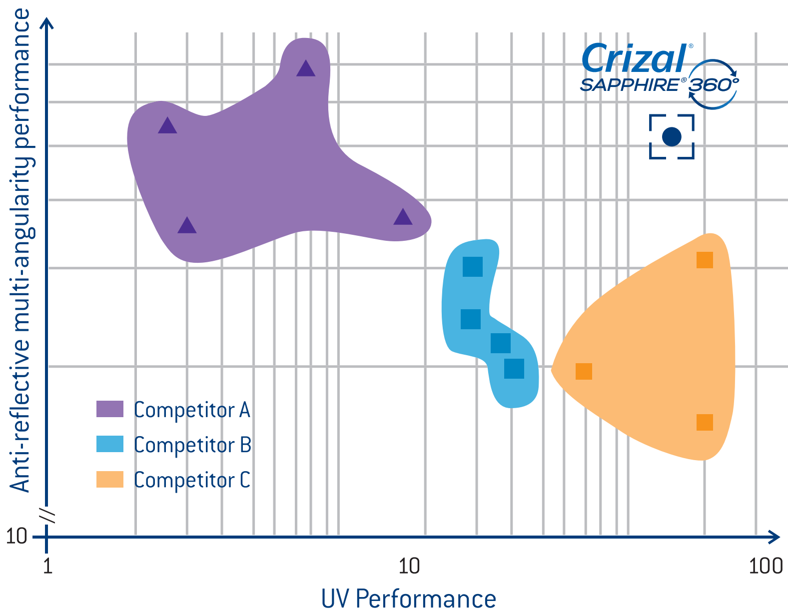
2. The **UV efficiency** is defined as $100/R_{uv}$, and the horizontal axis corresponds to $100/R_{uv}$ so that the best performance has the highest value.

The results are presented on the log-log graphic representation of Figure 14. ***Crizal® Sapphire™ 360˚*** coating's performance is compared to several anti-reflective products launched on the market from 2013 to 2016 by Essilor's main premium competitors.

This graphical representation clearly evidences the presence of three families of the competition's products.

- The family corresponding to the purple area has excellent multi-angular performance. All these products display multi-angular performance similar to *Crizal® Sapphire™ 360˚* coating but without the UV efficiency.
- The family corresponding to the orange area has good UV performance. However, the stacks have limited multi-angular performance.
- The family corresponding to the light blue area shows a low performance compromise along these two axes.
- ***Crizal® Sapphire™ 360˚* coating is a best-in-class product on the market**, and it is the only one to combine such level of anti-reflective multi-angular and UV performance, as well as an **aesthetic blue reflective color**.

FIGURE 14. CRIZAL® SAPPHIRE™ 360˚ COATING PERFORMANCE VS COMPETITION



*Logarithmic representation of multi-angular anti-reflective efficiency as a function of UV performance: **Crizal® Sapphire™ 360˚** coating is compared to competitors' products.*

Crizal® Sapphire™ 360˚ coating represents a true breakthrough in anti-reflective coatings. This is because it takes into account wearers' needs and real-life conditions where reflections on lenses don't just come from the front but from either side and even from behind the wearer.

Essilor has drawn on new calculation tools and a new nanolayer to create highly complex lenses to enhance anti-reflective efficiency without compromising on UV protection.

The 360˚ Multi-angular technology™ makes it the most sophisticated product in the Essilor Crizal® range, providing it with best-in-class transparency for optimal clarity and aesthetics.

In today's society driven by social media, self-image is extremely important and people control their image more than ever before. Understandably, everyone wants to be seen in their best light. Crizal® Sapphire™ 360˚ coating meets this need spot on.

KEY TAKEAWAYS

- In today's modern society, lighting environments are rapidly evolving. People feel they are constantly exposed to light, coming from various sources and from all directions.
- Essilor has optimized Crizal® Sapphire™ 360˚ coating to avoid reflections on lenses from light coming from 0˚ to 360˚.
- By developing new calculation tools and introducing the new nanolayer inside the stack, Essilor is able to manage various optical targets and optimize lens performance.
- Crizal® Sapphire™ 360˚ coating is the best anti-reflective coating on the market for the combination: multi-angularity performance + UV protection.
- Sensory evaluation has evidenced the overall preference of wearers for Crizal® Sapphire™ 360˚ coating when compared to Crizal Forte® UV coating with respect to light pollution.
- Real life study carried out by independent third party revealed that a very high percentage of wearers (90%) are satisfied overall with Crizal® Sapphire™ 360˚ coating. Up to 90% are satisfied with the lenses when doing indoor or outdoor activities with multiple light sources.
- In addition, 95% of wearers find the lenses highly transparent.

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