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Multilayered anti-reflection (MAR) coatings

by **Lisa A. Whittaker** BSc (Hons) FBDO

Dispensing opticians (DOs) can lose count of the number of times in a day that multilayered anti-reflection (MAR) coatings are discussed. Advancements in the field of optics and changes in patient lifestyles have meant that MAR coatings have become standard, with some practices offering MAR coatings included in lens prices.

INTRODUCTION

Anti-reflection coated spectacle lenses provide the following advantages:

- Reduced surface reflections
- Improved visual acuity
- Improved cosmesis

As many patients already wear MAR coated lenses, it is essential to understand a patient's work environment and lifestyle, to be able to prescribe the best lens and offer the correct advice. This has become more significant since the COVID-19 pandemic, which saw a complete change in many people's work-life balance – with a huge shift in remote working that still carries on to this day.

A recent study on digital eyestrain showed 89.5 per cent of participants reported ocular symptoms such as dry eye and asthenopia, and this was reported in higher numbers for those working 16 hours or more from home[1]. Workplace guidance from BUPA (British United Provident Association) now includes advice on eyecare in relation to home working[2].

In February 2022, Office for National Statistics (ONS) data showed how working attitudes had changed since COVID-19, with most adult workers adopting a hybrid working pattern and working predominantly from home[3]. This pattern was reported by 42 per cent of workers, which is an increase from 30 per cent in April 2021. Conversely, the proportion of workers planning to divide time equally between work and home, or primarily work from the office with occasional remote work, has decreased[3].

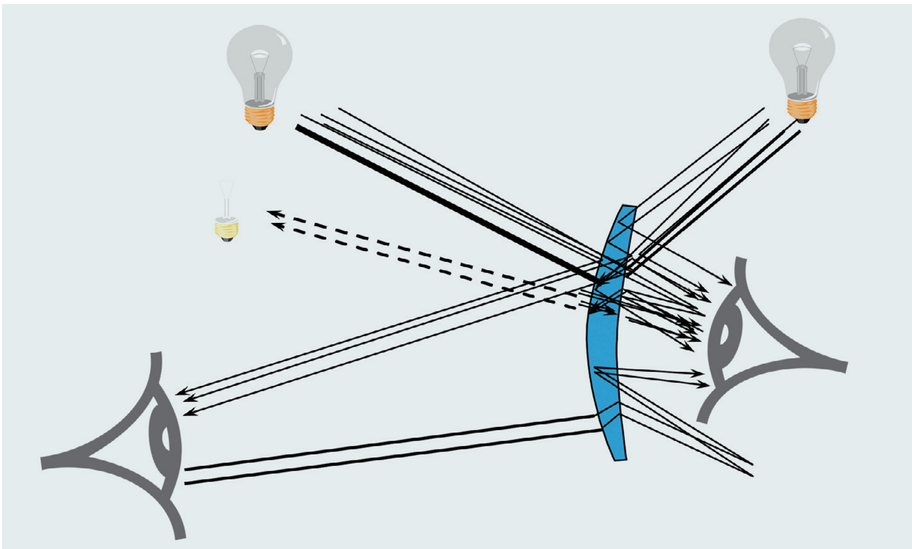

FIGURE 1: Light reflecting from an uncoated spectacle lens

Anecdotally, digital eyestrain has become a significant concern for eyecare practitioners – with complaints reported in practice regarding glare from the home working environment and adaptation to the ergonomics of working from home. Studies exploring digital eyestrain undertaken since the start of the COVID-19 pandemic confirm these issues as a concern[4-6].

In 2021, the Optical Consumer Complaints Service (OCCS) reported on a YouGov survey commissioned by Fight for Sight, regarding working from home and eyesight. This showed that out of 2,000 people surveyed, half reported using screens more since the pandemic, with 38 per cent of these people feeling their eyesight had worsened[7]. The OCCS went on to discuss how these findings were supported by the College of Optometrists[7].

In the UK, the Health and Safety Executive provides a downloadable display screen equipment (DSE) workstation checklist, which can be used by homeworkers as well as those in employer environments to support workstation practice[8].

With patients having easy access to the internet, and able to conduct their own searches on eyecare issues that concern them, such as glare whilst using digital devices, keeping up-to-date with current research and professional guidance is not only necessary for all optical registrants – but is expected[9]. This is particularly important when discussing blue light filter lenses and providing patients with correct advice[10].

Selling blue lens filters has caused some previous controversy for the profession, owing to potential misrepresentation of what the coatings do and how they are sold[11]. Blue light coatings filter blue-violet light from the spectrum, which lies between 400-450nm on the spectrum of light[5] blocking around 20 per cent of blue-violet light from entering the eye. Many patients subjectively find this comfortable for bright office environments and for VDU usage. As shown in the ABDO 'Blue light' guidance, the studies for the benefits of blue light coatings are still ongoing[12].

This article aims to explore why MAR coatings are an important consideration in spectacle dispensing. But before we look into the types of coatings available, we shall go back-to-basics with a refresher on reflections.

REFLECTIONS

As shown in **Figure 1**, internal reflections cause images to reflect from the surface of the lens back to the eye as the light refracts through the lens. Surface reflections vary according to the refractive index of the lens material and can be calculated using Fresnel's equation for each surface:

$$R = \left[\frac{n-1}{n+1}\right]^2$$

There are five troublesome reflections or ghost images seen by the wearer see **Figure 2**. A ghost image is an image formed when light from an object is reflected by at least one of the lens surfaces. For ghost images one to three, the object is situated in front of the lens; and for images four to five, the object is behind the lens. The latter are more troublesome, with larger lens apertures.

Jalie informs us of the conditions "under which ghost images may cause the spectacle wearer difficulty:

(i) The image must be bright enough to stand out against its background. Reflections are rarely noticed outdoors during the day because of the high level of the surrounding illumination.

(ii) The vergence of the reflected light, which leaves the lens and enters the eye, must be similar to the refracted vergence leaving the lens, or capable of being made similar by accommodation of the eye.

(iii) The ghost image must lie close to the fixation line so that it is almost superimposed upon the image which is under fixation. If it is superimposed, however, it may not be noticed – but if it lies just off the fixation line it may be sufficiently close to cause distraction"[13].

Ghost image one is caused by double internal reflections at the lens surfaces. In minus powered lenses, this ghost image appears closer to the centre of the patient's field of view than the image formed by the refraction of the lens. In a plus powered lens, the image is displaced towards the edge of the field of view.

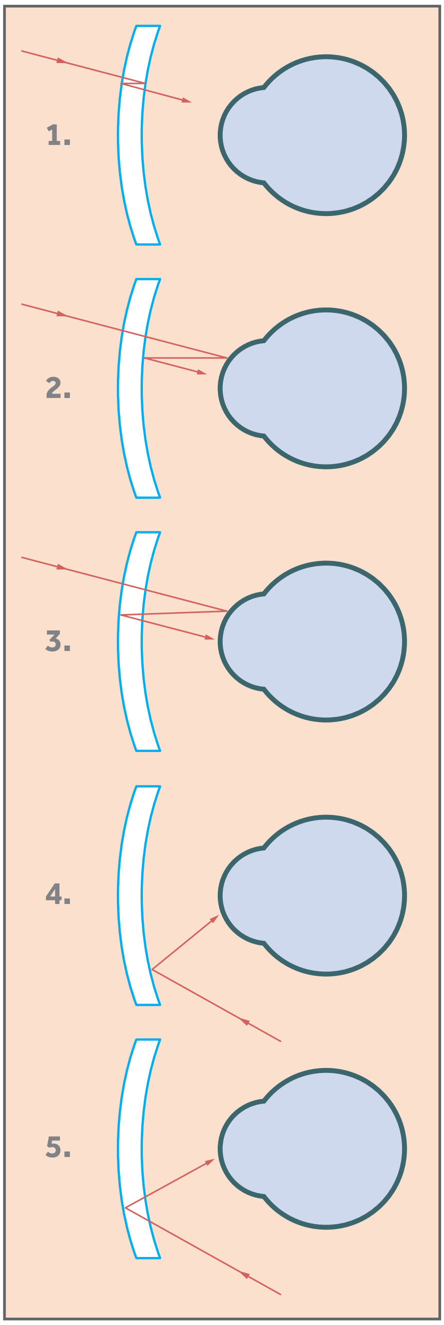

FIGURE 2. Ghost images one to five: reflections created by a spectacle lens

This ghost image can usually be ignored as when the eye looks along the optical axis, the source also sits on the optical axis the image will overlap with the source. Ghost image one tends to become problematic when prismatic correction is incorporated into the lens or when lenses are incorrectly centred.

Ghost images two and three arise by reflection at the cornea and the back and front surfaces of the lens respectively[13]. As the cornea has such a small radius of curvature the reflected corneal image itself is seen on the lens surfaces.

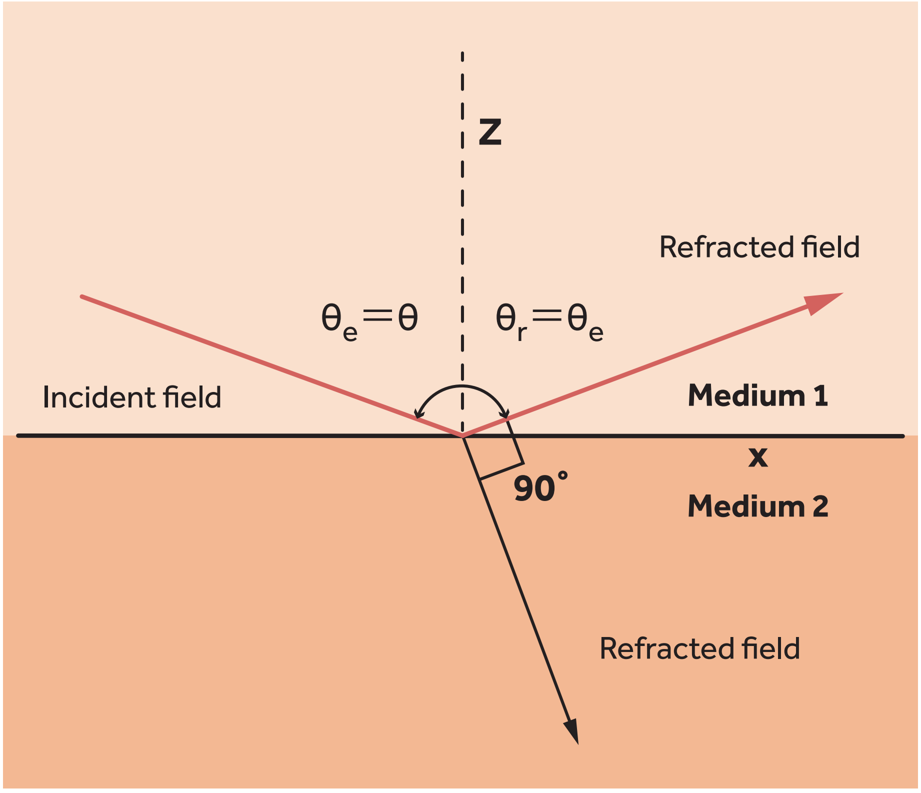

FIGURE 3: Brewster's Angle

On higher prescriptions, MAR coatings reduce ghost imaging from reflections caused by power rings. But how do these coatings reduce reflections? The different layers of anti-reflection coatings provide different benefits; as discussed earlier these include water, oil and scratch resistance. However, the main purpose of the coating is the reduction of glare and reflections. This is achieved through a process called destructive interference. The most simplistic way to describe this would be that using a coated layer to create its own reflections essentially cancels out the reflections that were causing an issue in an uncoated lens.

When incident light hits an MAR coated lens, the waves reflected from the surface are 180 degrees out of phase with those reflected from the surface of the lens, thus cancelling each other out. However, these wavelengths of light do not just disappear; the Law of Conservation of Energy states that energy can neither be created nor destroyed[14]. So, what happens to the energy from the cancelled light waves? It is transferred through the lens medium to the patient's eyes.

This increase in light transmission to the fovea improves contrast and clarity, and theoretically causes spectacle wearers to feel the benefits of a coated lens. Anecdotally, many spectacle wearers report that MAR coatings help them to feel more comfortable driving at night, using VDU devices such as a laptop or mobile phone, and improve cosmetic appearance as, by eliminating the reflections, the eyes are clearly visible to the viewer when seen and photographed.

MANUFACTURE OF MAR COATINGS

MAR coatings are layered upon the lens in several performative layers with the overall function to reduce glare and reflections. These layers are thin when applied and are now routinely joined with hydrophobic coatings, oleophobic (oil repellent) coatings and a scratch resistance layer to create a premium lens.

As shown in **Figure 3**, the internal reflections cause the images to reflect from the surface of the lens back to the eye as the light refracts through the lens. These coatings are usually marketed as anti-glare or anti-reflection, without the difference being stated. However, both are caused by light. The difference is that reflections are rays of light bounced off a surface, while glare is a type of reflection that causes an intense response such as discomfort or reduced vision. Glare is what leads to asthenopia and its known side-effects.

Whilst the manufacturing industry uses a consumer-friendly, jargon free definition of anti-glare and anti-reflection, the truth is harder for those in the eyecare sector when we consider the optics and how these terms work hand in hand. This takes into account the relationship between Brewster's Angle and destructive interference (**Figure 3**).

Brewster's Angle is the critical angle of incidence at which reflected light from a non-metallic surface becomes polarised causing the reflecting light waves to vibrate in a single plane. At Brewster's Angle, the refracted light is polarised perpendicular to the reflected light – meaning that these light rays are at a right angle. When these light rays are at a right angle, they cannot interfere with each other. Brewster's Angle does not affect the amplitude of the reflected wave, while destructive interference reduces or eliminates it.

Let's consider how the layers of the MAR coating are calculated. This thin layer is calculated by considering the path criterion for the interference of reflected light and amplitude conditions. The amplitude condition can only be fulfilled when the intensity of the reflections is equal. These reflection conditions can be expressed as p1 and p2 and calculated as follows, where n_G represents the glass refractive index and n_f the refractive index of the film:

***p* between air and film**

$$p_1 = \left[\frac{n_f - 1}{n_f + 1}\right]^2$$

***p* between film and the lens**

$$p_1 = \left[\frac{n_G - n_f}{n_G + n_f}\right]^2$$

$$n_f = \sqrt{n_G}$$

Originally, on glass (mineral) lenses heat was widely used to 'bake the lens' for its durability. A single layer coating was applied using magnesium fluoride (M_gF_2). This was used owing to its low refractive index and its durability for meeting the requirements of hardness and stability that the layer required. The dispensing profession now widely uses plastic lenses, as they are lighter in weight and are far less likely to shatter than glass, meaning they are generally a safer option.

MAR coatings are applied to organic plastic lenses by two coating substances of high and low refractive indices being applied to the plastic lens surface in a series of parallel layers. Each layer added to the lens substrate adds to the benefit of the lens design, such as the layers previously mentioned. Organic lenses are made from soft plastic polymers and are layered using vacuum deposition. As they are made from softer organic materials, these are layered for durability, e.g. the hard coat, and are set with UV.

MAR layers are required to be thin and there is a need to reduce exposure to external factors such as heat, because this can cause lens crazing and loss of the layer adhesion, by causing them to become unstable and for irregular patterns to form through the lens substrate. As stated by Jalie[13], because the co-efficients of expansion of the plastic material of the lens and coating materials differ so widely, these lenses must not be exposed to heat.

Plastic lenses, as shown in the example in **Figure 4**, are multi-layered and common metal oxides used in its manufacturing are silicon dioxide (SiO_2), zirconium dioxide (ZrO_2) and aluminium oxide (Al_2O_3). These oxides are widely available and provide durability and stability. As we will cover in the manufacturing process, these are applied using vacuum deposition.

The manufacture of anti-reflection coatings varies, with each manufacturer having their own processes and patented techniques, but the general process involves the following[15]:

CLEANING: All dust, debris, residue and oils are removed to make sure the lens contains no imperfections of contamination. This ensures the coating is applied in a uniform manner and ensures layer integrity. These are then safely transferred into the rack in a sterile vacuum chamber in preparation for coating.

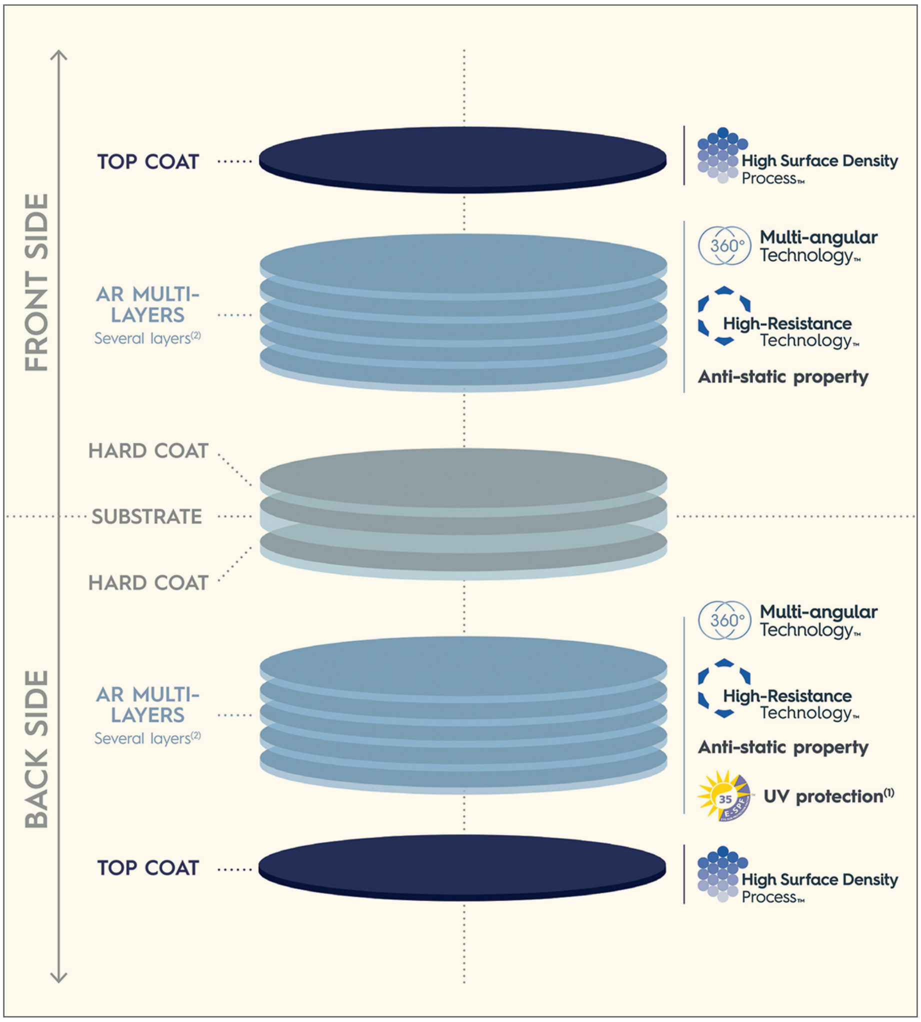

FIGURE 4: Layers of Crizal Sapphire coating (COURTESY OF ESSILORLUXOTTICA)

HARD COATING: At this point during layering, the hard coat is applied to the lens. This improves durability and scratch resistance. This is carried out by the rack being dipped into the hard coat material solution and then thermally cured. The lenses are then cleaned again before the AR coating is applied. This coating is applied first in the process to ensure a solid foundation to the lens that the layers are subsequently applied to.

VACUUM DEPOSITION AND LAYERING: Vaporisation occurs when applying the AR coating. The material then condenses on the lens in a micron thin layer. This is multi-layered and built up depending on the layer design. The solution is derived from metal oxides and varies in refractive indices. The layers are always applied to achieve an odd number of layers. This is so the destructive interference is effective and ensures the best optical performance. The precise number of layers and their composition depends on the specific requirements of the lens and the desired characteristics of the anti-reflection coating.

CURING: The lenses are then cured using ultraviolet light. This sets the lens, solidifies the coating and ensures the lens durability. The lenses would then be checked in quality control to ensure they meet industry standards and contain no flaws.

SPECTACLE LENS COATING ADVANCEMENTS

There have been advancements in coatings as patient environments have changed with new issues arising for spectacle wearers. In practice, there are a growing number of complaints regarding LED car headlights and the difficulty patients experience when driving at night. Reducing reflections whilst driving has always been a key benefit of any MAR lens, however, changes in car design and an increase in cars on the road have been big factors in complaints regarding nighttime glare and reflections.

Many manufacturers now offer specialised driving lenses and coatings to alleviate this form of discomfort glare. Some examples of this are Essilorluxottica's Crizal Drive MAR, Zeiss's Drivesafe and Hoya's EnRoute Pro.

The purpose of these coatings is to reduce glare for these conditions, so patients feel more confident and driver reaction times are not impeded.

For example, in relation to its Crizal Drive lens, EssilorLuxottica states that at night we are exposed to multiple and intense sources of light that create reflections and glare[10]. These reflections and glare disturb rod cells, creating discomfort and lower visual acuity. The company claims that Crizal Drive offers up to 90 per cent less reflection at night, at 507nm where eye sensitivity is the highest, compared to a lens with a hard coat. The bloom of this lens is a pinkish orange hue, which divides patients on its cosmetic appearance. Peers have reported that the cosmetics of many driving lenses is divisive, with some patients unwilling to overlook the cosmetics for the benefits.

Using the Essilorluxottica Crizal range as an example, a white paper released by Essilorluxottica in 2021 purported the benefits of its Crizal Sapphire MAR coating, providing advances in coating design since its last release in 2017[16]. The lens offers a front and back surface UV coating as shown in **Figure 4**, as well as the usual layers required for a premium MAR coating.

This lens incorporates '360° multi-angular technology', trademarked by Essilorluxottica as "a revolutionary way to reach high levels of transparency". This takes into account back surface reflections and a wider angular range. This is a nanolayer embedded within the MAR stack and made from SiO_2. The lens is calculated for multi-angular criterion to achieve these benefits. The multi-angular alpha (α) criterion, defined from an integral in the angular range (0°-45°), is used to quantify the overall anti-reflective efficiency whatever the light direction. Its measurement includes the luminance reflectance factor Rv, used in international standards to indicate light intensity reflected by the lens, as perceived by the human eye.

In another lens supplier example, Tokai recently released its No Reflection Coating (NRC), which does not have a bloom colour[17]. Tokai states that its NRC achieves "unparalleled low levels of perceived reflections" (approx. 0.19 per cent), claiming this "sets a new standard in luminous efficiency and reducing visible reflections". However, Tokai Optical is not the only manufacturer to offer an invisible bloom lens; the BBGR Neva Max Secret was the first of its kind and released in 2018. Tokai has gone a step further with its statistics, as competitors state a reduction of 99 per cent of perceived reflections.

CONCLUSION

These are just a couple of examples of lens coating developments. With a vast array of spectacle lens manufacturers bringing ever more coating advancements to the market, it is imperative for eyecare practitioners to stay abreast of developments and understand the range of lens coatings available, not only in their own place of work by the manufacturers they are familiar with, but in the market more generally.

As an industry, it will be interesting to see how advancements in our field and an increasing focus on artificial intelligence (AI) will affect spectacle lens design in the future[18]. Developments in coating solar panels is already being funded to improve their reliability and cost-effectiveness. Manufacturers are already using AI in their research to develop spectacle lenses[19] – so it may not be long before AI enhanced processes are used to produce spectacle lenses.

LISA WHITTAKER graduated from ABDO College in 2017, and has worked in both multiple and independent practice. She now balances working in an independent practice with clinical supervision at the University of Bradford.

REFERENCES

References can be found when completing this CPD module. For a PDF of this article with references email, abdocpd@abdo.org.uk

LEARNING OUTCOMES FOR THIS CPD ARTICLE

DOMAIN: Communication

1.3: *Assist patients in making informed decisions about their spectacle lens coating options.*

2.1: *Give patients information about spectacle lens coatings in a way they can understand, ensuring your communications are not misleading or confusing.*

DOMAIN: Clinical practice

7.5: *Provide effective spectacle dispensing when considering lens coatings, based on current good practice.*

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