Reflections on Anti-Reflection Coatings

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Abstract

Recently several ophthalmic suppliers have advertised lines of spectacle lenses with anti-reflection coatings. In this paper, the need for anti-reflection coatings and the underlying optical principles are reviewed, and manufacturers' claims are critically examined.

Abrégé

Depuis quelques temps certains laboratoires de produits optiques offrent des lentilles ophtalmiques ayant des couches anti-réflettantes. Ce travail revoie la raison d'être de leur utilisation et les principes d'optique régissant leur performance. Enfin ou scrute d'un oeil critique les réclames fait à leur sujet.

Introduction

Anti-reflection coatings are applied to ophthalmic lenses in order to reduce unwanted reflections from lens surfaces, and to increase the amount of light passing through the lens to the eye. They are usually applied to lenses of high power to improve cosmesis by reducing internal reflections, and to the back surfaces of tinted lenses to eliminate ghost images.

Recently several ophthalmic lens manufacturers have introduced lines of finished lenses which feature anti-reflection coatings. The aggressive approach which has been adopted by some in advertising these lenses to the public makes it necessary for the practitioner to review the rationale for prescribing single or multiple anti-reflection coatings to spectacle lenses.

Why anti-reflection coatings?

Reflections from lens surfaces can be annoying to the spectacle wearer for both cosmetic and visual reasons. Cosmetically, surface reflections are objectionable because of the appearance of power rings, especially in high-minus lenses, as well as the veiling effect of the reflected light which decreases the visibility of the lens wearer's eyes to an observer. (See Figure 1).

Visually, the surface reflections arising from the cornea and the two spectacle lens surfaces can be distracting. (See Figure 1). These ghost images are more significant with high lens powers, steeply curved surfaces, high index of refraction or dark lens tints. The effect of lens parameters on optical properties of ghost images is described in detail by Long[1-4], Jalie[5], and Brooks and Borish[6], among others.

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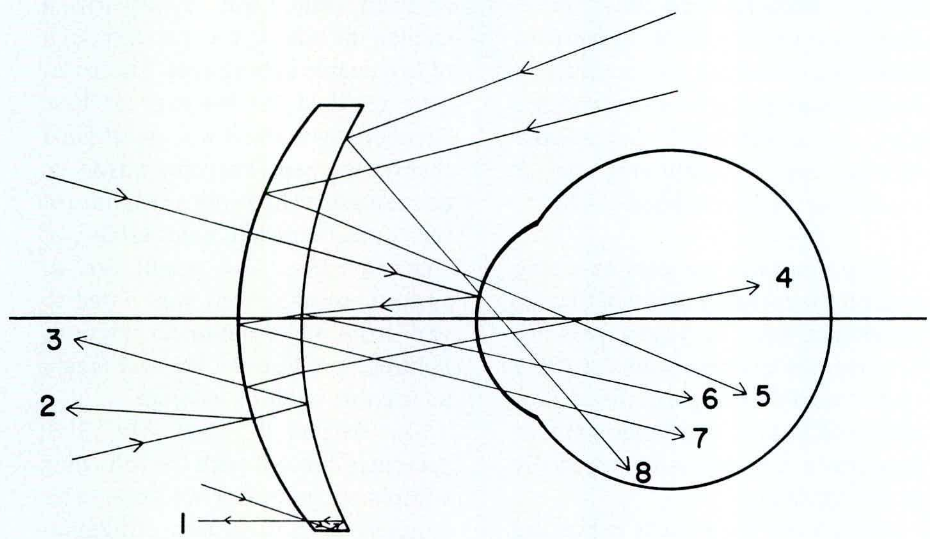

Fig. 1 Surface reflections from the cornea and the two lens surfaces give rise to power rings (1), veiling glare from light sources in front of the lens (2,3), and ghost images (4,5,6,7,8).

How do they work?

Fresnel's equation[5] gives the fraction of light reflected at an interface between two optical media for a beam at normal incidence:

$$\rho = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2$$

For a lens in air with a thin film deposited on its surface we can determine the reflection loss at each interface:

$$\rho_1 = \left(\frac{n_1 - 1}{n_1 + 1}\right)^2$$

at the air-film interface, and

$$\rho_2 = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2$$

at the film-lens interface where n_1 and n_2 are the indices of refraction of the film and lens materials.

The wave theory of light tells us that to eliminate reflections from the air-film-lens system we must satisfy two conditions.[5] Firstly, the two reflected beams must be 180° out of phase; this can only occur when the optical thickness of the film is ¼ — wavelength, or

$$nt = \lambda/4$$

This is the path condition.

We must also select a film which produces reflected beams of equal amplitude. The amplitude condition

$\rho_1 = \rho_2$

is satisfied when

$n_1 = \sqrt{n_2}$

Note that we are assuming light of a given wavelength λ at normal incidence. Clearly these conditions are not met when we consider light at oblique incidence with many wavelengths of radiation involved. The best we can achieve then is a minimum intensity of the reflected beam. While the transmittance in visible light of a crown glass lens is approximately 92%, the single thin AR coat increases the overall transmittance to approximately 96%.

The amount of reflected light can, however, be further reduced by using an appropriate selection of dielectric coating materials such as magnesium fluoride (our standard anti-reflection coating) and, say, oxides of titanium and silicon[5]. Vacuum-deposited at high temperature as a series of thin films on a lens surface, these materials can be used to minimize reflections over several wavelengths in a multiple anti-reflection coating (multi-AR). Using between 2 and 9 discrete layers, it is possible to achieve as high as 99.5% transmittance.

TABLE 1

Anti-reflection Coatings

Supplier	Trade Name	Layers	Colour of Reflections
Essilor	Superdiafal	Multiple	Purple (very dim)
Imperial	Hilite coated Titanium	Single MgF_2	Purple
Vilico Superlite	HMC	Multiple	Green (dim)
Zeiss	ET	Single MgF_2	Gold
Zeiss	Super-ET	Multiple	Gold (dim)

Reproduced below (Fig. 2) is a comparison among uncoated, anti-reflection coated, and multi-AR coated lenses. It is evident that both coated lenses transmit more visible light than the uncoated lens, and the multi-AR coated lens has the highest transmittance across the visible spectrum (400 to 700 nm). Surface reflections, power rings and ghost images would be least conspicuous in the multi-AR coated lens, and worst with the uncoated crown lens.

Available AR-coated lenses

Most, if not all, optical laboratories are set up to supply magnesium fluoride (MgF_2) single-layer anti-reflection coats; larger ones may also do multi-layer AR coats. In the latter case, the number of layers and their composition are determined by the individual laboratory.

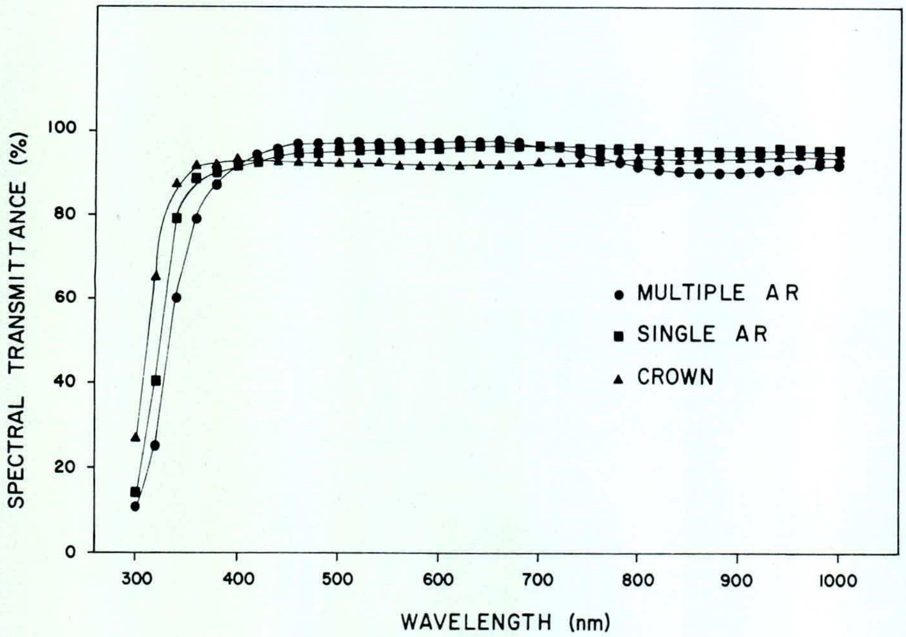

Fig. 2 Typical spectral transmittance curves of plano 2mm-thick ophthalmic crown glass lenses. a. uncoated; b. AR-coated; c. multi-AR coated. Transmittances were measured on a Zeiss DMR-21 dual-beam recording spectrophotometer.

The lenses advertised by Essilor (Superdiafal), Imperial Optical (Hilite Coated Titanium Lens), Vilico Superlite (Hoya Multi Coat or HMC), and Zeiss (ET or Super-ET) are manufacturers' standard glass lenses with the supplier's specific AR coating supplied on the lens. The information on these coatings is given in Table 1.

Readers should note that both the Zeiss Tital and Imperial Hilite Titanium lenses are made from the Schott titanium high-index glass. An order for Tital-ET or Hilite Coated Titanium is automatically filled with a single-layer MgF_2 AR-coating on both surfaces. The coating is therefore the same as the "Standard" AR coating which can be applied to any glass lens.

Superdiafal, HMC and Super-ET are proprietary multiple-layer coatings which can be distinguished by the colour of the surface reflections. (See Table 1). As advertised, these multi-layered coatings produce very faint residual reflected images.

What do you choose?

On the whole, it would appear that the anti-reflection coatings being advertised in the ophthalmic literature are not substantially different from those which have been supplied by most fabricating laboratories. They do have the advantages, in theory, of better quality control over the coating applied to the finished lenses. However, this is a moot point.

In terms of availability, certain lines of lenses (particularly HMC and Zeiss Filter-ET) are not *stocked* in a full range of spherocylinder power, but all can be ordered on a special order basis. By contrast, the "standard" laboratory treatments can be ordered for any lens.

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Rona from P. 29

glucose tolerance (but not always). I have yet to see a case of arcus juvenilis where these facts do not hold true. In Mr. R.B.'s case, it is clear that his risk for both coronary artery disease as well as diabetes mellitus is above average. Incidentally, Mr. R.B.'s father has both mild adult - onset diabetes as well as high blood pressure and a pacemaker at the age of 76.

By using arcus juvenilis as an alert for prevention of coronary artery disease as well as diabetes mellitus we may be doing many of our patients a great service. Arcus should alert the practitioner to arrange for appropriate biochemical testing (glucose tolerance test, lipid profile, liver function tests) to rule out the possibility of either existing or impending pathology. Certainly, it is not a sign that should be ignored.

Once the biochemical abnormalities are elucidated by blood, urine and hair mineral analysis, an appropriate diet can be discussed with the patient as well as possible lifestyle modifications.

We encourage other practitioners to at least look into this holistic approach to patient care (eye and otherwise).

We have seen one case where Wilson's disease, hepatolenticular degeneration, presented first as a faint corneal arcus in a teen-aged boy.

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The most important consideration in ordering AR coated lenses should be whether the patient is particularly annoyed by ghost images. A bright ghost image can be made dim enough to be negligible with *any* type of antireflection coating, regardless of whether the image is seen in or out of focus. Clearly patient complaints should have priority over fashion considerations.

In summary, there is little difference between the "new" brand-name lines of antireflection coatings and the coatings for any glass which have always been available from optical laboratories. However, the decision to use a "brand-name" or "no-name" anti-reflection coating is a matter of the prescriber's personal preference.

Acknowledgements

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