The popularity and extensive use of anti-reflection coatings provide benefits to patients and to practitioners. The aim of this article is two-fold.

First, to provide information to help the expansion in the use of coatings that will benefit the patient, plus broaden the knowledge base of staff involved when dealing with patients.

The consumer research companies are distributing data that shows consumers are expecting more information on their purchases from informed staff.

More and more patients research the internet before making any purchases; often the information is inaccurate. The patient will pose questions and expect the person dealing with them to be able to furnish an informed opinion.

Multi-layer anti-reflection coatings were introduced to the UK by manufacturers in the mid 1970s. Prior to that date the coatings were single layer. They had been available since the 1950s. However, the history of ‘thin film’ coatings dates from the last decade of the 19th century. The pioneering work in this field was by an English scientist named Dennis Taylor. Taylor lived in Yorkshire, was employed in the photographic industry and discovered that older glass lenses would transmit more light than newly manufactured lenses. He detected that the source of this phenomenon was a tarnish that had accumulated on the surfaces of older lenses. The tarnish had been caused by oxidation on the lens surfaces from environmental pollution. The original discovery was made in 1892.

Taylor continued working on this process and by 1904 he had obtained a patent to chemically cause the tarnish or oxidation to accumulate on the lens surfaces. This chemical reaction artificially aged the lenses to improve their light transmission. The outcomes from this process were a series of lenses that helped photographers take better quality photographs when their cameras had the Taylor lenses.

In 1935, the Zeiss Optical Company in Germany obtained a patent for a single-layer coating on a glass lens. Unfortunately, World War II brought a halt to development, but in the 1950s, Zeiss was once again a major manufacturer in the ophthalmic field and introduced the single-layer anti-reflection coated lenses as their Punktal lenses.

**Thin films**

Anti-reflection coatings are part of a large group known as ‘thin films’. Thin film coatings can be applied to transparent surfaces in order to:

- Reduce reflections and increase light transmission
- Create a mirror coating that will reflect incident light
- Add a metallic finish to plastic materials that can be used as covers on the tops of perfume bottles or tops for bottles containing soft drinks.

Mirror coatings will be discussed in future articles relating to tinted lenses. Additionally, mirrored coatings are used when dealing with lasers when a maximum reflection is needed when using lasers.

The lens covers for instruments in an aircraft cockpit have coatings applied to their surfaces. Once again it is important to increase the light transmission of a transparent material and eliminate the problems of ghost images. Ghost images could cause a pilot to misread the instruments and slow down or hinder his reactions in an emergency.

**Reflections**

From the outset manufacturers have placed a heavy emphasis on the cosmetic advantage and improvement that anti-reflection coatings provide for the spectacle wearer. The reflections that are the most obvious are those seen by an observer from the front surface of the spectacle lens. More than half of the reflections seen by the observer are also coming from the back surface of the lenses (Figure 1).

Additional problems detected by an observer arise when the wearer has a correction for myopia. The thick edge of the lens acts as a reflecting surface for incident light, causing the appearance of a white ring following the shape of the lens. These are internal reflections as shown in Figure 2.

The wearer of the spectacle lenses is also aware of the reflections; they appear as ghost images within the wearer’s visual field. This presents an annoying problem for the wearer and a distraction when they are carrying out any task.

Figure 3 illustrates how ghost images are caused by internal reflections. The problems with ghost images can be apparent in situations of low or high illumination. The wearer’s correction will influence this phenomenon, namely it is generally more annoying for patients with myopic prescriptions. Consider a person wearing uncoated spectacles and driving a car at night on a country road. Ghost images will be troublesome when a car approaches from the opposite direction. The situation will become worse when a car approaches from behind. The internal
mirror and the two door mirrors will reflect the headlights onto the face of the wearer. The headlights will cause reflections on the back surface of the spectacle lenses. All of this dazzle will have a disturbing effect on the wearer’s vision. Figure 4 illustrates this situation.

These problems do not occur in isolation, but simultaneously and can contribute to constant frustration encountered by the wearer. The next step is to consider the importance of the formula Fresnel developed to calculate reflectance at a single surface:

\[ r = \left( \frac{n - 1}{n+1} \right)^2 \]

By substituting the value of the refractive index of any lens material in the above formula, you can calculate the reflectance at each surface. Then obtain the overall percentage of light transmitted by a material. Bear in mind the percentage of incident light at the second surface will not be 100 per cent, it will reduced by the quantity lost to reflection at the first surface.

From Table 1 it can readily be deduced that as the refractive index of a lens material increases the percentage of incident light lost to reflection will increase.

**Theory of anti-reflection coatings**

An anti-reflection is extremely thin; it could be explained by considering the following illustration. A layer of snow 5mm in depth lying on top of the roof of a building that is 500m in height is the same ratio as an anti-reflection coating deposited on a lens that is 2mm thick. Light travels in the form of waves that have a length and amplitude that can be measured.

When light waves meet you may have a situation known as (a) constructive interference, or (b) destructive interference.

In (a) the waves colliding with each other add to the size and the wave becomes larger. However, in (b) if you reverse the direction of one of the waves (Figure 6) or create a negative image of the wave, then add it to the plus wave in Figure 5, the outcome will be zero. This is destructive interference.

Now consider the spectacle lenses being worn and how this application of a coating will benefit the wearer. A light wave can be seen entering the surface of the coating and reflecting from the front surface of the coating. As the wave of light progresses, the wave continues though the coating, it will reflect at the front surface of the lens. The wave path returns out from the lens (Figure 7). The wave has reversed and has now become a negative wave. It is alongside a positive wave. This will happen since the coating has a thickness that has been calculated accurately to be one quarter of a wavelength. The wave has travelled one quarter of its length to reach the front surface of the lens. Then a further one quarter wavelength as it reverses back from the front surface. Consequently, the wave has travelled one half of its length, thus reversing itself with the next wave approaching the coating. This causes the waves to exhibit destructive interference. The result is that the waves cancel out each other. In this example there is only a single-layer coating, therefore there will only be one wavelength of light cancelled; the other wavelengths will still be visible. The direct result is to increase the amount of light energy entering the wearer’s eyes. This benefit can be considered to be constructive interference.

The coatings so far have been single-
layer; when they were introduced in the 1950s the coating had a distinctive bluish purple appearance. The single-layer coating was designed to eliminate reflections at the 555nm wavelength. This left the blue and red ends of the spectrum untouched. Hence the bluish purple colour also described as a magenta appearance. This did not produce a good cosmetic effect for ophthalmic use. The single layer coating will be better as an application with instruments that have multi-lens systems.

Moving forward to employing a two-layer coating will create a wider reduction in reflections. Unfortunately it does not reduce any wavelength below 1.5 per cent reflectance. The application of multiple layers of coatings on a lens surface will provide the best reduction of reflections while showing the best improvement in light transmission. This will also demonstrate the best control of the residual colour of the multi-layer coated lens.

The manufacturers spent significant time and effort attempting to overcome the residual colour problem. By adding the additional layers, extra light energy wavelengths or colours will be eliminated. The formulae necessary to calculate these values are complicated and also commercially confidential to the various manufacturers. Therefore there will be subtle differences between coatings from different manufacturers. The coating companies are continuing to research the possibility of achieving a colourless coating.

### Manufacture

So far we have looked at single-layer coatings, two-layer coatings and multi-layered coatings. As stated above, a two-layer coating is superior to a single-layer coating. However, it does not follow that a 30-layer coating would be superior to a six- or seven-layer coating. The improvement in energy transmission is achieved by the contribution the individual layer makes to the overall efficiency of the coating. This returns to the individual recipe that each manufacturer follows when it is coating lenses. However, as the technology improved so did the reliability and durability of the coatings.

The process of coating lenses is a highly technical one involving a variety of techniques using expensive and very precise machinery. The various processes have to be carried out in a clean environment similar to an operating theatre in a hospital. The technicians have to wear protective clothing that will prevent any external contamination. Visitors to manufacturing plants are unable to see the process being carried out since microscopic-sized particles on their clothing could easily contaminate the sterile environment and cause financial loss to the manufacturers. Plus the contamination would have a negative effect on the quality of the coating. This contaminant could shorten the useful life of the coating. This would result in unhappy patients, frustrated practitioners and manufacturers who would be dealing with patient complaints. After the lenses have been thoroughly cleaned and dried they are loaded onto a carrier prior to being placed in the vacuum chamber (Figure 8).

The air in the chamber is pumped out to create a vacuum. This removes all air molecules that could hinder the evaporation process as the various layers are being deposited on the lens surfaces.

### Vision benefits

As mentioned earlier, the cosmetic benefits of coatings have always been easy to demonstrate. When multi-layer coatings were first introduced in the mid 1970s one manufacturer supplied optical practices with an uncut lens that had a coating applied in a central area of the lens. When this lens was placed against a black background the central portion of the lens gave the appearance of a lens with a hole in it. The coatings were viewed by patients as something that made their lenses disappear. This was a tremendous selling point of the benefits of multi-layer coatings.

Prior to 1981, there had been no direct clinical research demonstrating any vision benefits that a wearer would derive from multi-layer coatings. Two Canadian ophthalmologists named Coupland and Kirkham conducted a study on patients who had developing cataracts. They carried out vision testing of the patients in situations with different levels of illumination plus the distraction of additional glare. Their study was an earnest attempt to show that the patients would benefit from coatings. During the study the investigators created a glare source that they could turn off and on while the subject was viewing a test chart. The glare source for each subject was two small torch lamps attached to the inside of the spectacle frame sides. The glare sources did show that the coatings helped the wearer to overcome the distractions of the glare. However, one criticism of the method is, when would a patient encounter a glare source so close to their face? A second criticism
of their study was the sample size or number of study participants. There were fewer than 10 subjects in the study.

In 1997 a paper was published by two researchers at Indiana University that did show an increase in contrast sensitivity when patients were viewing targets of varying contrast through coated and uncoated spectacle lenses. All of the participants in this study had a corrected visual acuity of 6/6 or better and were free of any ocular disease. The participants were aged between 18 and 75 years. There were two glare sources in this study. During some parts of the test the glare was directed at the test letters. On another set of tests the glare source was shining on the subject’s face. Lastly there were occasions when the glare sources were simultaneously shining on the subject’s face and on the test letters. In this latter study all of the participants were wearing lenses made from CR39 with a mean refractive index of 1.49. When offered the choice, all of the participants preferred the coated lenses over the uncoated lenses. A side issue that emerged was that subjects who needed only a presbyopic correction for computer use and near work also needed only a presbyopic correction over the uncoated lenses. A side issue that emerged was that subjects who needed only a presbyopic correction for computer use and near work also needed only a presbyopic correction over the uncoated lenses. A side issue that emerged was that subjects who needed only a presbyopic correction for computer use and near work also

Checking AR coatings

When checking a pair of spectacles after they have been produced by a laboratory, the person carrying out the procedure needs to verify the accuracy of the prescription to ensure it meets the relevant EN standards. Next the lens surfaces should be checked visually for any minor blemishes. To make this process simple and accurate, have a matt black surface and a bright lamp. Hold the lenses so that you can view each surface independently and rotate the lens directly under the lamp. Any minor blemishes will be readily seen by an observer. The surrounding coating will make any small blemishes conspicuous. Also carry out a visual check to ensure that the residual colour of the coating appears uniform across the lens.

Lens care

If you refer back to Table 1, you will notice that as the refractive index increases it is a wise precaution to ensure that a multi-layer anti-reflection coating is added to the lenses. The lens materials of mean refractive indices higher than 1.54 offer many benefits for the wearer. Obviously the higher index allows the prescription to be made thinner and possibly lighter in weight.

If you use a material where the mean refractive index is greater than 1.523, the patient may be troubled by the reduction in light transmission. This problem may not be easily uncovered. The patient may complain that the new spectacle frames are ‘not as clear as their previous pair’, especially if they had a lower refractive index.

Most jobs today involve significant computer use. It is a wise precaution to ensure that lenses are multi-layer coated regardless of the refractive index of the lens material. Environmental factors, such as overhead lighting and the location of windows in their office, may further complicate the issue. By asking the patient a few pertinent questions during the initial dispensing visit, the eye care practitioner will possess information that can help them to suggest the benefits that coatings would provide to the wearer.

Patients who require detailed vision and have to make fast and important decisions in their work, for example a train driver, professional driver, an air traffic controller or pilot, all should have coatings on their prescription spectacles. A ghost image could distract the wearer and delay a decision process.

Patients who have impaired vision should be advised that coatings may increase their ‘comfort level’ when wearing their spectacles. The increase in light transmission would be beneficial for them. This is in no way stating that a coating has a therapeutic benefit.

Figure 9 shows the effects of substances that may adhere to a lens surface. Any of these substances will increase reflections and be clearly visible to an observer while irritating the wearer. Water usually dries quickly and is not too troublesome. Oil, usually in the form of sebaceous secretions from the wearer’s body, can cause smears that are highly reflective. The coating manufacturers have made great strides to eliminate this inconvenience for the wearer.

Whenever you are dispensing a pair of coated lenses it is important to communicate to the patient some of their responsibilities in taking care of their spectacles. Review with the patient the care instructions that you will receive from the manufacturer on methods of cleaning their lenses. Please ensure that there are no ambiguities on the part of the patient. Pass on any microfibre clothes and solutions that the coating company supplies with the lenses.

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### MULTIPLE-CHOICE QUESTIONS – take part at opticianonline.net

1. The reflections that spectacle lens wearers find most troublesome are mainly from:
   - A The front surface of the lens
   - B From internal reflections within the lens
   - C From the back surface of the lens
   - D All of the above

2. Anti-reflection coatings are applied to lenses in optical instruments in order to:
   - A Increase the amount light reaching the operator
   - B Reduce chromatic aberration of the system
   - C Minimise glare for the operator
   - D Extend the life of the instrument

3. The percentage of light reflected by an uncoated ophthalmic lens of mean refractive index 1.49 is:
   - A 12.39 per cent
   - B 87.61 per cent
   - C 7.59 per cent
   - D 92.41 per cent

4. Anti-reflection coatings will reduce reflections by:
   - A Destructive interference
   - B Reflecting light from the coating back into the lens
   - C Constructive interference
   - D Absorbing the incident light

5. The principal advantage of a multi-layer coating over a single-layer coating is that:
   - A Liquids do not adhere to a multi-layer coating
   - B There is less residual colour
   - C There will be greater transmission of incident light
   - D The number of reflections decreases

6. A single-layer anti-reflection coating will eliminate:
   - A A single wavelength of light energy
   - B All ultraviolet radiation
   - C More than two wavelengths from the visible section of the spectrum
   - D All infra-red radiation

Successful participation in this module counts as one credit towards the GOC CET scheme administered by Vantage and one towards the Association of Optometrists Ireland’s scheme.

The deadline for responses is April 19 2012