# Measuring AR performance and layer properties of Ophthalmic lenses - with the nkd *Series*

This application note Illustrates the use of the *nkd* optical coating measurement system for the characterisation of layer thickness and coating performance of ophthalmic lenses.

Introduction

Every few seconds a pair of glasses is sold, and that is just in the UK. Each one of the lenses in these, has been through a number of thin film coating processes to make them suitable for the modern spectacle wearer.

Spectacle lenses were traditionally made of glass, but are more commonly now made of moulded Polycarbonate. The average spectacle lens begins life as a polycarbonate blank, onto which a hard coating is applied by a dipping method. Sometimes this is the only processing the lens undergoes prior to installation in spectacle frames. More commonly now though the lenses have an anti-reflection(AR) coating applied to reduce glare. Tints are also added for UV screening and aesthetic purposes. If the anti reflection coating is present, another hard, scratch resistant coating is usually applied on top.

The PVD layers which make up the AR coating can range from relatively simple 4 layer structures to 12 layers or more, with typical materials being $SiO_2$ and $ZrO_2$. The lacquer and PVD coatings are all subject to QC control at the place of manufacture and of course, there is always some coating development in progress.

Standard industry practice for QC control in vacuum and other coating processes is to insert a witness plate in the vacuum chamber. It is assumed that this plate will be coated in the same way as the final product. The benefit of the witness plate is that it is flat, allowing for straightforward measurement and analysis of the films deposited. While this may be suitable when the end product is also a flat plate, ambiguities may arise when the product is highly curved, as is the case for Ophthalmic optics. The flat witness plate may be easy to measure but of course, it does not always simulate the distribution of the coating on the real product, a frustrating limitation. The coating thickness and optical properties are likely to change with the lens geometry, which has an impact on the final performance of the product. Ideally the coating engineer would like to have this information.

At Aquila we have developed a unique accessory, the confocal module, which easily overcomes the problems associated with measuring highly curved optics. It is suitable for measuring all types of lenses and other curved optics, but is especially useful for characterising ophthalmic lenses as we will demonstrate here. Coating engineers can now measure the coated product rather than the flat witness plate and as always with the nkd, no sample preparation at all is required.

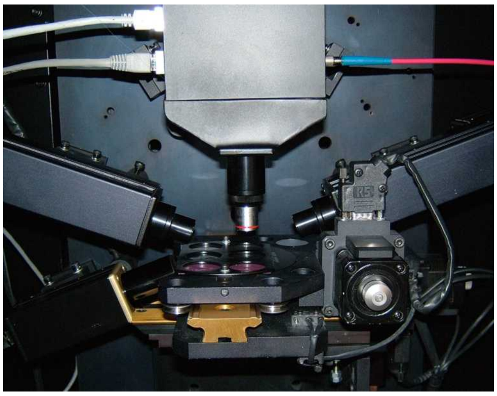

*Figure 1. The confocal accessory*

Using the powerful Pro-Optix™ analysis software film thickness and refractive index data can be determined automatically from the measured reflectance spectrum.

Utilising the confocal attachment is just one of the ways in which we can obtain data from Ophthalmic lenses with the nkd. We will demonstrate here the flexibility of the system for obtaining the most useful and accurate information from this type of sample.

Measurement requirements for Ophthalmic lenses.

Let us first look at what information we need as ophthalmic engineers, to feed back into the coating process. From the reflectance and transmittance spectra of a witness plate, the optical engineer has a measurement which gives the performance of the AR coating and an indication if any problems have arisen in the coating process. To feed this back to the deposition process, we need the thickness and optical properties of the individual layers, so that specific parameters can be modified. The same is true for the wet dip coating process. Thickness and dispersion are early indicators of problems with the solution or curing process. So the ability to extract n, k and d from the witness plate and the coatings on the lens is extremely useful.

For the purpose of qualifying the performance of the lens, If we can perform the T and R measurement on the curved surface of the lens, at any point, then we have a qualification of the performance of the final product. It would also be useful to compare these quickly against in house standards and tolerance limits.

A measure of the absolute absorption is also important, as is the ability to obtain a measure of the lens and coating colour. If we can do all this with one instrument, then we have a powerful tool suitable for any Ophthalmic QC and development lab.

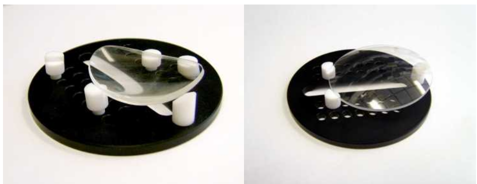

*Figure 2. nkd lens holder*

Obtaining lacquer thicknesses with the nkd

In the example shown here we have a typical Polycarbonate ophthalmic lens with a dip coated hard lacquer on both sides. The hard coating actually performs two functions. Firstly it acts as a scratch resistant coating and secondly it is a good base for the AR coating to adhere to. For this reason the performance of this coating is more important than we might at first think.

Before we analyse the coated lens for the first time, it is important to characterise the substrate first as this has an impact on the measurement we obtain for the coated lens. Having as much photometric information about the substrate as possible, in the form of a dispersion model and a table of n and k values, makes subsequent analysis of the coated lenses, straightforward

In Figure 3. below we show a standard Polycarbonate (PC) lens which has been measured on an nkd-7000 at and incident angle of 10°. Overlaid on the measured transmittance and reflectance spectra is a model fit which is used to extract the complex refractive index of the material, n-ik. The results of this analysis are displayed in Figure 4. This data for the lens is added to the Pro-Optix™ materials database.

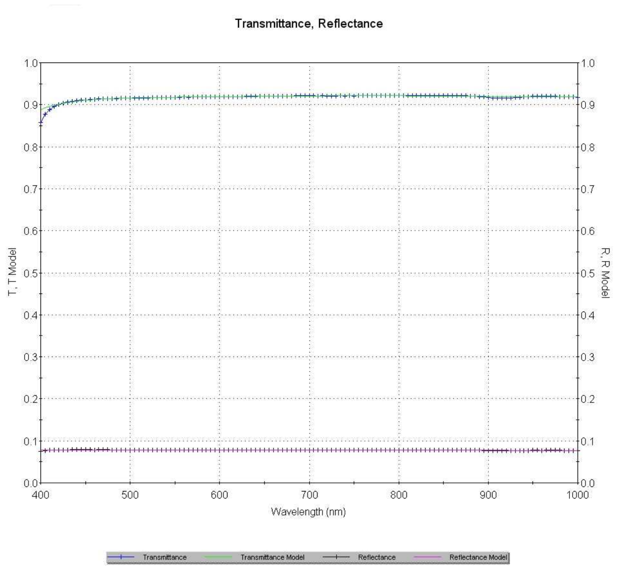


*Figure 3. T & R for PC substrate. Measured in centre with concave face towards the beam. Model fit overlaid in red & green.*

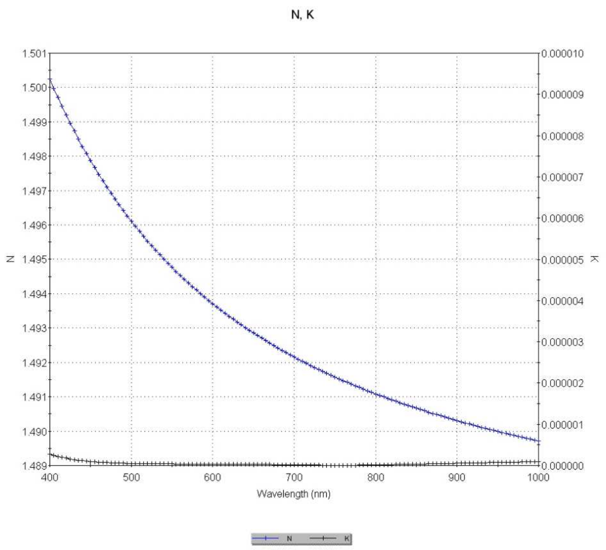


*Figure 4. n & k for the PC substrate*

The same measurement made on a lacquer coated version of the PC lens gives us the reflectance and transmittance spectra shown in Figure 5.

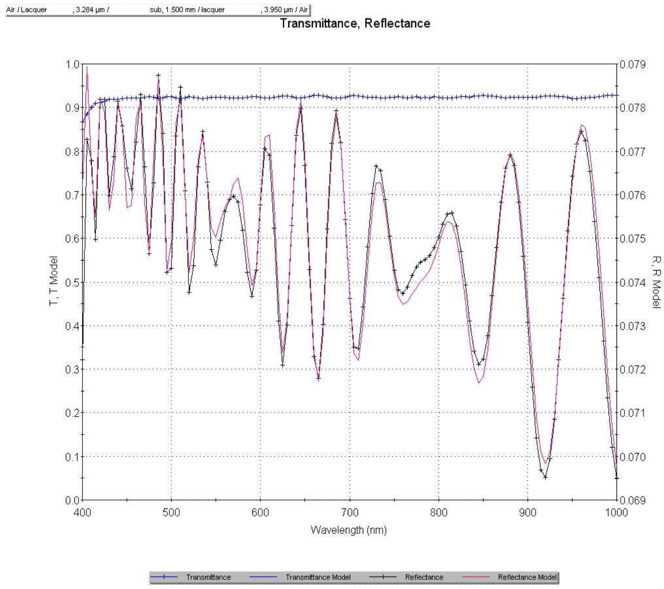


*Figure 5. Spectra shows T and R measurement at 10° for the centre of a PC lens, lacquer coated both sides. Overlaid in red is a model fitted for the lacquer.*

The reflectance and transmission spectra are measurements of the whole lens structure. The two lacquer layers are of different thicknesses, giving rise to an oscillation effect in the spectrum - higher frequency oscillations enveloped within a lower frequency oscillation. The powerful integrated Pro-Optix™analysis software, has been used to obtain a mathematical fit to these spectra, from which the optical constants and film thickness are extracted. Film thicknesses for both layers have been determined to be 3.28$\mu$m and 3 .95$\mu$m. Dispersion for the lacquer is shown in Figure 6.

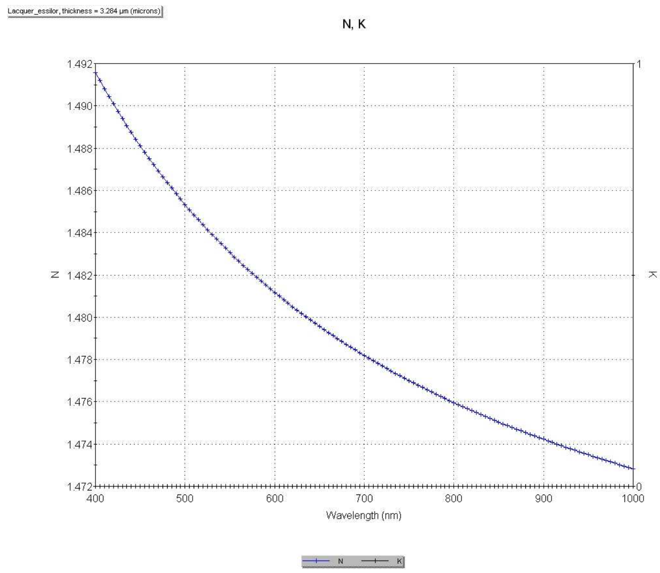


*Figure 6. n & k for the lacquer.*

This is an especially good result, given that the refractive index of the lacquer is very close to that of the substrate. Only the most sensitive, ultra high signal to noise detection system, such as that employed by the nkd, is able to detect these low levels of signal contrast.

The nkd can also make the same measurement at the edge of the lens, on the convex *or* concave side, using the specially designed ophthalmic lens holder - see Figure 2. In Figure 7. we show the measurement and analysis, now repeated for the edge of the same lens. We can see that the lacquer thicknesses are very similar in this region of the lens and it gives us some idea of the variability of the coating from edge to centre. Film thicknesses at the edge were determined to be 3.46$\mu$m and 3.57$\mu$m.

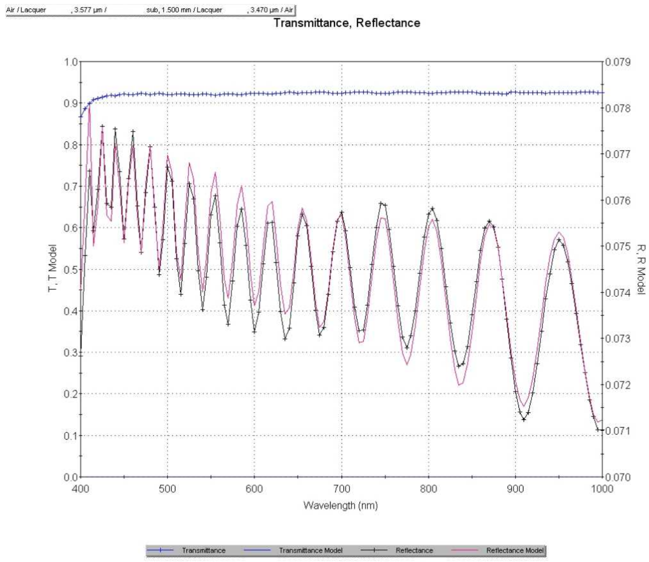


*Figure 7. Ophthalmic lens, lacquer coated both sides. spectra shows T and R measurement at 10° measured at the edge of the lens. Overlaid on this in red is a model fitted for the lacquer.*

## Measuring witness plates

When it comes to analysing the performance of the AR coating, the nkd offers the choice of either measuring the witness plate or simply measuring the finished product.

Figure 8. below shows the reflectance and transmittance spectra for a AR coated lens, with a prescription of +3, measured at normal incidence .

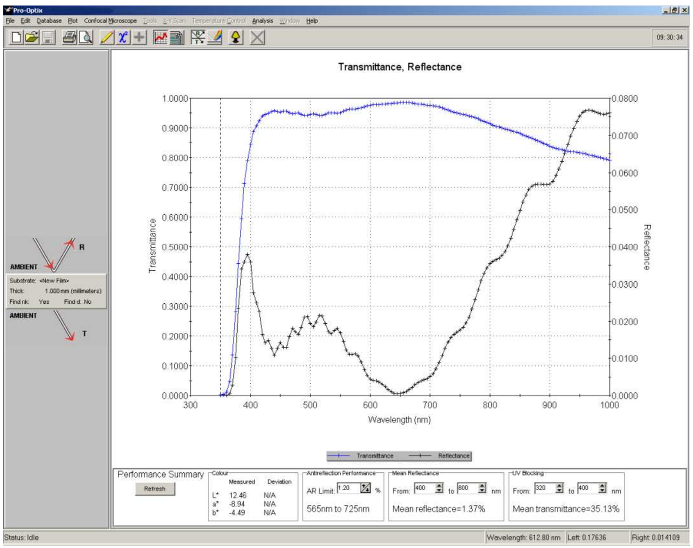


*Figure 8. Reflectance and Transmittance spectra for AR coated lens.*

At the bottom of this image is a performance summary function for the coating. To activate this function and obtain an instantaneous summary for the coating, the user simply selects "performance summary" from the drop down menu. The summary includes colour analysis values, antireflection performance, mean reflectance over a selectable wavelength range and UV blocking performance. This menu is easily modified to suit individual coating laboratory requirements.

We can also use the T and R data, which has been obtained simultaneously, to give us the absolute absorption A, from the relationship: A = 1-(T+R). T and R data can also be exported to excel and a number of thin film design packages .

## Isolating one interface with the nkd

In addition to measuring both interfaces the nkd can be configured very quickly, with the confocal attachment, to measure just one side of the lens. Figure 9. shows a single interface measurement from a lacquer coated lens. A model fit for the lacquer is shown overlaid on the measured spectrum. From this we have extracted the optical properties and the film thickness, which in this case was 1.131$\mu$m. In the same way, the confocal accessory can be used to measure just one side of an AR coated lens.

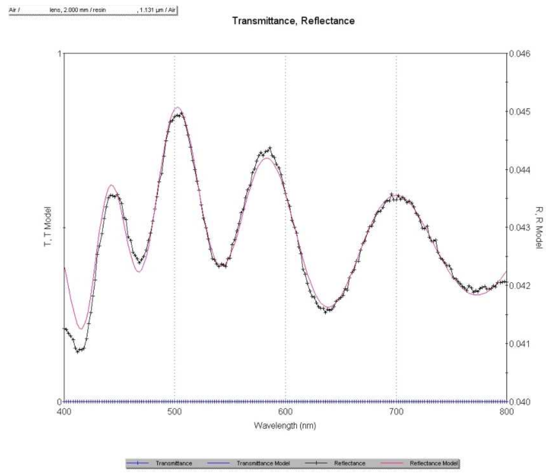


*Figure 9. Reflectance spectrum for lacquer on lens. One side of lens only measured, using the confocal accessory.*

## Multilayer analysis

The Pro-Optix[TM] analysis engine is powerful enough to analyse complex multilayer structures. In the example shown below, Figure 10., we have measured a lens with a lacquer layer, plus a four layer AR coating. The measurement was made at normal incidence, with the confocal attachment, so we have reflectance for just one side of the lens. Overlaid on the measured data, is a model fit used to obtain the dispersion and film thickness for the individual layers.

Film thickness fo r the individual layers of the AR coating have been determined as well as dispersion data for the $SiO_2$ and $ZrO_2$ . In this case, five layers plus the substrate have been analysed. For examples of layer analysis , up to 22 layers, with the nkd, please see our application note on DBR structures.

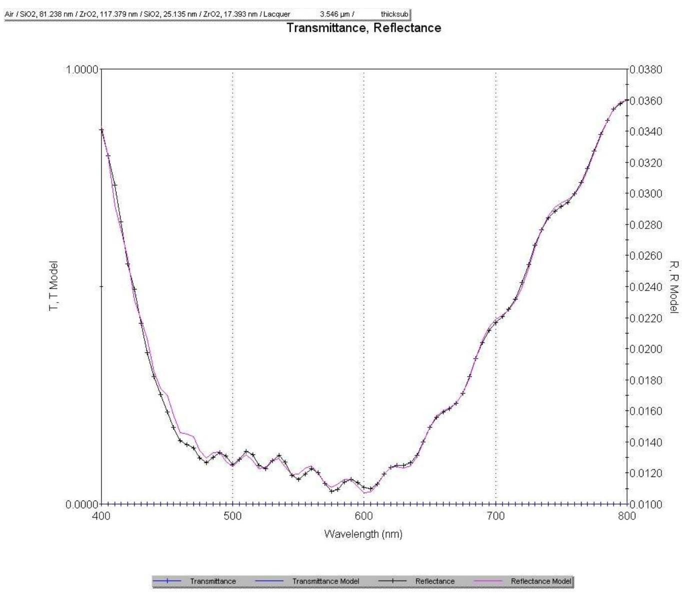


*Figure 10. Multilayer analysis. Reflectance of AR coated lens measured using the confocal attachment. The model fit is shown overlaid in red.*

## Obtaining colour analysis for tints and lens colours

In addition to providing precise measurements of total transmittance and reflectance over a wide wavelength range, the nkd has a built in colour measurement facility for calculating tristimulus values, chromaticity co-ordinates, **L*a*b** and **L*u*v** colour co-ordinates from either the measured or calculated curves, in transmission or reflection.

Colour calculations always depend on the type of illumination being used to make the observation and the way in which the sample is being observed. Pro-Optix™ has built in data on all common illuminants and observers, so the user simply has to select the required combination from the drop-down lists.

T and R measurements at 10° are shown below in Figure 11, for an AR coated lens. A colour analysis was performed on this and the results are presented in Figure 12.

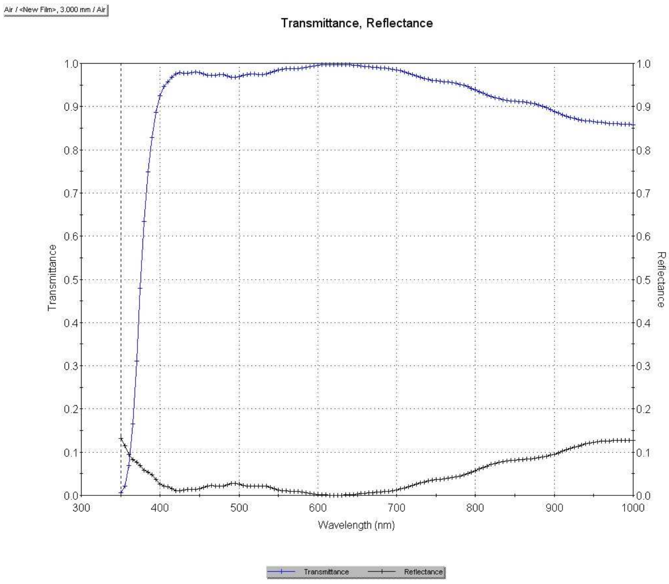


*Figure 11. Reflectance and transmittance spectra for an AR, coated lens, measured at 10°.*

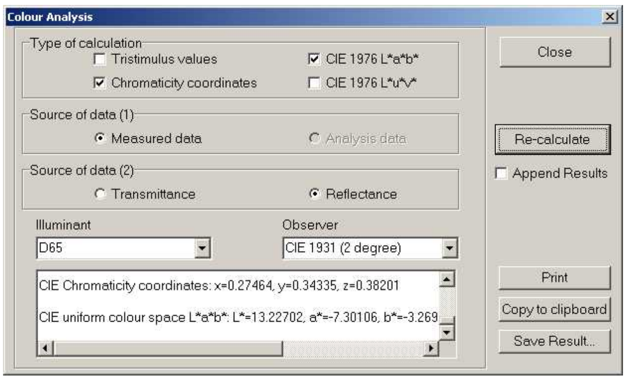


*Figure 12. The Pro-Optix™ Colour analysis dialogue window showing analysis of the data in Figure11.*

The colour analysis function can be used for comparing tint and lens colours against standards.

More information on the colour analysis function can be found in our colour analysis application note.

## Summary

We have shown how the unique capabilities of the nkd can be utilised for characterising ophthalmic lenses and coatings.

The nkd can be used to obtain simultaneous measurements of transmittance and reflectance at normal incidence and at any incident angle from 10° to 80°, even for lenses with a prescriptive power. A accurate measurement of absolute absorption can be obtained from the T and R data, which are measured from exactly the same area on the lens.

A convenient performance summary function provides the user with immediate calculations of the essential parameters – always useful in a busy QC lab.

In addition to this, the nkd can be used to determine the lacquer thickness, refractive index and absorption, at any point on a lens for a single side or both sides simultaneously.

The Pro-Optix™ analysis software can provide dispersion and film thickness for multilayer anti-reflection coatings, valuable information which can be fed back to the coating process.

Pro-Optix ™ also has a colour analysis module which can be used for analysing lens colours and tints.

With all this functionality and analysis power, the nkd is the instrument of choice for the modern ophthalmic coating laboratory.