Characterisation of Optical Substrates on the Aquila nkd Spectrophotometer

Aquila
Instruments

This application note demonstrates the ability of the Aquila nkd Spectrophotometer to characterise transparent optical substrates without sample preparation. A variety of commercially available substrates are analysed .

In the world of thin film technology, substrates cover a diverse range of materials from glass and silicon to metals, ceramics and polymers. For the purpose of this discussion we will focus on the analysis of optical substrates, typically glasses and polymers.
Characterising the substrate is an essential step in determining the optical properties of any subsequent layers, as well as checking the quality and suitability of the substrate for the intended application.
Manufactured glass suffers from a number of optical imperfections which can make it non-uniform or make the optical characteristics deviate from the desired values. Glass transmittance can be affected by the thermal history of manufacture and any thermal exposure post formation. Birefringence or anisotropy in index of refraction is another effect which can be caused by manufacturing stresses in the glass and unless it is a required characteristic of the material, it needs to be detected and removed.
Homogeneity within a glass melt is the amount of variation of refractive index within the manufactured glass blank and can often be due to impurity content. Metallic impurities for example, affect UV performance and OH (hydroxyl) bond fluctuations can account for Infrared variations.
Many measurement techniques require the back of the substrate or component to be coated or treated, because the analysis cannot handle secondary reflections from the substrate. Samples analysed in the nkd require no such treatment and in fact a transmissive sample is an advantage as the transmission measurement provides vital information on the material absorption.

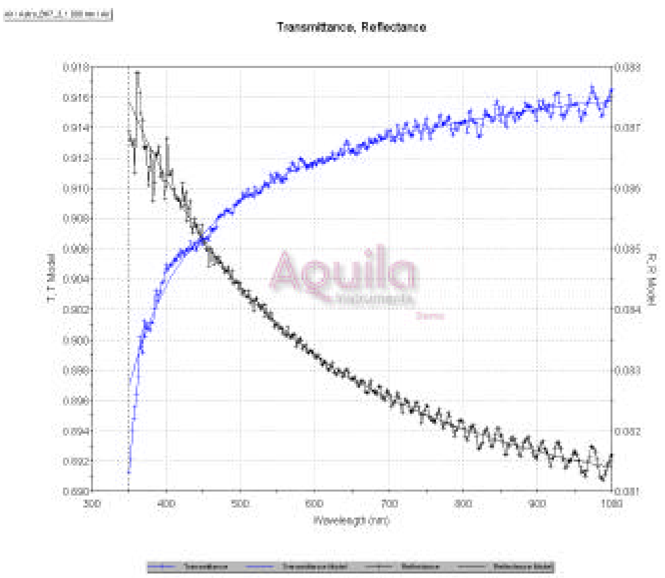

Figure 1. T and R measurements for BK7, 1mm thick - expanded view

BK7 is a Borosilicate crown glass very commonly used in optics.
Figure 1 is the T & R plot for a typical BK7 sample, measured on the nkd-7000 in the spectral range from 350 to 1000nm. A simple Cauchy power series dispersion model was used to fit the data and the plot for this can be seen overlaid on the measured spectra. The quality of fit is so good that it is difficult to discern the measured spectra from the calculated spectra, without examining the expanded view.

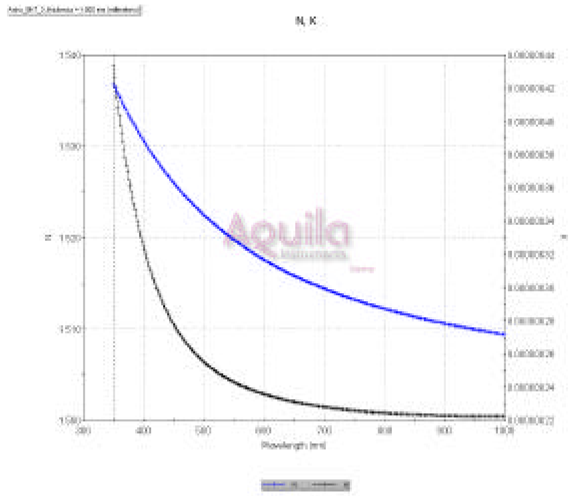

Figure 2. n and k spectra for BK7substrate 1mm thick

The T and R spectra in Figure 1, exhibits small substrate oscillation's, indicative of high quality parallel surfaces. The calculated optical characteristics are shown in Ffigure 2. For this sample, the refractive index is 0.0026 higher than the manufacturer's published data (BK7, Schott Glass) at 350nm. The difference decreases smoothly to 0.002 at 1000nm. The UV absorption varies slowly between 400 and 800nm and remains very close to zero.
Figure 3 below is the n and k data for another BK7 sample, showing the difference in absorption characteristics which can be found within the same material. Without quantifying this difference, any calculation made on the subsequent layers would suffer from an additive error.

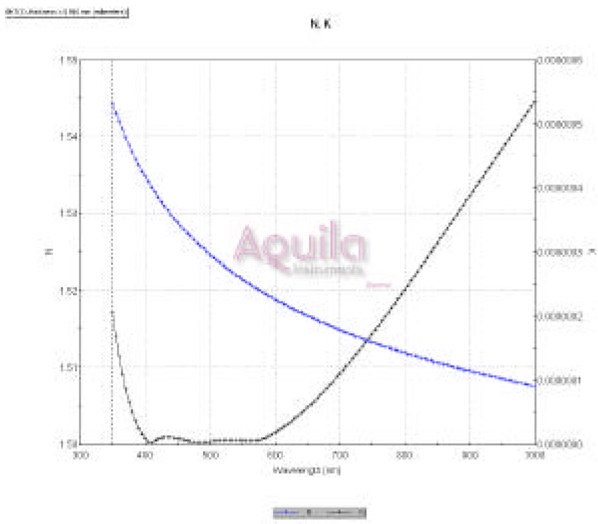

Figure 3. n and k spectra for BK7substrate - comparitive sample

Fused silica is another important substrate material, having excellent transmission characteristics deep into the UV. Synthetic Fused Silica is amorphous silicon dioxide made by the chemical combination of silicon and oxygen and its characteristics are well controlled. It is often confused with fused quartz which has much more variable optical properties. Fused silica typically has a refractive index of 1.46 and its excellent UV performance makes it one of the most important materials next to MgF, for Laser applications.

Figure 4 below shows the n & k curve for a good quality fused silica substrate as measured by the Aquila nkd, in the spectral range from 200 to 2000nm. Again the Cauchy model provides an adequate method of characterising this type of substrate. Fused silica UV grade has several orders of magnitude less absorption loss than BK7, across the visible spectrum - seen by the flat absorption curve in black.

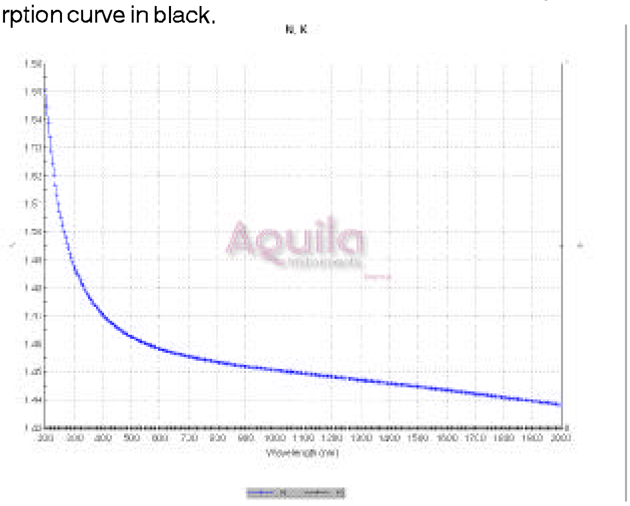

Figure 4. refractive Index & Absorption characteristics of Fused Silica

Float Glass or green plate as it is often referred to, is another common substrate material and presents a more complex set of T and R data for analysis.

A particular problem with the use of float glass substrates is due to the existence of a multitude of absorption peaks in the UV, which are of variable position and magnitude. This makes it difficult to construct an accurate dispersion model for the substrate in this region. Figure 5 below is a greenplate sample measured on the nkd. Note that the transmittance peaks in the green region and falls

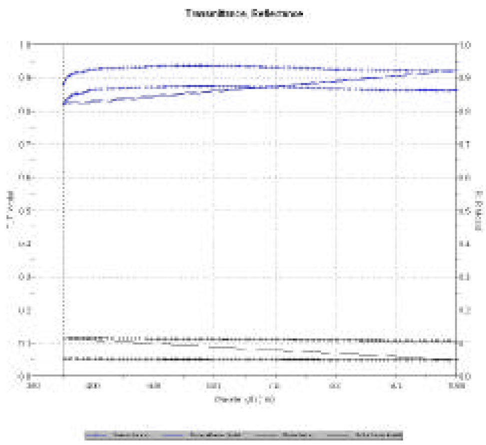

Figure 5. T and R Spectra for a typical greenplate Sample

off into the IR and UV. The dip in transmittance around 375nm is a characteristic of greenplate which can be difficult to model. The nkd has many types of greenplate in its database and is able to characterise these automatically using default mode.

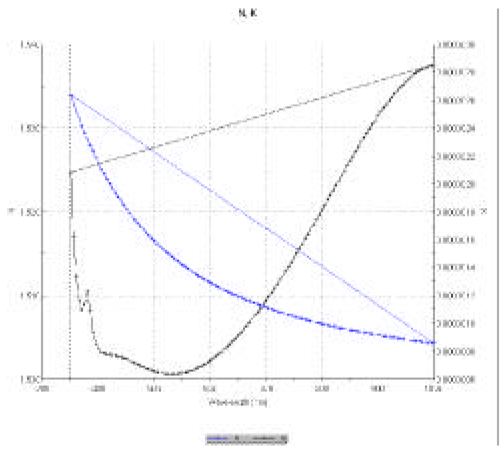

Figure 6. Fitted characteristics for greenplate in figure 5.

The refractive index and absorption results shown in Figure 6, have been generated using the Drude-Lorentz dispersion model with 5 oscillators to fit the measured T and R spectra.

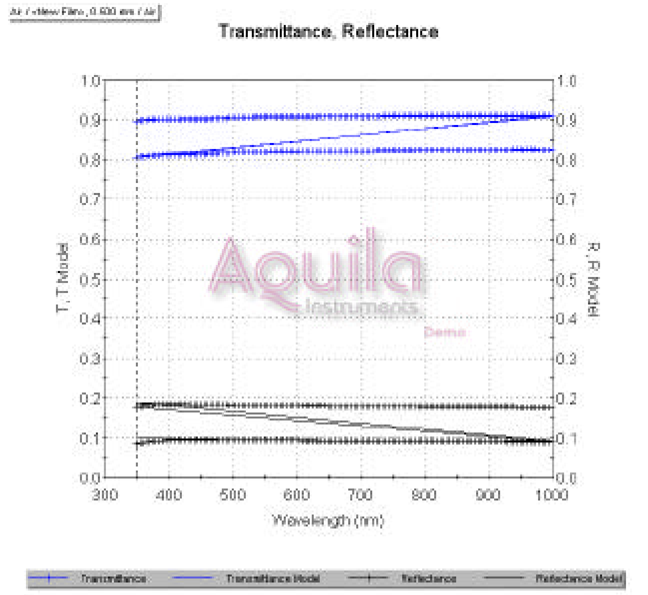

Figure 7. T and R spectra a polymer, measured with S- and P- polarised incident light

When the challenge of new, unknown and complex materials arises, the nkd has the inbuilt functionality required to analyse these materials with confidence. Ideally, as much spectroscopic information as possible is required to adequately describe an unknown material. The nkd can collect spectra over a wide range of incident angles and with s-, p- or unpolarised incident light. Figure 7 above, is the combined s- and p- polarised T and R spectra for a previously uncharacterised **polymer** sample. Fitting a dispersion model to the curves generated the refractive index and absorption values as plotted in Figure 8. The excellent fit achieved for both polarisation states ensures a high level of confidence in the calculated results.

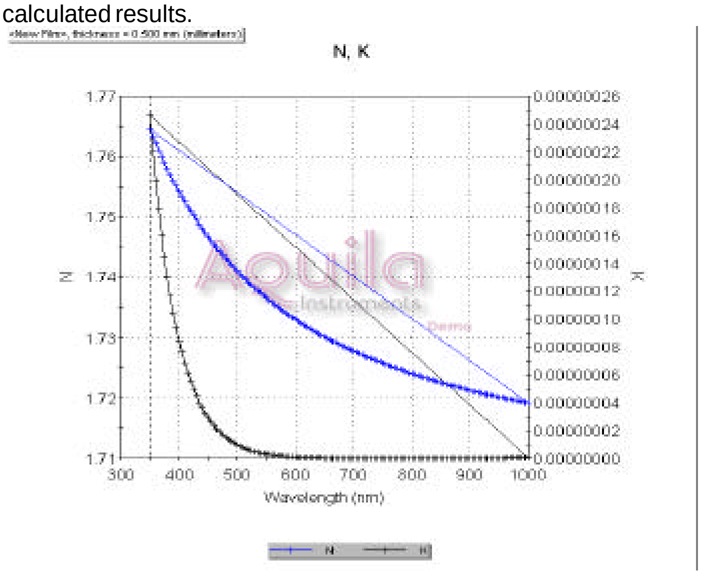

Figure 8. Resultant fit for Polymer in Fig.7.

To treat transparent substrates effectively means that some attention needs to be given to secondary reflections caused by light which penetrates through the substrate and reflects a second, or third time and eventually reaches one of the detectors. The approach taken in the nkd is to collect all such multiple-pass reflections with a carefully designed light collection system and large area detectors – to measure total transmittance and total reflectance. Therefore no sample preparation is required and thick or transparent materials represent no problem to the nkd.

It can be seen then that the nkd spectrophotometer is a truly comprehensive system for characterising thin films, coatings and substrates. It can be used to monitor the quality of optical substrates non destructively and provides the process or development engineer with the important optical information they require, quickly and easily.