Characterising solar control glass and coatings with the nkd thin film measurement system

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This application note Illustrates the benefits of the nkd optical coating measurement system for evaluating the performance and obtaining layer analysis of solar control glass and films.

Glass as a building material has been around for a very long time but in recent years its use as an architectural material has grown considerably. The relative abundance of the raw materials and its aesthetic appeal, make it an attractive resource for the building designer.

Of course, constructing a building with large quantities of glass brings about its own set of challenges – not least of which is how to maintain the interior temperature for the comfort of the occupants. It is a fact that heat loss from a building will always find the path of least resistance, which is usually the window glass. Keeping the buildings cool in summer, allowing light in but not too much heat and warm in winter, preventing the heat from escaping is very important and the properties of the glass have an important role to play in controlling this solar flow.

Architectural glasses are usually float glasses, formed by drawing the glass over molten tin baths, to produce a clear flat glass. This leads to impurities within the glass which affect the wavelength and degree of absorbed light. These impurities vary slightly from one manufacturer to another and are sometimes intentionally added to manipulate absorption effects.

The degree to which solar radiation of a given wavelength is either transmitted, absorbed or reflected by the glass, is dependent on the refractive index, absorption and thickness of the glass as well as the presence of any coatings.

Solar control glasses are used to minimise heat gain and control glare or to balance the heat output of a building with the natural light. Ideal solar glasses for temperate climates control the light and heat (UV, VIS, IR) input to comfortable levels, while reflecting heat energy from fires and radiators (IR) back into the room. The glasses do this through their reflectance, transmittance and absorption characteristics. Solar control glasses are usually given a "solar value" which is the proportion of light transmitted directly through the glass – nominally, the total transmittance. In most buildings, solar control window glazing provides in significant energy savings and improvements in comfort.

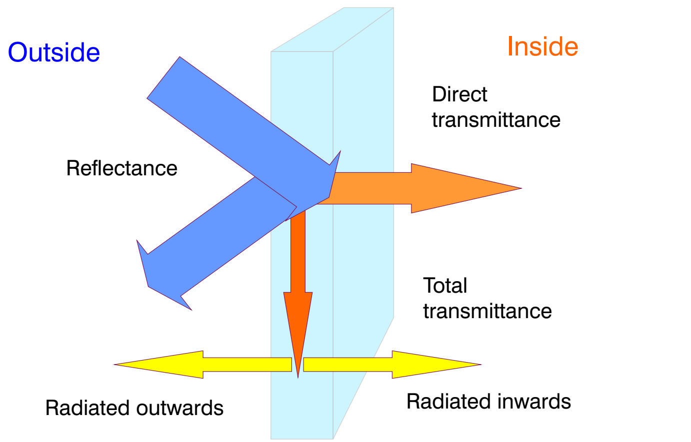

Figure 1. Schematic of heat and light flow on window glass

There are a number of different ways of achieving a solar control with glass:

Body tinted glass or heat absorbing glass works primarily by absorbing short-wave radiation(UV) and then re-radiating it as long-wave (IR). This type of glass appears darker with increasing thickness and can be manufactures in a range of colours.

Coated solar control glass, usually has a very thin semi-transparent Pyrolitic or Sputter coated metallic layer on the surface of clear or body-tinted glass.

A popular solution fro solar control is to use a retro-fit film which reduces solar heat, glare, and UV. These applied films are usually multi-layer assemblies of coatings and polyester films with an adhesive backing. Figure 2. shows a typical example.

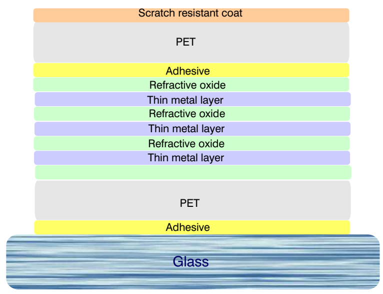

Figure 2. Typical retrofit solar control film structure laminated on glass

Spectrally selective glazing is another product used to screen out as much ultraviolet and short-wave infrared radiation as possible whilst allowing through the maximum amount of visible light.

Low-emissivity coatings, act to reduce the surface emissivity of glass and are transparent over the visible wavelengths of light, but reduce the amount of long-wave infrared thermal radiation both absorbed and emitted by the glass pane.

Characterising solar control glass

There are a number of standard tests in existence which are used used for qualifying solar control glass. Probably the most commonly used is the ASTM 424 standardised test, which describes the solar irradiance of the product according to a standard solar energy distribution curve defined by the ASTM and known as Sea Level air mass 2. This represents average solar irradiance at sea level in middle of the northern hemisphere.

From the perspective of the solar film developer or QC engineer there are a number of important measurements which can be made to qualify the performance of the solar film and monitor the manufacturing process.

The ideal optical test instrument for this purpose would likely provide the following:

- Transmission and reflection measurements, preferably probed simultaneously, from the same area on the sample, over a wide wavelength range, UV, Vis and IR.
- A measure of absolute absorption
- Good bandwidth so that small features can be picked out in the spectrum
- Analysis of layer thickness and refractive index, for single and complex multi-layer structures, so that data can be fed back to the coating process.
- Measurements of T and R at normal incidence and variable angles.
- Analysis of thin metal films and polymers
- Accurate measurements on birefringent materials
- The capability of making direct comparisons with defined standards
- The ability to handle large or very thick samples
- Colour analysis from the T and R spectra.

Ideally these measurements would be made without any destructive preparation of the test piece.

We aim to demonstrate in the following, that the nkd-*Series* has all this functionality and more and is the instrument of choice for characterising solar control films and glasses.

Measuring spectral performance and absorption with the nkd

One important unique feature of the nkd-*Series* instruments is the availability of both transmittance and reflectance measurements, which are actually measured simultaneously from the same area on a sample. For a sample deposited on a transparent substrate, this unique attribute leads also to the availability of a third parameter namely the absorption. Provided the experimental geometry is properly designed (as it is on the nkd) to measure total transmittance and total reflectance, taking account of multiple reflections inside the substrate, the relationship T+R+A=1 will hold and from this we can determine A. It is important to note that no sample preparation is required to measure transparent samples on the nkd and we can use both sets of data, T and R for the analysis.

Figure 3. shows a spectral measurement from an nkd-8000 for the a solar film with the layer structure illustrated in Figure 2. Simultaneous measurements of T and R were made from 350-1700nm in steps of 1nm. This data has been used to determine the overall absorption A=1-(T+R), shown in Figure 4. We can see from the T and R data that this coating transmits around 65% of the light in the visible region, absorbs strongly in the UV and reflects strongly in the IR - as we would expect from a solar control film. The high frequency oscillation we can see in the data, is a result of the polymer substrate behaving as a thick film, giving rise to an interference structure proportional to its thickness.

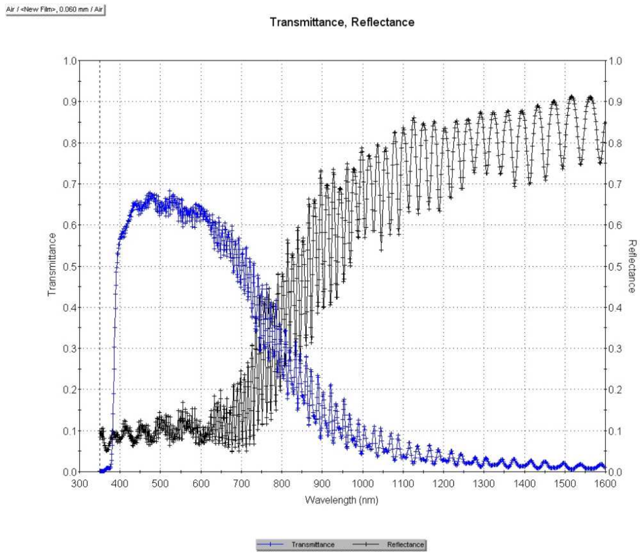

Figure 3. Spectrum of a reftrofit film as measured on the nkd.

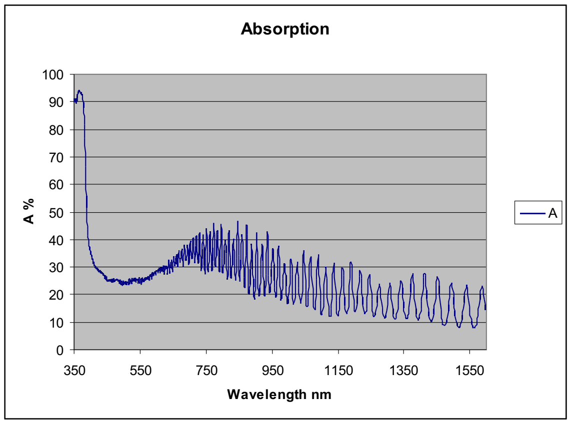

Figure 4. Calculation of absorption from T and R measurements of the retrofit film in figure 3.

Solar Irradiance Calculations with the nkd spectrophotometer

The nkd Pro-Optix™ analysis software has a built in solar analysis function which calculates solar transmittance/reflectance according to a ASTM standard E424.

For strict compliance with ASTM standard E424 the measurements should be made at an angle of incidence equal to 37 degrees. The nkd achieves this easily with a set manual angle of 37 or automatically using the motorised variable angle system in the nkd-8000.

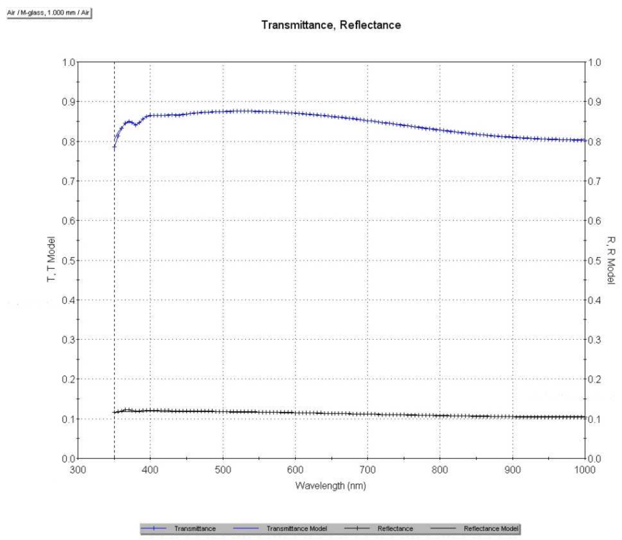

Figure 5. T and R of float glass with model fit overlaid

Figure 5. shows the total transmittance and reflectance of an uncoated float glass as measured on an nkd-7000. Pro-Optix has been used to fit a mathematical model to the T and R spectrum, which is shown overlaid on the measured data. The optical properties of the substrate have been extracted from this and are presented in Figure 6.

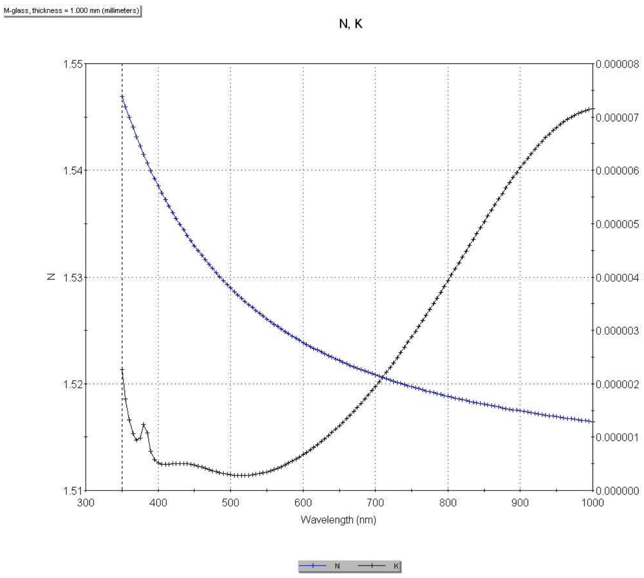

Figure 6. n & k for float glass measured in figure 5.

Using the built-in solar analysis function, we obtained the following results for the uncoated glass.

Float glass
Calculated for air mass 2 at sea level.
Percentage solar energy transmittance, Tse=83.91544.
Percentage solar energy reflectance, Rse=11.08220.
Percentage solar energy absorbance, Ase=5.00235.

Using the solar energy analysis package, is very simple. The user simply selects "Solar Transmittance/Reflectance" from the Analysis menu and the solar calculation window shown below opens. The solar analysis function can calculate the reflectance or transmittance of a sample weighted according a solar energy distribution curve using either the measured or calculated curves, in transmission or reflection.

Currently calculations for Sea level air mass 2 - standard E424. are available but other calculations can be added on request.

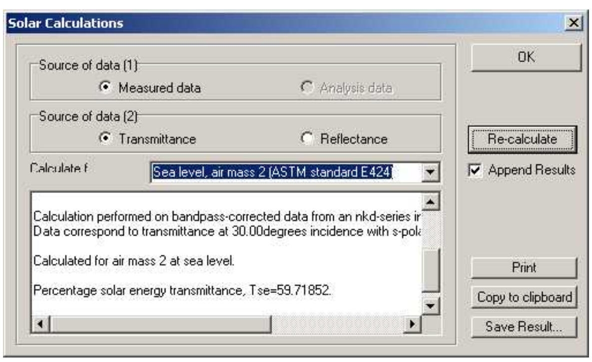

Figure 7. Dialogue window for the Pro-Optix™ solar calculations

Figure 8. shows the total transmittance and reflectance spectra for a solar coating on float glass, measured on an nkd-7000. Steps of 5nm were chosen but the bandwidth of the instrument allows for steps of 1nm and above to be selected automatically. Large area detectors capture all the transmitted and reflected light and not just an indiscriminate number of front and back surface reflections.

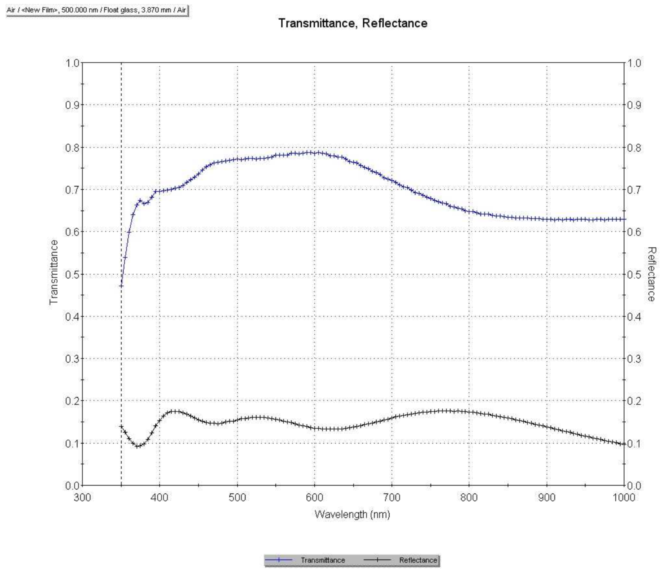

Figure 8. T and R for solar glass

A quick analysis of this using the solar analysis module yielded the following solar irradiance values.

Solar glass
Calculated for air mass 2 at sea level.
Percentage solar energy transmittance, Tse=69.45859.
Percentage solar energy absorbance, Ase=16.74014.
Percentage solar energy reflectance, Rse=13.80127.

Obtaining film thickness and optical properties

As well as providing all the control for automatic measurement, Pro-Optix™ is also a powerful analysis engine for obtaining film thickness and complex refractive index (n-*ik*)data for single and multilayer optical films. Several examples of the use of the nkd for obtaining these properties for solar control films are shown below. In the first instance a basic solar control film consisting of a thin metal layer has been measured and analysed. The Pro-Optix™ analysis engine contains the correct algorithms for performing analysis on metal films - which have complex dispersion profiles and a tendency for the refractive index to dip below 1.

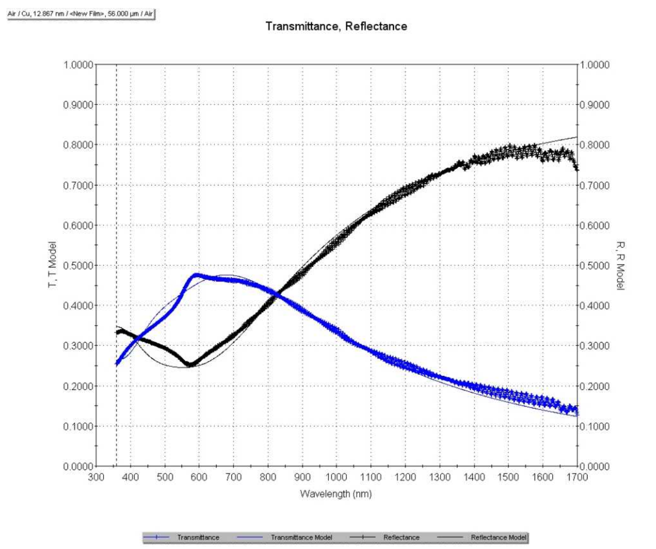

Figure 9. T & R of thin metal film - approx 12 nm.

Figure 9. shows the T and R measurement of a thin metal layer on a PET film substrate. A simple and common solar control film. A fitted model for the dispersion of the metal is shown overlaid on the measured spectra. The n, k and film thickness values determined by Pro-Optix™ from this single measurement are shown in Figure 10.

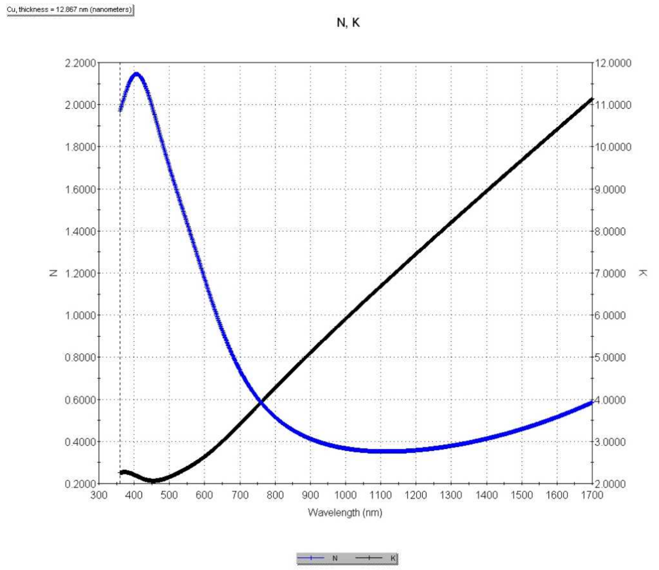

Figure 10. n & k for the thin metal layer - thickness = 12 nm.

TiO_2 is a common constituent layer in many solar control coatings. Below we show an example of TiO_2 on PET - measured and analysed with the nkd.

Special consideration needs to be given to measuring thin films on polymer substrates such as PET, as these often exhibit birefringence. That is their refractive indices are different for the ordinary and extraordinary rays.

The nkd overcomes these problems because it allows the user to define the polarisation of the incident light accurately, thereby probing only one of the refractive indices. This allows us to accurately characterise the substrate layer and any subsequent coatings. More information on this can be found in our application note on birefringent materials.

In Figure 11., a model fit for the TiO_2 is overlaid on the measured spectra. Subsequent analysis yielded the film thickness and dispersion presented in Figure 12.

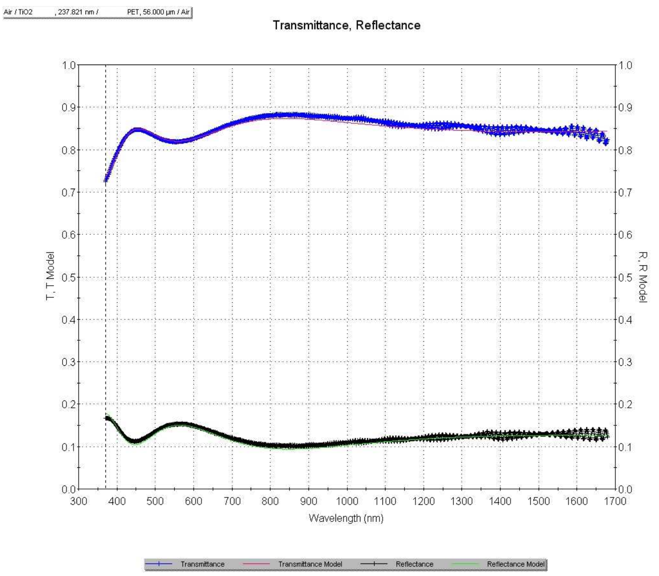

Figure 11. Example of analysis of TiO_2 on a birefringent polymer substrate

So we can see that analysis is straightforward for a single layer, but what about the complex multilayer structure shown in Figure 1.? Pro-Optix™ also has the capability to analyse this structure. Figure 13. shows a scaled up view of the original T and R data presented earlier for this type of structure. Overlaid on this is a model fit for the multilayer structure of the film. From this model fit we have determined the coating thickness and n, k for the refractive oxide, 30nm, the metal film, 7.5nm, the adhesive 1.7μm, the PET, 16μm, and the scratch resistant coat 11μm – with no prior knowledge about the films.

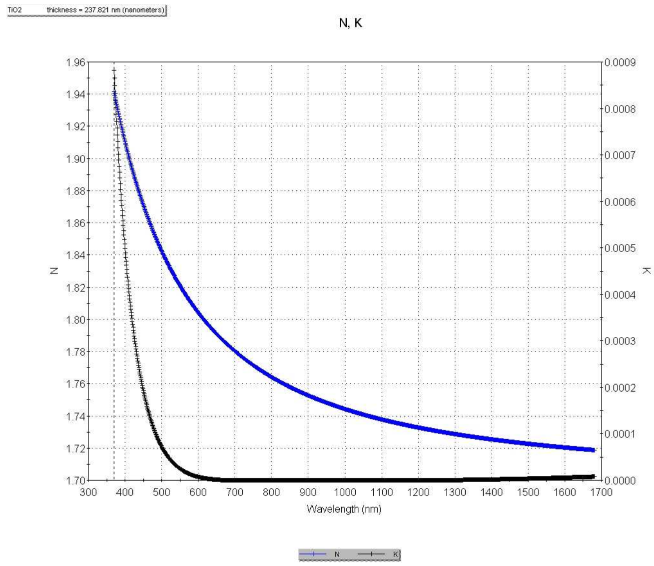

Figure 12. n & k for TiO_2 on a birefringent polymer substrate

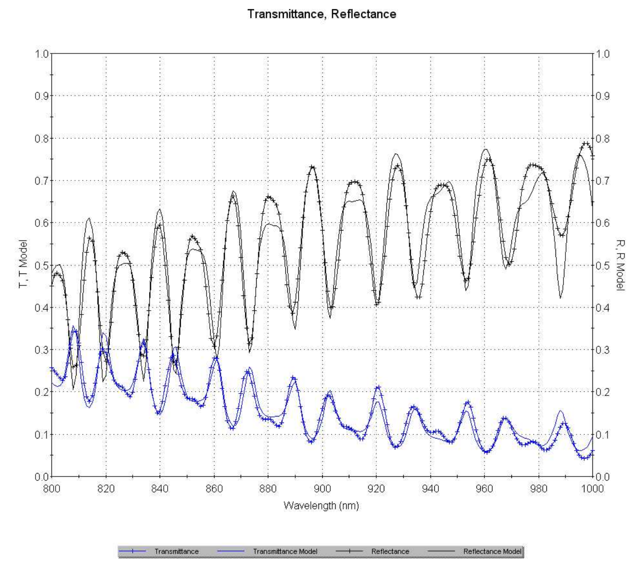

Figure 13. Analysis of a complex multilayer solar control film. The model fit is shown overlaid on measured spectra

Conclusion

We have demonstrated here that the nkd is a powerful and versatile analysis tool suitable for analysing all types of solar control coatings.

Solar irradiance calculations are provided as standard and a coating performance summary can be generated with the click of a button. Transparent materials are measured easily on the nkd and require no sample preparation whatsoever. Glass and polymers are easily analysed using database values or the dispersion models in advanced analysis. Special metal film algorithms have ben included in the powerful Pro-Optix™ analysis software - allowing for the accurate determination of optical properties and layer thickness. Determination of the thickness and optical constants is quick and easy even for new and absorbing films. The nkd-8000 can be set automatically at any incident angle from 10 to 80 ° degrees including the 37° required for the ASTM standard. The nkd includes a colour analysis function which can be used for a wide variety of functions such as checking the variation of glass and tint colours across batches. Please see our application note on colour analysis for more information on this.

So we can see the nkd is an ideal tool for use in development and quality control of value added glass and films.