SURFACE ANALYSIS AND OPTICAL COATINGS

an application note

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Introduction

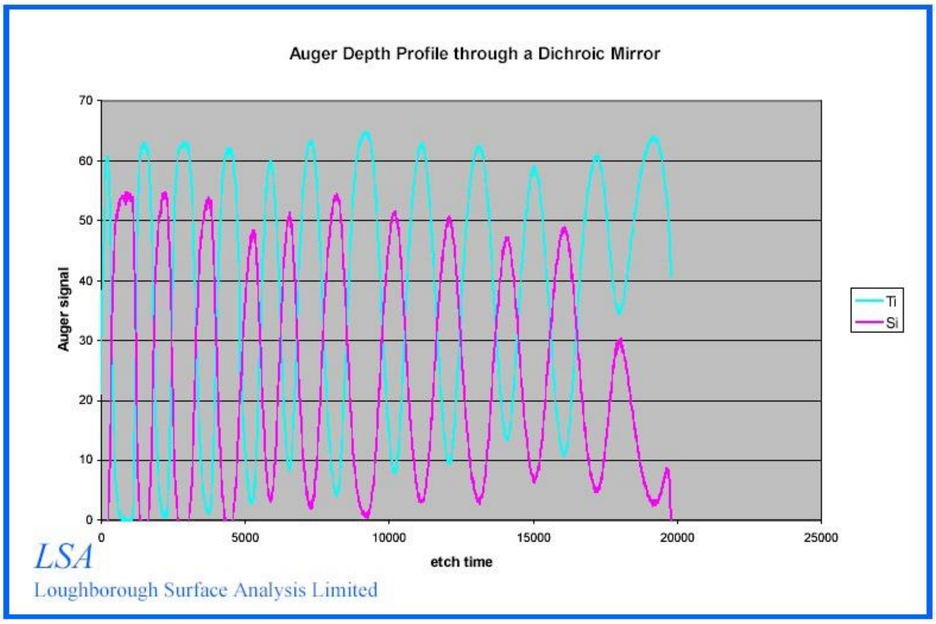
This application note is intended to illustrate the potential of surface analysis coupled with optical coating design understanding. This combination can be used to reverse engineer existing thin film products and so gain a shortcut to producing and improving your own products.

Dichroic reflectors - an example

A simple and familiar example of an optical coating is the dichroic reflector in a tungsten halogen spotlight. The dichroic reflector has a simple task - to reflect as much visible light as possible forwards while transmitting the infra-red backwards. This gives a bright but cold light.

Surface Analysis – Auger electron spectroscopy

We chose a bulb at random from the many on offer and broke it up to get access to the coated surface. Auger electron spectroscopy (AES) gives a complete elemental analysis of the surface. Combining AES with an ion gun to etch the surface back gives a depth profile so that we can scan down through the dichroic reflector and see the composition as we go. This gives the figure below (oxygen omitted for clarity).

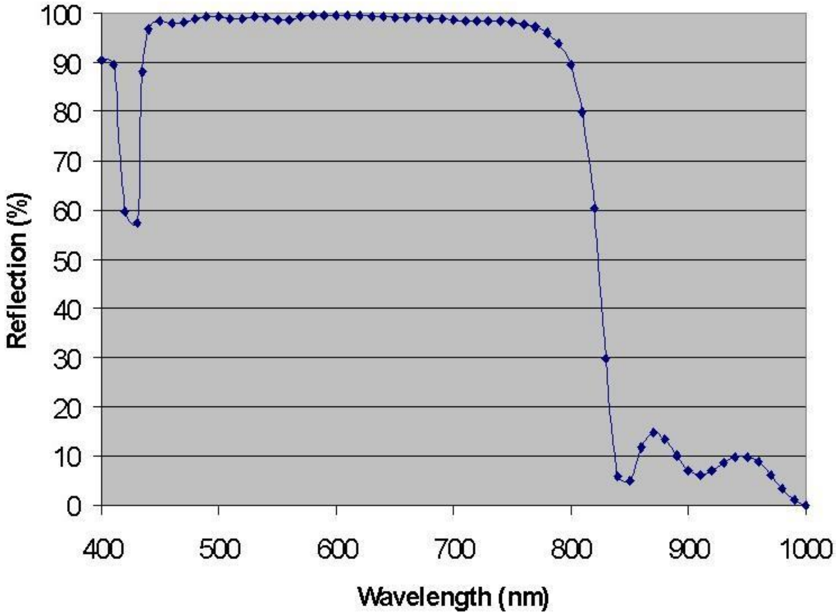


Inspecting this measured depth profile we can get several facts about the coating

- the dichroic reflector consists of 24 layers alternating between TiO2 and SiO2.
- The first TiO2 layer is about half the thickness of the others.
- The first 10 or so layers are thinner than the last 10 by a factor of 1.36.

Optical measurements

The optical performance was measured in the visible and near infra-red regions. This clearly shows the high visible reflection and the low infra-red reflection.



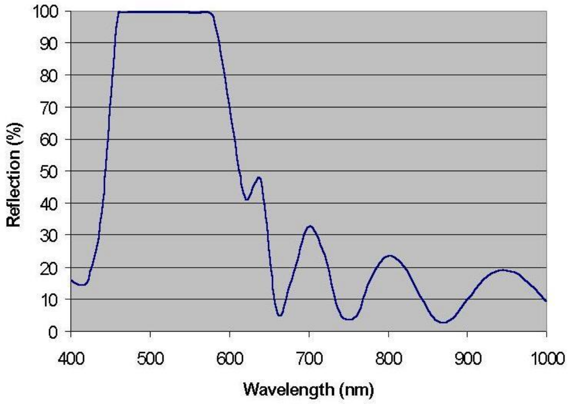
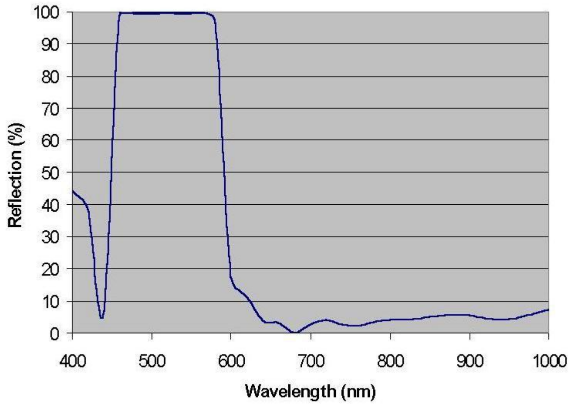
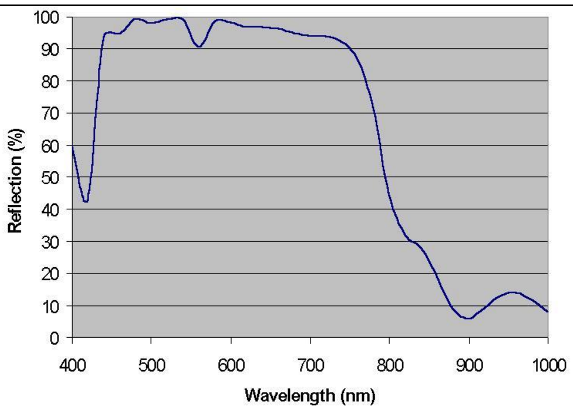
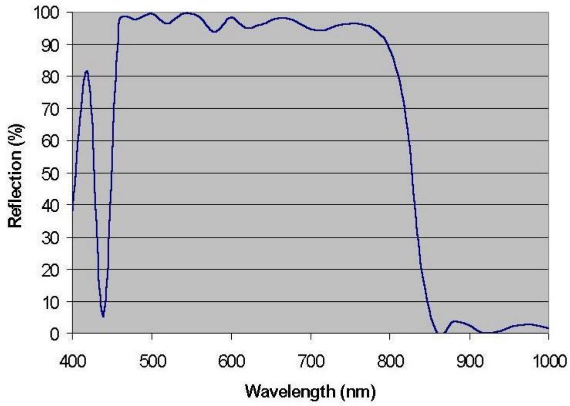
Optical coating design

This type of coating (a quarter wave stack) is a common one, used for mirrors, edge filters and as a basis for many other optical coating designs. Each layer produces two reflections. In a 'quarter wave' layer these two reflections are in phase and re-enforce each other. Each extra quarter wave layer then boosts the reflection of the whole stack. This continues until 100% reflection is reached.

The thin first layer (actually half a quarter wave) acts to reduce the ripple at the long wavelength end. This produces a sharper cut off between visible reflection and infra-red transmission. The use of two stacks one on top of the other but with different width layers gives a wider reflection zone. The figures below show the theoretical performance of a TiO_2\SiO_2 quarterwave designs as the various features measured by the surface analysis are added.

The final computer optimisation of the design is beyond what can be interpreted from the surface analysis as the changes applied during optimisation are generally only a few percent on each layer.

The final optimised design repeats many of the features of the measured performance. There is not an exact match. This is probably due to the uncertainty in the refractive index of the TiO_2 layers. TiO_2 thin films typically show 2 crystal phases, anatase and rutile. These two phases have significantly different refractive indices. As a result TiO_2 thin films typically have refractive indices anywhere between 2.2 and 2.6. I have assumed a worst case index of 2.2 for these calculations. It would appear that the dichroic lamp coating contains TiO_2 with an index higher than 2.2.

Optical design	Comments	Calculated performance
Simple stack of quarter wave layers all the same thickness.	• Lots of ripple at long wavelength side • Reflecting region too narrow	
As above but eighth wave layer added as measured by the surface analysis.	• Ripple greatly improved • Reflecting region still too narrow	
As above but quarter wave stack split into 5 pairs of quarterwaves and a second thicker (by factor 1.36 as measured by the surface analysis) 5 pairs of quarterwaves	• Reflecting region now much wider • Reflection not as high in reflecting region	
As above but computer optimized (i.e., individual layer thicknesses adjusted automatically to give optimum performance)	• Replicates well the overall measured performance. • Similar reflection zone width • Similar features either side of the reflection zone • Reflection not quite as high as measured.	

Discussion

In this simple example surface analysis has given us :-

- Details of the materials used in the product
- Thickness information (in this case only relative thicknesses were used, but by using known sputter rates absolute thicknesses can be derived).

Adding to this a measurement of the optical performance of the coating and some thin film knowledge and calculation we can :-

- Model the expected performance using the indicated materials
- Confirm and refine the measured structure
- Infer that the TiO_2 refractive index is better than the worst case of 2.2

This information allows us to reverse engineer this product and see how and why the given materials have been used. TiO_2 and SiO_2 are not absorbing in the visible or infra-red, this means that this quarter wave stack does not absorb the visible or infra-red energy emitted by the bulb. A simple aluminium reflector reflects about 90% and absorbs the remaining 10%. An aluminium reflector would therefore heat up due to the absorbed energy from the bulb. It would also not transmit the infra-red. It would also reflect forwards the infra-red emitted by the bulb and this would heat up the illuminated area.

Conclusions

- Auger analysis gives elemental composition and rapid depth profiling.
- For optical coatings this gives information on the materials used and the layer thicknesses.
- Combined with optical modelling of the coating this information can give a full understanding of the coating.
- These are powerful tools for reverse engineering coatings of interest and optimizing your own coatings.