Analysis of DBR layers and devices using the nkd thin film analysis system

DBR analysis, 20 layer+ structure analysis with the nkd Series.

In this application note we bring you an example of the unique capabilities of the nkd for analysing complex multilayer structures. A specific case of this is DBR structures which are seeing increasing use today.

Distributed Bragg reflector (DBR) gratings are wave guide structures, formed from multiple alternating dielectric layers of periodic refractive index. Each layer boundary causes a partial reflection of the incident light wave. When the light is of wavelengths such that the multitude of reflections interfere constructively, the periodic structure forms a high quality reflector.

DBR's are critical components in vertical cavity surface emitting lasers and other types of narrow-linewidth laser diodes. They are also used to form the optical cavity in fiber lasers. Typical DBR structures can consist of Si_3N_4/SiO_2 pairs on glass, or GaAs/AlAs on semiconductor substrates. An example of this is represented in the image below. For laser cavities this structure is mirrored across a central spacer which forms the active region. Each layer has a thickness of a quarter of the laser wavelength in the material, yielding intensity reflectivities above 99%. The whole assembly can consist of 22 layers or more.

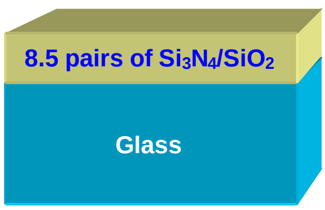

Figure 2. Typical DBR structure

The plot shown in Figure 3. below shows an 8.5 Si_3N_4/SiO_2 pair structure designed around the 1550nm Telecoms wavelength. It has been measured on the nkd for the purpose of evaluating the device performance as well analysing the layer structure, to ensure that the layer deposition is as expected. The graph is a plot of transmittance (in blue) and reflectance (in black) measured at 1 nm intervals, over a wavelength range of 350-2500nm, at normal incidence.

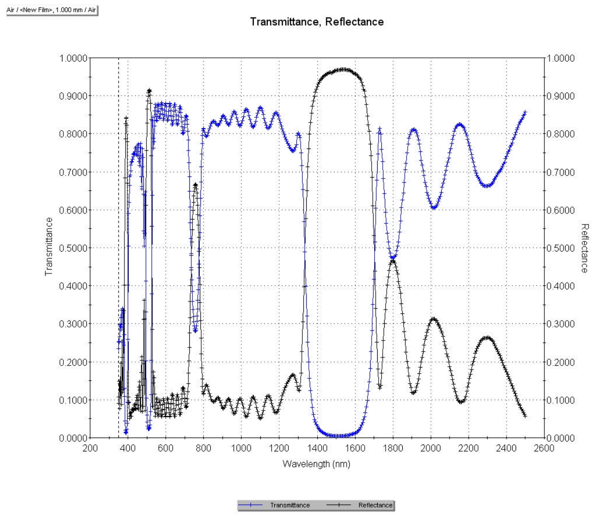

Figure 3. Transmission and reflectance spectrum measured on the nkd for an 8.5 pair Si_3N_4/SiO_2 DBR structure on glass.

The spectrum obtained above provides the user with a great deal of informaiton about the device. We can see immediately how the reflector is performing and can determine whether the structure supports the optical mode or modes required. We can also determine whether absorption has been introduced, giving undesirable effects in the active passband region. The plot also tells us about the efficiency of the reflectors.

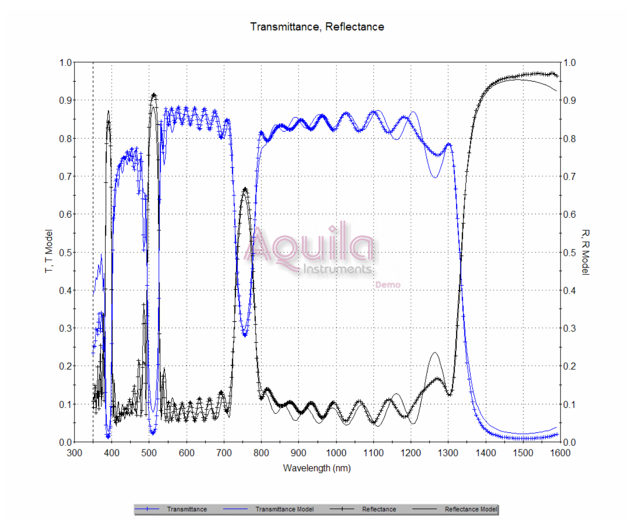

Figure 4. Model fitted to the 17 layer structure. 350-1700nm is shown for clarity. The model is seen as a continuous smooth lines overlaids on the T and R plot.

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We can perform a layer analysis on this structure using our powerful Pro-Optix™ analysis engine. Figure 4. shows a model fitted to the measured DBR structure which has allowed the values of thickness and dispersion of all the layers to vary. For this layer structure of 8.5 pairs of $Si_3N_4/SiO_2/Si_3N_4$ we have been able to extract the film thickness and dispersion from the model fit, which is shown overlaid in the measured spectrum.

Figure 5 shows an example of a microcavity structure measured on the nkd. The reflectance only is shown for clarity here. One important unique feature of the nkd-series instruments is the availability of both T and R measurements.

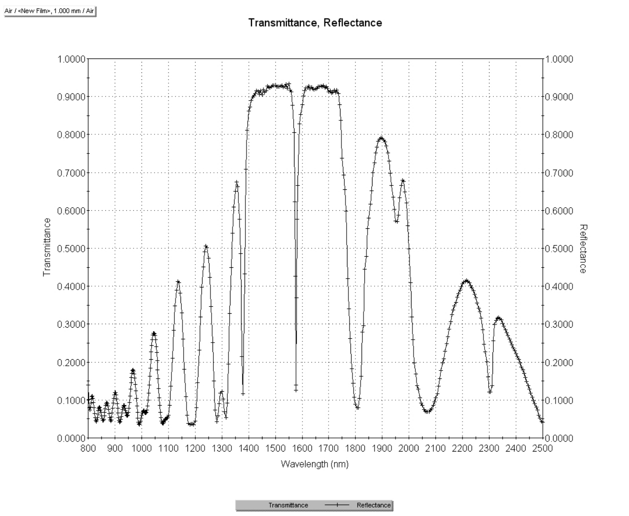

Figure 5. Microcavity structure reflectance from 800-2500nm.

For a sample deposited on a transparent substrate, this unique feature leads also to the availability of a third parameter – namely the absorption. Provided the experimental geometry is properly designed to measure total transmittance (taking account of multiple reflections inside the substrate) and total reflectance, 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 this obtain an accurate and reliable measurement of absolute absorption.*

In the case of the resonant cavity filter, this is particularly interesting since at resonance, the electric field in the spacer layer will be an antinode - i.e. maximum. Absorption due to a non-zero k can only occur where the electric field inside the structure is non-zero, i.e. away from the nodes.

Figure 6. shows a plot of T, R and absorption, A for the resonant cavity filter. Notice the sharp absorption spike as the filter comes into resonance at approx. 1500nm. This indicates that the SiO_2 spacer layer is in fact absorbing since at resonance, the strongest electric field antinode occurs in the spacer layer. Since high-quality stoichiometric SiO_2 has very little absorption, this points to the (surprising) result that the SiO_2 layers in this device, do exhibit some non-negligible absorption.

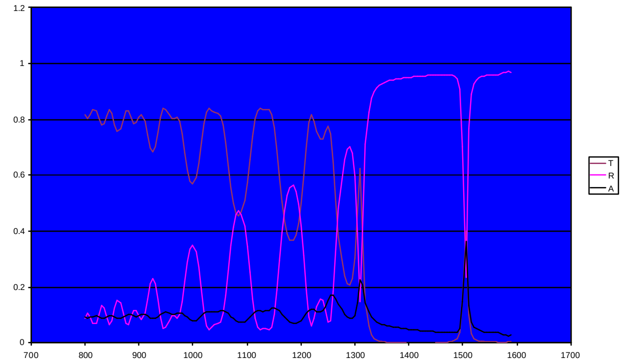

Figure 6. Absorption for the microcavity – black line.

These same measurements can also be made for layers deposited on opaque substrates

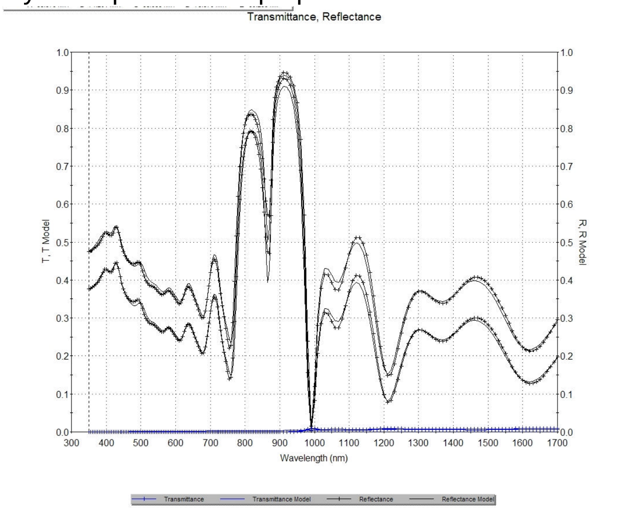

Figure 7. Reflectance for s- and p- polarised incident light at 30° for a 21 layer DBR structure on Ge.

The spectrum shown in Figure 7. is the reflectance of a DBR device, measured on the nkd, which has 10 layers either side of the central spacer, a 5 x 2 repeated structure of GaAs/AlAs. Overlaid on this reflectance spectrum is a model fitted by Pro-Optix™ for the 21 layer structure. The fit is so close that only one line can be discerned for T and R. This data was measured at 30 degrees incidence, with p- and s- polarised incident light. The p- and s- polarised measurements have been merged for analysis and presentation here. The upper reflectance trace is the s- polarised reflectance.

In addition to obtaining normal incidence data, taking measurements at non-normal angles of incidence on the nkd gives us a further useful piece of information where analysis of the structure is to be undertaken - namely s- and p-polarisation splitting.

Such angular measurements are fast and easy with the *nkd*-series instruments, which have designed specifically for thin film analysis. It also demonstrates one of the unique advantages of the *nkd* - namely the simultaneous acquisition of transmittance and reflectance spectra.

Film thickness and dispersion for the GaAs, AlAs and spacer layer have been determined from the fitted model.

The power of our Pro-Optix™ software in the analysis of a complex structure has been demonstrated and shows that, with some knowledge of the structure in question, a full analysis of layer thicknesses and optical parameters can be made.

There are a number of strong characteristics of the nkd which make it ideally suited to analysing this type of sample. Firstly the nkd measures transparent samples easily with no sample preparation required. Secondly the range of photometric data available from the *nkd* measurements allows the user to derive more optical information about the layer structure, without the ambiguity seen in other techniques. When you have the powerful combination of precise photometric data and advanced analysis software available on the *nkd*, you have everything you would ever need in a thin film analysis instrument.

The nkd measures transmittance and reflectance simultaneously from the same area on a sample – ensuring direct correlation between both sets of data. Large area detectors are used to ensure that all the light is measured, allowing for determination of the absolute absorption, A=1-(T+R). Having both sets of data, T & R at well defined polarisation and incident geometry, provides more precise photometric data for accurate analysis. Determination of the thickness and optical constants is quick and easy with the integrated Pro-Optix™ analysis software, even for new and absorbing films.

The nkd has the ability to measure the performance of a DBR or edge filter over a wide wavelength range from 250-2500nm with 1nm steps and ultra low signal to noise. Perfomance and layer structure analysis can be determiend form one easy measurement.

Additional application notes are available for download from our website. If you would like any further information on this topic or any of our other applications notes, please contact Louise Stonebridge at louise.stonebridge@aquila-instruments.com and we will be pleased to provide you with the information you require.