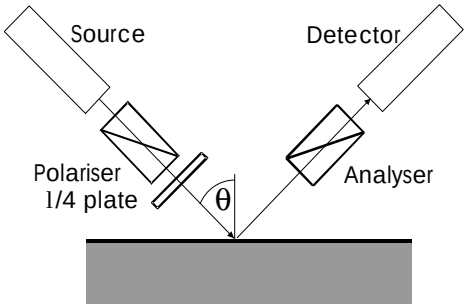
Spectrophotometry versus Ellipsometry

This application note is intended to hi-light the differences, between the methods of Ellipsometry and Spectrophotometry for the determination of multilayer thin film characteristics.

Thin films have many important technological applications. Common examples are; anti-reflective coatings on glass and layers in semiconductor devices. They can be formed in a variety of ways, and their use in scientific development today is ever growing.
The performance of these films, in any application, depends greatly on their optical characteristics and thickness. These properties need to be measured at all stages of fabrication and there exist several optical techniques which achieve this. All have benefits and limitations and we will discuss the two most widely used techniques here, Ellipsometry and Spectrophotometry.



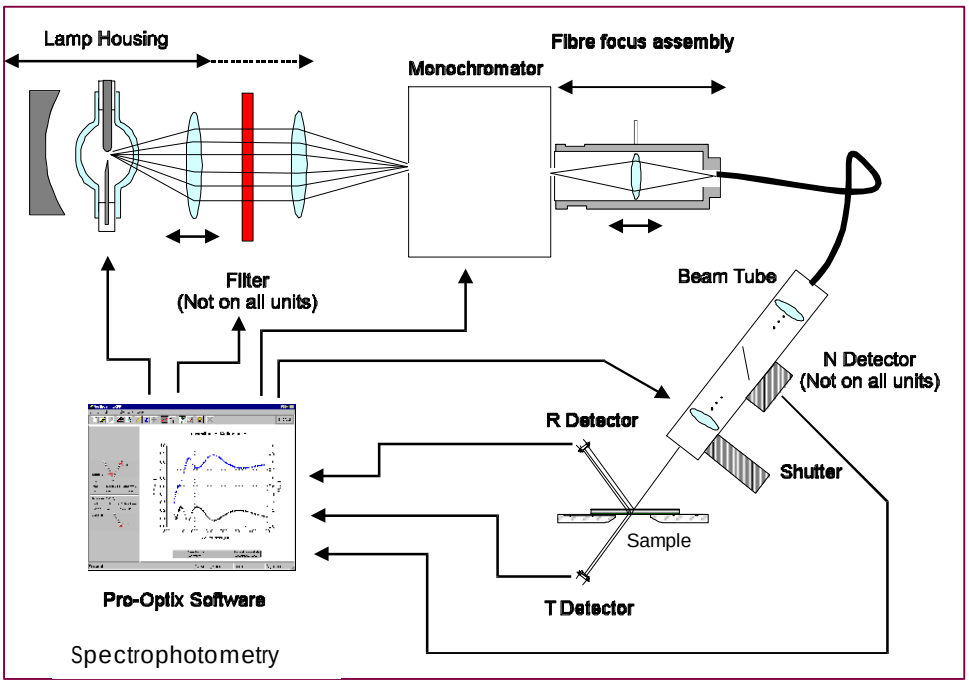
1) Set compensator (say +45 degrees)
2) Find orientations of polariser and analyser giving minimum detected Intensity
3) Calculate relative phase change for s- and p-polarised components, Δ
4) Calculate relative amplitude change for s- and p-polarised components, Ψ
5) Analysis depends on structure of sample. Δ and Ψ can be used to solve for two unknowns.

Ellipsometry

Ellipsometry is a measurement of how the polarisation of a beam of light changes on reflection from a surface. It involves illuminating a sample with a collimated beam of polarised light and analysing the polarisation of the reflected beam, using for example a rotating polariser. Ellipsometry can only be performed at high angles of incidence. The polarising components used in an ellipsometer are generally very costly and the data are complex to analyse, often involving specialised personnel.
A major disadvantage of Ellipsometer measurements is the fact that the analysis cannot account for secondary reflections from the substrate, and samples must be prepared very carefully for Ellipsometry to avoid these. Frequently this is a destructive process, involving techniques such as bead blasting.
An advantage of Ellipsometry stems from the fact that the changes in polarisation of light when it reflects from a surface are quite sensitive to thin layers deposited on the surface. Ellipsometry measurements are therefore able to detect ultra-thin layers (less than 5 nm) more easily than reflectance and transmittance measurements alone.

Spectrophotometry involves measuring the reflectance and/or transmittance of light through thin films and substrates as a function of wavelength. We will consider only the Aquila nkd system as all other spectrometers do not have the performance to match an ellipsometer. Budget spectrometers usually measure just reflectance and at normal incidence, severely limiting their ability to characterise very thin or multi layer and complex films.
In the case of the Aquila nkd system, T and R are measured over a range of incident angles from 0 to 90 degrees, using s-, p- or unpolarised light. The nkd measures both T and R simultaneously from the same place on the sample. Usually, special accessories need to be purchased to adapt a reflectance spectrophotometer for transmittance measurements. Evidently, with such a system it is impossible to ensure that "exactly "the same part of the sample is measured in both transmittance and reflectance. Therefore, conventionally only a single spectrum is analysed.
The amplitude and periodicity of the reflectance and transmittance spectra for a system of thin films is a function of its optical properties. These spectra can be solved for n, k and d using complex mathematical models, with just a few adjustable parameters. Powerful analysis software achieves this quickly and easily. The enhanced functionality of the nkd spectrophotometers over other instruments greatly increases the amount of information available for analysis and guaranties photometric precision.

Aquila instruments Ltd. Ickleton Road, Duxford, Cambridge, CB2 4XQ, UK
Phone: +44 (0)1223 832599 Fax: +44 (0)1223 837027
Email: info@aquila-instruments.com Web: www.aquila-instruments.com



To summarise, the table below provides a performance comparison between the two methods.

Ellipsometry	Spectrophotometry (nkd series)
Analyse polarisation of reflected beam at high incidence angles. Only high incidence angles.	Measure Reflectance and Transmission vs. wavelength, of polarised or unpolarised light over a range of incident angles. 0 to 90 degrees.
Transparent substrates need to be prepared. Cannot handle reflections within substrate. Preparation method is often destructive. Characterisation of substrate not possible.	No sample preparation at all required. Characterise multi-layer films and substrate. Transparent substrate an advantage.
Most expensive method. Costly polarising components.	Cost effective, Turn Key Instrument.
Sensitive to very thin layers $<\lambda/2$	Sensitive to all layers, but excels for thicker layers $>\lambda/2$
Analyse multi layer and complex films	Analyse multi layer and complex films, but more easily with powerful integral automatic analysis software.
Cannot get n and k from single measurement.	n and k determined from single measurement.
Cannot measure T and R simultaneously. Additional attachments required.	T and R measured simultaneously from exactly the same area of the sample, guaranteeing accuracy of results.
Data analysis time consuming and difficult, requiring specialised personnel and third party software.	Data analysis fast and easy with powerful integral automatic software.
Subject to many sources of inaccuracy.	Photometric precision using powerful modelling technique and maximum optical data.
Baseline offsets required.	Full spectrum gives dispersion of n and k. No baseline offsets or corrections required.

The nkd spectrophotometer has the performance of any ellipsometer, with many more advantages.