Hybrid Mode Optical Monitoring – Benefiting from Monochromatic and Broadband Algorithms in the same Coating Process

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Abstract: Broadband monitoring with high signal quality enables use of both broadband and monochromatic layer termination algorithms in the same process when depositing optical interference coatings. Case studies using a bandpass filter and an absorbing layer show how such a “hybrid” approach can lead to the most accurate layer termination.

1. Introduction
An essential component of state-of-the-art deposition systems for the development and production of optical interference coatings is an in-situ optical monitor. By measuring either transmittance or reflectance on a product or a specific monitor substrate during film growth, the termination of each layer can be controlled based on the actual optical performance of the coating.

While monochromatic optical monitors measure the intensity at a selectable wavelength, broadband optical monitors simultaneously measure the intensity of a large number of wavelengths and therefore allow for monitoring and evaluating the performance over a wide spectral range. This enables detailed analysis of thicknesses and refractive index dispersions as well as in-situ reoptimization [1,2].

In most cases, both monochromatic and broadband monitoring can be applied, but in certain situations – as shown in the examples below – one of the methods will lead to a more accurate layer termination.

2. Broadband monitoring with high signal quality
By evaluating just a single or a narrow range of wavelengths from the array detector, a broadband monitor can be used with the same layer termination algorithms as a monochromatic monitor [3,4]. A prerequisite for this is a high signal to noise ratio in order to avoid wrong detections of turning points, which would lead to coating failure.

High signal to noise is possible by (a) selection of a spectrometer with a highly sensitive and low noise array detector, (b) optimization of the optical measurement path to eliminate disturbing light arising from the deposition process, and (c) frequent calibration of the measurement. If transmission is measured directly on a substrate moving in the coating chamber, reference measurements can be taken through a small aperture in the substrate holder as shown in Fig. 1. With the aperture close to the measurement position, reference and sample measurement are performed within a few milliseconds and therefore fluctuations in the measurement conditions can be greatly eliminated. Transmission is directly calculated as \( T_{\text{Mod}}(\lambda) = \frac{I_{\text{Mod}}(\lambda)}{I_{\text{Ref}}(\lambda)} \), where \( I_{\text{Mod}} \) and \( I_{\text{Ref}} \) are the intensities measured at the monitor and reference position, respectively.

The above developments are realized on evaporation as well as magnetron sputter deposition tools with the Evatec GSM1101 optical monitor, which covers a wavelength range of 380nm to 980nm (standard version) or 260nm to 980nm (UV extended version).
3. Hybrid mode optical monitoring

On the basis of broadband monitoring with high signal quality, “hybrid mode optical monitoring” now offers the user the possibility to select between monochromatic and broadband layer termination algorithms for each layer in the design individually. For this purpose the Evatec “Strategy Generator” software loads the coating design and refractive index dispersions and simulates the deposition process. From this simulation, the optimum layer termination criterion and monitoring parameters can be determined for each layer. In the case of monochromatic monitoring, in addition to the wavelength also a width can be specified in order to integrate the signal over a narrow wavelength range.

The monitoring data is then uploaded to the deposition tool controller. During deposition, the broadband spectra are stored for each layer, even if layers are terminated in monochromatic mode. Engineers that are used to develop their well-known and proven monochromatic monitoring strategies therefore can benefit from measured and simulated spectra for each layer for analysis, optimization, or in-situ reoptimization.

4. Application examples

4.1. Absorbing layer material

Materials suitable for coatings in the infrared region like Germanium show a low absorptance in the 8µm to 12µm wavelength range. The layer thickness can very well be controlled by optically monitoring the “standard” visible and near infrared range [5]. Unfortunately, the extinction coefficients vary significantly in that range with deposition conditions and may be difficult to determine.

Fig. 2 shows the monochromatic monitoring curve measured in a BAK evaporation system. Due to the absorptance the amplitude of the extrema is decreasing. However, by tracking the extreme values and the time between them, the layer termination can be triggered accurately at the intended thickness.

![Fig. 2. Monochromatic monitor signal (reflectance at 906nm) of an absorbing layer material deposited in a BAK tool.](image-url)
4.2. Bandpass filter

Fig. 3. Optical layer thicknesses of the bandpass filter design and transmission spectra of the design and from 6 coating runs.

As an example for the mixed use of monitoring strategies a simple bandpass filter is considered. The design is made of 11 layers with TiO$_2$ and SiO$_2$ as coating materials on a float glass. A starting design made of multiples of quarter-waves was optimized to flatten the transmission band. Fig 3 shows the optical layer thicknesses and the design and measured transmission spectra.

For this class of designs it is well known that the final filter performance mainly depends on the accuracy of the thick spacer layers. Fig. 4 shows the simulated spectra after layers 6 and 10, respectively, with the layer thicknesses of these layers varied ±3%. The significant change in the spectrum of layer 6 indicates that broadband monitoring allows for accurate layer termination. However, layer 10 shows only a small variation in the spectrum. Here monochromatic monitoring at wavelength 550 nm and layer termination relative to the last minimum and maximum is suitable. Reverse engineering of the deposited thicknesses revealed highly reproducible results for layer 6 (broadband), whereas layer 10 showed a variation of ±1% for the broadband layer termination and less than ±0.1% for the monochromatic termination.

Fig. 4. Transmission spectra with thickness variation at the end of layers 6 and 10 and monitoring signals of layer 6 (broadband, 420nm…800nm) and layer 10 (monochromatic, 550nm).
5. Summary

Hybrid mode optical monitoring combines broadband and monochromatic strategies within the same process. This allows for choosing the most appropriate monitoring method for each layer in a design, which ensures excellent control of the coating processes.

6. References


