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## Extended Abstract

# Optical In-line Control of Web Coating Processes

### 1. Benefits of Inline Monitoring

Increasingly stringent quality standards and enormous cost pressure in the manufacturing of vacuum coated products require not only the identification of disruptions in the production process at an early stage, but also an improved understanding of processes in general. Spot checks are no longer sufficient in view of the zero fault rates specified today. For effective quality assessment, it must be possible to identify the quality features online on the basis of the process data. The increasing automation of these quality and process monitoring procedures is an enormous challenge for the precision, accuracy and reliability of the in-line measuring systems also used for 100% inspection. These are “ideal” conditions for the use of optical measurement techniques and compact spectrometer systems designed for industrial applications.



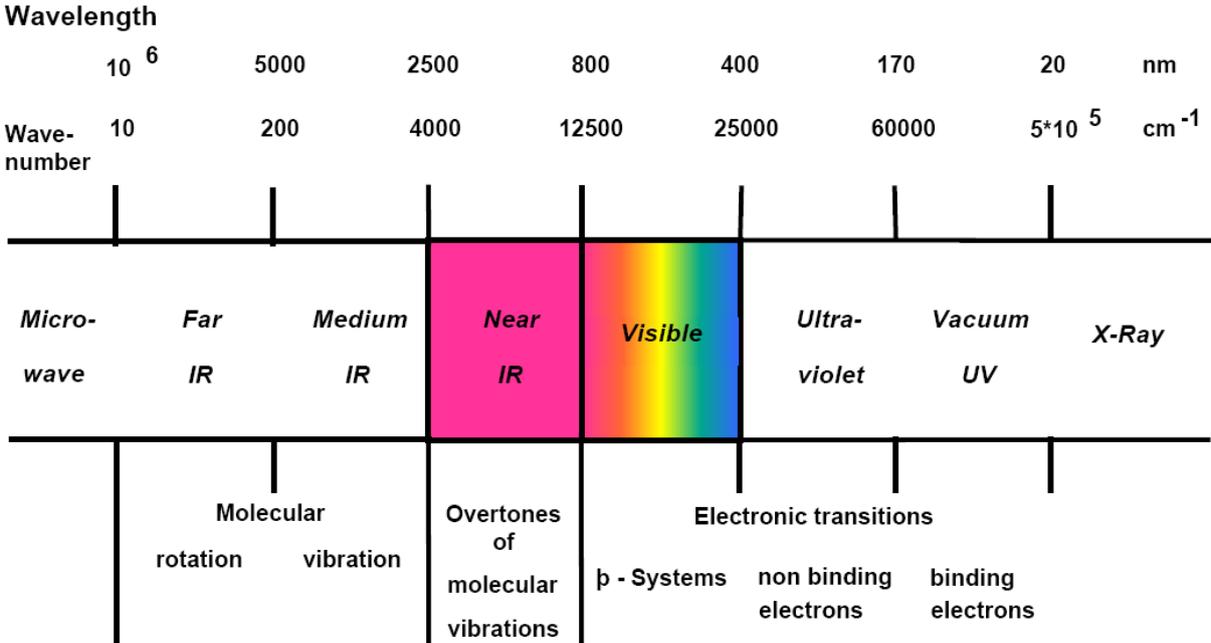
Pic 1: Benefits of Inline-Monitoring

An effective inline process and quality control can be achieved with measurement systems using compact diode array spectrometer technology, providing in-line measurement of spectral reflectance and transmittance including the calculation of color values and layer thicknesses. They are designed for large area and high through-put coating systems with the data displayed in real time, an outstanding measurement speed, excellent data reproducibility and high reliability.

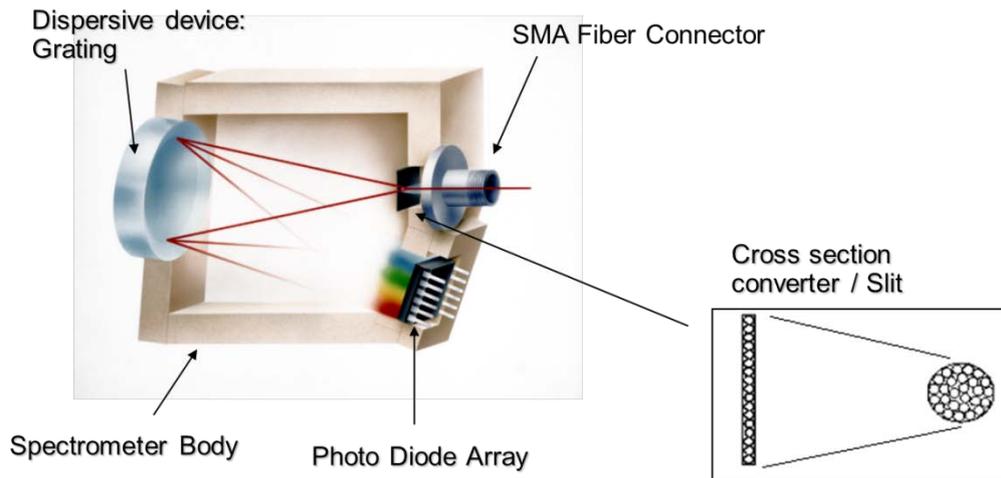
## 2. Photo Diode Array Technology

A classic spectrometer or a classic monochromator typically consists of a dispersive medium, entrance and exit slit, and imaging components which produce a parallel beam path. To record a spectrum, a detector located behind the exit slit must subsequently record the incident light, while the dispersive component or the exit slit is moved.

The mechanical movement requires time and is prone to failure. In many applications – in industry in particular – short measuring times and insensitivity to external influences are a major advantage. This is why, at the end of the 1970s, Carl Zeiss started to develop diode array spectrometers which feature a diode array instead of an exit slit and which simultaneously record a complete spectrum within a fraction of a second and hence make moving components unnecessary. The concept of the spectrometer module family of Zeiss is based on reducing the optomechanical design and the number of components to the physical minimum and, at the same time, to share a maximum number of components in all versions.



Pic 2: Electromagnetic Spectrum. UV-VIS-NIR Spectroscopy range: 190nm to 2.200nm



Pic 3: Schematic of a Polychromator



Pic 4: Spectrometermodules

### 3. Measured Spectra and calculated values

For most applications the Reflection- and Transmission Spectra in the visible or near infrared wavelength-range are of interest per se. There is additionally the opportunity to calculate parameters like Colorvalues or Layerthickness from these spectra to gain further information about the product and the process.

#### Color Measurement

The human eye captures visible light in the range between about 380 nm and approx. 700 – 750 nm. The eye captures three different color stimuli: blue, green and red. The color impression is achieved by addition of these three stimuli in the brain. Any color can be composed by adding red, green and blue.

Color impression depends on three interrelated factors:

### Light source

E.g. daylight or filament lamp, with different intensities of their individual spectral components.

### Sample

The composition defines the components of reflection, absorption and refraction.

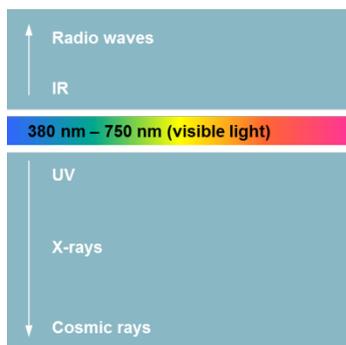
### Observer

Different sensitivities of the three light-sensitive receptors on the retina convey different color impressions.

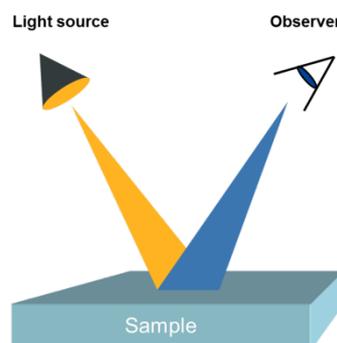
In addition to the CIE color system, it is mostly the  $L^*$ ,  $a^*$ ,  $b^*$ -system developed by Judd and Hunter, standardized in 1976 and also based on sensitivity.

The  $L^*$ -value indicates the position of the bright/dark axis, the  $a^*$ -value the position of the red/green axis and the  $b^*$ -value the position of the blue/yellow axis.

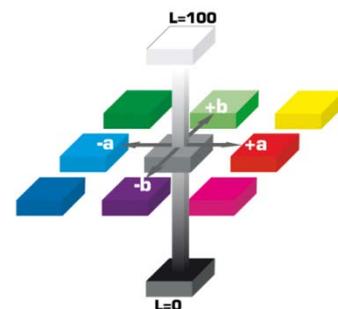
The  $L^*$ ,  $a^*$ ,  $b^*$ -coordinates are directly related to the standard color values X, Y and Z.



Pic 5: VIS – range



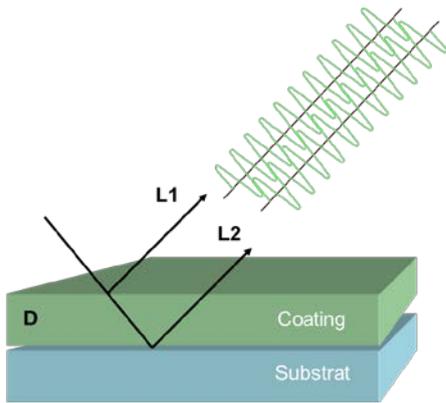
Pic 6: Color Measurement



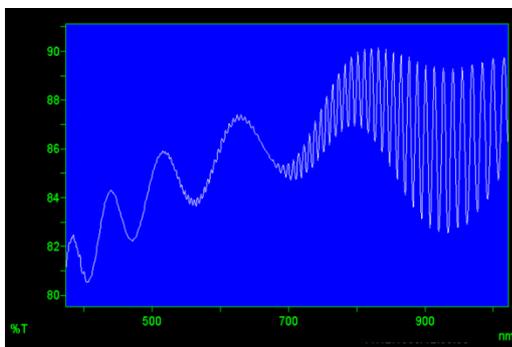
Pic 7: CIE color system

## Layerthickness Measurement

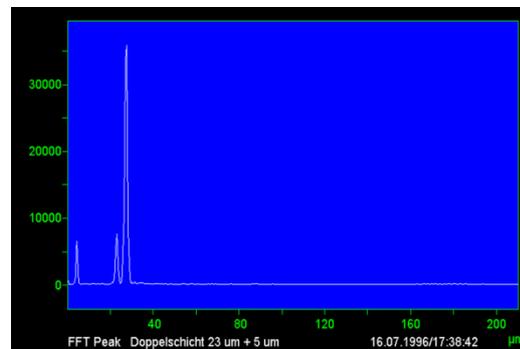
In Spectroscopy the measurement of layer-thickness is based on White light interference (Pic 8). By illuminating samples with white light, interference spectrums are created as a function of the geometric layer thickness and refraction index due to the superposition of reflection spectrums caused by the upper and lower sides of the coating. For some layerstacks with one or two layer the thicknesses can calculated simply with a Fourier Transformation (Pic 9 + 10).



Pic 8: Layer Thickness Measurement

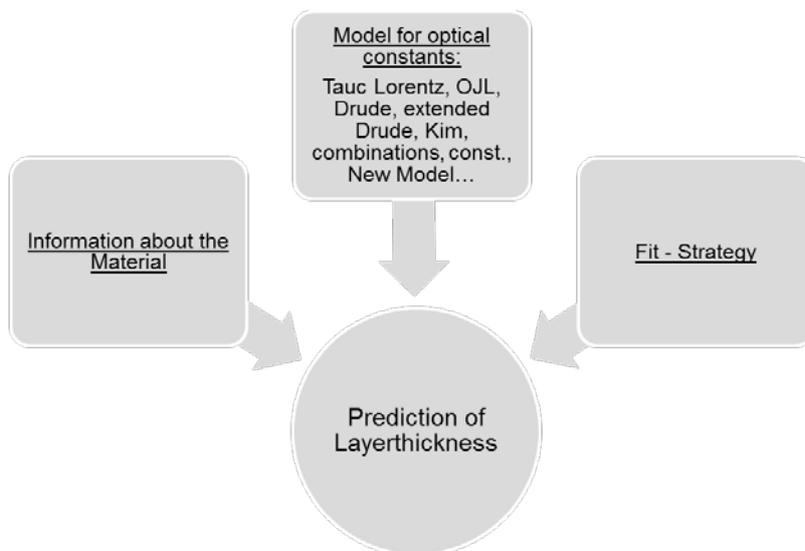


Pic 9: Spectrum of a double-layer



Pic 10: Fourier Transformation

For the majority of used Layer compositions this doesn't lead to success. For more sophisticated Layerstacks it is necessary to approach the Layerthickness calculation with a Fit-Model.



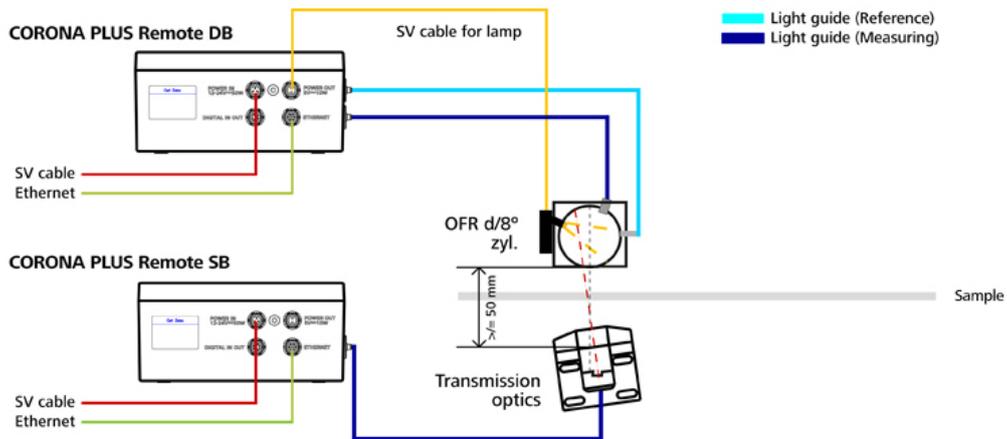
Pic 11: Prediction of Layerthicknesses

#### 4. Measurement Geometries

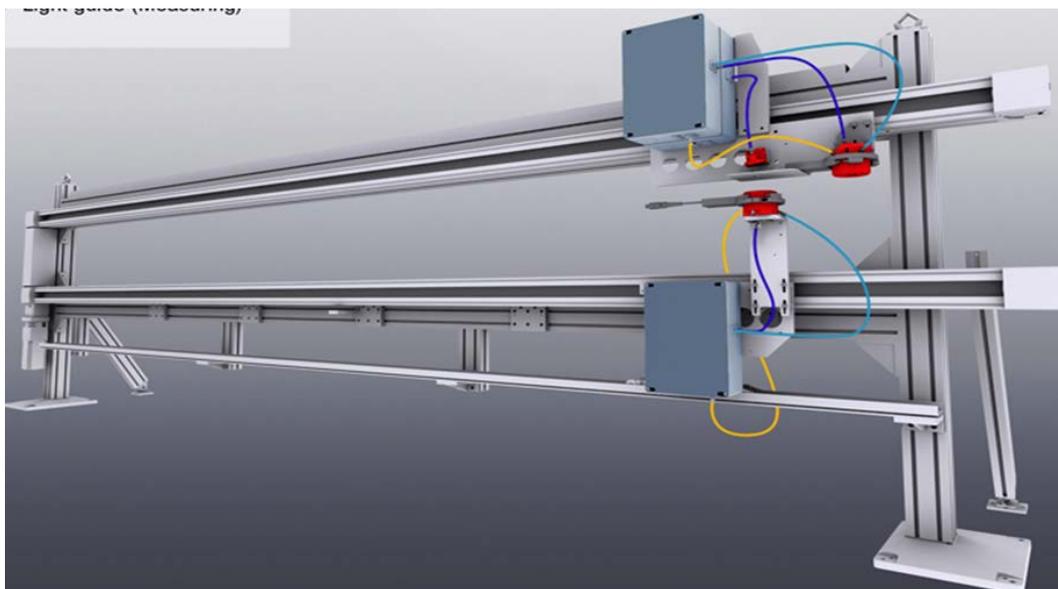
Dependent on the design of a glass or web coating line, different measurement geometries and spectrometer configurations (Ex-situ and In-situ) are common.

Picture 12 shows a standard configuration for the measurement of the transmission spectrum and the reflection spectrum in a glass coating line.

One of the advantages of this patented geometry is the possibility to measure the transmission spectrum and the reflection spectrum at exactly the same spot to exactly the same time.

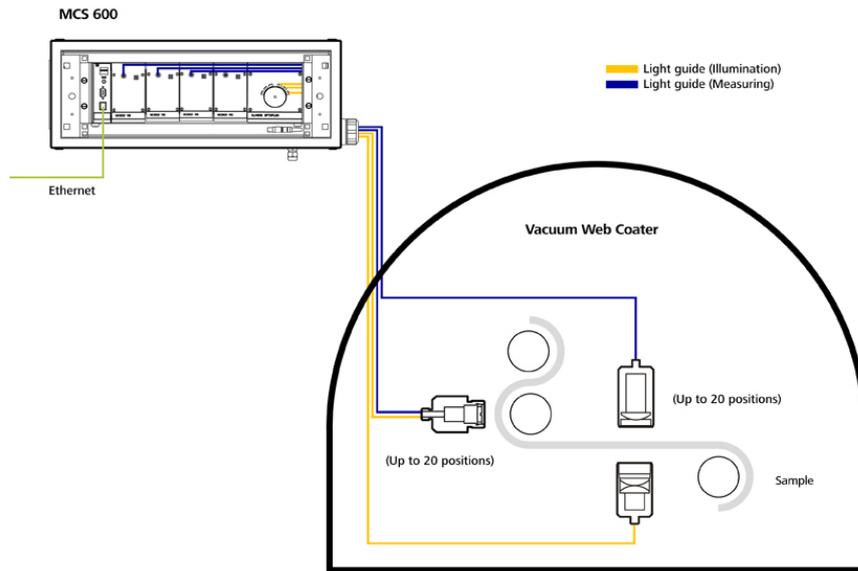


Pic 12: Patented Geometry for the measurement of Transmission and Reflection



Pic 13: Traversed System for Ex-Situ measurement in a glass coating line

In a Web coater it is possible to use configurations either with parallel optics or integration spheres combined with optics.



Pic 14: Possible configuration in a Web Coater

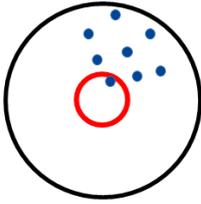
## 5. Requirements and Challenges of Inline Monitoring

Requirements for an Inline Measurement System:

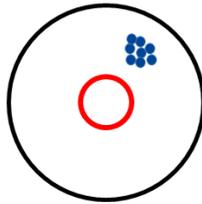
- Non destructive / Contact-free
- Shortterm ROI
- Easy Integration in production line
- User Maintenance and Service Friendliness
- High Reliability / Robustness/ Stability
- High Accuracy / Precision
- High Performance

The compliance to some of those requirements goes without saying and just needs some experience in measurement systems for industrial applications. For others, like High Accuracy (Pic 15) or Reliability, the spectrometer design (Pic 16) and the integration of the measurement system into the coater is crucial.

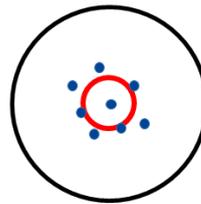
Not precise and not accurate



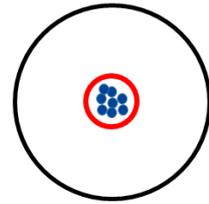
Precise, but not accurate



Accurate, but not precise



Precise and accurate



Pic 15: Definition of Accuracy and Precision

### Design Principles of a Spectrometer:



- Fiber cross-section converter as optical input
- SMA connector
- Holographically recorded and blazed imaging grating
- Photodiode Read-out
- Robust housing, no moving parts

#### **Benefits**

- Highly reliable
- Permanently calibrated
- No moving parts
- Wide dynamic range
- Robust
- Fiber optic input
- Diode array equipped

#### **Challenges:**

- Distance- /Angle variations
- Calibration (Material, Methode...)
- Waviness of Substrate
- Adjustment of the Measurement Heads
- Ambient Reflections / Ambient Light
- Space/ Footprint
- Contamination

## 6. Conclusion

Optical Inline measurement with Photodiode array technology can provide “Lab-values” and is a perfect tool for process optimization.