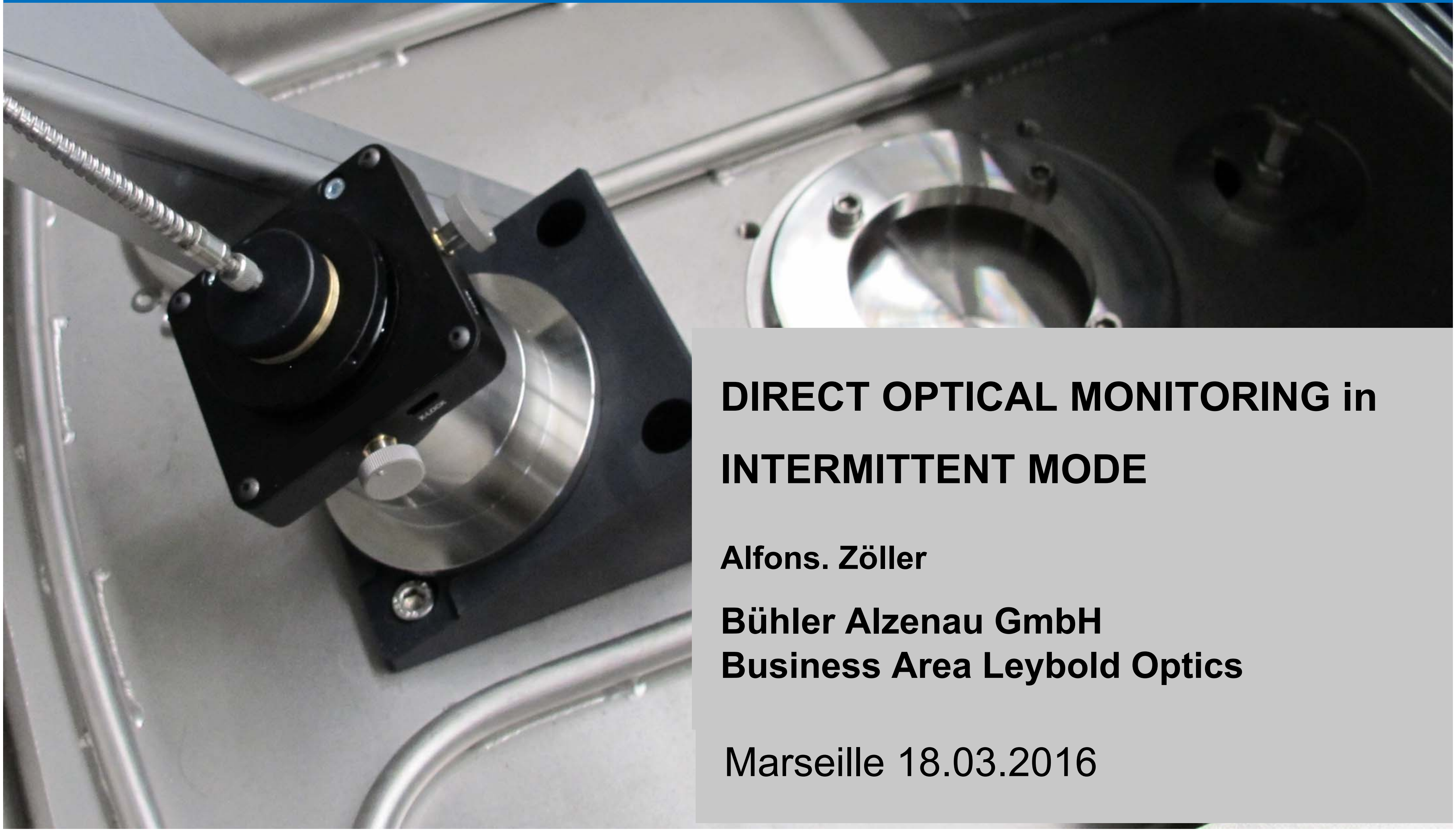
3ème Journée Thématique COUCHES MINCES OPTIQUES

Vendredi 18 mars 2016 - Institut FRESNEL (Marseille)



DIRECT OPTICAL MONITORING in INTERMITTENT MODE

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Business Area Leybold Optics

Marseille 18.03.2016

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DIRECT OPTICAL MONITORING in INTERMITTENT MODE

Part I Monochromatic Monitoring

- **Introduction.**
- **Measurement set-ups and Instrument performance.**
- **From design through manufacture (process download, simulation)**
- **Applications.**

Part II Wideand Monitoring System

- **Schematic and technical data.**
- **Functionalities.**
- **Applications and outlook.**

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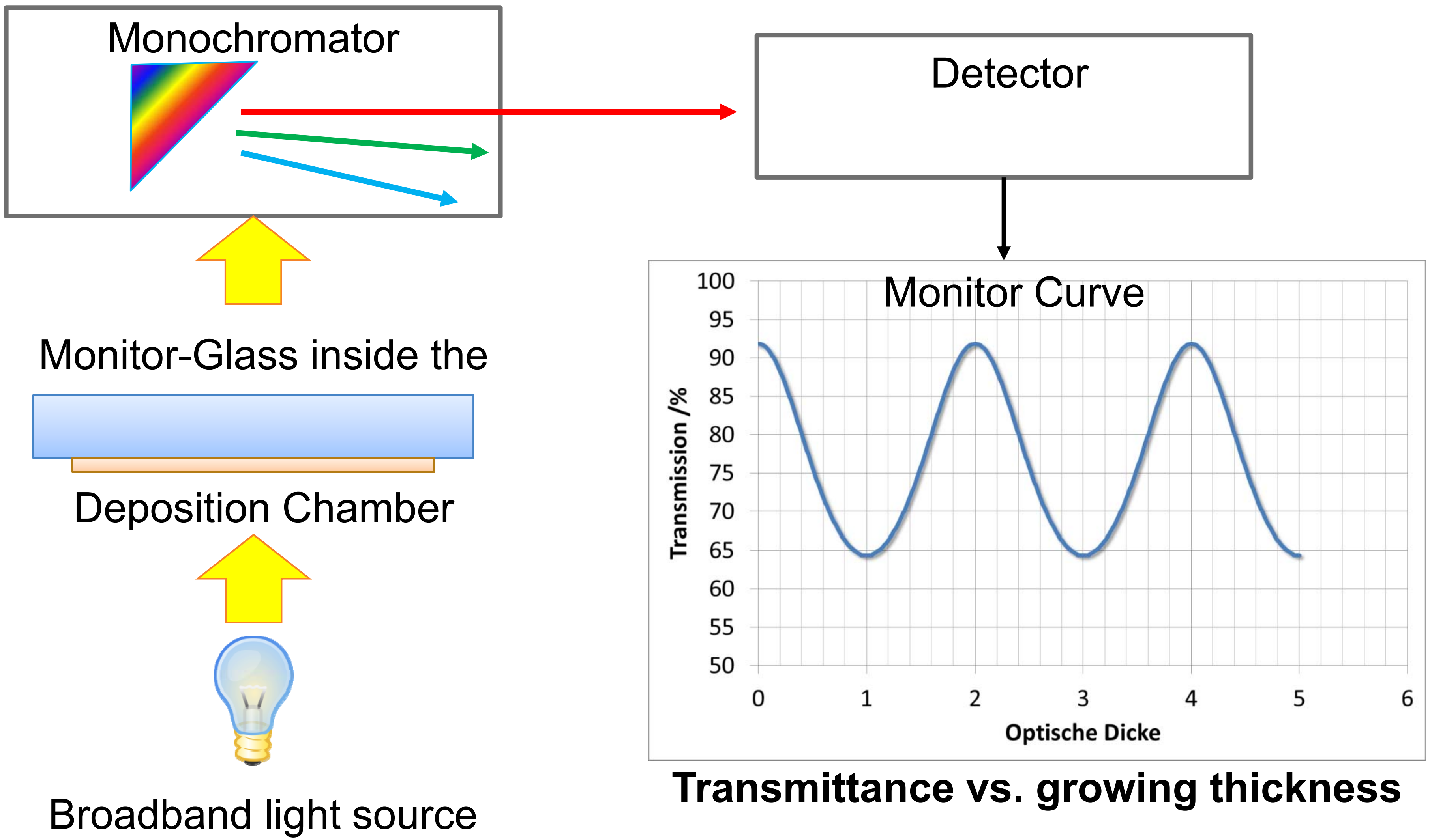
Principle of Monochromatic Monitoring



Monitoring the optical thickness n x d

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Monochromatic Monitoring

Advantages of Monochromatic Monitoring
1. Layer cut-off conditions coupled on turning points and therefore linked to the optical thickness.
2. Small refractive index variations are compensated automatically. (very robust in a production environment).
3. Errors made during the deposition of a layer are compensated in subsequent layers (true for many layer systems).

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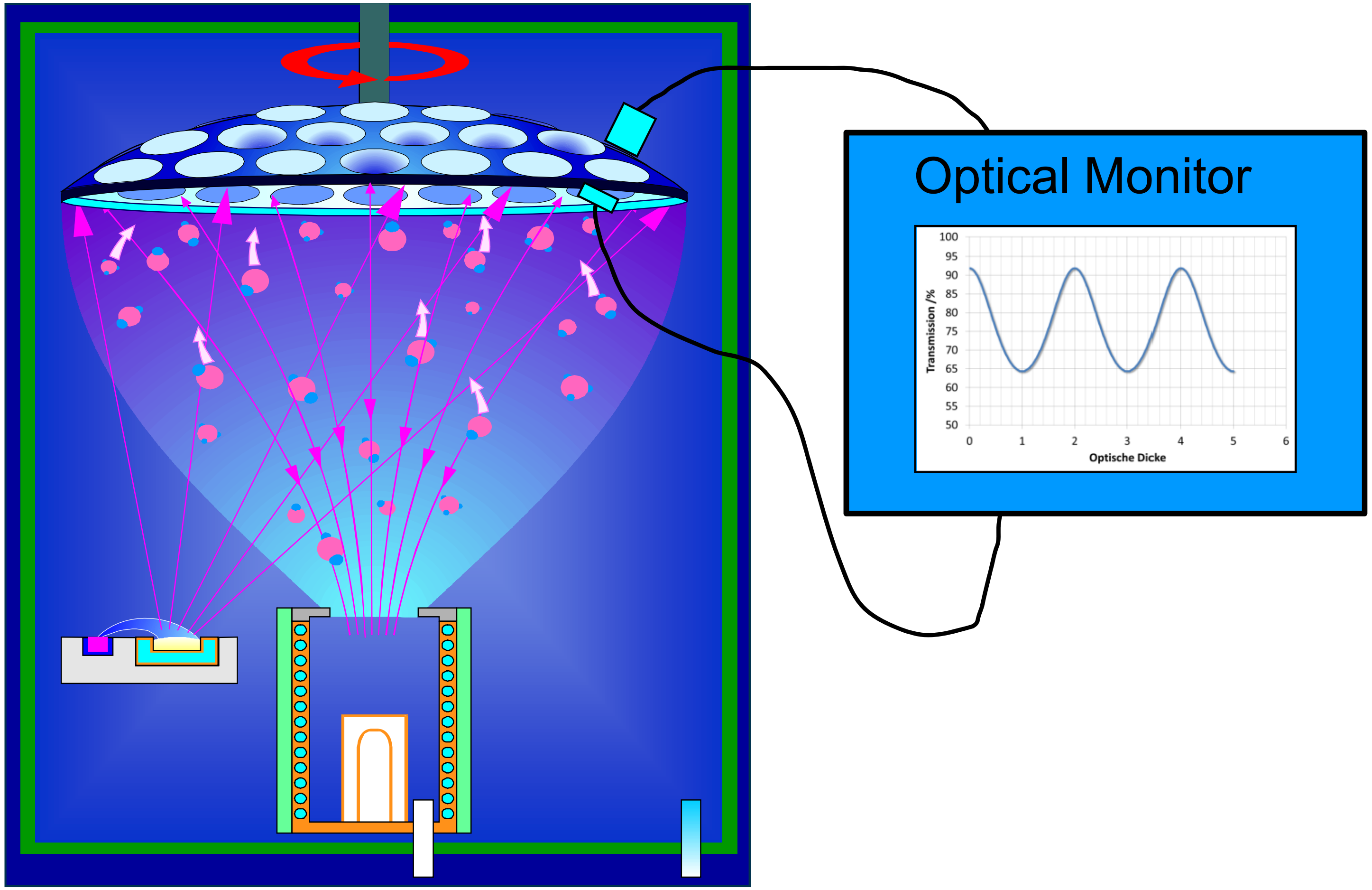
Direct Monochromatic Monitoring on Dome



Boxcoater with intermittent measurement (typical rotation speed app. 30 rpm)

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Syrus*pro* 1100 with testglass changer on calotte

Testglass changer assembled on a dome shaped calotte

View from the deposition side

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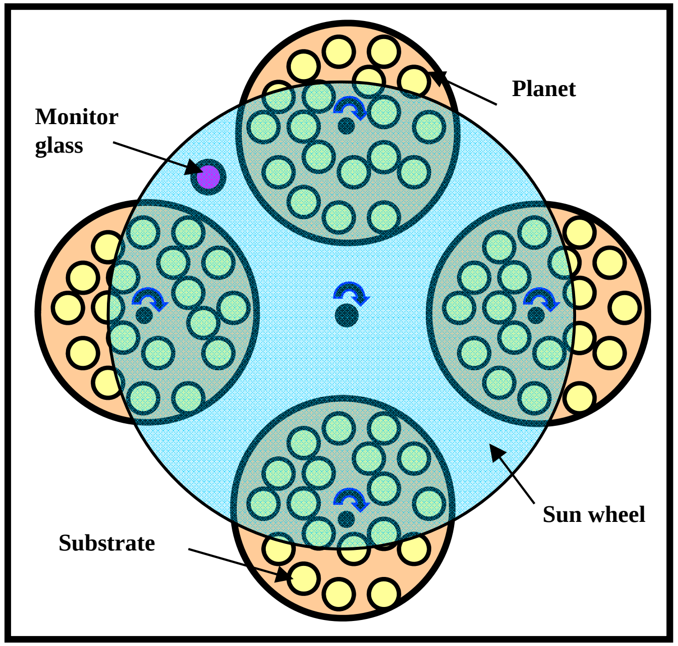
Direct Monitoring with Planetary Substrate Montion



Planetary system: top view with monitor glass

Syrus*pro* 1110 Boxcoater mit ∅300mm Planets

Boxcoater with intermittent monitoring between planets (typical rotation speed 20 rpm)

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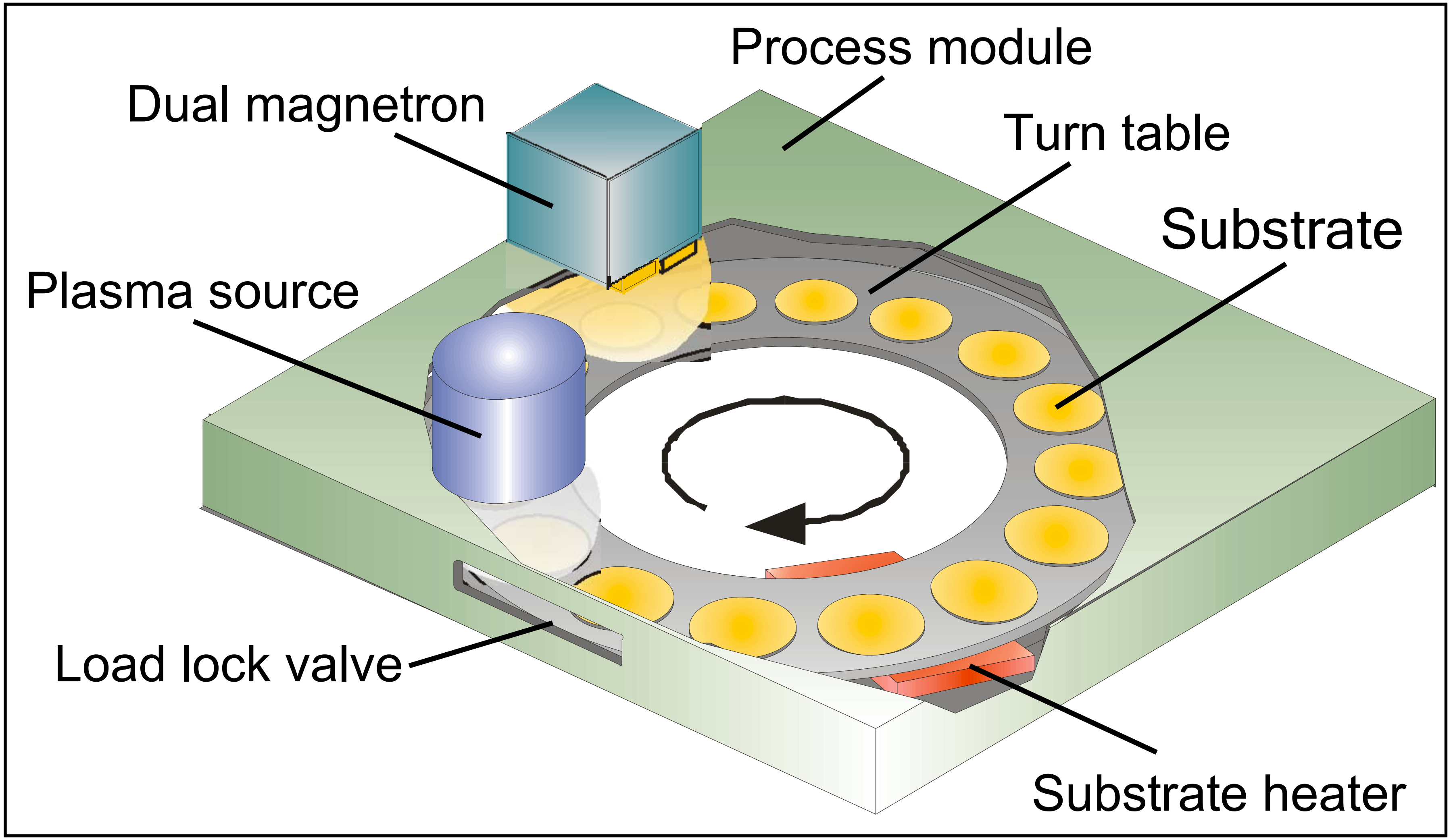
HELIOS Magnetron Sputter System

Plasma **A**ssisted **R**eactive **M**agnetron **S**puttering **(PARMS)**



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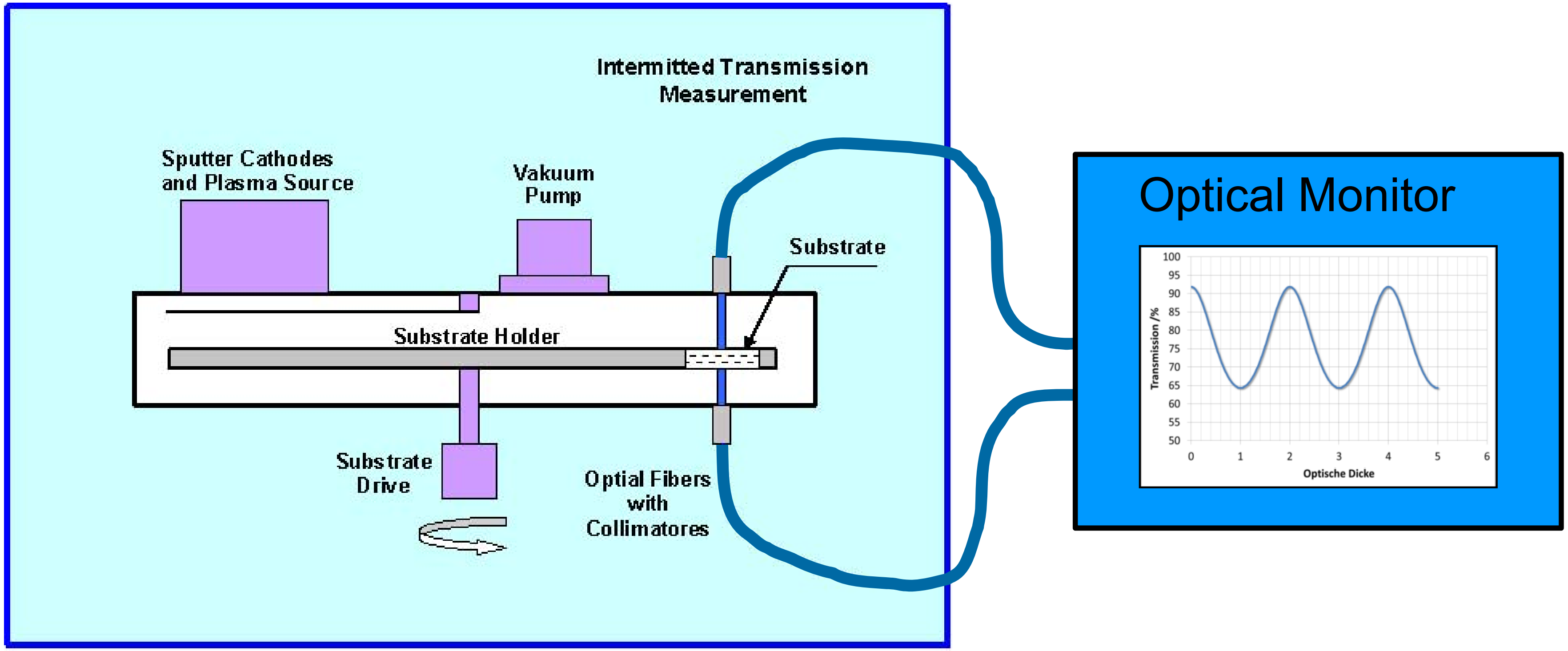
Direct Monitoring on fast rotating substrate holder



Helios Magnetron sputtering system with intermittent monitoring (typical rotation speed app. 200 rpm)

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Direct Monochromatic Monitoring

Advantages of Direct Monitoring
1. No tooling factor between monitor glass and substrates. Note: A tooling factor is never constant ! It depends on process parameters and varies with the actual condition of the coating equipment.
2. Film properties on the monitor glass almost identical to those of the substrates.

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Typical performance data OMS 5000/5100

- noise/signal ratio of the raw signal
  (<0.02% rms; depends on hardware set up and detector performance)
- wavelength accuracy (<0.5nm; depends on monochromator calibration)
- monochromatic bandwidth (0.5nm – 15nm; depends on slit width)
- measurement frequency (15rpm – 250rpm; determined by the rot. speed)
- signal drift (negligible due to self compensation)
- calibration error (< 1%, importance depends on cut off algorithm)
- signal processing (extensive software algorithm)
- cut-off algorithm (turning point, trigger-point algorithm absolute or relativ)

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Syrus*pro* Box Coater with direct monitoring

Single layer SiO_2 on glass ($T_{max} - T_{min} \approx 1\%$)

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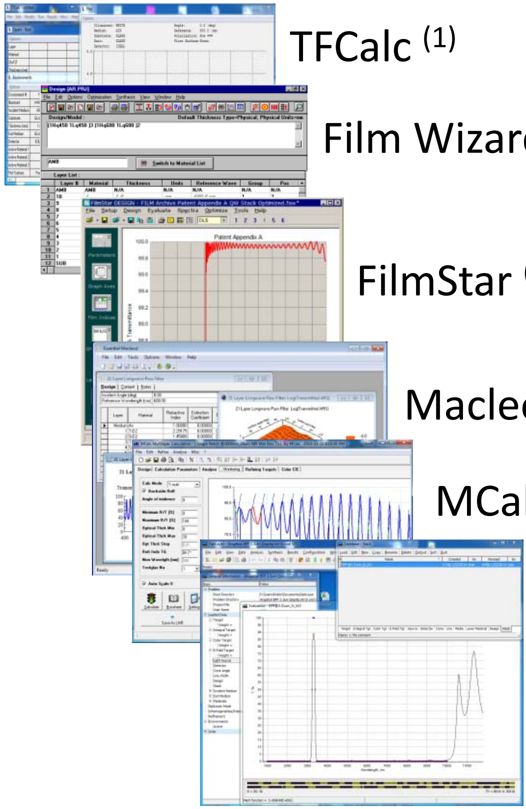
From design through manufacture

Specification

Design and monitoring strategy



TFCalc [1]

Film Wizard [2]

FilmStar [3]

Macleod [4]

MCalc [5]

Optilayer [6]

Coating

Imr file

Process Simulation

[1] Software Spectra Inc. [2] SCI Inc. [3]FTG software Inc. [4] Thin Film Center Inc. [5] D.Arhilger [6] Optilayer Ltd.

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Monochromatic Monitoring

Establish Monitoring Strategy
1. Select monitor wavelength in order to get useful cut-off conditions.
2. The monitor wavelengths may vary from layer to layer.
3. Select potential test glass changes if a chip changer available.

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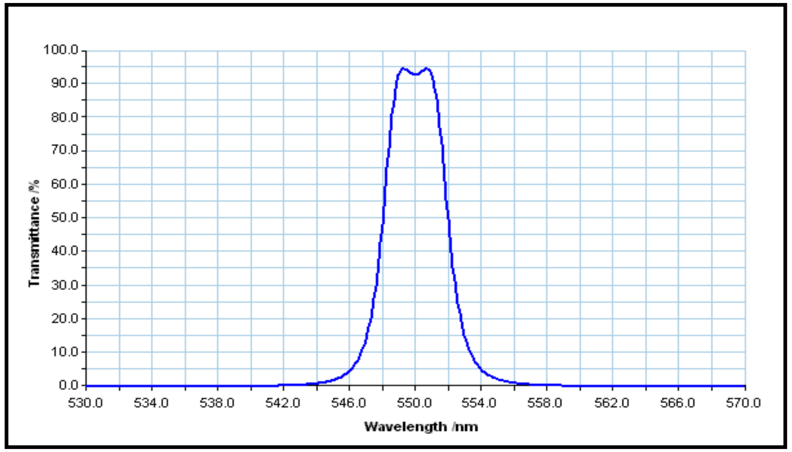
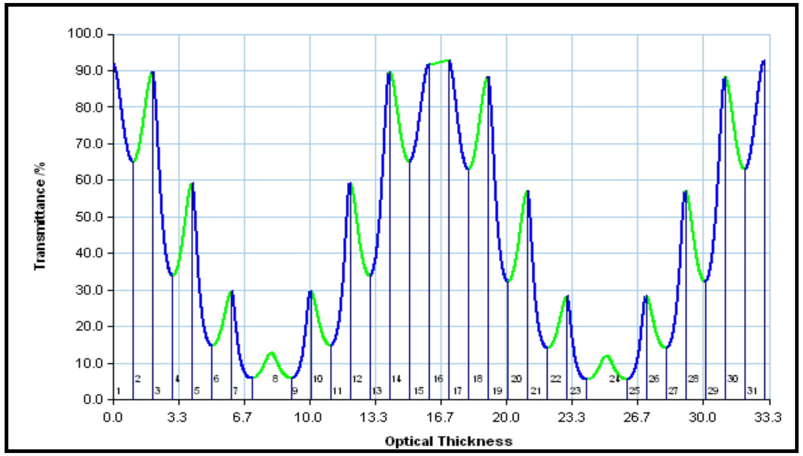
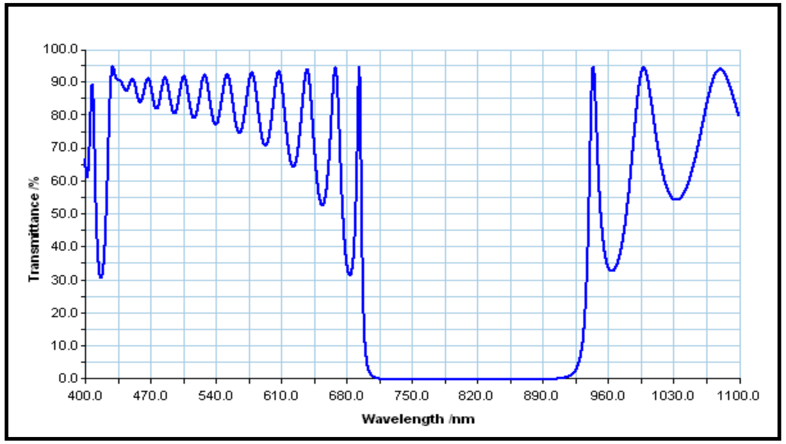
Monochromatic Monitoring

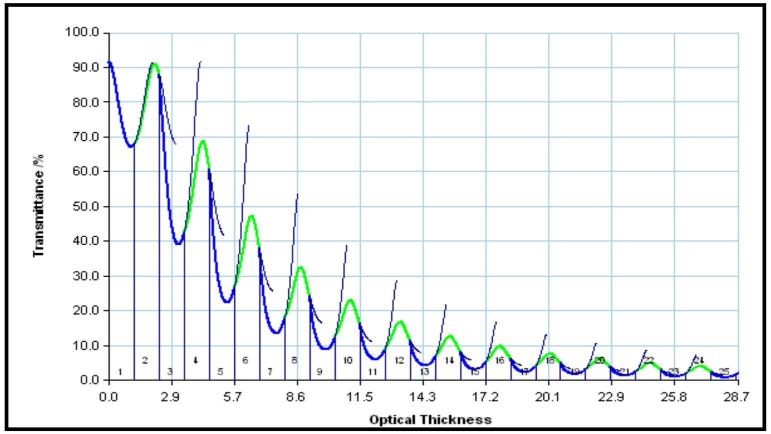
Establish Monitoring Strategy





2-Cavity filter fabry perot design





Mirror with $\lambda/4$ stack

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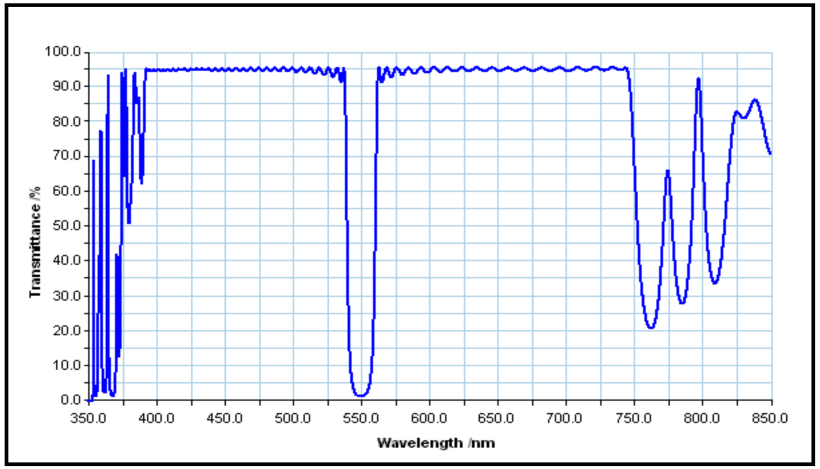
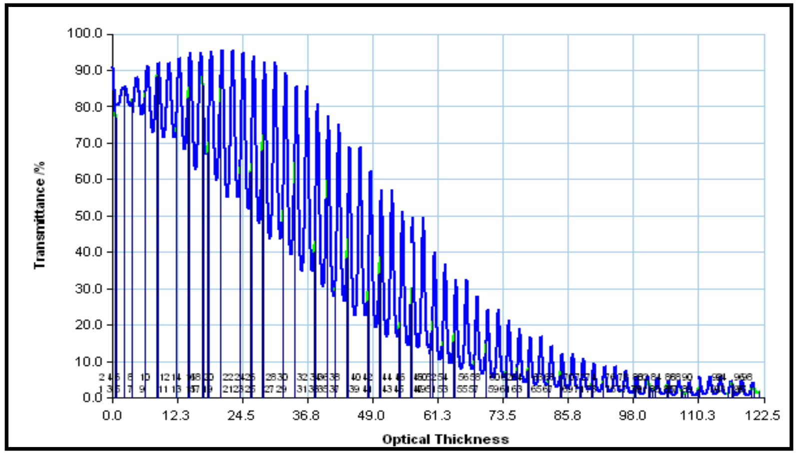
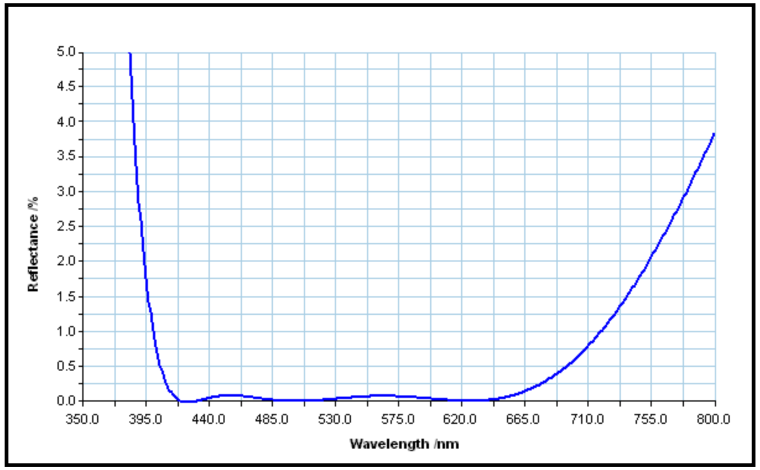
Monochromatic Monitoring

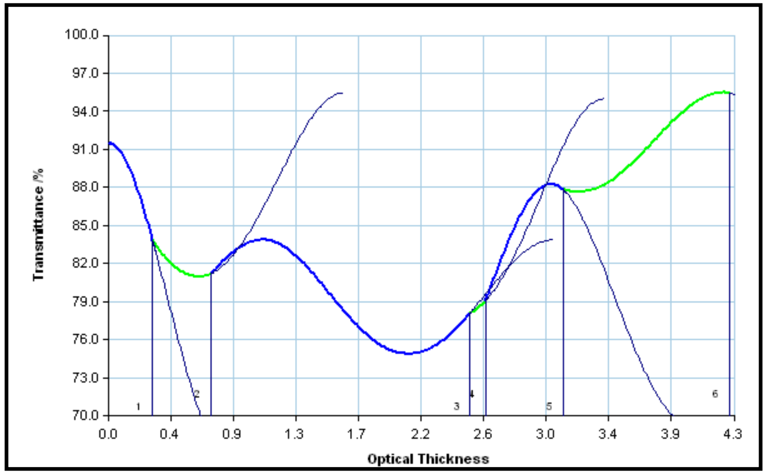
Establish Monitoring Strategy





98 Layer Notch filter





6-Layer BBAR Coating

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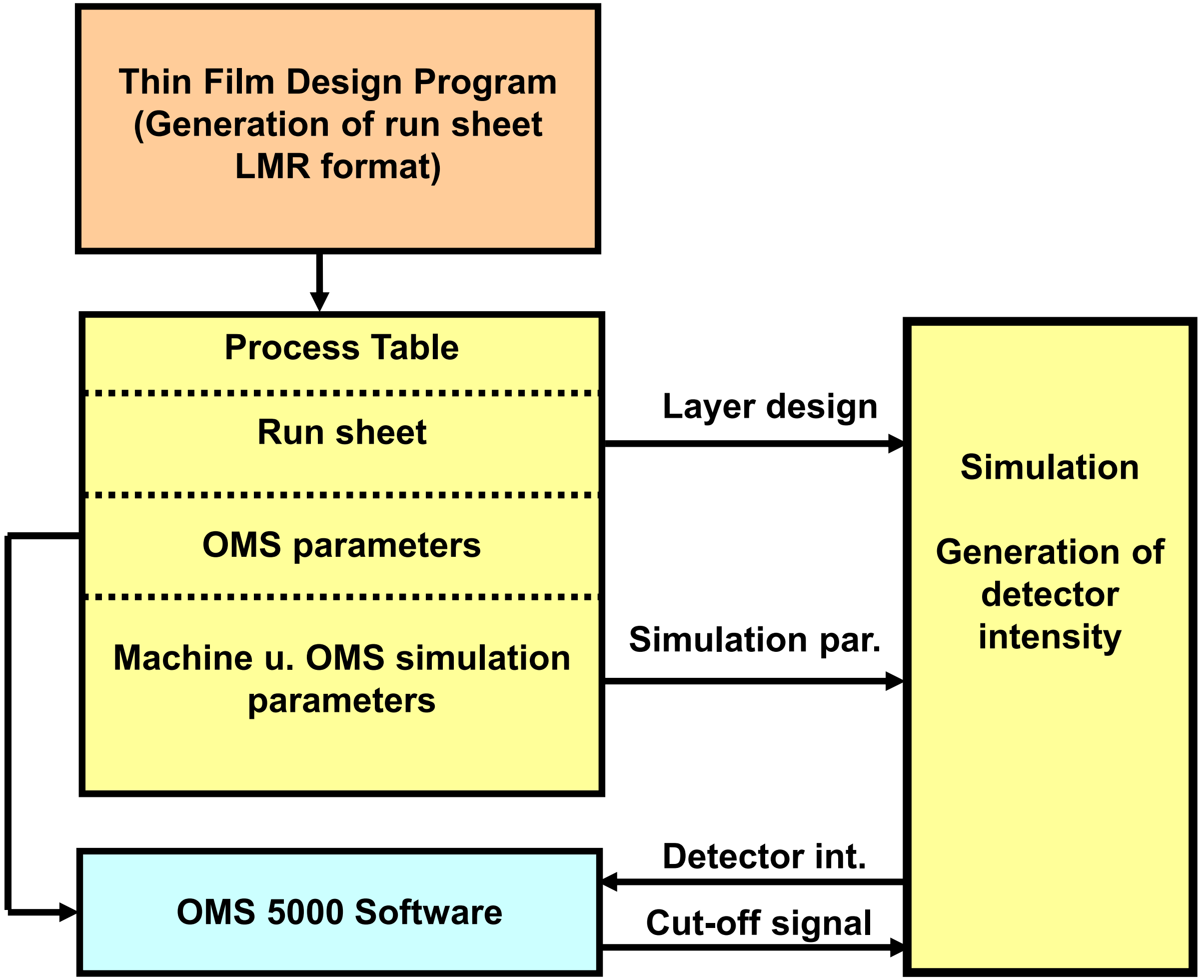
Monochromatic Monitoring

Establish Monitoring Strategy

- Selection of the monitoring strategy is still a manual process.

- Optilayer gained some progress in automation.
- Some criteria like wavelength range, number of different wavelengths, swing-in and swing-out can be parameterized.
- A special software is automatically selecting monitor wavelengths in order to meet the programmed criteria.

Softwarestructure of the OMS 5000 process simulation tool



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Direct Monochromatic Monitoring

Basic Parameters of the machine performance are used for process simulation

Monitoring system	**Coating machine** **(systematic and random errors)**
■ Signal Noise ■ Measurement frequency ■ Monochromator bandwidth ■ Nonlinearities	■ Refractive Index variations (n,k) ■ Rate variations ■ Shutter delays

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Monochromatic Monitoring

Process Simulation

- **Process simulation is a big step to avoid bad coating runs !**

- Process simulation proofs the stability of the monitoring strategy.
- Process simulation supports optimization of thre process parameters.
- The simulation software exports a file with monitor run-sheet and process parameters which is used for transfer to the machine control system.

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From design through manufacture

Design and Monitor Run Sheet Data stored in LMR Format

LMR = Leybold Monitoring Runsheet

- **LMR file includes layer thicknesses, material dispersion data, monitor wavelengths.**
- **Simulation software tool creates lmr files.**
- **The machine control system imports lmr files.**
- **With a few mouse clicks one can program a process with hundreds of layers.**

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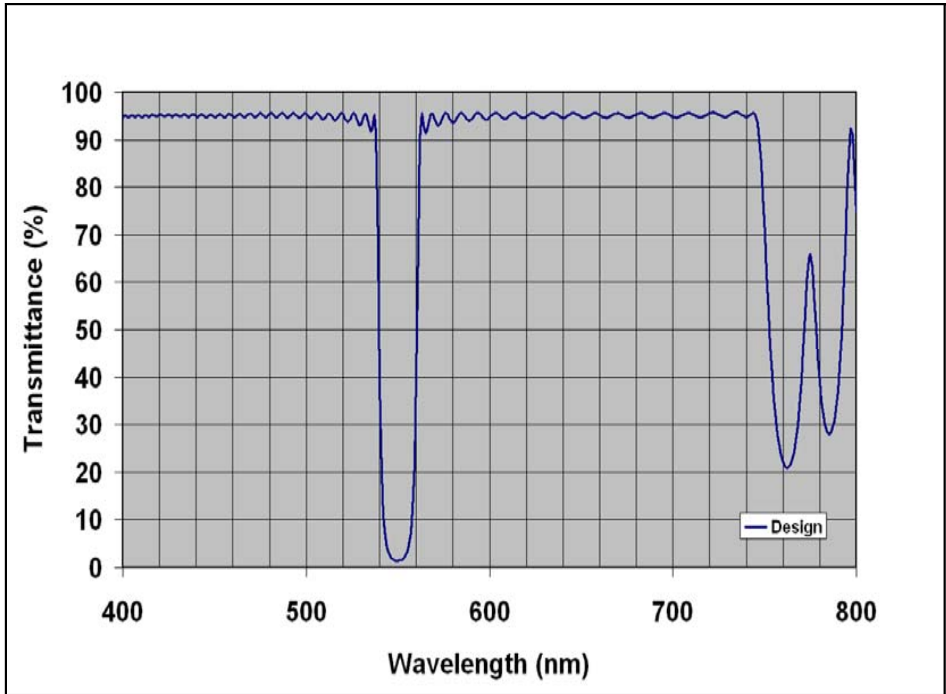
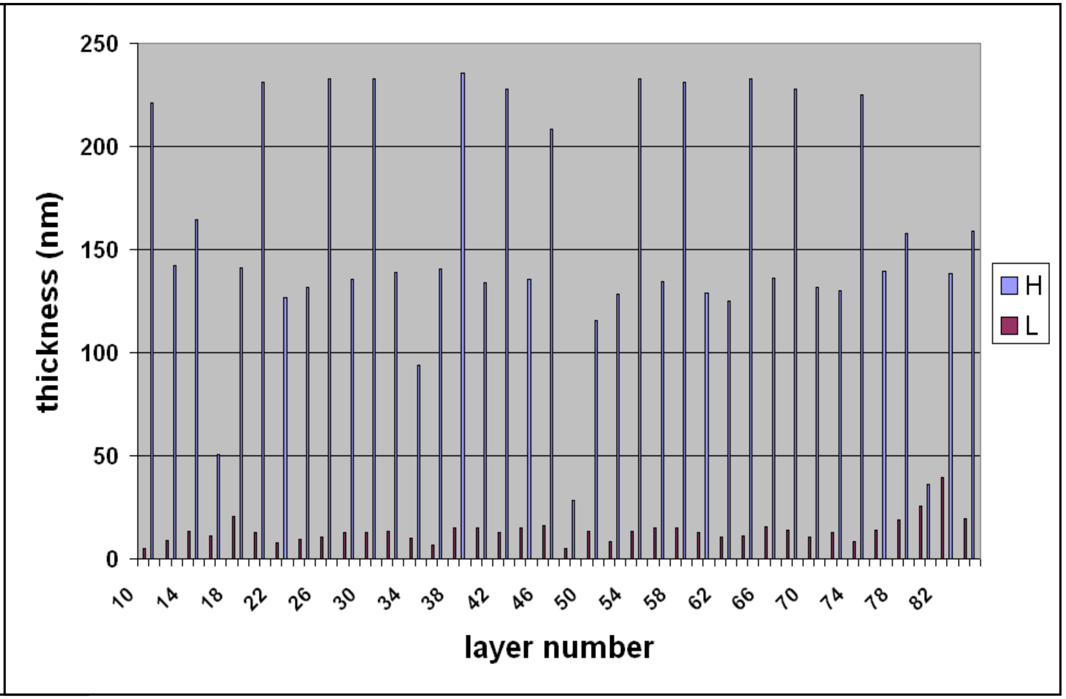
Direct Monochromatic Monitoring

98-layer notch filter coating with Ta_2O_5/ SiO_2





Theoretical design **Basic layer thickness structure**

- **The majority of the L index layers vary between 5nm and 15nm**
- **The H index layers vary between 50nm and 240nm**
- **Total thickness: ≈ 8µm**

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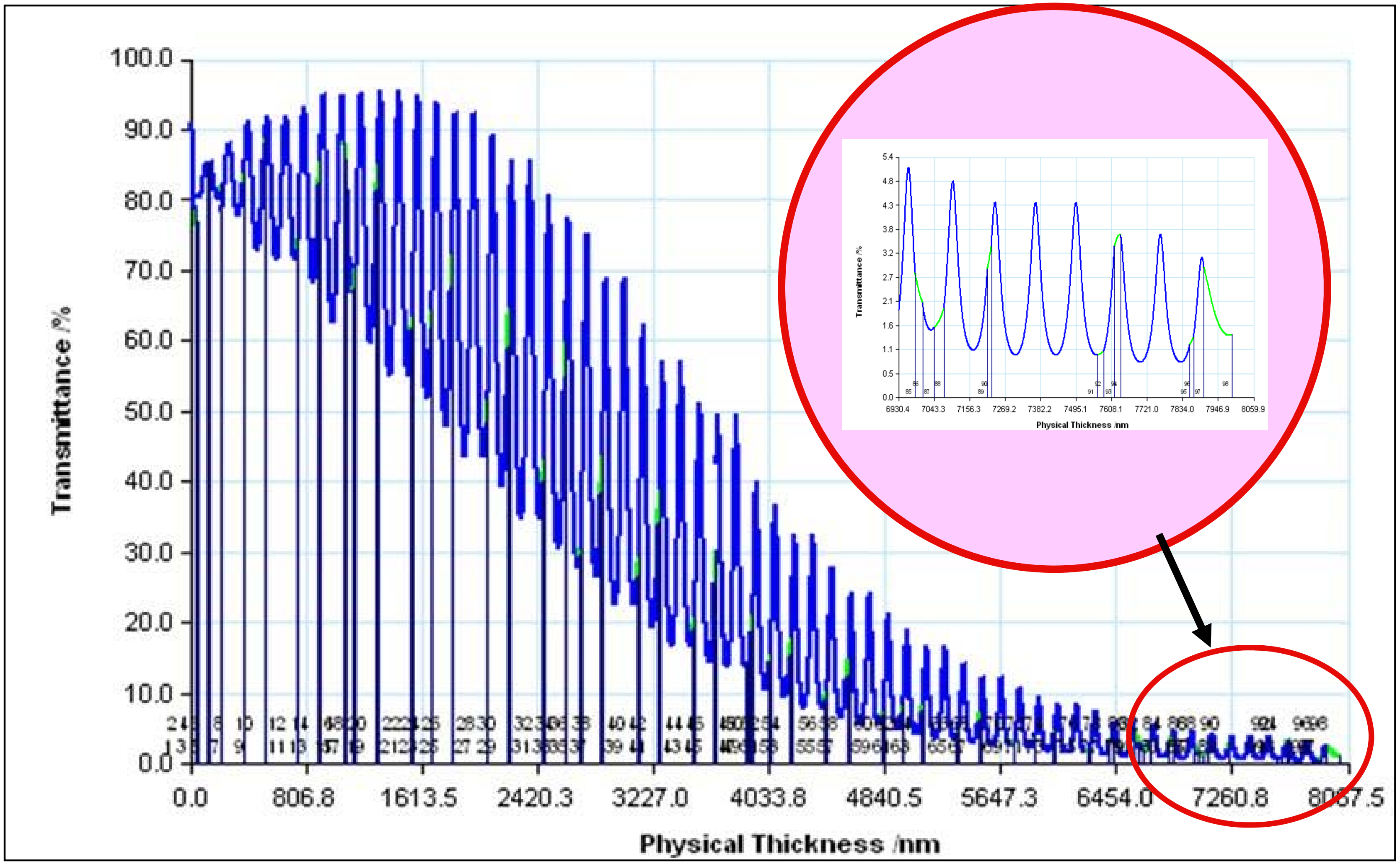
Direct Monochromatic Monitoring

Theoretical monitoring curves

Monitor wavelength are close to the centre of the notch



Transmittance vs. Physical thickness

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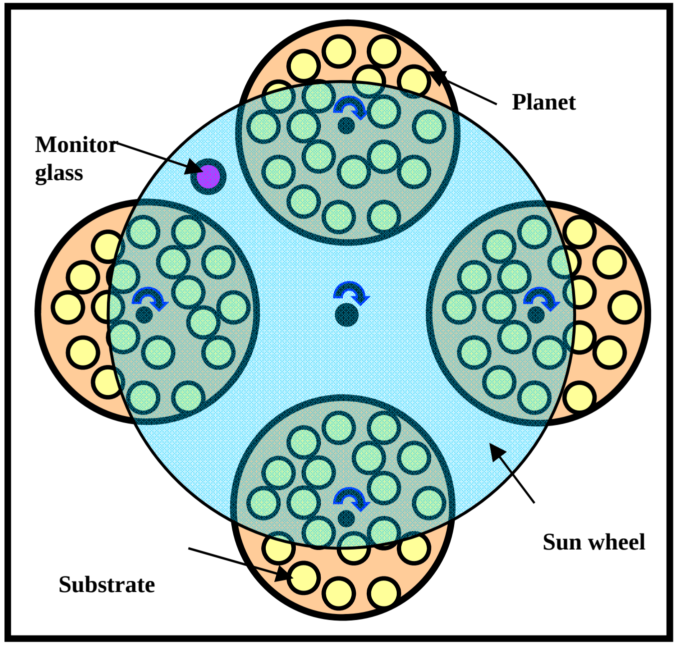
Direct Monochromatic Monitoring

Syrus*pro* 1350 with planetary drive

Direct monitoring with planetary substrate holder



Top view of a planetary system with monitor glass

Syrus*pro* 1350 coating system with 400mm planets

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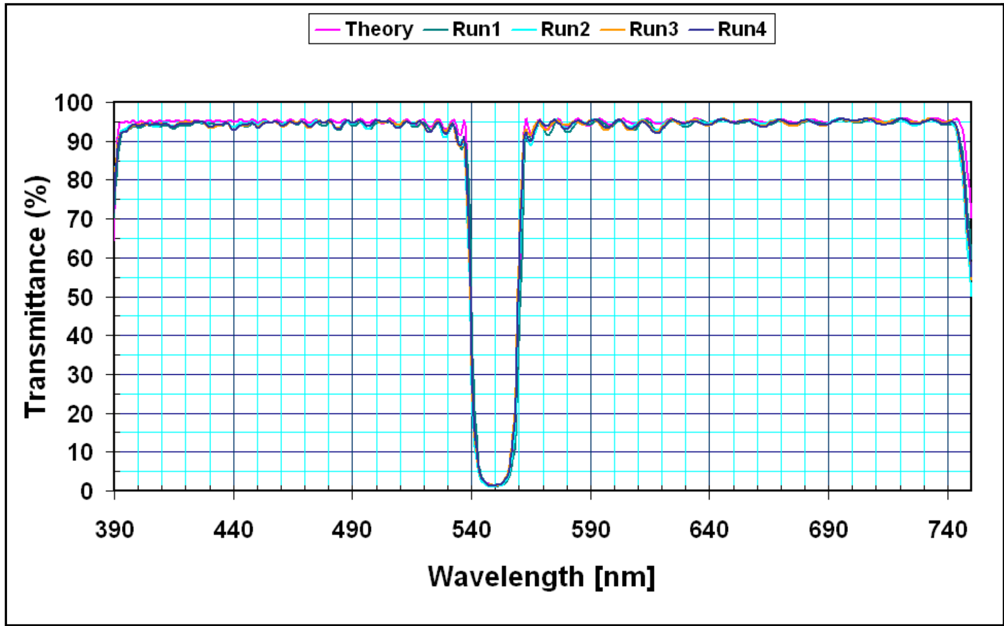
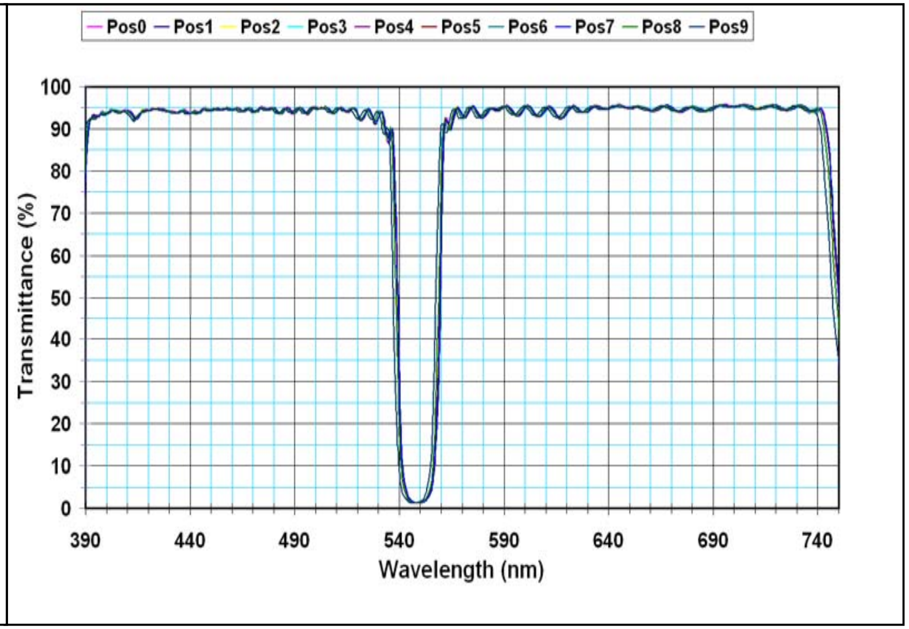
Direct Monochromatic Monitoring

98-layer notch filter deposited in a Syruspro 1350 with planetary system





Reproducibility in the centre of the planet

(Between run 3 and run 4 the chamber was cleaned)

Uniformity on a 400mm planet

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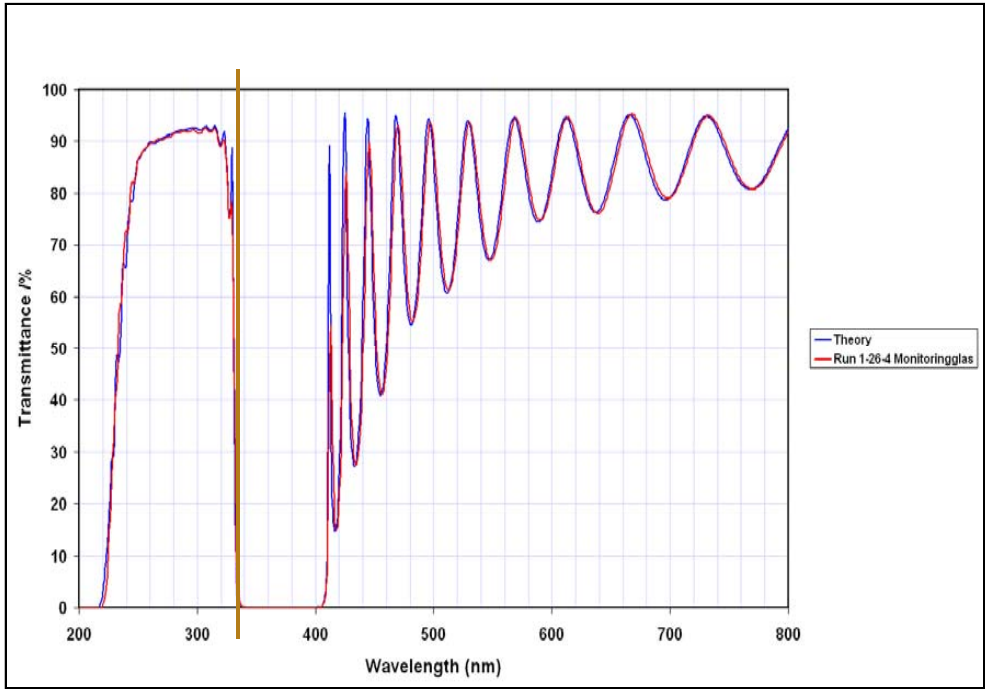
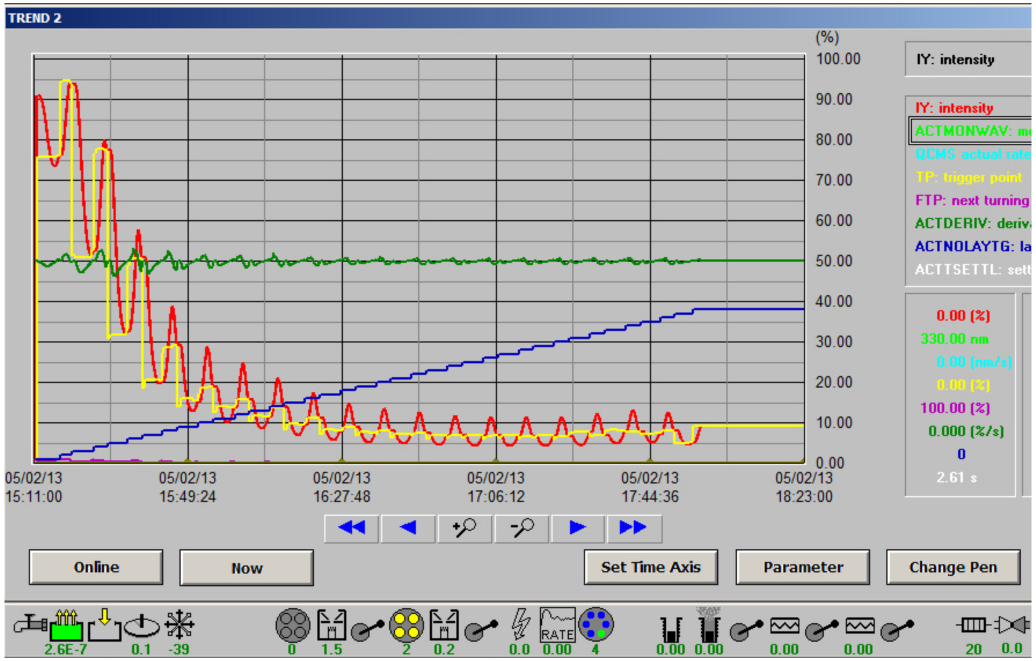
Direct Monochromatic Monitoring

UV Filter coating with HfO_2/SiO_2 in Syrus*pro* 1100 with planets



Spectral performance of the monitor glass vs. theory



Screenshot of the monitoring @ 330nm monitor wavelength

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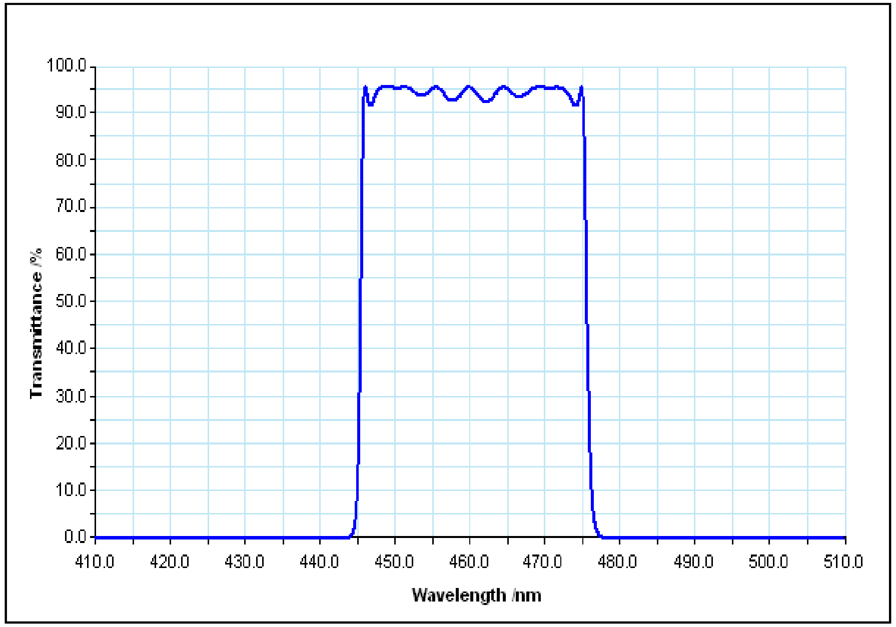
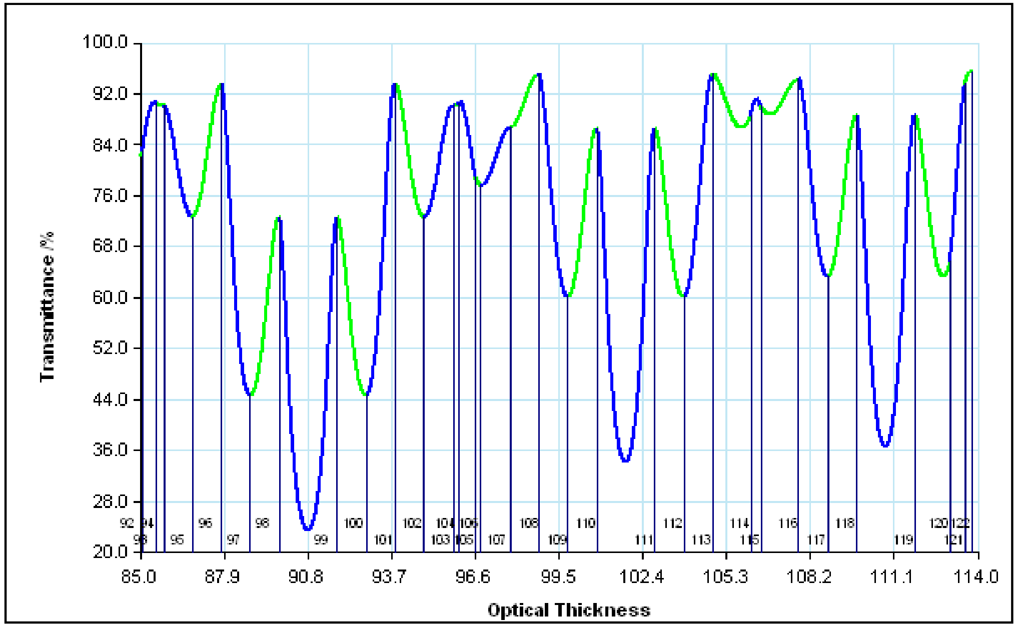
11-Cavity Band pass Filter with 122 layers

with maching layers ≠ $\lambda/4$



Optical Performance theory



Monitor curves of the last 3 cavities

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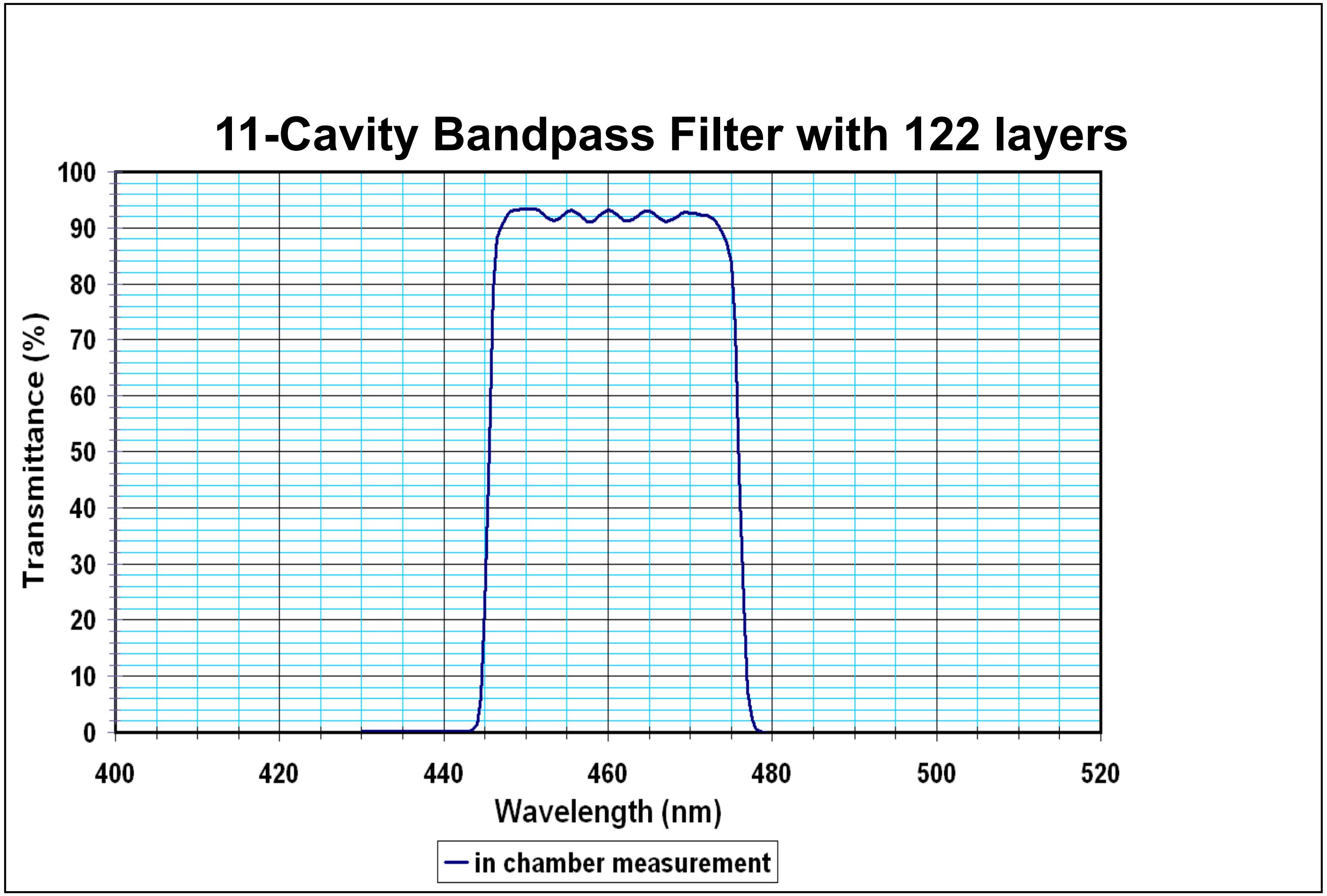
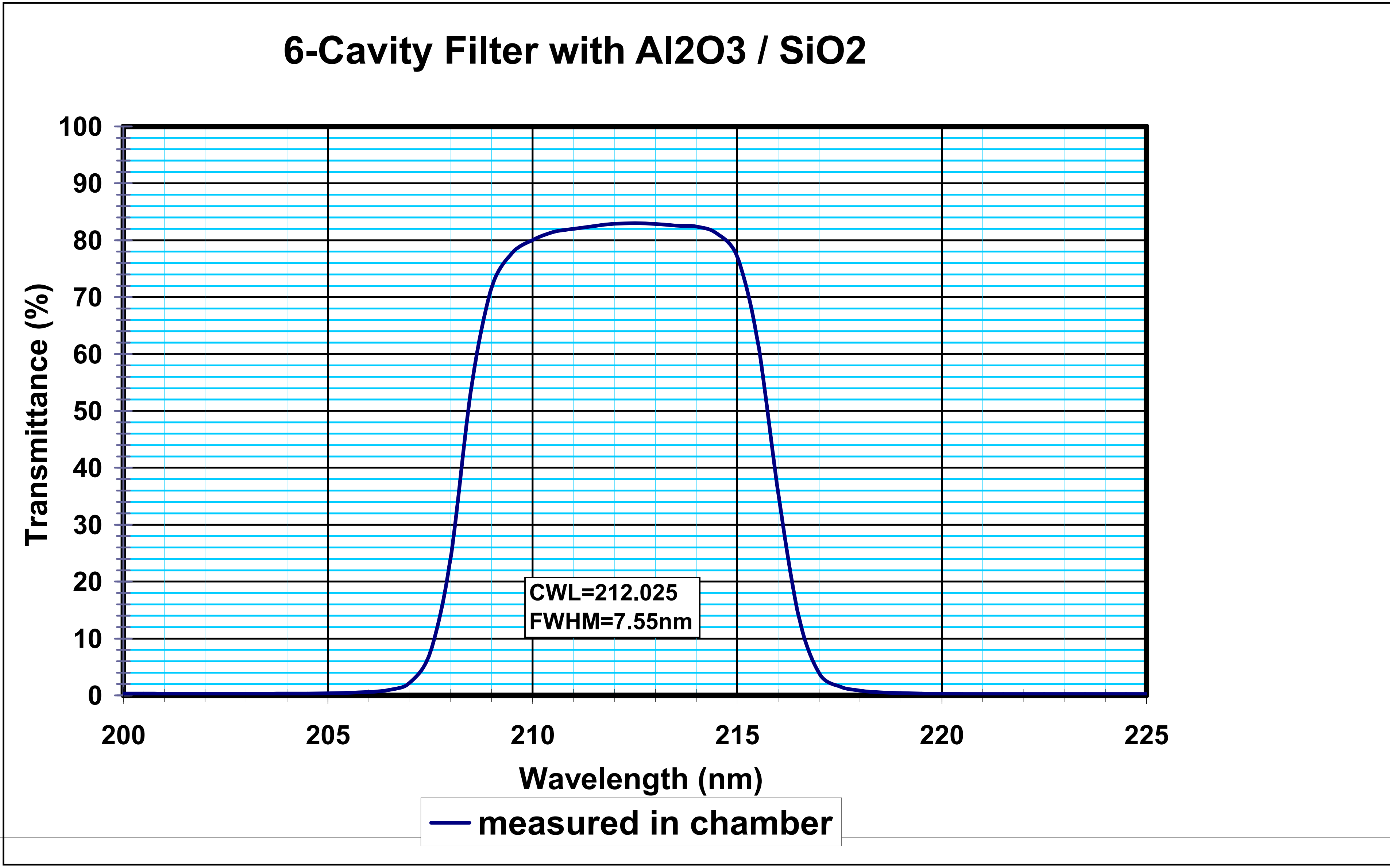
Helios magnetron sputtering system with direct monitoring



Optical Performance of the monitor glass measured in chamber

(w/o backside AR coating)

Helios magnetron sputtering system with direct monitoring



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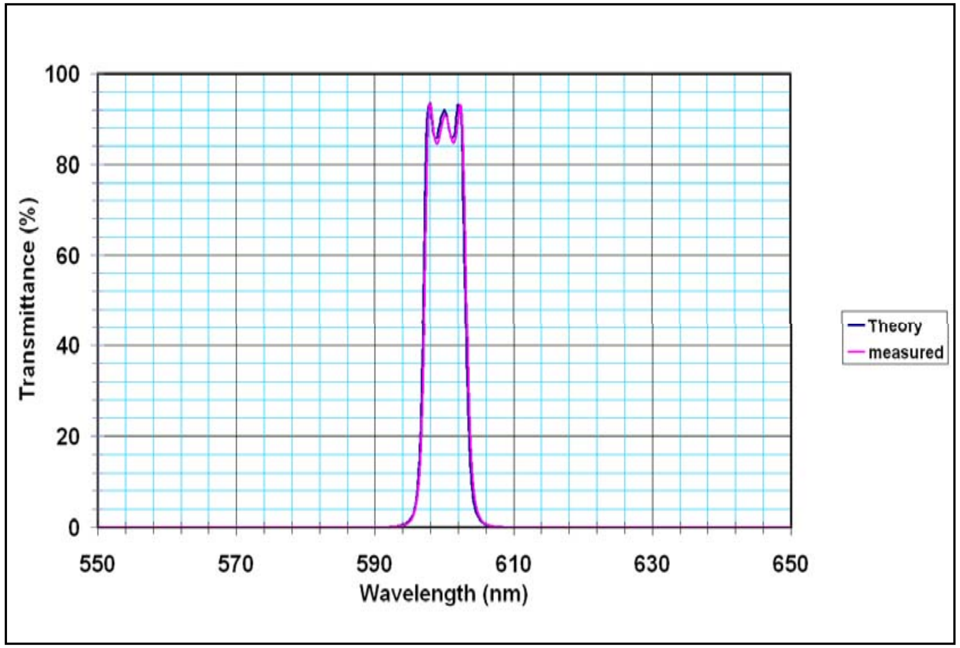
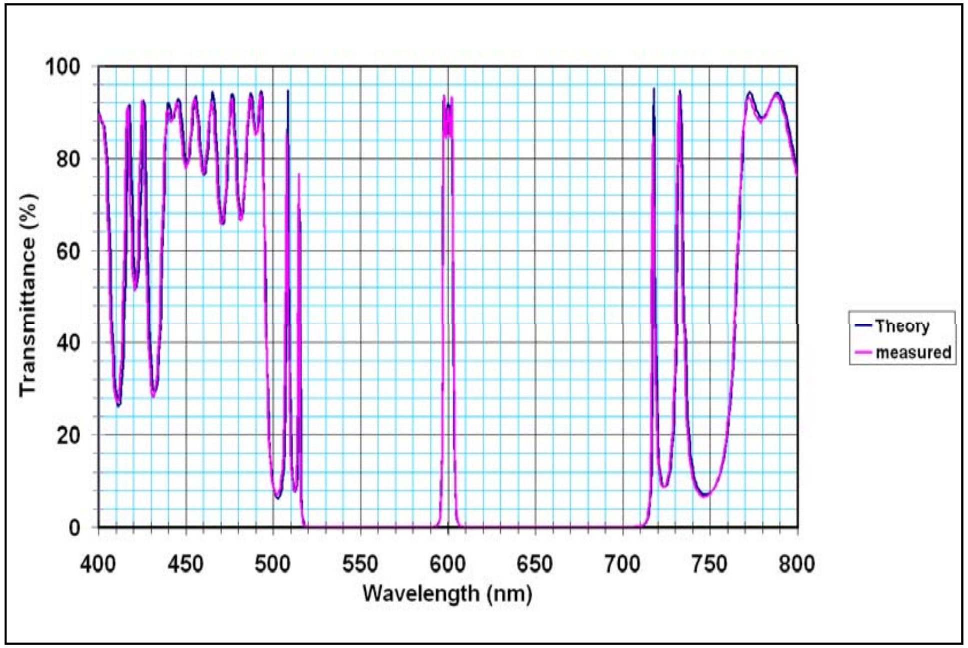
41 layer design with H-index spacers with high ripple

The symmetry of the ripple in the passband is very sensitive to thickness errors !

Theory vs. experiment of a 3-cavity band-pass filter deposited in a Helios PARMS system





- **excellent coincidence with theory in the band-pass and in the side bands due an advanced algorithm for turning point cut-offs**

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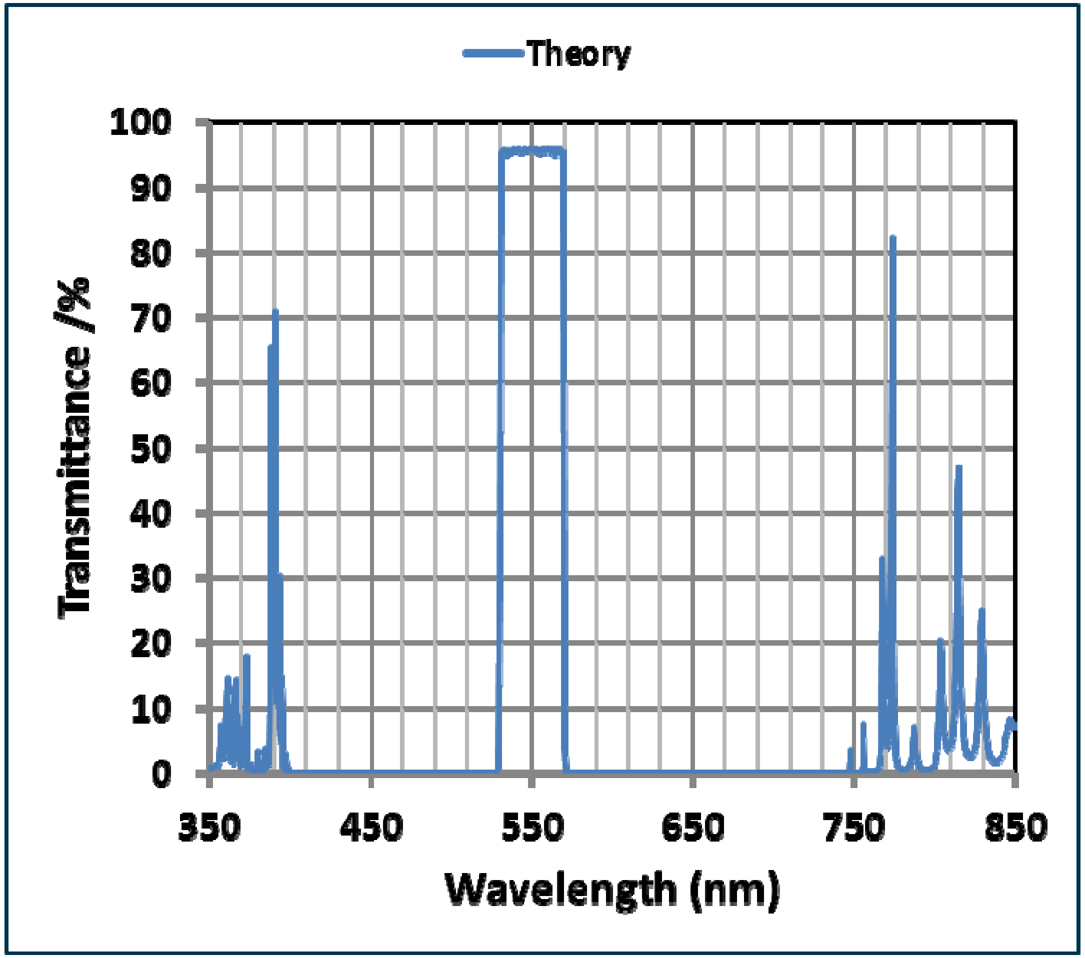
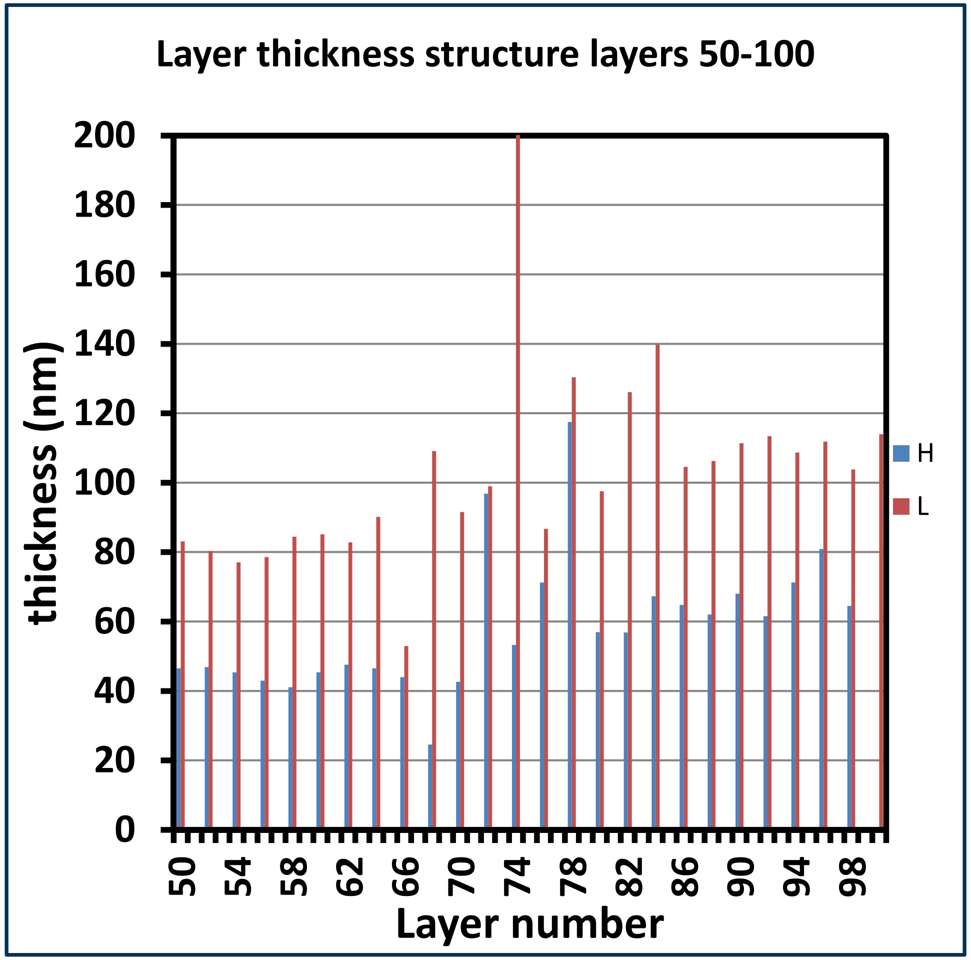
OMS 5000 Direct Optical Monitoring

Helios magnetron sputtering system with direct monitoring

Bandpass Filter with 138 non λ/4 layers Nb_2O_5/SiO_2 (single side coating)





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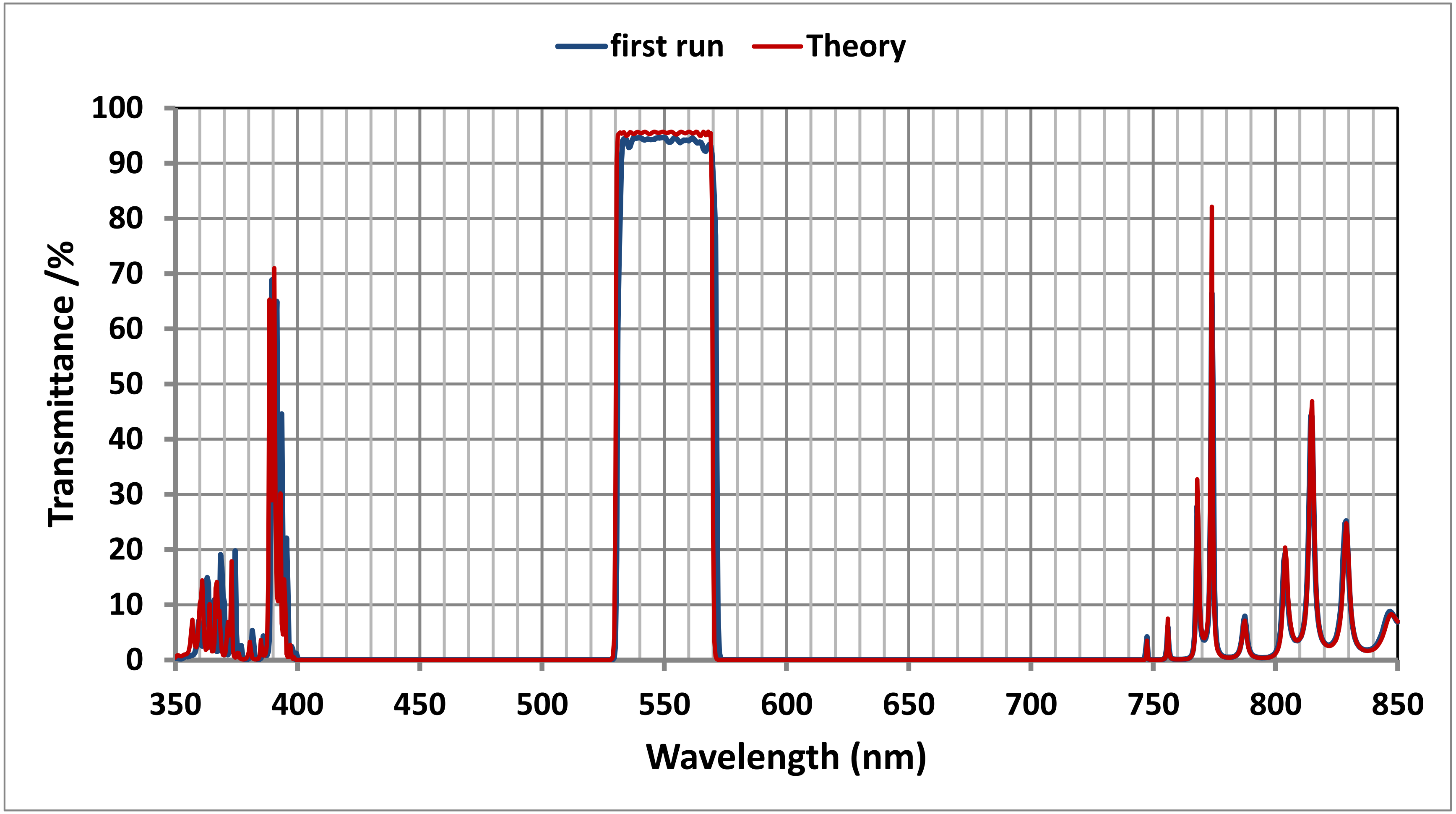
Helios magnetron sputtering system with direct monitoring

Bandpass Filter with 138 non λ/4 layers Nb_2O_5/SiO_2



Optical Performance of the first run

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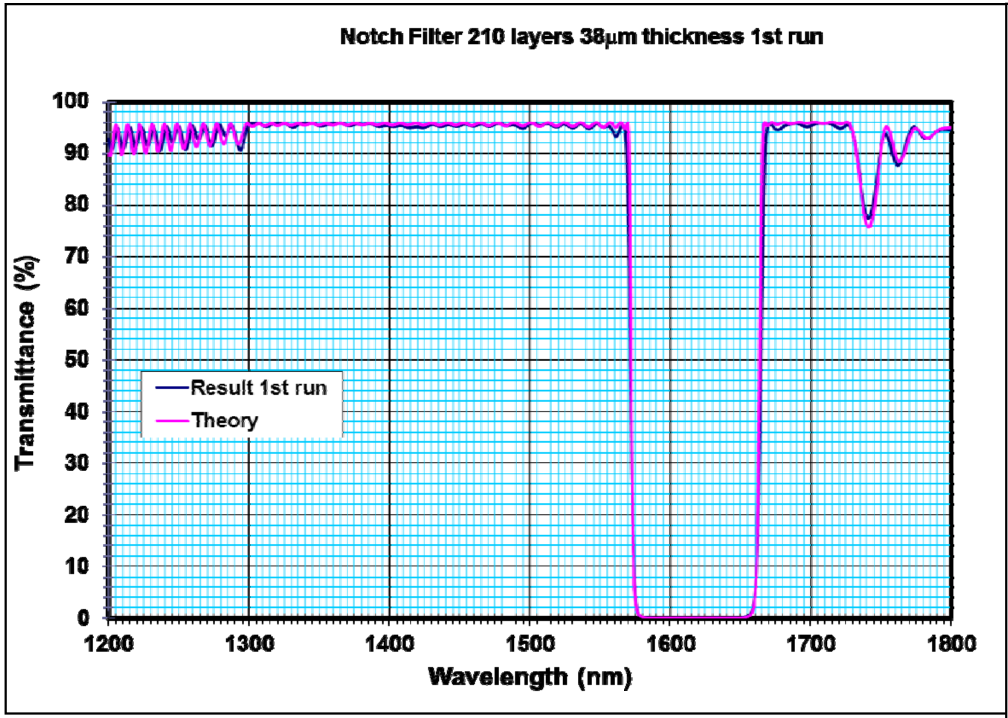
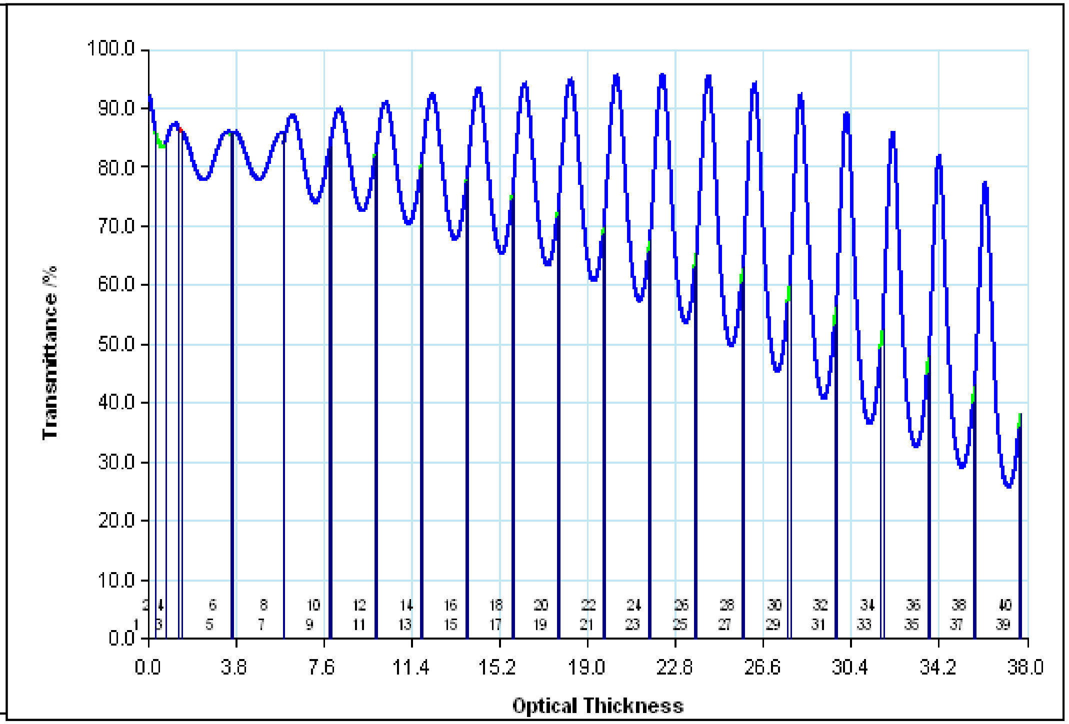
Notch filter coating with Helios magnetron sputtering system

1st run result vs. theory



Monitoring curves of the 1st 40 layers



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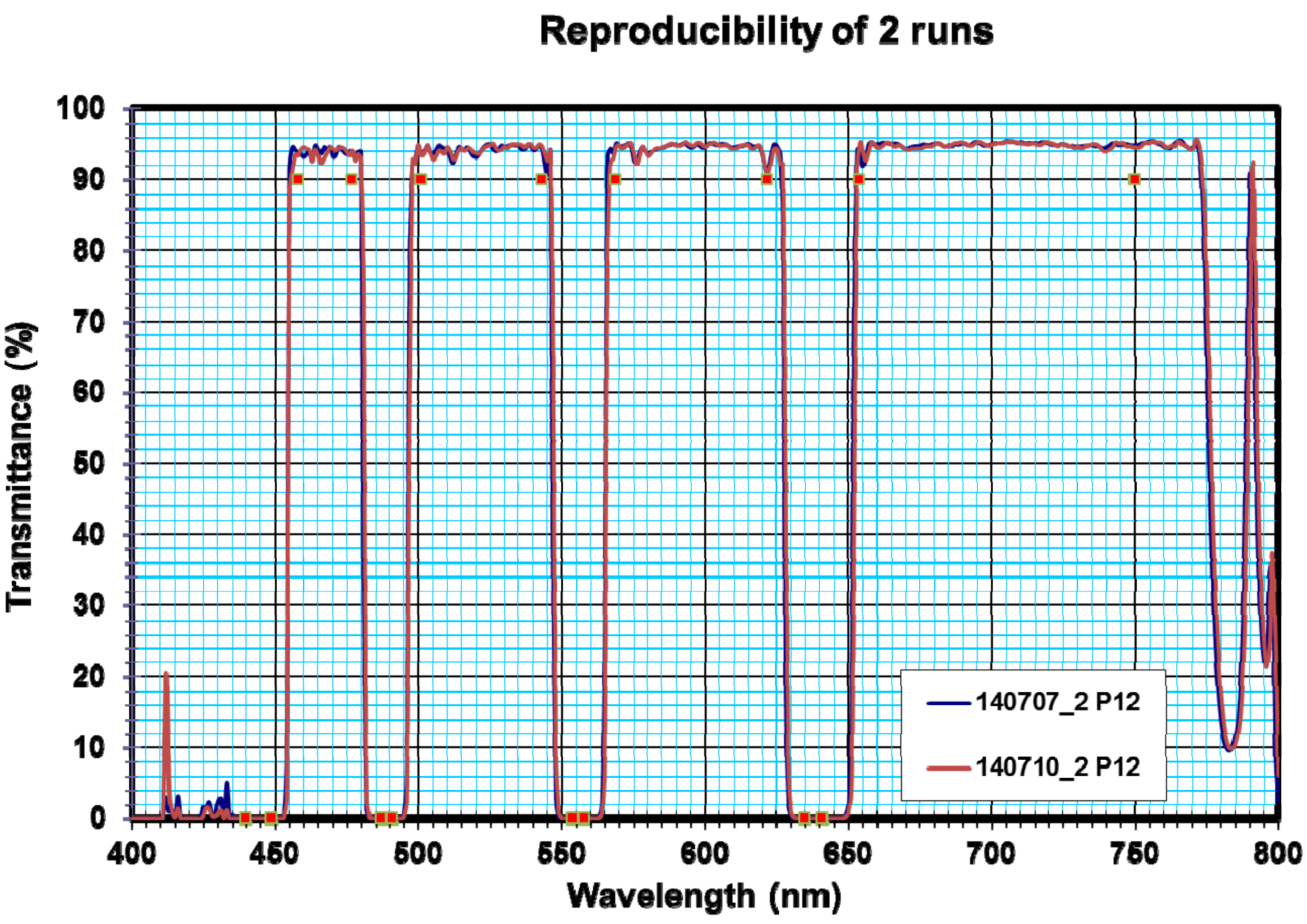
OMS 5000 Direct Optical Monitoring

Helios magnetron sputtering system with direct monitoring

190 layer notch filter coating



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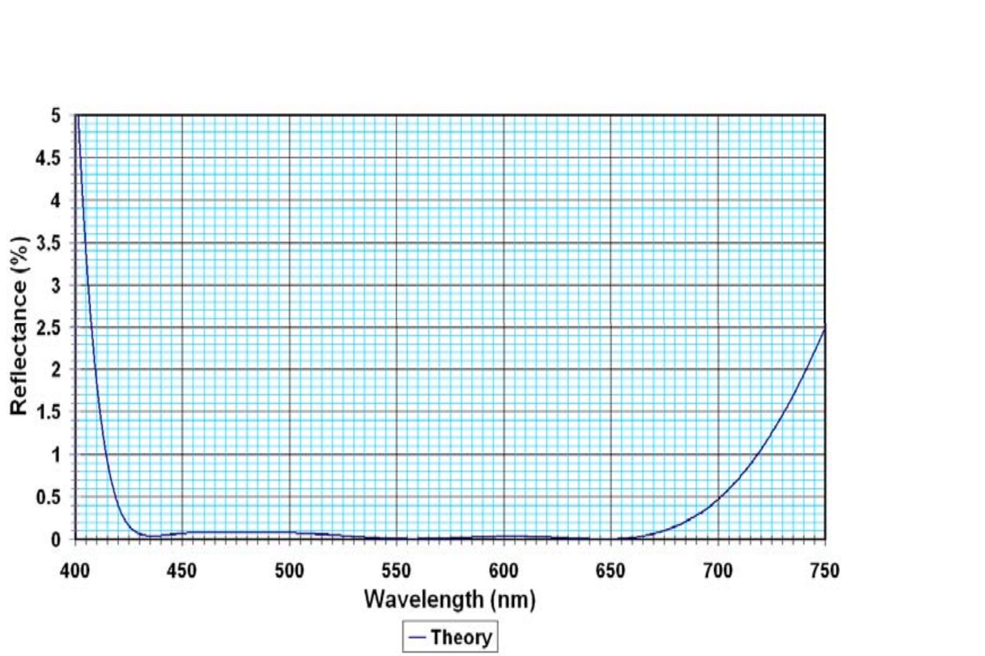
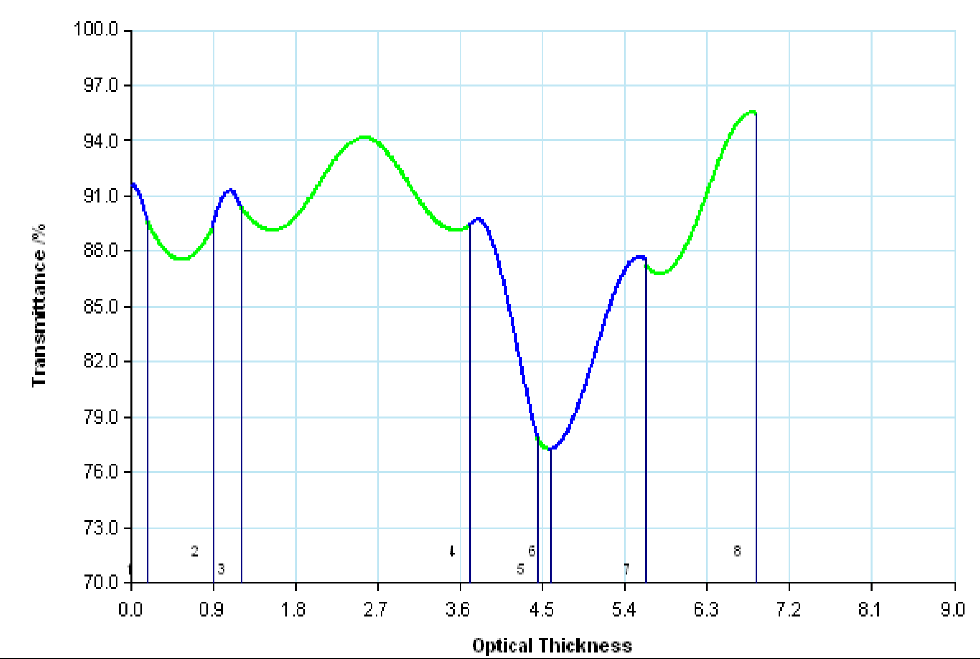
8 Layer BBAR Coating in SYRUS*pro* 1500 chamber

Theory



Monitoring curves



BK7/0.155H 0.620L 0.258H 2.174L 0.628H 0.124L 0.900H 0.927M / Air

Reference Wavelength : 570 nm

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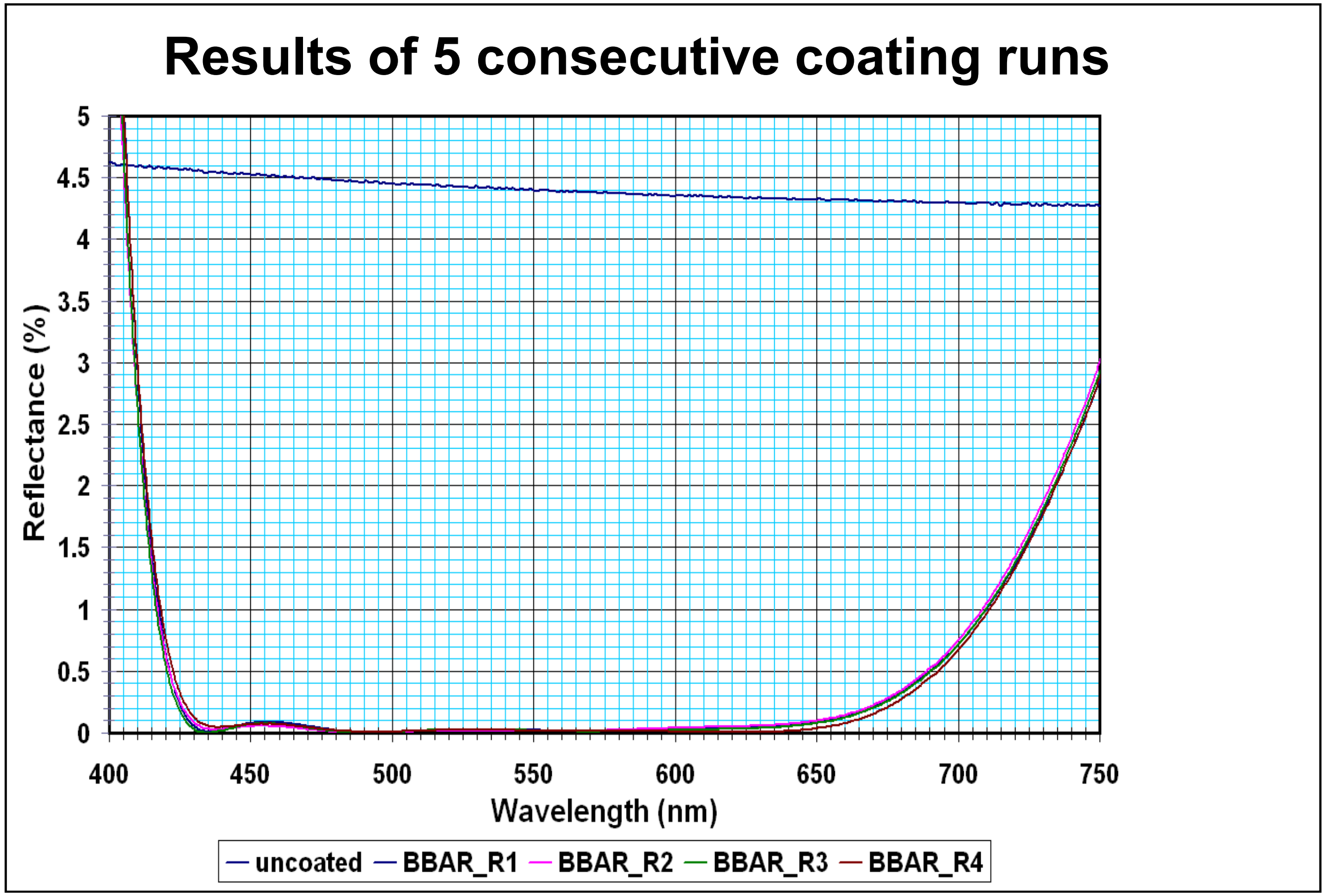
OMS 5000 BBAR monitoring

- Coating materials: Ta2O5, SiO2, MgF2
- Optical monitoring on dome 530mm out of centre
- Substrate temperature: 300°C
- Oxide layers with LION PIAD



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Direct Monochromatic Monitoring

Summary

- The goal is that the first run is a success.
- Process simulation prior to the coating is a big step to achieve the above goal.
- LMR (Leybold Monitor Report) files are used for data exchange between thin film design software, process simulation and coating machine.
- LMR files are also useful for data exchange between different design programs.
- It was shown that direct monitoring enables to manufacture very complex filters with PIAD and PARMS.
- In many cases the first run result is very close to theory even with challenging designs for band-pass, notch filter and BBAR coatings.

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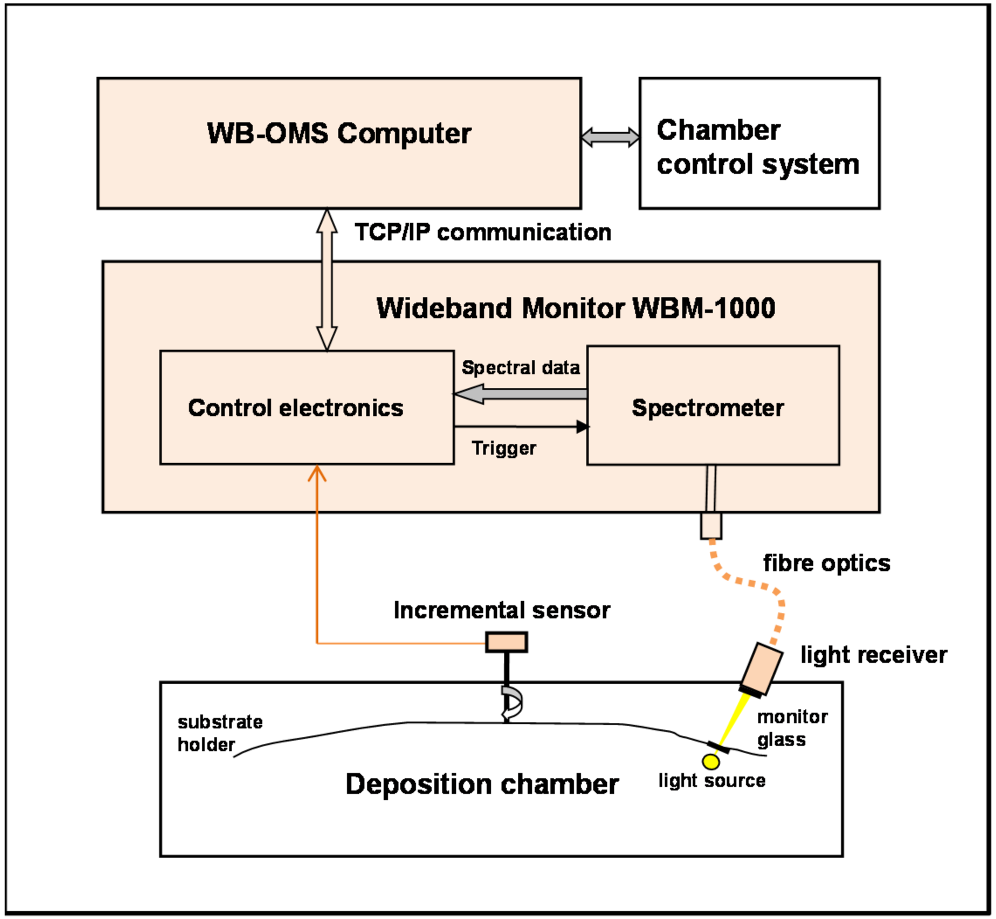
WB-OMS (wideband optical monitoring system) – schematic



WB-OMS

- Light source with light receiver
- Incremental sensor.
- Spectrometer with control electronics.
- WB-OMS Computer
- Software with server client structure

WBM-1000 – Spectrometer with control electronics

Spectrometer WBM-1000

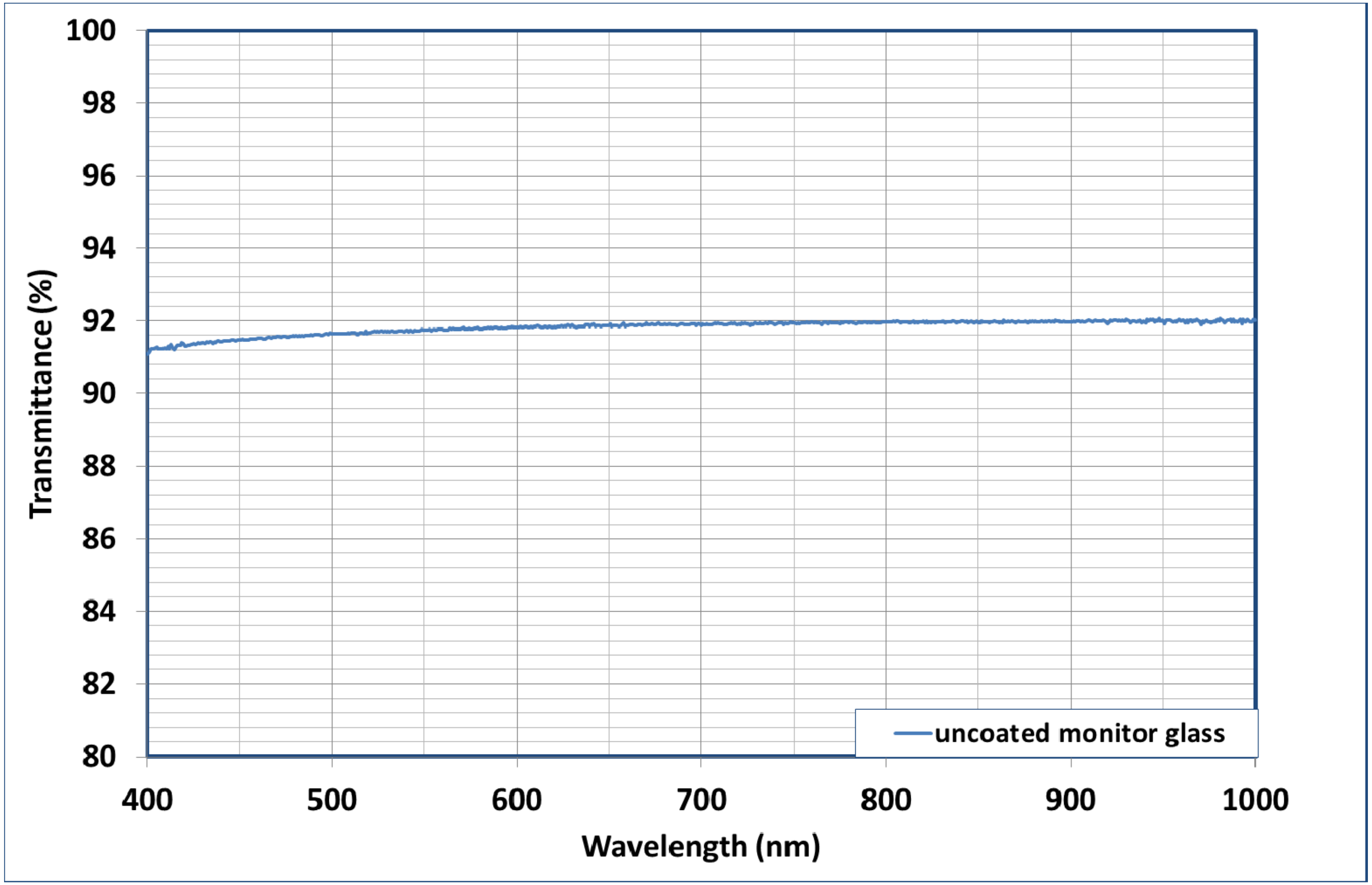
Size: 300 x 100 x 170

- Real time fast triggered spectrometer.
- Wavelength range useful with halogen lamp: (400nm – 1050nm).
- Optical resolution app. 3.5nm FWHM.
- Incremental sensor interface.
- TCP/IP Ethernet interface.
- Diode array detector (1024 pixel) low signal noise.
- Integration time 1.2ms – 6500ms.
- Dynamic range 16 bit.
- Detector noise best case 0.005% rms.
- Noise < 0.025% rms (400nm – 1000nm)..
- SMA fibre connector.

WB-OMS Measurement performance

In chamber measurement of an uncoated monitor glass

w/o averaging or smoothing (3ms integration time)



WB-OMS – Functionalities

- ***Spectrometer module.***

Control of intermittent data acquisition. Measurement data provided for display and further processing. After the deposition of each layer the normalized measured transmittance spectra are stored.

- ***Automatic thickness control.***

The chamber control system transfers the layer number and some control signals like “shutter open” to the WB-OMS. The shutter is closed when the “layer terminate” signal from the WB-OMS is received.

- ***Thickness control with monochromatic strategies.***

Using a selected single wavelength from the array detector. The high dynamic detector supports the classical turning point monitoring as well as trigger-point cut-offs with online corrected end points. The monochromatic monitor curves and the measured spectra are displayed during the deposition.

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WB-OMS – Functionalities under development

- ***Thickness control based on broadband strategies.***

Thickness control based on broadband monitoring strategies is under development.

- ***Reverse engineering.***

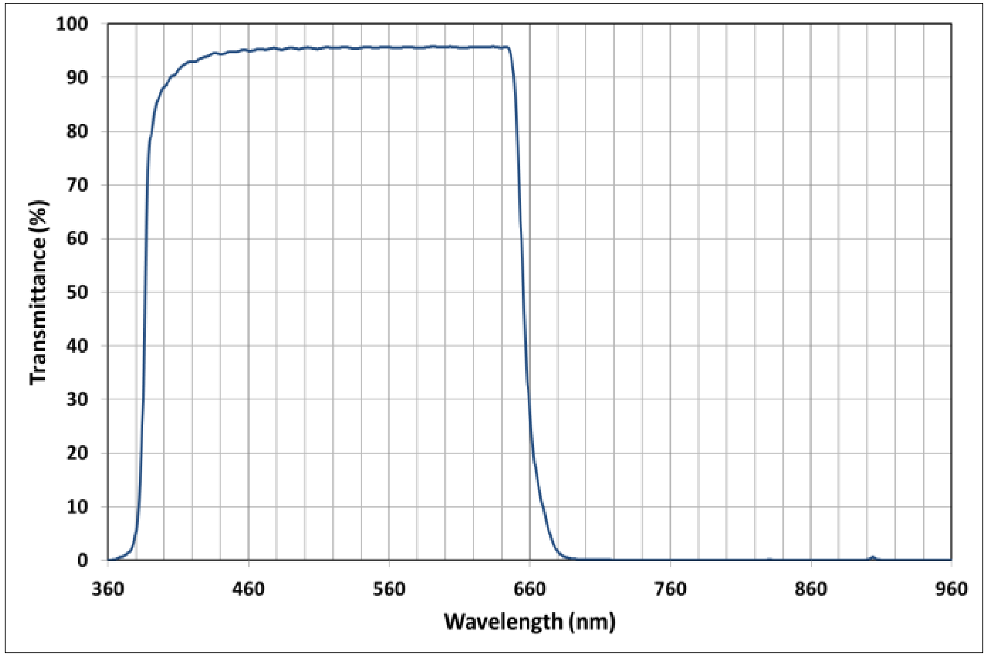
Reverse engineering of the individual layer thicknesses based on the measured spectra after the deposition of each layer is also under development. It stores and displays the calculated thickness errors.

SYRUSpro 1510 with RF Lion 300 plasma source

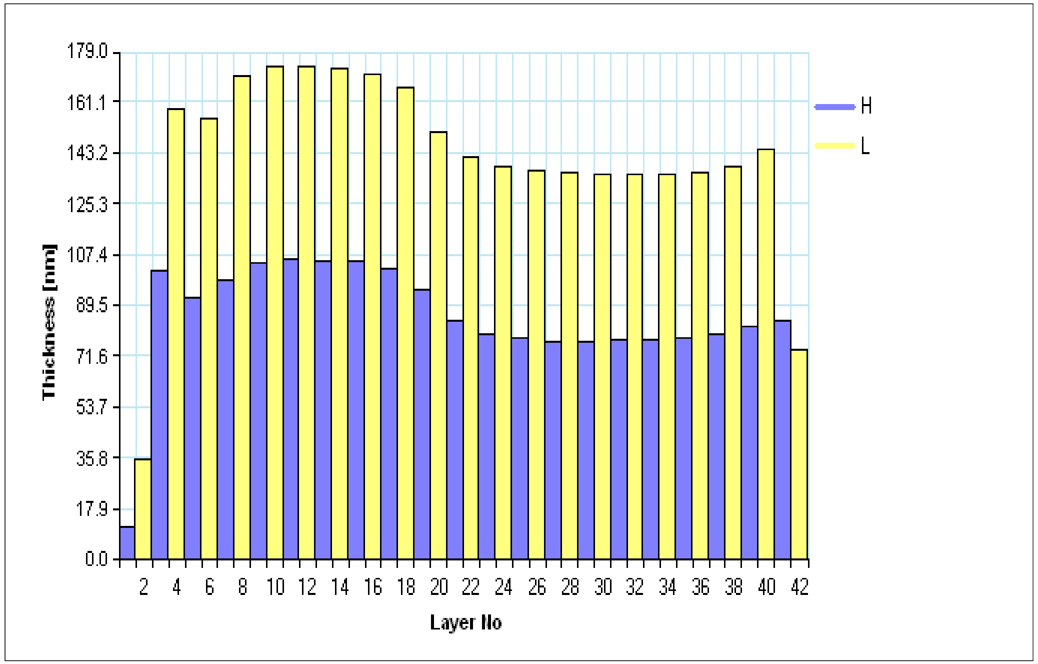
- **SP1510 with WB-OMS.**
- **Monitor glass 550mm out of centre.**

UV-ir cut filter coatings in SP1510

- *42 layer design with TiO_2/SiO_2*
- *PIAD process with LION 300 plasma source with 6.5KW rf-power*
- *Dep. rates: H-0.35nm/s; L-1.5nm/s*
- *Rotation speed 33 rpm*



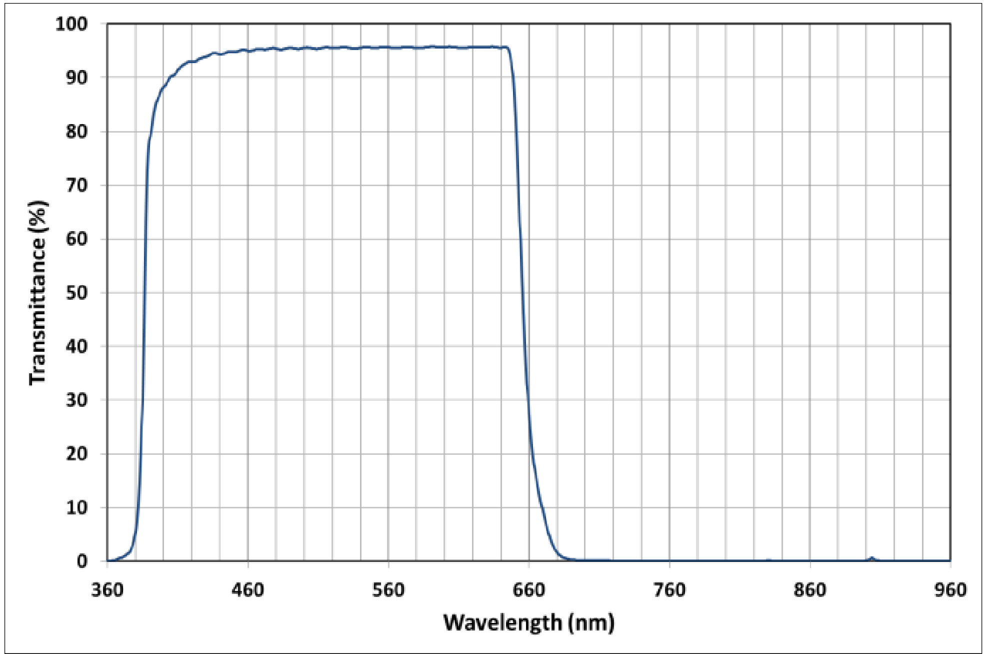
Theoretical performance



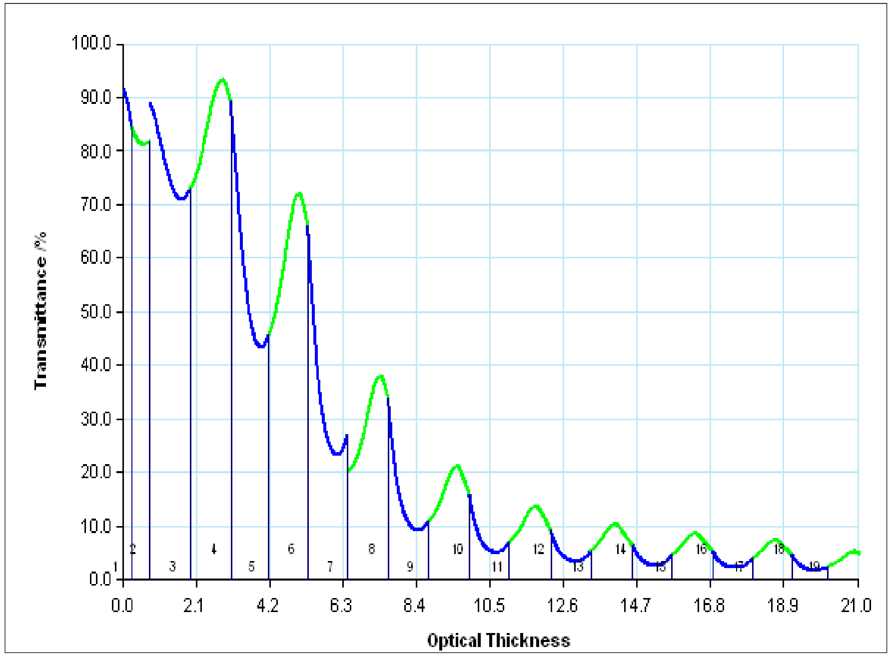
Layer thickness structure

UV-IR cut filter coatings in SP1510

Thickness control for all layers with WB-OMS using monochromatic monitoring strategies on one monitor glass



Theoretical performance



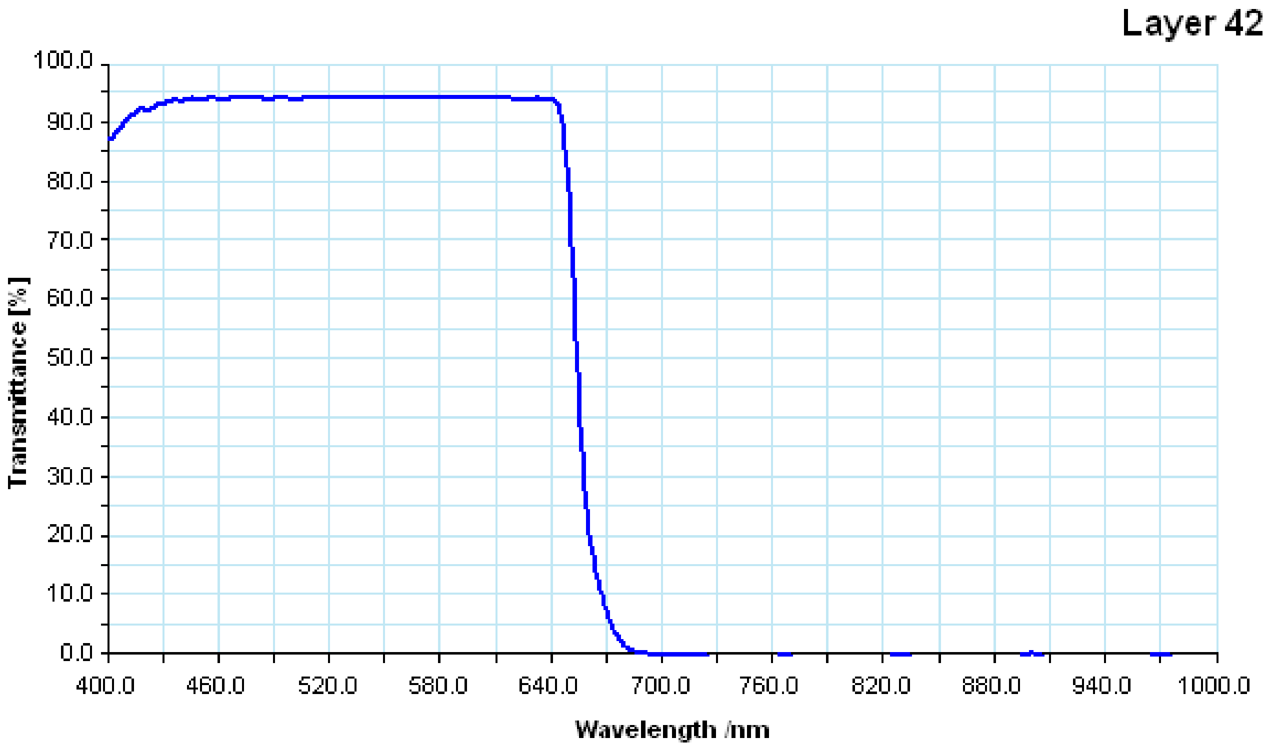
Theoretical monitor curves layer 1-21

UV-IR cut filter coatings in SP1510

IR-Cut Filter

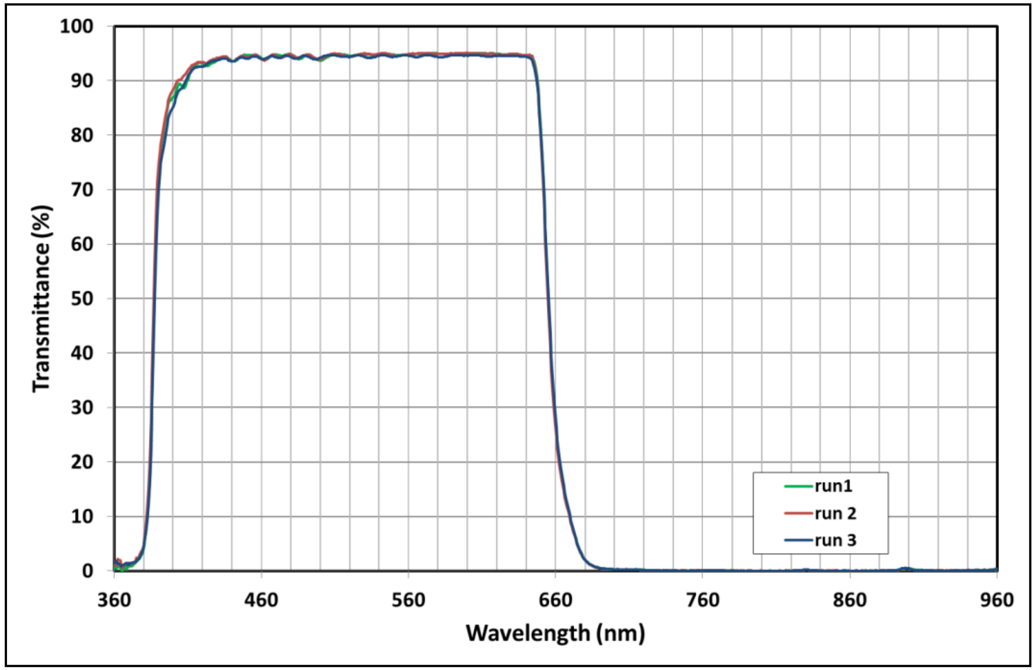
WB-OMS measures and stores the spectral curve after each layer

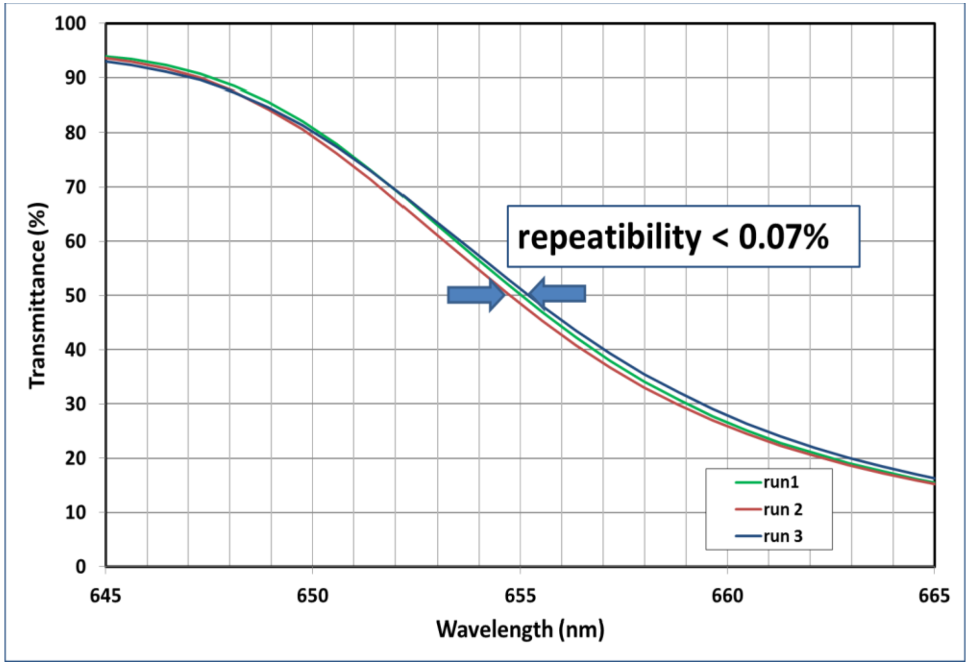
deposition time < 3h



UV-ir cut filter coatings in SP1510

Thickness control for all layers with WB-OMS using monochromatic monitoring strategies on one monitor glass



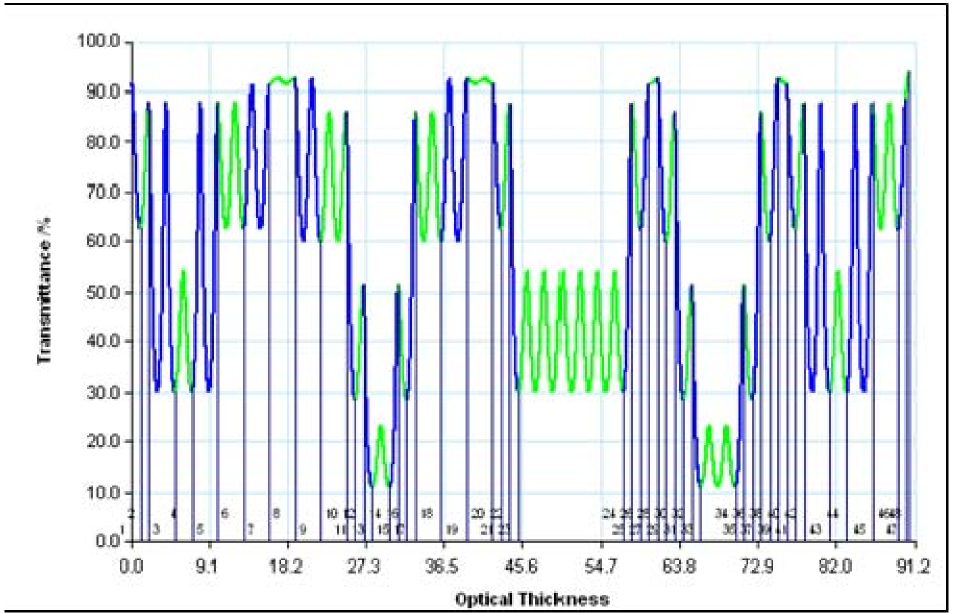


in chamber measurement of 3 consecutive runs

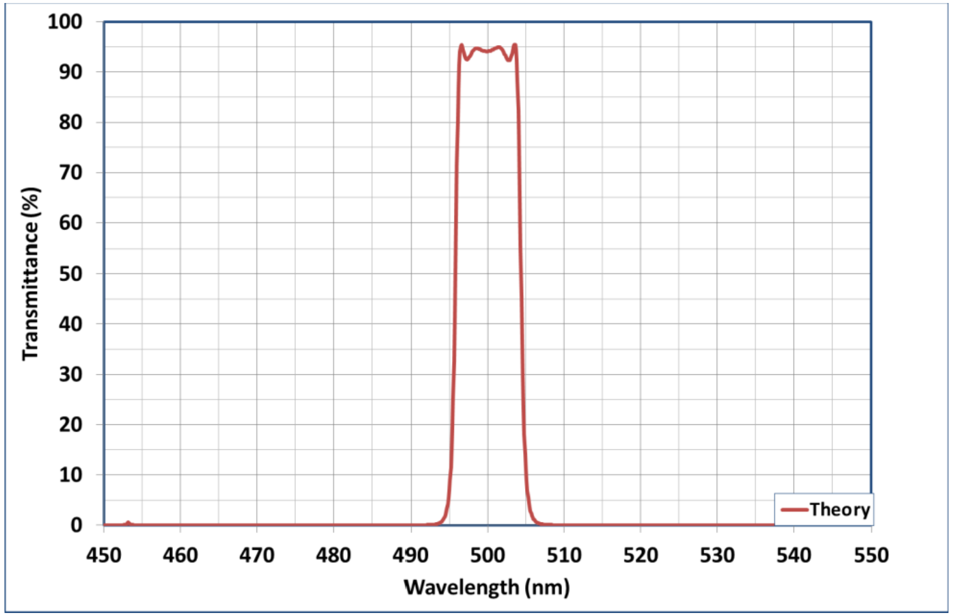
Bandpass Filter coating in SP1510

Fabry Perot 5-cavity bandpass filter (FWHM 8.5nm @ 500nm)

48 layers TiO_2/SiO_2



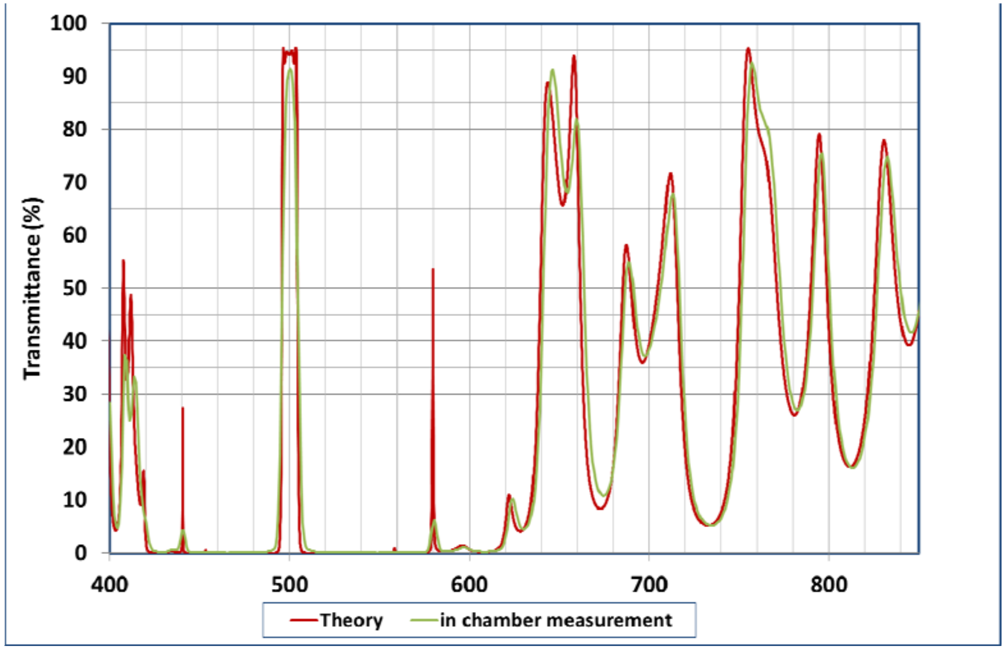
Theoretical monitoring curves

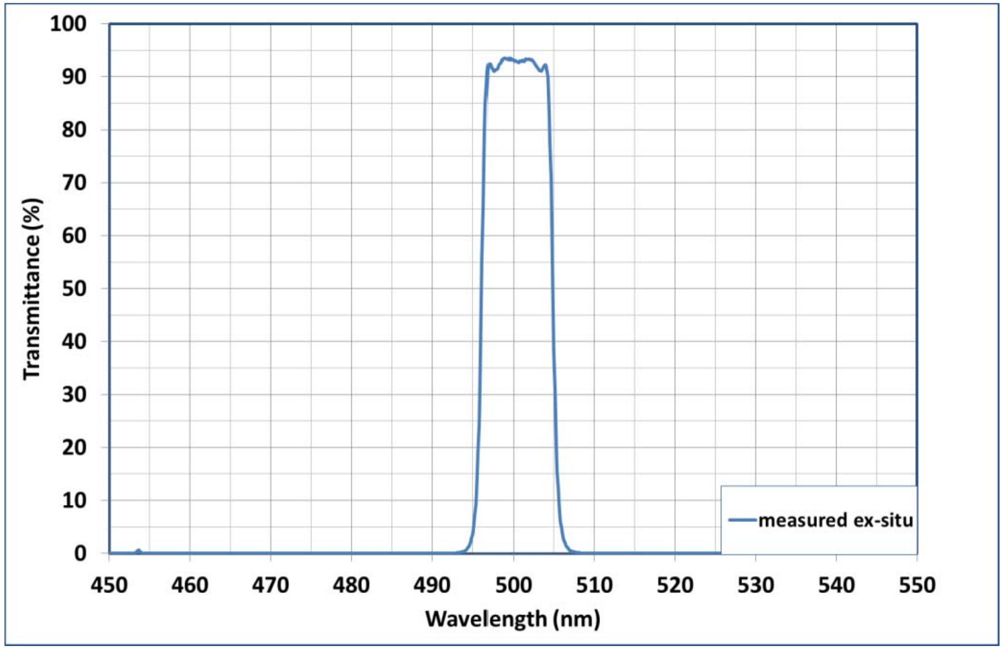


Theoretical performance

Bandpass Filter coating in SP1510

Results of a Fabry Perot 5-cavity bandpass filter (FWHM 8.5nm @ 500nm)





In chamber measurement in comparison to theory

Ex-situ measurement

Bandpass Filter coating in SP1510

Screen shot of the WB-OMS GUI during the process after the 3rd spacer layer

Summary and Outlook

- ***A wideband optical monitoring system with high dynamic array detector with low signal noise was introduced.***
- ***Useful for fast transmittance measurements on the rotating substrate holder (up to 250 rpm).***
- ***Layer thickness control with monochromatic monitoring strategies was applied by using a selected single wavelength from the array detector.***
- ***UV-ir cut filters with performance close to theory and excellent reproducibility < 0.07% were demonstrated with a PIAD process with high deposition rates (1.5nm/s for SiO_2).***
- ***A 5-cavity fabry perot filter with performance close to theory in a broad spectral range was produced.***
- ***Reverse engineering and thickness control using a broad spectral range are under development.***

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Thank you for your attention.

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