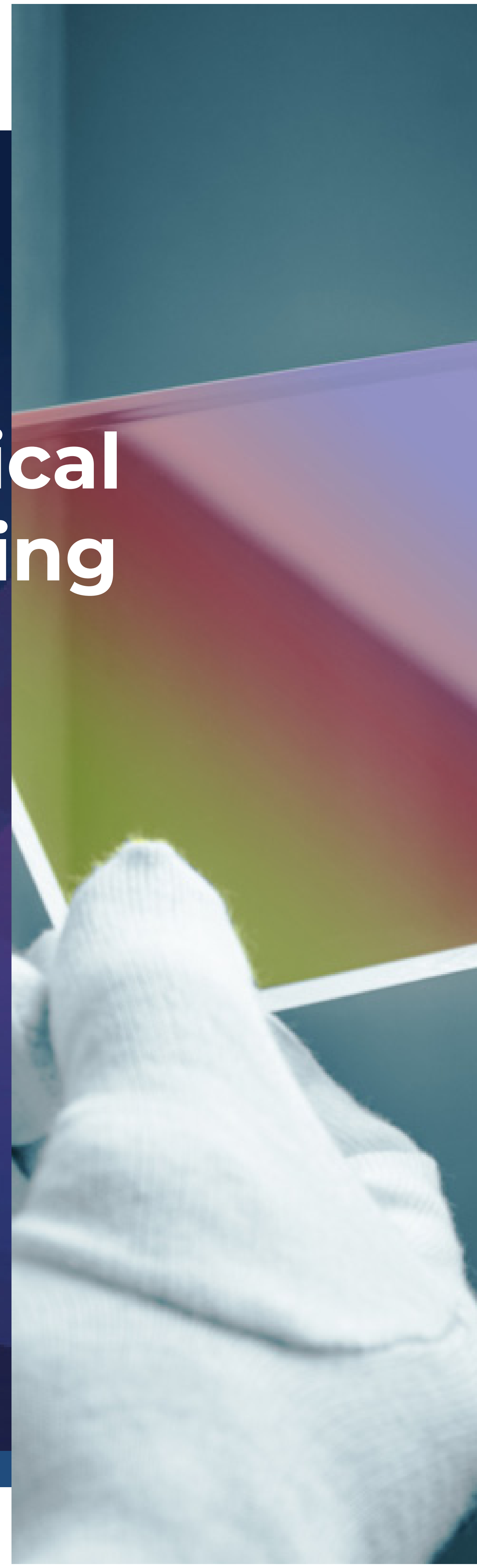
Improving the Accuracy of Optical Coating Monitoring



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Improving the Accuracy of Optical Coating Monitoring

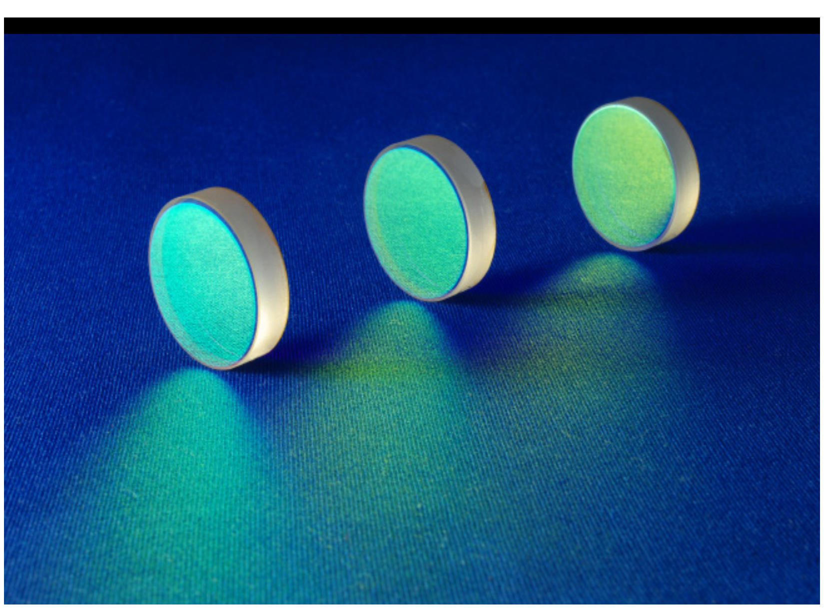
Avantes is a leader in the field of fiber optic spectroscopy offering a complete line of spectrometers, light sources, fiber optics and sample interface accessories. Avantes has nearly 25 years of experience working with optical spectroscopy applications across many industries.

Boulder Optical Design is dedicated to serving the optics industry with high-level scientific and technical support in optical physics. Our services including system integration/implementation for thin film materials characterization, design and process monitoring, laser damage, optical measurements, mathematical modeling, and scientific writing.

Content Outline

- *Description of thin film optical monitoring.*
- *Current achieved accuracy.*
- *What is limiting accuracy?*
- *Improvements.*
- *Equipment Considerations*

Introduction



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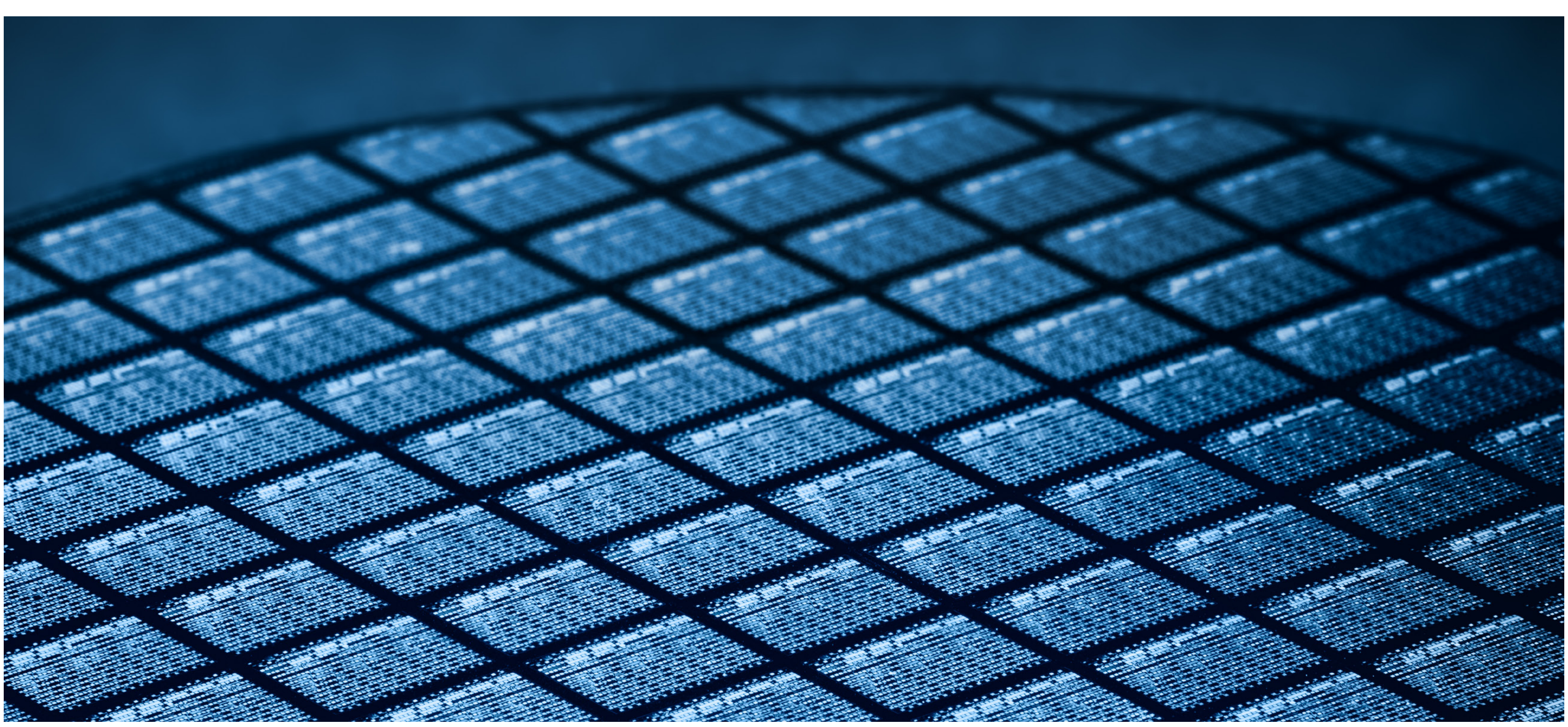

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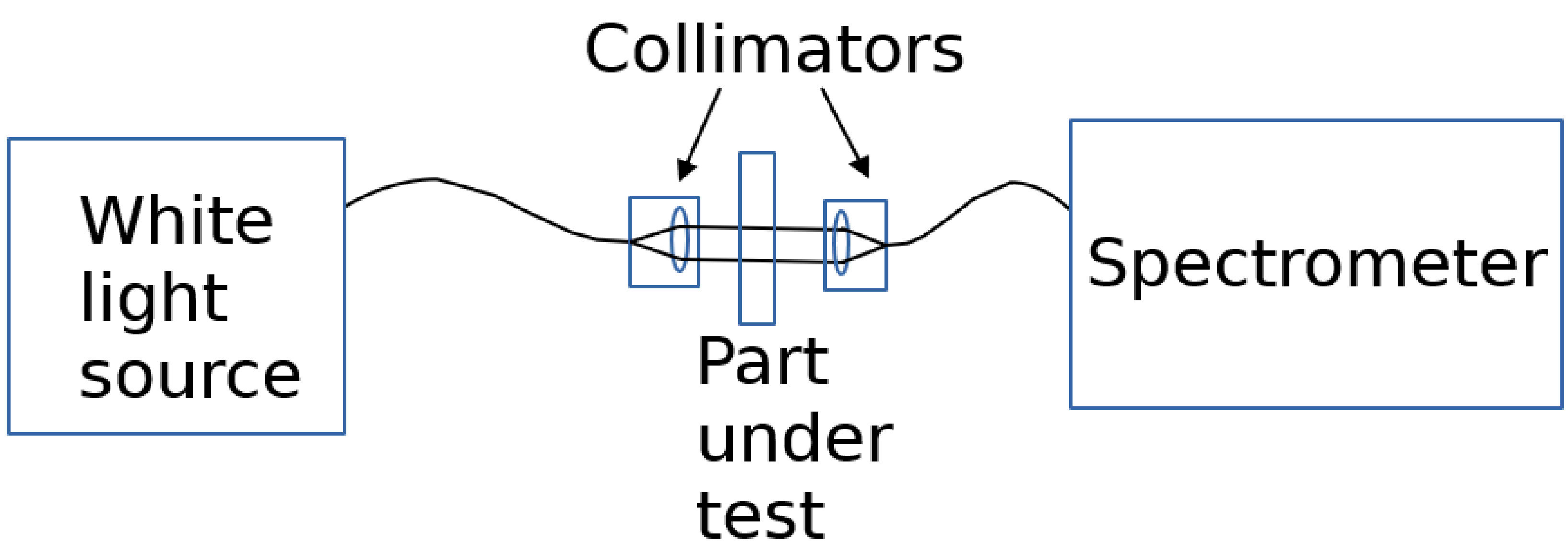
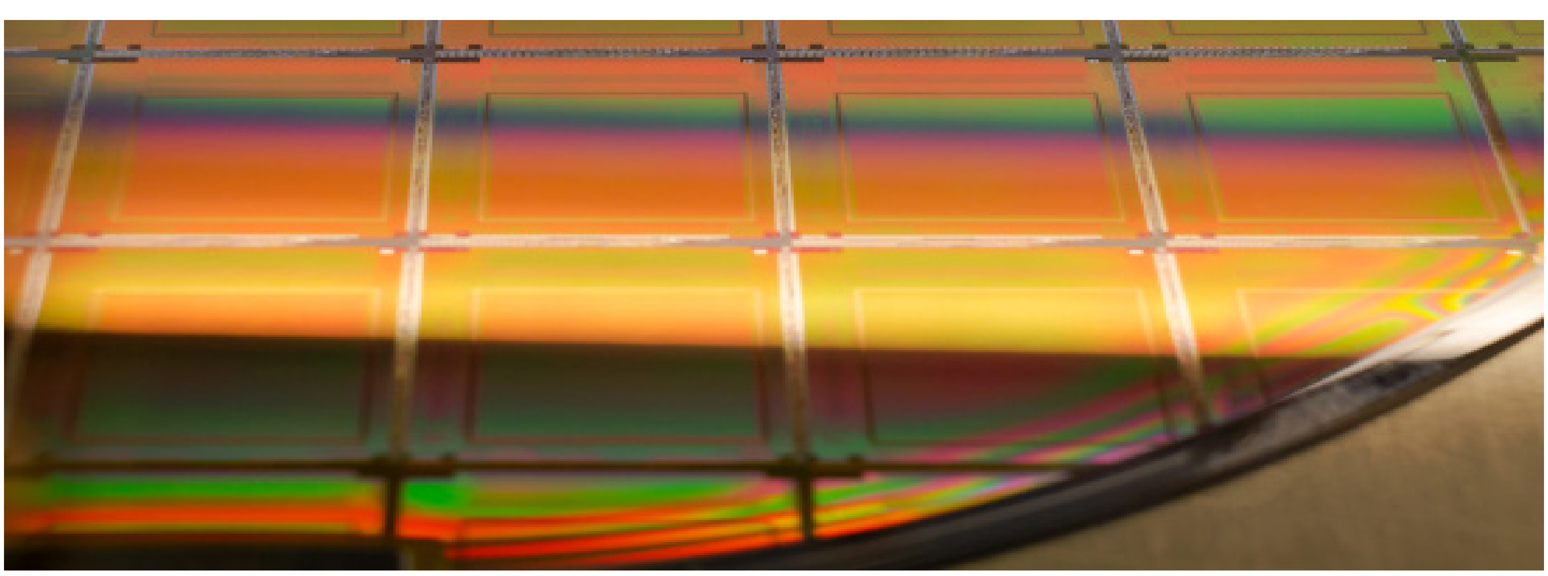
Basic Transmission Element



- Measure blocked: $S_{blocked}(\lambda)$, where S is the 'raw' spectrum.
- Measure without part: $S_{ref}(\lambda)$,
- Measure with part: $S_{par}(\lambda)$,
- Transmittance



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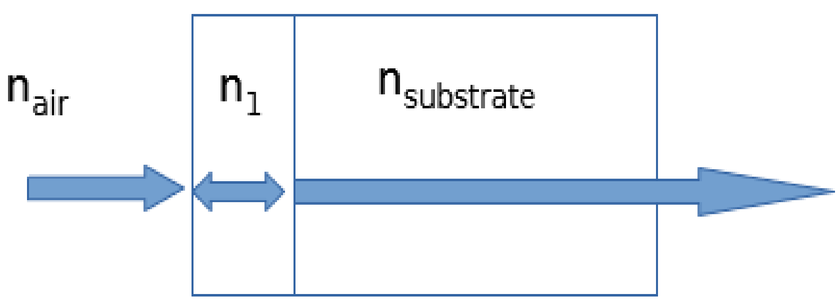
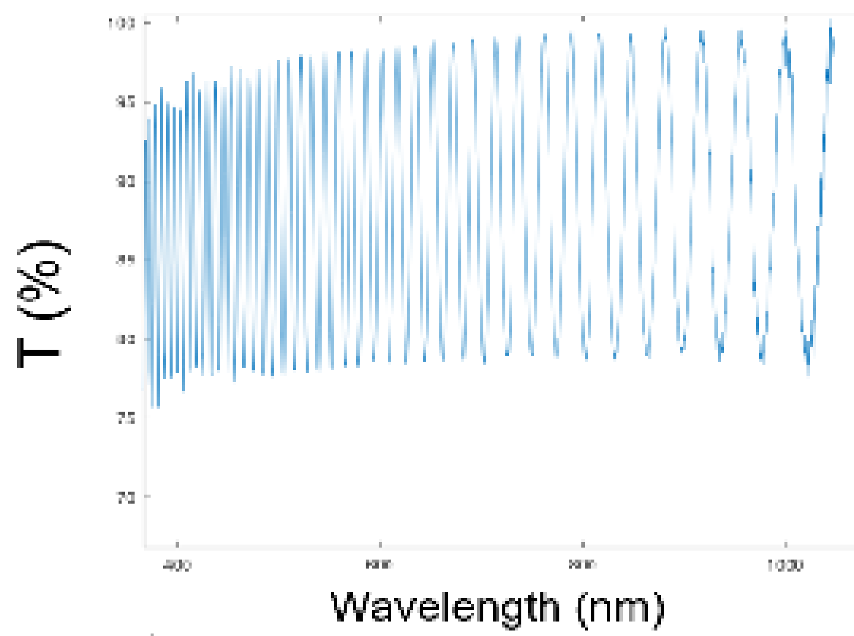
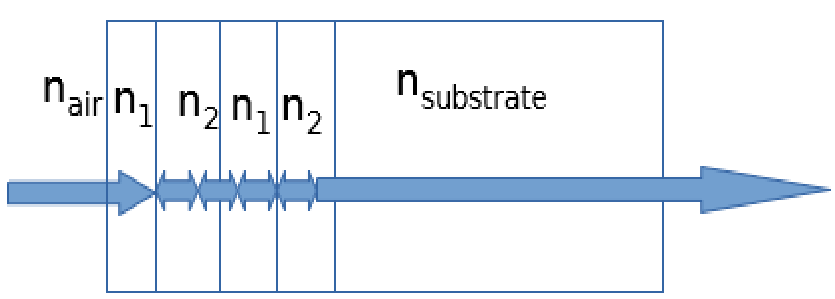
Thin Film Examples

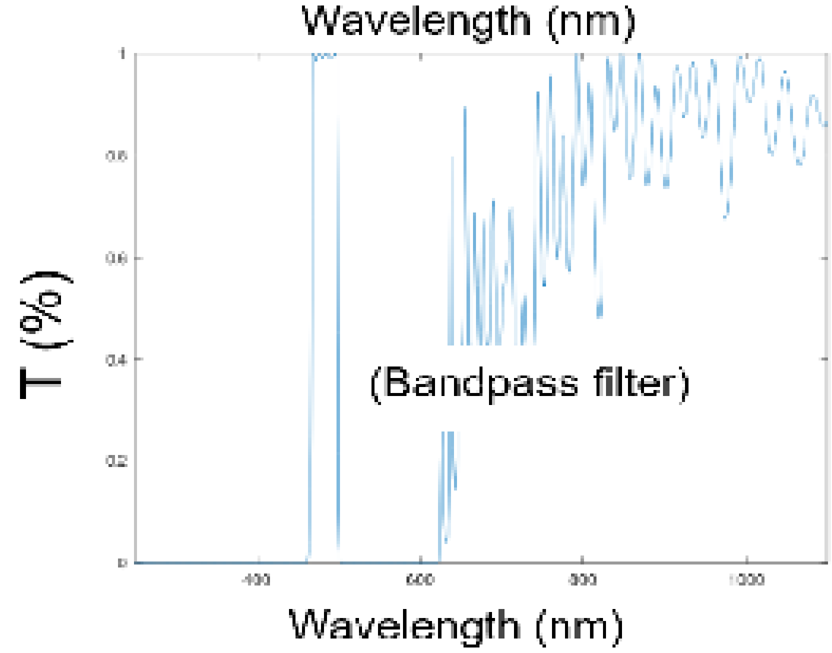


Single-layer





Multi-layer

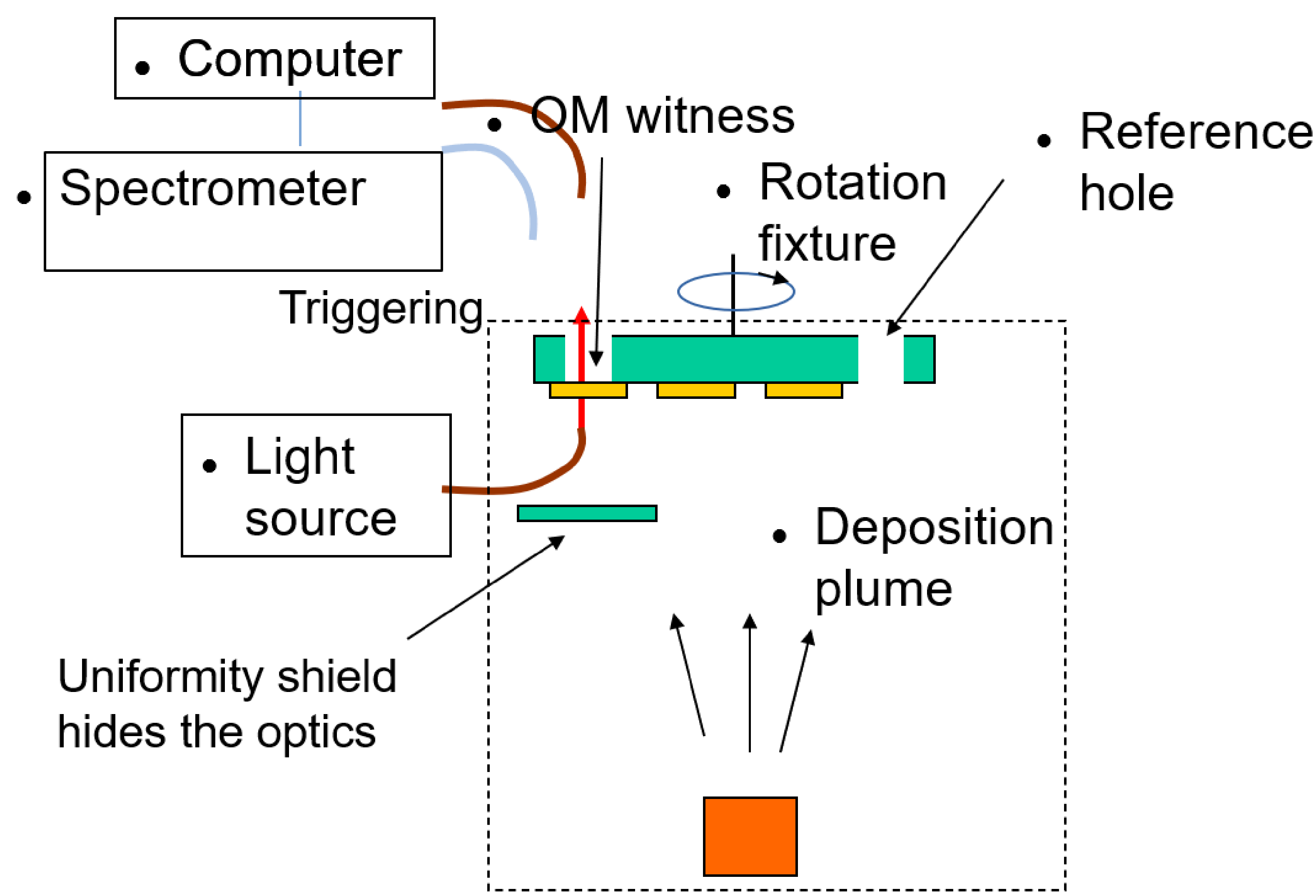


Broadband optical monitoring to control thin film deposition

Outline

- *Measurement is in a vacuum chamber. Monitor the thin film grow.*
- *Transmission or reflection.*
- *Stop when desired layer thickness is achieved.*
- *Ion beam sputtering (IBS) is good for high precision because it can be stopped suddenly. Also materials are consistent.*

Chamber Geometry: Simplified



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Example Run: Layer Endpoint Spectrum

- *Description of thin film optical monitoring.*
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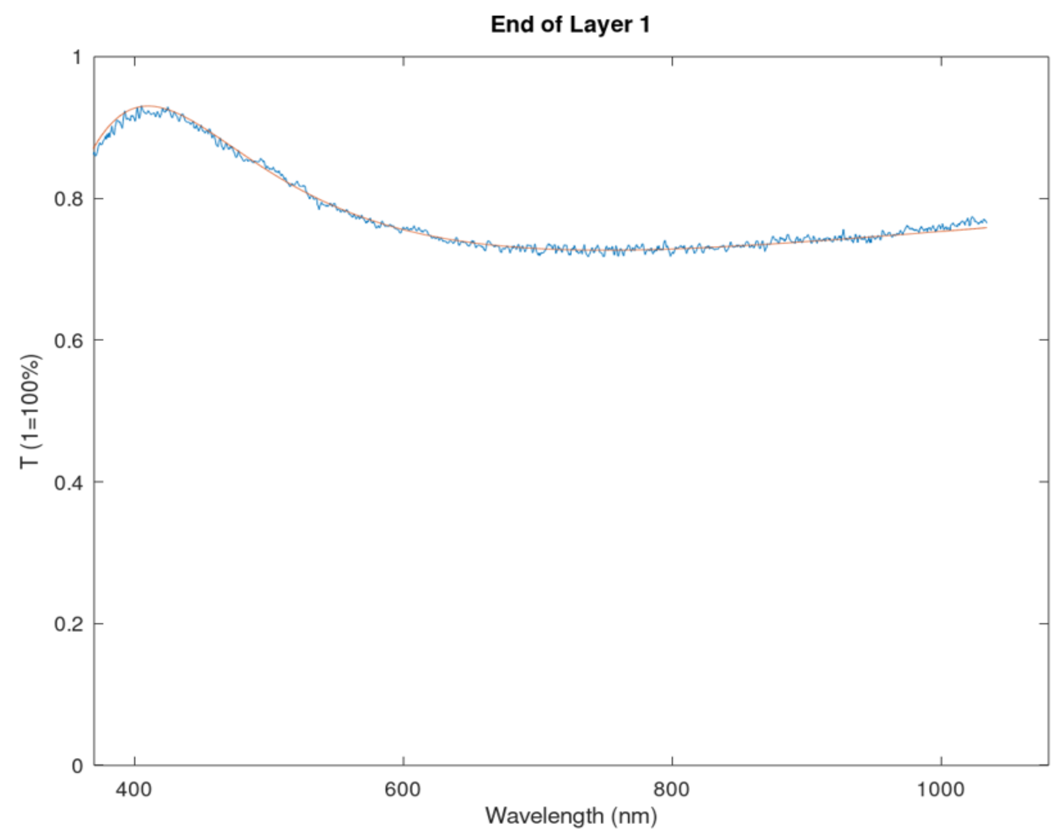
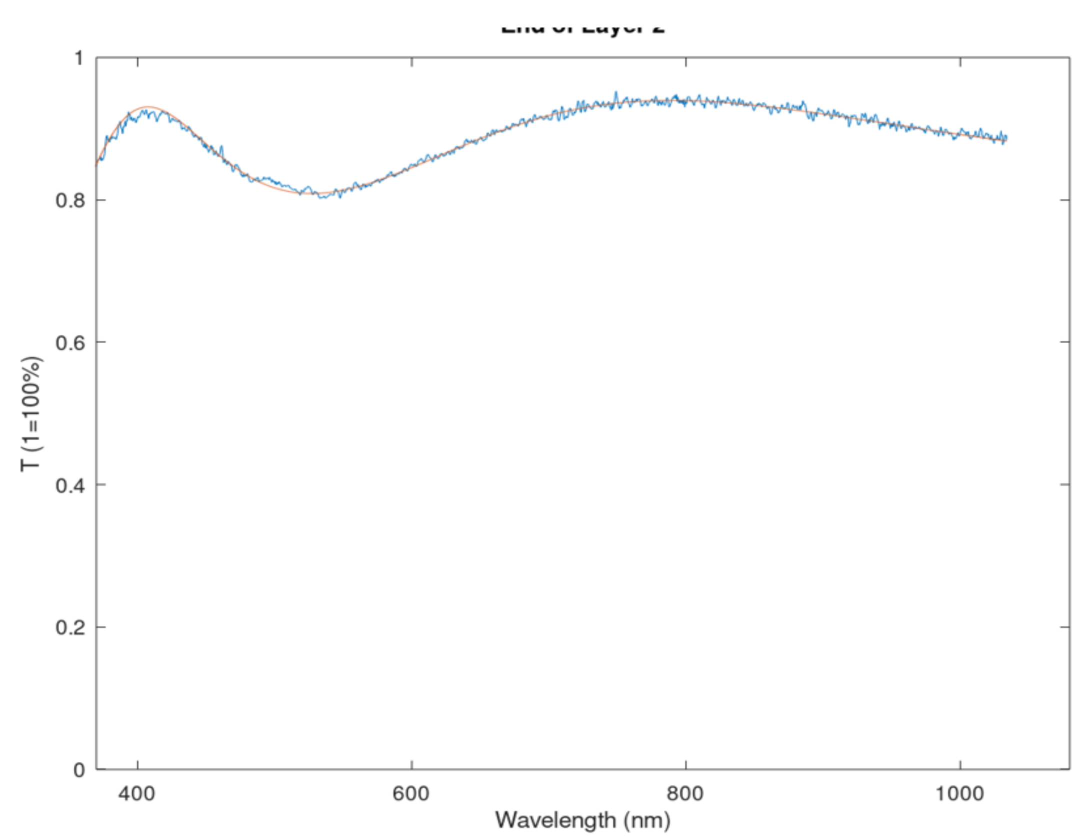
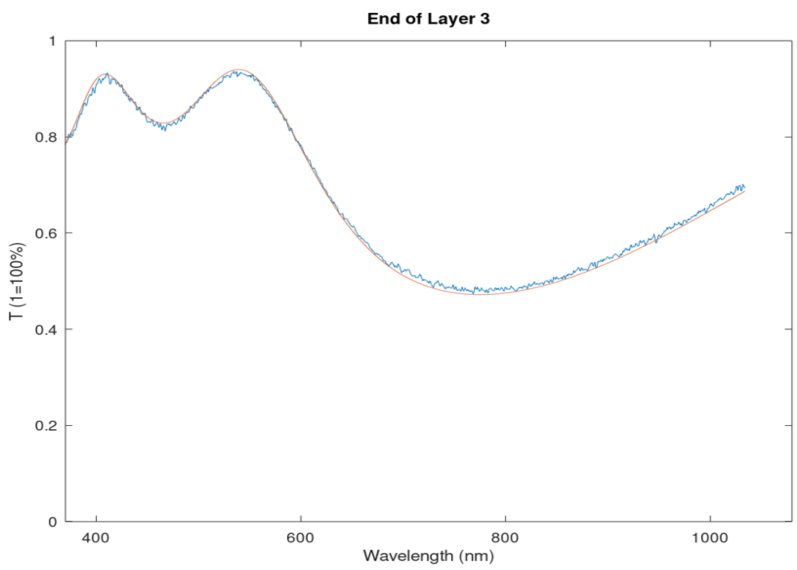
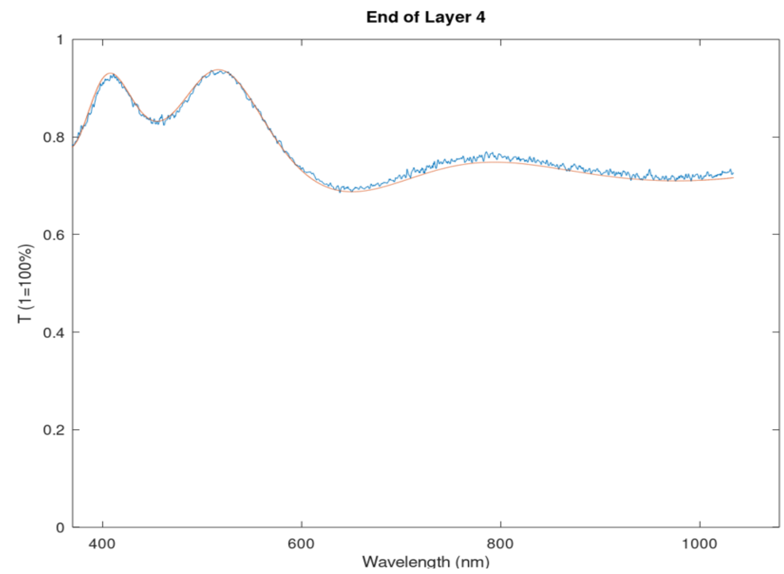
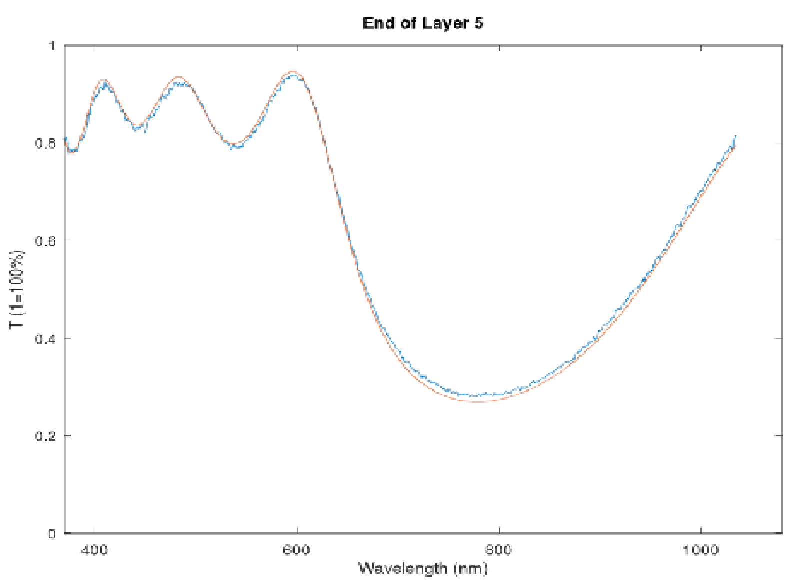


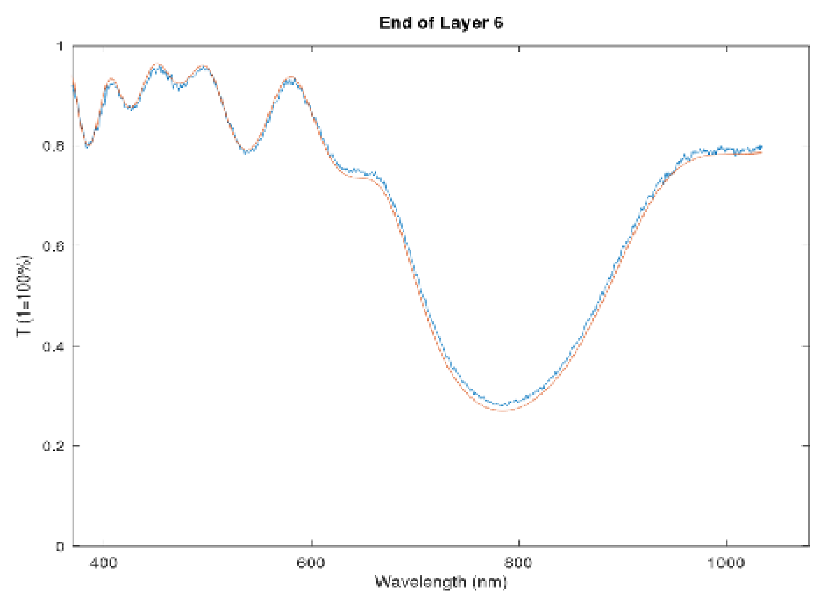


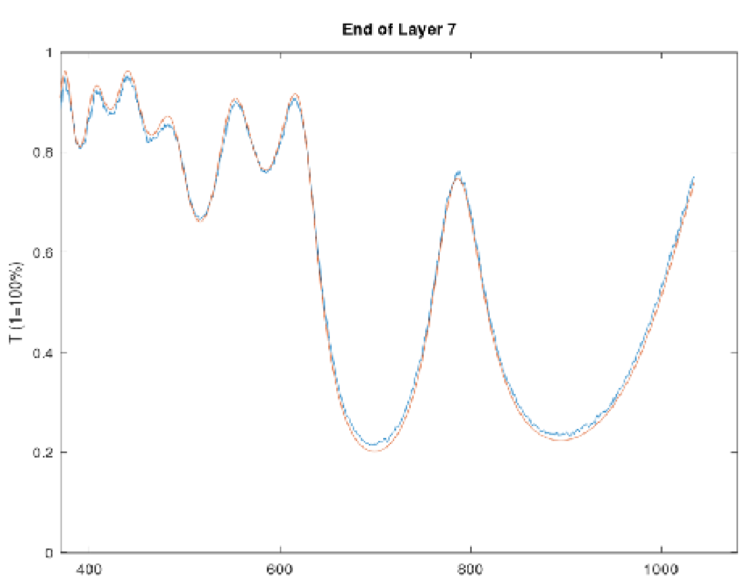
Example Run: Layers 3 -8

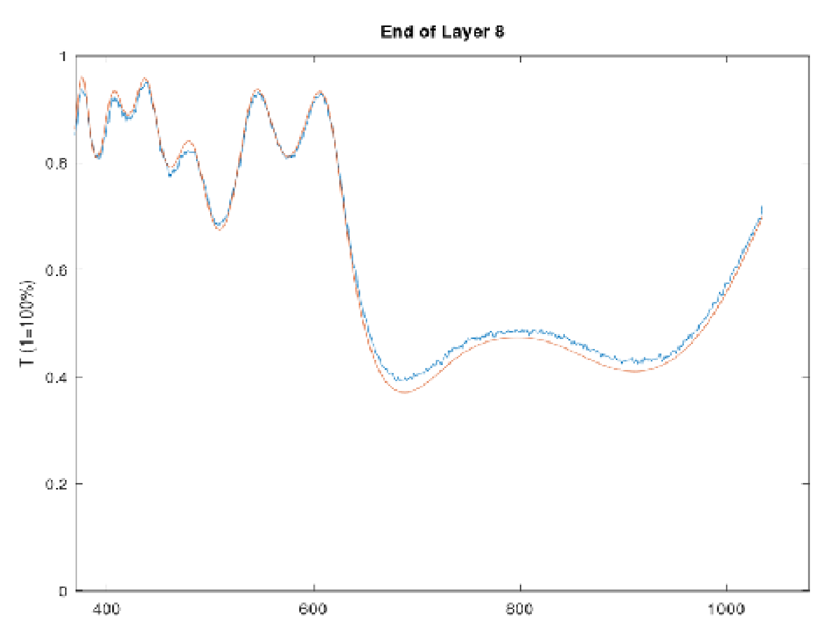




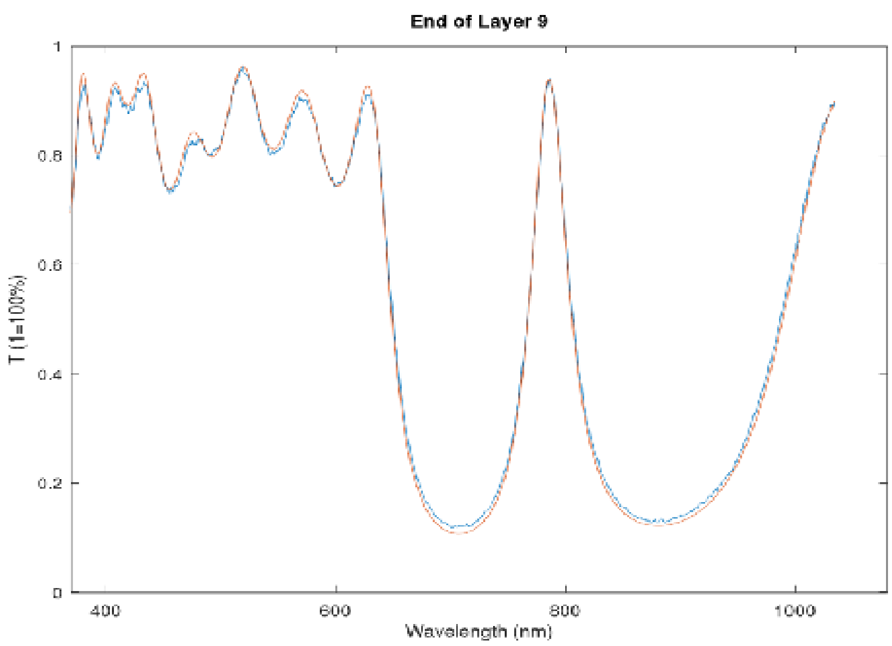


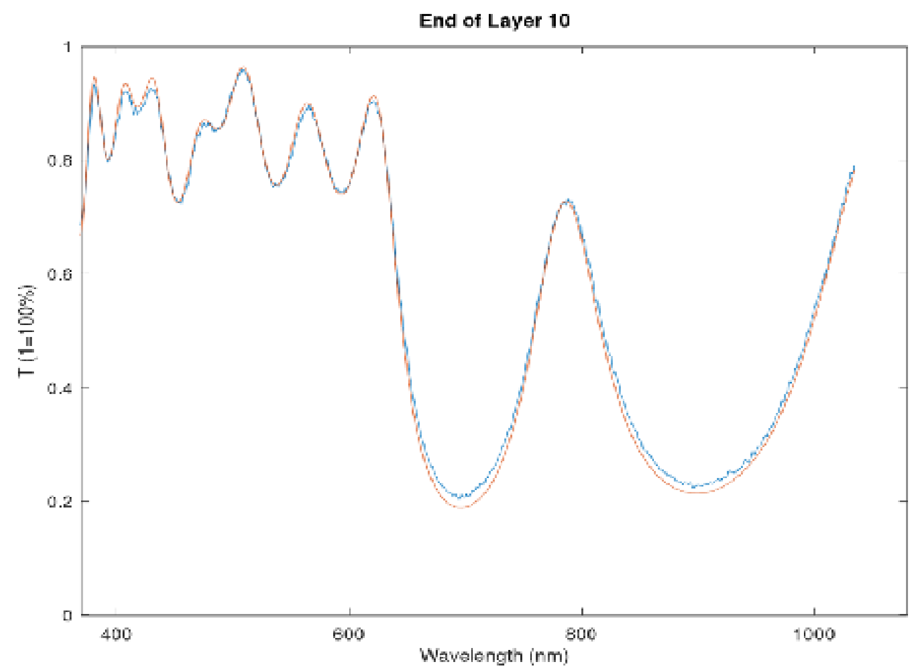


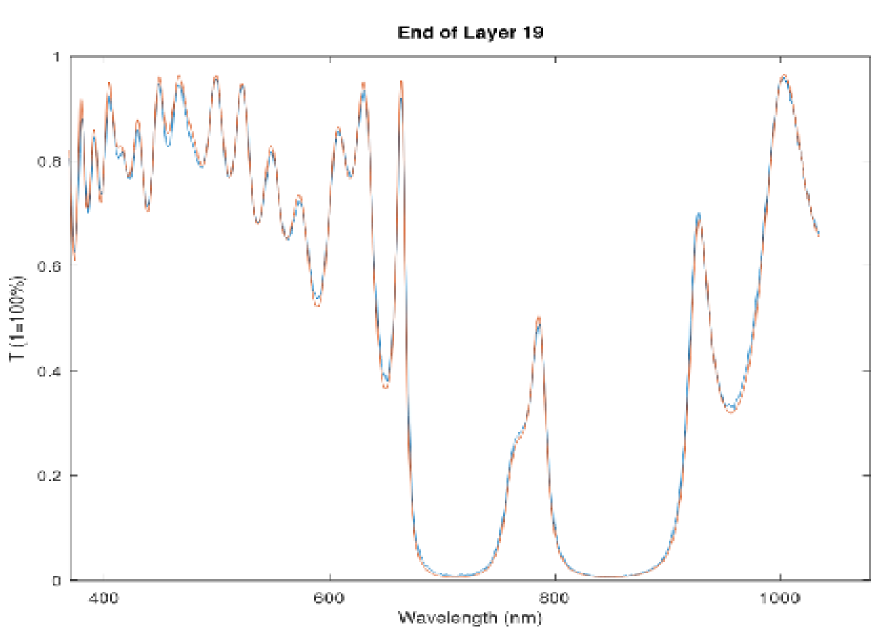


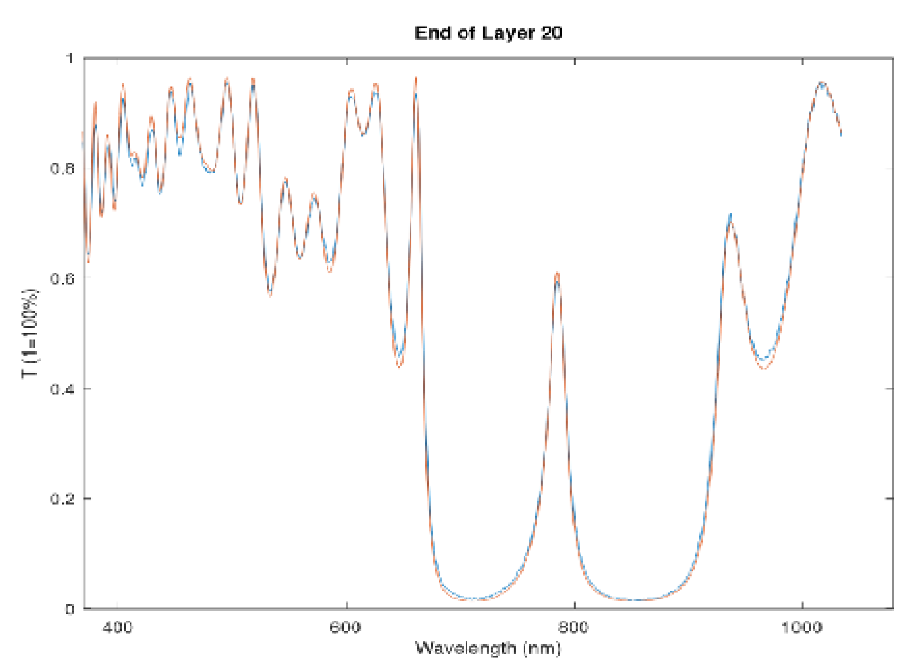


Example Run: Layers 9 and 10 and Layers 19 and 20









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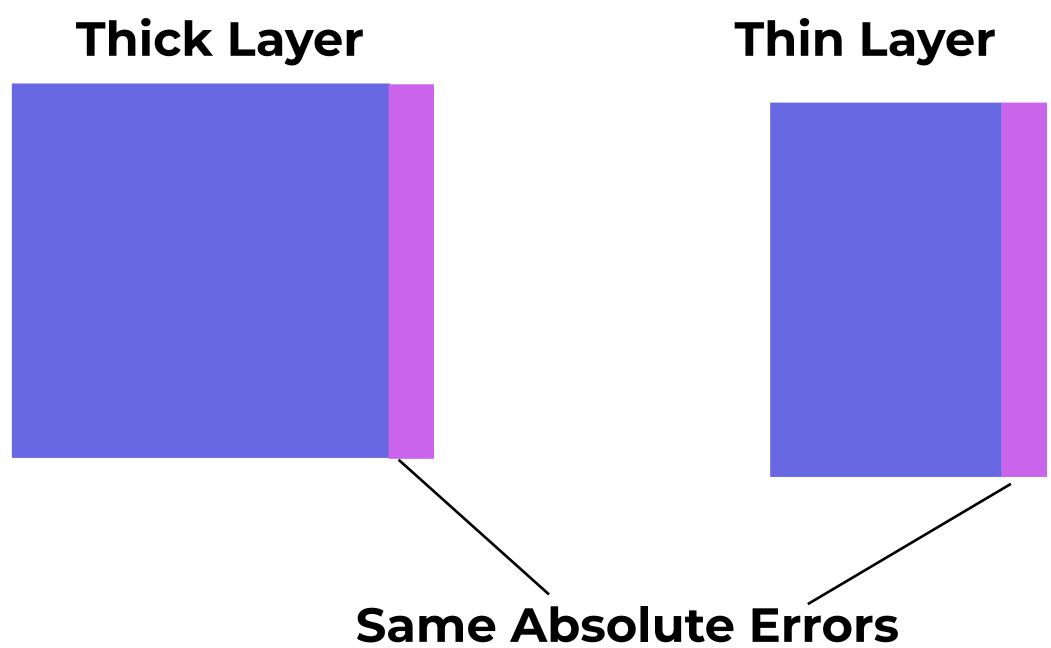
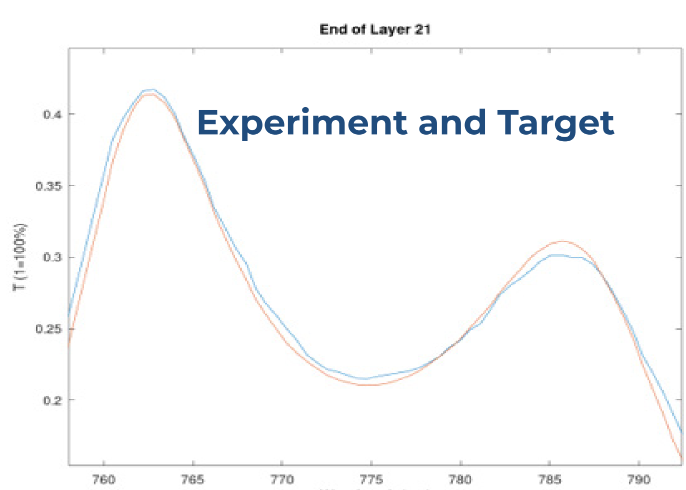
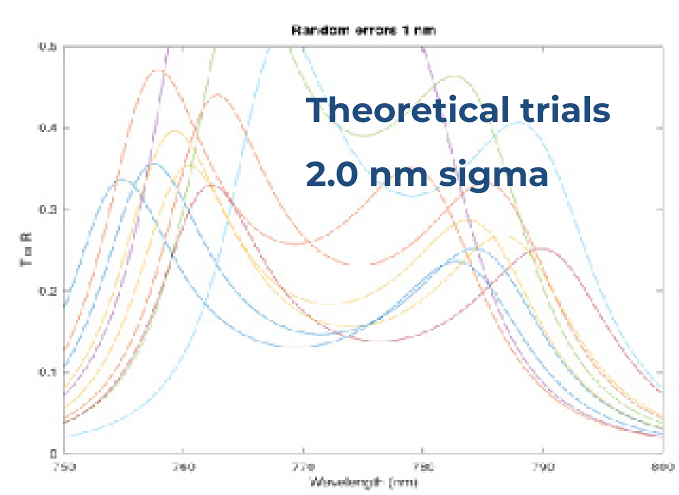
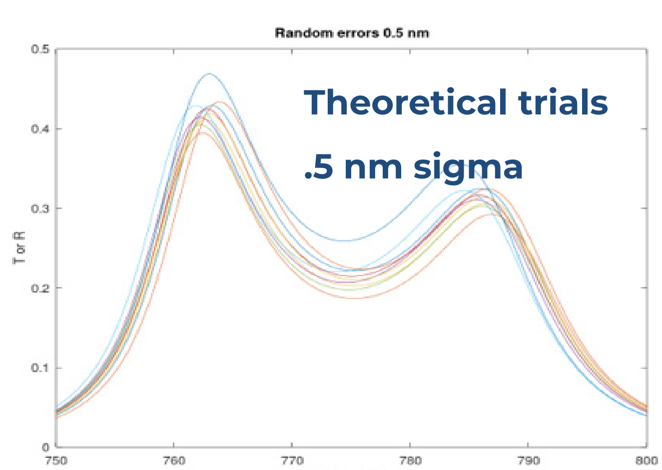
Layer Thickness Errors

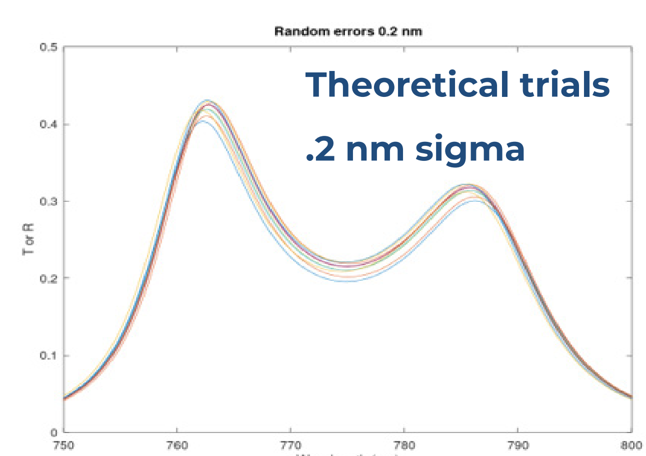
- Strong model: normally distributed random errors of the absolute thickness. This absolute thickness error can be specified in nm.
- The *fractional error* is therefore smaller for designs with thicker layers, e.g. for telecom parts at 1550 nm.
- For this design, the double-peak is very sensitive to layer thickness error, so it is good to zoom in on that.





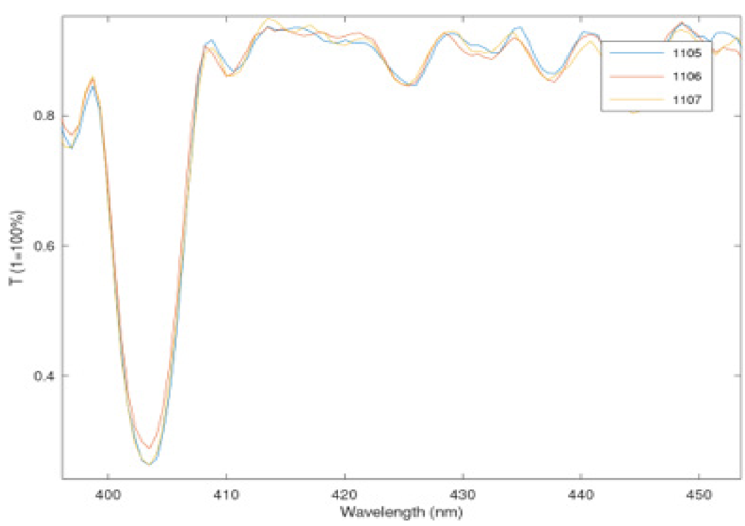




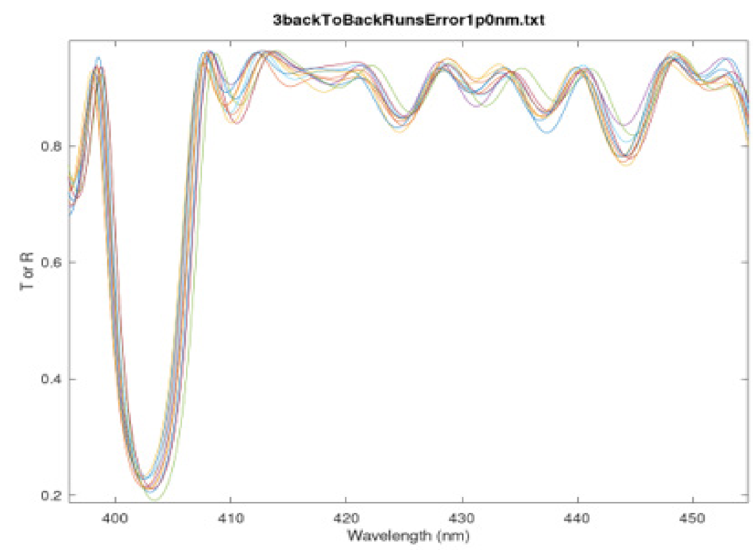


Previous Thicker Example

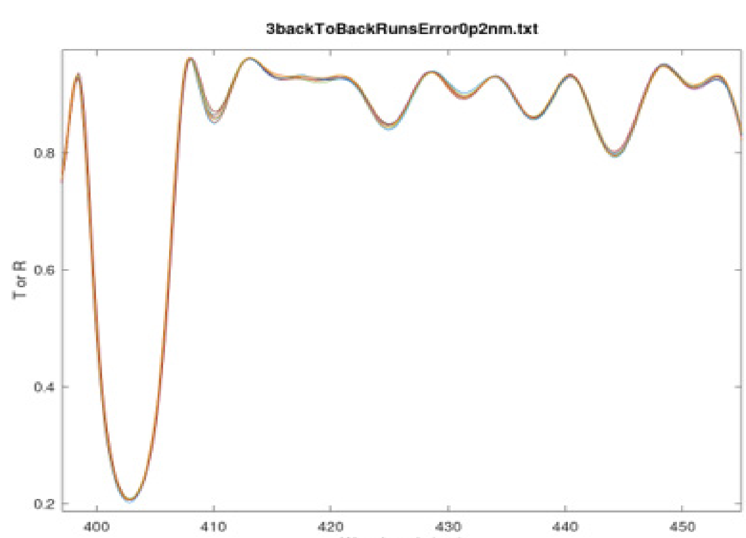
Experiment 3, runs Back-to-Back



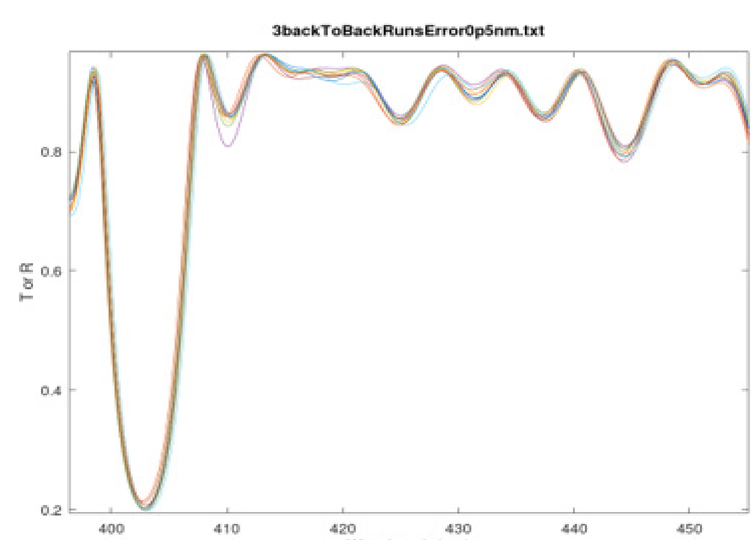
Theoretical trials 1.0 nm sigma

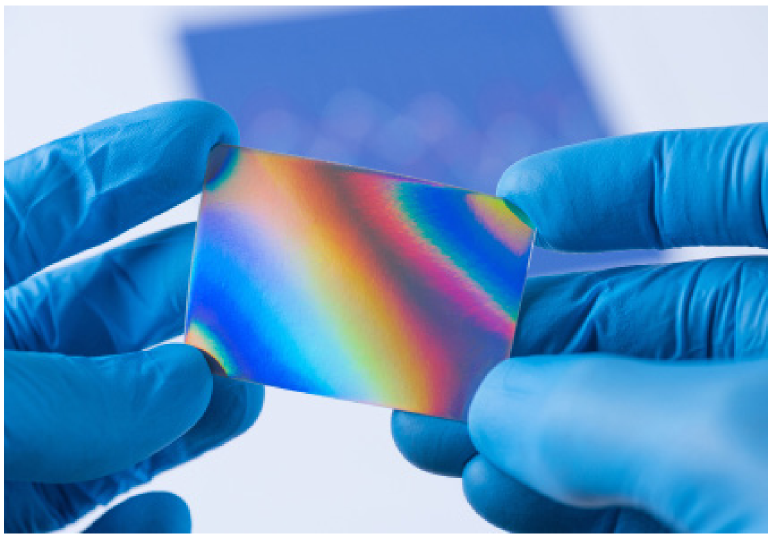


Theoretical trials 0.5 nm sigma



Theoretical trials 0.2 nm sigma





Further Improvements

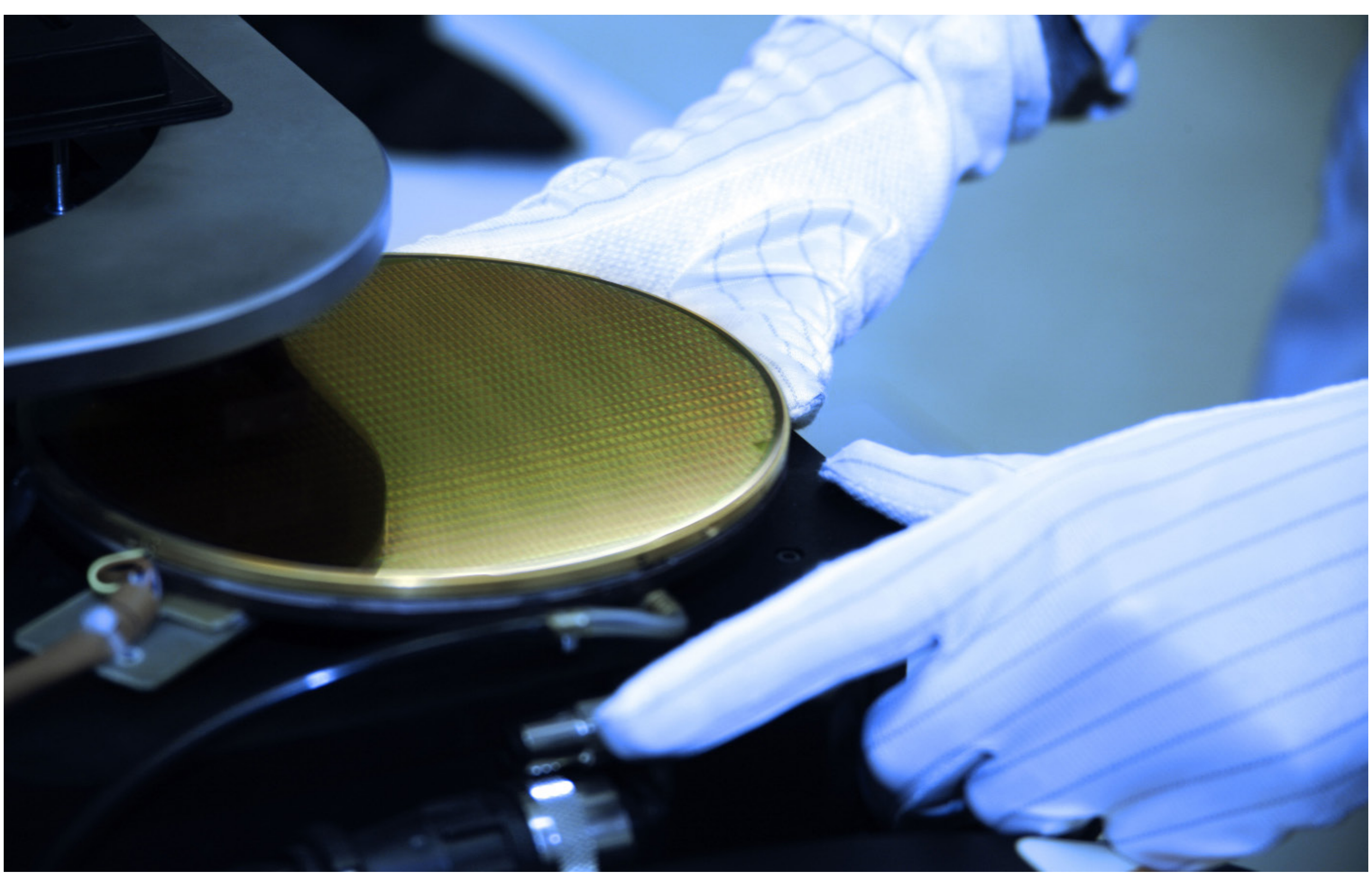
- Iterative process. Improvements reveal other sources of error.
- Improved signal to noise in the near infrared can be acheived with higher performance back-thinned detector spectrometers from Avantes Sensline

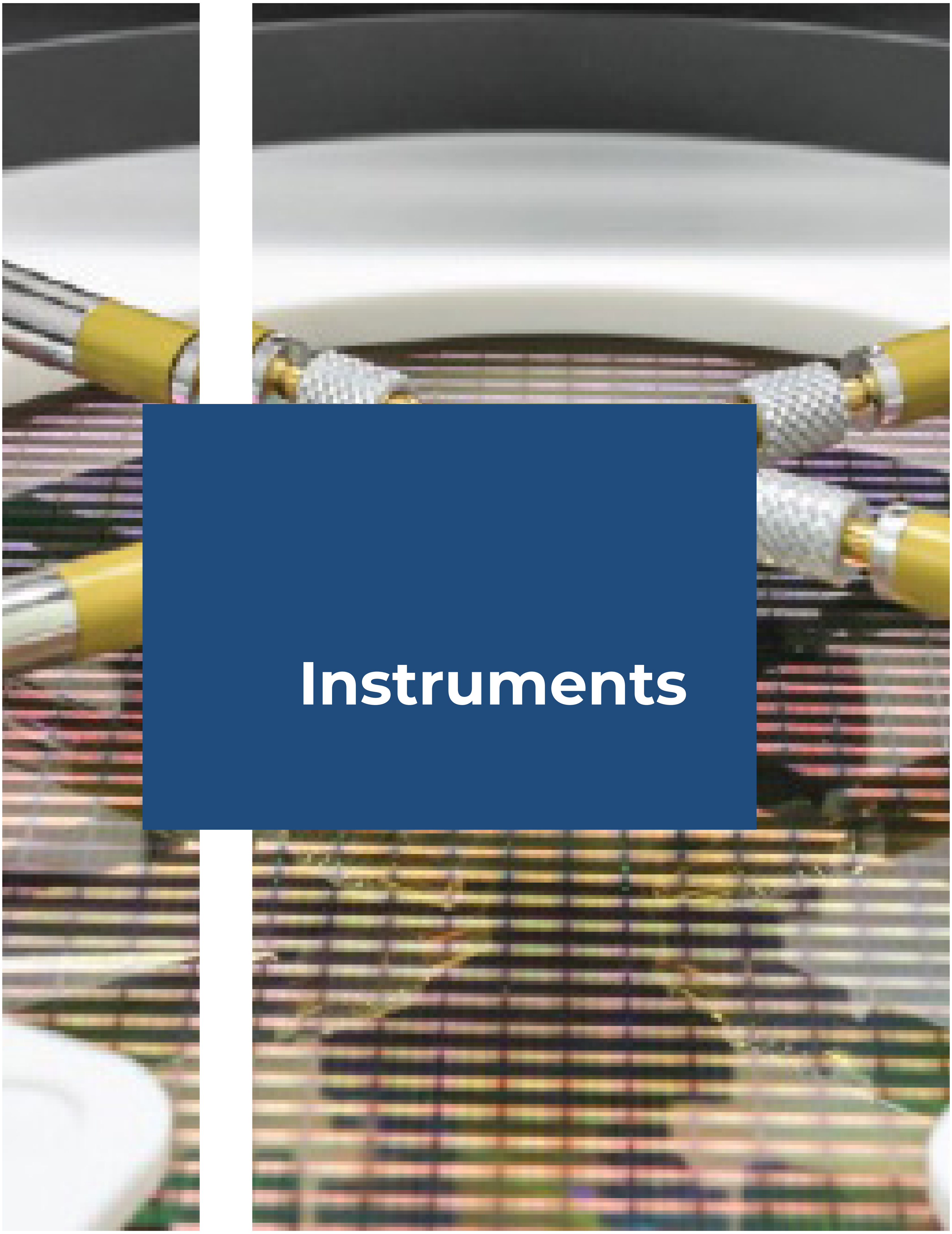
Current Level of Errors

- Better than 1 nm for my optical monitor installations, for monitoring in the visible.
- With recent improvements Boulder Optical Design is able to claim better than 0.4 nm for monitoring in the visible. This is a relative error of 0.03%.

Factors that Contribute to Errors

- Good analysis, that is insensitive to the types of errors that are most common. (Very important.)
- Good characterization of materials.
- Measurement noise.
- Measurement accuracy and linearity.
- Good uniformity over OM witness part. (This matters more for thicker coatings.)





Instruments

14 Optical hardware considerations for thin film measurement

Spectrometer Considerations

- Sensitivity: Consider back-thinned CCD spectrometers such as AvaSpec-ULS2048XL-EVO for most demanding applications. Most commonly used instrument for Optical Monitoring is the AvaSpec-ULS2048CL-EVO from the Starline. The use of a cylindrical detector lens (DCL-UV/VIS-200) and larger core fiber optics improve throughput.
- Resolution: Particularly important for thicker coatings - Choice of grating and slit size is important
- Stray Light Rejection: Usage of linear variable order sorting filter
- Signal to Noise (SNR): Typically Starline instruments are adequate but for the best the Sensline back-thinned CCD spectrometers should be evaluated.
- Sampling speed: External triggering performance is critical. Jitter or uncertainty as the start time of an integration is also important and may affect the selection of the detector.

AvaSpec-ULS2048XL-EVO

Wavelength Range: 200 - 1160nm
Resolution: 0.09 -20 nm, depending on configuration

Features/Applications:
High-Speed
High Signal to Noise
Thin Film
Low-Stray Light

AvaSpec-ULS2048CL

Wavelength Range: 200-1100 nm
Resolution: 0.06-20 nm, depending on configuration

Features/Applications:
General Spectroscopy
High-Speed
LIBS
Thin Film
Low-Stray Light

Light Source Considerations

- Combined halogen/deuterium source has best range, especially into UV.
- Simple halogen source has more power, and is often best for thicker coatings.
- Boulder Optical Design has developed a specialized filter that smooths out the raw raw signal for deuterium sources, and this gives an improved transmission spectrum.

AvaLight-HAL-S-Mini

Wavelength Range: 360-2500 nm
Stability: <0.1% / °C
Warm-up Time: <10 minutes
Output: 12.0 VDC / 0.83A
Lamp Lifetime: 4000 hrs
Temperature Range: 0-55°C
Power Supply: PS-12V/1.0A Included
Bulb Color Temperature: 2,850 K

AvaLight-D(H)s

Technical Data

	Deuterium (Deep-UV) Long life	Deuterium (Standard) Long life	Halogen
Wavelength Range	175-400 nm	190-400 nm	360-2500 nm
Warm-up Time	30 min.		20 min.
Lamp Power	78W / 0.75A		5W /0.5A
Lamp Lifetime	2000 h		1000 h
Noise (AU)	2x 10^{-5}		10^{-4}
Max. drift	± 0.5%/h		±0.1%/h
Color Temperature	-	-	3000 K
Optical Power* in 200µm fiber	11 µW	11 µW	43 µW
Optical Power* in 600µm fiber	72 µW	72 µW	239 µW
Optical Power* in 1000µm fiber	206 µW	206 µW	354 µW
Power consumption	90 Watt (190Watt for heating D-Lamp 4-5 sec.)		
Power Requirements	100-240VAC 50/60 Hz		
Dimensions / Weight	315 x 165 x 140 mm / ca 5 kg.		
Lifetime shutter	1,000,000 cycles (typical)		

** total power for the specified wavelength range*

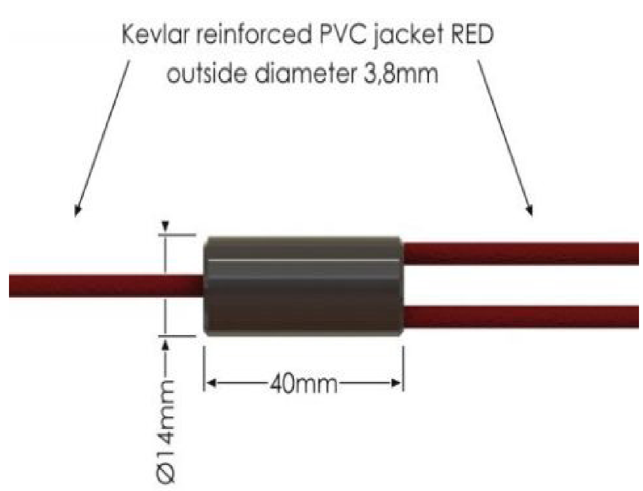
AvaLight-DHc

	Deuterium light source	Halogen light source
Wavelength range	200-400 nm	400-2500 nm
Stability	< 1 mAU	< 1 mAU
Warm-up time	8 min	1 min
Drift	< 0.25%/h	< 0.25%/h
Optical power in 600 µm fiber	0.2 µWatt	7 µWatt
Lamp lifetime	1000 hours	2000 hours
Temperature range	5°C – 35°C	
Power supply	12VDC / 450mA	
Dimensions, weight	175 x 110 x 44 mm, 570 g	

Fiber Optics and Accessories Considerations

Fiber Optics

- Larger core fibers optics provide more signal but this affects the spot size.
- 400 or 600 micron core are good options.
- Avantes broadband fibers covering 200-2500 nm are an excellent option covering the full range without having to choose between high OH and low OH fiber.



Accessories

- Collimator:
  - » Size (Need larger for greater beam travel.)
  - » Must have fused silica lense if range includes UV.

Meet the Presenter

Boulder Optical Design
BoulderOpticalDesign.com

Dr. Alan D. Streater

President of Boulder Optical Design, Inc.

11+ Years

Alan D. Streater, president of Boulder Optical Design Inc., has a Ph.D. in physics (JILA/NIST, U. of Co. 1985). He worked 2.5 years on postdoctoral research (Leiden University), and then spent 11 years in the Physics Department at Lehigh University (tenured 1995), specializing in the interaction of light and matter, followed by 11 years in the optics industry (Research Electro-Optics and Boulder Optical Design, Inc.). Dr. Streater has 40 publications, including several patents and pending patents.

PhD in Physics

University of Colorado (JILA/NIST)

AVANTES

MEMBER OF THE NYNOMIC GROUP

Avantes, part of the Nynomic Photonics group, is the leading innovator in the development of fiber-optic spectroscopy instruments and systems. Headquartered in the Netherlands, Avantes celebrated 26 years in business in 2020. Globally we have more than 36,000 spectrometers installed and growing. Avantes North America is based in Louisville, CO, with Asian headquarters in Beijing, China. We also work with over 40 distributors worldwide. Additionally, we are an ISO 9001: 2015 certified manufacturer of spectrometers.

Our mission is to provide state of the art, innovative measuring equipment that helps mankind live longer, healthier, and saving the planet for generations to come.

NYNOMIC
THE PHOTONICS GROUP

Lemnatec
MEMBER OF THE NYNOMIC GROUP

LAYTEC
Knowledge is key

tec5 USA
Technology for Spectroscopy

SENSOR THERM
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SPECTRAL ENGINES

m·u·t
efficient photonic solutions

Thank you

If you would like to learn more about thin film optical monitoring, Avantes has the expertise to guide you to solutions for your measuring challenges
Inquiries are welcome.

Follow up Questions can be directed to the following:

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