Improving the Accuracy of Optical Coating Monitoring
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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
• Measure blocked: $S_{\text{blocked}}(\lambda)$, where S is the ‘raw’ spectrum.
• Measure without part: $S_{\text{ref}}(\lambda)$,
• Measure with part: $S_{\text{par}}(\lambda)$.
• Transmittance
Thin Film Examples

Single-layer:
- $n_{\text{air}}$
- $n_1$
- $n_{\text{substrate}}$

Multi-layer:
- $n_{\text{air}}$
- $n_1$
- $n_2$
- $n_1$
- $n_2$
- $n_{\text{substrate}}$

Graphs showing transmission $T(\%)$ vs. wavelength (nm) for single-layer and multi-layer systems.
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

- Computer
- Spectrometer
- Light source
- OM witness
- Rotation fixture
- Reference hole
- Deposition plume
- Uniformity shield hides the optics
Example Run: Layer Endpoint Spectrum

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Example Run: Layers 3 - 8
Example Run: Layers 9 and 10 and Layers 19 and 20
• 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 achieved 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
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 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

AvaLight-DHc
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
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, 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.
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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