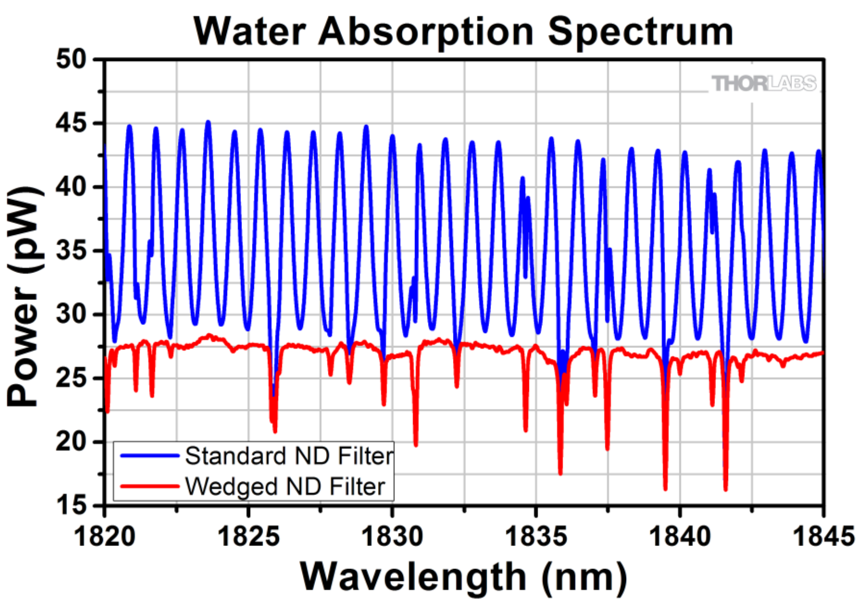
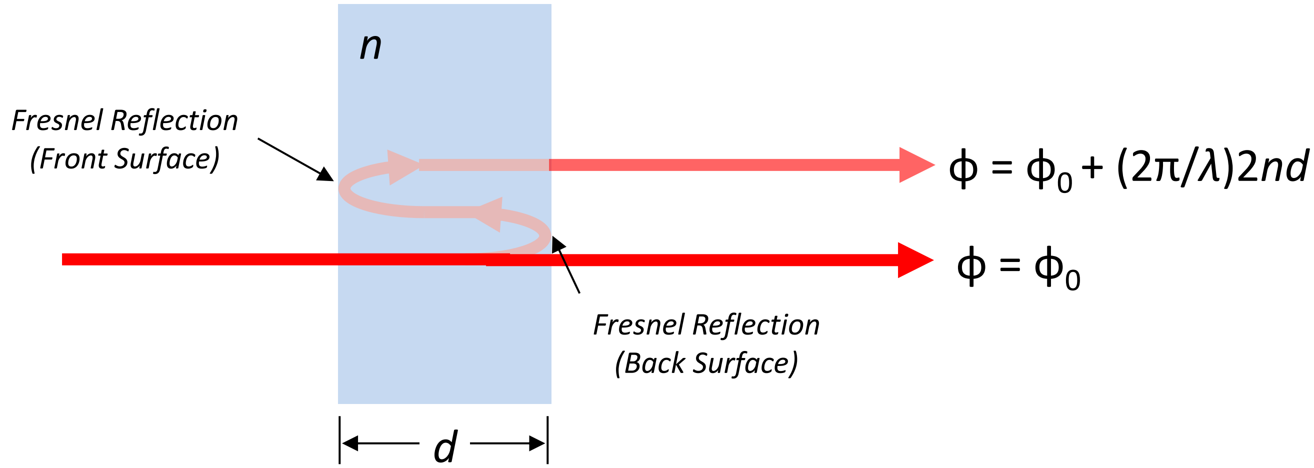
Wedged Neutral Density Filter Etalon Effect

- Thorlabs' Neutral Density (ND) Filters provide uniform attenuation over a broad spectral range. Due to the parallel front and back surfaces, the standard ND filters can exhibit a significant etalon effect.
- Thorlabs' Wedged Neutral Density (ND) Filters also provide uniform attenuation over a broad spectral range, but a 30 arcmin wedge on one side of the filter helps to eliminate etalon effects that can arise when using that can plague the standard ND filter line.



Background

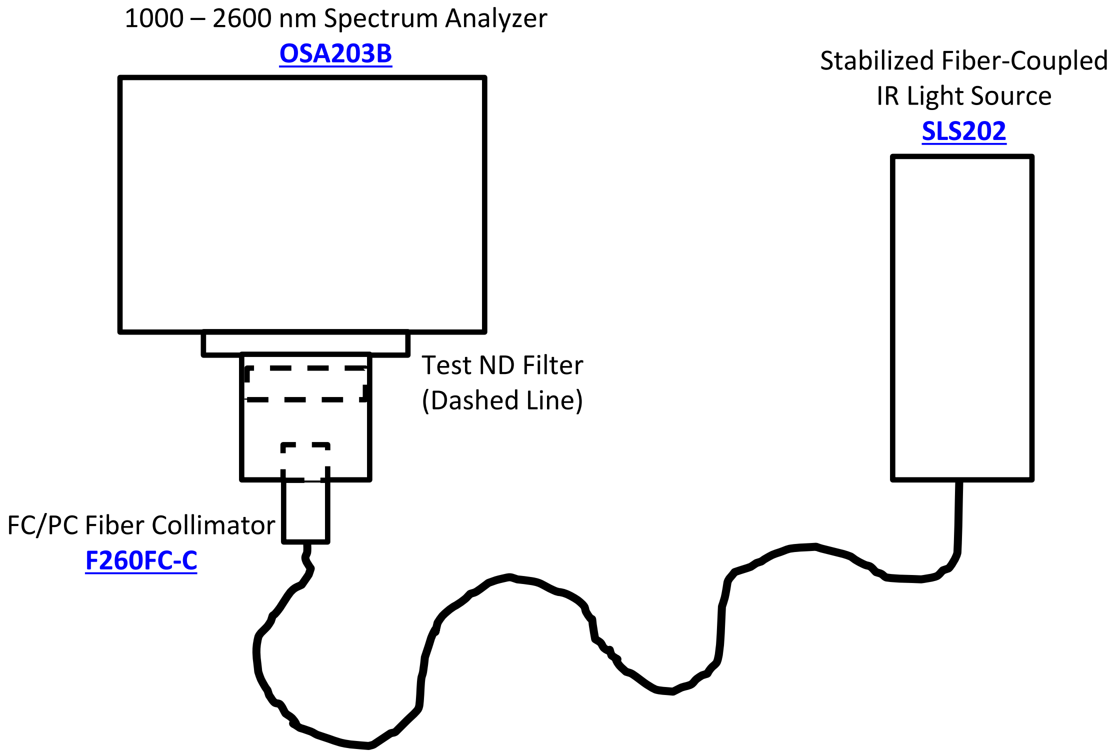
- Etalons occur due to reflections between parallel surfaces within the beam path.
- Fresnel reflections from the front and back surfaces of a parallel optic result in secondary beams with a phase shift $\phi = k(2\pi/\lambda)2nd$, where λ is the wavelength of light, n is the refractive index of the optic, d is the physical thickness of the optic, and k is number of round trips. It is important to note that this equation assumes normal incidence at the optic/air boundary.
- These secondary beams mix with the original beam, even when the thickness of the optic is larger than the coherence length of the source. The result in a sinusoidal intensity pattern in wavelength space.
- This effect is exploited within Fabry-Perot interferometers and thin film (dielectric) coatings but can be problematic for broadband spectroscopy experiments.



The above is an illustration of Fresnel reflections in a substrate with an index of refraction of *n*. The displacement of the beam path shown above is for pictorial clarity and does not represent the actual beam path, which would be coaxial at normal incidence

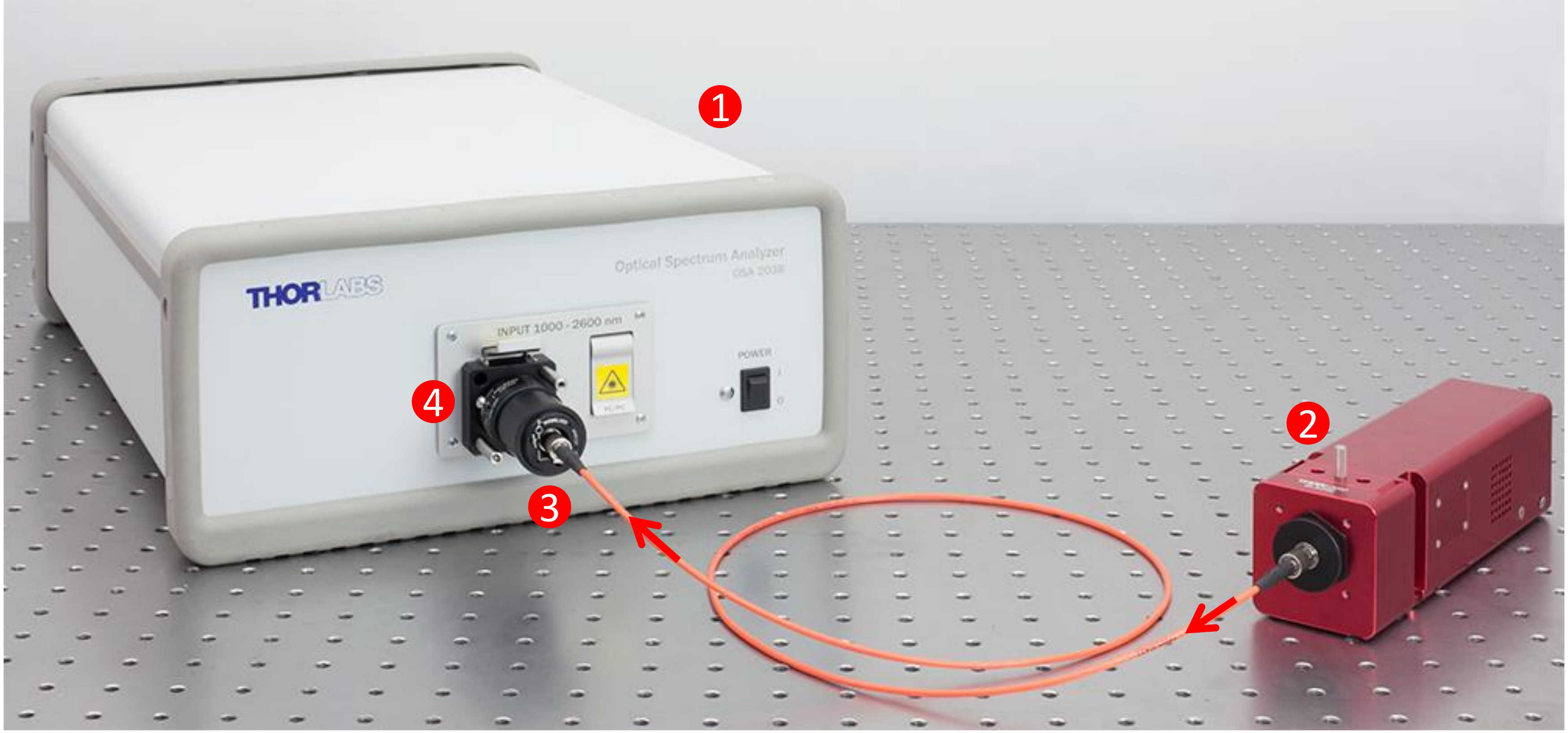
Experimental Design

- The light from a SLS202 fiber-coupled light source is coupled to a F260FC-C fiber collimator with a Ø50 µm multimode patch cable (M42L01)
- The fiber collimator is mounted within a kinematic pitch/yaw mount (KAD11F) in order to align the input with the OSA203B free space port.
- Both the wedged and regular ND filters cycled into a SM1QP lens tube filter holder, a brass spacer (SM1S3M) secures the filter within the filter holder. The spectra is recorded and analyzed to evaluate resulting etalon effects.
- The OSA traces were averaged (>100 times) to reduce noise and to better visualize the etalon effect more accurately in high resolution, high sensitivity, and automatic gain settings.



Experimental Setup

The experimental setup for measuring the etalon through standard ND filters (ND03B, ND10B, ND30B) and wedged ND filters (NDW03B, NDW10B, NDW30B) is shown below. The filters were mounted in a lens tube that was placed, between the fiber collimator and the spectrum analyzer.



1) 1000 – 2600 nm Spectrum Analyzer: **OSA203B**
2) Stabilized Fiber-Coupled IR Light Source: **SLS202**
3) Fiber Collimator: **F260FC-C**
4) ND Filter Under Test (Not Visible), held in place with an **SM1S3M** Optic Spacer (Not Visible)

Results

- The wavelength of the etalon (λ) was measured with markers in the OSA software and then converted to a measure of thickness using $t = \lambda_0/2n\lambda$, where λ_0 is the wavelength where the etalon was measured within the spectrum, and we assumed an index *n* of 1.5. The OSA has a spectral resolution of 7.5 GHz (0.25 cm^{-1}).
- All of the standard ND filters exhibited an etalon on the order of 1.2 mm which is within the 1.0 ± 0.25 mm thickness specification.
- All of the wedged ND filters provided an etalon on the order of 0.5 mm, which matches the etalon provided by the light source alone and corresponds to the thickness of the window on the front of the OSA detector.
- Overall, the wedged ND filters design appears to have removed the etalon.

[Normal ND Filters]

Filter Item #	Etalon*
ND03	1.22 mm
ND10	1.23 mm
ND30	1.18 mm

[Wedged ND Filters]

Filter Item #	Etalon*
NDW03	0.53 mm
NDW10	0.54 mm
NDW30	0.49 mm

Source (No Filter): 0.51 mm Etalon

*Etalon calculated assuming index of 1.5

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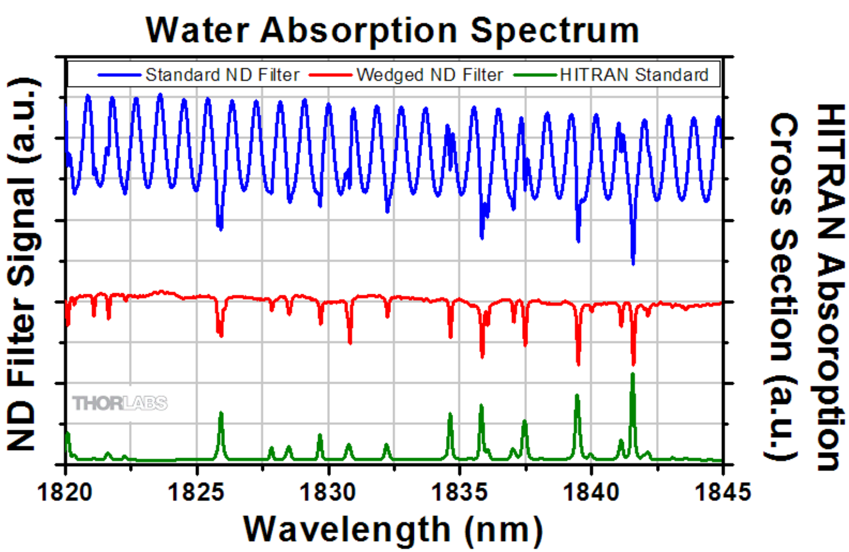
Application Demonstration

- Here we provide a simplistic demonstration for the advantage of using wedged ND filters in a spectroscopic application.
- Using the same broadband source in the experimental setup slide, we zoomed into a region with visible water absorption lines (1820 – 1885 nm/5304 – 5493 cm^{-1}).
- The offset blue trace, which shows the spectrum recorded with a standard ND filter, exhibits clear sinusoidal etalon effects across the spectrum; some of the absorption bands are visible on top of the sinusoidal signal. Additional processing would be required to remove the etalon and measure the true features of interest.
- The offset red trace shows the spectrum recorded with the wedged ND filter. Here, a clear baseline from the light source is defined and the smaller water absorption lines are readily observed.
- The green trace shows the HITRAN data for water in this region (available within OSA software).



Spectra of water absorption lines using standard (blue) and wedged (red) ND filters compared to the HITRAN spectrum of water (green). Spectra offset and plotted in arbitrary units to visualize differences. It is important to note that this result describes a brief investigation to provide insights into the general behavior of our components and should be interpreted with the specified limitations of the devices in mind.

Experimental Limitations

- The spectral resolution of the OSA203B is 7.5GHz (0.25 cm^{-1}), any etalon or spectral variation with features below the resolution were not visible in the spectra.
- The amount of power per wavelength measured with the wedged ND filter was slightly less than that for the standard ND filter, as seen in the plot on slide 1. This difference was assumed to be a combination of experimental error and slight variation between filters.
- It is important to note that the ND filters used in this experiment were designed for use from 350 - 1100 nm. This experiment was performed with a near-infrared OSA203B to demonstrate the effect with water absorption bands, which do not exist in the designed wavelength range, and not to characterize the filters themselves. Information about how the filters perform outside the specified wavelength is available on the pages for our standard and wedged ND filters.

Summary

- Etalons occur from reflections between parallel plate objects within the beam path and can drastically affect data analysis by distorting or hiding features within the oscillation.
- Wedged ND filters significantly limit the etalons by preventing the reflection from the back surface from traveling along the same optical path.
- Spectra acquired using a broadband source and optical spectrum analyzer showed that the etalon observed with the standard ND filter was completely removed when using a wedged ND filter.
- The use of wedged ND filters is extremely benefitial when using broadband sources to visualize small features in spectroscopic applications, as doing so minimizes the amount of data processing necessary.

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