Thin film filters: optical testing with the CTP10 test platform

Challenges and solutions for fast and accurate swept IL-RL measurements

app note

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1. Introduction

This application note describes the challenges related to the optical testing of thin film filters (TFF). TFFs are probably the most versatile and widely used optical components, and yet come with unique challenges when it comes to optical testing.

TFFs are free-space optical components that consist of a substrate (typically glass) coated with a succession of layers of high and low index materials that give the TFF its desired transmission and reflection profiles.

TFFs can be found in a wide variety of optical systems, such as WDM multiplexers, Fabry-Perot etalons, gain flattening filters (GFFs) or PON coexistence elements. TFFs have several advantages, including a large choice of transmission and reflection profiles for bandpass, notch, edge-pass or multiband filters. Custom designs can also be manufactured to meet specific needs. In addition, TFFs have a small footprint, typically below 2 mm, low insertion loss (IL) and an excellent environment durability.

This application note first discusses the challenges related to TFF optical testing and the usual measurement principle. The configuration using the CTP10 test platform for TFF testing is then detailed, followed by a discussion about the different approaches available for in situ monitoring during the deposition.

Figure 1. The CTP10 component test platform is a 10-slot modular platform for swept IL, RL and PDL measurement of passive optical components.

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TFFs are probably the most versatile and widely used optical components, and yet come with unique challenges when it comes to optical testing.

2. Testing challenges

Measuring the optical properties of TFFs poses several unique challenges. Unlike most fiber optic components, TFFs are free-space components and therefore require very specific test stations to align the different optical elements with each other.

Once packaged and deployed in the field, TFFs are typically assembled in configurations where they are used both in transmission and reflection. As a result, return loss (RL) also needs to be measured in addition to IL to verify the TFF performances in transmission and reflection. Adding to the complexity of dealing with a free-space component, the transmission and reflection spectrum are very sensitive to the angle of incidence (AOI) of the optical beam on the TFF.

In addition, telecom TFFs are also available in a wide range of wavelengths, typically between 1240 and 1680 nm. While some filters are only specified within certain bands, like DWDM TFFs which operates in the C and L bands, PON filters are specified and must be tested over the full telecom range, typically from 1260 to 1640 nm.

3. IL, RL measurement principle

A schematic representation of the typical measurement configuration is shown in the figure below. A collimator is used to create a free-space optical beam that enters the TFF with the desired AOI.

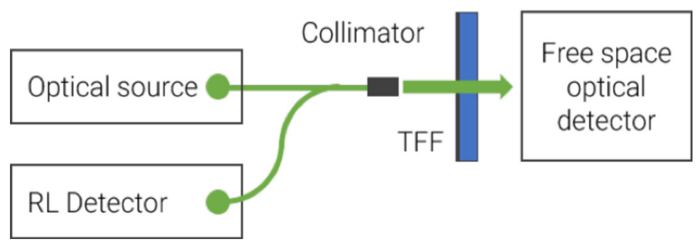

Figure 2. Measurement principle for IL and RL measurement.

A swept tunable laser is usually used as the optical source in order to rapidly sweep across the wavelength range and record the IL and RL spectrum as a function of wavelength. The swept method considerably speeds up measurement time as opposed to a stepped approach.

Optical testing of TFF is typically performed at two different stages in manufacturing:

1. During the deposition process to monitor the growth and adjust the process in real time to meet desired specifications.

2. After dicing and prior to shipping to customers, as a final QA step to ensure that components meet all expected specifications.

The measurement principle remains the same whether it is employed for QA testing or during the deposition process for process control and monitoring. The light transmitted through the TFF is measured using a free-space detector with a clear aperture larger than the beam diameter. A free-space detector relaxes the alignment tolerances (lateral and angular), ensuring reliable results as well as easing the alignment procedure.

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4. CTP10 platform for TFF measurement

The CTP10 is a swept measurement platform for passive optical component testing. The CTP10 platform operates together with EXFO's series of swept tunable lasers to measure IL, RL and PDL with picometer resolution.

4.1 Remote optical head

For free-space components and TFF measurement, a remote optical head with a Ø 3.7-mm clear aperture is available. With a 1-cubic-inch form factor, this remote head can be conveniently placed after the TFF to measure the transmitted power. Several mounting holes are available to maintain the remote head in place.

The remote head uses an innovative design and combines a Ø 1-mm high-speed InGaAs photodetector together with a lens of Ø 3.7 mm clear aperture mounted on a fiber optic adapter (FOA) placed in front of the detector. The lens focuses the free-space beam on the photodiode and provides a large clear aperture, relaxing lateral and angular alignment tolerances.

The remote head uses an innovative design and combines a Ø 1-mm high-speed InGaAs photodetector together with a lens of Ø 3.7 mm clear aperture.

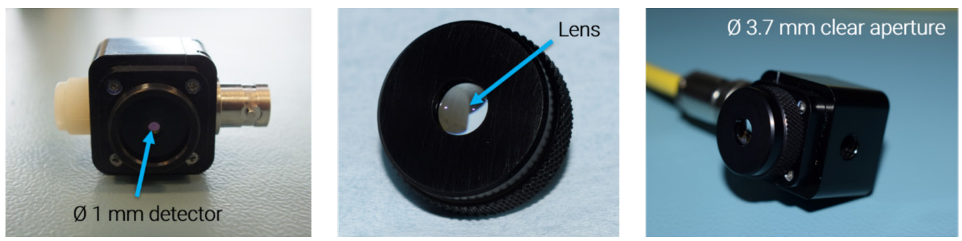

Figure 3. Left: remote optical head without any FOA, showing the Ø 1-mm InGaAs photodetector. Middle: lensed FOA with a Ø 3.7-mm clear aperture. This FOA can be mounted on the remote optical head. Right: remote optical head with lensed FOA mounted.

Smaller size photodetectors are inherently faster than large area detectors. With an active area of Ø 1 mm, the photodetector integrated in the remote head has a minimum averaging time of 1 µs, as opposed to 100 µs typically for large area detectors of Ø 4 mm or more. For swept measurements, the averaging time of the detector directly influences the sampling resolution in the wavelength domain: *Sampling resolution = Laser sweep speed x Averaging time.*

Having a faster detector therefore allows to achieve a better sampling resolution for a given sweep speed. Conversely, this allows to use a faster sweep speed for a given sampling resolution, improving throughput in manufacturing.

	CTP10 remote optical head + lensed FOA	Traditional large area photodetector
Clear aperture	3.7 mm	4 mm
Photodetector size	Ø 1 mm	Ø 5 mm
Min. averaging time	1 µs	100 µs

In the case of traditional large area photodetectors, the 100 µs averaging time limits the sampling resolution to 10 pm at 100 nm/s sweep speed. This prevents high-resolution measurements at 100 nm/s, forcing to compromise either the resolution or the measurement time.

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> Thanks to its range-free design, the OPM2-NS2629 module used with the remote optical head offers a >70 dB dynamic range in a single scan at 100 nm/s.

The picture below shows an example measurement configuration where the collimator, TFF, and detector are visible.

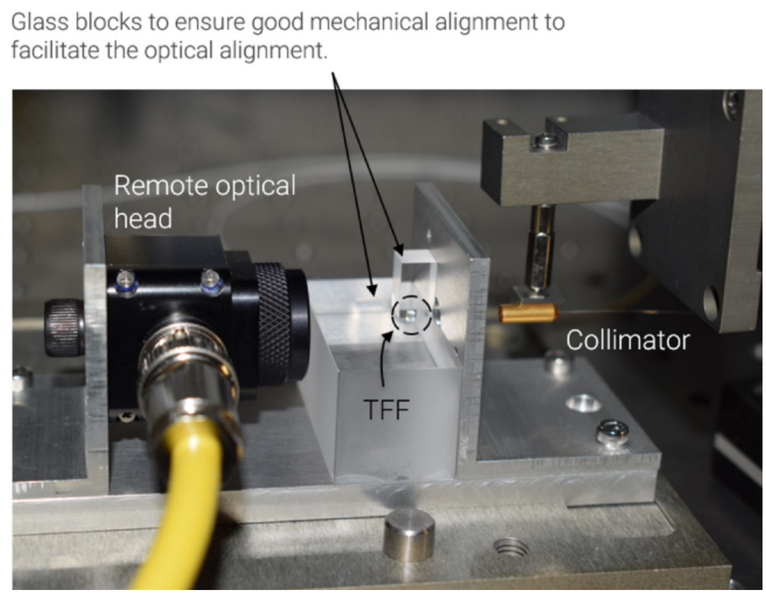

Figure 4. Example of experimental setup for IL and RL measurement of a 100 GHz DWDM TFF (size 1.4 mm²). The remote optical head visible on the picture has a Ø 3.7-mm clear aperture and measures the light transmitted through the TFF.

EXFO's remote optical head outputs an electrical signal via a triaxial BNC connector that should be connected electrically to the OPM2-NS2629 module within the CTP10 platform.

4.2 OPM2-NS2629 module

The OPM2-NS2629 is a non-standard module derived from the OPM2 module, with two electrical input connectors instead of two optical detectors. It is designed to operate with the remote optical head for free-space component characterization.

When used together with the remote optical head, this module provides the same optical performance as an OPM2 module. Thanks to its range-free design, the OPM2-NS2629 module used with the remote optical head offers a >70 dB dynamic range in a single scan at 100 nm/s.

The triaxial cable that connects the remote optical head to the OPM2-NS2629 module (in yellow in Figure 4) ensures accurate and consistent results even in harsh EM environments.

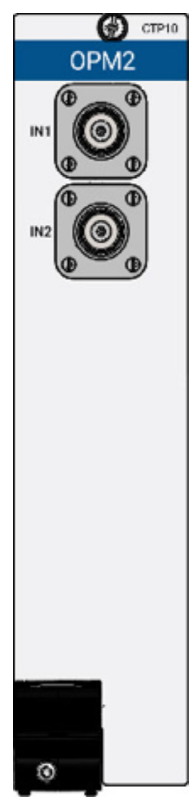

Figure 5. Front view of the OPM2-NS2629 module, with 2 electrical BNC connectors.

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The CTP10 includes a suite of advanced analysis functions to analyze pass-band filters and calculate parameters of interest such as central wavelength, filter width and loss.

4.3 Measurement configuration

Figure 6 below shows a schematic representation of the typical CTP10 configuration for TFF testing.

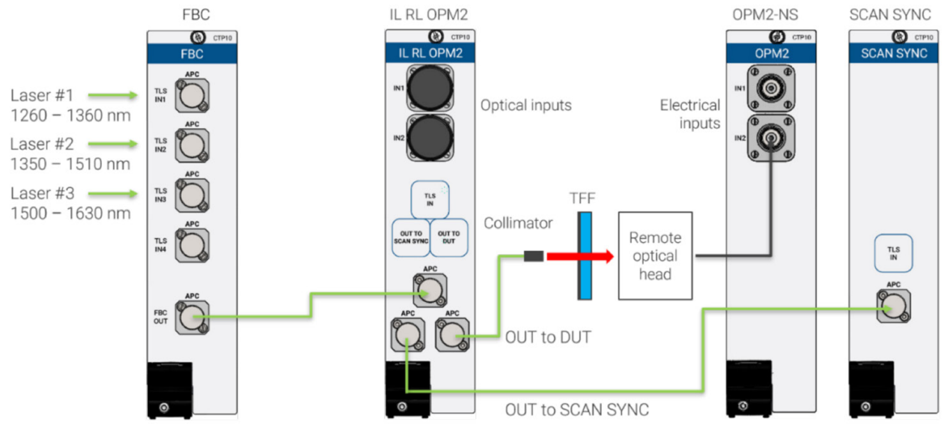

Figure 6. Schematic representation showing the CTP10 modules used for full-band (1260 – 1630 nm) IL-RL measurement of a TFF.

The IL RL OPM2 module is placed before the DUT and measures in real time the laser power to the DUT, to monitor and compensate any power variation that comes from the laser source. This module also has a built-in detector for RL measurement, eliminating the need for an external coupler.

The SCAN SYNC module is used for optical triggering and measures the laser wavelength during the sweep by tapping some optical power from the IL RL OPM2 module.

Finally, the FBC module allows to perform measurements over several lasers, for example in the case of PON filters that have a broad operating wavelength range. The FBC module can be considered as a switch that links several lasers to the IL RL OPM2 module.

The image below shows a screenshot of the CTP10 GUI with an IL and RL trace measured on a 100 GHz DWDM TFF using the setup shown earlier in Figure 4.

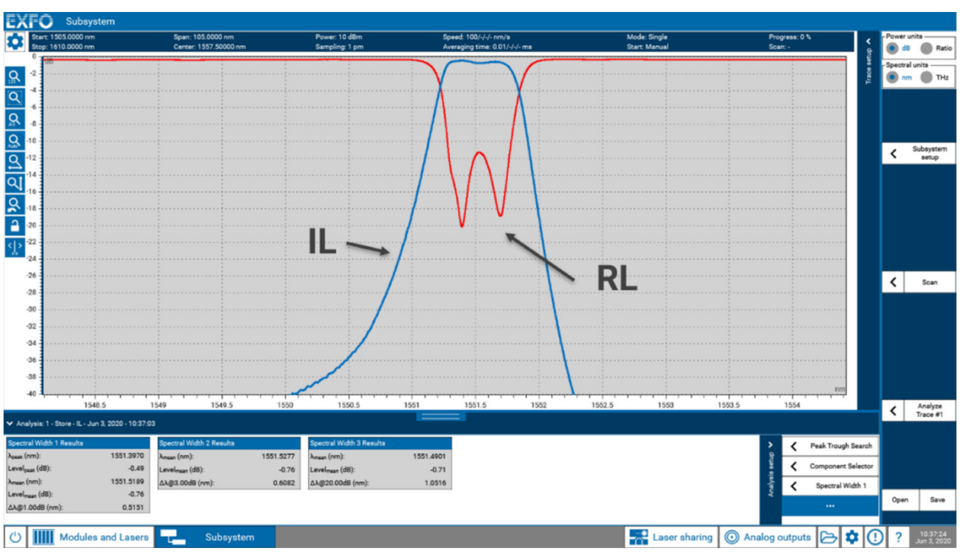

Figure 7. Screenshot of the CTP10 GUI showing the IL (in blue) and RL (in red) traces of a 100 GHz DWDM TFF.

The CTP10 includes a suite of advanced analysis functions to analyze pass-band filters and calculate parameters of interest such as central wavelength, filter width and loss.

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A step forward to more accurately assess the optical properties of the TFF under test is to use optical monitoring.

5 In situ monitoring

Monitoring the deposition provides an important feedback signal useful to create a closed-loop system where the deposition process can be adjusted in real time based on the feedback signal.

TFF designs are increasingly complex and must meet tighter and tighter specifications. It is now common for TFFs to be coated with hundreds of layers, which raises the need for more advanced process control. Having a closed-loop deposition process improves the yield and allows to meet tighter specifications that would otherwise be difficult to achieve by design.

Monitoring methods can be coarsely divided into 3 categories:

1. Non-optical monitoring
2. Single wavelength optical monitoring
3. Broadband optical monitoring

5.1 Non-optical monitoring

Non-optical monitoring methods include for example quartz crystal microbalance (QCM) and time monitoring. These monitoring methods are still used as part of the process control but only provide indirect information about the optical characteristics of the TFF being manufactured. When trying to retrieve optical information about the TFF, indirect monitoring heavily relies on calibration coefficients. For instance, the thickness of a layer can be estimated based on the elapsed time and estimated deposition rate. However, any deviation from the nominal deposition rate will result in uncertainties that build-up over time during the deposition process.

5.2 Single λ optical monitoring

A step forward to more accurately assess the optical properties of the TFF under test is to use optical monitoring rather than an indirect method as presented above. Single wavelength monitoring relies on the measurement principle shown in Figure 2 but uses a laser at constant wavelength instead of a swept laser source. In this configuration, the transmitted and reflected powers are recorded as a function of time and processed to determine when to stop the deposition of a layer. The turning point monitoring (TPM) method is widely used to monitor the growth of quarter-wave layers where the zero-derivative points of the P(t) signal indicates that the optical thickness of the current layer is λ/4.

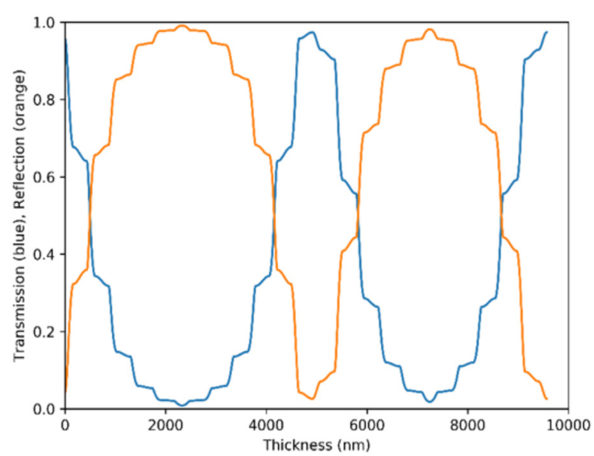

Figure 8. Simulation showing the insertion loss (blue) and return loss (orange) of the TFF as a function of deposited thickness. The simulation consists of 43 layers, $(HL)^5S(LH)^5L(HL)^5S(LH)^5$, where n(H)=2.35 and n(L)=1.45.

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Although single wavelength monitoring measures the optical properties of the TFF, the spectral characteristics of the TFF as a function of wavelength can only be inferred indirectly by processing the IL(t) and RL(t) traces measured at one wavelength. For example, Figure 8 does not directly provide any information on the filter central wavelength, width or ripple.

For custom TFF designs using, for example, non-quarter-wave layers the TPM method does not work and more sophisticated algorithms must be used, adding to the complexity of retrieving the spectral characteristics of the TFF based on the P(t) signal measured at one wavelength.

Broadband optical monitoring provides direct access to key optical parameters found in TFF acceptance test reports and specification sheets.

5.3 Broadband optical monitoring

Broadband optical monitoring is the most advanced method and consists of measuring the transmission and reflection spectrum of the TFF as a function of wavelength during the deposition. Broadband optical monitoring provides direct access to key optical parameters found in TFF acceptance test reports and specification sheets, such as central wavelength, filter width, loss or ripple.

The measurement configuration uses a swept laser and is similar to the one presented in Figure 2, but with part of the setup inside the deposition chamber.

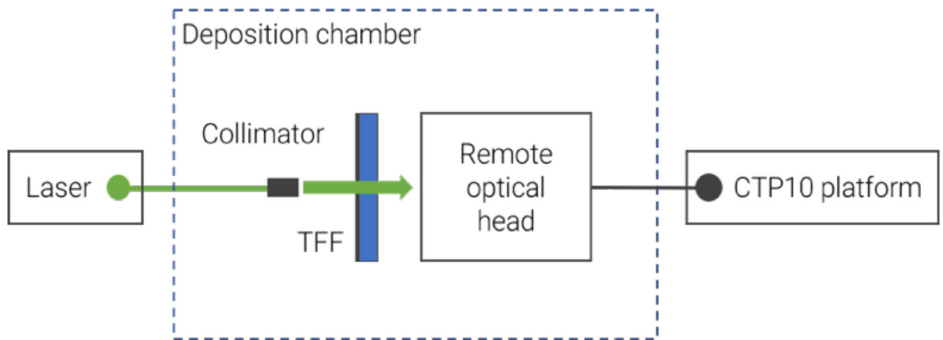

Figure 9. Schematic representation of the measurement configuration for in situ broadband optical monitoring.

Swept measurements typically takes a few seconds and allows to take snapshots of the TFF's IL and RL spectral characteristics during the deposition, providing a direct and accurate real-time control of the spectral characteristics of the TFF. The measured IL(λ) and RL(λ) traces can be processed using specific merit functions to adjust the deposition process in real time.

It is worth highlighting the fact that the feedback signal used in the case of broadband optical monitoring contains a lot more information than in the case of single wavelength monitoring. At a given time during the deposition, single wavelength monitoring provides a single value P(t) whereas broadband monitoring provides an IL(λ) trace that usually contains 100,000+ data points. This allows a more precise process control, ultimately leading to tighter tolerances and an improved yield.

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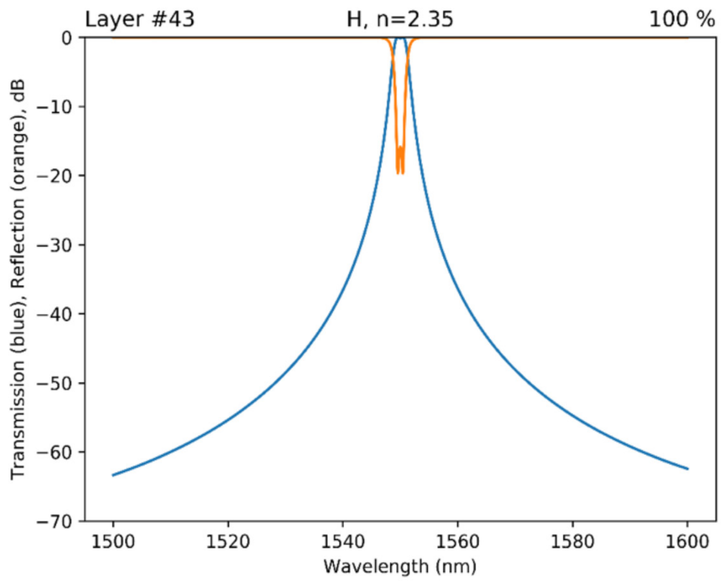

Figure 10. Simulation showing the insertion loss (blue) and return loss (orange) characteristics of the TFF as a function of wavelength at the end of the deposition. The deposition consists of 43 layers, $(HL)^5S(LH)^5L(HL)^5S(LH)^5$, where n(H)=2.35 and n(L)=1.45.

Although the CTP10 is primarily aimed at performing swept measurements together with EXFO's swept tunable lasers, the optical detectors can also measure the power as a function of time and be employed for single wavelength monitoring by setting the laser at a given wavelength.

6 Conclusion

This application note described the main challenges for TFF optical testing and how the CTP10 test platform addresses these specific requirements.

The OPM2-NS2629 module and the remote optical head were specifically developed to meet the requirements of TFF testing. With a Ø 3.7 mm clear aperture, the remote optical head provides a high-speed InGaAs photodetector while offering relaxed lateral and angular alignment tolerances thanks to the large clear aperture of the lens.

The use of optical triggering with the SCAN SYNC module also provides consistent performance even when scanning at 100 nm/s, with a ±5 pm accuracy and 1 pm resolution. In addition, the electronic design of the optical detectors provides a >70 dB dynamic range in a single scan, making it possible to measure the TFF in a single scan with best wavelength and power accuracy.

The IL RL OPM2 and FBC modules also include valuable features for TFF testing. The IL RL OPM2 module internally measures the return loss of the DUT, eliminating the need for external couplers and complex referencing procedures. The FBC module enables measurements over a broad wavelength range.

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