Measuring optical filters

Application Note

Author

Don Anderson and Michelle Archard

Agilent Technologies, Inc.
Mulgrave, Victoria 3170,
Australia

Introduction

Bandpass filters are used to isolate a narrow region of the optical spectrum. The filter's operation is based on interferometric principles and hence is angularly sensitive. Most commercial bandpass filters have full width, half max (FWHM) bandwidths of approximately 10 nm. Figure 1 illustrates some of the characteristics of interest when studying bandpass filters

Note: Applications Development Language programs, suitable for use when measuring filters, are available free of charge from your local Agilent office.

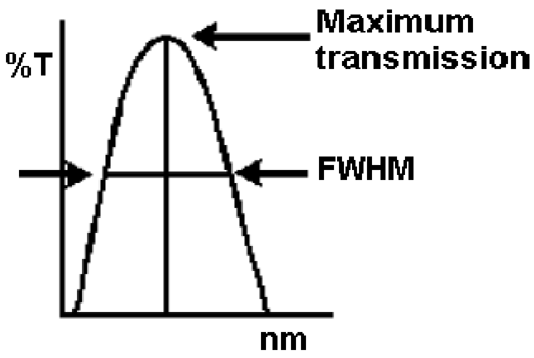

Figure 1. The FWHM is measured as the band width at half the maximum peak height

Measuring the optical characteristics of bandpass filters requires special techniques. In this study, techniques to negate the angular and polarization sensitivity of the filters were examined. The blocking capabilities of bandpass filters were measured and various instrument corrections were performed on the data.

Experimental

Instrumentation

- Cary 5 UV-Vis-NIR spectrophotometer
- Solid Sample holders
- 2 mm beam masks
- Glan Taylor polarizer
- Depolarizer

Sample types

Two different types of bandpass filters were examined. One was a very narrow filter, nominally 0.3 nm centered at 630 nm, the other, a comparatively broad filter with a FWHM of 50 nm centered at 260 nm. Both the angular sensitivity and the effects of various instrument parameters were studied.

A sharp cut filter was also used, to study the effects of polarization. A ‘sharp cut’ filter has low transmission in one region and a very sharp change to high transmission in another. They are often called ‘cut-on’/‘cut-off’ filters or ‘hot’/‘cold’ filters.

Optimum instrument parameters

Spectral Band Width

As is the usual practice with UV-VIS spectrophotometry, the Spectral Band Width (SBW) was set to less than one 10th of the expected bandwidth. This ensures the best resolution of the data. When measuring the narrow filter the SBW was set to 0.03 nm (0.04 measured). A wider SBW of 2 nm was suitable for the 50 nm bandpass filter.

The Cary 5 has an NIR ‘Fixed SBW’ mode that facilitates the measurement of NIR filters. The normal method of operation in the NIR is to keep the ‘Energy level’ (the voltage on the detector) constant while varying the spectral band width. This allows the complete dynamic range of the instrument to be used. The ‘Fixed SBW’ mode of operation reverses this and keeps the spectral band width constant while varying the Energy level. This allowed the effects of varying the spectral band width to be studied. Figure 2 illustrates the effects of changing the spectral band width.

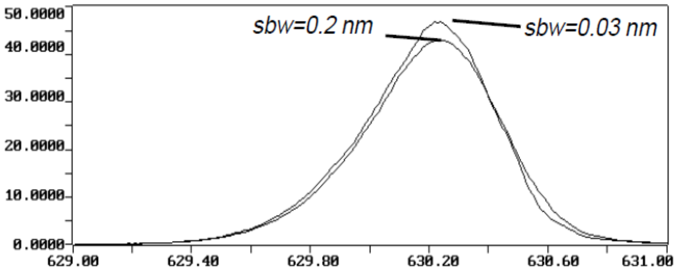

Figure 2. The spectral band width should be set to less than 1/10th of the expected natural bandwidth of the filter. Setting a wider SBW will result in peak suppression and broadening

Signal Averaging Time

The Signal Averaging Time (SAT) is the time that the instrument spends at each wavelength averaging the signal. This affects both the photometric noise associated with the measurement as well as the time it takes to collect the data. As the filters were being scanned over a very short wavelength range, the scan time was not an issue. The SAT was set to 0.1 second to provide acceptable photometric noise levels. Figures 3a and 3b illustrate the effect of changing the Signal Averaging Time.

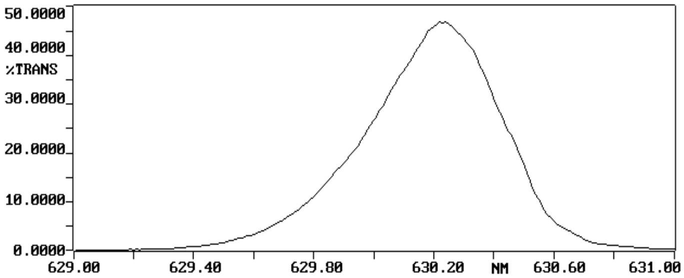

Figure 3a. The Signal Averaging Time should be selected to produce acceptable noise levels. This scan was performed with 0.1 s SAT

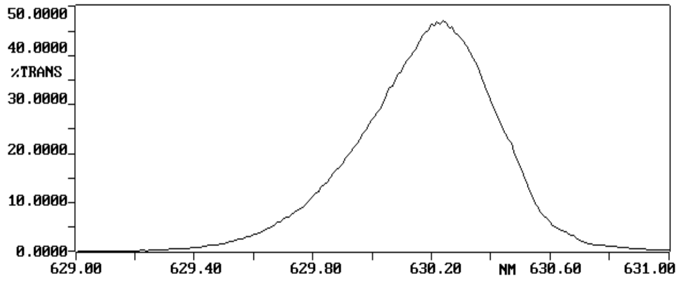

Figure 3b. The same sample, with the Signal Averaging Time set to 0.033 s

Data interval

It is recommended that the data interval be set to ensure that at least three data points are collected across each spectral band width. With the SBW set to 0.03 nm, the Data interval was set to 0.01 nm. This provided 200 data points in the 631 nm to 629 nm scan. The interval was increased to 1 nm when the 50 nm filter was measured. The effect is shown in Figure 4.

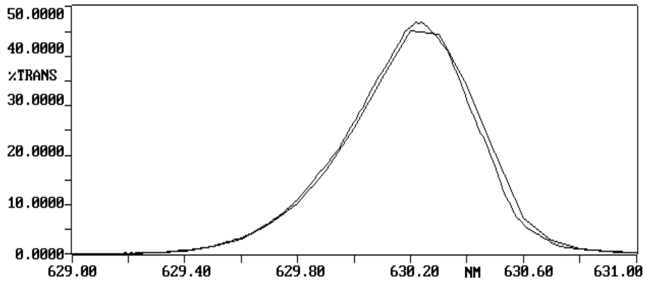

Figure 4. The Data interval should be set to less than 1/3 of the SBW. Setting too large an interval will result in poor resolution.

Angle of incidence

The centre wavelength of a bandpass filter changes with the angle of the incident radiation. As the angle increases, the peak moves to a shorter wavelength. This relationship is given by;

$\lambda\theta = \lambda_0 (n_{eff}^2 - \sin^2\theta)/n_{eff}$

Where:

$\lambda\theta$ = Peak wavelength when $\theta \neq 0$

n_{eff} = effective refractive index. This is typically in the range 1.3 to 3 (refer to manufacturer's details)

θ = Angle of incidence

λ_o=Peak wavelength when $\theta \neq 0$

In any optical system the beam must have a solid angle for there to be any flux transmitted. The result of this is that the measured profile will be broadened. This broadening becomes more significant with narrow filters; particularly when the spread in peak wavelengths due to the finite solid angle becomes comparable with the filter bandwidth.

The Cary 5 in the standard configuration has beam angles that are within ±3.2° horizontally and ±7.6° vertically. Reducing the slit height limits the vertical angles to ±5.0.

For the critical applications of very narrow band filters, (FWHM of less than 1 nm) suitable masking can be introduced to limit the solid angle further. Inserting a 5 mm aperture at the vertical grating image (50 mm after the sample compartment centre) limited the vertical angles to ±2.8°. Placing a 2 mm aperture at the vertical slit image (50 mm prior to the sample compartment centre) and at the vertical grating image (50 mm after the sample compartment center) limited the horizontal and vertical beam angles to ±0.6°. In this case suitable Rear Beam Attenuation was used to preserve the dynamic range of the instrument. The attenuation value was chosen so that the transmittance did not exceed 100 %T when a baseline was collected. In this case about 1 Absorbance (optical density) attenuation was adequate. Care was also taken in the mounting of the filter to ensure that it was not tilted.

The first set (Figures 5 to 9) of overlaid traces below show the effect of various configurations on a very narrow (nominally 0.3 nm) filter. Figure 5 is from the instrument in the standard configuration, and shows some asymmetry. Figure 6 is in the reduced slit height configuration, note the improved symmetry. Figure 7 is for reduced slit height and a 5 mm aperture placed at the vertical grating image. Figure 8 is with 2 mm apertures at the vertical slit and vertical grating images. Figure 9 shows all the scans overlaid for comparison purposes.

As the solid angle is reduced, the measured bandwidth of the filter decreases (refer to Table 1), the peak wavelength gradually moves to a longer wavelength, and the peak transmission increases. The increase in peak transmission is due to the better overlap of contributions from different angles.

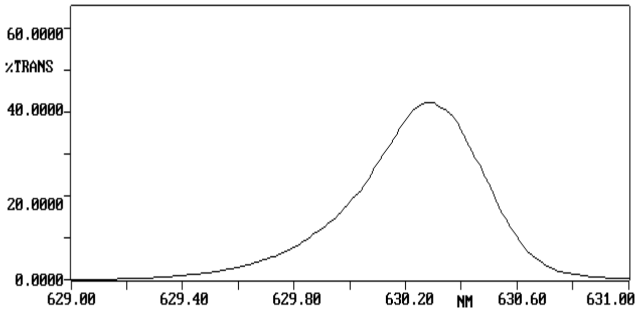

Figure 5. The 0.3 nm Bandpass filter measured with the standard configuration of the Cary 5

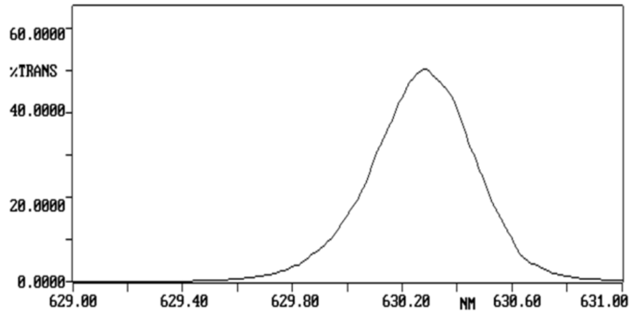

Figure 6. The 0.3 nm Bandpass filter measured with reduced slit height

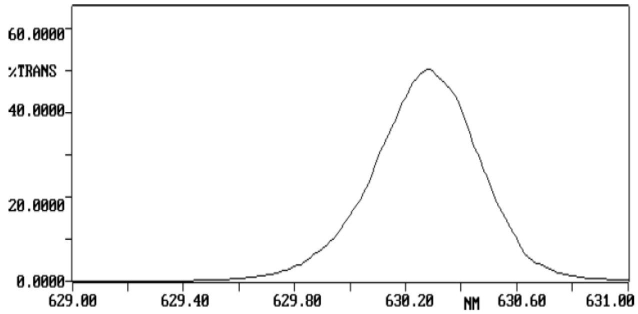

Figure 7. The 0.3 nm bandpass filter measured with reduced slit height and 5 mm apertures

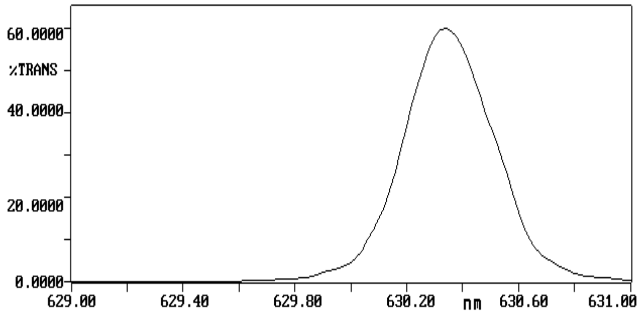

Figure 8. The 0.3 nm bandpass filter measured with 2 mm apertures

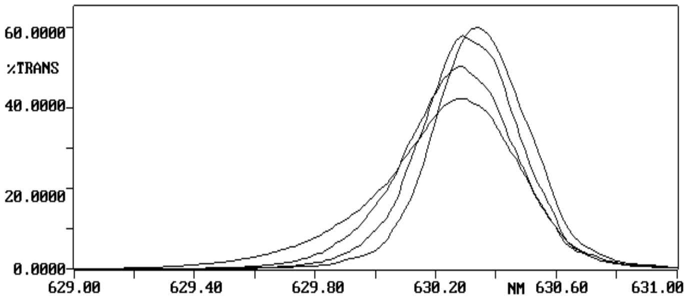

Figure 9. The 0.3 nm bandpass filter - all configurations

Table 1. The measured bandwidth for each configuration studied

Configuration	Bandwidth (nm)
Standard	0.462
Reduced height slit	0.397
Reduced height slit and 5 mm mask	0.361
2 mm masks	0.360

The second set (figures 10 to 14) of traces are for the same configurations on the relatively broad (50nm) filter. Clearly this filter is not as sensitive to the solid angle effects. There was no change in the measured FWHM of 46.93 nm.

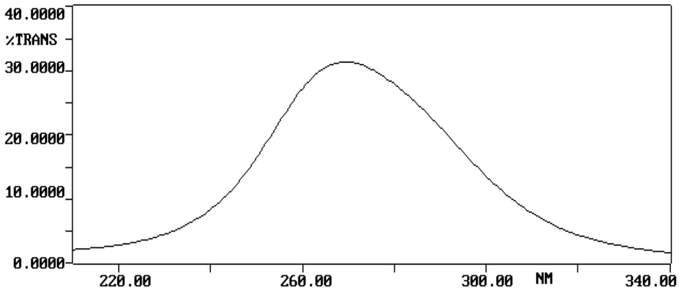

Figure 10. The 50 nm Bandpass filter measured with the standard configuration of the Cary 5

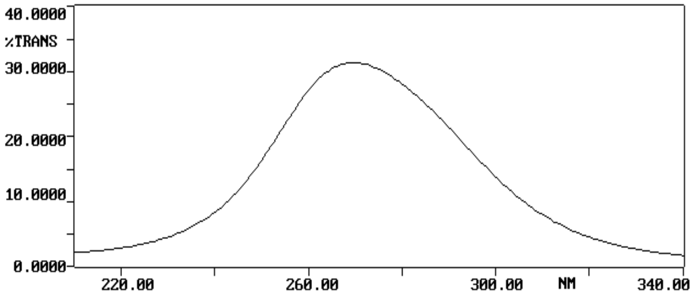

Figure 11. The 50 nm Bandpass filter measured with reduced slit height

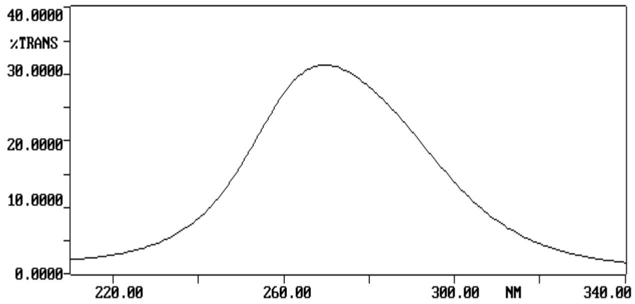

Figure 12. The 50 nm bandpass filter measured with 5 mm apertures

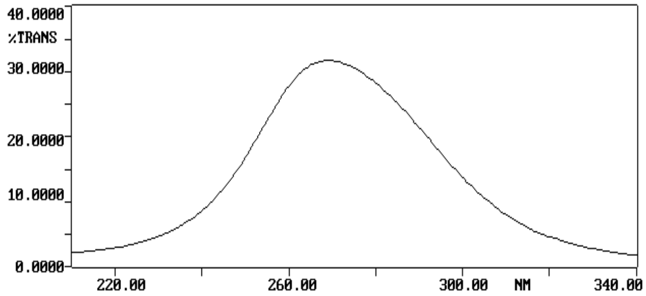

Figure 13. The 50 nm bandpass filter measured with 2 mm apertures

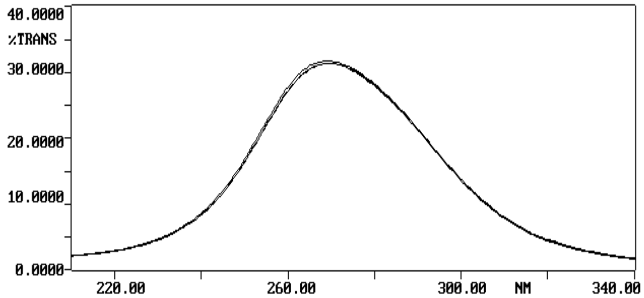

Figure 14. The 50 nm bandpass filter - all configurations

Blocking

The 'Blocking' capability of a filter is a measure of the transmission outside the bandpass region (out-of-band leakage). This should be very low, so that the only light that the filter transmits is that of the required wavelengths.

In general a second scan will be performed over a wide wavelength range to assess the blocking capabilities. Often the transmission values will be very small. To highlight small values and compress peak transmittance values so that all points remain on the plot, the scan should be plotted on a logarithmic scale - Absorbance (Optical Density) is the norm.

The instrument stray light level directly effects the measurement of out-of-band leakage. The amount of stray light present determines the maximum absorbance that can be measured. Many applications require blocking levels in the range of 10^{-6} T or 6 absorbance units.

The two scans shown in figures 15 and 16 are of the two bandpass filters. The narrow bandwidth filter has blocking of approximately 5 Abs (0.001 % T). The broader filter had poorer blocking capabilities. As both filters were to be used in applications where the detector is a photomultiplier, the upper wavelength was set to 800 nm. The filters could have been scanned up to 3300 nm if they were to be used in photodiode/NIR detector applications.

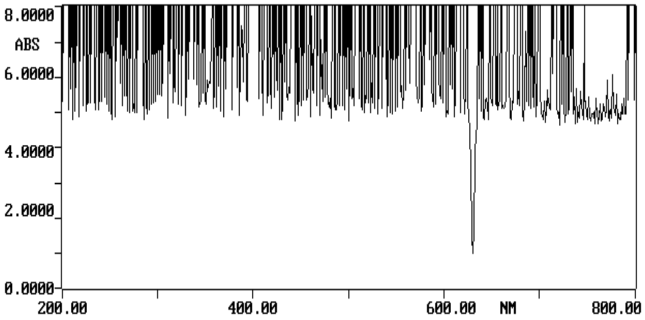

Figure 15. The blocking capability of the 0.3 nm bandpass filter

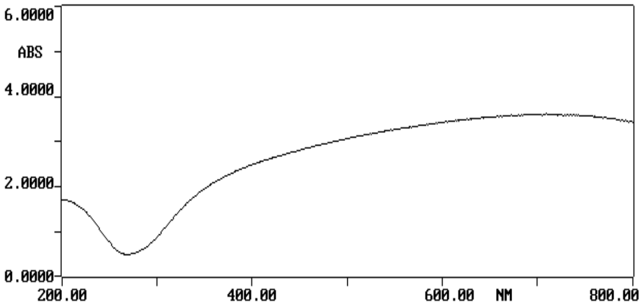

Figure 16. The blocking capability of the 50 nm bandpass filter

Polarization

The optical characteristics of many filters are affected by the plane polarization of the incident light. Figure 18 illustrates the effects that plane polarized light can have on filter measurements.

The 'step' at the detector change (800 nm) is due to the change in polarization of the incident light as the grating changes from the UV-Vis to the NIR. To remove this effect a depolarizer was placed before the filter. The depolarizer changed the plane polarized light exiting the monochromator into randomly polarized light, before it reached the sample. Figure 17 shows the data collected with the depolarizer in place.

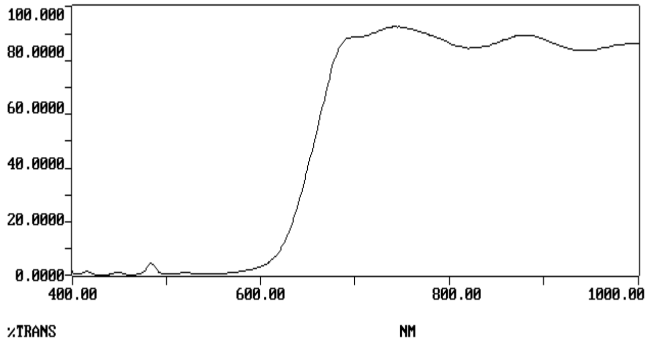

Figure 17. Measuring a sharp-cut filter with a depolarizer prior to the filter eliminates any change in %T at the grating/detector change point

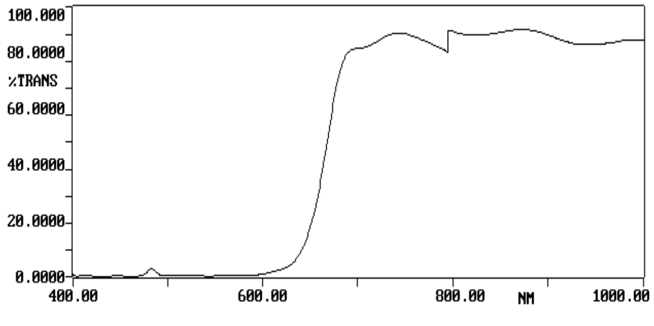

Figure 18. Measuring a filter which is sensitive to the plane polarization of the incident light results in a different response when the grating is changed (800 nm)

Data corrections

When measuring very low transmission levels it is important to consider the intrinsic electronic and optical errors associated with the measurement and correct for these The Cary instruments typically have a zero transmission level of approximately 0.000005 T.

The American Society for Testing and Materials (ASTM) have published[1] a method for the correction of "Solar absorptance, reflectance and transmittance of materials using integrating spheres" which can also be applied to transmission measurements performed without an integrating sphere. The correction is in the form:

$T(\lambda) = (S_\lambda - Z_\lambda)/(100_\lambda - Z_\lambda)$

Where:

S_λ = the signal recorded with the sample in place

Z_λ = the zero line reading, with the sample beam blocked

100_λ = the 100% line reading with no sample

To perform these corrections, the following measurements were performed over the wavelength range of interest:

1. A scan with nothing in the sample beam
2. A scan with the sample beam blocked with a piece of black painted sheet metal
3. A scan with the filter in place

Each scan was performed without baseline correction as the ASTM correction is inherently a baseline correction. In a batch measurement situation the first two scans would be only performed at the start of the measurement session.

The correction was then performed using an ADL program written for the purpose. Figure 19 shows the difference between the uncorrected and the corrected data. Most of the error was introduced by the zero line, which caused the uncorrected data to have higher transmission than actual.

This correction can be easily performed after each scan and the corrected data stored for later use.

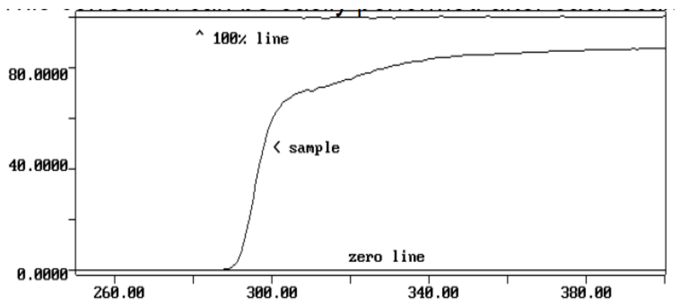

Figure 19. ASTM method E903 was used to correct the data for the 100% and zero line errors

Discussion

The measurement of optical filters requires consideration of the optical effects of the incident light. This study found that several techniques can be employed to improve the accuracy of such measurements, including;

- Beam masking to reduce the solid angle
- Selection of optimum instrument parameters
- Instrument considerations when determining the blocking capabilities of bandpass filters
- The use of depolarizers
- The correction of data for instrumental errors

The use of a high performance spectrophotometer with flexible parameter settings and excellent optical performance was also highlighted.

References

1. ASTM Standards on Color and Appearance measurement, American Society for Testing and Materials, Philadelphia, **1987**

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www.agilent.com/chem

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