# Selecting interference filters for optical applications

Optical interference filters are specialist devices that allow the transmission of a selected wavelength, or range of wavelengths, whilst ensuring non-selected wavelengths do not pass through. These filters are precise, yet affordable, making them ideal for a range of applications from academic research to commercial engineering.

**Types of interference filter**

There are several types of interference filters available, all of which require expert thin-film production and complex instrumentation to build. The type of filter you select will depend on the requirements of your application. All interference filters are useful where a particular wavelength needs to be selected, and are often more efficient and cost effective than other devices such as monochromators for a specific wavelength selection requirement.

**Bandpass filters** – this filter is designed to pass pre-selected frequencies of a certain range, and to block those that are not selected. The width of these filters is normally categorised by the wavelength range they allow, and most common bandpass filters cover the 330nm to 1650nm range. These filters are commonly used in spectral analysis where the target wavelength is already well defined.

**Broadband filters** – these allow for a wider range of wavelengths, typically operating at around 450nm to 700nm. These filters are usually very stable and used in telecommunications and military applications.

**Long pass filters** – these filters transmit longer wavelengths and reject shorter wavelengths. The sharp slope in the transition between to 50% cut-off or cut-on to rejection in these Long Pass filters has also given them the name of 'Edge filters' and they are popular for use in fluorescence microscopy.

**Short pass filters** – letting through shorter wavelengths and rejecting longer wavelengths, the Short Pass filter has similar characteristics to the Long Pass filter but works in reverse where wavelengths are concerned.

**Laser line filters** – designed for use with laser light sources, these filters eliminate unwanted radiation from monochromatic light. Typically, these filters are used with Helium-Cadmium, Helium Neon, Argon, Nd:YAG and DPSS lasers.
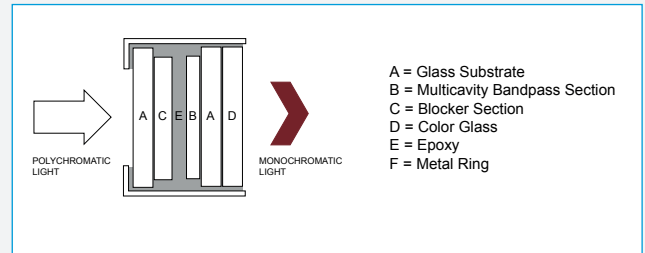


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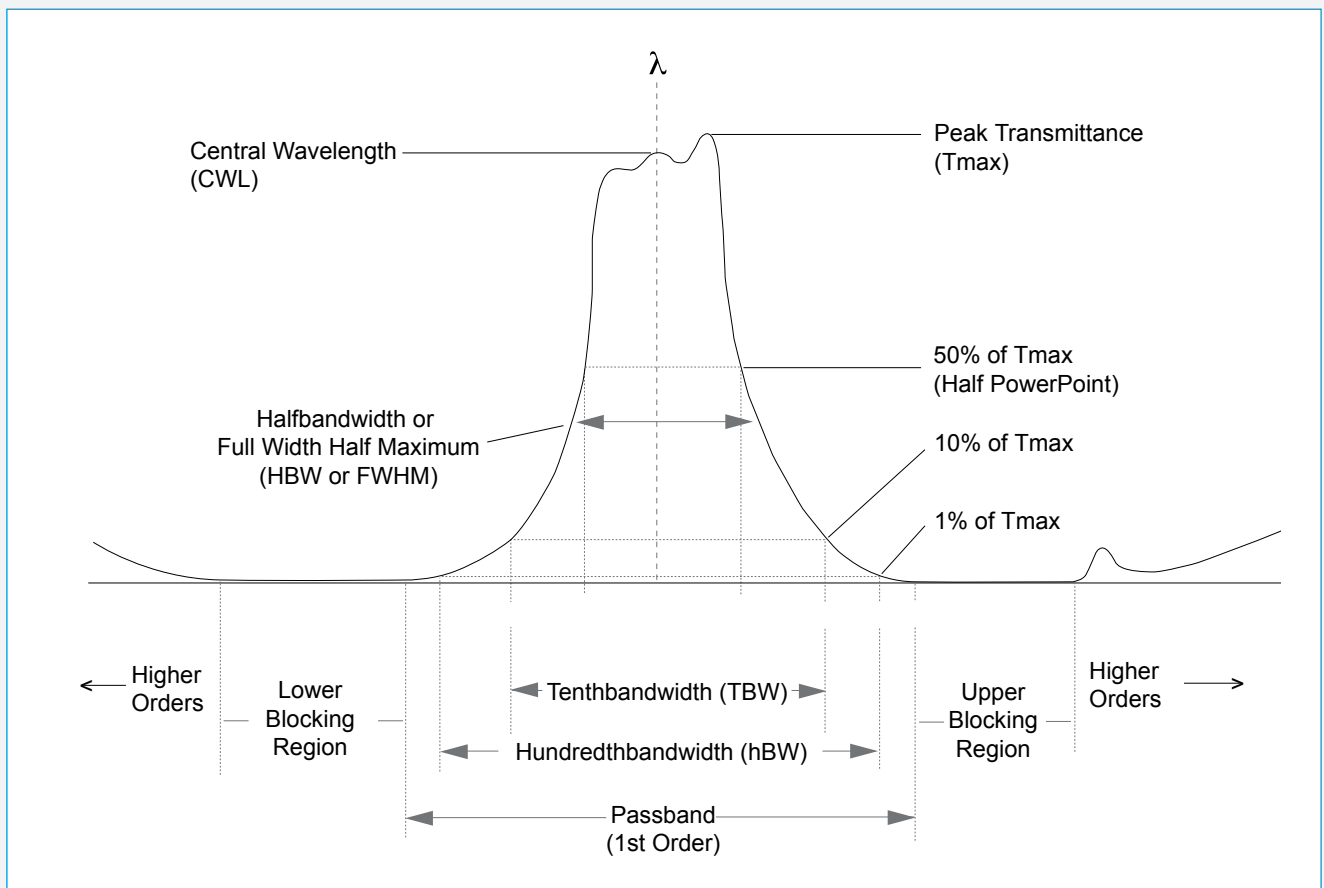
# Design and fabrication

Interference filters are traditionally designed as a range so that customers can choose the filter that meets their requirements in terms of wavelength selection and performance. They can be custom-designed but in the majority of cases this is unnecessary as the standard range will meet most needs.

Three main elements make up the fabrication of optical interference filters. The first determines the central wavelength, the half-bandwidth and the shape of the transmittance curve – known as the passband. The second and third control the degree and range of wavelength blocking outside the passband. Sections are built up by repeated deposits of thin layer material onto polished glass substrate. Each layer is precisely controlled in terms of thickness and where it is deposited. A stack of layers is created by alternating dielectric materials of high and low refractive indices.

Spacer layers are formed by depositing a half wave layer between symmetric stacks, forming the cavity which is the central element of the filter. The number of cavities determines the transmittance curve. Metallic blockers are added to reject non-selected wavelengths and are enhanced by coloured glass and custom dyes which absorb additional long wavelength or UV radiation.



POLYCHROMATIC LIGHT

A C E B A D

MONOCHROMATIC LIGHT

A = Glass Substrate
B = Multicavity Bandpass Section
C = Blocker Section
D = Color Glass
E = Epoxy
F = Metal Ring

*Typical interference filter*



λ

Central Wavelength (CWL)

Peak Transmittance (Tmax)

50% of Tmax (Half PowerPoint)

10% of Tmax

1% of Tmax

Halfbandwidth or Full Width Half Maximum (HBW or FWHM)

Higher Orders

Lower Blocking Region

Tenthbandwidth (TBW)

Upper Blocking Region

Higher Orders

Hundredthbandwidth (hBW)

Passband (1st Order)

*Interference filter terminology*

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# Choosing and using interference filters

Several considerations influence the selection of interference filters. These include the wavelength you want to select, the application you will use the filter for and your budget. Always talk to filter experts to see what ranges are available and which might work best for your requirements. You will also need to ensure you use the filter properly and pay particular attention to:

### Temperature
High temperatures can have a detrimental effect on these filters, expanding or contracting the layers. Manufacturers suggest that prolonged exposure to temperatures above 75°C will set the central wavelength lower and this is not reversible.

At the other end of the temperature scale, filters should be allowed to cool no faster than 5°C per minute, as cooling faster than this can cause the substrate to crack or the filter to delaminate. Interference filters can perform at temperatures down to -50°C provided the cooling rate is managed.

### Angle of incidence
The light source, which should be collimated radiation, should always be perpendicular to the surface of the filter. Large deviations – more than three degrees – will shift the waveband, causing a decrease in transmittance and a change to the passband shape. The same is likely to happen if a non-collimated radiation source is used.

### Orientation
Whilst these filters will function with any side facing the light source, they will perform better if the most reflective surface is facing the source. This is because the surface will reduce the thermal effect from any absorption of heat by the coloured glass or dyes on the reverse of the filter.

# Life time

Interference filters are subject to environmental deterioration due to moisture penetration of the hygroscopic dielectric layers. Though the bandpass and blocking sections of interference filters are laminated with epoxy, a high humidity environment can cause delamination.

A process known as scribing results in excellent moisture protection. Scribing removes all dielectric material from the periphery of a filter, allowing a glass-to-glass epoxy seal that minimizes moisture penetration. While most filters are also sealed in a metal ring, the primary purpose of the ring is to protect the filter from physical damage, particularly the relatively soft color glass.

So called hard coating technologies (with very high density) have also been developed to minimize the sensitivity to humidity. Understanding the environmental operating conditions is a very important parameter when selecting an interference filter, our team will guide you to make the best choice.



Glass Substate
High Index Dielectric (1/4)
Low Index Dielectric (1/4)
Color Glass
Epoxy
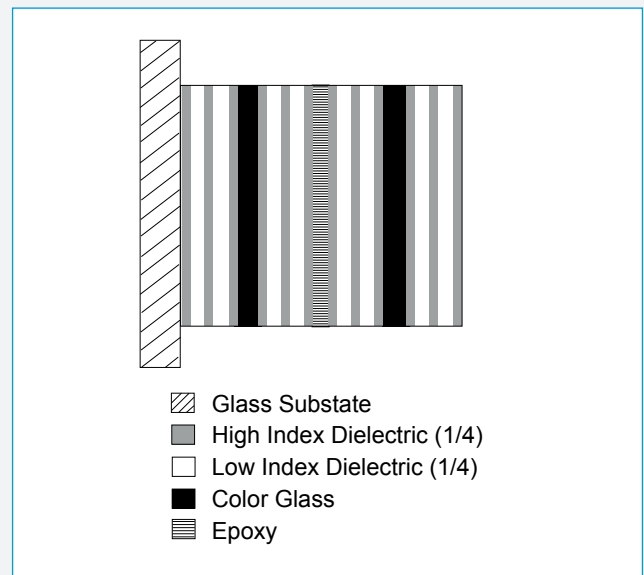
*Multi cavity bandpass section.*

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# Integrated blocking

Blocking refers to the degree to which transmitted radiation outside the filter passband is restricted. A blocking specification should state the wavelength range over which it is measured. Both the degree and range of blocking required are application dependent. Too little blocking will result in unacceptable stray light (high noise); too much will decrease throughput (low signal) and increase costs. Blocking is one of the most important specifications to be considered when selecting an interference filter.

Blocking is sometimes defined in "absolute" terms, which refers to the ratio of the largest peak outside the passband to the peak within the passband. Absolute blocking does not measure the total radiation (energy) outside the passband and has little meaning in spectroscopy, where all radiation outside the passband is considered stray light.

Integrated blocking is a more useful way to define blocking. It is the ratio of the total radiation (energy) outside the passband to the total radiation within the passband. For an integrated blocking value to be meaningful, the conditions under which the filter is to be used must be known. For example, the integrated blocking value of a 340 nm filter in an optical system with a UV source and photomultiplier will be considerably better than the same filter used with a tungsten lamp and silicon photodiode. The spectral response of a UV source and PMT detector system may overlap from about 200 nm to 400 nm, with considerable energy and detector sensitivity at 340 nm (high signal). Under these conditions, radiation detected through the filter outside the passband (stray light) is limited by both source and detector and can be easily controlled by standard blocking. If, however, the same 340 nm filter is used with another source and detector, stray light could be a problem and additional blocking may be required. The spectral response of a tungsten source and a silicon photodiode detector system may overlap from about 320 nm to 1100 nm, but with very little source energy or detector sensitivity at 340 nm (low signal). These conditions require that the filter have additional blocking to compensate for the source radiation and detector sensitivity from 400 nm to 1000 nm (ultra low noise).

Several equivalent notations are used by various manufacturers to specify blocking including absorbance, optical density, transmittance, scientific notation, rejection ratio and signal-to-noise ratio. It is important to understand the meaning of the blocking specification and the way it is defined by the manufacturer.

The requirement is very much application driven. As an example, for spectroscopic applications, the degree of blocking should be consistent with the sample being used. Integrated blocking to 0.1%T (standard performance filter) will not cause an appreciable error with a low absorbing sample. For a highly absorbing sample (Abs $\geq$ 2.0), the 0.1% stray light would be 10% of the total transmitted signal, grossly affecting the accuracy of an assay. Therefore, a high performance filter is required, where integrated blocking is 0.01%T.

## Expert help from Acal BFi

At Acal BFi we have an expert optical team that can help you to select and source the best interference filters for your application. With close links to manufacturers, an in-depth understanding of the technology and the ability to respond quickly to your requirements, we provide a valuable service before, during and after the selection and buying process.

To find out more, or ask us a specific question about interference filters, please get in touch today.

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# Appendix A
# Definitions and terminology[*]

**Absolute Blocking:**
The ratio of the largest peak outside the passband to the peak within the passband. Expressed as an area or %T.

**Absorbance:**
The logarithmic function of transmittance. Sometimes used to express the degree of blocking. A = log(Iø/I). Also known as Optical Density (OD).

**Angle of Incidence:**
The angle formed by radiation arriving (incident) at the filter surface and the perpendicular to the surface at the point of arrival.

**Bandwidth:**
Specified wavelength interval of transmitted radiation.

**Blocking:**
The degree to which detectable radiation outside the passband is rejected. Expressed as transmittance, absorbance, optical density, scientific notation, signal-to-noise or rejection ratio. Blocking requirements are specified over a useful wavelength range.

**Cavity:**
Basic component of an interference filter consisting of two layers of reflective stacks separated by a spacer layer. Also known as a Period.

**Clear Aperture (CA):**
The central, usable area of a filter through which radiation can be transmitted.

**Central Wavelength (CWL):**
The mean of the two wavelengths corresponding to the half power points.

**Half Power Points:**
Points on both sides of the passband curve of a filter, with a value 50% of the peak transmittance. Used to calculate HBW and CWL.

**Half Bandwidth (HBW):**
The wavelength interval of the passband measured at the half power points (50% of peak transmittance). Expressed as halfbandwidth (HBW), full width half maximum (FWHM) or half power bandwidth (HPBW).

**Incident Radiation (Iø):**
The radiation, usually polychromatic, that impinges on a filter.

**Interference Filter:**
A filter that, operating on the principles of constructive and destructive interference, transmits radiation in a discrete, narrow wavelength range while rejecting other radiation. Also known as a bandpass filter.

**Integrated Blocking:**
The ratio of the total transmitted radiation (energy) outside the passband to the total transmitted radiation within the passband. Integrated blocking is influenced by the source output and detector response as functions of wavelength.

**Passband:**
A wavelength interval through which incident radiation is transmitted. The first order passband is at the filter design wavelength.

**Peak Transmittance:**
The highest transmittance value of a filter.

**Peak Wavelength:**
The wavelength at which a filter has its peak (highest) transmittance.

**Rejection Ratio:**
The ratio of the maximum transmittance outside the passband to the total transmittance within the passband.

**Signal to Noise Ratio (S/N):**
The ratio of detected energy transmitted through the passband to the detected energy transmitted outside the passband. It is source and detector dependent.

**Stray Light:**
Unwanted energy transmitted through the filter.

**Transmittance (Tx):**
The ratio of the transmitted radiation to the incident radiation, expressed as a percent. %T = I/Iø x 100.

**Transmitted Radiation (I):**
Radiation passing through a filter, either inside or outside the passband.

*Courtesy of Optometrics Corporation*

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## Appendix B
## Common wavelengths / applications

193 nm – Excimer laser line
248 nm – Excimer laser line
266 nm – Frequency quadrupled Nd:YAG
334 nm - Mercury Emission Line
337 nm - N2 Laser Line
340 nm - NAD/NADH, NADP/NADPH Chemistries
351 nm – Excimer laser line
355 nm – Frequency tripled Nd:YAG
365 nm- Hg Emission Line
394 nm - S Emission Line
400 nm - Clinical Chemistry, Phosphate
405 nm - Hg Emission Line, Alkaline Phosphatase,
　　　　　Acid Phosphatase, GGT, Amylase
410 nm - H Emission Line, Cholinesterase, Silica
415 nm - Ar Emission Line, Clinical Chemistry
420 nm - Ar Emission Line, Ammonia
430 nm - Ar Emission Line
436 nm - Hg Emission Line
442 nm - HeCd Laser Line
450 nm - He Emission Line, Nickel, Clinical Chemistry
455 nm - Cs Emission Line
458 nm - Ar Laser Line, Chloride, Copper, Hydrazine
467 nm - Xe Emission Line, Chloride
470 nm - Cd Emission Line
480 nm - Cd Emission Line
486 nm - H Emission Line
488 nm - Ar Laser Line or DPSS lasers
492 nm - Clinical Chemistry
500 nm - He Emission Line, Cholesterol, Glucose,
　　　　　Phenol, Triglycerides
505 nm - He Emission Line
508 nm - Cd Emission Line
510 nm - Creatinine, Water Analysis, Iron,
　　　　　Co Emission Line
515 nm - Ar Laser Line
520 nm - Barium, Triglycerides, Magnesium, Uric Acid,
　　　　　Cholesterol
532 nm - Frequency Doubled, Nd: YAG Laser Line
535 nm - Ti Emission Line
540 nm - Total Protein, Ne Emission Line
546 nm - Hg Emission Line

550 nm - Bilirubin
568 nm - Kr Laser Line, Calcium
580 nm - Hg Emission Line, Cyanide
589 nm - Na, He Emission Lines
600 nm - BUN-Colorimetric, Serum Iron, UIBC
610 nm - Water Analysis
620 nm - Calcium, Albumin
632/633 nm - HeNe Laser Line
636 nm - Zn Emission Line
640 nm - Ne Emission Line
647 nm - Kr Laser Line
650 nm - Calcium, Total Phosphates
656 nm - H Emission Line
671 nm - Lithium, Laser Diode
676 nm - Kr Laser Line
690 nm - Clinical Chemistry, Hg, O2 Emission Lines
694 nm - Ruby Laser
730 nm - GaAlAs Laser Diode
766 nm - Potassium
780 nm - GaAlAs Laser Diode
800 nm - Ar Emission Line
830 nm - GaAlAs Laser Diode
852 nm - Cs Emission Line
855 nm - GaAlAs Laser Diode
880 nm - GaAlAs Laser Diode
905 nm - GaAs Laser Diode
940 nm - GaAs Laser Diode
1064 nm - Nd: YAG Laser Line
1100 nm - Clinical Chemistry
1150 nm - Clinical Chemistry
1200 nm - Clinical Chemistry
1250 nm - Clinical Chemistry
1300 nm - Laser Diode Cleanup
1350 nm - Clinical Chemistry
1400 nm - Clinical Chemistry
1450 nm - Clinical Chemistry
1500 nm - Clinical Chemistry
1550 nm - Laser Diode Cleanup
1600 nm - Clinical Chemistry
1650 nm - Clinical Chemistry

*Courtesy of Optometrics Corporation.

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