ENVIROMENTAL FACTORS

Temperature

Most Oriel Band Pass Interference Filters are designed to operate from -50°C to +80°C; they may be operated intermittently to 100°C. The rate of temperature change should not exceed 10°C/minute. At 120°C or above, permanent changes and possible destruction can occur.

Apart from irreversible changes at high temperatures, the most noticeable temperature effect is the variation of central wavelength. At increased temperature, the central wavelength increases. This wavelength change is almost linear between -60°C and +60°C with values between 0.01 and 0.03 nm/°C; above 120°C, the change in central wavelength may be irreversible. There are also very slight changes in bandwidth (about 0.001 nm/°C) and peak transmittance (about 0.01%T/°C) with increasing temperature.

Humidity

All Oriel ultraviolet and near infrared Band Pass Interference Filters are edge sealed as a barrier to environmental moisture. We test our filters to MIL-STD-810C method 507, procedure 1. This test consists of placing the filter in an environmental test chamber and cycling the temperature and humidity over a 24 hour period. Each 24 hour time period is termed a cycle, and the number of cycles to which it is tested, is specified for each filter type. After the completion of the test, the filter is inspected for spectral performance and physical damage.

Other Oriel multi-layer filter products such as long and short pass filters comply with the slightly less stringent MIL-C-675A (para. 4, 6 and 9) Temperature and Humidity Specification. This test consists of placing the test sample in an environmental chamber for 24 hours at 95% relative humidity and at 50°C. Then the filter is inspected for spectral performance and physical damage.

Some infrared interference filters have extremely hard and durable coatings. These coatings are unaffected by ambient humidity and are left exposed to the atmosphere. These coatings also meet the requirements of MIL-STD-810C method 507, procedure 1.

Filter Orientation

Most band pass interference filters are constructed using some type of auxiliary absorptive blocking filters. Each side of the filter has a distinctly different appearance. One side will be highly mirrored while the other side will be colored (opaque or anywhere from deep violet to deep red).

Always orient the band pass filter so the highly mirrored side is facing the source of radiation. Most of the rejected radiation is reflected and does not heat the internal components of the filter.

Angle of Incidence

Filter specifications are usually given for collimated radiation incident normal to the filter surface. In many applications, collimated, normal incidence radiation is not practical or even possible. You can, however, estimate the results of using off-normal incident radiation.

Band pass interference filters are composed of a series of layers of precisely controlled thicknesses of dielectrics and metals. Changing the angle of incidence increases the apparent thickness of these layers. However, the phase difference between the interfering waves decreases as angle increases. The effects of off-normal radiation are three fold; there is a decrease in the central wavelength; the transmittance decreases and the bandwidth increases; for off-normal angles less than 25°, the effect on transmittance and bandwidth are minimal. The shift in central wavelength with angle of incidence can be used to precisely “tune” a narrow band filter.

The decrease in central wavelength is a function of the refractive indices of the deposited films and the angle of incidence. The effective refractive index, n*, of the filter, is used to simplify the relational formula. For collimated radiation incident at angle θ, where θ < 25:

\[ \lambda_i = \lambda_0 \left[ 1 - \left( \frac{n_0}{n^*} \right)^2 \sin^2 \theta \right]^{1/2} \] .............(6)

Where:

\[ \lambda_i = \text{Central wavelength at angle of incidence } \theta \]
\[ \lambda_0 = \text{Central wavelength at normal incidence} \quad (\theta = 0) \]
\[ n_0 = \text{Refractive index of the medium surrounding the filter} \]
\[ n^* = \text{Effective refractive index for the filter} \]

Fig. 9 Approximate wavelength shift with angle of incidence for the n* values of our interference filters.
For typical visible and near infrared band pass interference filters (400 - 1100 nm), the experimental values of \( n^* \) have been found to be 2.0 for high index spacer layers, and 1.45 for low index spacer layers.

When the angle of incidence is large, > 30°, the spectral pass band characteristics of the filter can be so degraded as to yield two distinct peaks and transmittance becomes dependent on polarization.

Table 3 lists multiplying factors for off-normal collimated incident radiation. To find the new central wavelength at an off-normal angle, simply multiply the wavelength at normal incidence by the appropriate factor for that angle.

**Table 3** Multiplying Factors for Off-normal Collimated Light

<table>
<thead>
<tr>
<th>Angle (degrees)</th>
<th>High Index Spacer Layer (( n^* = 2 ))</th>
<th>Low Index Spacer Layer (( n^* = 1.45 ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>0.5</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>1.0</td>
<td>0.9999</td>
<td>0.9999</td>
</tr>
<tr>
<td>2.0</td>
<td>0.9997</td>
<td>0.9994</td>
</tr>
<tr>
<td>3.0</td>
<td>0.9994</td>
<td>0.9998</td>
</tr>
<tr>
<td>4.0</td>
<td>0.9991</td>
<td>0.9982</td>
</tr>
<tr>
<td>5.0</td>
<td>0.9979</td>
<td>0.9959</td>
</tr>
<tr>
<td>7.5</td>
<td>0.9962</td>
<td>0.9928</td>
</tr>
<tr>
<td>10.0</td>
<td>0.9916</td>
<td>0.9839</td>
</tr>
<tr>
<td>15.0</td>
<td>0.9853</td>
<td>0.9718</td>
</tr>
<tr>
<td>20.0</td>
<td>0.9774</td>
<td>0.9566</td>
</tr>
<tr>
<td>25.0</td>
<td>0.9683</td>
<td>0.9387</td>
</tr>
<tr>
<td>30.0</td>
<td>0.9623</td>
<td>0.9228</td>
</tr>
</tbody>
</table>

**Divergent or Convergent Incident Radiation**

A diverging or converging beam incident on a filter means a spread of incident angles. The result is a broadening of the apparent band pass and a shift to lower wavelengths. Since the transmittance is angle dependent, the beam which passes the filter will have a slight angular wavelength dependence.

The change in center wavelength can be obtained by using the half cone angle in equation (6), on the previous page.

For solid cone angles to 20°, the change will be about half of that calculated. Band pass interference filters with bandwidths of less than 3.0 nm have negligible center wavelength changes with convergent or divergent beams with up to 5° full cone angle (F/11).

**FILTERS AND MONOCHROMATORS**

**A Monochromator or an Interference Filter?**

For maximum throughput efficiency with a monochromator, the F/# of the input optics must match that of the monochromator. This puts a fundamental limit on the demagnification of a source to try to get as much light as possible through the slit. An interference filter, on the other hand, has a large acceptance aperture and can have transmission in the range of 50 - 60%. With extended (large) sources, an interference filter can have up to 500 times greater throughput than a monochromator.

**A Monochromator Used With an Interference Filter**

Interference filters are effective in reducing the stray light accompanying the output from a fixed wavelength grating monochromator. If a high intensity continuous source is used, the filter should be placed between the exit slit and the detector to reduce the thermal load on the filter.

\[\text{TRANSMITTANCE (\%)}\]

\[\text{WAVELENGTH (nm)}\]

Fig. 10 530 nm center wavelength filter at normal incidence and at -20°.
INTERFERENCE FILTER TRANSMISSION/REJECTION

With an interference filter, it is very common to think of the ratio of peak transmission to blocking as a system signal to noise ratio. This assumption can lead to very serious errors. In order to obtain a true system signal to noise ratio, the spectral power distribution of the source and response of the detector must be considered as well as the peak transmission, bandwidth, band shape and blocking of the interference filter.

For example, consider the use of an interference filter with a central wavelength of 400 nm, a bandwidth of 10 nm, a peak transmission of 40% and blocking of 0.01% from X-ray to the far infrared in a system which has a tungsten light source and a silicon photodetector. With a typical tungsten source, the intensity in the 1000 nm region can be up to 100 times that at 400 nm. Additionally, the silicon photodetector can have 3 to 5 times as much response in the 800 to 1000 nm region as at 400 nm. If the combination of interference filter, light source and detector described above were to be used in a 400 nm absorbance photometer, the result would probably be misleading.

To obtain a good indication of the real signal to noise ratio in such a system, make a signal measurement with the 400 nm interference filter, light source and detector in place. Then place a sharp cut-on colored glass filter in series with the interference filter and take a measurement. The colored glass filter will absorb the signal at 400 nm leaving most of the “noise” component.

A simple way to improve a system signal to noise ratio is to use two filters in series. The second filter could be a colored glass to eliminate most of the visible and near infrared, or the same type of interference filter.

A near worst case measurement with 53810 Filters (10 nm bandpass at 420 nm), a tungsten halogen source (3200 K) and a silicon detector gave the results below. A 470 nm long pass filter was used to block all the light coming through the filter bandpass to record the leakage signal.

<table>
<thead>
<tr>
<th>Relative Signals</th>
<th>Single Filter</th>
<th>Two Filters</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 - 1100° nm</td>
<td>100</td>
<td>47.5</td>
</tr>
<tr>
<td>Leakage Signal above 480 nm</td>
<td>3 x 10⁻⁵</td>
<td>&lt;1 x 10⁻⁸</td>
</tr>
</tbody>
</table>

* Most of this signal is in the 400 - 440 nm transmitting region of the filter.

Contact us for further information on any of the products in this catalog.