Technical Information:

Filter Spectra at Non-normal Angles of Incidence

Many of the filters in this catalog (with the exception of dichroic beamsplitters and the MaxMirror®) are optimized for use with light at or near normal incidence. However, for some applications it is desirable to understand how the spectral properties change for a non-zero angle of incidence (AOI).

There are two main effects exhibited by the filter spectrum as the angle is increased from normal:

1. the features of the spectrum shift to shorter wavelengths;
2. two distinct spectra emerge – one for s-polarized light and one for p-polarized light.

As an example, the graph at the right (Figure A) shows a series of spectra derived from a typical RazorEdge long-wave-pass (LWP) filter design. Because the designs are so similar for all of the RazorEdge filters in the series, the set of curves in the graph can be applied approximately to any of the filters. Here the wavelength λ is compared to the wavelength λ_0 of a particular spectral feature (in this case the edge location) at normal incidence. As can be seen from the spectral curves, as the angle is increased from normal incidence the filter edge shifts toward shorter wavelengths and the edges associated with s- and p-polarized light shift by different amounts. For LWP filters, the edge associated with p-polarized light shifts more than the edge associated with s-polarized light, whereas for short-wave-pass (SWP) filters the opposite is true. Because of this polarization splitting, the spectrum for unpolarized light demonstrates a “shelf” near the 50% transmission point when the splitting significantly exceeds the edge steepness. However, the edge steepness for polarized light remains very high.

The shift of almost any spectral feature can be approximately quantified by a simple model of the wavelength λ of the feature vs. angle of incidence θ, given by the equation:

$$\lambda(\theta) = \lambda_0 \sqrt{1 - (\sin\theta / n_{eff})^2}$$

where n_{eff} is called the effective index of refraction, and λ_0 is the wavelength of the spectral feature of interest at normal incidence. Different shifts that occur for different spectral features and different filters are described by a different effective index. For the RazorEdge example above, the shift of the 90% transmission point on the edge is described by this equation with $n_{eff} = 2.08$ and 1.62 for s- and p-polarized light, respectively. More details...

Other types of filters don’t necessarily exhibit such a marked difference in the shift of features for s- and p-polarized light. For example, the middle graph, as shown in Figure B, shows a series of spectra derived from a typical MaxLine laser-line filter design curve. As the angle is increased from normal incidence, the center wavelength shifts toward shorter wavelengths and the bandwidth broadens slightly for p-polarized light while narrowing for s-polarized light. The center wavelength shifts are described by the above equation with $n_{eff} = 2.19$ and 2.13 for s- and p-polarized light, respectively. The most striking feature is the decrease in transmission for s-polarized light, whereas the transmission remains quite high for p-polarized light. More details...

As another example, the graph, as shown in Figure C, at the bottom shows a series of spectra derived from a typical StopLine notch filter design curve. As the angle is increased from normal incidence, the notch center wavelength shifts to shorter wavelengths, the notch depth decreases, and the notch bandwidth decreases (with a greater decrease for p-polarized light than for s-polarized light). The shift of the notch center wavelength is described by the above equation with $n_{eff} = 1.76$ for both s- and p-polarized light. Note that it is possible to optimize the design of a notch filter to have a very deep notch even at a 45° angle of incidence. More details...

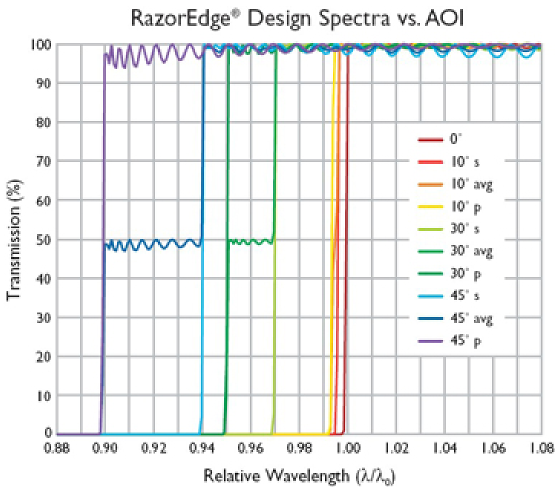

Figure A

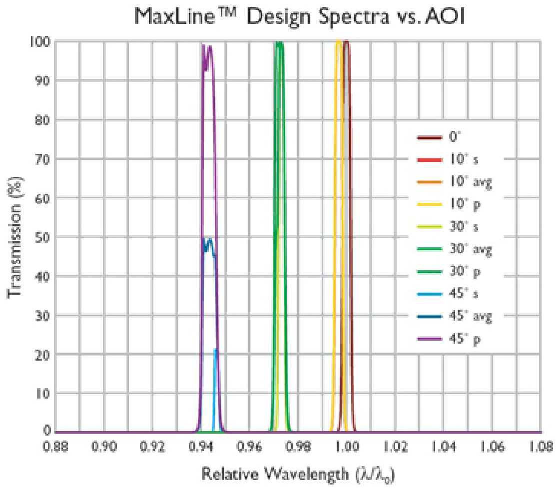

Figure B

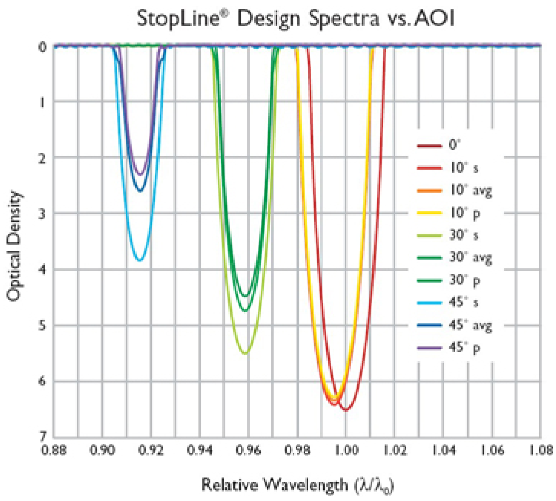

Figure C