Low Angle Shift Coatings

New Technology Delivers High Performance Filters

Overview

Optical systems frequently use filters to increase signal-to-noise by isolating wavelength bands containing information from a broad background of other signals (the noise). Optical filters which limit the wavelength response of a system are frequently called Band Pass filters. These filters can have a nearly infinite variety of attributes in terms of the wavelengths of light they transmit and suppress depending on the optical system in which they are deployed.

Depending on the level of performance and wavelengths of interest, various physical mechanisms can be used to produce a band pass filter such as: materials dependent absorption, scatter, dispersion and mechanical selection, optical interference, and induced transmission. Each of these filtering mechanisms has its place in optical instrumentation. As a general rule though, **the all dielectric optical interference filter is the most cost effective solution for fixed response, high throughput, robust, optical systems suitable for commercial electronic applications**.

Optical interference coatings use the principle of interference to produce a variety of spectral profiles. A fundamental aspect of interference is the phase change on traversal of the film. This phase change can be thought of as the optical path difference between light waves reflected off the two interfaces that makeup an idealized optical thin film. The path through the material will change when the angle of incidence changes. The propagation angle at any interface between two materials is governed by Snell's Law

$$n_1 \, \mathrm{Sin}(\theta_1) = n_2 \, \mathrm{Sin}(\theta_2)$$

where n is the refractive index and θ is the angle of propagation and the subscripts refer to two arbitrary materials.

This leads to many interesting optical effects. One of particular interest is that **the angle of propagation for a material is inversely proportional to the real part of its refractive index**. The angle of propagation determines the phase change on traversal of the layer. The shift in spectral performance is determined by the phase change. As a result, **a high effective index of refraction results in lower angle sensitivity of a filter**. The effective index of a film is a result of the materials used in its construction and the distribution of those materials.

Effect of Effective Refractive Index on Angle Shift

For example, the shift in angle for a Fabry-Perot Narrow Band Pass filter as a function of index of refraction of the space layer is shown in *Figure 1.*

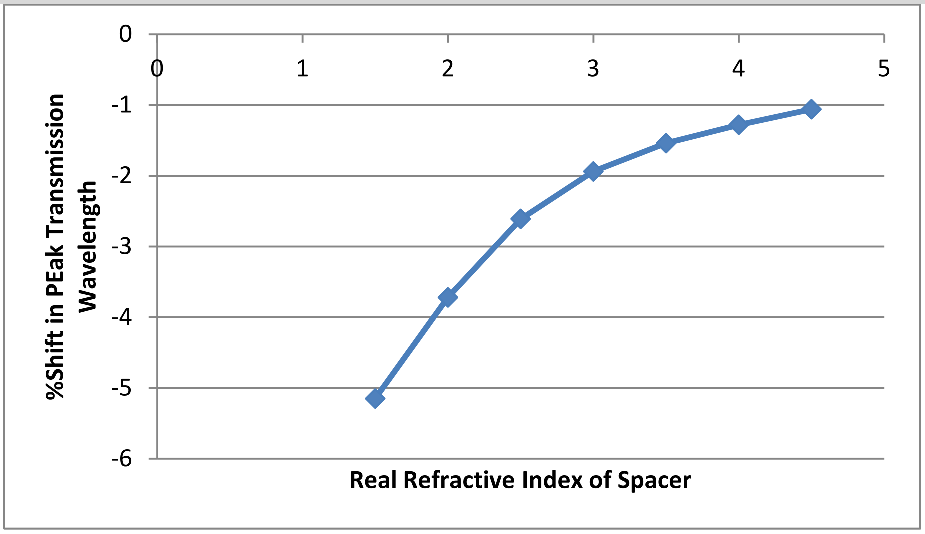

Figure 1 - Change in Center wavelength of single cavity Narrow Band Pass filter (Fabry-Perot) as a function of index of refraction of the spacer layer for a 30° change in angle of incidence.

Clearly, **the higher the refractive index of the spacer layer, the lower the center wavelength (CWL) shift experienced by the filter for a given angle change.** Thirty degrees is a large angle but serves to illustrate the point that as required bandwidth of a filter decreases, the angular field over which it is useful drops off quickly. A filter with a 1% Bandwidth (e.g. 10 nm FWHM @ 1µm CWL) would shift by its entire width, even with refractive index of 4.5. **Narrow filter width and large angular fields are inherently conflicting requirements.**

The materials available for a given band pass design are determined by their region of transparency, their stability and their durability. Depending on the attributes of the optical system in question different materials can be utilized. Typical coating materials include metals, metal oxides, fluorides, nitrides and semiconductors.

In band pass filters utilized in the real world, the illumination is often a cone of angles (F/#) used over an angular Field of View (FOV). The net angular field (FOV+F/#) in conjunction with the filter design determines the spectral response of the system. As the angles increase, the filter's response is the weighted average of the response. The weighting is determined by the vignetting of the optical system. As this is usually not known to the filter designer, we usually model either with Uniform or Lambertian illumination. In uniform illumination, it is assumed that the irradiance is independent of angle. In Lambertain illumination, the irradiance goes as the cosine of the angle.

Materion Case Study – Low Angle Shift

The emergence of higher power LEDs at near infrared (NIR) wavelengths in the range between 700nm and 1100nm is of increasing interest for commercial and consumer applications. These NIR LEDs are emerging as the cost effective and compact light source of choice (signal). Then, in order to maximize signal to noise in their system, it requires the use of a matched NIR band pass filter with very low angle shift (reduced noise).

Materion has developed precisely these types of high performance filters for the NIR with very low angle shift. In order to reduce the wavelength shift in this wavelength region, we have changed from our traditional approach of metal dielectrics to a new material set. This proprietary and patent-pending technology change allows us to drastically increase the effective refractive index to around 3.1 from around 1.9. This results in **filters that shift much less over the 30° angle of an f/1 cone - typically about half as much.** Additionally, we will show that **the band shape is better preserved with Materion's proprietary high effective index filters.**

In the following illustrations, we compare the performance of two filters. *Filter 1* utilizes our new material set and *Filter 2* is based on our standard metal oxide material set. *Figure* 2 demonstrates that the predicted performance of both filters is very similar at normal incidence in collimated light (AOI = 0 degrees).

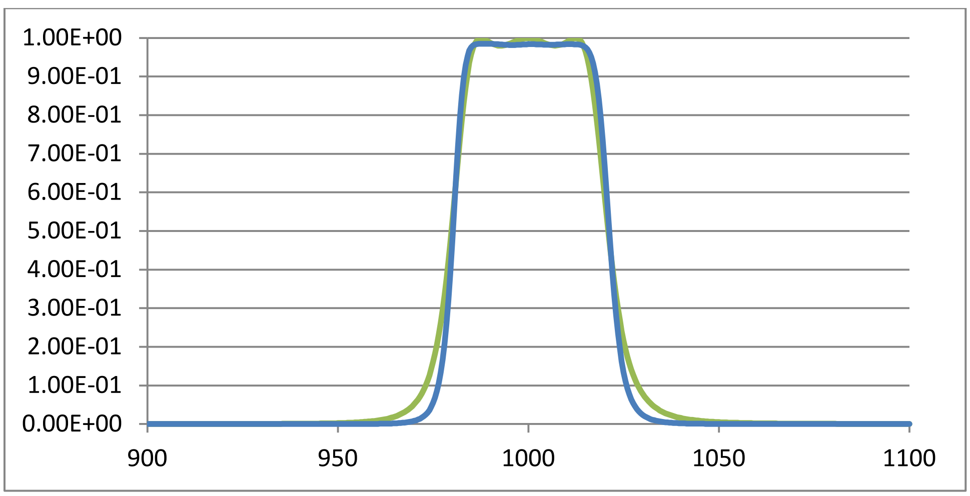

Figure 2 - Two filters with similar performance but with differing effective index at normal incidence in collimated light. The blue line represents Low Shift Coating; the green line represents Conventional Metal Dielectric Materials.

However, the performance of the two filters at non-normal angles of incidence is shown to be drastically different in *Figures 3 and 4.* Figure *3* shows the performance of Filter 1 when the angle of incidence is changed from 0 degrees to 30 degrees - for a collimated beam of light (no cone angle). Similarly, *Figure 4* shows the performance of Filter 2 when the angle-of-incidence is changed from 0 degrees to 30 degrees - for a collimated beam of light (no cone angle). Clearly, when the performance of the two filters is compared, Filter 1 shows breakthrough performance with approximately half of the angle shift exhibited by Filter 2.

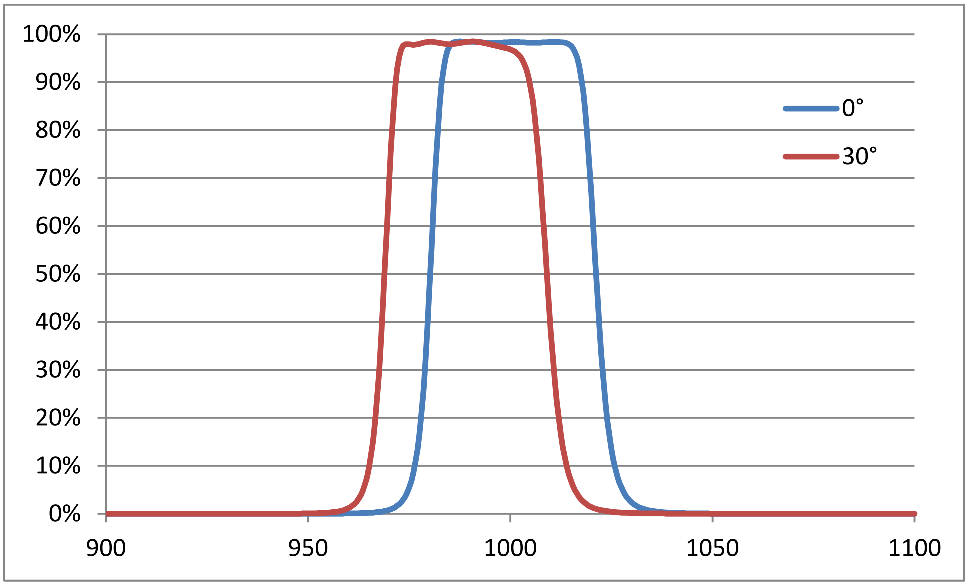

Figure 3 - Shift of Filter 1 using Materion's proprietary high effective index filter as a function of angle of incidence for a collimated beam of light (no cone angle).

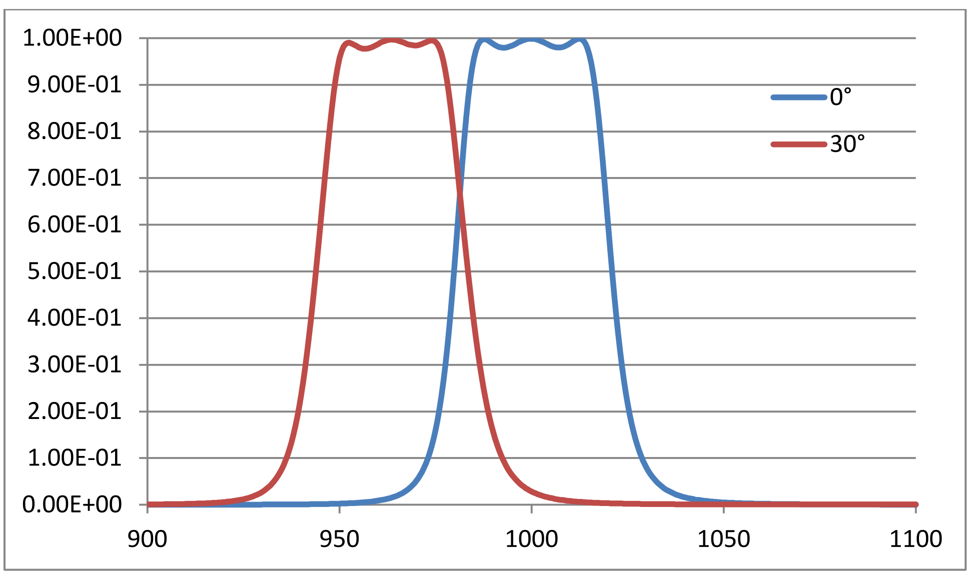

Figure 4 - Shift of Filter 2 utilizing standard filter materials (metal dielectrics) as a function of angle of incidence for collimated beam of light (no cone angle).

As discussed, it is typical that an optical illumination system will often exhibit a cone angle of light (rather than just collimated light). *Figure 5* and *Figure 6* show the impact on the spectral response of Filters 1 and 2 respectively of imposing an F/1 cone on the illumination. Clearly, Filter 1 exhibits much less angle shift and maintains its band shape much better than Filter 2.

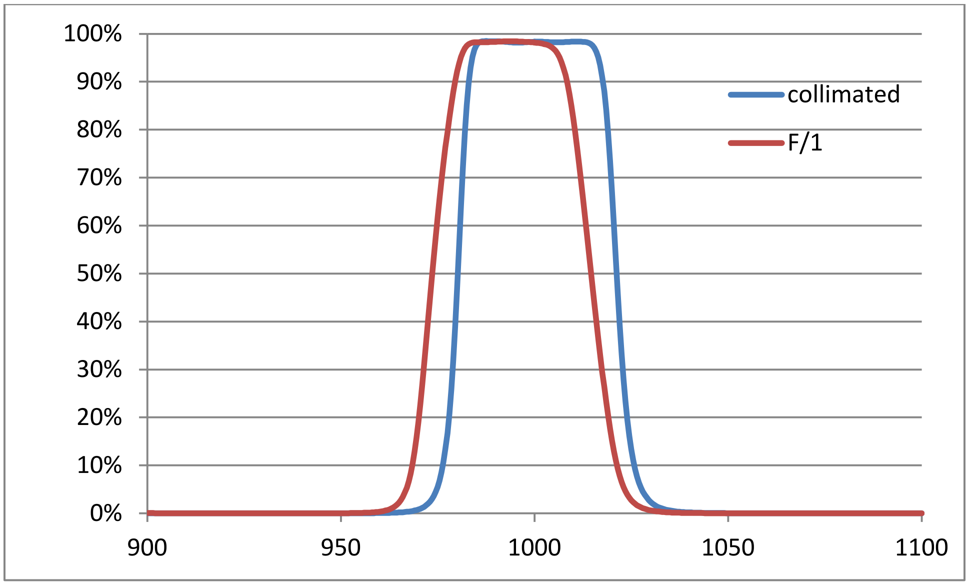

Figure 5 - Effect of F/1 cone on Filter 1 spectral profile for Materion's proprietary high effective index filter.

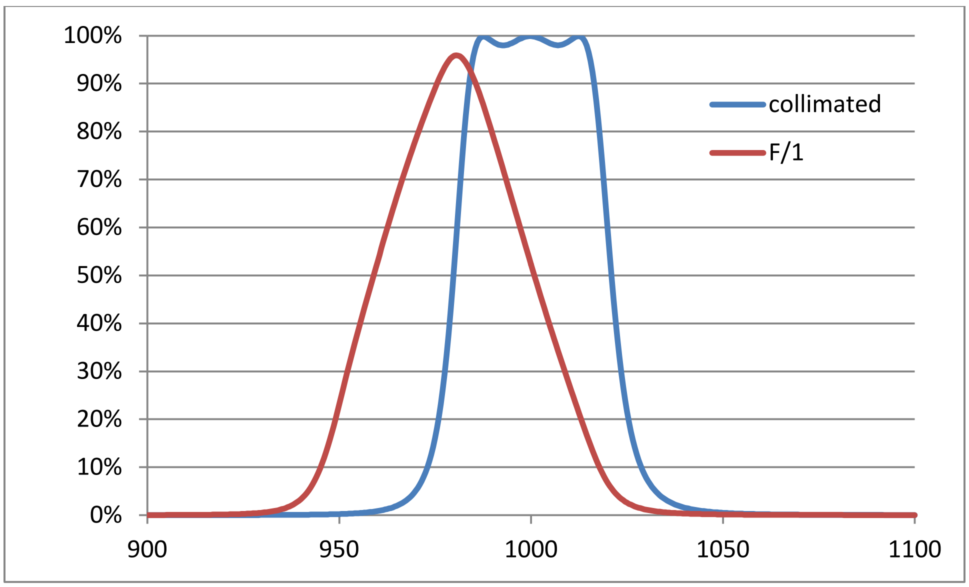

Figure 6 - Effect of F/1 cone on Filter 2 spectral profile for standard filter design (metal dielectrics).

Superior Performance

In conclusion, we have shown that high effective index filters using Materion's proprietary and patent pending technology exhibit far superior performance in the NIR when compared with standard interference filter approaches. The advantages include:

- Drastically reduced spectral shift as a function of angle of incidence ("angle shift")
- Far superior band shape at high angles of incidence

These high index filters in the NIR wavelength range with very low angle shift offer an exciting opportunity for optical systems in commercial and consumer applications requiring high throughput and enhanced signal-to-noise ratios. To learn more about Materion's high index filters, contact Robert Legg, Product Line Manager, Robert.Legg@Materion.com