Optical Filters: Non-normal Angles of Incidence

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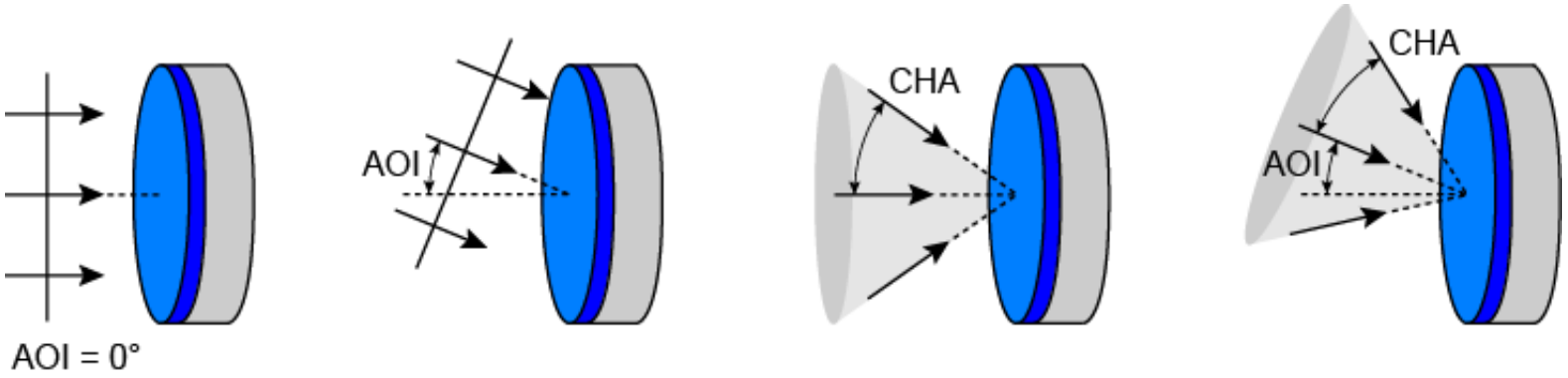
Filters at non-normal angles of incidence

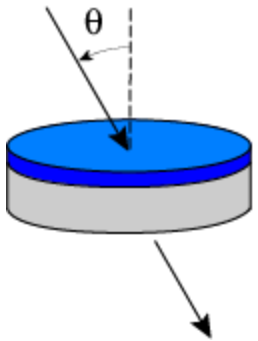
- Filters do not always operate in a system in which light is incident only at normal incidence
- In some systems, collimated light is incident on the filter at a non-zero “Angle of Incidence” (**AOI**)
- In other systems, non-collimated light is characterized by a non-zero “Cone Half Angle” (**CHA**)



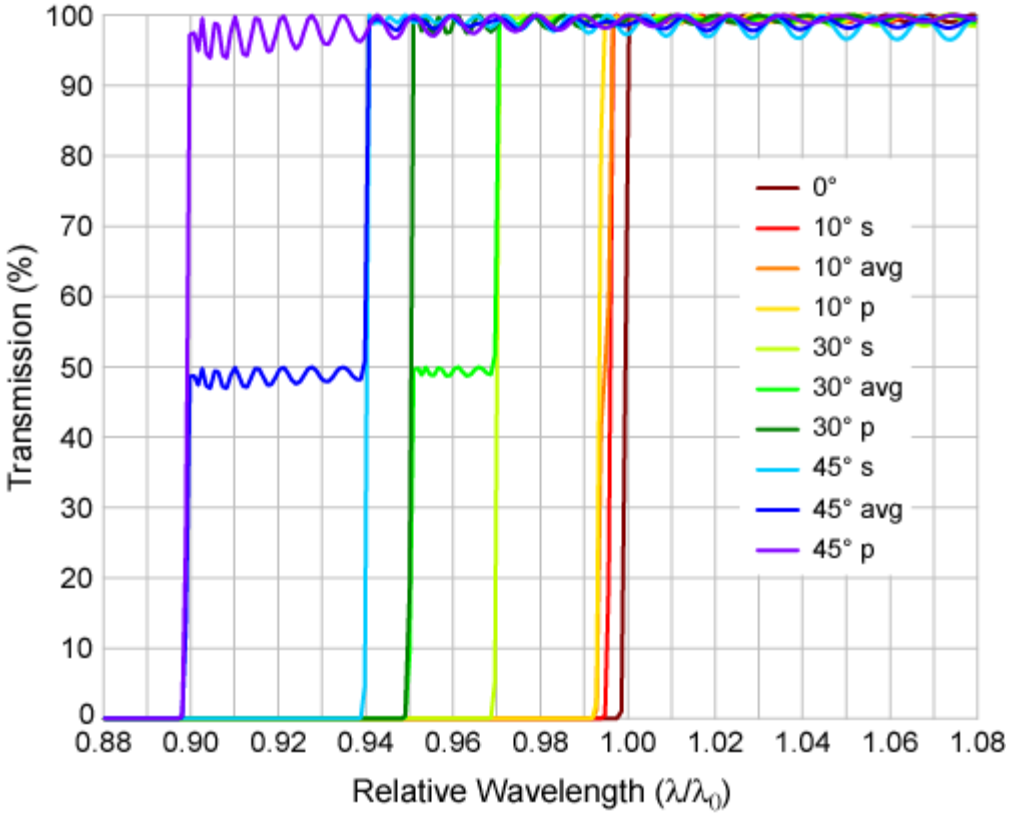
  - In a fluorescence microscope, the AOI is between 0° and 5° for exciters and emitters and 45° for dichroics; the CHA of light in the imaging path is typically between 1.5° and 3°.

Filters at non-normal angles of incidence

- When light is incident at increasingly larger angles:
  - features of the spectrum shift toward shorter wavelengths
  - two distinct spectra emerge for s- and p-polarized light



Edge filter



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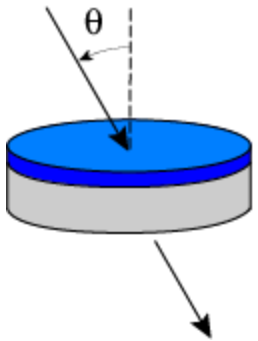
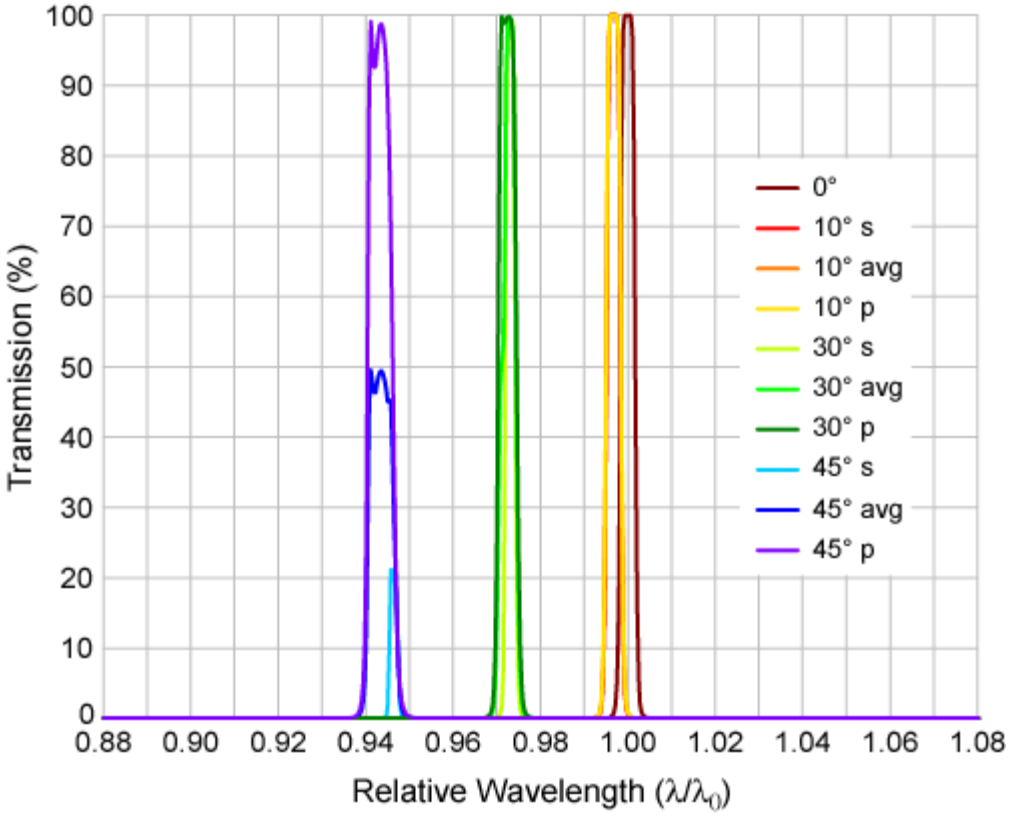


Narrowband filter



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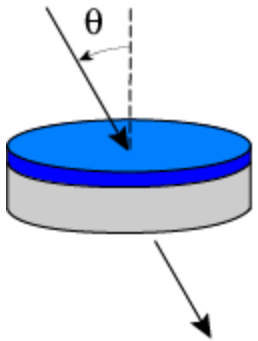
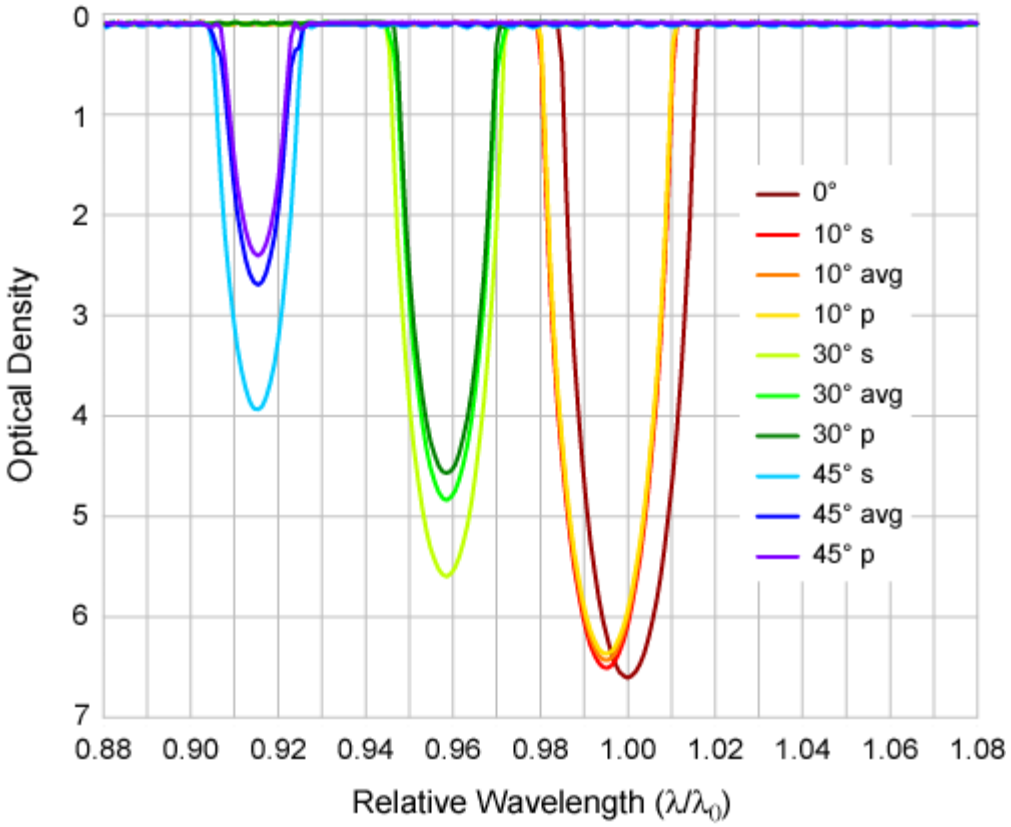


Notch filter (U- and S-grade)



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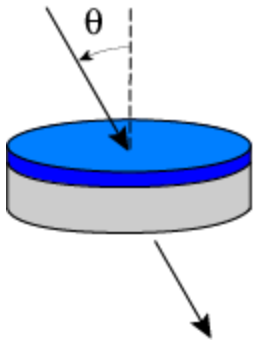
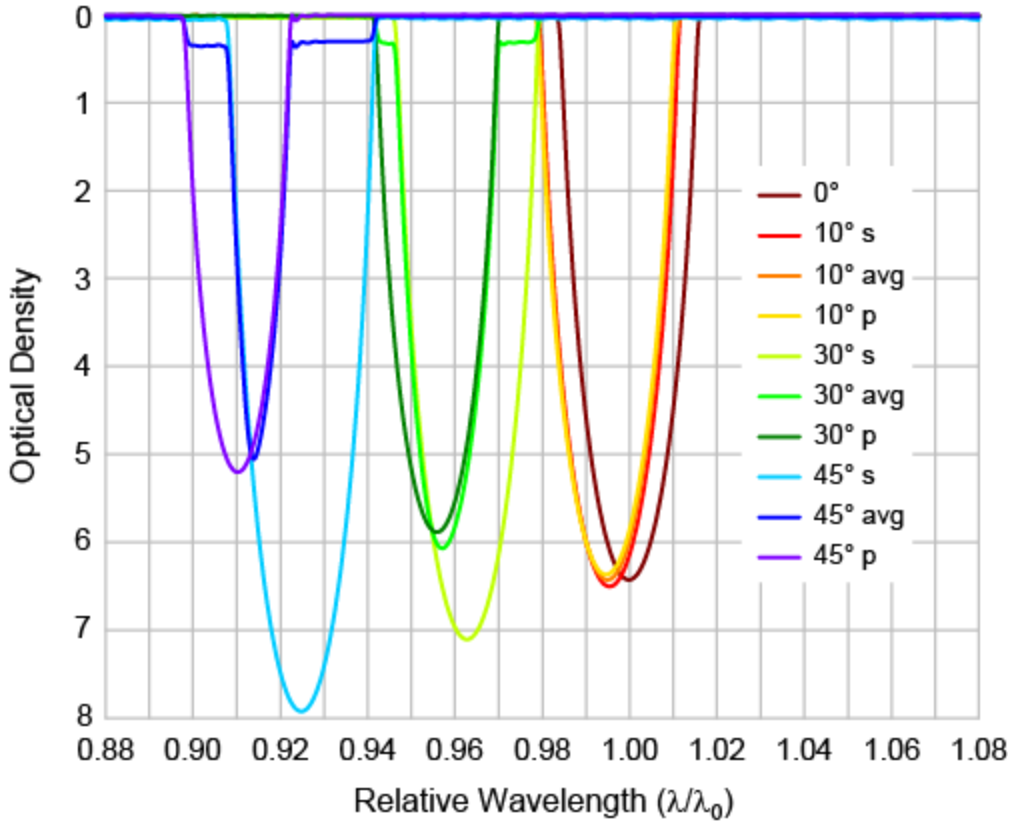


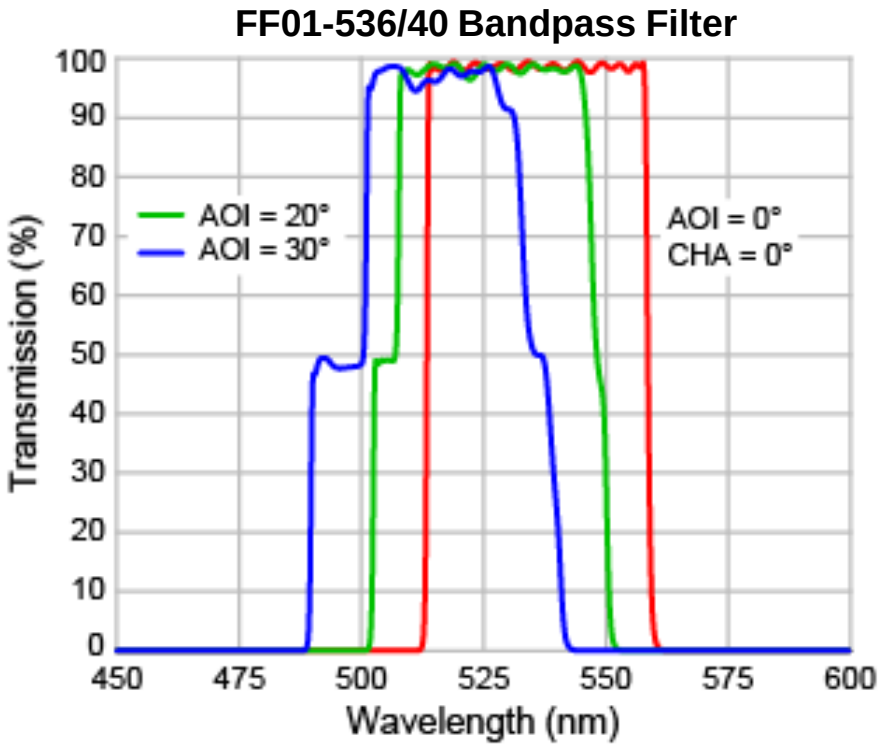
Notch filter (E-grade)



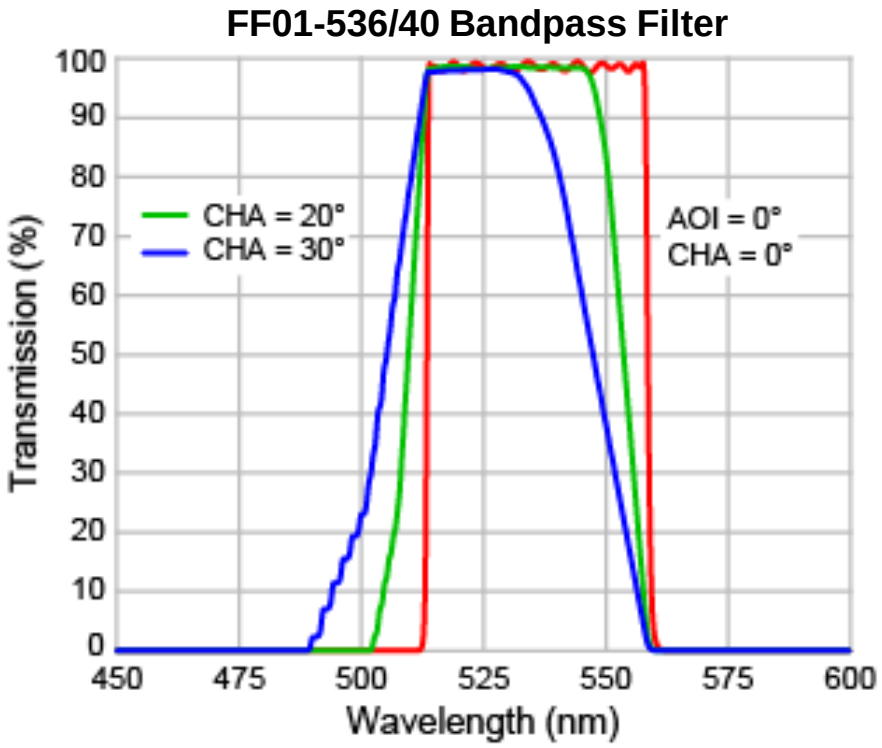
Bandpass spectrum at different AOIs and CHAs

- Specifying a given AOI range is **not** the same as specifying a filter with the same value of CHA!

Different values of AOI

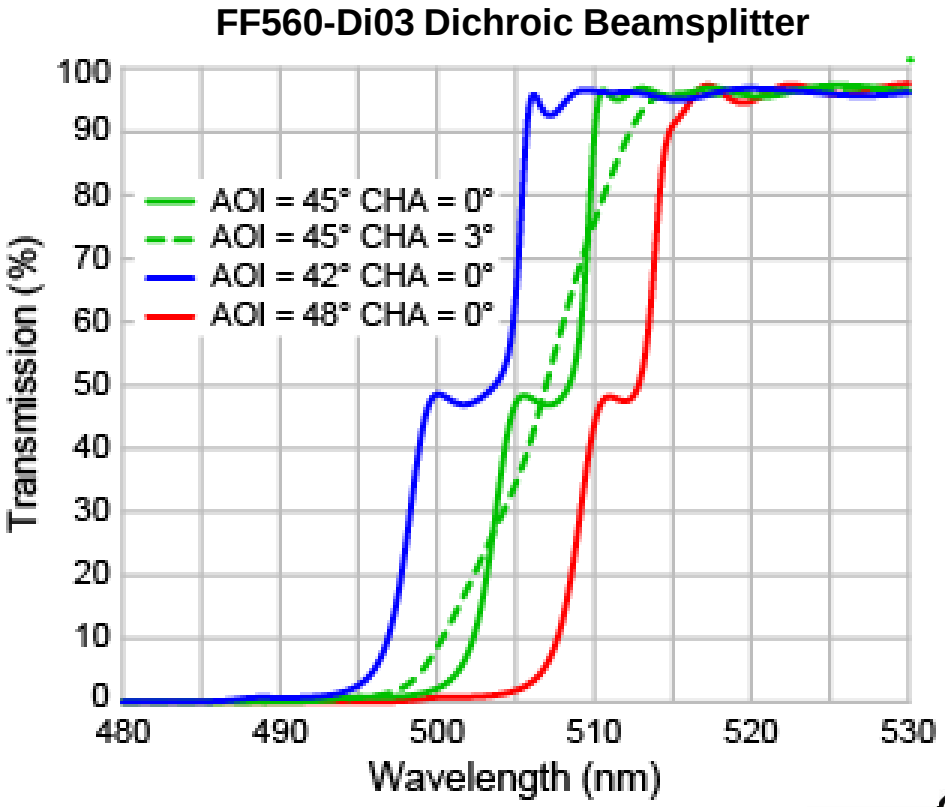


Different values of CHA



Dichroic spectrum at different AOIs and CHAs

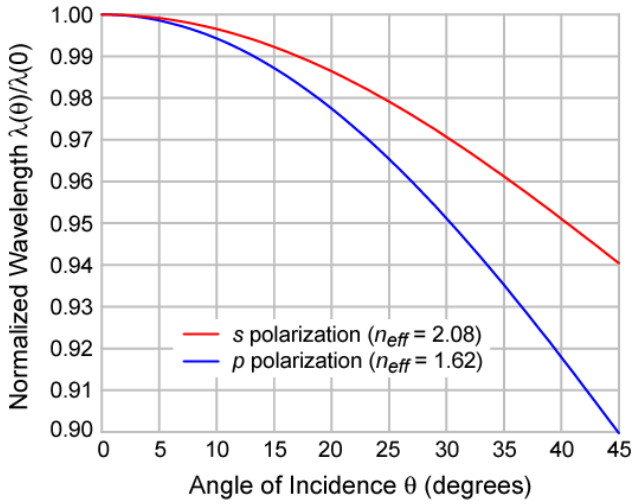
- Filters at high AOI's are particularly sensitive to small ranges of AOI and to small values of CHA
- This example shows spectra of a dichroic at AOI = 45° ± 3° for collimated light and for CHA = 0° and 3°

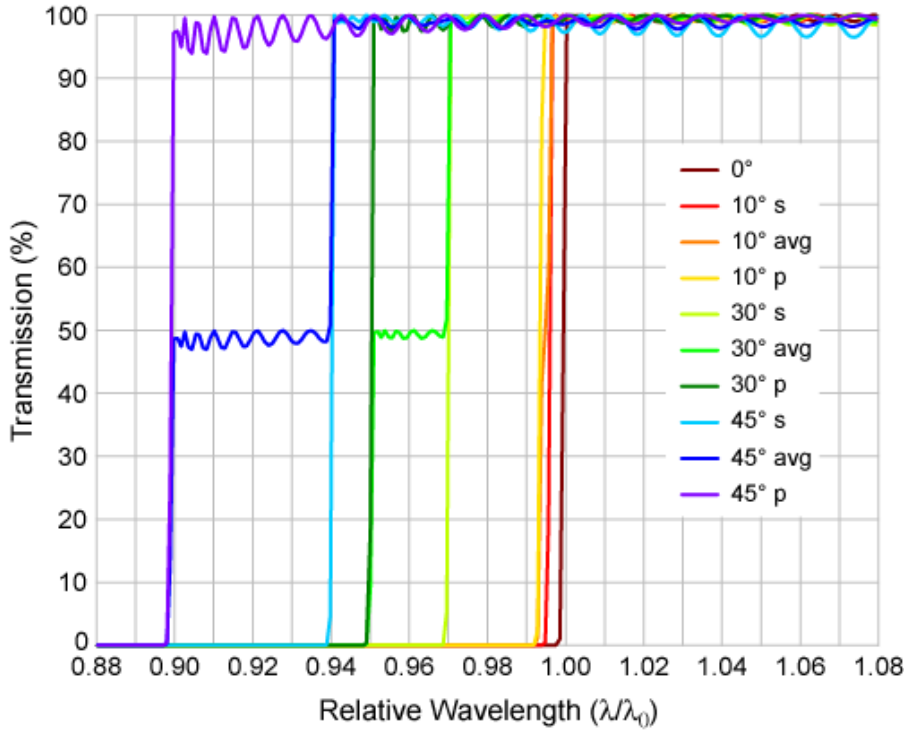


Filters at non-normal angles of incidence

- The wavelength shift of any given feature can be accurately described by the equation below using an "**effective index**" n_{eff}
- The effective index can be different for different filters, different spectral features, and different polarizations

$$\lambda(\theta) = \lambda(0)\sqrt{1 - \sin^2\theta / n_{eff}^2}$$





Thank you!