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Material Properties Overview

Optical Properties

The most important optical properties of a material are its internal and external transmittances, surface reflectances, and refractive indices. The formulas that connect these variables in the on-axis case are presented below.

Transmission

External transmittance is the single-pass irradiance transmittance of an optical element. Internal transmittance is the single-pass irradiance transmittance in the absence of any surface reflection losses (i.e., transmittance of the material). External transmittance is of paramount importance when selecting optics for an image-forming lens system because external transmittance neglects multiple reflections between lens surfaces. Transmittance measured with an integrating sphere will be slightly higher. Let T_e denote the desired external irradiance transmittance, T_i the corresponding internal transmittance, t_1 the single-pass transmittance of the first surface, and t_2 the single-pass transmittance of the second surface:

$$T_e = t_1 t_2 T_i = t_1 t_2 e^{-\mu t_c}$$

where e is the base of the natural system of logarithms, μ is the absorption coefficient of the lens material, and t_c is the lens center thickness. This allows for the possibility that the lens surfaces might have unequal transmittances (for example, one is coated and the other is not). Assuming that both surfaces are uncoated,

$$t_1 t_2 = 1 - 2r + r^2$$

where

$$r = \left(\frac{n-1}{n+1} \right)^2$$

is the single-surface single-pass irradiance reflectance at normal incidence as given by the Fresnel formula. The refractive index n must be known or calculated from the material dispersion formula given in the next section. These results are monochromatic. Both μ and n are functions of wavelength.

To calculate either T_i or the T_e for a lens at any wavelength of interest, first find the value of absorption coefficient μ from the equation given below. Typically, internal transmittance T_i is tabulated as a function of wavelength for two distinct thicknesses T_{c1} and T_{c2} , and μ must be found from these. Thus

$$\bar{\mu} = -\frac{1}{2} \left[\frac{\ln [T_i(t_{c1})]}{t_{c1}} + \frac{\ln [T_i(t_{c2})]}{t_{c2}} \right]$$

where the bar denotes averaging. In portions of the spectrum where absorption is strong, a value for T_i is typically given only for the lesser thickness. Then

$$\mu = -\frac{1}{t_c} \ln(T_i).$$

When it is necessary to find transmittance at wavelengths other than those for which T_i is tabulated, use linear interpolation.

The on-axis T_e value is normally the most useful, but some applications require that transmittance be known along other ray paths, or that it be averaged over the entire lens surface. The method outlined above is easily extended to encompass such cases. Values of t_1 and t_2 must be found from complete Fresnel formulas for arbitrary angles of incidence. The angles of incidence will be different at the two surfaces; therefore, t_1 and t_2 will generally be unequal. Distance t_c , which becomes the surface-to-surface distance along a particular ray, must be determined by ray tracing. It is necessary to account separately for the s - and p -planes of polarization, and it is usually sufficient to average results for both planes at the end of the calculation.

Refractive Index and Dispersion

The Schott Optical Glass catalog offers nearly 300 different optical glasses. For lens designers, the most important difference among these glasses is the index of refraction and dispersion (rate of change of index with wavelength). Typically, an optical glass specified by its index of refraction at a wavelength in the middle the visible spectrum, usually 587.56 nm (the helium d-line), and by (the Abb? ν_d -value, defined to be

$$\nu_d = \frac{n_d - 1}{n_F - n_C}$$

The designations F and C stand for 486.1 nm and 656.3 nm, respectively. Here, ν_d shows how the index of refraction varies with wavelength. The smaller ν_d is, the faster the rate of change is. Glasses are roughly divided into two categories: crowns and flints. Crown glasses are (those with $n_d < 1.60$ and $\nu_d > 55$, or $n_d > 1.60$ and $\nu_d > 50$). The others are flint glasses. The refractive index of glass from 365 to 2300 nm can be calculated by using the following formula:

$$n = \left(\frac{B_1 \lambda^2}{\lambda^2 - C_1} + \frac{B_2 \lambda^2}{\lambda^2 - C_2} + \frac{B_3 \lambda^2}{\lambda^2 - C_3} + 1 \right)^{1/2}$$

Here λ , the wavelength, must be in micrometers, and the constants B_1 through C_3 are given by the glass manufacturer. These constants are provided for most of the individual glasses in this catalog. Values for other glasses can be obtained from the manufacturer's literature. This equation yields an index value that is accurate to better than 1×10^{-5} over the entire transmission range, and even less in the visible spectrum.

Other Optical Characteristics

Homogeneity within Melt

Homogeneity within melt is the amount of refractive index variation within the manufactured glass blank. Inhomogeneity of refractive index can result in transmitted wavefront distortion. The maximum value for homogeneity within melt for all Schott optical glasses used in Melles Griot catalog components is 1×10^{-4} .

Striae Grade

Striae are thread-like inclusions within an optical glass. Striae grades are specified in U.S. military

specification MIL-G 174B. All Melles Griot catalog components that utilize Schott optical glass are specified to have striae that conform to MIL-G 174B grade A. Grade A means that no visible striae, streaks, or cords are present in the glass.

[Stress Birefringence](#)

Mechanical stress in optical glass leads to birefringence (anisotropy in index of refraction) which can impair the optical performance of a finished component. Optical glass is annealed (heated and cooled) to remove any residual stress left over from the original manufacturing process. Schott Glass defines fine annealed glass to have a maximum of 12 nm/cm of residual stress birefringence for blanks of up to 800 mm in diameter and 100 mm in thickness.

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