TECHNICAL SERIES: OPTICAL PROPERTIES

Refractive Index & Dispersion

Refractive index (n) is one of the principle defining characteristics of an optical material. In simplified terms, the refractive index defines to what degree light is bent or "refracted" when crossing the boundary between two mediums. It is derived from the relationship between the speed of light in a vacuum, to its speed in the new medium and is represented as:

$$n = c\,/\,v$$

n = refractive index
c = velocity of light in a vacuum
v = velocity of light in the new medium

Consider for a moment that light travels fastest in a vacuum. When the same light enters a new medium, it will always slow down. There are quantifiable reasons for the deceleration, namely the interaction of the electric and magnetic fields of the light with the properties of the new material, however, for simplicity, it is enough to understand that light always slows down when moving from a vacuum into a new medium.

Now, given that the speed of light in a vacuum represents its fastest propagation, vacuum as a medium has a refractive index where n = 1. It is therefore used as the comparative standard against which all other mediums can be defined. For example, one of the most common optical materials, borosilicate crown, has a refractive index of 1.517. Again, understanding that refractive index demonstrates the relationship between the speed of light in a vacuum to the speed of light when it enters a new medium, and using the equation n = c / v, we now know that light travels 1.517 times slower in borosilicate crown than it does in a vacuum. The higher a material's refractive index, the more light slows down and is therefore bent or "refracted" to a higher degree.

Optical designers choose materials based on their ability to bend light and when designing multi-element systems, understanding the refractive indices of each element will allow them to accurately define how light will behave as it passes through the entire optical pathway. To this end, all optical materials are associated with a 6-digit international code whose first 3-digits list the refractive index. For example, borosilicate crown has a 6-digit code of 517-642. You will notice that the first three digits are representative of the 1.517 value derived above. The second three digits define the optical dispersion which we shall discuss next.

Optical Dispersion (Vd) builds upon the concept of refractive index and is

derived by the same principle. Whereas the refractive index allows optical designers to understand how light will bend in a generalized sense, dispersion more accurately defines the extent to which each specific wavelength of light will bend.

A common example of this phenomena is produced when white light passes through a prism. Due to the fact that different wavelengths slow down at different rates when passing through the prism, each wavelength also bends at slightly different angles.

Optical materials vary greatly in their ability to disperse light. Some materials exhibit wide dispersion, while others are specifically designed to provide as little dispersion as possible. Companies that manufacture optical materials, whether they be glass, fused silica, crystals or any number of other options, provide data on the dispersive properties using the Abbe Value (Vd), which corresponds to the second three digits in the 6-digit international code, in the case of a borosilicate crown, 517-642. The lower the Abbe value, the higher the dispersion.

So why is dispersion important? Let's consider a simple two-element telescope design and the effects of dispersion on the final image when viewed through an eyepiece. For practical reasons of this example, we'll assume the eyepiece itself has theoretically perfect optics that do not affect the image. We will focus simply on the two focusing lenses inside the telescope. Now the purpose of these optics is to provide a crisp, undistorted view where all the refracted rays of light meet at the same, precise point of focus. However, since all materials exhibit some dispersive properties, an optical designer faces challenges when attempting to bring

all the dispersed rays back together. In poorly designed systems, the rays never quite realign. An individual using the telescope to bring the target object into focus will notice it cannot be done. A slight twist of the focusing knob will bring the red end of the spectrum into focus but the blue end will show a type of halo. Conversely, a slight refocus in the other direction will bring the blue part of the spectrum into focus but now the red end exhibits a halo. This effect is called Chromatic Aberration. Optical design-ers have many tools at their disposal to correct for this effect, the most obvious being the proper choice of materials, however, often times designers will incorporate several additional lenses which, when used in series manipulate the dispersed rays back to a tack-sharp point of focus.

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Oct 12, 2016