Index Inhomogeneity Effects on Imaging Systems

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Abstract: Large field of view, high power, lithography, and laser fusion systems are all limited by refractive index variations of their constituent glass elements. To estimate how the image degrades, a model of the bulk index inhomogeneity must be formed.

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1. Introduction

The image quality produced by an optical system made from lenses is ultimately limited by variations of refractive index within the glass. Manufacturers of glass have developed processes that limit this inhomogeneity, but it remains a dominant error source in imaging systems where light goes through more than a few centimeters of glass. Currently, the refractive index inhomogeniety is specified using a single number -- the peak to valley variation found within a glass blank. This specification is insufficient for determining the optical performance of the glass because it gives doesn't fully describe the form of the spatial variations. By taking measurements of a sufficient number of samples to characterize a glass, or process, we can generate a statistical model of the inhomogeneity. This model allows a direct simulation of imaging systems to evaluate the likely effects of refractive index variations.

For high quality optical systems, the bulk variations of refractive index are the limiting factors for imaging. Once apertures get above four to six inches, the index fluctuation can be a concern. Lithography systems are a good example because of their large aperture, and several inches of transmission through the glass.

A statistical model must be developed for refractive index inhomogeneity. This requires a characteristic power spectral density (PSD) to be formed for different types of glass [1]. Using the PSD is the best way to describe the change in phase by going through a section of glass.

We must look at how index variations change the image. We know that a variation in the index at a single spatial frequency will move energy out of the central spot into lobes determined by the orientation of the index variation. By applying discrete frequencies to a lens element, we can see how the phase of each frequency is changed. Once a histogram of frequencies is built for a specific glass, the imaging ability of that element can then be evaluated.

This will be created analytically and applied using commercially available software. Our analysis will consist of phase spectra based on Fourier diffraction. The phase spectra will describe the changes in the wavefront due to random phase distributions within the lens. This will be most important in the region of transition from negligible errors to large aberrations. Monochromatic systems may be much more sensitive to a band spatial frequencies [2].

An important aspect of understanding bulk index inhomogeneity is taking accurate measurements. A method for mapping the three dimensional index of a glass sample must be used to build an accurate model. Computerized Tomography is a natural solution for measuring bulk index variations. However, there are difficulties that must be taken into account. Since the glass samples are plates, the full range of angles cannot be tested. Beyond a specific angle, the test beam will begin to enter the edge of the plate instead of going through the plate. In tomography, this is referred to as the limited angle problem [3], and care must be taken when reconstructing the object from the data.

2. References

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