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14. ABSTRACT

We have developed an analytic approximation useful for designing achromatic singlet lenses. The designs are based on gradient index lenses fabricated from nanolayered polymer materials. Raytraced results confirm the achromatic performance of the designs.

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Gradient Index Polymer Optics: Achromatic Singlet Lens Design

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Abstract: We have developed an analytic approximation useful for designing achromatic singlet lenses. The designs are based on gradient index lenses fabricated from nanolayered polymer materials. Raytraced results confirm the achromatic performance of the designs.

OCIS codes: (110.2760) Gradient-index lenses; (160.5470) Polymers; (230.4170) Multilayers.

1. Introduction

Today's applications are driving the need for smaller, lighter optical devices. At the same time, they require even better imagery. The only way to accommodate the conflicting demands of improved imaging with smaller systems is to pack more functionality into each lens element. Gradient refractive index (GRIN) materials are attractive candidates for meeting this need. Earlier work demonstrated a high-quality lens [1] fabricated via a new method [2] for constructing GRIN optics. This work discusses some new opportunities in optical design enabled by the fabrication technique. For example, the contours of the gradient index can be combined with the shape of the lens to provide color correction in a single lens element.

2. Model

The chromatic aberration of a GRIN lens obeys a relationship analogous to that of a homogeneous lens. As in the design of a conventional achromatic doublet, a flat, negative GRIN can be compensated by applying a positive front-side curvature. The GRIN serves as the low-dispersion "crown" element, while the front-side polish serves as the "flint" element. To provide guidance for the design parameters of such a lens, we developed an analytic expression for the focal length of a GRIN lens of specific geometry, based on the thin lens approximation. The geometry for the lens is shown in Fig. 1.

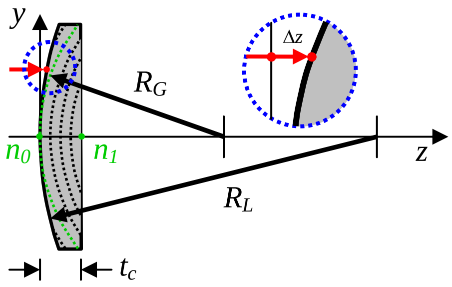

Fig. 1: GRIN lens geometry. The front surface is spherical, the back planar. Refractive index contours have a common origin a distance R_G from the left vertex. Surface curvature is given by R_L. The index varies linearly along the optic axis from n_0 to n_1.

The expression for the approximate focal length of such a lens is given by:

$$f(\lambda) = \left(\frac{n_0(\lambda) - 1}{R_L} - \frac{n_0(\lambda) - n_1(\lambda)}{R_G} \right)^{-1} \tag{1}$$

The first term is recognized as the focal power of a conventional plano-convex lens, with a uniform index given by n_0. The second term is the focal power contributed by the gradient index. Chromatic balancing can be achieved over a limited wavelength range provided R_L and R_G can be found such that $f(\lambda_{red}) = f(\lambda_{blue})$ when accounting for the dispersion of the materials at the extremes of the lens, $n_0(\lambda)$ and $n_1(\lambda)$.

3. Results

To explore the validity of Eqn. (1) and its ability to predict achromatic singlets, we simulated a series of GRIN lenses in Zemax®. In order to model these lenses, user-defined surfaces had to be developed for the software.

Raytrace results of the custom code, interfaced with Zemax®, were carefully validated against ray trajectories calculated independently using previously published GRIN propagation algorithms [3,4]. In the example presented here, $n_0(\lambda)$ is given by a glass described by a d-line (587.6 nm) index of 1.6 and an Abbe number of 30, while $n_1(\lambda)$ has corresponding values of 1.4 and 70. When constructed from these materials, assuming a linear variation of d-line index from one vertex to the other, the theory predicts chromatic balance for a lens R_G equal to 20 mm and front surface curvature R_L equal to 28 mm. For comparison purposes, a plano-convex homogeneous lens was also modeled. The glass of the homogeneous lens was given a d-line index of 1.50 and Abbe number of 50. The front surface curvature was adjusted to give the same back focal length as the model GRIN lens. The back focal lengths of these lenses were near 85 mm.

The simulated chromatic focusing properties of the homogeneous lens, the model GRIN lens, and GRIN lenses with slightly-altered front surface curvature are all plotted in Fig. 2. The plots show the location of the paraxial image plane, relative to the d-line image plane, as a function of wavelength across the visible region of the spectrum. The solid line shows the chromatic aberration expected of a conventional singlet: blue light focuses in front of red light. From the F-line (486.1 nm) to the C-line (656.3 nm) the difference in focal position is 1.7 mm. By contrast, the gradient index in the model GRIN lens (with R_L = 28 mm) *overcorrects* the chromatic aberration. Blue light focuses behind the red light, with a much smaller focal shift of -0.2 mm. Increasing the chromatic power of the surface by curving more strongly (R_L = 26 mm) changes the balance back to a normal sign. The GRIN achromat is found at an intermediate value, R_L = 27.095 mm. This lens exhibits a maximum paraxial focal shift less than 0.14 μm across the visible spectrum.

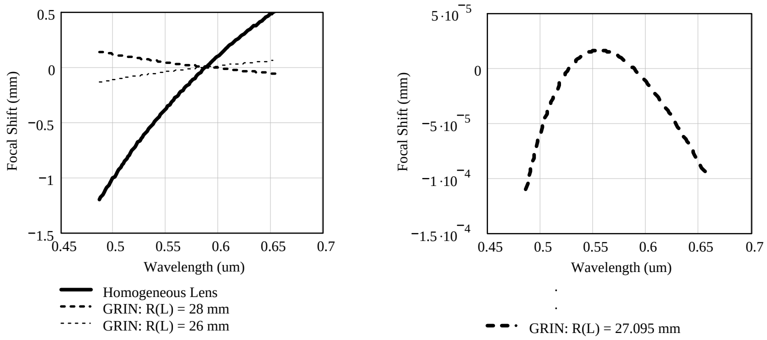

Fig. 2: Computed longitudinal focal shifts as a function of wavelength. Plots are for a single homogeneous lens (solid line) and for several GRIN lenses. On the right is the GRIN achromat, plotted on vertical scale 10,000x smaller than the plot on the left.

4. References

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