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Gradient-Index Lenses in Imaging Applications Using Zemax Program

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ABSTRACT: GRIN lenses represent an interesting alternative to conventional spherical lenses since the lens performance depends on a continuous change of the refractive index within the lens material. This paper using of the high-index-of-refraction lanthanum crown glass (SLS-1.0) which helps to reduce spherical aberration the design and analysis the gradient – index lenses by using Zemax software that we can see the changing in refractive index. wave length extends from (0.500 to 0.600) µm and diffraction limited over a large field of angles with F/#2.5 that have been studied in this research .This paperdeals how to design and analysis work and how to take advantage of gradient index image applications,which helps to reduce the modulation of the refractive-index profile.

KEYWORDS: GRIN lenses**,** refractive index**,** image applications**,** Zemax software

I. INTRODUCTION

Gradient-index (GRIN) lenses are lenses fabricated from optically inhomogeneous materials ,i.e. from materials where the refractive index varies from point to point. Studies in the past two decades have shown that the use of inhomogeneous materials in optical design may lead to a substantial reduction of the number of components as compared topurely homogeneous optical systems having the same specifications. Therefore, lens design with GRIN lenses alone or together with homogeneous lenses receives presently considerable attention.If the refractive index distribution inside the GRIN lens is rotationally symmetric, many of the familiar imaging properties of homogeneous optical systems are retained.Thus, in the paraxial approximation, a conjugate image plane exists for any object plane, the transverse magnification being the same for all pairs of object and image points[1]. Beyond paraxial approximation, the aberration types are also the same as for homogeneous lenses. For the design of optical imaging systems, up to now two types of GRIN media having both a rotationally symmetric refractive index distribution have been found to be particularly useful: the axial gradients, where the refractive index is a function of the coordinate along the symmetry axis, and the radial gradients, where the index is changing with the distance to the axis. In both cases, the presence of the inhomogeneous medium has two kinds of effects upon the imaging properties of the lens:

1. Surface effects. At the refraction of a ray at a spherical end surface, the local refractive index is a function of the height of the ray- surface intersection point. The local refractive index change produces an effect on the ray aberrations which is similar to that produced by the local change of surface curvature in the case of an homogenous a spherical surface.
2. Effects due to the ray transfer through the GRIN medium. Because of the inhomogeneity of the medium, the ray path inside the lens is curved. Thus, unlike homogeneous media, transfer through GRIN media influences the monochromatic and chromatic aberrations of the rays. In radial gradients, the medium contributes also to the total power of the lens. Therefore, with radial GRIN media focusing can be obtained also if the lens has plane end faces.

As compared to homogeneous media, varying the refractive index distribution inside the lens introduces additional degrees of freedom in the lens design process. These additional possibilities for controlling the aberrations can be used

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to improve the system performance over the equivalent homogeneous system. Alternatively, the number of elements required to meet fixed performance criteria can be reduced[2-5].

II. THEORY OF OPERATION

A gradient index lens is one in which the index of refraction changes with position. The lens in the Human eye is an example of a natural GRIN lens. It has been recently shown that a normal lens, but with the index a function of Z, can correct for more aberrations than a lens with the index gradient. This material is called Gradium, and is only available from Light Path Technologies, Inc. The GRADIUM surface type is included in the Zemaxprogram, and several stock lenses from Light Path are available in the Zemax lens catalog. This finds uses where there is not room for a more complex lens, but a higher degree of aberration correction is required.The more usual type of GRIN lens is a cylindrical rod of glass with an index that varies in a radial direction with distance from the axis of the cylinder. You can see how this could focus light conceptually by considering a discrete approximation – a cylinder with layered indices: (θ_i is the angle inside the central layer, w.r.t. the z-axis.)[6,7].

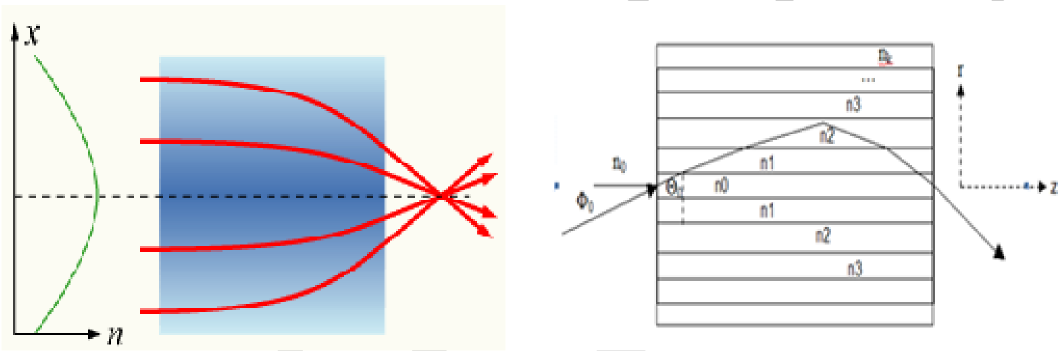

Fig-1.gradient-index lens with a parabolic variation of refractive index (n) with radial distance (x). The lens focuses light in the same way as a conventional lens.

Assuming that n0 > n1 > n2 > n3, we can see that the input ray will have decreasing angles with the axis as it passes each successive interface, until it finally undergoes Total Internal Reflection and heads back to the axis, since $n_i \sin\theta_i = n_{i+1} \sin\theta_{i+1} = \cdots = n_k \sin\theta_k$, and $\theta_i = 90 - \theta_0$. Assuming that n_k is the index of the last layer (which could be air, or a cladding layer), then the ray will escape the rod, if $n_0 \sin\theta_0 < n_k$ .Since $\sin(\theta_0) = \cos(\Phi_0) \equiv Z_0$, the direction cosine of the ray in the 0^{th} layer – and this also holds true for all other layers (i.e., $\sin(\theta_n) = Z_n$), we can re-write Snell's law for GRIN media in terms of Z-direction cosines as:

$$N(r).z(r)=n_0 z_0 \quad \ldots\ldots\ldots\ldots.(1)$$

An inhomogeneous gradient-index lens possesses a refractive index whose change follows the function $n = f(x, y, z)$ of the coordinates of the region of interest in the medium. According to Fermat's principle, the light path integral (L), taken along a ray of light joining any two points of a medium, is stationary relative to its value for any nearby curve joining the two points. The light path integral is given by the equation

$$L=\int_{s_0}^{s} n ds \quad \ldots\ldots\ldots\ldots\ldots..(2)$$

where n is the refractive index and S is the arc length of the curve. If Cartesian coordinates are used, this equation is modified to incorporate the change in arc length for a spherical gradient, to each physical dimension:

$$L=\int_{s_0}^{s} (x,y,z)\sqrt{x'^2 + y'^2 + z'^2 ds} \quad \ldots\ldots\ldots\ldots.(3)$$

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where prime corresponds to d/ds (Marchand, 1978). The light path integral is able to characterize the path of light through the lens in a qualitative manner, such that the lens may be easily reproduced in the future[8].

The refractive index gradient of GRIN lenses can be mathematically modeled according to the method of production used. For example, GRIN lenses made from a radial gradient index material, such as SELFOC Microlens (Flores-Arias et al., 2006), have a refractive index that varies according to:

$$n_r = n_0\left(1 - \frac{Ar^2}{2}\right) \ldots\ldots\ldots(4)$$

where n_r the refractive index at a distance, r, from the optical axis; n_o is the design index on the optical axis, and A is a positive constant[10].

III. DESIGN AND DISCUSSION

To design GRIN lens works in region the visible .The design consists of surfaces, radius curvature, thickness and types of glass also using the aperture value of objective lens. Therefore, from all the input data, we can see the results the design as in below. Confined within a wavelength of (0.500 to 0.600) µm , so that all the input data that represented in the figure below. The use of the high-index-of-refraction lanthanum crown glass (SLS-1.0) in this design helps to reduce spherical aberration. Lenses of that kind are commercially available under the trade name SELFOC, a derivative from "self-focusing."From designs the down we can see that the aberrations in each design ,Therefore ,we describe the geometrical aberrations by the transverse ray fan plot, And also the optical path diffraction, spot size diagram and the diffraction MTF.

Table(1): gradient – index design

Surf:Type		Radius	Thickness	Glass	Semi-Diameter	Par1 (unused)
OPJ	Standard	0.000	0.8983146		0.000000	
STO	Standard	0.000	3.800000	SLS-1.0	0.600000	0.100000
2*	Gradient9	0.000	0.8983146		0.600000	
3*	Standard	0.000	0.00000		0.035597	
IMA	Standard	0.000	-		0.035597	

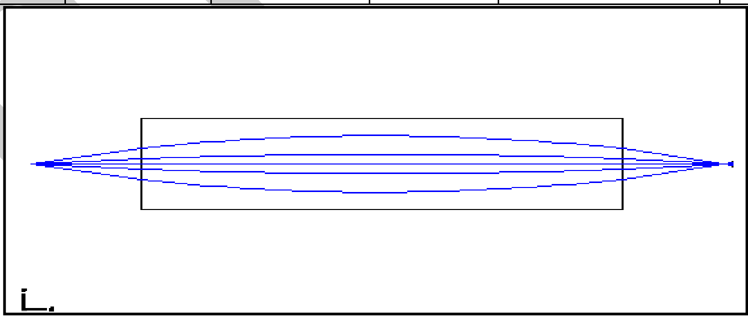

Fig (2) the structure of the gradient – index lens [11].

Fig-2a shows the same lens as Fig-1 but now the object is located at a finite distance. To better understand the function of a GRIN lens, an "equivalent" thin lens has been superimposed for reference. This clarifies the object and image distances and, with the fields added, the magnification=s'/s=h'/h.A half-pitch lens images an object on the entrance surface inverted to the exit surface of the lens. A quarter-pitch lens images a point source on the entrance surface of the lens into infinity or collimated it, respectively. This configuration is usually applied to the collimation of single-mode and multi-mode optical fibers and laser diodes. For high-power laser diodes, GRIN cylindrical lenses are used for the Fast-Axis-Collimation.-pitch lens images a point source placed in the working distance s into infinity or collimated it

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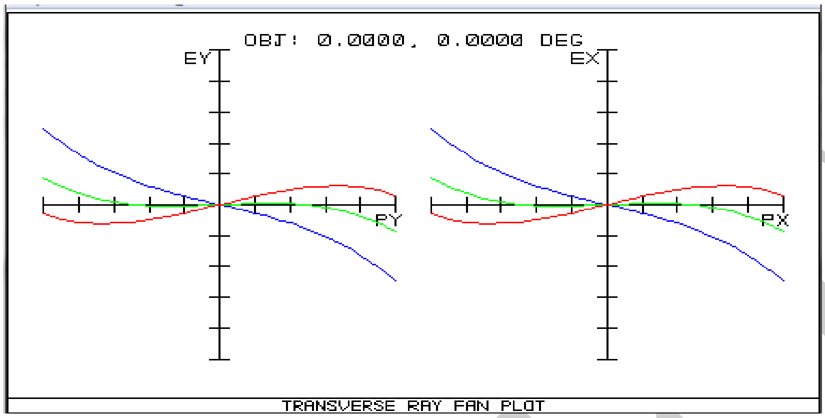
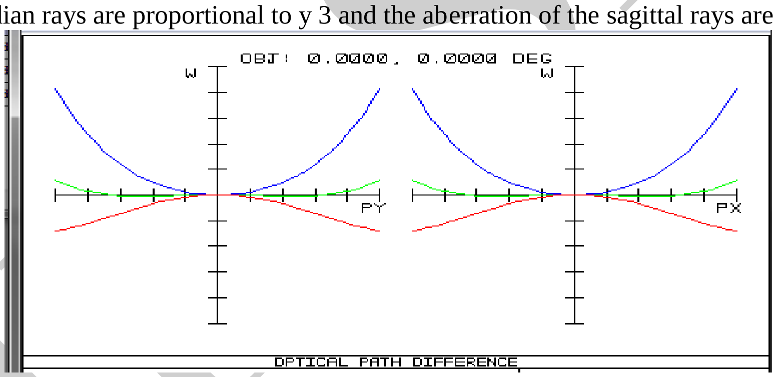
As shown above,The geometrical gradient constant and the lens lengthdetermines the focal length f and the working distance s of the lens.



Fig(3) the transverse ray fan plot[11].

we can see that the aberration for the lenses design of the gradient – index lens, shows that transverse ray aberration of rays from an axial object point. shows that transverse ray aberration of rays from an axial object point. we have introduced two new terms(p y) and (p x) stands for "tangential section" which refers to the section of the pupil in which the x-coordinates are zero. in the meridian plan ,"s" is the sagittal section .this figure shows the tangential and sagittal section varies with each other in the same time.we are considering plots of transverse ray aberration, the aberrations of the meridian rays are proportional to y 3 and the aberration of the sagittal rays are proportional to x^3 .



Fig(4) The optical path diffraction[11].

The optical path difference (OPD) for a given ray is the difference between the optical path length (OPL) of the ray and the OPL of the chief ray. This difference can be referenced back to the difference between the ray path lengths at the system exit pupil.We have in the figure above two areas and each area represents three curves and the curves represent in fig (4)the optical path difference illustrates curves passers through the system and note the curves and the area under the curves direction of ±X, the defects within acceptable spaces where the Y-axis represents ,as well X-axis represents and the value maximum scale ±5 waves ,From fig-4,Spot diagrams give little information about which parts of the entrance pupil particular rays pass through. In a perfect optical system, the optical path of the wave front will be identical to that of an aberration-free spherical wave front in the exit pupil In addition to plots of the ray error in an evaluation plane , another aberration plot is one that expresses wave front aberrations as an optical path dif ference (OPD) from a spherical wave front centered about the image point . These OPD plots are particularly useful for applications where the lens must be close to dif fraction-limited.

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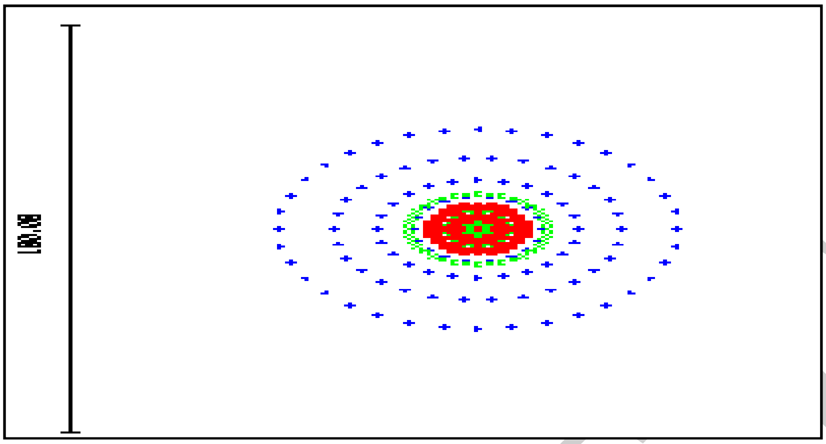
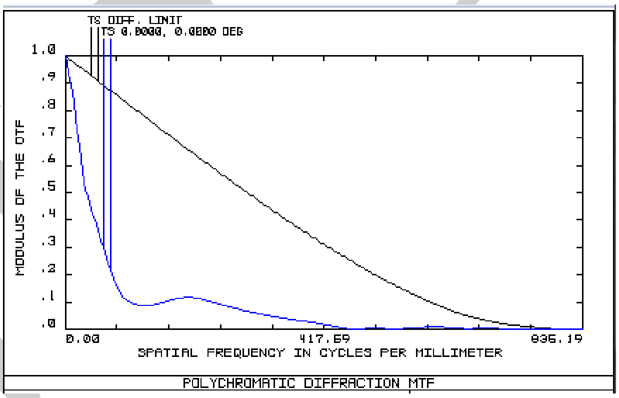


Fig(6) spot size diagram[11] .

Note the spot diagram is a collection of points, with each point representing a single ray. There is no interaction or interference between the rays. The spot diagram is very effective at showing the effects of the geometric, or ray aberrations of the telescope. The off axis geometric PSF clearly shows the coma and astigmatism of the system. On axis however, the spot diagram predicts perfect imagery.we can see that the spot size has less aberration . The variation of effective with spot size also calculated and plotted . The value of (EFF) of design(1.34187),filed (1) , RMS radius (10.508),GED radius(24.492),scale bar(100),aperture type (object space NA the value (0.2)),apodization type Uniforms an apodization function is used to purposely change the input intensity profile of an optical system, and may be a complicated function to tailor the system to certain properties. Usually it refers to a non-uniform illumination or transmission profile that approaches zero at the edges.



Fig(7)The diffraction MTF[11].

Modulation Transfer Function (MTF) is an important method of describing the performance of an optical system. A consequence of applying Fourier theory to image forming optical systems, MTF describes the contrast in the image of a spatial frequency presented in the scene being viewed. Note that in fig-7 there are curves on the plot just one and also that the maximum spatial frequency is only 835.19cy/mm. The blue curve (labeled TS 0.00 deg) is for the center of the image. A black curve which is the diffraction limited of this system shows the best performance. The rays come from the center of the optical axis provide the better performance than the edge of the optical axis.

IV. CONCLUSIONS

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From the results above, we can conclude that GRIN are a proven technology that is employed in many areas of optic systems Within a narrow region of(0.500-0.600) µm, New developments include the design of New developments include the design of lenses. The goal of this talk is to give an overview of how design Gradient-Index Lenses and limit or reduce aberrations, where the design lenses includes detailed accounts of aberrations so it applied in imaging applications, and also considered the highest efficiency of lenses manufactured Traditional. Entered a number of different materials for the lenses gradient index including optical glasses, plastics, germanium, zinc sulphide, and sodium chloride

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