

TITLE OF THE INVENTION

Optical Lens and Method of Controlling Astigmatism of Same

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to an optical lens and a method of controlling astigmatism of the optical lens.

Description of Related Art

Fig. 1 shows an optical system 1 wherein astigmatism is generated in an optical lens 2. In Fig. 1, an off-axis object is focused by the optical lens 2. Due to the asymmetry of the optical lens 2, the optical lens 2 appears to have two different focal lines or surfaces. Astigmatism is defined as the separation between these two focal lines.

It is helpful to define some terms here in order to understand the discussions which will be mentioned later.

A tangential plane(TP) of the optical lens 2 shown in Fig. 1 is a plane containing both an optical axis and an object point(OP). Rays which lie in this tangential plane(TP) are called tangential rays. A principal ray goes from the object point(OP) through a center(C) of the aperture of the optical lens 2. Rays not in this tangential plane(TP) are referred to as skew rays. A plane perpendicular to the tangential plane(TP) that contains the principal ray is called a sagittal plane (SP) or a radial plane.

990 4 117 - 0

23 AUG 1999

If the optical lens 2 is designed in such a way that respective optical paths of the tangential and radial rays are not the same in length, then astigmatism will be introduced to the optical lens 2. Conventionally, this can be done by introducing asymmetry to the grinding process for glass lenses and to the molding process through the asymmetric shape of optical inserts for plastic lenses. However, this requires extensive time and accuracy during the design process for lenses. In addition, the grinding and the molding processes are irreversible, hence once the lenses are formed using these processes, their astigmatism value cannot be changed.

SUMMARY OF THE INVENTION

Therefore, it is an object of the present invention to provide an optical lens wherein astigmatism is introduced by applying an asymmetric coating on a lens main body, and a method of controlling astigmatism of the optical lens.

When the optical lens is coated, the reflection/transmission properties are modified at the surface of the optical lens.

In one aspect, the present invention provides an optical lens having a lens main body on which a strip asymmetric coating is applied.

In the optical lens, the lens main body is made of a plastic lens.

In the optical lens, the lens main body is made of an optical glass lens.

In another aspect, the present invention provides a method of controlling astigmatism of an optical lens wherein a strip asymmetric coating is applied on a lens main body, and wherein a magnitude of astigmatism is controlled by varying the width

of the asymmetric coating.

In another aspect, the present invention provides a method of compensating astigmatism due to the birefringence of the plastic material by a strip asymmetric coating on a lens main body.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic diagram showing an optical system to define astigmatism.

Fig. 2 is a schematic diagram showing an optical lens of the present invention to present astigmatism caused by asymmetric coating on the optical lens.

Fig. 3 is a schematic diagram showing an optical system of the optical lens of Fig. 2.

Fig. 4 shows source parameter of Code-V for defining the optical lens.

Fig. 5 shows multi-layer coating on the optical lens.

Fig. 6 shows source codes of Code-V for defining multi-layer coating on the optical lens.

Figs. 7A and 7B show simulation results of astigmatism changes of the optical system, by varying the width of the coating and by rotating the optical lens.

Figs. 8A and 8B show simulation results of coma and spherical aberrations of the optical system.

Fig. 9 shows dependence of astigmatism magnitude on the width of the coating for the optical system.

Fig. 10 is a schematic diagram of a coating machine.

Fig. 11 shows a coated lens observed under microscope.

Fig. 12 Twyman-Green interferometer for evaluating aberrations of the optical lens.

Figs. 13A and 13B are experimental results showing the circular astigmatism contour and the two-dimensional image obtained from the interferometer.

Fig. 14 is experimental results showing astigmatism data for the optical lens with symmetric coating.

Figs. 15A and 15B are experimental results showing astigmatism contours for lenses coated with $w=0.5\pm0.2$ mm and the corresponding images obtained from the interferometer.

Figs. 16A and 16B are experimental results showing astigmatism contours for lenses coated with $w=1.0\pm0.2$ mm and the corresponding images obtained from the interferometer.

Figs. 17A and 17B are experimental results showing astigmatism contours for lenses coated with $w=2.0\pm0.2$ mm and are the corresponding images obtained from the interferometer.

Figs. 18A and 18B are experimental results showing astigmatism contours for lenses coated with $w=3.0\pm0.2$ mm and the corresponding images obtained from the interferometer.

Fig. 19 is experimental results showing the effect of the width of coating on astigmatism magnitude.

Figs. 20A and 20B are experimental changes in spherical aberration and coma aberration.

DETAILED DESCRIPTION OF THE INVENTION

Preferred embodiment of the present invention will now be described with reference to the drawings.

The present invention is applied to an optical lens 11 structured as shown in Fig. 2, for example.

As shown in Fig. 2, the optical lens 11 includes a lens main body 12 on which a strip of coating 13 is coated.

It is obvious that, with this configuration, tangential and radial rays experience different optical path length, even though the lens main body 12 itself is not astigmatic. It is because, in this situation, all the radial rays will pass through the coating 13 and experience extra optical path $n_1 d_1$, where n_1 is the refractive index of the coating 13 and d_1 is its thickness, while some of the tangential rays will pass through the coating 13. The width(w) of the coating 13 has an important effect on the amount of astigmatism to be generated. Namely, if the width(w) is too large or too small, the value generated will be close to zero. When the coating 13 is too wide, both the tangential and radial rays have to pass through the coating 13, resulting no difference in optical path length, and hence no astigmatism will be generated. Similarly, when the coating 13 is too narrow, no effect on astigmatism will be observed.

The lens main body 12 is made of a plastic lens. Alternatively, the lens main

body 12 can be is made of an optical glass lens.

In the following, simulation and experimental results will be presented by taking optical pickup lenses as examples. It must, however, be emphasized that the approach that will be discussed can be applied to all lenses.

Simulation Model and Results

Figure 3 displays an optical system 10 of the optical lens 11 that is characterized by its numerical aperture $NA=0.45$, the operating wavelength $\lambda =780\text{nm}$, and the image-output (I/O) distance of the optical lens 11 $=24.2\text{ mm}$. In this optical system 10, an optical disc 22 is irradiated from a laser 20 via an aperture 21 and the optical lens 11. Its codes in Code-V, an optical design software, are shown in figure 4 where the data of the optical system 10, such as refractive index of the elements and the separation between them, are depicted.

The first column indicates the sequence of the surfaces; the second column is the radius of the corresponding surface; the third column shows the thickness of the corresponding surface; the fourth column indicates the mode of the surface-reflective or refractive; and the last column shows the refractive medium of the surface. The code !NSS displayed in surface 4 (S4) to surface 9 (S9) means that the surfaces are non-sequential.

On the rear surface of the lens main body 12 is applied coating 13 consisting of three layer coatings 13A,13B,13C as illustrated in Fig. 5. A first layer 13A has a refractive index of 1.7 with its thickness 8nm. A second layer 13B has a refractive

index of 1.84 with its thickness 56nm. A third layer 13C has a refractive index of 1.42 with its thickness 135nm. The reflective index and the thickness of each layer 13A,13B,13C are shown in Table 1.

Table 1

	Refractive Index	Thickness (nm)
First layer	1.7	8
Second layer	1.84	56
Third layer	1.42	135

The effect of this coating on the aberration of the optical system 10 is investigated by evaluating the wave front aberration at the exit pupil on an off-axis image point.

In order to create the strip coating 13 onto the lens main body 12, a non-sequential surface system is applied to the lens main body 12. Fig. 6 displays source codes in Code-V for defining the multi-layer coating 13 on the lens main body 12. Holes and edges are included on the surfaces as shown in Fig. 6.

As shown in Fig. 7A, by varying the width(w) of the coating 13 in the y-direction in Fig. 3 and keeping the length of the coating 13 constant, the aberrations of the optical system 10, such as coma, spherical aberrations and astigmatism, are evaluated. Then by rotating the optical lens 11 along the z-axis, these aberrations are calculated again.

Figure 7B displays the simulation results of astigmatism for two different values($w=2.0\text{mm}$, $w=2.4\text{mm}$) of the width(w) of the coating 13 for an image point located at $(0.02,0.02)$ mm. The center spot is the astigmatism value of the optical system 10 when there is no coating 13 on the lens main body 12. As the optical lens 11 rotates, the contour of astigmatism forms a circle. From the results, it can be seen clearly that the strip coating 13 has a very significant effect on astigmatism of the optical system 10.

The radius of the circles is dependent on the width of the coating 13. Since astigmatism aberration terms involve even powers of $\cos \theta$, where θ is the angular argument of the polar coordinates defined at the exit pupil, the contour of the graph will be encircled twice when the optical lens 11 rotates by 360° . Thus, by having the strip coating 13 on the lens main body 12, the magnitude and direction of astigmatism can be controlled to desired values.

So far, only astigmatism has been analyzed. It is, however, important to study the effect of the coating 13 on other optical aberrations.

Fig. 8A and 8B show the results of coma and spherical aberrations of the optical system 10 when the lens main body 12 is coated with 2 mm strip coating 13. Small dots in Fig. 8A correspond to the coma values when the optical lens 11 is rotated and a large dot is the result without coating. It can be observed clearly that the coating 13 and its orientation have a very minimal effect on coma aberration of the optical system 10. In Fig. 8B, the effect of the coating 13 introduces less than 0.01 changes in

spherical aberration. Since the spherical aberration is a symmetric term, rotation of the optical lens 11 does not affect its value. Therefore, applying the strip coating 13 on the lens main body 12 is a very effective way in controlling astigmatism of the optical system 10 while at the same time keeping coma and spherical aberrations more or less constant.

It must be noted that there is a limit within which the amount of astigmatism change can reach when the strip coating 13 is applied to the lens main body 12. Fig. 9 displays the results of astigmatism magnitude when the width(w) of the coating 13 on the lens main body 12 shown in figure 3 is varied. It can be observed that, for this optical system 10, astigmatism reaches its maximum value when the width(w) of the coating 13 is 1.4 mm. That is, with this width(w), the radius of the circle of the astigmatism contour is the longest. Deviating from this width(w), the tangential and radial rays will experience lesser differences in the optical path length, and hence the astigmatism magnitude decreases.

Experimental Results

Tests were carried out using a Zeonex material which is a cyclo-olefin polymer. Using this material, the lenses main body 12 were molded to the shape according to the data shown in Fig. 4. The lenses main body 12 were then masked and were applied a coating process by using a coating machine 50 structured as shown in Fig. 10.

As shown in Fig. 10, the coating machine 50 includes a vacuum chamber 51 evacuated by a pumping port 52. In the vacuum chamber 51 are provided a heating

element 53, an electron beam gun 54 and a rotating substrate holder 55. The oxygen O_2 is filled into the vacuum chamber 51 from a filler hole 56. In this coating machine 50, a coating process is carried out in which the heating element 53 and the electron beam gun 54 heat and vaporize coating elements 57, with the lens main body 12 set in the rotating substrate holder 55.

Fig. 11 shows the appearance of the optical lens 11 observed under a microscope after the coating process. The strip coating 13 can be observed.

The aberrations of the optical lenses 10 were then evaluated by a Twyman-Green interferometer 100 shown in Fig. 12. The Twyman-Green interferometer 100 is made up of a laser diode 101, a PZT mirror 102 as a movable mirror driven by a piezoelectric element, a microscope objective 103, a reference mirror 104, a spatial filter 105, a beam splitter 106 and so on.

The Twyman Green interferometer configuration displayed in Fig. 12 can be described in the following. The beam from the laser 101 is divided in amplitude by means of the beam splitter 106. After reflection, light from the PZT mirror 102 and from the reference mirror 104 impinges again on the beam splitter 106. Two interference patterns are then formed, one going back to the laser source and the other going to a camera for measurement.

Fig. 13A displays the results when the coating width is 1.5 ± 0.2 mm. The angles were measured to the accuracy $\pm 5^\circ$. The graph shows clearly that the experimental data form a circular contour when the optical lens 11 was rotated. The center of the

circle is obtained from Fig. 14 where the lens main body 12 was coated symmetrically. This point indicates the value of birefringence of the optical lens 11 and will serve as the center for all the other contours. From Fig. 14, one can observe that the astigmatism of the lens in radial direction cannot reach positive values regardless of its rotation angle. Hence, asymmetric coating can compensate astigmatism due to the birefringence of the plastic material as shown in Fig. 13A. Fig. 13B is the two-dimensional image of the optical lens 11 obtained from the Twyman-Green interferometer 100.

Figs. 15 to 18 are a series of diagrams, that show how the circles of the astigmatism contour change with the width(w) of the coating 13, and the images captured by the Twyman-Green interferometer 100.

Figure 15A,15B are experimental results showing an astigmatism contour for the optical lenses 10 coated with $w=0.5\pm0.2$ mm and the corresponding image obtained from the Twyman-Green interferometer 100.

Figure 16A,16B are experimental results showing an astigmatism contour for the optical lenses 10 coated with $w=1.0\pm0.2$ mm and the corresponding image obtained from the Twyman-Green interferometer 100.

Figure 17A,17B are experimental results showing an astigmatism contour for the optical lenses 10 coated with $w=2.0\pm0.2$ mm and the corresponding image obtained from the Twyman-Green interferometer 100.

Figure 18A,18B are experimental results showing an astigmatism contour for

the optical lenses 10 coated with $w=3.0\pm0.2$ mm and the corresponding image obtained from the Twyman-Green interferometer 100.

It can be seen from the graphs in Fig. 15 to 18 that, while the center of the contours remains, the radius of the contours increases until the width(w) of the coating 13 reaches 1.5 ± 0.2 mm, and it shrinks as w expands from 1.5 to 3.0 ± 0.2 mm. The results were best illustrated by plotting the radius against the width of the coating 13 as shown in Fig. 19. They agree very well with the simulation results depicted in Fig. 9.

In order to verify experimentally that other aberrations such as coma and spherical aberrations are not much affected by coating, the results of coma and spherical aberrations are shown in Fig. 20. Fig. 20A shows that, as predicted by the theory, less than 0.01 changes in spherical aberration were observed before and after the lens main body 12 was coated, and the values remain more or less constant as the lens main body 12 was rotated. Same results were observed for coma aberration as shown in Fig. 20B. Thus, the results prove that asymmetric coating on optical lenses 12 is a fast and effective way to control their astigmatism direction and value. In addition, the process is reversible, that is, the coating 13 can be detached by applying some chemical on the lens main body 12 so that the lens main body 12 can be re-coated again.

As described above, according to the present invention, astigmatism direction and magnitude of an optical lens can be controlled by applying an asymmetric coating

on a lens main body. The theoretical and experimental results agree very well with one another. It has been shown the radius of astigmatism contours depends on the width(w) of a strip coating, reaching its maximum limit when the width(w) is not too narrow or too wide. Moreover, it has also been proven that asymmetric coating has a very minimal effect on other aberrations such as coma and spherical aberrations. This new technology has been successfully implemented to improve the push-pull signal in laser coupler typed OPs. This new technology has a variety of applications. In fact, any optical systems that require some residual astigmatism, for example, a mini-disc lens for compensating the birefringence of a disc, can employ this new technology.



WHAT IS CLAIMED IS:

1. An optical lens wherein
a strip asymmetric coating is applied on a lens main body.
2. The optical lens as claimed in Claim 1 wherein said lens main body is made of a plastic lens.
3. The optical lens as claimed in Claim 1 wherein said lens main body is made of an optical glass lens.
4. A method of controlling astigmatism of an optical lens wherein
a strip asymmetric coating is applied on a lens main body, and wherein
a magnitude of astigmatism is controlled by varying the width of said asymmetric coating.
5. A method of compensating astigmatism due to the birefringence of the plastic material by a strip asymmetric coating on a lens main body.