PHASE SHIFT MULTIFOCAL ZONE PLATE

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of application Ser. No. 970,751 filed Dec. 18, 1978, now U.S. Pat. No. 4,210,391.

BACKGROUND OF THE INVENTION

This invention relates to multifocal optical devices which have their multifocal property distributed approximately throughout said devices, and more particularly to multifocal zone plates as described in my patent application Ser. No. 970,571.

A multifocal Fresnel lens has been previously described as a lens consisting of a plurality of annular rings, the surfaces of which are made part of a carrier lens, and have the same inclinations to the optical axis, in a repetitive interleaving pattern, as the individual surfaces of the separate single focal power lenses that they wish to combine.

The concept of a multifocal zone plate was developed as an improvement on the multifocal Fresnel lens, wherein the geometrical spacings of the annular rings of said multifocal Fresnel lens, were set to obey the usual spacing of a zone plate diffraction grating.

Multifocal zone plate mirrors as well as lenses have been described.

However, one can make an improvement in these designs as relates to the level of light intensity available at each of the focal points. Multifocal Fresnel lenses and multifocal zone plates can be designed in such a manner as to cause the intensity of light coming to focus at each focal point, to approach the intensity of light available at the focus of an ordinary monofocal lens.

In order to understand the nature of the problem, we should make note first, that in an ordinary monofocal lens all of the incident light comes to focus in phase at the single focal point. However, in an annular zone multifocal Fresnel lens with two focal points, the incident light is shared between the two focal points. For example, we may have half of the incident light brought to focus in phase at one focal point, and half the incident light brought to focus in phase at the other focal point. However, since brightness is proportional to the square of the convergent in phase light, the intensity of the focussed light at each of the two focii, is only 25% of the usual intensity of light focussed by an ordinary monofocal lens.

The situation is even more dramatic in the case of a zone plate. In this case, the incident light is again reduced at each of the two primary focii. However, the light arriving at each focal point is not in perfect phase and achieves an amplitude of only $1/\pi$th of that at the focal point of an ordinary monofocal lens. Again, since brightness is proportional to the square of the amplitude, the intensity of focussed light at each of the two primary focii of a zone plate is approximately 10% of the usual intensity of focussed light in a monofocal lens.

Finally in the case of a multifocal zone plate, we have a number of different focii, some of them with a 25% image brightness and some of them with a 10% image brightness. However, by judiciously arranging the design of a multifocal zone plate, we can cause some of the zone plate focii to coincide with some of the multifocal Fresnel lens focii. At these double focii we will have an amplitude of light equal to 0.818 (i.e. $\frac{1}{2}+1/\pi$) of that at the focal point of an ordinary monofocal lens. And since brightness is proportional to the square of amplitude, the intensity of focussed light at each of the double focii is approximately 67% of the usual intensity of focussed light in a monofocal lens. FIG. 1 shows the annular zone spacing of such a lens.

SUMMARY OF THE INVENTION

The purpose of a multifocal lens, is to increase the number of foci to which incident light will converge. Unfortunately, whenever this has been done, it has been at the expense of the image brightness at each of the foci.

The present invention makes use of the fact that multifocal zone plates have many subsidiary zone plate foci in addition to the multiple Fresnel lens foci. By properly adjusting the annular zone spacings in a multifocal zone plate, we can shift some of the zone plate foci until they coincide with some of the Fresnel lens foci. In this case there will be a significant increase in intensity of light at these double foci.

The present invention is summarized in a multiple power optical device having a plurality of alternating odd and even, annular, concentric zones, bounded on the outside by radii r_n, with $n=1,3,5, \ldots$, for the odd zones and $n=2,4,6, \ldots$, for the even zones; first focal power means within at least some of the odd zones for directing incident parallel light to a first focal point; second focal power means within at least some of the even zones for directing incident parallel light to a second focal point different from said first focal point; wherein the radii r_n of said odd and even zones are substantially proportional to the square root of n; and wherein the absolute value of r_1 is set equal to $\sqrt{\lambda d}$, with λ equal to the wavelength under consideration, and d is substantially equal to the reciprocal of the absolute value of the difference between the first and second focal powers.

An important advantage of this invention, is that its performance as a multifocal optical element is not limited by dim focal images inherrent in the usual multifocal lens designs.

Other objects and advantages of the present invention will be more fully apparent from the following description of the preferred embodiments when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a pattern of concentric circles demarcating the half wave zones of a phase shift multifocal zone plate.

FIG. 2 shows a cross-sectional view of a phase shift bifocal zone plate spectacle lens in accordance with the present invention.

FIG. 3 shows a cross-sectional view of a portion of a phase shift bifocal zone plate in accordance with one modification of the present invention.

FIG. 4 shows a cross-sectional view of a portion of a phase shift bifocal zone plate formed without any ledges in accordance with another modification of the present invention.

FIG. 5 shows a cross-sectional view of a portion of a phase shift bifocal zone plate formed by ion implementation in accordance with still another modification of the present invention.

FIG. 6 shows a cross-sectional view of a portion of a phase shift bifocal zone plate formed by ion implanta-