MULTIFOCAL PHASE PLACE

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. 970,751 now U.S. Pat. No. 4,210,391.

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 comcept 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 plane mirrors as well as lenses have been described.

However, one can make an improvement in these designs as relates to the quality of the images formed at each of the focal points, by applying phase plate considerations as described by A. I. Tudorovskii in his article "An objective with a phase plate", Optics & Spectroscopy, Feb. 1959. Multifocal phase plates can be designed in such a manner as to cause the light coming to focus at one focal point, to be bright and clear, without the superposition of light passing through zones meant to focus such light to the other focal points.

In order to understand the nature of the problem, we note 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 bifocal 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 pass through the odd zones before being brought to sharp focus at one focal point. But, we will also have, superimposed at this focal point, a blurred image formed by incident light passing through the even zones.

SUMMARY OF THE INVENTION

The purpose of a multifocal lens, is to increase the number of focii to which incident light will converge. Unfortunately, whenever this has been done, it has been accompanied by the superposition of spurious blurred images at each of the focii.

The present invention makes use of the fact that, in a phase plate, the Fresnel echelettes (or optical facets) can be adjusted to diffract light to particular focii of the zone plate. In this case there will be a significant improvement in the quality of imaged light as these focii.

To explain how this invention achieves its purpose, we may refer to FIGS. 1-4. In FIG. 1, we see an interface I, between two different optical media with respective indices of refraction n and n', an optical axis AA' cutting the interface at O, and two focal points +d and −d, on the optical axis. We also see, that the region of index n', is divided into conical half-wave zones bounded by the surfaces $s_1, s_2, s_3, \ldots$, which intersect the interface I, in circles of radii $r_1, r_2, r_3, \ldots$, as shown in FIG. 2. The radii are given by the half-wave zone plate formula, $r_m=\sqrt{m\lambda d}$ with λ = wavelength of light, m is an integer, and the positions $\pm d/N$ along the optical axis are called "focal points", with N an integer not related to m. Now let us consider the odd zones (those bounded on the outside by r_m with m odd) separately from the even zones (those bounded on the outside by r_m with m even). Considering first the odd zones, we introduce sphero-triangular Fresnel echelettes as shown in FIG. 3. If the index of refraction of the Fresnel echelettes is n'', then we can choose the depth of each ledge to be $\lambda/2(n''\text{-}n)$. In this situation all of the odd zones will focus light parallel to the optical axis AA' and incident upon the interface I, to the focal point +d. Furthermore, all of the focussed light will arrive in phase, contributing to a "brightened" image as compared to an image produced by a zone plate without Fresnel echelettes.

Now considering the even zones, we introduce the Fresnel echelettes to diffract incident parallel light as if it came from the focal point −d. This situation is shown in FIG. 4. Now this composite lens of FIG. 4, exhibits an unexpected property. When we consider incident parallel light passing through the even zones, we find that such light approximately exhibits, complete destructive interference at the focal point +d. The situation is similarly true for incident parallel light, passing through the odd zones, with respect to the focal point −d. This means, that at these two focal points, we can get sharp clear images without the superposition of blurred images.

Finally, we can complete the construction of a bifocal phase plate lens, by altering the front surface I and providing a back surface B, in order to produce a carrier power F, that can shift the focal points, −d and +d, to any desired positions such as $f_1=f-d$ and $f_2=F+d$ (see FIG. 5).

In identical fashion, we can construct another multifocal phase plate, by choosing the odd zone optical facets to direct light to the +d/2focal point, and the even zone optical facets to direct light to the −d/2 focal point. In fact, we can construct clear image multifocal phase plates as described above, by using optical facets (echelettes) that alternately focus light to the +d/N focal point and the −d/N focal point, where N is an integer.

The present invention is summarized in a multiple power annular, concentric zones, bounded on the outside by radii r_n, with n=1, 2, 3, . . . ; a focal power means within at least some of the zones for directing incident parallel light to the focal point +d/N, with N an integer; another focal power means within at least some of the zones for directing incident parallel light to the focal point −d/N; wherein the radii r_n of said 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 an arbitray focal point, relating to the use of the invention.

An important advantage of this invention, is that its performance as a multifocal optical element is not degraded by the superposition of blurred images at the