MULTIFOCAL ZONE PLATE

BACKGROUND OF THE INVENTION

This application is a continuation-in-part of application Ser. No. 833,368 filed Sept. 14, 1977, now U.S. Pat. No. 4,162,122.

This invention releates to multifocal optical devices and, more particularly, to multifocal optical lenses and mirrors, which have their multifocal property distributed approximately throughout said lenses and mirrors.

Multifocal optical lenses, in which the multifocal property is distributed approximately throughout the lens, have been previously produced. Such lenses generally follow the design of Fresnel lenses as described, for example, by H. Rühle in his U.S. Pat. No. 3,004,470. That is, they consist 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 widths of the individual zones are not usually specified.

This concept of a multifocal Fresnel lens is illustrated in FIG. 1. Here we see a lens which is divided into concentric annular zones labeled **1–6**, each zone presenting an inclined optical facet A. The separate facets may be variously inclined or of differing optical indices, so as to correspond to more than one focal power in order to achieve a multifocal effect. For example, in FIG. **1**, it may be that the facets of the even numbered zones are inclined to correspond to a particular focal power, while the facets of the odd numbered zones are inclined to correspond to a specific but different focal power.

Of course multifocal Fresnel mirrors have also been constructed along these same principles.

A major problem inherent in these designs, however, occurs whenever the annular zones have to be constructed with very small widths. In these cases optical aberrations are introduced by diffraction effects. Nevertheless, it is sometimes imperative to design Fresnel lenses with small annular zone widths; such as in contact lenses where the zone widths are limited by the small size of the contact lens itself, or in spectacle lenses where large zonal widths might be cosmetically unacceptable, or in camera lenses where large zonal widths will cause shadows to be cast by the deep non-refractive ledges between adjacent annular zones, or in many other important optical systems.

In the past, optical devices which make use of the well known concept of the zone plate have also been constructed. To understand a zone plate, illustrated in FIG. **2**, consider a flat glass plate with a series of concentric circles drawn on its surface such that the radius r_n, of the nth circle, is given by $r_n \simeq \sqrt{n\, d\, \lambda}$, where λ is the wavelength of light under consideration, d represents a focal length, and $n=1,2,3,\ldots$. This formulation of r_n is not exact, but represents an excellent approximation, even of the more detailed expressions which account for a curvature of the surface of the glass plate. Now these circles divide the glass plate into annular zones. If these annular zones are numbered consecutively, **1**,**2**,**3**, . . . , from the center zone outward, then the significant property of a zone plate is based on the fact that most incident parallel light, of wavelength λ, passing through the odd numbered zones will come to focus in phase, at a distance d from the zone plate. Similarly, incident parallel light passing through the even numbered zones, will also come to focus in phase at the distance d from the zone plate. Of course, the light passing through the odd numbered zones, will be out of phase with the light passing through the even numbered zones. Considering the above, "opaque-transparent" zone plates have been constructed to block out light incident upon either the odd or even numbered zones. Also, "phase-shift" zones plates have been constructed, which optically shift the phase of the light incident upon the even (or odd) numbered zones with respect to the odd (or even) numbered zones, so as to bring all of the light focused at d back into phase.

An important property of zone plate devices makes use of the fact that a zone plate has two primary (first order) focal powers, $+1/d$ and $-1/d$. In many situations we can use both of these focal powers. This has been previously demonstrated by Herbert Jefree in his British Pat. No. 802,918.

Still another property of zone plate devices, occurs because diffractive chromatic dispersion is usually opposite to refractive chromatic dispersion. The advantageous use of this phenomenon has been previously demonstrated by A. I. Tudorovskii in his article "An Objective with a Phase Plate," Optics and Spectroscopy, February 1959, where is showed how a zone plate could compensate for the chromatic aberrations inherent in standard optical lenses.

The prior art has also shown composite devices which utilize both Fresnel zone optics and zone plate spacings. But in these cases the Fresnel zones were monofocal. For example, in A. Walsh's Letter to the Editor, J. Opt. Soc. Am., Vol. 42, No. 3, March 1952, a Fresnel mirror with zone plate spacings was disclosed. However, the mirror was not multifocal, and its advantages are at best limited. Other composite devices have been reported by J. G. Hirschberg and P. Platz, Appl. Opt. 4,1375 (1965), and J. G. Hirschberg and F. N. Cooke, Jr., Appl. Opt. 9,2807 (1970). These devices however, are also monofocal in the usual sense of having a single focal plane, although light passing through each annular zone is shifted transversely before being brought to focus in the single focal plane of these devices. These optical elements are disadvantageous for ordinary uses, such as in spectacles or cameras, in that they require multiple sensors.

SUMMARY OF THE INVENTION

In a multifocal lens, we wish to share the incident light between the various focal points, but naturally do not wish to introduce diffraction related aberrations. In a zone plate we make use of diffraction so that it is not an aberration problem, but we must split the incident light into two separate bundles and either block one bundle out, or phase shift it with respect to the other bundle.

The present invention makes use of the fact that both multifocal Fresnel lenses and zone plates, are divided into annular zones which separate incident light according to the zone upon which it is incident. By combining the two distinct entities, that of the multifocal Fresnel lens with that of the zone plate, we eliminate the diffraction problems of the narrow zone multifocal Fresnel lens, while at the same time we separate the two out of phase zone plate bundles of light without blocking out or phase shifting any of the light.