MULTIFOCAL OPHTHALMIC LENS

This application is a division of application Ser. No. 08/592,164 filed Jan. 26, 1996 now U.S. Pat. No. 5,657,108 which is a division of application Ser. No. 08/122,822 filed Sep. 16, 1993 now U.S. Pat. No. 5,521,656 which is a division of application Ser. No. 07/935,586 filed Aug. 26, 1992 now U.S. Pat. No. 5,270,744 which is a division of application Ser. No. 07/465,477 filed Jan. 16, 1990 now U.S. Pat. No. 5,166,712 which is a division of application Ser. No. 07/366,319 filed Jun. 14, 1989 now U.S. Pat. No. 4,898,461 which is a continuation of application Ser. No. 07/056,050 filed Jun. 1, 1987 now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to ophthalmic lenses, e.g., intraocular lenses (IOLs), contact lenses, and corneal implant and onlay lenses; and it concerns the problem of providing ophthalmic lenses which successfully handle bifocal, and other multifocal, corrections.

Where spectacles, or eyeglasses, are used, the movement of the eyes relative to the lenses selects the different focal powers for near and far vision. Where ophthalmic lenses are used, other means must be provided for such selection. At least three types of lens designs, primarily for contact lenses, have been suggested as possible means of satisfying this need. In each of these types of contact lens designs, problems have been encountered, primarily due (a) to the need for centering of the lens on the eye, and (b) to the effects of normal changes in the size of the eye's pupil.

One form of multifocal ophthalmic lens design is illustrated by U.S. Pat. No. 4,593,981, which discloses a bifocal contact lens designed to correct for near vision in the center portion of the lens and for far vision in the peripheral portion of the lens. With this type of lens, centering on the eye is essential for satisfactory performance; and correct size of the optical zones is also important. If either of these requirements is not met, a lens of this type can produce diplopia or fringing.

Another form of multifocal ophthalmic lens design is illustrated in U.S. Pat. No. 4,580,882, which discloses a multifocal contact lens having optical power which continuously varies from minimum at the optical center point to maximum at the periphery of the optical zone. Usually this progressive (aspheric, variable focus) type of lens is constructed with a centrally placed small zone of constant curvature from which aspheric curves are grown towards the periphery in all meridians. The central area serves as the power for the distant correction, while the peripheral curves provide a varying amount of additive plus power for the near point. The curves may be placed on the front surface in which case they increase in convexity, or on the back surface in which case they decrease in concavity (flatten). If the surface of progressive curvature is placed on the front of the lens, the tear layer interferes with the lens performance. If the progressive curvature is placed on the back surface of the lens, this will affect the fitting characteristics of a contact lens. In both cases the image is "undercorrected", which is more natural for human vision. This "progressive" power lens has the advantage that flare or diplopia does not occur if the lens is slightly off-center. However, pupil size affects vision with this lens, as it does with the lens discussed in the preceding paragraph.

A third form of multifocal ophthalmic lens design is illustrated in U.S. Pat. Nos. 4,549,794 and 4,573,775 which disclose bifocal contact lenses of the segmented type, i.e., lenses in which a segment having different refractive characteristics is embedded at a selected position in the lens body. The segments are positioned along the vertical axes. Lenses of this type do not have symmetry around their centers; and they require some form of ballast to assure maintaining the desired orientation. Deviation from proper orientation affects the image quality.

One attempt to solve the centralization and orientation problems in a bifocal lens is represented by U.S. Pat. No. 4,162,122, which discloses a zonal bifocal contact lens in which annular concentric zones alternate between the near and far vision powers. This is accomplished by providing an anterior lens surface having characteristics similar to a Fresnel lens, except that sharp zonal edges are avoided. This structure has disadvantages due to the multiple diffraction caused by the abrupt curvature change of the lens surface from one zone to another; and also due to uncertainty as to the tear layer distribution on the anterior surface of the contact lens.

Designs similar to those described above are proposed also for intraocular lenses: e.g., U.S. Pat. No. 4,636,211 and European Patent 0-140-063. Both of them describe several zones of different curvatures for far and near vision. Continuity of the surface curvature is also important for an intraocular lens because it has an effective optical zone of only 3 mm diameter for daytime vision. Disruption of this relatively small optical zone can reduce the image performance. Besides, such lenses suffer from all of the problems described for contact lenses.

In general, multifocal ophthalmic lenses previously developed have tended to provide unstable optical systems because of random changes in lens position relative to the pupil of the eye, and also because of changes in the pupil size which significantly affect the imaging performance.

SUMMARY OF THE INVENTION

The present invention provides an improved multifocal ophthalmic lens by combining (a) a series of alternating power zones with (b) a continuously varying power within each zone as well as in transition from one zone to another. In other words, a plurality of concentric zones (at least two) are provided in which the variation from far to near vision correction is continuous, i.e., from near correction focal power to far correction focal power, then back to near, and again back to far, or vice versa. This change is continuous (progressive), without any abrupt correction changes, or "edges". The construction may also be such that the radial width of the zone for far-to-near transition is larger than the radial width of the zone for near-to-far transition, in order to provide "undercorrected" performance of the lens overall.

Two versions of the invention are disclosed. In the first version continuous, alternating power variation is accomplished by a continuously changing curvature of the lens posterior surface, thereby altering the angle of impact of light rays on the eye.

In the second version continuous, alternating power variation is accomplished by creating non-homogeneous surface characteristics having refractive material indexes which continuously vary in tile lens radial direction (out from the optical axis). This technique has a similar effect to the aspherizing of the surface by utilizing continuous curvature variation as described above. Such surface refractive variations may be provided either on the convex anterior or on the concave posterior surface of the lens. This variation in the refractive index may be accomplished by ion-implantation techniques. This approach is particularly suitable for a