MULTIFOCAL DIFFRACTIVE LENS

FIELD OF THE INVENTION

The present invention relates to opthalmic lenses having a plurality of focal lengths.

BACKGROUND OF THE INVENTION

Bifocal spectacle lenses have been known for hundreds of years. In such lenses a first region of the lens is typically provided with a first focal length while a second region of the lens is provided with a second focal length. The user looks through the appropriate portion of the lens for viewing near or far objects.

In recent years as the popularity of contact lenses has grown, there has been an increased interest in multifocal contact lenses. Multifocal contact lenses utilizing an approach similar to that used in spectacle lenses are described in *Contact Lenses: A Textbook for Practitioner and Student,* Second Edition, Vol. 2 on pages 571 through 591. Such lenses have serious drawbacks, however, because they require that the lens shift on the eye so that different portions of the lens cover the pupil for distant and close vision. This design is disadvantageous because it is difficult to insure that the lens will shift properly on the eye for the desired range of vision.

In another design for a bifocal contact lens described in the above-referenced textbook, a central zone of the lens is provided with a first focal length and the region surrounding the central zone is provided with a second focal length. This design eliminates the necessity for shifting the lens by utilizing the phenomenon of simultaneous vision. Simultaneous vision makes use of the fact that light passing through the central zone will form an image at a first distance from the lens and light passing through the outer zone will form an image at a second distance from the lens. Only one of these image locations will fall on the retina and produce a properly-focused image, while the other image location will be either in front of or behind the retina. The human eye and brain will, to a great extent, work together to ignore the improperly-focused image. Thus the user of such a lens receives the subjective impression of a single, well-focused image. A disadvantage of such a lens is that, if the central zone is made large enough to provide sufficient illumination in its associated image location in low light situations, i.e., when the patient's pupil is dilated, the central zone will occupy all or most of the pupil area when the pupil contracts in a bright light situation. Thus bifocal operation is lost in bright light. Conversely if the central zone is made small enough to provide bifocal operation in bright light situations, an inadequate amount of light will be directed to the image location associated with the central zone in low light environments. Because the central zone is commonly used to provide distant vision, this can create a dangerous situation when the user of such a lens requires distant vision in low light situations such as when the user must drive a motor vehicle at night.

U.S. Pat. Nos. 4,210,391; 4,340,283; and 4,338,005, all issued to Cohen, teach the use of a plurality of annular regions that direct light to multiple foci and rely upon simultaneous vision to discard unfocused images. The annular zones are designed to provide the lens with a diffractive power. Typically a first focal length will be associated with a zero order diffracted light and a second focal length will be associated with the first order diffracted light.

In a typical prior art contact lens having diffractive power the various zones are separated by steps having an optical height equal to $\lambda/2$ where λ is the design wavelength of light. The optical height is defined as $h/(n_1-n_2)$ where h is the physical height, n_1 is the index of refraction of the lens and n_2 is the index of refraction of the surrounding medium, typically the tear fluid. The steps are usually made as sharp as possible in order to provide efficient diffraction. The use of such sharp steps, however, has two significant disadvantages. The first disadvantage is that sharp outer steps have been known to cause corneal damage known as staining and also scarring. The second is that deposits from the tear fluid components tend to accumulate in the inner corners of the steps. Furthermore such deposits are difficult to remove from the lens when the inner corner is sharp.

SUMMARY OF THE INVENTION

In the present invention a multi-focal ophthalmic lens has a plurality of concentric diffractive zones. Adjacent zones are separated by steps having predetermined heights. Each step has an outer corner and each outer corner has a radius of curvature equal to at least one half the height of the step associated therewith. Each step also has an inner corner and in some embodiments each inner corner has a radius of curvature equal to at least one half the height of the step associated therewith.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-sectional view of a portion of a multi-focal contact lens having diffractive power according to the prior art; and

FIG. **2** is a cross-sectional view of a portion of a multi-focal contact lens having diffractive power according to the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention may be used in various types of ophthalmic lenses, such as contact lenses, intraocular lenses, intralamellar implants and artificial corneas. It has, however, the greatest benefits when used in conjunction with a contact lens and so will be described in that context.

FIG. **1** shows a portion of a cross-section of a typical diffractive bifocal contact lens of the prior art **10**. Lens **10** has an anterior side **12** and a posterior side **14**. Anterior side **12** is generally smooth while posterior side **14** is a structured surface. The structures on posterior surface **14** include a plurality of diffractive zones such as zone **16** and zone **18**. These diffractive zones typically include a circular central zone surrounded by a plurality of concentric annular zones. Typically the diffractive zones, such as zones **16** and **18**, are smoothly curving and are separated by steps such as step **20**. Step **20** has outer corner **22** and inner corner **24**. Generally practitioners in the prior art have believed that such corners should be made as sharp as possible. Thus typically an outer corner such as corner **22** will have no measurable radius of curvature while an inner corner such as corner **24** will have a radius of curvature dictated by that of the cutting tool used to form the structured surface.

Sharp corners **22** and **24** contribute significantly to two problems that have been common to diffractive